# Tri Band Dual Polarized Patch Antenna System For Next Generation Cellular Networks

Syed Daniyal Ali Shah

**Abstract:** In fifth generation networks, much emphasis is given to reduce the handset and base station sizes while incorporating even more features for ubiquitous connectivity. Polarization diversity is one of the methods in which a single multi-polarized antenna brings the advantages of antenna diversity. The multiband handset antennas can be made dual-polarized for improved compensation of fading effects of propagation environment, especially in terrestrial bands. This paper focuses on the outcomes of the development of a horizontal and vertical polarized patch antenna scheme that operates on 3 bands, 900 MHz, 1.8 GHz and 2.4 GHz. The antenna system is tested for gain, directivity, reflection loss, polarization, radiation pattern and other parameters. The results are published and found are found to satisfy the requirements of cellular and data communication networks in the specified bands.

**Index Terms:** Tri Band, Dual Polarized, Patch Antenna, Antenna Modeling, 5G Patch Antenna, Patch Antenna Prototype.

## 1 Introduction

The emergence of high data rate wireless networks like 3G HSPA and 4G LTE-A, the wireless connectivity that has diversity incorporated is ever more required between mobile devices and base stations. The hardware level modifications in existing devices or completely new devices is ever more required to satisfy the requirements of modern day usage which include the Internet of Things along with the broadband like expertise. Modern handsets incorporate more than three antennas for GPS, Cellular, and Wi-Fi connectivity simultaneously over multiple bands [1]. Many antennas are being frequently designed to implement spatial multiplexing or diversity techniques as in LTE and WCDMA to increase the wireless link capacity. Diversity techniques are one of the major areas that enable 5G systems to meet the standards. Two diversity techniques that are most commonly implemented are Space Diversity (SD) and Polarization Diversity (PD). In order to meet the requirements of compact systems, PD is more favored due to its less space requirement to achieve diversity [2]. The use of PD can significantly enhance the performance of 5G systems as it offers the benefit of Diversity with smaller size. Polarization diversity method of transmission and reception is used to minimize the effects of frequency selective fading of the horizontal and vertical components of a radio signals [3]. Traditionally, fading is countered by implementing space diversity using two separate receiving antennas for each sector with dual polarized antennas, this number can be reduced to one [4]. It has been proved as an efficient way of reducing the size and numbers of the antennas needed for a mobile terminals working in modern wireless networks. This method does not require any extra bandwidth or more space for physical separations between the antennas. Antennas with multiple bands are needed widely in wireless communication [5]. For desired applications, the critical requirements include high bandwidth, compact size, low cost, high isolation etc. Microstrip antennas are required in order to reduce the constraints like cost, easy installation, size and weight and to fulfil the requirements of multiband antennas as far as impedance, resonant frequency, polarization and frequency are concerned when a particular shape, mode and size are selected, these antennas are very versatile [6]. These antennas are robust when mounted on hard surfaces, low-profile to facilitate non-planar surfaces as well as planar surfaces, compatible with MMIC (Monolithic Microwave Integrated Circuit) designs, simple and inexpensive to manufacture using modern printed circuit technology [7]. Microstrip antennas are the standard for the compact antenna design, but the insulation performance of standard Microstrip antennas may not be up to the mark. The techniques like dual feed and aperture coupling feed may be used to enhance the insulation properties of these antennas, but these techniques increase complexity of the antennas. So far, the handset antennas are uni-polarized. In order to add link reliability and spectral efficiency at the same time, dual-polarized antennas can be used. This would help implement diversity while reducing the size of the antennas and the handset as a whole. Polarization diversity technique in wireless communication up till now has been implemented only between the base stations due to the advantage of line-of-sight communication.

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## 2 Goals and Objectives

The fundamental emphasis was on development of Tri band dual polarized patch antenna system that operates for 900 MHZ, 1.8 GHZ and 2.4 GHz having high gain, good isolation and polarization characteristics. Critical analysis was conducted for almost every aspect of design through simulation and testing of the prototype.

**1. Antenna Design:** Various different geometries for microstrip patch antennas were shortlisted and tested, finally a suitable geometry was selected which can give better performance in terms of cross-polarization, gain and directivity for the desired bands.

**2. 3D Modelling:** A 3D model of the antenna of the selected configuration was developed using CST electromagnetic simulation and modelling software.

**3. Simulation:** Radiation characteristics and other parameters including return losses and VSWR measurements of the antenna were acquired.

**4. Optimization:** To improve the radiation characteristics of the antenna, a few parameters like feedline length, width and antenna size were optimized. These characteristics were then finely tuned to provide operation for 2.4 GHz band.

**5. Fabrication:** Antenna was fabricated primarily using etching machine facility using FR-4 substrate. The results achieved are acceptable and are shown in network analyser results of the microstrip patch antenna.

**6. S Parameters Measurement:** Return loss of the antenna is measured using network analyser that conform with the simulated the results satisfactorily.

**7. Radiation Pattern Measurement:** The radiation pattern of the antenna was measured in anechoic chamber and compared with the simulated results.

## 3 TRI BAND DUAL POLARIZED PRINTED ANTENNAS

Dual polarization is becoming important in patch antennas. Good selection of geometry of patch antennas allow the return loss of -40dB having linear polarization. If two polarizations are required which are orthogonal to each other at different frequencies, the rectangular patch antenna can be used which is fed at diagonal to excite the [0, 1] and [1, 0] modes. The operating frequency of the antenna is measured by the length of the patch. Impedance matching for patch antenna, operating in three bands can be achieved, one way is to cut two inclined slots in the ground plane of the antenna [8]. The main objective was to achieve tri band operation by using only a single slot cut into the antenna ground plane and fine tuning it to operate in 3 band with fairly high gain and low return loss. Separate feed points were used to excite the orthogonal modes and they were also used to get high isolation. The beamwidth of these modes can be controlled by the patch dimensions. For frequency bands close to each other, such as L-band used for GPS satellite communication for handsets, circular or square patches are used. In this case isolation depends upon the geometry of the antenna and defines the quality of the antenna. Isolation depends on the Q-factor of the feed geometry and the patch. For example, as the thickness of the substrate increases from 3.2 to 12.3 the isolation decreases from -50 to -28dB [9]. Generally coupling increases as feed port size increases and isolation decreases [10]. However, isolation can be improved by changing the position of feed.

## 4 BANDWIDTH ENHANCEMENT OF MICROSTRIP

One of the main drawbacks of microstrip antenna is its low bandwidth. In order to compensate various techniques were studied. We can improve the bandwidth up to 18% by the use of shorted patch with a thick air substrate [11]. Use of aperture coupled slots can also help to get a bandwidth enhancement of up to 21% [11]. Proximity coupling can also be employed and Shorted patch with Microstrip feed line can give better impedance matching and higher bandwidth but were not employed in order to reduce the complexity [12]. We can also use two stack sorted patches by which one can obtain enhanced impedance bandwidth for a fixed antenna volume but both the antennas should radiate almost equally and have a radiation quality factor as low as possible which can be quite challenging to achieve [13]. The bandwidth enhancement in this antenna system was achieved by selecting a suitable distance between the two offset shorting walls and finely tuned in order to achieve wider bandwidth of operation. Microstrip antennas loaded with chip resistor and chip capacitor can also result in a similar enhancement of bandwidth.

## 5 MODELLING AND SIMULATION

### 5.1 Introduction

There are four major parts in the designing of antenna system. The first two parts are the designing of the rectangular ring patch and notched rectangular patch for the 900 MHz, 1.8 GHz operation and then altering and modifying them such that they also provide operation for 2.4 GHz respectively. The two patches are printed on the same dielectric substrate. The notched rectangular patch is placed within the rectangular ring patch to obtain a compact structure and adjusted to provide operation on all three bands. The third part is the arrangement of the coupling slots in the antenna's ground plane and also the feed network design. All of these parameters were carefully handled in order to optimize the operation on all three bands of operation. The coupling slots and the feed network are printed on either sides of a dielectric substrate. In this design, both the patches and feed substrates used were inexpensive FR4 substrates of thickness 0.8 mm with relative permittivity of 4.40. This selection was done intentionally to maintain a low cost of the project. The two substrates are also separated by air of thickness about 12.8mm wide.

### 5.2 Structure of the Antenna

A compact geometry was chosen for the patch antenna suitable to radiate at 900 MHz, 1.8 GHz and 2.4 GHz. The rectangular ring patch is primarily designed for radiating at 900 MHz and the notched rectangular patch for radiating at 1.8 GHz. The notched rectangular patch is printed on the other side of the rectangular patch ring and the dimensions and placement are fine tuned to provide operation on all three bands. For feeding purpose aperture coupled feed method is used. Four coupling slots in H shape are cut in the ground plane of the antenna to couple the radiation from feed network to the patches. The geometric parameters of the selected dielectric substrate are shown in Table 5-1. The geometry and measurements of two patches is shown in Table 5-2 and Table 5-3 respectively.

***Table 5-1***

| Dielectric Substrate 1,2/FR4 | |
|---|---|
| Length | 150mm |
| Width | 150mm |
| Height | 0.8mm |

***Table 5-2***

| PATCH 1 | |
|---|---|
| Length | 99mm |
| Width | 109mm |
| Height | 0.03mm |

***Table 5-3***

| PATCH 2 | |
|---|---|
| Length | 59mm |
| Width | 49mm |
| Height | 0.03mm |
| Slit Length | 1mm |
| Slit Width | 1mm |

## 6 DESIGN OF PATCHES AND COUPLING SLOTS

The rectangular ring patch is primarily designed to get 900 MHz band. This patch is aperture coupled by two coupling slots A and D as shown in Fig.6-1 to achieve dual polarization. The two coupling slots have a middle arm of 0.5mm and the side arms of 1mm.

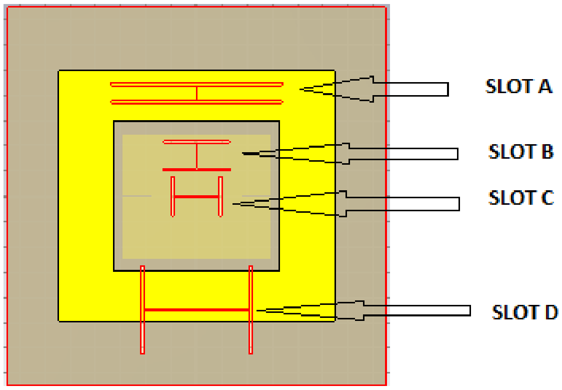


***Figure 6-1:*** *Coupling Slots for Rectangular Ring Patch*

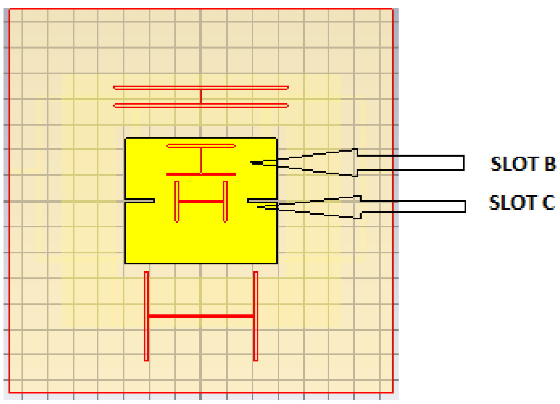


***Figure 6-2:*** *Coupling Slots for Notched Rectangular Patch*

The rectangular patch having notches is primarily designed to get 1.8 GHz band of operations. By inserting slits of length and width 1mm each, the size of the patch in the vertical direction can be reduced. This helps in obtaining larger air gap between rectangular ring patch and the notched rectangular patch in the vertical direction which reduce the coupling between two patches. The slots B and C are used to couple electromagnetic energy from the feed network to the notched rectangular patch as shown in the Figure 6-2.

## 7 Design of Feed Network

To feed the antennas, a feed network is designed such that the 1.8 GHz signal is blocked in the rectangular ring patch and the 900 MHz signal is blocked in the notched rectangular patch. To achieve this goal, the microstrip feed network is designed. The design of the feed lines is same for port 1 and port 2 as shown in Fig.6-3.

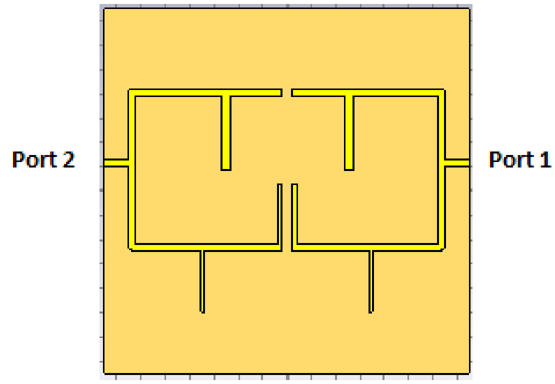


***Figure 6-3:*** *Feeding Network of Antenna*

## 8 Microstrip Patch Antenna Modelling

CST simulation software is used to get efficient and accurate computational solutions for electromagnetic design and analysis. To design the Tri-band dual-polarized patch antenna five primary steps were involved.

1. The dielectric substrate was selected as FR-4 lossy.
2. The patches were drawn according to the dimensions given in Table 5-2 and Table 5-3.
3. The ground plane was inserted and H-shaped coupling slots were cut into the ground plane of the antenna.
4. The feed network of the antenna was designed.
5. The feeding ports were inserted.

The two dielectric substrates in the design are separated by an air gap of 12.8mm. In antennas having air gap, tuning is achieved by adjusting the thickness of air gap to provide operation for all three bands. The reason behind this is the effective dielectric constant $\varepsilon_r$ is a function of air gap thickness as well as the parameters of the patch, when the thickness of air gap is changes the value of $\varepsilon_r$ also changes which results in a new resonating frequency. The final design of Tri Band Dual Polarized Patch antenna is shown in the Fig.6-4. The Figures below shows the geometry of the simulated antenna in CST. Fig.6-4a shows the dielectric substrate having rectangular ring patch and notched rectangular patch. The Fig.6-4b shows the feed network of the antenna system.

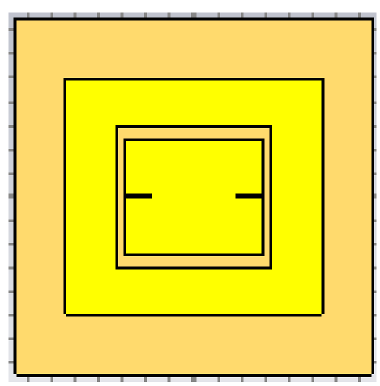

***Figure 6-4a:*** *First Layer Substrate with Two Patches*

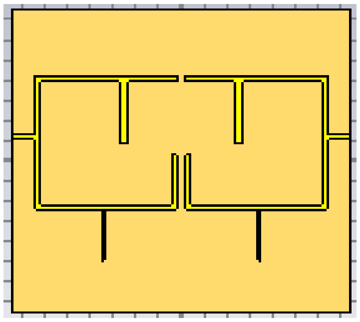

***Figure 6-4b:*** *Lower Layer Substrate with Feed Network*

## 9 Simulation Results

After the completion of 3D modeling, the performance of the antenna system was measured. The return loss, gain and directivity plots, E and H field patterns in order to check for dual polarization and Tri band operation.

### 9.1 Return Loss

The simulation results for the return loss of the antenna is shown in Fig.9-1. Results show that the antenna is radiating at 900 MHz, 1.8 GHz and also in the wideband range of 2.3-2.5 GHz. From the Fig.9-1 it is clear both the S11 and S22 parameters results are approximately same so the antenna is radiating on the desired bands of frequencies from port 1 and 2.

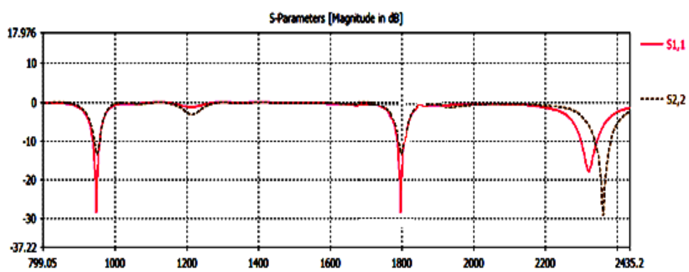


***Figure 9-1:*** *Return Loss of Simulated Antenna*

### 9.2 Directivity

The simulation result for the directivity of the antenna is shown in Fig. 9-2. The directivity of the simulated antenna is 19.3 dB at 900 MHz, 9.9 dB at 1.8 GHz and 10.2 dB at 2.4 GHz for port 1 and port 2. Fig 9-2a and Fig.9-2b shows the polar plot for the directivity of antenna.

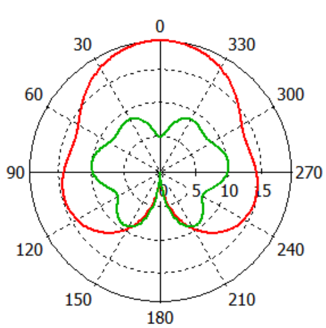


***Figure 9-2a:*** *Directivity of Simulated Antenna (Port 1, 2)*

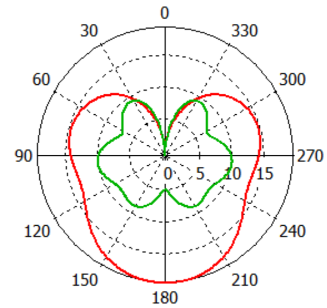


***Figure 9-2b:*** *Directivity of Simulated Antenna (Port 2, 1)*

From figures it is clear that the directivities of both ports are orthogonal to each other which is the requirement of the dual-polarized antenna.

### 9.3 Gain

The simulation result for gain of the designed antenna is shown in Fig.9-3.

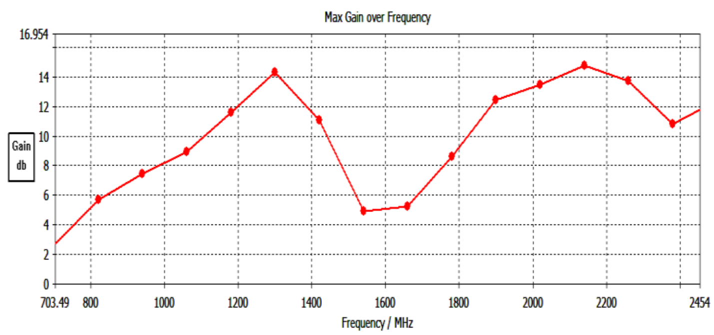


***Figure 9-3:*** *Gain of Simulated Antenna*

From the figure it is quite clear that the gain of the antenna system is 7.5db at 900 MHz, 9db at 1.8 GHz and just above 10 dB at 2.4 GHz approximately which is acceptable at all the three bands of operation and are greater than 6db.

### 9.4 Field Characteristics

The simulation results of E-field show that the antenna is dual-polarized. Fig. 9-4 shows the dual polarization characteristics of the simulated antenna.

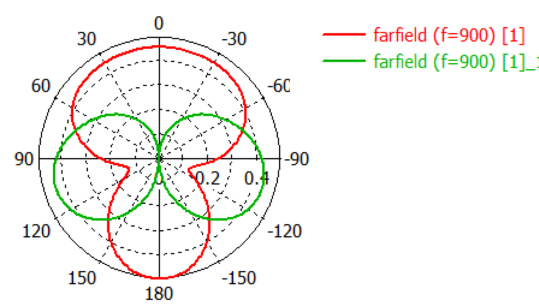


***Figure 9-4a:*** *Port 1 Cross-pol vs. Co-pol at 900 MHz*

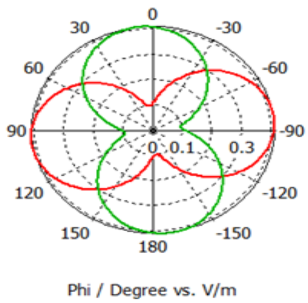


***Figure 9-4b:*** *Port 1 Cross-pol vs. Co-pol at 1.8 GHz*

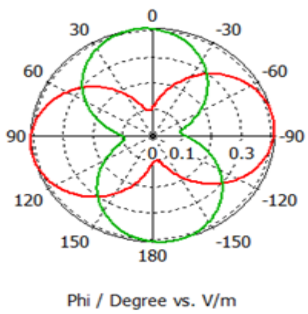


***Figure 9-4c:*** *Port 1 Cross-pol vs. Co-pol at 2.4 GHz*

Fig.9-4a, Fig.9-4b and Fig.9-4c clearly show the dual polarization of the antenna. The direction in which antenna is radiating at 900 MHz is orthogonal to the direction in which it is radiating at 1.8 GHz and 2.4 GHz. The same justification is true for port 2 E-field radiation patterns shown in Fig.9-5.

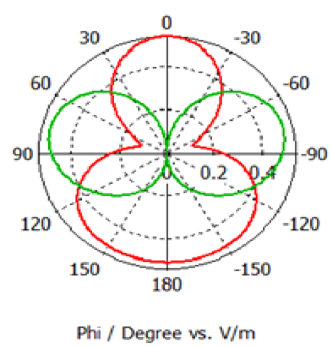


***Figure 9-5a:*** *Port 2 Cross-pol vs. Co-pol at 900 MHz*

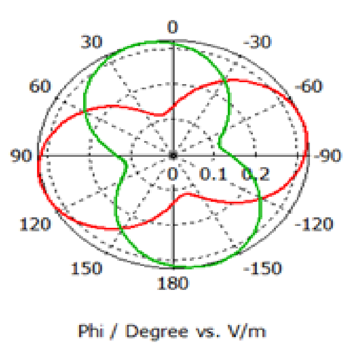


***Figure 9-5b:*** *Port 2 Cross-pol vs. Co-pol at 1.8 GHz*

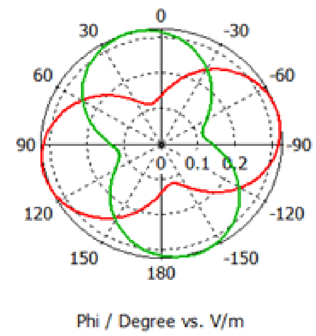


***Figure 9-5b:*** *Port 2 Cross-pol vs. Co-pol at 2.4 GHz*

## 10 FABRICATION AND TESTING

The dielectric material that is being selected for the fabrication of antenna is FR-4. FR-4 glass epoxy is well known and versatile in high pressure bearing ability named as thermoset plastic laminate grade. Its strength to weight ratio are good. Its water absorption ability is near to zero [14]. FR-4 is usually used as electrical insulators with sufficient mechanical strength. Such materials are well known due to its high mechanical and electrical insulating value. It also has good fabrication qualities which makes it excellent for wide range of electrical and mechanical applications. The etching of the selected FR-4 dielectric is done by using Milling machine. In this project manual etching is used to develop the antenna by setting axis on the machine. 1.5 mm V-shaped End-mill tool is used to remove copper from large area of PCB.

### 10.5 Assembly

The fabricated antenna has two layers and there is an air gap of 12.8 mm in between the layers. For the spacing purpose PCB spacers of 12.8mm were used. After completing the fabrication and assembling process of the antenna, SMA female (PCB mount) were soldered onto the feed lines of the antenna. The final fabricated antenna is shown in Fig.10-1 to Fig.4-3.

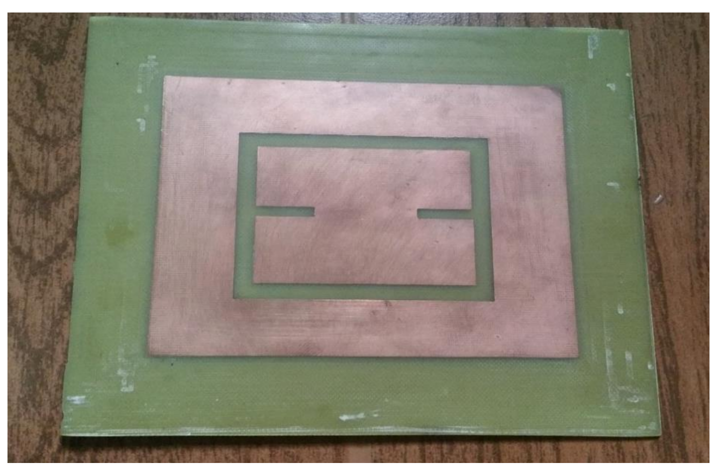

***Figure 10-1:*** *Dielectric with Two Patches*

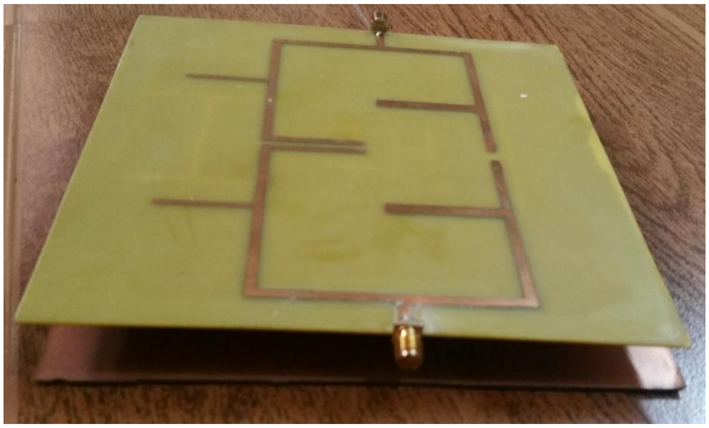

***Figure 10-2:*** *SMA Female Connected at the Feed Network*

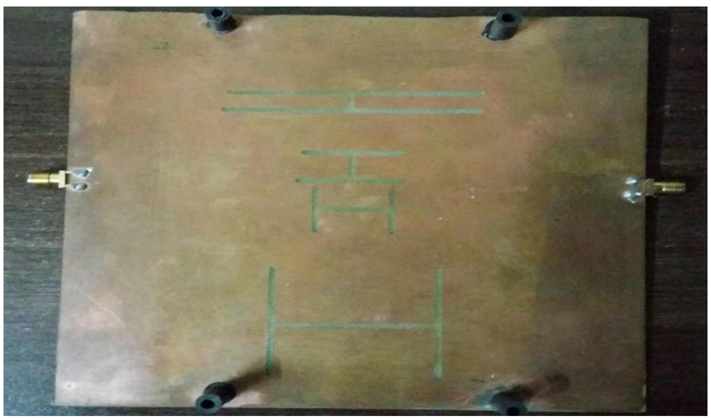

***Figure 10-3:*** *Coupling Slots on Ground Plane of Antenna*

Fig.10-1 shows the rectangular ring patch and the notched rectangular patch of the etched antenna. Fig.10-2 shows the feed network of the fabricated antenna. Fig.10-2 shows the SMA female connector connected to the feed terminals of the antenna and Fig.10-3 shows the four coupling slots cut at the ground plane of the feed network to couple more energy to the patches. The testing and measurements of the fabricated antenna system is discussed in detailed below.

### 10.6 NETWORK ANALYZER RESULTS

The return loss of the designed Tri Band and Dual Polarized microstrip patch antenna was measured with VNA (Vector Network Analyzer). Male to male SMA adapter were used to interface antenna with VNA. Before testing procedure of the antenna VNA is calibrated with different tests such as short circuit, open circuit, match circuit and throughput test. After calibration 2.4 mm adapter was used to make SMA compatible with VNA. Different plots of S11, S22 with respect to frequency were taken as shown in Fig.4-7.

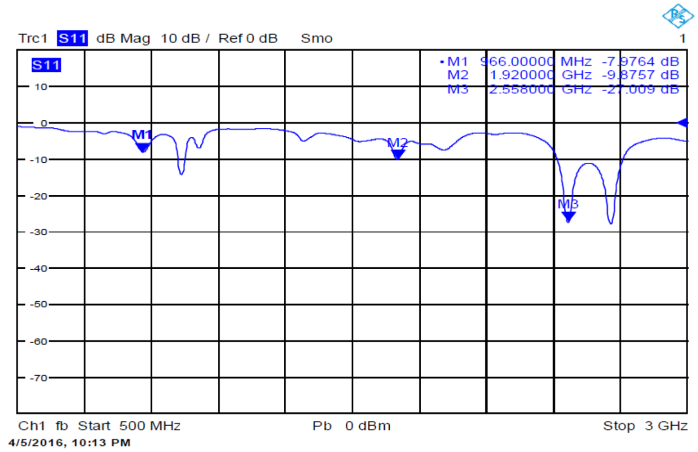


***Figure 10-1:*** *S11 Response of the Antenna*

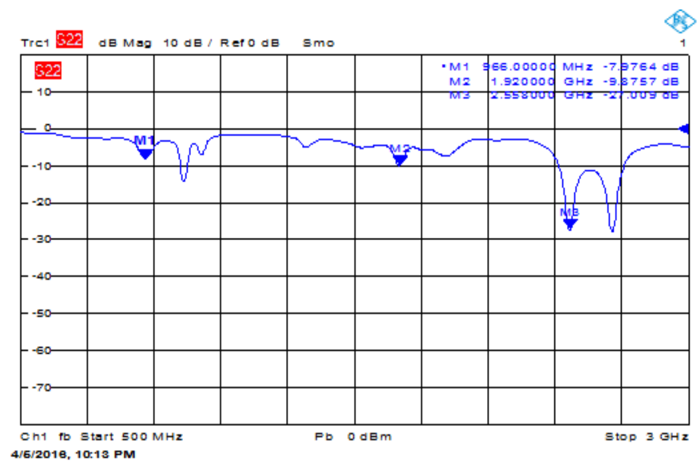


***Figure 10-2:*** *S22 Response of the Antenna*

Fig. 10-1 shows the S11 parameters of the fabricated antenna which shows that the antenna is radiating on the desired frequencies i.e. 900 MHz, 1.8 GHz and 2.4 GHz. Fig. 10-2 shows the S22 parameters of the fabricated Tri band Dual Polarized patch antenna. There are little variations in the results which are due to fabrication tolerances and can be removed by using material having good dielectric constant like Duroid, or by using automatic etching etc.

### 10.7 Radiation Pattern Measurement

Anechoic chamber is used to test the radiation pattern of fabricated antenna. While on the receiving side of anechoic chamber reference antenna is connected in horizontal and then in vertical direction. Then SMA connector is connected with port 2 of antenna and again the position of reference antenna is changed in horizontal and vertical direction and the radiation patterns are taken in both directions. The testing of antenna in anechoic chamber is shown in Fig. 10-1.

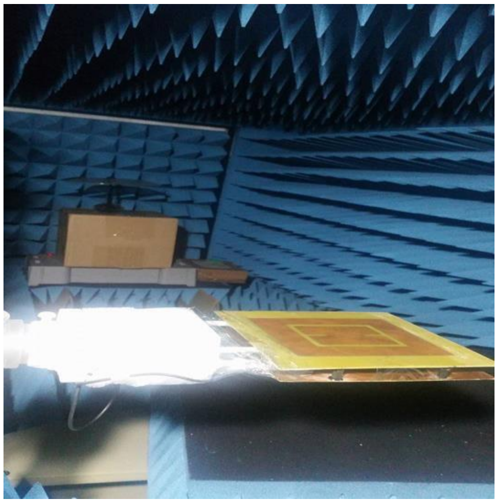

***Figure 10-1:*** *Antenna Testing Using Anechoic Chamber*

The radiation patterns taken from anechoic chamber for port-1 at 900 MHz, 1.8 GHz and 2.4 GHz are shown in Fig.10-2 and are compared with simulated results.

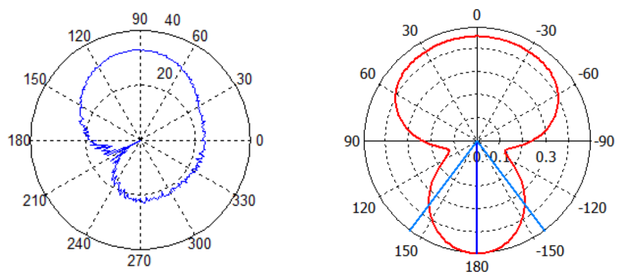

***Figure 10-2:*** *Measured and simulated Radiation Pattern of Port-1 at 900 MHz*

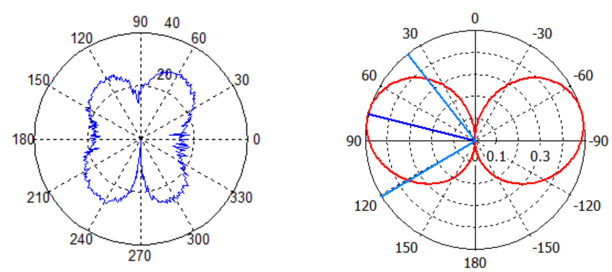

***Figure 10-3:*** *Measured and Simulated Radiation Pattern of Port-1 at 1.8 GHz*

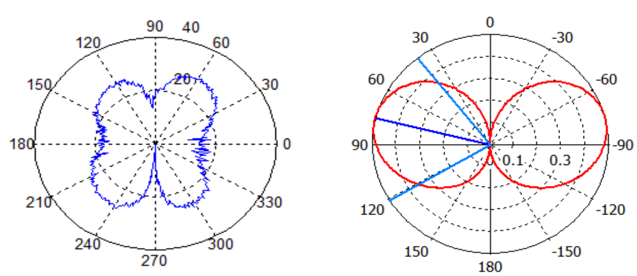

***Figure 10-4:*** *Measured and Simulated Radiation Pattern of Port-1 at 2.4 GHz*

From Fig. 10-3 we can observe that the radiation characteristics of port-1 at 900 MHz are orthogonal to that of it at 1.8 GHz and 2.4 GHz. If we compare Fig. 10-2, Fig. 10-3 and Fig. 10-4 we can notice the both the simulation and measured results are approximately the same. The direction in which port-1 is radiating at 900 MHz is orthogonal to the direction in which it is radiating at 1.8 GHz and 2.4 GHz.

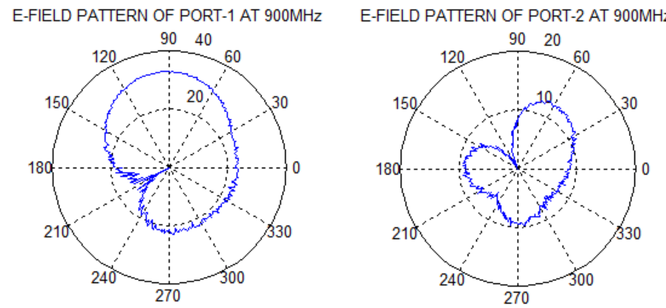


***Figure 10-5:*** *Measured Polarization Discrimination of Port - 1 & 2 at 900 MHz*

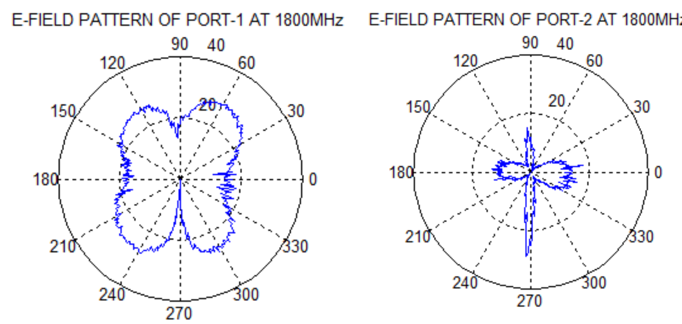


***Figure 10-6:*** *Measured Polarization-Discrimination of Port – 1 & 2 at 1.8 GHz*

Fig. 10-5 and Fig. 10-6 shows the cross polarization discrimination of port-1 and port-2 at 900 MHz and 1.8 GHz respectively. The cross-polarization behavior is found to be good at 900 MHz and 1.8 GHz which is the required characteristic of dual polarized antenna.

## 11 Conclusion

The work in this paper is primarily focuses on the design, fabrication and testing of Tri Band Dual Polarized microstrip patch antenna. The antenna was developed on FR-4 dielectric. If Duroid dielectric is used for the fabrication, then losses will be minimized and efficiency will be increased. Due to constraints FR-4 dielectric for the fabrication of the antenna is used. In future if dielectric material like Rogers Duroid is available for fabrication, then size of antenna will be reduced and its efficiency will be increased. Further by using good dielectric material we can improve this Dual Polarized antenna for next generation networks applications. The software simulation was conducted and the two patches were finely tuned and placed such that they also provide operation in the 2.4 GHz band. After the successful simulation of the antenna, the fabrication was conducted. In testing s-parameters of the antenna was verified on network analyzer. For the measurement of radiation patterns, the anechoic chamber was used. It has been found that the patch antennas can be used to radiate at other frequencies rather than their own fundamental operating frequency in the antenna system is planned and tested accordingly.

## Acknowledgment
Special gratitude to my professors and teachers their assistances in stimulations, suggestions and encouragement helped me to coordinate the project and develop some useful outcomes. Furthermore, I would also like to acknowledge with much appreciation the crucial role of all the faculty members for testing the antenna using Network Analyzer and Anechoic Chamber and his feedback on fabrication quality, substrate selection, useful suggestions and comments on design. I would like to thank all the technical staff of Electrical Engineering labs for assisting us in correct utilization of fabrication facility.

## References
[1] D. Wang and Q.Rao, “Integrated Design of Multiple Antennas for WiFi/Bluetooth/GPS Mobile Communication,” Progress In Electromagnetics Research Symposium Proceedings, pp. 755-757, July 2010.

[2] J. Jootar and J. F. Zeidler, “Performance of Polarization Diversity in Correlated Nakagami-m Fading Channels,” in IEEE Transactions on Vehicular Technology, vol. 55, pp. 128-126, 2006.

[3] B. Guo, “Antenna Diversity in Mobile Phone,” 2008.

[4] Foschini, G. J., & Gans, M. J. On limits of wireless communications in a fading environment when using multiple antennas. Wireless personal communications, 6(3), 311-335, 1998.

[5] H. F. AbuTarboush, H. S. Al-Raweshidy and R. Nilavalan, “Multi-band antenna for different wireless applications,” in IEEE International Workshop on Antenna Technology, Santa Monica, 2009.

[6] Geyi, W. Rao, Q. Ali and S. Wang, “Handset Antenna Design: Practice and Theory,” Progress in Electronic Research, pp. 123-160, 2008.

[7] Garg, Ramesh. Microstrip antenna design handbook. Artech house, 2001.

[8] Y. Murakami, W. Chujo and a. M. Fujise, “Mutual Coupling Between Two Ports of Dual Slot Coupled Circular Patch Antennas,” IEEE AP-S Int. Symp. Digest, pp. 1469-1472, 1993.

[9] Y. Murakami, “Dual Slot-Coupled Microstrip Antenna for Dual Frequency Operation,” Electron. Lett, vol. 29, pp. 1906-1907, 1993.

[10] A. Ali, S. H. Pramono and M. Sarosa, “Handset Antenna Design for Mobile Communication System,” Journal of Electronics and Communication Engineering, vol. 2, pp. 30-35, September 2012.

[11] S. Islam and M. Latrach, “Bandwidth enhancement and size reduction of patch antenna by etching linear slots in the ground plane,” in Radio Science Conference, Gran Canaria, 2015.

[12] Latif, Saeed I., Lotfollah Shafai, and Satish Kumar Sharma. "Bandwidth enhancement and size reduction of microstrip slot antennas." IEEE Transactions on Antennas and Propagation 53.3 (2005): 994-1003.

[13] DAVID, M. POZAR. "A review of bandwidth enhancement techniques for microstrip antennas." Microstrip Antennas: the analysis and design of microstrip antennas and arrays (1995): 157.

[14] Khan, Anzar, and Rajesh Nema. "Analysis of five different dielectric substrates on microstrip patch antenna." International journal of computer applications 55.14 (2012).