DESIGN OF RECTANGULAR MICROSTRIP PATCH ANTENNA

A PROJECT REPORT

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BONAFIDE CERTIFICATE

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ABSTRACT

The rectangular microstrip patch antenna (RMPA) with microstrip line inset feed is presented. The design involves finding the length and width for microstrip rectangular radiator with suitable thickness of dielectric substrate at 2.4GHz. The proposed RMPA is etched on Fibre Reinforced Plastic (FRP-4) PCB dielectric material with a relative permittivity of dielectric (ε_r) 4.4 and thickness of 1.58mm. Simulation is carried out to validate the antenna network and radiation parameters. The return loss and gain of the proposed antenna is 21dB and 1.5dB respectively. The RMPA radiation patterns are plotted with co-polarization and cross polarization. The results are compared with analytical values to the simulated parameters of the antenna and it shows good agreement.

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LIST OF SYMBOLS AND ABBREVATIONS

λ_0	Free space wave length
λ_g	Guided wavelength
ε_r	Relative dielectric constant
ε_{reff}	Effective dielectric constant
Z_0	Characteristics impedance
Z_L	Load impedance
H	Height of dielectric substrate
Hz	Hertz
dB	Decibel
WLAN	Wireless local area network
RL	Return loss
f_r	Resonating Frequency
RMPA	Rectangular Microstrip Patch Antenna

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CHAPTER 1

INTRODUCTION

1.1 WIRELESS COMMUNICATIONS

Wireless local networks (WLANs) provide connections between computers over short distances. Typical indoor applications may be in hospitals, office buildings, and factories, where the coverage distances are usually less than a few hundred feet. Outdoors, in the absence of obstructions and with the use of high gain antennas, ranges up to a few miles can be obtained. Wireless networks are especially useful when it is impossible or prohibitively expensive to place wiring in between buildings, or when only temporary access is needed between computers. Mobile computers users, of course, can only be connected to a computer network by a wireless link.

Currently most commercial WLAN products in the US operate in the Industrial, Scientific, and Medical(ISM) frequency bands, and use either frequency-hopping or direct sequence spread spectrum techniques in accordance with IEEE Standards 802.11a, 802.11b, 802.11g, or Bluetooth standard. Maximum bit range ranges from 1-1Mbps.

1.2 TYPES OF ANTENNAS

- Wire Antennas
- Aperature Antennas
- Microstrip Antennas
- Array Antennas
- Reflector Antennas
- Lens Antennas

1.3 ANTENNA PARAMETERS

1.3.1 Input Impendance

For an efficient transfer of energy, the impedance of the radio, of the antenna and of the transmission cable connecting them must be same. Transreceivers and their transmission lines are typically designed for 50 ohm impedance. If the antenna has impedance different from 50 then there is a mismatch and an impedance matching circuit is required. An antenna’s impedance relates the voltage to the current at the input to the antenna. An antenna with real input impedance (zero imaginary part) is said to be resonant. An antenna’s impedance will vary with frequency.

1.3.2 Bandwidth

The bandwidth of an antenna refers to the range of frequencies over which the antenna can operate correctly. The antenna’s bandwidth is the number of Hz for which the antenna will exhibits an VSWR less than 2:1. The bandwidth can also be described in terms of percentage of the carrier frequency of the band

$$\text{BW in \%} = \frac{F_H - F_L}{F_C} \times 100 \tag{1.1}$$

Where F_H is the highest frequency in the band, F_L is the lowest frequency in the band, and F_C is the center frequency in the band. In this way, bandwidth is constant relative to frequency. If bandwidth was expressed in absolute units of frequency, it would be different depending upon the frequency. Different types of antennas have different bandwidth limitations.

1.3.3 Directivity and Gain

Directivity in the ability of an antenna to from energy in a particular direction when transmitting, or to receive energy better from a particular direction when receiving. In a static situation, it is possible to use the antenna directivity to concentrate the radiation beam in the wanted direction. However is a dynamic system where the trans-receiver is not fixed , the antenna should radiate equally in all direction, and this is known as an Omni-directional antenna.

$$D = \frac{U}{U_0} = \frac{4\pi U}{P_{rad}} \quad \text{(Dimension less)} \tag{1.2}$$

Where U is radiation intensity and P_{rad} is power radiated. Gain is not a quantity which can be defined in terms of a physical quantity such as the Watt or the ohm, but it is a dimension ratio.

$$G=\frac{4\pi U(\theta,\varphi)}{P_{in}} \quad \text{(Dimension less)} \tag{1.3}$$

Gain is given in reference to the standard antenna. The two most common reference antennas are the isotropic antenna and the resonant half-wave dipole antenna. The isotropic antenna radiated equally well in all directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas. Any real antenna will radiate more energy in some directions than in others. Since it cannot create energy, the total power radiated is the same as an isotropic antenna, so in other directions it must radiate less energy. The gain of the antenna in a given direction is the amount of energy radiated in that direction compared to the energy an isotropic antenna would radiate in the same direction when driven with the same input power. Usually we are only interested in the maximum gain, which is the gain in the direction in which the antenna is radiating most of the power. An antenna gain 3dB of compared to an isotropic antenna would be written as 3dBi. The resonant half-wave dipole can be useful standard for comparing to other antennas at on frequency or over a very narrow band of frequencies. To compare the dipole to an antenna over a range of frequencies require a number of dipoles of different lengths. An antenna gain of 3dB compared to a dipole antenna would be written as 3dBd.The method of measuring gain by comparing antenna under test against a known standard antenna, which has a calibrated gain, is technically known as a gain transfer technique. Another method for measuring gain is the 3 antennas method, where the transmitted and received power at the antenna terminals is measured between three arbitrary antennas at a known fixed distance.

1.3.4 Beamwidth

An antenna's beamwidth is usually understood to mean the half-power beamwidth. The peak radiation intensity is found and then the points on either side of the peak which represent half of the peak intensity are located. The angular distance between the half power points is defined as the beamwidth. Half the power expressed in decibels is 3dB,so the half power beamwidth is sometimes referred to as 3dB the beamwidth .Both horizontal and vertical beamwidths are usually considered. Assuming that most of the radiated power is not divided into site lobes, then the directive gain is inversely proportional to the beamwidth: as the beamwidth decreases, the directive gains increases.

1.3.5 Polarization

Polarization is defined as the orientation of the electric field of an electromagnetic wave. Polarization is in general described by an ellipse. Two special cases of elliptical polarization are linear polarization and circular polarization. The initial polarization of a radio wave is determined by the antenna. With linear polarization the electrical field vector stays in the same plane all the time. Vertically polarized radiation is somewhat less affected by reflections over the transmission path. Omni directional antennas always have vertical polarization. With horizontal polarization, such reflections cause variations in received signal strength. Horizontal antennas are less likely to pick up man-made interference, which ordinarily is vertically polarized. In circular polarization the electric field vector appears to be rotating with circular motion about the direction of propagation, making one full turn for each RF cycle. This rotation may be right hand or left hand. Choice of polarization is one of the design choices available to the RFsystem designer.

1.3.6 Return loss

This is the best and convenient method to calculate the input and output of the signal sources. It can be said that when the load is mismatched the whole power is not delivered to the load there is a return of the power and that is called loss, and this loss that is returned is called the 'Return loss'. This return loss is determined in dB

$$RL = -20\log|K| \ \text{dB} \tag{1.5}$$

$$|K| = \frac{(Z_L - Z_0)}{(Z_L + Z_0)} \tag{1.6}$$

Where

K is the reflection coefficient.

Z_L and Z_0 are the load and characteristics impedances.

To have a perfect matching between the antenna and the transmitter, K=0 and RL=∞, this indicates that there is no power that is returned or reflected but when K=1 and RL=0 dB, this indicated that the power that is sent is all reflected back.

1.4 RADIATION MECHANISM

It simply states that to create radiation, there must be a time-Varying current or an acceleration (or deceleration) of charge.

Therefore:

1. If a change is not moving, current is not created and there is no radiation.
2. If the charge is moving with a uniform velocity:
    a. There is no radiation if the wire is straight and infinite in extent.
    b. There is radiation if the wire is curved, bent, discontinuous, terminated, or truncated.
3. If the charge is oscillating in a time-domain, it radiates even if the wire is straight.

CHAPTER 2

RECTANGULAR MICROSTRIP PATCH ANTENNA

2.1 MICROSTRIP ANTENNA

One of the most exciting developments in antenna and electromagnetic history is the advent of microstrip antenna(also known as patch antenna).It is probably the most versatile solution to many systems requiring planner radiating element. Microstrip antenna falls into the category of printed antennas: radiating elements that utilize printed circuit manufacturing processes to develop the feed and radiating structure. Of all the printed antennas, including dipole, slots, and tapered slots; microstrip antenna is by far the most popular and adaptable. This is because of its silent features including ease of fabrication, good radiation control, and low cost of production. The micro strip patch antenna is constructed from dielectric substrate and patch metal and that a portion of metallization layer is responsible for radiation. Microstrip antenna was conceived in the 1950s, and then extensive investigations of the patch antennas followed in the 1970s and resulted in many useful design configurations. Through decades of research, it was identified that the performance and operation of a microstrip antenna is driven mainly by the geometry of the printed patch and the material characteristics of the substrate onto which the antenna is printed.

2.2 BASIC CHARACTERISTICS

As shown in Fig. 2.1 microstrip patch antennas of a pair of parallel conducting layers separating a dielectric medium, referred as substrate. In this configuration, the upper conducting layer or “patch” is the source of radiation where electromagnetic energy fringes off the edges of the patch and into the substrate. The lower conducting layer acts as a perfectly reflecting ground plane, bouncing energy back through the substrate and into a free space. Physically, the patch is a thin conductor that is an appreciable fraction of a wavelength in extent. The patch which has resonant behavior is responsible to achieve adequate bandwidth. The patch designs yield few perfect band widths. In most practical applications, patch antenna is rectangular or circular in shape; however, in general, any geometry is possible.

Microstrip antenna should be designed so that its maximum wave pattern is normal to the patch. This is accomplished by proper choice of mode of excitation beneath the patch. Generally, patch of microstrip antenna thickness is very thin in the range of t<<$\lambda_\circ$ (is free space wave length) and the height h of dielectric material is between 0.003$\lambda_\circ$<h<0.05$\lambda_\circ$. For a rectangular path, the length L of the element is usually $\lambda_\circ$/3<L<$\lambda_\circ$/2.There are numerous substrate that can be used for the design of micro strip antenna, and their dielectric constants are usually in the range 2.2<ε_r<10, where is relative dielectric constant. The substrate whose size is thick and dielectric constant is in the range of lower end provides better efficiency and bandwidth; but it expenses large element size.

2.3 MODEL ANALYSIS OF MICROSTRIP PATCH ANTENNA

2.3.1 Transmission line model

In this model we can see the microstrip patch antenna in 2 slots with the design of height ‘h’, and width ‘W’ and are separated by the transmission line ‘L’. It can be seen in Fig. 2.1. The electric field lined in the antenna mostly move in the substrate and even in a bit out of the substrate into the air. Due to this the transmission lines are not able to support the pure transverse electric magnetic

(TEM) mode of transmission because the lines in the substrate and lines in the air have different phase velocities. In order to have a notice of wave propagation and the fringing in the line, ε_{reff} (effective dielectric constant) has to be calculated. The value of ε_{reff} is slightly less than that of ε_r as we can see that the fringing fields are not confined only in the substrate but some are out in the air.

ε_{reff} is calculated as follows

$$\varepsilon_{reff} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2}\left[1 + \frac{12h}{w}\right]^{-1/2} \qquad (2.1)$$

where

ε_r - Relative dielectric permittivity of the substrate

ε_{reff} - Relative effective dielectric constant

h - Height of the dielectric substrate

W - Width of the patch

Let us consider a rectangular microstrip patch antenna with width W, height h, and length L, shown in Fig. 2.2.

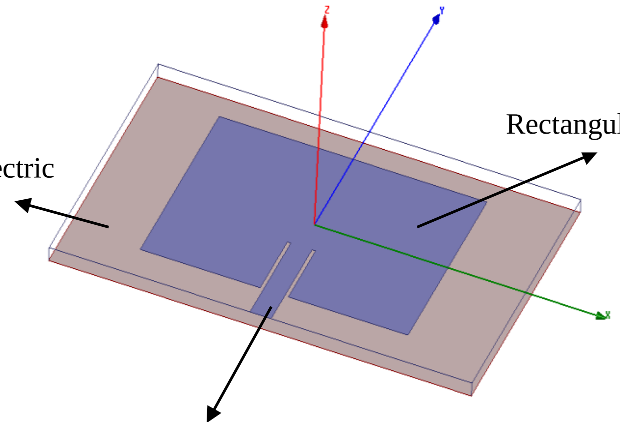


Fig. 2.1 Microstrip patch antenna

The parameters are given on the co-ordinate axis such as length on y-axis height on z direction and width on x direction. For the analysis it has to be operated in the basic mode i.e TM_{10} and for this the length of the patch should be less than $\lambda/2$ where λ-the wave length in the dielectric medium and should be equal to $\lambda_0/\sqrt{(\varepsilon_{reff})}$ where λ_0 – free space wave length. In TM_{10} mode the field varies by one $\lambda/2$ cycle towards length is no variation along the width of the patch. The microstrip patch antenna is represented by 2 slots, which are separated by the transmission line has said previously with a length L and it is open circuited on the two ends. The width of the structure has a maximum voltage and minimum current as it is an open ended circuit. The tangential and the normal components of the fields at the edges are resolved with respect to the ground plane.

The field lines, some reside in the substrate and some are spread into the air, the normal components are towards the width and opposite in direction, i.e. they are not in phase as the patch is $\lambda/2$ long. So they are cancelled as they are opposite in direction. The tangential components are in phase which makes the resulting fields to combine for a maximum radiating field to the surface of the structure. The fringing fields along the width of the structure are taken as radiating slots and the patch of the antenna electrically seen to be a bit larger than usual design. So the dimensions are changed and extended a bit for a better performance i.e. it is been extended by ΔL, E_H

ΔL is calculated as below

$$\Delta_L = 0.412h \frac{(\varepsilon_{reff} + 0.3)(w/h + 0.264)}{(\varepsilon_{reff} - 0.258)\ (w/h + 0.8)} \tag{2.2}$$

L_{eff} - the effective length of the patch is given by

$$L_{eff} = L + 2\Delta L \tag{2.3}$$

For the particular resonate frequency the effective length of the patch is calculated by

$$L_{eff} = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} \tag{2.4}$$

Where ‘c’ is velocity is light $3x10^8$ m/s

Considering the rectangular patch antenna the resonating frequency for the mode TM_{mn} is given by

$$f_r = \frac{c}{2\sqrt{\varepsilon_{reff}}} \left[\left(\frac{m}{L}\right)^2 + \left(\frac{n}{W}\right)^2 \right] \tag{2.5}$$

m, n is the operating modes of the microstrip patch antenna, along with L-length and W-width.

2.4 DESIGN OF RECTANGULAR PATCH ANTENNA

The rectangular patch is the basic and most commonly used microstrip antenna. The basic antenna element is a strip conductor of dimensions L x M on a dielectric substrate of dielectric constant (ε_r) and thickness h backed by a ground plane. When the patch is excited by a feed, a charge distribution is established on a underside of the patch metallization and the ground plane. At a particular instant of time, the underside of the patch is positively charged and the ground plane is negatively charged. The attractive force between these sets of charges tends to hold a large percentage of the charge between the two surfaces. However, the repulsive force between positive charges on the patch pushes some of these charges toward the edges, resulting in large charge density at the edges at the edges. These charges are the source of fringing field and the associated radiation power can be increased by using a thicker substrate with a lower value of dielectric constant.

2.5 DESIGN PARAMETERS OF RECTANGULAR MICROSTRIP PATCH ANTENNA

Specification used

- Relative dielectric constant (ε_r)
- Resonant frequency (f_r)
- Height of dielectric substrate (h)

2.5.1 Design of element path

Patch width is a minor effect on the resonant frequency and radiation pattern of the antenna. It affects the input resistance and bandwidth to a larger extent with proper excitation one may choose a patch width W greater than the patch length L without exciting undesired modes a constraint against a larger patch width is the generation of grating lobes in antenna array, and a small patch size might be preferred to reduce the real estate requirements .For the given design resonant frequency (f_r) and dielectric constant (ε_r) then the element width is given in equation 2.6

2.5.2 Design of effective dielectric constant

The amount of frequency is a function of the dimensions of the patch and the height of the substrate. An effective dielectric constant ε_{reff} is introduced to account for fringing and the wave propagation in the line. The effective dielectric constant is also a function of frequency. As the frequency of operation increases,most of the electric field lined concentrate in the substrate height h, and element width W, the effective dielectric constant is given in equation 2.1

2.5.3 Design of element width and length

Because of fringing effects, electrically the patch of microstrip antenna looks greater than its physical dimensions. The dimensions of the patch along its length have been extended on each end by a distance 3L, which is function of the effective dielectric constant (ε_{reff}) and the width-to-height ratio (W/h).

For the effective radiation the design of the structure is the most important aspect and for this the width is calculated as

$$w = \frac{c}{f_r}\sqrt{\frac{2}{\varepsilon_r + 1}} \tag{2.6}$$

A very popular and practical approximate relation for a normalized extension of the length is given in equation 2.3

The actual length (L) of the patch is expressed as

$$L = \frac{c}{2 f_r \sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{2.7}$$

2.5.4 Calculation of inset feed point location

To determine the feed point (x_0,y_0) so as to obtain a good impedence match between the generators impedence are input impedence of the patch element. The feed point location y_0 is calculated by the following expression

$$R_{in} = \frac{1}{2(G_1 \pm G_{12})}\cos^2\left(\frac{\pi}{L} y_0\right) \tag{2.8}$$

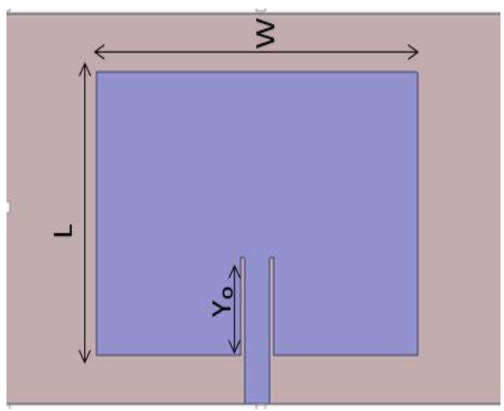
Where R_{in} =input resistance (Ω)

Where G_1 is slot conductance and it is calculated by the following expression

$$G_1 = \begin{cases} \frac{1}{90}\left(\frac{W}{\lambda_0}\right)^2 & W \ll \lambda_0 \\ \frac{1}{120}\left(\frac{W}{\lambda_0}\right) & W \gg \lambda_0 \end{cases} \tag{2.9}$$

G_{12} is mutual conductance And G_{12} is calculated by the following expression

$$G_{12} = \frac{1}{120\pi^2} \int_0^{\pi} \left[\frac{\sin\left(\frac{k_0 W}{2}\cos\theta\right)}{\cos\theta} \right]^2 J_0 \left[k_0 L \sin\theta \right] \sin^3\theta d\theta \qquad (2.10)$$



w_0

Fig. 2.2 Geometry of inset feed RMPA.

To find G_{12} Refer APPENDIX 2

y_0 is given by from equation 2.8

$$y_0 = \frac{L}{\pi} \cos^{-1} \sqrt{2R_{in}\left(G_1 \pm G_{12}\right)} \qquad (2.11)$$

The rectangular patch antenna is designed to operate at 2.4GHz with the following parameters:

Microstrip element width W=38mm

Microstrip element length L=29mm

Feedpoint location(x_0,y_0)=(0,10)mm

Inset feed line impedence Z_0=50Ω

Relative permittivity of dielectric substrate ε_r =4.4

Height of dielectric substrate h =1.58mm

CHAPTER 3

RESULTS AND DISCUSSION

The designed rectangular patch antenna is simulated using a full wave electromagnetic solver-High Frequency Structure Simulator (HFSS) to optimize the impedance matching at frequency of operation and radiation performance. The return loss of a proposed RMPA is -21dB and presented in Fig. 3.1. Fig.3.2 shows the real and imaginary part values of the input impedance with different modes of operation. It can be seen that the proposed antenna resonates at 2.4GHz. The impedance match is achieved by calculating the 50 Ohm impedance point using equation 2.11 and inset feed microstrip line method.

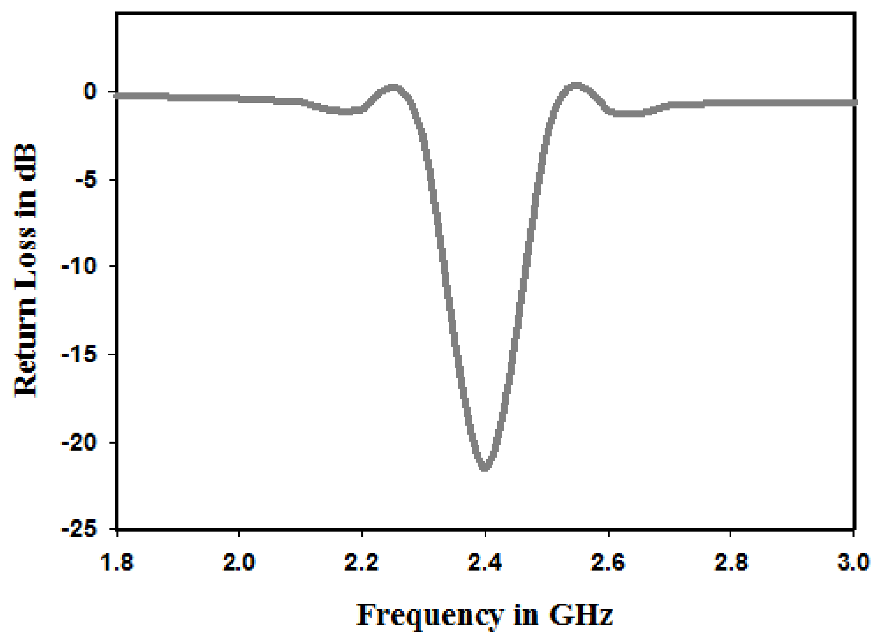


Fig. 3.1 Simulated return loss of inset feed rectangular microstrip antenna.

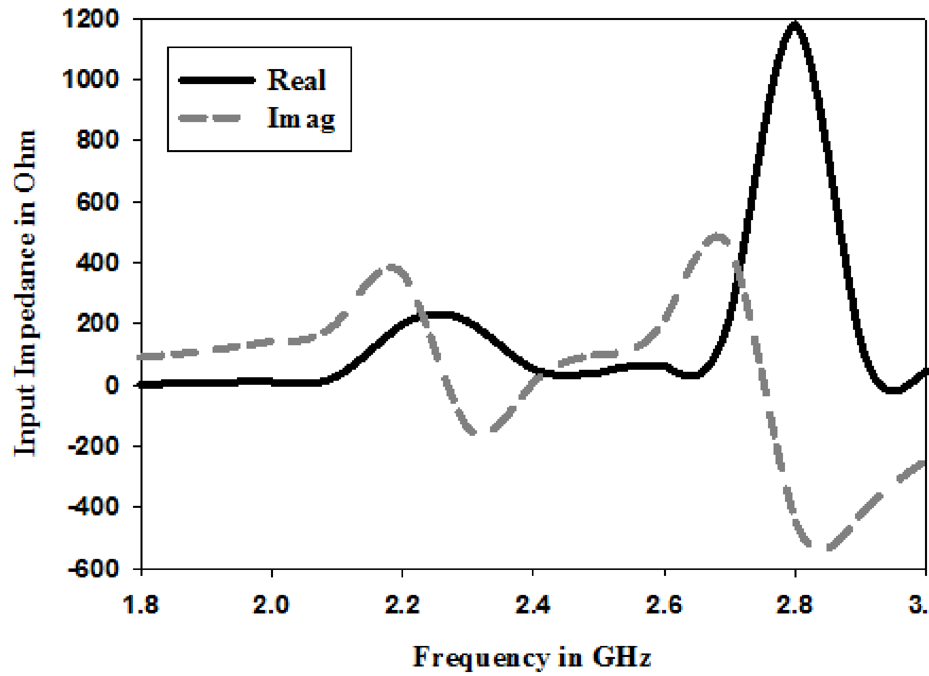


Fig. 3.2 Simulated input impedance of inset feed RMPA.

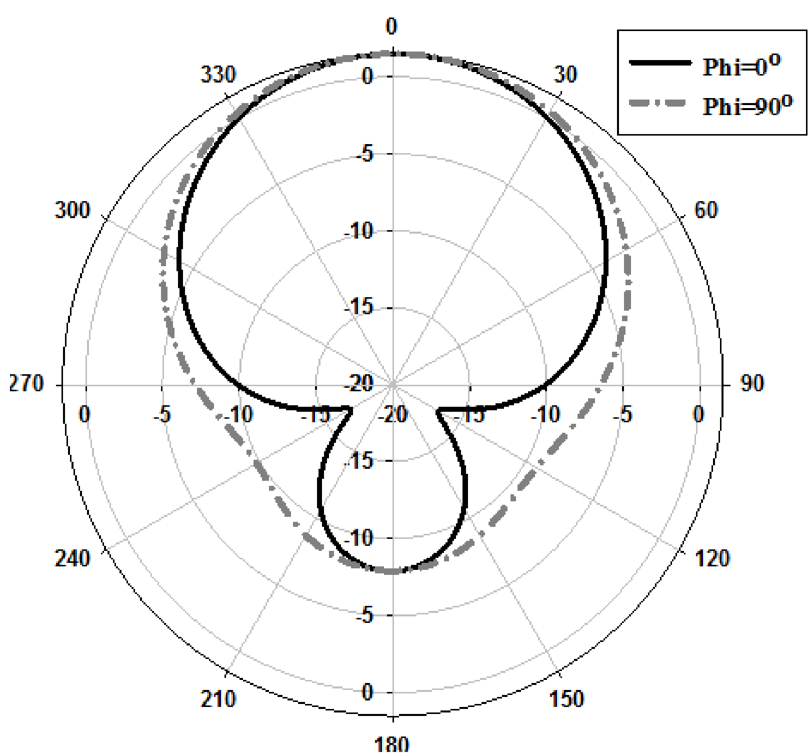


Fig. 3.3 Radiation pattern for $Gain_{Total.}$

The proposed RMPA radiation patterns in both phi=0 and phi=90 plane were plotted at operating frequency 2.4GHz in Fig. 3.3, Fig. 3.4, Fig.3.5, clearly depicting typical antenna characteristics with half space radiation patterns in both planes. The gain of the proposed antenna is 1.5dBi and the simulated cross polarization discrimination level between two planes is around 40dB.

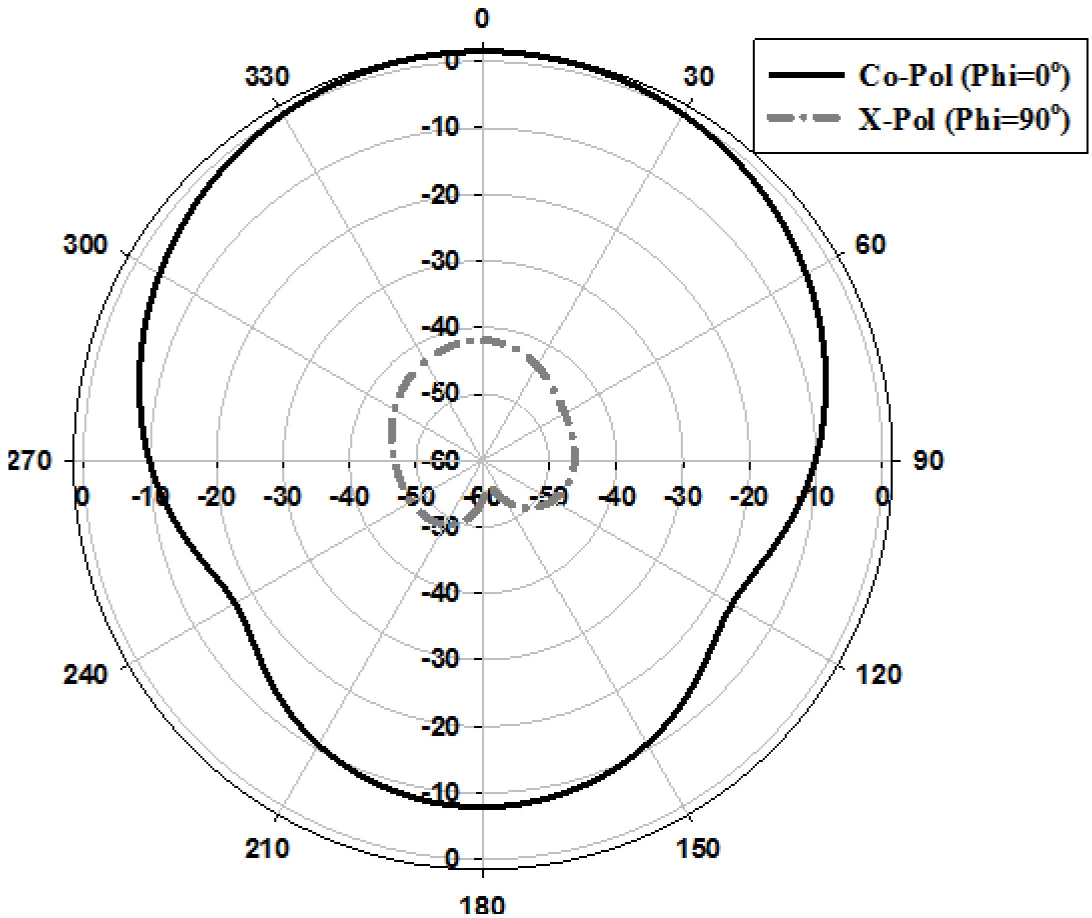


Fig. 3.4 Radiation pattern for $Gain_{phi}$.

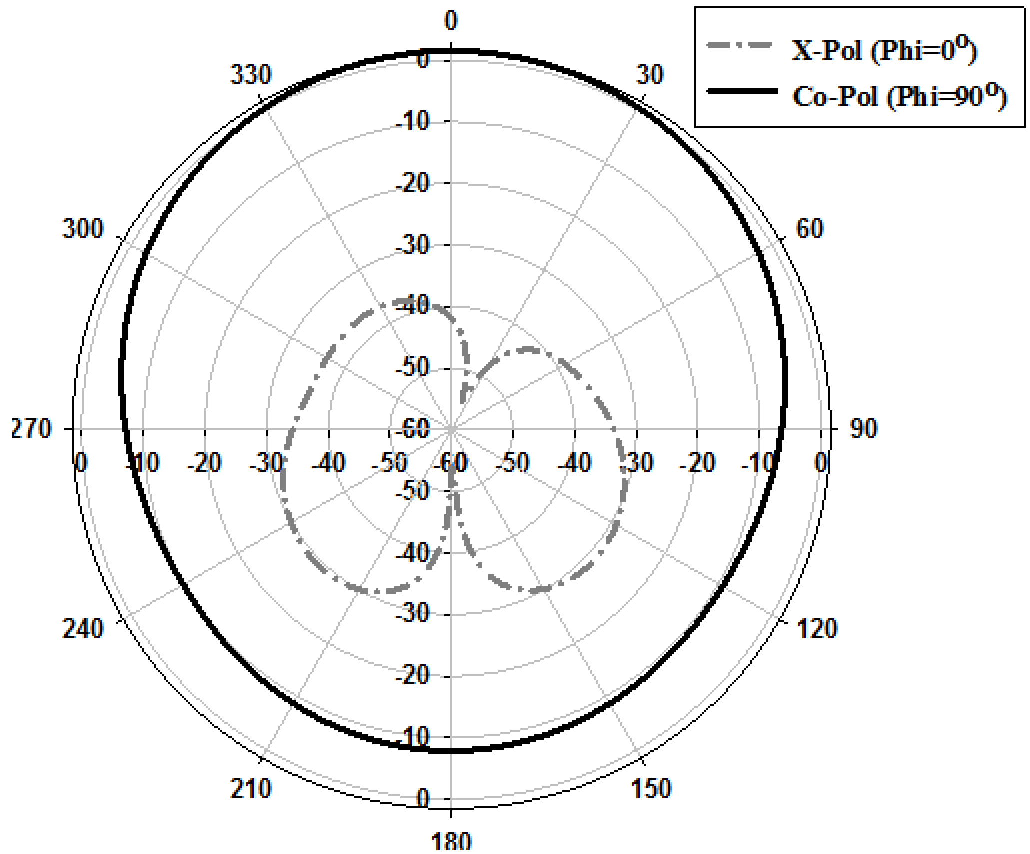


Fig. 3.5 Radiation pattern for $Gain_{Theta}$.

CHAPTER 4

CONCLUSION

A rectangular microstrip patch antenna has been designed and simulated at 2.4GHz with dielectric thickness of 1.58mm and its relative permittivity is 4.4. The radiation patterns and realized gain of Rectangular microstrip patch are plotted on both G_{theta} (co-pol & X-pol) and G_{phi} (co-pol & X-pol) at designed resonating frequency. The gain of the proposed RMPA is 1.5dB and cross polarization discrimination level is approximately 40dB. Results are obtained and compared with analytical values; it gives good agreement of antenna performance.

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APPENDIX 1

SIMULATION SOFTWARE

HFSS

High Frequency Structure Simulator (HFSS) is a 3D electromagnetic simulation tool based on finite element method. In this the structure is formulated as number of tetrahedrons. To provide the optimal mesh, HFSS uses an iterative process, called an adaptive analysis, in which the mesh is automatically refined in critical regions. The value of a vector field quantity(H-field or E-field) at points inside each tetrahedron is interpolated from the vertices of the tetrahedron. At each vertex, HFSS stores the components of the field that are tangential to the three edges of the tetrahedron. At each vertex, HFSS stores the components of the field that are tangential to the three edges of the tetrahedron. In addition, HFSS can store the component of the vector field at the midpoint of selected edges that is tangential to a face and normal to the edge. The field inside each tetrahedron is interpolated from these nodal values. By representing in this way, the system can transform Maxwell’s equations into matrix equations that are solving traditional numerical methods. There is a trade-off among the size of the mesh, the desired level of accuracy, and the amount of available computing resources. The geometry of the structure should be drawn and appropriate boundary and excitation condition should be set. HFSS generates the necessary field solutions and associated port characteristics and S-parameters. First, it generates a solutionnbased on a course initial mesh. Then, it refines the mesh in area of high error density and generates a new solution. When the number of passes is over or converges to a desired limit, the solution converges.

APPENDIX 2

MATLAB PROGRAM FOR CALCULATING OF G_{12}

```
clc;
clear all;
w=38;
l=29;
lamda=30;
k=(2*pi)/lamda;
syms x;
g=(((sin(((k*w)/2)*cos(x))/cos(x))^2)*(besselj(0,k*l*sin(x)))*sin(x)*sin(x));
q=(1/120*pi*pi)*int(g,x,0,pi);
q
```

(Note:

Type the following syntax in command window:

double(q)

now the value of q= G_{12})