Simulative Investigations on Different Shapes of Antenna

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***Abstract*—**The goal of this thesis is to design and analysis the Microstrip patch antenna with different shapes which covers the Ultra Wide Band 2.42 GHz frequency. This thesis covers study of basics and fundamentals of microstrip patch antenna. How the different characteristics of the antenna depend on its various geometrical and other parameters, a series of parametric study were done to find it. The various geometrical parameters of the antenna are the dimensions of the patch and the dimensions of the ground planes and the separation between them. It also includes the dielectric constant of the substrate material. The parametric study also includes the study of different shapes to optimize the different parameters of antenna to get the optimum results and performance. This is a simulation based study. The design and simulation of the antenna is carried out using MATLAB (matrix laboratory) software which is a multi paradigm numerical computing environment and a high performance language for technical computing. In this paper, return loss curve, antenna gains, 3d pattern, directivity, azimuth pattern, elevation pattern and the far field results are shown for all the designed antennas. Various results reflect the good antenna performance in the UWB range of frequency. Then the effects of varying the parameters of the antenna on its performance are investigated and shown. In now a days it is essential for an antenna designed for a system to avoid the interference from the other existing wireless system.

Effect of desired parameter modifications are observed, analyzed and plotted. All the design antennas are fabricated on an inexpensive dielectric substrate air with relative permittivity ($\in_r$) of 1 with thickness of 0.006 mm. The simulation results of different shapes of microstrip antennas indicate that the proposed rectangular microstrip patch antenna achieve the more gain and directivity as compare to another two shapes (circular and triangular)

Keywords- *Directivity, Return loss, Efficiency, Microstrip patch antenna, Azimuth pattern, Elevation pattern.*

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I. INTRODUCTION

In modern communication system, the wireless systems has become a one of the important system because most of the electrical and electronics equipment or applications around us are using the wireless system and it has become a very important part of human life. In wireless system, antenna is an essential and important element and antenna can be defined as an electrical device at transmitter side which transmits the electromagnetic waves into the space by converting the electric power and at the receiver side the antenna intercepts these radio waves and then converts them back into the electrical power. There are so many applications that uses antenna such as cellular phones, remote controlled television, satellite communications, spacecraft, radars, wireless computer networks and wireless phones. Day by day new wireless devices are introducing which increasing the demands of compact, cheap and low weight antennas. Increase in the spacecraft and use of antennas in the satellite communication has also increased the demands a low profile, compact, cheap and low weight antenna that can provide a reliable communication.

There are many types of antennas are existing, such as helical antenna, horn antenna, reflector antennas etc but from all only microstrip antenna is one who offers low profile, compact, cheap and low weight. It is a wide beam narrowband antenna and it can be manufactured very easily by the printed circuit technology such as a metallic layers in which a particular shape is bonded on a dielectric substrate which forms a radiating element and another continuous metallic layer on the other side of substrate reacts as a ground surface. As a radiating patch, it is not necessary to use only the basic shapes, any continuous shape can also be used as the radiating patch. Instead of using same dielectric substrate, some of the microstrip antennas use different dielectric materials and dielectric spacers which results in wider bandwidth but at the cost of less ruggedness. The applications of microstrip antennas are above the range of microwave frequencies because below these frequencies the use of microstrip antenna doesn't make a sense due to the size of the antenna. Now a day's microstrip antennas are used in many commercial sectors due to its inexpensiveness and easy to manufacture benefit with the advanced printed circuit technology. Due to the ongoing research and development in the field of microstrip antenna it is expected that in future after some time most of the conventional antenna will be replaced by microstrip antenna.

II. VARIOUS PARAMETERS OF ANTENNA

(a) Antenna Gain:

Antenna gain is defined as such parameter which can measures the degree of directivity of antenna's radial pattern. To achieve maximum gain, antennas should be designed in such a manner that the power raises in wanted direction and decreases in unwanted directions and an antenna with a maximum gain is more efficient in its radiation pattern.

$$G = \frac{\text{Power radiated by antenna}}{\text{Power radiated by reference antenna}}$$

(b) Reflection Coefficient and VSWR (Voltage Standing Wave Ratio):

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Reflection Coefficient= $\gamma(Gamma) = \frac{Z_i - Z_0}{Z_i + Z_0}$

Z_i = Input impedance

Z_0 = Characteristic impedance

- If $\gamma^2 = 0$, i.e. no power is radiated or maximum power will be transmitted.
- According to Maximum power transfer theorem, the power transmitted to load will be maximum, when output impedance is equal to input impedance.
- Antenna impedance is a complex quality. For example, if we use dipole antenna, then

$$Z_i = 73 + j45$$

Similarly:

$$VSWR = \frac{V_{max}}{V_{min}}$$

$$= \frac{1+\gamma}{1-\gamma}$$

Reflection coefficient's magnitude can varies from 0 to 1.

(c) Aperture

The power received by the antenna gets associated with collective area and this collective area is known as aperture or effective aperture. It participates in transmission and reception of electromagnetic waves.

$P_r = P_d * A$ (Watts)

$$A = \frac{P_r}{P_d}\ (m^2)$$

(d) Directivity and Bandwidth

Concentrated power radiation in a particular direction is known as the directive of antenna and it may be considered as the capability of an antenna to direct radiated power in a given direction.

$$Directivity = \frac{\text{Radiation intensity in a given direction}}{\text{Average radiation intensity}}$$

Directivity of antenna is 1, when antenna radiates equally in all the directions and is 0 in case of isotropic antenna.

$$D = \frac{41253}{Q_E Q_H}$$

Q_E = Half Power beamwidth in E plane

Q_H = Half Power beamwidth in H plane

Or

$$D = \frac{4\pi A}{wavelength^2}$$

A= Aperture area.

- If we fix wavelength and varies only aperture, then the D will be increase and Q_E and Q_H decreases.
- Similarly Gain = efficiency ∗ D
- If efficiency=100%, the gain is directly depends upon directivity.

Like directivity, Bandwidth is also an important desired parameter to choose an antenna and it can be defined as the range of frequencies over which an antenna can properly radiates and receives energy.

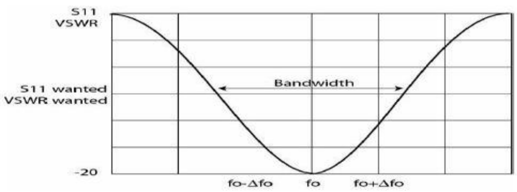

Figure 1: Bandwidth

(e) Antenna polarization

Polarization of an antenna is defined as the polarization of the electromagnetic waves which radiated from the antenna. As a function of time polarization on a wave is also defined as the orientation or path traces by the electric field vector.

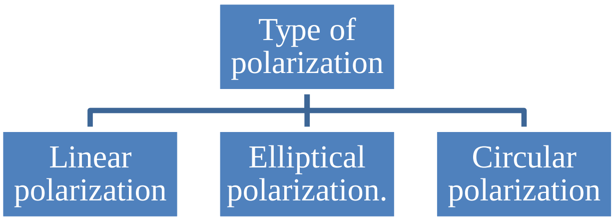

Figure 2: Types of Polarization

In free space, at a given point when electric field vector of the wave follows a linear path then the polarization is known as linear polarization and it can be categorized into two categories such as Vertical and Horizontal. Similarly, when electric field vector of the wave follows circular or elliptical path, then the polarization is known as circular or elliptical polarization and it can also be categorized into Left hand polarization when the electric field vector tracking the path by making clockwise rotation and Right hand polarized, when the vector tracking the path by making anti-clockwise rotation.

(f) Radiation Pattern

Radiation pattern is also known as Antenna Pattern or Far-Field Pattern and is defined as a graphical representation of radiated power at as fix distance from the antenna as a function of elevation and azimuth angle. Basically, antenna pattern shows that how the power is distributed in the free space at a given point. For simplicity the radiation pattern can also be drawn in 2D plane for different azimuth and elevation angle which referred as azimuth plane pattern and elevation plane pattern respectively.

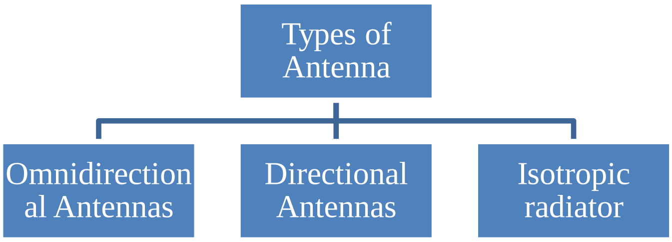

Figure 3: Types of Antenna

Where the side lobes levels play an important role, especially when antenna radiation pattern consists of different side lobes, then it is good to plot the radiation patterns in Cartesian (rectangular)

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coordinates. These antenna patterns can also be categorized into different categories such as:

Isotropic antenna: Antennas which radiates in all the directions or actually in entire space or sphere.

Omni directional antenna: Such antennas radiates equally but only in one direction. Example: Dipole antenna, Monopole antenna, Slot antenna and Normal mode helical antenna etc. **Directional antenna:** Such antenna shows maximum radiation in one direction and a little bit of a side radiation on other sides. The radiators where there is a maximum radiation is known as major loop and other are designated as minor lobe. Minor lobes are again subdivided into two lobes:

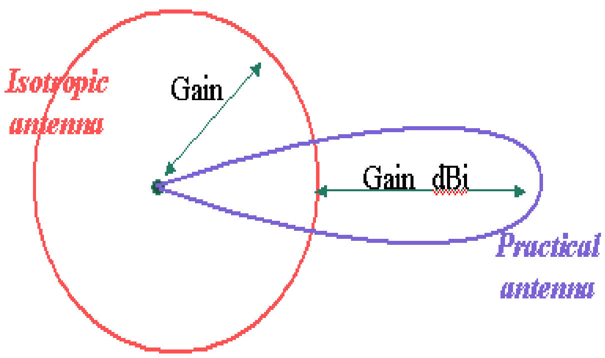

Figure 4: Isotropic antenna

- **Side lobe:** Lobe which are adjacent to the main lobe
- **Back lobe:** Lobe which is in the back side of side lobe.

Half power beam width (HPBW): When the antenna field is reduced by 50%, i.e. when E field pattern is reduced, example. From 1 to 0.7, then the power will be halved and thus half power field will be formed.

First null beam width (FNBW): It is defined as the angular difference between two nulls or it can be also generated when one end goes to maximum and other is to null.

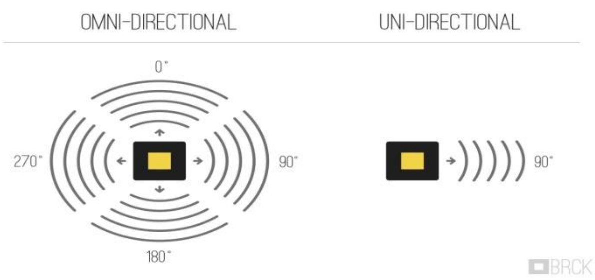

Figure 5: Omni directional and Unidirectional antenna

(g) Effective Length

The effective length is that parameter of antennas which characterizes the efficiency of the antennas in both transmitting and receiving electromagnetic waves and thus it can be defined for both transmitting and receiving antennas.

$$\textbf{Effective Length} = \frac{\textbf{Area under non} - \textbf{Uniform current distrbution}}{\textbf{Area under uniform current distribution}}$$

$$\text{Receivers' effective length} = \frac{\text{EMF at the receiver input}}{\text{Intensity of the electric field occurred on the antenna}}$$

$$\text{Effective length of the transmitter} = \frac{\text{length of the free space in conductor}}{\text{Current distribution across length}}$$

(g)Polar diagram

The radiation pattern or polar diagram is one of the most significant properties of antenna. In case of a transmitting antenna, this plot discusses about the strength of the power field radiated by the antenna in various angular directions. It can be obtained for both vertical and horizontal planes it is also named as vertical and horizontal pattern respectively.

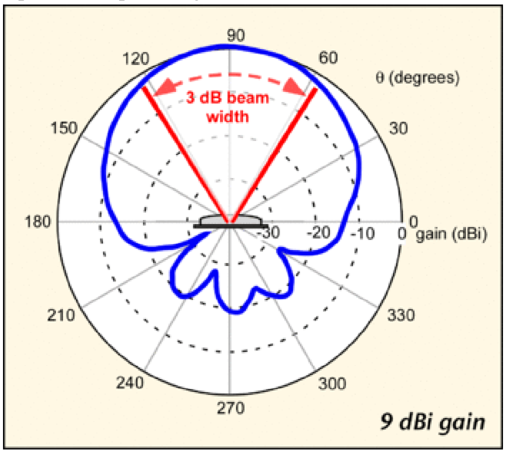

Figure 6: Polar diagram

(III) Steps to design antenna by assuming different parameters

Step 1: Determine approximate size of patch

$$\epsilon_{\mathbf{eff}} = \frac{\mathbf{1+\epsilon_r}}{\mathbf{2}}$$

Let ϵ_r=2.54 (Fr4 epoxy), Then

$$\epsilon_{\mathbf{eff}} = \frac{1+2.54}{2} = \frac{3.54}{2} = 1.76$$

Step 2: Determine wavelength (lemda) $= \frac{c}{f_o\sqrt{\epsilon_{\mathrm{eff}}}}$

(Let $f_o = 2.425$)

$$= \frac{3\times10^8}{2.425\times\sqrt{1.76}}$$

$$= \frac{3\times10^8}{3.208}$$

$$= 0.935 \times 10^8$$

$$= 93\text{ mm}$$

Thus Length (L_p) and Width (w_p) of patch = $\frac{\text{Lemda}}{2} \cong 45$ mm

Where L_p = Length of patch and w_p = Width of patch.

Step 3: Determine the line width of a microstrip antenna

$$w_f = \frac{L_p \text{ or } W_p}{10} = \frac{45}{10} \cong 4.5\text{ mm}$$

Similarly, Length will be equal to nearly quarter of the wavelength. Therefore,

$$L_f = \frac{\text{Lemda}}{4} = \frac{45}{4} \cong 20 \text{ mm}$$

Step 4: Determine the size of substrate size as $B_X \times B_Y$

$$\begin{aligned} B_X &= W_P + 2L_F \\ &= 45 + 40 \\ &= 85 \text{ mm} \end{aligned}$$

Similarly,

$$\begin{aligned} B_Y &= L_P + 2L_F \\ &= 45 + 40 \\ &= 85 \text{ mm} \end{aligned}$$

B_X = Length of substrate
B_Y = Width of substrate
B_t = 1.6 mm (assumed value) = Thickness of substrate.

Step 5: Determine the size of air box $d_x \times d_y \times d_z$

$$d_x = \frac{\text{Wavelength of free space}}{2} + B_x$$
$$d_y = \frac{\text{Wavelength of free space}}{2} + B_y$$
$$d_z = \frac{\text{Wavelength of free space}}{2} + B_z$$

Step 6: Determine the position of substrate = $\left(-\frac{\boldsymbol{B_X}}{\mathbf{2}}, -\frac{\boldsymbol{B_Y}}{\mathbf{2}}, -\frac{\boldsymbol{B_Z}}{\mathbf{2}}\right)$

$= (-43, -43, -0)$ **(**Position of substrate**)**

Step 7: Create patch surface and assign position as of substrate

$$\left(\frac{L_P}{2}, \frac{W_P}{2}, 0\right) \cong (-22.5, -22.5, 0)$$

Step 8: Create the position and size of feed line

$$\begin{aligned} \text{Position of substrate} &= \left(-\frac{W_f}{2}, -\frac{B_Y}{2}, -B_t\right) \\ &= \left(-\frac{4.5}{2}, -\frac{85}{2}, -1.6\right) \\ &\cong (-2.25, -42.5, 1.6) \end{aligned}$$

Similarly, Size of feed line = (W_f, L_f) = (4.5, 20)

Step 9: Create the position and size of ground plane

$$\begin{aligned} \text{Position of ground plane} &= \left(-\frac{B_x}{2}, -\frac{B_Y}{2}, -0\right) \\ &= \left(-\frac{\mathbf{85}}{\mathbf{2}}, -\frac{\mathbf{85}}{\mathbf{2}}, -0\right) \\ &\cong (-43, -43, 0) \end{aligned}$$

Similarly, Size of ground plane = (B_x, B_y) = (85, 85)

Step 10: Create the surface for a lumped port at the end of microstrip line

$$\begin{aligned} \text{Position} &= \left(-\frac{W_f}{2}, -\frac{B_Y}{2}, -0\right) \\ &\cong (-2.25, -42.5, 0) \end{aligned}$$

Similarly, Size = (W_f, B_t) = (4.5, 1.6)

Step 11: Assign Perfect electrical conductor (PEC) boundary to substrate and Perfect magnetic conductor (PEC) boundary to patch, feed line and ground.
Step 12: Assign Radiation boundary to the air box**.**
Step 13: Assign lump port to the port surface.
Step 14: Perform a simulation from 1GHz to 3 GHz (assumed value). Set solution frequency to 3GHz. Set maximum number of passes to 99.
Step 15: Add fast sweep from 1GHz to 3 GHz and set Step size 0.01.
Step 16: Perform simulation. Check simulation results and convergence.
Step 17: Plot S_{11} and smith chart.

Dimensions of Purposed design:

Height =0.29112
Width= 0.0012388
Area= 3.606

Radius for circular patch = $\sqrt{\frac{\text{Area}}{\pi}} = \sqrt{\frac{25.242}{22}} \cong 1.07$

Substrate = air
$\epsilon_r = 1$
$\epsilon_{eff} = \frac{1+1}{2} = 1$
Lemda= $\frac{3\times10^8}{2.425\times1} \cong 0.123$
Length of patch= $\frac{0.123}{2} = 0.061$
Width of patch = 0.061
B_x = 0.061+ 0.030 = 0.091
B_y = 0.091

IV. SIMULATION RESULTS

(a) SIMULATION SETUP FOR RECTANGULAR SHAPED MICROSTRIP PATCH ANTENNA

TABLE 1
SIMULATION PARAMETERS

Parameters	Value
Shape of Patch	Rectangle, circular, triangular
Ground Patch length	0.091
Ground Patch Width	0.091
Patch center offset	[0 0]
Area	0.003
Length	0.061
Width	0.061

B. RESULTS

In this thesis, three different shapes of antenna are analyzed with same substrate and area with different parameters. Table 1 shows simulation parameters for the required system.
Figure 7 shows the antenna properties for rectangular patch antenna. Figure 8 shows the design of rectangular patch antenna. Figure 9 shows the S parameter of rectangular patch antenna. Figure 10 shows the current distribution of microstrip rectangular patch antenna. Figure 11 shows the 3d pattern of microstrip rectangular patch antenna. Figure 12 shows the azimuth pattern of microstrip rectangular patch antenna. Figure 13 shows the elevation pattern for microstrip rectangular patch antenna. Table 2 shows the simulation parameters for rectangular patch antenna. Figure 14 shows the

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complete design of rectangular patch antenna with all desired parameters.

Table 2: Simulation Parameters for rectangular patch antenna

Parameters	Value
Shape of Patch	Rectangle
Ground Patch length	0.091
Ground Patch Width	0.091
Patch center offset	[0 0]
Area	0.003
Length	0.061
Width	0.061
Height	0.006

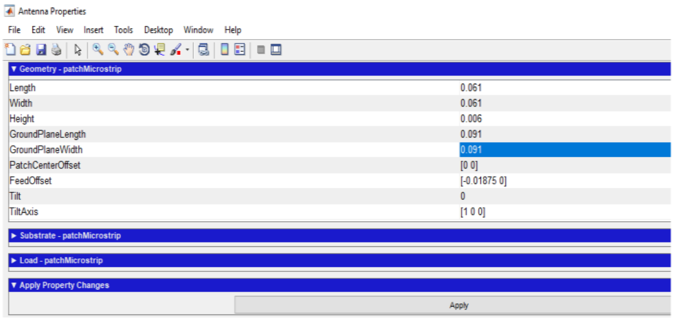

Figure 7: Antenna Properties for Rectangular Patch Antenna

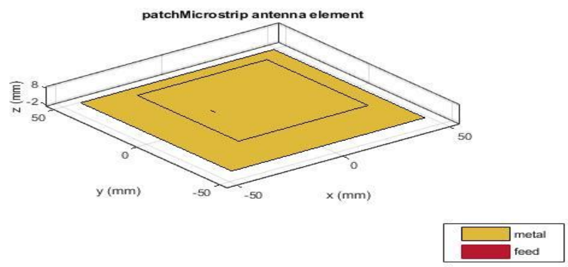

Figure 8: Design of rectangular patch antenna

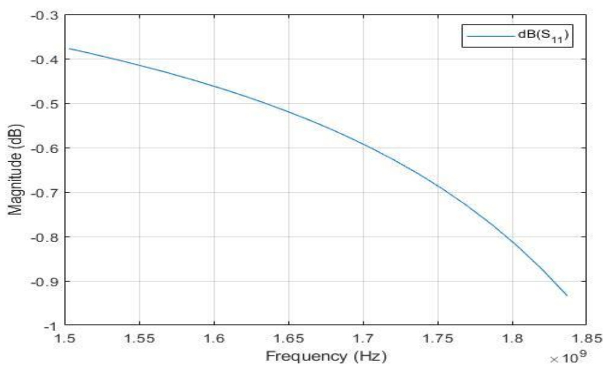

Figure 9: S parameter of rectangular patch antenna

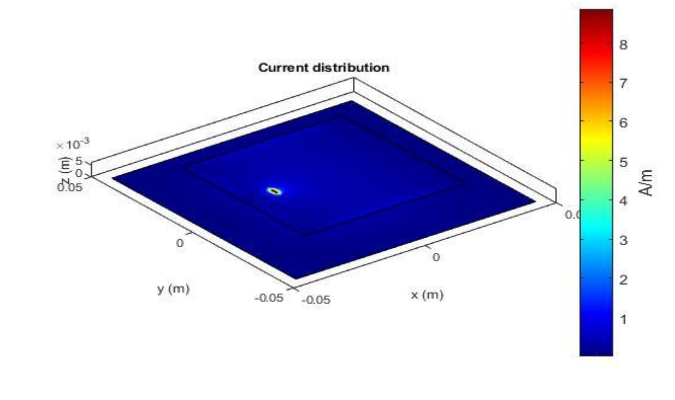

Figure 10: Current distribution of microstrip rectangular patch antenna

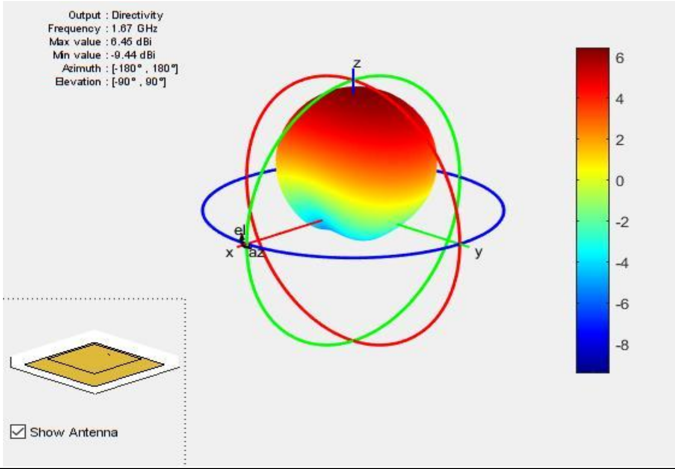

Figure 11: 3-d Pattern of rectangular patch antenna

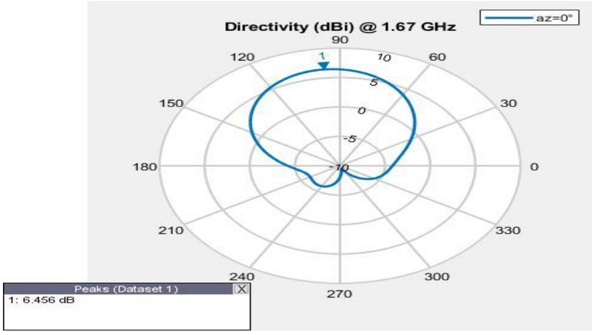

Figure 12: Azimuth Pattern for rectangular patch antenna

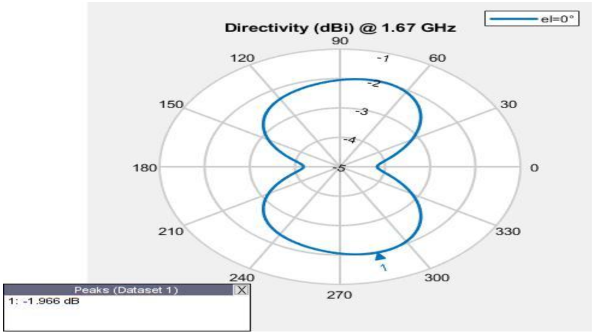

Figure 13: Elevation pattern of rectangular patch antenna

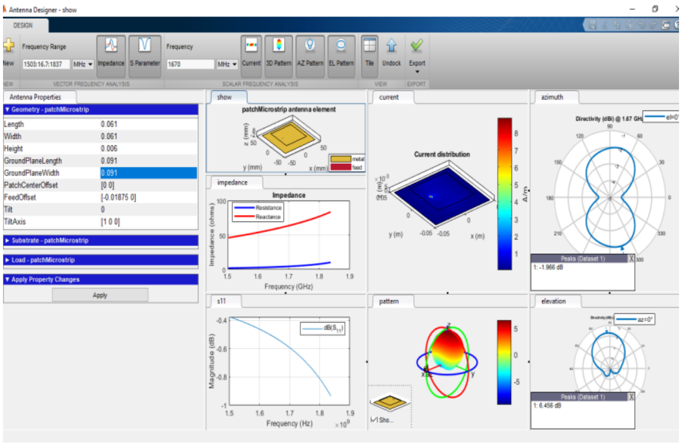

Figure 14: Complete design of rectangular patch antenna with all parameters

Figure 15 shows the antenna properties for circular patch antenna. Figure 16 shows the design of circular patch antenna. Figure 17 shows the S parameter of circular patch antenna. Figure 18 shows the impedance of circular patch antenna. Figure 19 shows the current distribution of circular patch antenna. Figure 20 shows the 3d pattern of circular patch antenna. Figure 21 shows the azimuth pattern of circular patch antenna. Figure 22 shows the elevation pattern for circular patch antenna. Table 3 shows the simulation parameters for rectangular patch antenna. Figure 23 shows the complete design of circular patch antenna with all desired parameters.

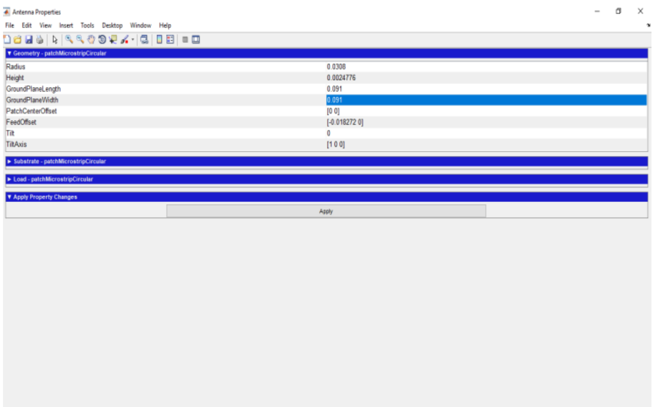

Figure 15: Antenna properties for circular patch antenna.

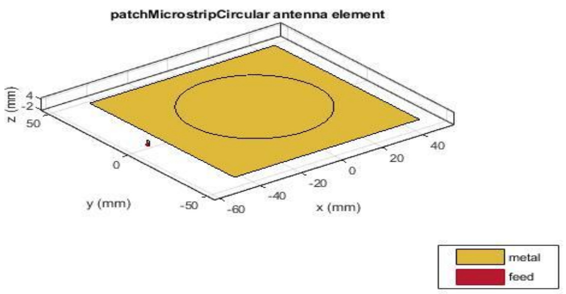

Figure 16: Design of circular patch antenna.

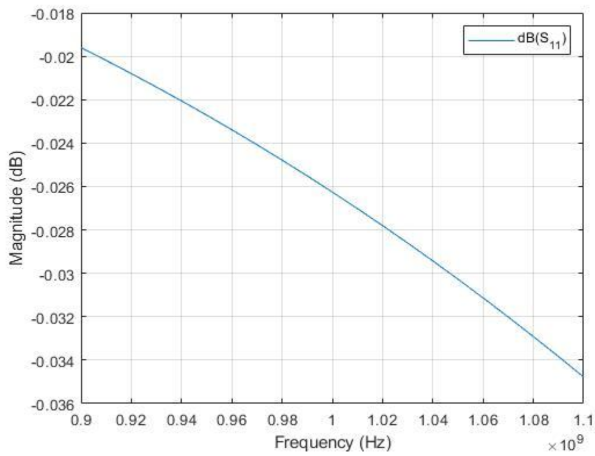

Figure 16: S-parameter of circular patch antenna

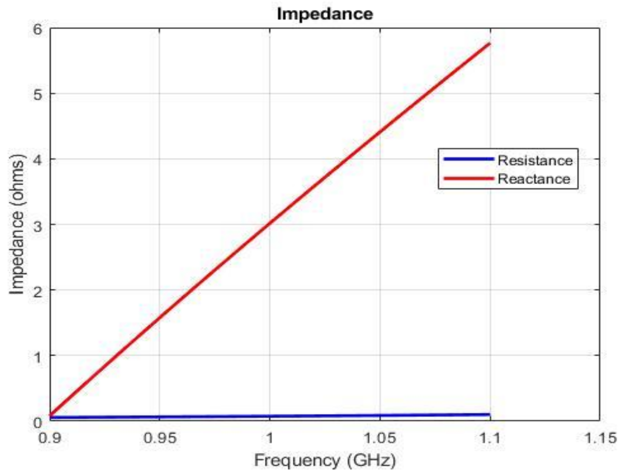

Figure 18: Impedance of circular patch antenna.

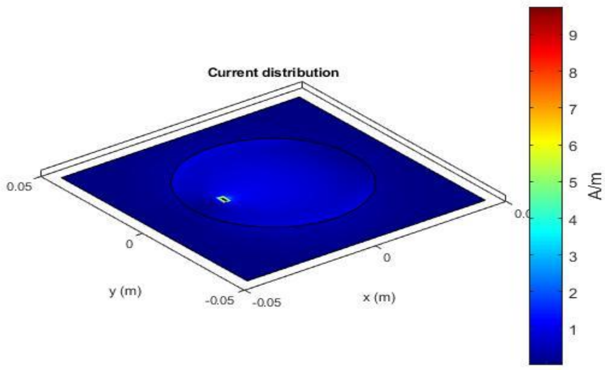

Figure 19: Current distribution of circular patch antenna

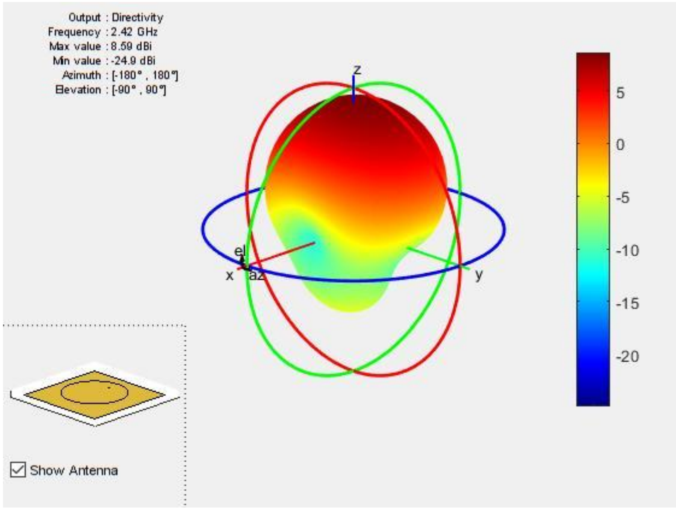

Figure 20: 3d pattern of circular patch antenna

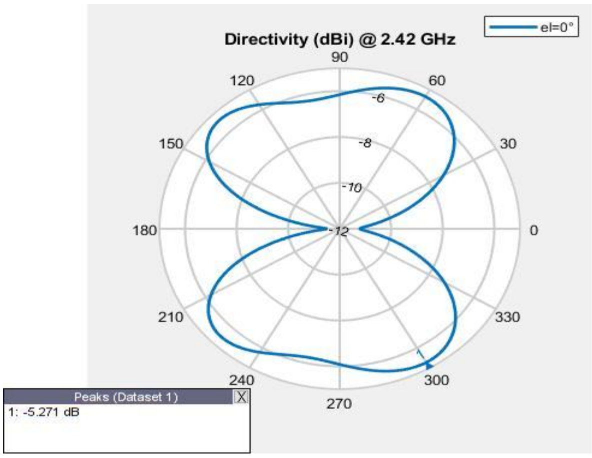

Figure 21: Azimuth pattern of circular patch antenna

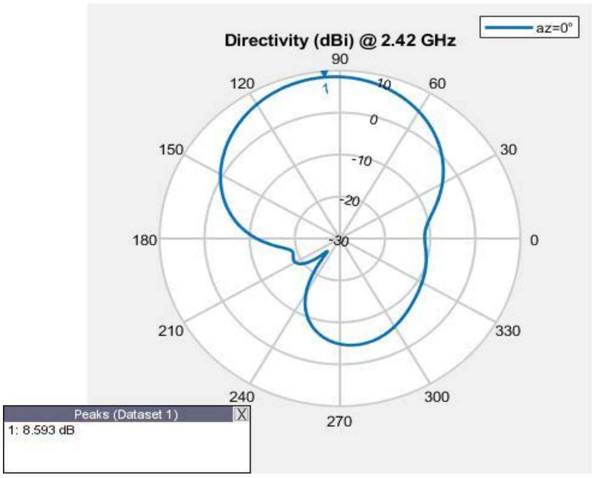

Figure 22: Elevation pattern for circular patch antenna

Table 4.3: Simulation parameters of circular patch antenna.

Parameters	Value
Shape of Patch	Circular
Ground Patch length	0.091
Ground Patch Width	0.091
Patch center offset	[0 0]
Area	0.003
Radius	0.0308

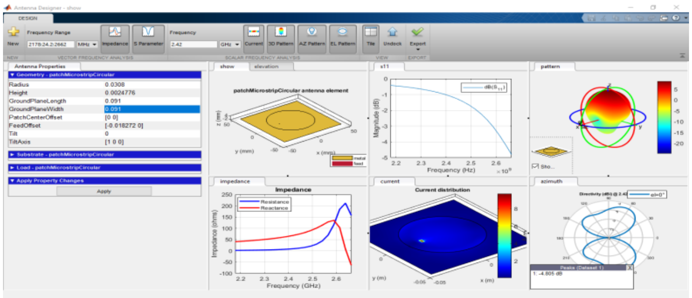

Figure 23: Complete design of circular patch antenna with all desired parameters

Figure 24 shows the antenna properties for triangular patch antenna. Figure 25 shows the design of triangular patch antenna. Figure 26 shows the S parameter of triangular patch antenna. Figure 27 shows the impedance of triangular patch antenna. Figure 28 shows the current distribution of triangular patch antenna. Figure 29 shows the 3d pattern of triangular patch antenna. Figure 30 shows the azimuth pattern of circular patch antenna. Figure 31 shows the elevation pattern for circular patch antenna. Table 4 shows the simulation parameters for rectangular patch antenna. Figure 32 shows the complete design of circular patch antenna with all desired parameters.

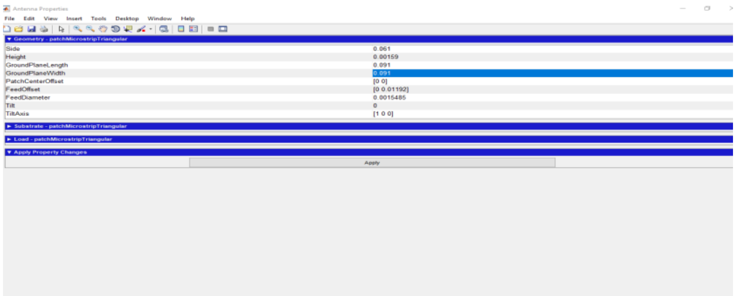

Figure 24: Antenna properties for triangular patch antenna.

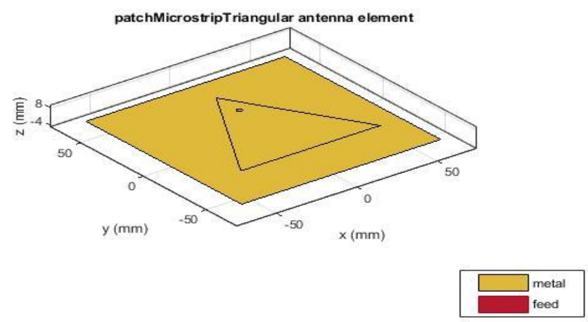

Figure 25: Design of triangular patch antenna.

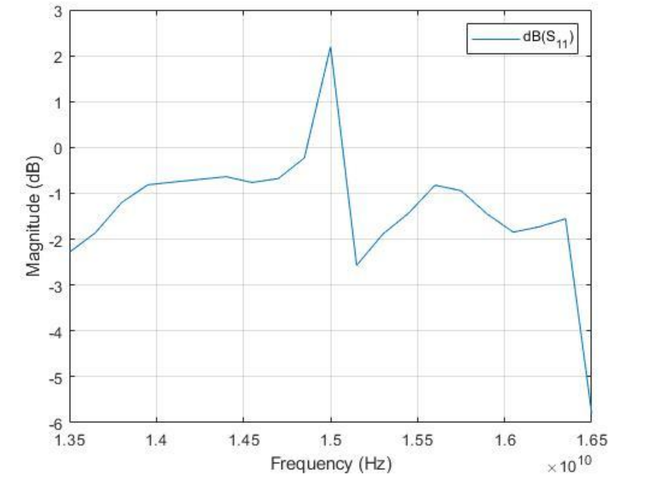

Figure 26: S parameter of triangular patch antenna. patch antenna.

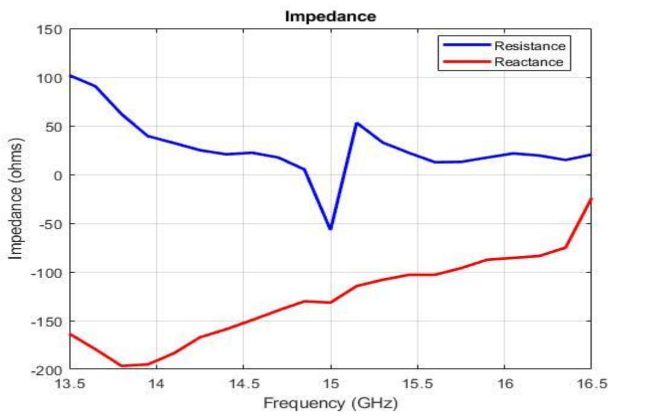

Figure 27: Impedance of triangular patch antenna

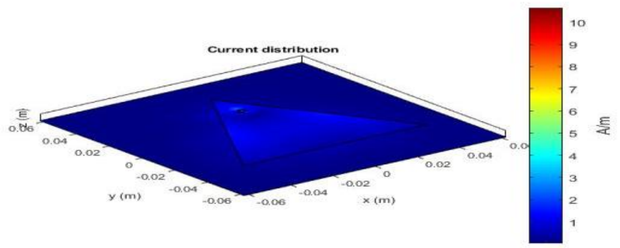

Figure 28: Current distribution of triangular patch antenna.

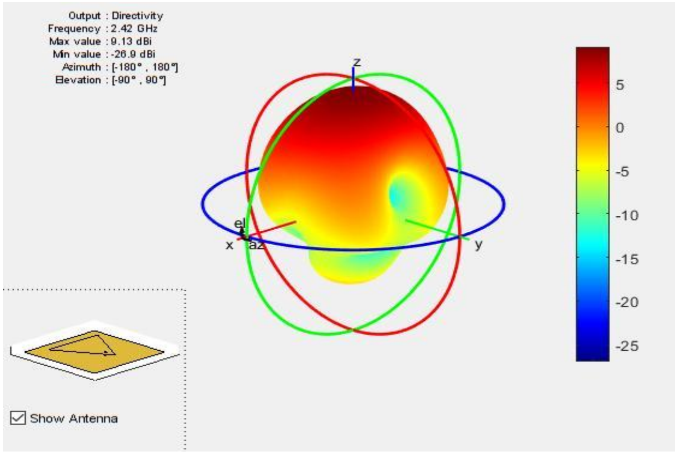

Figure 29: 3d pattern of triangular patch antenna.

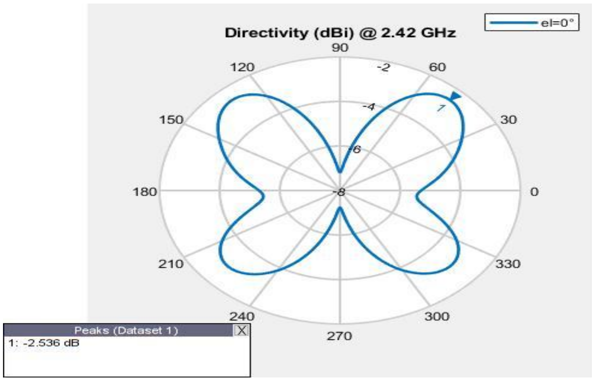

Figure 30: Azimuth pattern of circular patch antenna.

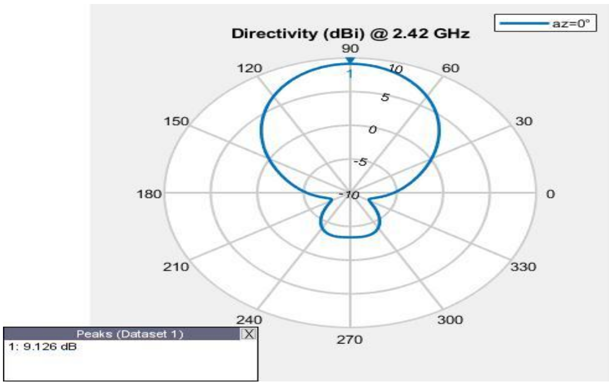

Figure 31: Elevation pattern for circular patch antenna

Table 4.4 Simulation parameters for triangular patch antenna

Parameters	**Value**
Shape of Patch	Triangle
Ground Patch length	0.091
Ground Patch Width	0.091
Patch center offset	[0 0]
Area	0.003
Side	0.061
Height	0.00159

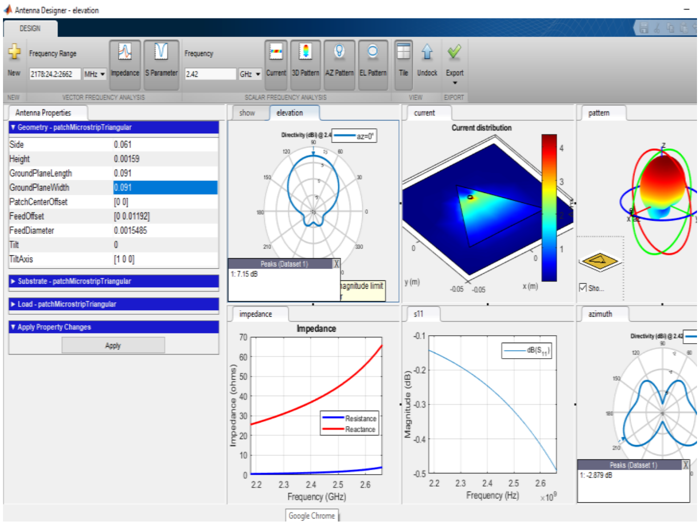

Figure 32: Complete design of circular patch antenna with all desired parameters

V. CONCLUSION

UWB technology has been an important area of research in modern communication system ever since the FCC declaration of UWB frequency band in 2002. Thus UWB antenna is an essential component in the UWB system. With the existing narrow band systems, interference and efficient performance of several parameters are the serious problems of UWB antenna. In the proposed design, to remove interferences and to achieve better performance of several parameters, compact microstrip line fed planar UWB antennas with several shapes with a band dispensation feature is designed.

In this thesis, different shapes (rectangular, circular and triangular) of antennas are compared and analyzed for same area, frequency, size and substrate in terms of performance of various parameters such as impedance, S1 parameter, 3d radiation pattern, current, azimuth and elevation pattern, directivity, gain and beamwidth etc.

First a compact rectangular microstrip patch antenna which operates at ultra wideband frequency of 2.42 GHz is designed on the bottom of the substrate air with same size of 0.006 length and width, 2.42 GHz frequency and area. The far field radiation pattern of antenna is stable. From above results it is also concluded that designed antenna provides band dispensation characteristics to minimize the interference with WLAN, directivity of 6.2 db and 42 db beamwidth at angles of 74 and 116 degree.

In the second design, a compact circular microstrip patch antenna is designed on the bottom of the substrate air with radius of 0.00308 db, frequency 2.42 GHz and with same area as that of rectangular patch. The return loss, VSWR and radiation pattern of proposed antenna have satisfactory values within operating frequency band. From the results it is also concluded that designed antenna provides band dispensation characteristics to minimize the interference with WLAN, directivity of 1.2311 db and 30 db beamwidth at angles of 115 and 145 degree.

In the third design, a compact triangular shape microstrip patch antenna is designed on the bottom of the substrate air with same size and area as that of rectangular and circular patch. Proposed design also obtained satisfactory values of return loss, VSWR and radiation pattern within operating frequency band. From the results it is also concluded that designed antenna provides band dispensation characteristics to minimize the interference with WLAN, directivity of -8.0187 db and 98 db beamwidth at angles of 131, 229, 311 and 49 degree.

From the simulations and results it is also concluded that rectangular patch antenna achieved better or satisfactory values in terms of azimuth pattern, directivity, beamwidth, elevation pattern, current, impedance and S1 parameters etc.

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