ANALYSIS OF MICROSTRIP ANTENNA USING ARBITRARILY
SHAPED PATCHES HAVING SIMILAR SURFACE AREA

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I56/21439/2012

A thesis submitted in partial fulfillment of the requirements for the award of
the degree of Master of Science (Electronics and Instrumentation) in the
School of Pure and Applied Sciences of Kenyatta University

May 2016
DECLARATION

This thesis is my original work and has not been presented for the award of a degree or any other award in any other university. All sources of information have particularly been acknowledged by means of references.

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DEDICATION
This thesis is dedicated to my beloved sons Sammy and Teddy, My Brothers and Sisters, My parents, and all those who encouraged me throughout my studies.
ACKNOWLEDGEMENT

I want to recognize the guidance and encouragement I received from my supervisors Prof Dominic B.O. Konditi of The Technical University of Kenya and Dr Mathew K. Munji of Kenyatta University, who were always available to guide me through my research. Many thanks to my colleagues whom we kept constantly discussing challenging areas in our research fields, to Mr. Bernard Munyore and Mr. Richard Rotich of University of Nairobi for guidance in the fabrication of the patch antennas. I should not forget Communication Authority of Kenya for granting me permission to use their equipment. Special thanks go to the Technicians Mary, Irungu and Alice from Engineering Department of Kenyatta University. Last but not least, I would like to salute Kenyatta University for providing the infrastructure used to do my research through internet access and the lecturers who gave valuable criticism during my presentations. To all of you who contributed to the success of this research in one way or the other may the Almighty God reward you abundantly.
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## Abbreviations, Acronyms and Symbols

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<th>Description</th>
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<tbody>
<tr>
<td>ATC</td>
<td>Automatic Toll Collection</td>
</tr>
<tr>
<td>BW</td>
<td>Bandwidth</td>
</tr>
<tr>
<td>CAR</td>
<td>Collision Avoidance Radar</td>
</tr>
<tr>
<td>CV</td>
<td>Cellular Video</td>
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<tr>
<td>dB</td>
<td>decibel</td>
</tr>
<tr>
<td>DBS</td>
<td>Direct Broadband Satellite</td>
</tr>
<tr>
<td>FEM</td>
<td>Finite Element Method</td>
</tr>
<tr>
<td>FR4</td>
<td>Flame Retardant 4</td>
</tr>
<tr>
<td>G</td>
<td>Gain</td>
</tr>
<tr>
<td>G (Θ, Φ)</td>
<td>Gain in a specific direction</td>
</tr>
<tr>
<td>GHz</td>
<td>Gigahertz</td>
</tr>
<tr>
<td>GPS</td>
<td>Global Positioning of Satellite</td>
</tr>
<tr>
<td>GSM</td>
<td>Global System of Mobile Communication</td>
</tr>
<tr>
<td>HFSS</td>
<td>High Frequency Structure Simulator</td>
</tr>
<tr>
<td>IVHS</td>
<td>Intelligent Vehicle Highway System</td>
</tr>
<tr>
<td>MSA</td>
<td>Microstrip Antenna</td>
</tr>
<tr>
<td>MSC</td>
<td>Mobile Satellite Communication</td>
</tr>
<tr>
<td>PCB</td>
<td>Printed Circuit Boards</td>
</tr>
<tr>
<td>PCS</td>
<td>Personal Communication System</td>
</tr>
</tbody>
</table>
RL          Return loss
Sqrt        Square root
VSWR        Voltage Standing Wave Ratio
$W_c$       Width of the centre of bow-tie
WLAN        Wireless Local Area Network
$a$         Real area of the circle
$a_e$       Effective area of circle
$C$         Capacitance
$f_c \! / \! f_r$ Centre frequency
$f_H$       Higher frequency
$f_L$       Lower frequency
$F$         Fringing effect
$h$         Height of substrate
$j$         Imaginary axis
$K_o$       Free space phase constant
$l_f$       Length of feed line
$l_{\text{eff}}$ Effective length
$l'$        Minimum length of ground plane
$\ln$       natural logarithm
\( \text{Length} \)

\( L \)

\( L_i \)  Inductance

\( \text{Radiated power} \)

\( P_r \)

\( P_{\text{tot}} \)  Total power input

\( P_c \)  power dissipated by conductor

\( P_d \)  Power dissipated by dielectric constant

\( P_{\text{sw}} \)  Power launched into surface wave

\( Q \)  Quality factor

\( R_{\text{in}} \)  Resistance of antenna

\( R_s \)  Resistance of transmitter

\( R_s \)  Surface resistance of metals

\( S \)  Power density

\( S_{12} \)  Return loss

\( U_{\text{max}} \)  Maximum radiation intensity

\( U_o \)  Average radiation intensity

\( U(\theta, \phi) \)  Radiation intensity

\( V_e \)  potential in an element

\( V_e(x,y) \)  potential of an element at a position \((x,y)\)

\( V_o \)  Free space speed of light
$V_o^-$  Minimum voltage

$V_o^+$  Maximum voltage

$W$  Width

$W_c$  Distance of separation at the centre of bow-tie

$w$  Minimum width of ground plane

$W_p$  Width of the feed line

$X_{in}$  Reactance of antenna

$X_s$  Reactance of transmitter

$Z_{in}$  Impedance of antenna

$z_o$  Characteristic impedance

$Z_t$  Impedance of the antenna

$Z_s$  Impedance of transmitter

$\Gamma$  Coefficient of reflection

$\Delta l$  Change in length

$\varepsilon_r$  Dielectric constant

$\varepsilon_{\text{reff}}$  Effective dielectric constant

$\theta$  Theta

$\lambda_g$  Wavelength in substrate

$\lambda_o$  Wavelength in free space
\phi \quad \text{Phi}

\Pi \quad \text{pi}

\Sigma \quad \text{Sigma}

\nu \quad \text{Wavelength}

\sigma \quad \text{Conductivity}

\delta \quad \text{Skin depth}
ABSTRACT

Microstrip patch antenna (MSA) has become very vital in communication system due to its attractive features such as its light weight, small size, low cost, low profile, ease of installation and its conformability to planar and non planar surfaces, when a particular mode and shape is selected. MSA are versatile in terms of resonant frequency, impedance, polarization and electromagnetic wave pattern. However, MSA have been found to suffer from relatively narrow bandwidths. The consumers of these devices can enjoy diversity of shapes aesthetically pleasing to them without compromising the efficiency of the device. Designing of the rectangular patch of the Microstrip antenna was done for the five sets, circular, cross shaped and bow-tie Microstrip antenna patches were also designed but having similar surface area to the designed rectangular patch in the respective set. The four shapes of the antenna namely rectangular, circular, cross shaped and bow-tie were analyzed using HFSS software to determine the characteristic of the designed MSA, Bow-tie MSA radiated in two direction which is neither end-fire nor broadside but the other 3 shapes radiated in one direction along the z-axis, Bow-tie also provided the largest beamwidth. The prototype was fabricated on printed circuit board (PCB) and tested in the laboratory. The results of the research showed that the Rectangular patch had the best gain due to good Electric field distribution, Circular patch performed at the lowest frequency as compared to the other 3 shapes due to its shorter dimensions. Comparison of simulated data with data in the open literature was done. The percentage impedance bandwidth in this research of between (2-8) % is comparable to the impedance bandwidth in the open literature of about (3-5) %. The optimum performance of the designed Microstrip antenna for the four shapes was ascertained at a range of frequencies (1-10) GHz.
CHAPTER 1

INTRODUCTION

1.1 Background of the study

Rapid progress in wireless communication promises to replace wired communication in the near future in which an antenna plays an important role. The population of the world is increasing rapidly resulting in tremendous demand and application of mobile phones, (Jegadeesha et al., 2012). Due to advancement in wireless communication technology there’s need for lightweight and miniature size antenna (Sharma et al., 2013). Hence the need to research on different patch shapes to assist in minimizing the materials used to make the patch of the Microstrip antenna.

An antenna is an electrical conductor, it can transmit or receive electromagnetic waves, as a transmitter it radiates electromagnetic waves (energy) into space and as a receiver it collects electromagnetic waves (energy) from space (Ramachandran et al., 2006). Stutzman and Thiele (1998) defined an antenna as “that part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves. Microstrip antenna received considerable attention in the 1970’s although the idea is traced back to 1953 Dechamps (1953). Figure1.1 shows the parts of a rectangular Microstrip antenna, with resonant length 'L’, width ‘w’ and thickness of the substrate ‘h’, x and y represent the x axis and y axis respectively. Microstrip antenna consists of a radiating patch (of width, W, and length, L) on one side of a
substrate ‘x’ and a ground plane ‘y’ on the other as shown in figure 1.1. L is the resonant frequency dimension and the width, W, is usually chosen to be larger than L to achieve higher bandwidth. The patch has a thickness ‘t’ where t << \( \lambda_0 \), where \( \lambda_0 \) is the free space wavelength.

Figure 1.1 Schematic Diagram Showing the Geometry of a Microstrip Patch Antenna

Microstrip antennas are very big physically for frequencies less than 0.5GHz hence applicable for frequency greater than 0.5GHz. The height, h, of the substrate is in the range of \( 0.003 \lambda_0 \leq h \leq 0.05 \lambda_0 \) above ground plane. The bandwidth of a Microstrip antenna is best for low dielectric constant substrates. Most researchers found that dielectric constant is in the range of \( 2.2 \leq \varepsilon_r \leq 12 \). (Kwaha et al., 2011), The best substrates for fabricating MSA are those whose dielectric constant lie in the lower end of this range because they provide better efficiency (Kwaha et al., 2011), large bandwidth, loosely bound fields for radiation into space but at the expense of large element size. When substrate thickness is increased in an attempt to improve bandwidth, spurious feed radiation and surface wave power increases. This leads to scan blindness where the antenna is unable to receive or transmit at a particular scan angle. Microstrip antennas have attracted attention due to their size, weight, cost, performance, and ease of installation. They are used in high performance
aircrafts, space crafts and missile application due to their qualities. Many system successes rely on the design and performance of the antenna. Despite the above advantages MSA has its own disadvantages such as, low efficiency, low power, poor polarization parity, high quality factor sometimes in the excess of 100, poor scan performance, spurious feed radiation, and narrow frequency band width (Balanis, 2005). Microstrip antenna are simple and inexpensive to manufacture using modern printed circuit technology, it is mechanically robust and compatible with Monolithic Microwave Integrated Circuit designs, when mounted on rigid surfaces. They are conformable with planar and non planar surfaces (Rahim et al., 2005).

1.1.1 Types of Microstrip Antenna Radiators (Single radiating patches)
There are several other types of Microstrip antenna patches. Most of them depending on the shape have different antenna characteristic. The shapes of MSA patches are shown in figure 1.2.

Fig 1.2 Various Types and Shapes of MSA Patch
When a particular shape and mode is selected it is versatile in terms of resonant frequency, impedance, polarization, pattern etc. The efficiency of the MSA can be increased by increasing the height of the substrate, but as the height
increases, surface waves are introduced which are not desirable because they extract power from the total available for direct radiation. (Jackson et al., 1997). Surface waves travel within the substrate and are scattered at bends and surface discontinuities such as truncation of dielectric and ground plane and degrade the antenna pattern and polarization characteristic (Jackson et al., 1997).

1.2 Problem Statement and Justification

Rapid development in personal communication systems (PCS), mobile satellite communication (MSC), direct broadcast system (DBS), Wireless local area network (WLAN) and intelligent vehicle highway system (IVHS) demands that Microstrip antenna and arrays must improve further in design, shape and performance. The dimension of electronic devices are decreasing and there is a need to develop Microstrip antennas which are smaller in size and in different shapes so that the consumers can enjoy diversity of shape which are aesthetically pleasing to them without compromising the efficiency of the device in terms of frequency of operation and the bandwidth, hence the need to analyze Microstrip antennas using arbitrarily shaped patches to ascertain optimum performance.
1.3 Objectives

1.3.1 General Objective

To design, and analyze Microstrip antenna patch with arbitrarily shaped patches.

1.3.2 Specific Objectives

i) To design and simulate a rectangular shaped microstrip antenna.

ii) To design and simulate Microstrip patch antenna with bow-tie, circular, cross shaped patches of similar surface area.

iii) To fabricate and test the MSA for validation of simulated results.

1.4 Significance of the Study/Rationale

The purpose of this research was to investigate, via simulation of Microstrip patch antennas with arbitrarily shaped patches of similar surface area, this would enable fabrication of Microstrip antenna without trial and error experimentation with specimen. Hence enhancing efficiency and lowering cost of fabrication.
CHAPTER 2

LITERATURE REVIEW

2.1 Introduction

With the aim of improving the performance of Microstrip patch antenna, various studies have been done focusing on the size, the shape of the patch and substrate, a quandary has arisen about how to develop small antenna that can satisfy the performance requirement for these systems as well as aesthetically pleasing to the user, the later point is important in mobile communication because the market is customer driven although technically it has little merit.

2.2 Related Studies

Sharma et al. (2013) analyzed 4 MSA of different shapes namely Square, Elliptical, Annular Ring and Triangular at 2.43 GHz using HFSS software. Their results showed that the size of the antenna for square shape was smallest followed by elliptical shape, triangular shape, and finally annular ring shape in terms of miniaturization but in terms of antenna performance parameters i.e. directivity, return loss, bandwidth, voltage standing wave ratio, and radiation pattern, elliptical shaped patch had the best followed by square shaped triangular shaped and annular shaped in that order.

Gupta et al. (2006) compared the gain and bandwidth at a frequency of 2.46 GHz of a square slotted patch configuration with 4 equal length slit along the
diagonal and 4 angular grooves were made along the edges of the patch and a fractal Microstrip patch using IE3D from Zealand software based on Method of Moments, The patch antennas showed a significant reduction in size compared to the conventional square antenna.

Prasad et al. (2011) investigated a circular patch and a rectangular patch antenna at a frequency of 2.4 GHz using MATLAB software simulation and results showed that directivity of circular patch was found to be better than that of a rectangular patch for same given parameters.

Dahiya et al. (2012) studied a Bow shaped MSA and Rectangular MSA with substrate Bismuth Niobato of permittivity $\varepsilon_r = 47.8$, and showed that bow shaped MSA had high resonant frequency at 3 GHz while rectangular showed lower frequency at 0.86GHz for the same surface area, To obtain a resonance frequency of 3GHz the size of the Rectangular Microstrip will need to be increased. However, the overall surface area is reduced by over 30% for $TM_{10}$ mode for 3GHz.

Kumar and Zafar (2012) compared three different shapes of substrate namely Square, Rectangular and circular but with a similar patch size and shape using RT/Duroit5880 substrate material at 6.46 GHz. Results showed that a Square substrate gives better Return Loss and voltage standing wave ratio because of good Electric field, $\vec{E}$, distribution in patch radiator. In these studies the
researchers have not considered investigating optimum operating frequency and comparison of the shapes in this study hence important for to cater for consumer satisfaction.

2.3 Feeding Technique

Microstrip feed line is a conducting strip connected directly to the edge of the microstrip patch this has an advantage to other feeding techniques in that it can be on the same substrate to provide a planar structure, it provides ease of fabrication, simplicity in modeling and in impedance matching, it is considered as an extension of the patch, hence the feeding used in this research.

2.4 Losses

Microstrip transmission line suffers from three types of losses

i) Conduction loss, this depends on the type of metal use, metals which are better conductors have reduced loss;

\[ R_s = \frac{1}{\sigma \delta} \]

\( R_s \) – Surface resistance of metal
\( \sigma \) - Conductivity of metal
\( \delta \) - Skin depth of metal

ii) Dielectric loss is a function of the printed circuit board (PCB) substrate material used, the lower the dielectric constant the lesser the loss.
iii) Radiation loss is the ratio of the power radiated into space to the input power, radiation efficiency is less than 100% because of numerous factors which include the dielectric material, its thickness, surface wave, shape of transmission line structure, it also depends on the frequency, and it increases with increase in frequency;

$$e_r = \frac{P_r}{P_{tot}} = \frac{P_r}{P_r + (P_c + P_d + P_{sw})}$$

$e_r$ - radiation efficiency

$P_r$ – radiated power

$P_{tot}$ - total power input

$P_c$ - power dissipated by conductor

$P_d$ – power dissipated by dielectric constant

$P_{sw}$ - power launched into surface wave

Dielectric constants of below 5 are used in Microstrip antenna circuits because of their low cost and versatility they yield in larger circuit geometries for a given frequency compared to circuit materials with a higher dielectric constant. With low dielectric constant, however, less of the conducted electromagnetic energy (EM) is concentrated in the substrate and the Microstrip metal conductor leading to losses as a result of radiation effect. Higher dielectric constant circuit materials reduce radiation losses because the EM field is concentrated in the dielectric material between the ground plane and the metal conductor (patch). Increase in substrate dielectric constant will also miniaturize the dimension of the Microstrip patch antenna by a factor approximately equal
to the square root of the dielectric constant but caution should be taken not to trade radiation loss to dielectric loss. The substrate used in this research is FR4 of dielectric constant 4.4, height 1.6mm and a loss tangent of 0.002, this substrate is cheap and gives good results.

2.5 Method of Analysis

Analysis of Microstrip patch antenna involves modeling the antenna using appropriate techniques so as to gain some insight into its operation, the method used in this research is the finite element method (FEM) which is a technique applied in analyzing complex structures by subdividing them into small tetrahedron called elements, the field in each element is approximated using mathematical expressions. The advantage of FEM is that the electrical and geometrical properties of each element can be defined independently hence inhomogeneous and complex structures can be modeled easily, FEM results are closer to experimental results. High Frequency Structure Simulator (HFSS) is the software used in this study which uses FEM, it constructs a mesh that conforms to the electrical performance of the antenna, and by applying adaptive meshing, the mesh is automatically tuned to give the most accurate and efficient mesh possible, after each adaptive pass HFSS compares the scattering parameters from the current mesh to the results of the previous mesh if the answers have not changed a frequency sweep is performed using the current or previous mesh.
CHAPTER 3
THEORETICAL BACKGROUND

3.1 Introduction
In this chapter the four shapes of the Microstrip antenna namely Rectangle, Circular, Cross shaped and Bow-Tie are discussed and the formula for designing them shown, antenna parameters are also discussed.

3.2 Rectangular Microstrip antenna
Figure 3.1 shows the top and the side view of Rectangular Microstrip antenna. Rectangular MSA patch is made using a rectangular conductor of length ‘L’ and width ‘W’ on a substrate, ∆L shows the fringing field.

Fig 3.1(a) and (b) Schematic Diagrams of Top and Side View of Rectangular MSA (Prasad et al., 2011)
3.2.1 Length

The length ($l$) of the rectangular patch antenna controls the resonance frequency of the patch. The relationship between the length and resonance frequency of a TM$_{10}$ mode is given by:

$$l = \frac{c}{2f_r \sqrt{\varepsilon_r}}$$  \hspace{1cm} (3-1)

$l$ is length, $f_r$ is resonant frequency, $c$ is velocity of light in air and $\varepsilon_r$ is dielectric constant.

The factor $\sqrt{\varepsilon_r}$ is due to loading by substrate and is valid for very wide patches. A fraction of the field is outside the physical dimension of the patch as shown in figure 3.1 (a) hence the effective dielectric constant ($\varepsilon_{re}$) is used because some of the field will pass through air before going through the substrate figure 2 (b) (Bhatia, 2001).

Effective dielectric constant of the substrate is given by:

$$\varepsilon_{re} = \frac{(\varepsilon_r + 1)}{2} + \frac{(\varepsilon_r - 1)}{2} \left[ 1 + 12 \frac{h}{w} \right]^{\frac{1}{2}}$$  \hspace{1cm} (3-2)

Where $h$ is height of substrate and $w$ width of substrate (Balanis, 2005)

Hence the formula for length is given by:

$$l_{\text{eff}} = \frac{c}{2f_r \sqrt{\varepsilon_{re}}}$$  \hspace{1cm} (3-3)

When the effect of the additional length ($\Delta l$) is included the design length ($l$) is given by:
The actual length plus the effect of the fringing fields is given by;

\[ l_{re} = l + 2\Delta l \]  

(3-5)

The small change in length due to fringing is found by;

\[ \Delta l = \frac{(\varepsilon_r + 0.3)\left(\frac{w}{h} + 0.264\right)}{\left(\varepsilon_r - 0.258\right)\left(\frac{w}{h} + 0.8\right)} \]  

(3-6)

(Balanis, 2005).

### 3.2.2 Width

Equation (3-7) gives the width of the rectangular patch, the width of the patch controls the input impedance, Bandwidth and the radiation pattern, the wider the patch the lower the input impedance and the higher the bandwidth (Balanis, 2005);

\[ w = \frac{c}{2f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \]  

(3-7)

### 3.2.3 Ground

Infinite ground produces best results, but for practical reasons an infinite ground is impossible, hence finite length \( l' \) and width \( w' \) is found, which has the same results as the infinite ground, the minimum length and width is given by;
\[ l' = l + 6h \]  \hspace{1cm} (3-8)

\[ w' = w + 6h \]  \hspace{1cm} (3-9)

(Balanis, 2005).

3.2.4 Wavelength in the Substrate

The wavelength in substrate \( \lambda_g \) is given by;

\[ \lambda_g = \frac{c}{\sqrt{\varepsilon_{reff}}} \]  \hspace{1cm} (3-10)

3.2.5 Feed Line

The feed line \( l_f \) is taken to be a quarter wavelengths given by;

\[ l_f = \frac{\lambda_g}{4} \]  \hspace{1cm} (3-11)

The width of the feed line is found using equation (3-12), \( Z_o \) is the characteristic impedance;

\[ z_o = \frac{120\pi}{\sqrt{\varepsilon_{reff} \left[ \frac{w}{h} + 1.393 + 0.667 \ln \left( \frac{w}{h} + 1.444 \right) \right]}} \text{ for } \frac{w}{h} \geq 1 \]  \hspace{1cm} (3-12)
3.3 Circular Patch Microstrip Antenna

A circular MSA is made by fabricating a circular shaped conductor of radius ‘a’ on a substrate of thickness ‘h’ and dielectric constant $\varepsilon_r$. Figure 3.2 shows the geometry of a circular Microstrip patch antenna.

The actual radius of the patch is given by (kwaha et al., 2011);

$$a = \frac{F}{\left[1 + \frac{2h}{\pi \varepsilon_r F} \left(\ln\left(\frac{\pi F}{2h}\right) + 1.7726\right)\right]^\frac{1}{2}}$$

(3-13)

Where F is the fringing effect given by:

$$F = \frac{8.791 \times 10^9}{f_r \sqrt{\varepsilon_r}}$$

(3-14)

Fig 3.2 Schematic Diagram Showing the Geometry of a Circular Patch Antenna

The effective radius of the patch considering the fringing fields makes the patch electrically long and is given by;

$$a_e = a \left[1 + \frac{2h}{\pi \varepsilon_r a} \left(\ln\left(\frac{\pi a}{2h}\right) + 1.7726\right)\right]^\frac{1}{2}$$

(3-15)

Resonance frequency of the dominant mode TM$_{110}$ is given by:
$f_{r(110)} = \frac{1.8426v_0}{2\pi a\sqrt{\varepsilon_r}}$  \hspace{1cm} (3-16)

Where $v_0$ is the free space speed of light.

Free space constant is calculated by using the equation below;

$k_o = \frac{2\pi f}{v_0}$  \hspace{1cm} (3-17)

Where $k_o$ is the free space phase constant (Bhatia, 2001).

Wavelength in substrate is found using equation (3-10) and the dimensions of the ground using equation (3-8) and (3-9).

### 3.4 Cross Shaped Microstrip Antenna

A cross shaped MSA is made by fabricating a cross shaped conductor of Length ‘L’ and width ‘W’ on a substrate. Length ‘L₁’ and width ‘W₁’ are the dimensions of the ground plane of the cross shaped MSA. Figure 3.3 shows a cross shaped patch of a Microstrip antenna.
Fig 3.3 Schematic Diagram of a Cross Shaped Patch

Length (l) is found by using equation (3-4),

Width (w) is calculated using equation (3-7),

Effective dielectric length is calculated using equation (3-2),

Wavelength in substrate and feed line is found using equation (3-10) and (3-11) respectively,

Ground plane dimension is found using equation (3-8) and (3-9).

3.5 Bow-Tie

A Bow-tie antenna makes the antenna have a multi frequency operation they are attractive because a smaller size than the convectional rectangular patch. Figure 3.4 is the geometry of bow-tie shaped Microstrip antenna.
Fig 3.4 Schematic Diagram of a Bow-Tie Shaped MSA

Equations of rectangular MSA are modified to get the equations of Bow-tie antenna.

Equation (3-18) is used to calculate the operating frequency of the bow-tie MSA:

\[ f_r = 1.152 \frac{c}{2\sqrt{\varepsilon_r l}} \frac{l (w+2\Delta l) + (w_c + 2\Delta l)}{(w+2\Delta l)(s+2\Delta l)} \]  

(3-18)

Where the length extension \( \Delta l \) due to fringing is found by:

\[ \Delta l = \frac{0.412 h (\varepsilon_{\text{reff}} + 0.3) \left( \frac{w + w_c}{2h} + 0.262 \right)}{\left( \varepsilon_{\text{reff}} - 0.258 \right) \left( \frac{w + w_c}{2h} + 0.813 \right)} \]  

(3-19)

Effective dielectric constant is calculated by:

\[ \varepsilon_{\text{reff}} = \frac{(\varepsilon_r + 1) + (\varepsilon_r - 1) \left( \frac{24 h}{(w + w_c) + 1} \right)^{\frac{1}{2}}}{2} \]  

(3-20)

The frequency of the Bow-tie antenna is changed by altering the values of \( w_c \) and \( l \).
3.6 Antenna Parameters

3.6.1 Impedance Bandwidth

Impedance bandwidth is the range of frequency over which performance does not suffer due to poor impedance match, the lower frequency \( f_L \) and the higher frequency \( f_H \) for which the performance is acceptable are obtained, the central frequency of the lower and higher frequency is known as the centre frequency \( f_C \) or Resonance frequency \( f_r \). The Bandwidth as a percentage of centre frequency is given by:

\[
BW = \left( \frac{f_H - f_L}{f_C} \right) \times 100\%
\]  
\( (3-21) \)

3.6.2 Gain

Gain is the measure of the ability of an antenna to direct the input power into radiation in a particular direction and is measured at the peak radiation intensity (Prasanna et.al., 2007). Power density \( S \) radiated by an isotropic antenna with input power \( P_o \) at a distance \( R \) and the Gain \( G \) given by:

\[
S = \frac{P_o G}{4\pi R^2}
\]  
\( (3-22) \)

An isotropic antenna radiates equally in all direction and is considered to be 100% efficient. Gain of an antenna increases the power density in the direction of peak radiation.

Power density can further be calculated by;
\[ S(\theta, \phi) = \frac{P_o G(\theta, \phi)}{4\pi R^2} \] 

(3-23)

Radiation intensity \( U(\theta, \phi) \) is the power radiated from an antenna per solid angle it’s a far field parameter is given by;

\[ U(\theta, \phi) = \frac{P_o G(\theta, \phi)}{4\pi} \] 

(3-24)

### 3.6.3 Directivity

Directivity is the measure of radiation in the direction of maximum concentration given by;

\[ \text{Directivity} = \frac{U_{\text{max}}}{U_o} \] 

(3-25)

\( U_{\text{max}} \) = maximum radiation intensity,

\( U_o \) = average radiation intensity

When direction of maximum power is not given equation (3-26) is used to find directivity;

\[ \text{directivity} = \frac{4\pi U}{P_{\text{rad}}} \] (Nakar, 2004).

(3-26)
3.6.4 Quality Factor

Quality factor is the measure of the bandwidth of an antenna relative to the centre frequency of the bandwidth, if an antenna operates over a band between \( f_1 \) and \( f_2 \), the centre frequency is given by;

\[
f_c = \frac{f_1 + f_2}{2}
\]  

(3-27)

Quality factor \( Q \) is given by;

\[
Q = \frac{f_c}{f_2 - f_1}
\]  

(3-28)

Microstrip antenna devices are high quality factor devices \((Q)\) with \( Q \) exceeding 100 for the thinner substrates. Elements with high \( Q \) factor have small bandwidth. The higher the \( Q \) factor of an element the lower the efficiency. The higher the \( Q \) factor the more sensitive the input impedances to small changes in frequency. However, there are limits as the thickness is increased, an increasing fraction of the total power delivered by the source goes into surface wave. The surface wave contribution is unwanted power loss since it scatters at dielectric bends and discontinuities and have an effect on the radiation pattern of an element One disadvantage of small bandwidth is sometimes counted as an advantage for narrow band application, the antenna itself can act as a filter for unwanted frequency component.

3.6.5 Feeding Technique

The feeding techniques are classified into 2 categories
i) Contacting

ii) Non contacting

### 3.6.5.1 Contact Methods

In contacting method the RF power is fed directly to the radiating patch using a connecting element such as Microstrip line and coaxial probe.

#### 3.6.5.1.1 Microstrip Line

Microstrip line feeding is the easiest feeding technique to fabricate, the patch and the feed line are on the surface of the substrate and has no discontinuity like the other three feeding techniques namely coaxial probe, aperture coupling and proximity coupling. It is one of the original excitation methods for a Microstrip antenna, the feed line is in direct contact with the patch, and it also comes into contact with one of the radiating edges of the patch. Figure 3.5 shows the diagram of line feed Microstrip antenna.

![Microstrip Diagram](image)

**Fig 3.5 Schematic Diagram of a Rectangular MSA**

#### 3.6.5.1.1.1 Advantages

1) Ease of fabrication because both are etched on the same board

2) Easy to control input impedance
3) Easy to model.

3.6.5.1.2 Disadvantage
1) Narrow bandwidth
2) Low Gain.

3.6.5.1.2 Coaxial probe
In coaxial probe feeding technique the feed line passes through the substrate and is soldered on the patch, soldering has to be carefully done to avoid air gaps which lead to power losses. Figure 3.6 shows the diagram of coaxial probe feed.

Fig 3.6 Schematic Diagram of a Coaxial Fed MSA

It extends through the ground plane and is connected to the patch conductor through Soldering, the probe or feeding pin is the inner conductor of the coaxial line hence coaxial fed, the probe position provides the impedance control and is in direct contact with the patch hence direct contact excitation.

3.6.5.1.2.1 Advantages
1) Isolated from radiating element via ground plane
2) Feed mechanism is in direct contact with the antenna and most of the feed network is isolated from the patch minimizing spurious feed.

**3.6.5.1.2.2 Disadvantage**
1) Narrow bandwidth
2) Difficult to analyze accurately
3) Complicated to make.

**3.6.5.2 Non Contact Method**

In non contacting method Electromagnetic field coupling is done to transfer power between the Microstrip line and the radiating patch.

**3.6.5.2.1 Aperture Coupling**

Is a Non contact method of feeding and were introduced because of the shortcomings of the contact methods namely small bandwidth and effect of surface waves, separate laminates are used for the feed network and patch antenna, the laminates are separated by the ground plane, coupling between the feed and the patch is done through a small slot in the ground plate. Figure 3.7 shows an aperture coupling MSA.

![Fig 3.7 Schematic Diagram of Aperture Coupling MSA](image-url)
3.6.5.2.1.1 Advantages
1) Independent optimization of the feed and antenna substrate can be achieved
2) No vertical interconnection is required like in probe feed
3) Has more design parameters than direct contact hence more flexible.

3.6.5.2.1.2 Disadvantages
1) Presence of small gaps between layers can alter the input impedance nature of antenna especially at high frequency.

3.6.5.2.2 Proximity Coupling
It is a feeding method that consists of a grounded substrate where a Microstrip feed line is located, above the material is a dielectric laminate with a patch etched on its top surface. NB: there is no ground plane separating the two dielectric layers, the power of the feed network is coupled to the patch electromagnetically, its coupling mechanism is capacitive in nature as opposed to direct feed which is inductive in nature. Figure 3.8 shows a proximity coupling MSA.

![Fig 3.8 Schematic Diagram of Proximity Coupling MSA](image)

3.6.5.2.2.1 Advantage
1) Greater bandwidth
2) Lack current discontinuities between the feed network and the radiating element as opposed to direct contact.

**3.6.5.2.2 Disadvantages**

1) Feed and antenna layer are not fully independent because efficient coupling must be done

2) Have high spurious feed radiation

3) Alignment procedure is very important and must be observed

3) Small air gaps affect the coupling of the patch.

There are 3 essential parameters for calculating dimensions of the patch

i) Frequency of operation

ii) Height of dielectric substrate

iii) Dielectric constant of the substrate.

**3.6.6 Impedance Matching**

For an antenna to operate efficiently maximum transfer of power must take place between the transmitter and the antenna patch. It takes place only when the impedance of the antenna (Z<sub>in</sub>) is matched to that of transmitter (Z<sub>s</sub>), according to maximum power transfer theorem, maximum power can be transferred only if the impedance of the transmitter is a complex conjugate of the impedance of the antenna under consideration and vice versa.
Table 1 Microstrip Antenna Feed Technique

<table>
<thead>
<tr>
<th></th>
<th>Microstrip Line Feed</th>
<th>Coaxial Feed</th>
<th>Aperture Coupled Feed</th>
<th>Proximity Coupled Feed</th>
</tr>
</thead>
<tbody>
<tr>
<td>Spurious</td>
<td>more</td>
<td>more</td>
<td>less</td>
<td>Minimum</td>
</tr>
<tr>
<td>Reliability</td>
<td>better</td>
<td>poor due to soldering</td>
<td>good</td>
<td>Good</td>
</tr>
<tr>
<td>Ease of fabrication</td>
<td>easy</td>
<td>soldering and drilling needed</td>
<td>alignment required</td>
<td>Alignment required</td>
</tr>
<tr>
<td>Impedance matching</td>
<td>easy</td>
<td>easy</td>
<td>easy</td>
<td>Easy</td>
</tr>
<tr>
<td>Bandwidth (achieved with impedance matching)</td>
<td>2.5%</td>
<td>2.5%</td>
<td>2.5%</td>
<td>12%</td>
</tr>
</tbody>
</table>

Condition for matching is given by;

\[ Z_{in} = Z_s * \]  \hspace{1cm} (3-29)

Where \( Z_{in} \) the impedance of the antenna and \( Z_s \) the impedance of the transmitter is given by equation (3-30) and (3-31) respectively;

\[ Z_{in} = R_{in} + jX_{in} \]  \hspace{1cm} (3-30)

\[ Z_s = R_s + jX_s \]  \hspace{1cm} (3-31)

If the condition in equation (3-29) is not satisfied some power is reflected back leading to creation of standing wave. (Nakar, 2004).

3.6.7 Return Loss

When the load and transmission line are mismatched all the power is not delivered to the load, there is a return of the power reflected which is called loss hence return loss.

It is defined in dB and is given by;

\[ RL = -20 \log |\Gamma| \text{dB} \]  \hspace{1cm} (3-32)
The formula for calculating coefficient of reflection is given by:

\[ \Gamma = \frac{V_0^-}{V_0^+} = \frac{Z_L - Z_0}{Z_L + Z_0} \]  \hspace{1cm} (3-33)

Voltage standing wave ratio (VSWR) represents the extent to which an antenna is mismatched to the system impedance. Modern wireless transceivers ideally require the antenna to operate into \((50+j0)\) ohms system impedance so that \(\text{VSWR} \to 1\). However, in practice the preferable standard for maximum allowable VSWR across the entire bandwidth of a system is 1.5:1, this means that the antenna impedance should lie around 37.5ohms to 75ohms. A voltage standing wave ratio in excess of 2:1 may not be acceptable since it amounts to undue reflection losses caused by the associated match. Reflection of power that leads to standing wave characterized by Voltage standing wave ratio is given by (Balanis, 2005):

\[ \text{VSWR} = \frac{V_{\text{max}}}{V_{\text{min}}} = \frac{1 + |\Gamma|}{1 - |\Gamma|} = \frac{1 + s_{12}}{1 - s_{12}} \]  \hspace{1cm} (3-34)

As reflection coefficient ranges between \(0 \leq |\Gamma| \leq 1\), VSWR ranges from \(1 \leq \text{VSWR} \leq \infty\), \(\text{VWSR} = 2\) is acceptable for practical application as the return loss would be -9.54dB (Nakar, 2004).
3.6.8 Finite Element Method

Finite element method is a powerful and versatile numerical technique for handling problems involving complex geometries and inhomogeneous medium. It involves four steps.

i) Discretizing the solution region into a finite number of sub regions or elements such as triangular for planar configuration and tetrahedral or prismatic elements for three dimensional configurations.

ii) Deriving governing equations for the typical element.

iii) Assembling of all elements in the solution region.

iv) Solving the system of equation obtained.

The problem of solving wave equations with inhomogeneous boundary conditions is tackled by decomposing it into two boundary value problems. One with Laplace’s equation with inhomogeneous boundary while the other one corresponding to an inhomogeneous wave equation with homogeneous boundary (Kumar et al., 2003).

3.6.8.1 Finite Element Discretization

To find the potential distribution \( V_{(x,y)} \) the region is divided into a number of finite elements.
Figure 3.9(a) shows an object, and Figure 3.9(b) shows an object divided into finite elements.

**Fig 3.9 (a) object and (b) object divided into finite elements**

a=approximate boundary,

b=actual boundary

The approximation of potential within an element (e) $V_e$ is interrelated with the potential distribution in various elements such that the potential is continuous across interrelated boundaries (Singiresu, 2011), approximate solution for interrelated boundaries for the whole region is, $V(x,y) \approx \sum_{e=1}^{n} V_e(x,y)$

Where $n$ is the number of triangular elements into which the solution region is divided. The most common approximation for $V_e$ within an element is polynomial approximation namely, $V_e(x,y) = a + bx + cy$ for triangular element and, $V_e(x,y) = a + bx + cy + dxy$ for quadrilateral element.

Governing equation + boundary conditions = a set of simultaneous algebraic equation;

$L\Phi + f = 0$  \hspace{2cm} $B\Phi + g$
3.6.9 Beam width

An antenna beamwidth is found by getting the half power beamwidth, the peak radiation intensity is found, then the points on either side of the robe which represent half the power of the peak intensity is located, the angular distance between the half power points is the beamwidth, in decibels in taken to be 3dB(Bhatia et al., 2014).
CHAPTER 4  
MATERIALS AND METHODS

4.1 Introduction  
In this chapter the designing of Rectangular Microstrip patch antenna is done and the three other shapes namely Circular, Cross shaped and Bow-tie are designed having similar surface area as the Rectangular patch in their respective set, the surface area of the rectangle is found by multiplying the length and width of the rectangle.

4.2 Designing Rectangular Patch of Set 1 of Area (1,857.1826mm²)

4.2.1 Calculation of Width  
\[ (w) = \frac{c}{2f_r} \sqrt{\frac{2}{\varepsilon_r + 1}} \]

Where \( (c) = \frac{1}{\sqrt{\mu_r \varepsilon_r}} \)  

(4-1(a))

4.2.1.1 Manual Calculation gives  
\[ w = \frac{3 \times 10^8}{2 \times 1.86 \times 10^9} \sqrt{\frac{2}{4.4 + 1}} = 49.0791 \text{mm} \]

4.2.1.2 Mat Lab Code  

```matlab
>> w = inline('c/(2*f_r)*sqrt(2/((e_r)+1))')  
(4-1(b))

>> f_r = 1.86e9; c = 3e8; e_r = 4.4;
>> w(f_r,c,e_r)
>> ans49.0791 \text{mm}
```
4.2.2 Effective Dielectric Constant

Effective dielectric constant is calculated by;

\[
\varepsilon_{\text{eff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left[ 1 + \frac{12h}{w} \right]^{\frac{1}{2}}
\]

(4-2(a))

4.2.2.1 Manual Calculation gives

\[
\varepsilon_{\text{eff}} = \frac{4.4 + 1}{2} + \frac{4.4 - 1}{2} \left[ 1 + \frac{12 \times 1.6}{49.0791} \right]^{\frac{1}{2}} = 4.3729
\]

4.2.2.2 Mat lab code

\[
>> \varepsilon_{\text{eff}} = \text{inline}\left('\left(\frac{\varepsilon_r + 1}{2}\right) + \left(\frac{\varepsilon_r - 1}{2}\right) \times \text{sqrt}\left(\frac{1}{1 + 12 \times \frac{h}{w}}\right)\right)'
\]

\[
>> \varepsilon_r = 4.4; w = 49.0791; h = 1.6;
\]

\[
>> \varepsilon_{\text{eff}}(\varepsilon_r, w, h)
\]

\[
\text{ans} = 4.3729
\]

4.2.3 Length

Length of the Rectangular patch is found by;

i) Length

\[
l \approx \frac{c}{2f_r \sqrt{\varepsilon_{\text{eff}}}}
\]

(4-3(a))

4.2.3.1 Manual Calculation gives

\[
l = \frac{3 \times 10^8}{2 \times 1.86 \times 10^9 \sqrt{4.3729}} = 38.5650\text{mm}
\]
4.2.3.2 Mat Lab Code

```
>> l = inline ('c / (2 * f_r * sqrt(epsilon_eff))
>> f_r = 1.86e9; c = 3e8; epsilon_eff = 4.3729;
>> l(f_r, c, epsilon_eff)
>> 38.5650 mm
```

(4-3(b))

4.2.4 Length due to Fringing

Length due to fringing $\Delta l$ is found by:

$$
\Delta l = 0.412h \frac{(\epsilon_{\text{eff}} + 0.3)(\frac{w}{h} + 0.264)}{(\epsilon_{\text{eff}} - 0.258)(\frac{w}{h} + 0.8)}
$$

(4-4(a))

4.2.4.1 Manual Calculation gives

$$
\Delta l = 0.412 \times 1.6 \frac{(4.3729 + 0.3)(\frac{49.0791}{1.6} + 0.264)}{(4.3729 - 0.258)(\frac{49.0791}{1.6} + 0.8)}
$$

$\Delta l = 0.7358 mm$

$h = 1.6; w = 49.0791; \epsilon_{\text{eff}} = 4.3729$

$\Delta l = 0.7358 mm$

$2\Delta l = 1.4716 mm$
4.2.4.2 Mat Lab Code

\[ l = \text{inline}(0.412 * h * ((\varepsilon_{\text{eff}} + 0.3) * (\frac{W}{h} + 0.264)) * ((\varepsilon_{\text{eff}} - 0.258) * (\frac{W}{h} + 0.8))) \]  

\[ (4-4(b)) \]

\[ >> h = 1.6; \varepsilon_{\text{eff}} = 4.3729; w = 49.0791; \]
\[ >> l(h, \varepsilon_{\text{eff}} ; w) \]
\[ \text{ans} = 0.7358 \text{mm} \]
\[ l = l_{\text{eff}} - 2\Delta l \]
\[ l = 38.5650 - 1.4716 \]
\[ l = 37.0934 \text{mm} \]

After a parametric sweep the length becomes 37.8406mm.

4.2.5 Feed Line Dimension

a) The length of the feed line is given by:

\[ l_{f} = \frac{\lambda_{g}}{4}, \]

\[ \lambda_{g} = \frac{\lambda_{0}}{\sqrt{\varepsilon_{\text{eff}}}} \]  

\[ (4-5(a)) \]

4.2.5.1 Manual Calculation gives

\[ l_{f} = \frac{\lambda_{g}}{4} = 19.5128 \text{mm} \]

4.2.5.2 Mat Lab Code

\[ >> \lambda_{g} = \text{inline}(\frac{\lambda_{0}}{\sqrt{\varepsilon_{\text{eff}}}}) \]
\[ >> \lambda_{0} = 158.8142; \varepsilon_{\text{eff}} = 4.1402; \]
\[ >> \lambda_{g}(\lambda_{0}, \varepsilon_{\text{eff}}) \]
\[ \text{ans} = 78.0510 \text{mm} \]
4.2.6 Feed Line Length is found by;

4.2.6.1 Manual Calculation gives

\[ l_f = \frac{\lambda_s}{4} = \frac{78.0510}{4} \]

\[ = 19.5128 \text{ mm} \quad \text{(4-6(a))} \]

4.2.6.2 Mat Lab Code

\[ >> l_f = \text{inline}(\frac{\lambda_s}{4}) \]

\[ >> \lambda_s = 78.0510; \]

\[ >> l_f(\lambda_s) \quad \text{(4-6(b))} \]

\[ \text{ans = 19.5128 mm} \]

Where

\[ \lambda_o = \frac{\nu_o}{f_r} \quad \text{Where} \quad \nu_o = 3 \times 10^8 \text{ and } f_r = 1.86 \times 10^9 \]

The length becomes 37.8406 mm

Total area of the patch = 1,857.1826 mm².

4.2.7 Width of the Feed Line

Em-talk calculator was used to calculate the width

Value = 3.0590 mm.

4.2.8 Ground Plane Dimension

Should be at least \( l' \) length and \( w' \) width,

\[ l' = l + 6h \quad \text{Where} \quad l \text{ is the length and } h \text{ the substrate height}, \quad w' = w + 6h \text{ and } w \]

is the width of the ground plane and \( h \) the substrate height.
Figure 4.1 Shows the Diagram of Rectangular Patch

![Diagram of Rectangular Patch]

Fig 4.1 Rectangular MSA

4.2.9 Patch Dimension
The dimension of the patches was calculated using the formulas of the rectangular patch above and the corresponding effective dielectric constant.

<table>
<thead>
<tr>
<th>Set1</th>
<th>set2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\varepsilon_r = 4.4$</td>
<td>$\varepsilon_{\text{reff}} = 4.3726$,</td>
</tr>
<tr>
<td>$h = 1.6\text{mm}$</td>
<td>$h = 1.6\text{mm}$,</td>
</tr>
<tr>
<td>$\varepsilon_{\text{reff}} = 4.3729$</td>
<td>$\varepsilon_r = 4.4$</td>
</tr>
<tr>
<td>$\Delta l = 0.7358\text{mm}$</td>
<td>$\Delta l = 0.7313\text{mm}$</td>
</tr>
<tr>
<td>$w = 49.0791\text{mm}$</td>
<td>$2\Delta l = 1.4626\text{mm}$</td>
</tr>
<tr>
<td>$l = 37.8406\text{mm}$</td>
<td>$w_p = 3.059\text{mm}$</td>
</tr>
<tr>
<td>$l_f = 19.9670\text{mm}$</td>
<td>$f_c = 1.88 \times 10^9 \text{GHz}$</td>
</tr>
<tr>
<td>$w_p = 3.059\text{mm}$</td>
<td>$c = 3 \times 10^8 \text{m/s}$</td>
</tr>
<tr>
<td>$f_c = 1.86 \times 10^9 \text{GHz}$</td>
<td>$w = 48.5759\text{mm}$</td>
</tr>
<tr>
<td>$c = 3 \times 10^8 \text{m/s}$</td>
<td>$l = 37.3176\text{mm}$</td>
</tr>
</tbody>
</table>
Set 3

$\varepsilon_{\text{reff}} = 4.3715,$

$h = 1.6\, \text{mm},$

$\varepsilon_r = 4.4$

$\Delta l = 0.7352\, \text{mm}$

$2\Delta l = 14704\, \text{mm}$

$w_p = 3.059$

$f_o = 1.96 \times 10^9\, \text{GHz}$

$c = 3 \times 10^8\, \text{m} / \text{s}$

$w = 46.5750\, \text{mm}$

$l = 35.7548\, \text{mm}$

Set 4

$\varepsilon_{\text{reff}} = 4.3719,$

$h = 1.6\, \text{mm},$

$\varepsilon_r = 4.4$

$\Delta l = 0.7291\, \text{mm}$

$2\Delta l = 1.4582\, \text{mm}$

$w_p = 3.059\, \text{mm}$

$f_o = 1.93 \times 10^9\, \text{GHz}$

$c = 3 \times 10^8\, \text{m} / \text{s}$

$w = 47.2990\, \text{mm}$

$l = 36.7145\, \text{mm}$

Set 5

$\varepsilon_{\text{reff}} = 4.3711,\, h = 1.6\, \text{mm},\, \varepsilon_r = 4.4$

$\Delta l = 0.7350\, \text{mm},\, 2\Delta l = 1.4700\, \text{mm}$

$w_p = 3.059\, \text{mm},\, f_o = 1.99 \times 10^9\, \text{GHz}$

$c = 3 \times 10^8\, \text{m} / \text{s},\, w = 45.8729\, \text{mm}$

$l = 35.2158\, \text{mm}$

Diagram 4.2 Shows the Simulated Rectangular Microstrip Antenna

Fig 4.2 Diagram of Simulated Rectangular MSA
4.2. Circular Microstrip Antenna

Figure 4.3 below is the diagram of a circular patch

![Circular Microstrip Antenna Diagram](image)

**Fig 4.3 Schematic Diagram Showing Circular MSA**

4.2.1 Calculating Radius of the Patch.

4.2.1.1 Manual Calculation.

a) Area of circular patch

\[(A) = \pi r^2\]  \hspace{1cm} (4-8(a))

\[1,857.1826\text{mm}^2 = \pi r^2\]

\[r = 24.3089\text{mm}\]

4.2.1.2 Matlab code

\[>>r=inline('\text{sqr}(A/(22/7)))''\]  \hspace{1cm} (4-8(b))

\[>>A=1857.1826;\]

\[>>r (A)\]
>>ans

24.3089mm.

The above formulas for Circular patch were used to calculated the dimension for the other 4 sets.

<table>
<thead>
<tr>
<th>Set1</th>
<th>set2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A = 1.857.1826mm^2, r = 24.3089mm$</td>
<td>$A = 1.812.7361mm^2, r = 24.0162mm$</td>
</tr>
<tr>
<td>$l_f = 4.9248mm$</td>
<td>$l_f = 5.4945mm$</td>
</tr>
<tr>
<td>$w_f = 3.059mm$</td>
<td>$w_f = 3.059mm$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Set3</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A = 1.735.4485mm^2, r = 23.4987mm$</td>
</tr>
<tr>
<td>$l_f = 5.4077mm$</td>
</tr>
<tr>
<td>$w_p = 3.059mm$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Set4</th>
<th>Set5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$A = 1.665.2798mm^2, r = 23.0187mm$</td>
<td>$r = 22.6717mm$</td>
</tr>
<tr>
<td>$l_f = 5.269mm$</td>
<td>$l_f = 6.2mm$</td>
</tr>
<tr>
<td>$w_p = 3.059mm$</td>
<td>$w_p = 3.059mm$</td>
</tr>
</tbody>
</table>

Figure 4.4 Shows the Diagram of a Circular Patch Microstrip Antenna

Fig 4.4 Schematic Diagram of Circular Patch MSA
4.3 Cross Shaped MSA

Cross shaped Microstrip antenna dimension are found by dividing the rectangular patch along the shorter length into two equal halves, one half is further divided into two halves as shown in figure 4.5, and fixed on the sides of the half not cut. Figure 4.5 shows a Rectangular Microstrip antenna cut along the length into two equal parts.

\[ b = 24.5396 \text{ mm} \]
\[ a = 18.9203 \text{ mm} \]
\[ L = 37.8406 \text{ mm} \]
\[ c = (L - b) / 2 \text{ mm} \]
\[ W = 49.0792 \text{ mm}. \]

**Fig 4.5 Layout Design of a Cross Shaped Patch**

One piece is further divided into two equal halves then fixed on both sides of the length of the Rectangular patch.

**Fig 4.6 Diagram of a Cross Shaped Patch**
<table>
<thead>
<tr>
<th>Set1</th>
<th>SET2</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b = 24.5396\text{mm}$</td>
<td>$b = 24.4083\text{mm}$</td>
</tr>
<tr>
<td>$a = 18.9203\text{mm}$</td>
<td>$a = 18.5668\text{mm}$</td>
</tr>
<tr>
<td>$c = 6.4940\text{mm}$</td>
<td>$c = 6.3627\text{mm}$</td>
</tr>
<tr>
<td>$d = 6.8123\text{mm}$</td>
<td>$d = 14.077\text{mm}$</td>
</tr>
<tr>
<td>$e = 3.059\text{mm}$</td>
<td>$e = 3.059\text{mm}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Set3</th>
<th>set4</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b = 23.6145\text{mm}$</td>
<td>$b = 23.2875\text{mm}$</td>
</tr>
<tr>
<td>$a = 18.3727\text{mm}$</td>
<td>$a = 17.8774\text{mm}$</td>
</tr>
<tr>
<td>$c = 6.5655\text{mm}$</td>
<td>$c = 6.2337\text{mm}$</td>
</tr>
<tr>
<td>$d = 14.2711\text{mm}$</td>
<td>$d = 14.7664\text{mm}$</td>
</tr>
<tr>
<td>$e = 3.059\text{mm}$</td>
<td>$e = 3.059\text{mm}$</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Set5</th>
</tr>
</thead>
<tbody>
<tr>
<td>$b = 22.9365\text{mm}$</td>
</tr>
<tr>
<td>$a = 17.6079\text{mm}$</td>
</tr>
<tr>
<td>$c = 6.1397\text{mm}$</td>
</tr>
<tr>
<td>$d = 15.0359\text{mm}$</td>
</tr>
<tr>
<td>$e = 3.059\text{mm}$</td>
</tr>
</tbody>
</table>

Figure 4.7 Shows the Diagram of Simulated Cross Shaped MSA

![Diagram of Simulated Cross Shaped MSA](image)

**Fig 4.7 Schematic Diagram of Simulated Cross Shaped MSA**
4.4 Dimensions of Bow-Tie Microstrip antenna

The dimension of the bow-tie MSA is found, manually by;

\[
\text{area} = \frac{1}{2} \ast b^2 \ast \sin 60^0
\]

(4-9(a))

One Equilateral triangle is half the area of Rectangular patch, Bow-tie is made by using two Equilateral triangles.

4.4.1 Manual Calculation

\[
b = \sqrt{\frac{\text{area}}{0.866}}
\]

\[
b = \sqrt{\frac{1.857.1826}{0.8660}}
\]

\[
b = 46.3093
\]

4.4.2 Matlab Code

\[
>> b = inline('sqrt(\text{area})/0.866')
\]

\[
>> b(area)
\]

\[
>> \text{area} = 1.857.1826;
\]

\[
>> b(area)
\]

\[
\text{ans} = 46.3093mm
\]

(4-9(b))

4.4.3 The Height of the Equilateral Triangle

4.4.3.1 Manual Calculation

\[
\text{area} = \frac{1}{2} \ast b \ast h
\]

1.857.1826 = 46.393 * h

\[
h = 40.1039mm
\]

(4-10(a))

4.4.3.2 Matlab
\[ h = \text{inline}(\text{area} / b) \]
\[ b = 46.3093; \]
\[ h(b) \]
\[ \text{ans} = 40.1039 \]  \hspace{1cm} (4-10(b))

### 4.4.4 Effective Dielectric Constant

#### 4.4.4.1 Manual Calculation

\[ \varepsilon_r = 4.4, \ h = 1.6, \ w = b = 46.3093, \ w_c = 0 \]

\( w_c \) is the distance of separation at the middle of Bow-tie

\[ \varepsilon_{\text{reff}} = \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \left( \frac{24h}{w + w_c} + 1 \right)^{1/2} \]

\[ \varepsilon_{\text{reff}} = \frac{4.4 + 1}{2} + \frac{4.4 - 1}{2} \left( \frac{24 \times 1.6}{46.3093 + 0} + 1 \right)^{1/2} \]

\[ \varepsilon_{\text{reff}} = 3.9569 \]  \hspace{1cm} (4-11(a))

#### 4.4.4.2 Matlab Code

\[ \varepsilon_{\text{reff}} = \text{inline} \left( \left( \frac{\varepsilon_r + 1}{2} + \frac{\varepsilon_r - 1}{2} \right) / \text{sqrt} \left( \frac{24h}{w + w_c} + 1 \right) \right) \]

\[ \varepsilon_r = 4.4, h = 1.6, w = 46.3093, w_c = 0, \]

\[ \varepsilon_{\text{reff}}(\varepsilon_r, h, w, w_c) \]

\[ \varepsilon_{\text{reff}} = 3.9569 \]  \hspace{1cm} (4-11(b))

C and d are found using equation (3-11) and (3-12) respectively.
The figure 4.8a shows a Bow-Tie patch dimension and 4.8b the separation at the middle of the Bow-tie patch.

![Fig 4.8 Schematic Diagram of Bow-Tie Patch MSA](image)

Using the above Bow-tie formulas the dimensions of the bow-tie patch for other sets were calculated.

<table>
<thead>
<tr>
<th>Set</th>
<th>Dimensions</th>
</tr>
</thead>
<tbody>
<tr>
<td>Set 1</td>
<td>( b = 46.3093, \text{mm}, \varepsilon_{\text{eff}} = 3.9569 )</td>
</tr>
<tr>
<td></td>
<td>( h = 40.1039, \text{mm} )</td>
</tr>
<tr>
<td></td>
<td>( c = 39.4737, \text{mm} )</td>
</tr>
<tr>
<td></td>
<td>( d = 3.059, \text{mm} )</td>
</tr>
<tr>
<td>Set 2</td>
<td>( b = 45.7818, \text{mm}, \varepsilon_{\text{eff}} = 3.9537 )</td>
</tr>
<tr>
<td></td>
<td>( h = 39.5951, \text{mm} )</td>
</tr>
<tr>
<td></td>
<td>( c = 39.4737, \text{mm} )</td>
</tr>
<tr>
<td></td>
<td>( d = 3.059, \text{mm} )</td>
</tr>
<tr>
<td>Set 3</td>
<td>( b = 44.7659, \text{mm}, \varepsilon_{\text{eff}} = 3.9472 )</td>
</tr>
<tr>
<td></td>
<td>( h = 38.7672, \text{mm} )</td>
</tr>
<tr>
<td></td>
<td>( c = 39.1703, \text{mm} )</td>
</tr>
<tr>
<td></td>
<td>( d = 3.059, \text{mm} )</td>
</tr>
<tr>
<td>Set 4</td>
<td>( b = 43.8515, \text{mm}, \varepsilon_{\text{eff}} = 39413 )</td>
</tr>
<tr>
<td></td>
<td>( h = 37.9754, \text{mm} )</td>
</tr>
<tr>
<td></td>
<td>( c = 39.4737, \text{mm} )</td>
</tr>
<tr>
<td></td>
<td>( d = 3.059, \text{mm} )</td>
</tr>
</tbody>
</table>
Set 5

\[ b = 43.8542, \varepsilon_{\text{off}} = 3.9369 \]
\[ h = 36.8375\text{mm} \]
\[ c = 37.9893\text{mm} \]
\[ d = 3.059\text{mm} \]

Figure 4.9 Shows the Diagram of Simulated Bow-Tie Microstrip Antenna

**Fig 4.9 Schematic Diagram of a Bow-Tie Shaped MSA**

### 4.5 FABRICATION OF THE ANTENNA

The substrate used for fabrication of the antenna is FR4 because it is cheap and gives good results, the feeding technique used is feed line method because it’s easier to match the impedance than the other 3 methods.

**4.5.1 Process Followed in Fabrication of the Antenna**

i) Designing was done using HFSS software
ii) Printing was done on a transparent polythene sheet for the patch and ground plane of set 2 for Rectangular, Circular and Cross shaped and set4 for Bow-tie because it gave better results.

iii) The transparent polythene sheet printed was placed on the substrate, one on top for the patch and another at the bottom for the ground, and then put in an air tight envelope finally put in an exposure unit which had upper and lower exposure.

iv) Developing and removing of photo resist exposed to UV light was done using sodium hydroxide, and etching of exposed copper was done using chloride (III) ferrite.

Oiling of the patch was done to prevent oxidation, drilling, soldering and fixing of connectors was also done.
Fabricated microstrip antennas

Antennas are ready for testing.

4.6 VARIATION IN AREA BY INCREASING AND DECREASING BY 10%

The area of the four shapes namely Rectangular, Circular, Cross shaped and Bow-tie is varied to study its effect on optimum frequency.

4.6.1 RECTANGULAR PATCH

Calculation

Original area = 1,812.7454mm$^2$

Reducing area by 10%

Change in Area $\frac{90}{100} \times 1,812.7454 = 1631.4619mm^2$

To find change in dimension of the rectangular patch, since total change is 0.9

Change in length is $\sqrt{0.9 \times 37.1336} = 35.2280mm$ and

Change in width is $\sqrt{0.9 \times 48.8166} = 46.3115mm$
Increasing area by 10%

Change in Area \( \frac{110}{100} \times 1.812.7354 = 1.994.0090 \text{ mm}^2 \)

Total change is 1.1

Change in length is \( \sqrt{1.1} \times 37.1336 = 38.9460 \text{ mm} \)

Change in width is \( \sqrt{1.1} \times 48.8166 = 51.1993 \text{ mm} \).

<table>
<thead>
<tr>
<th>Table 2 Dimensions of the Rectangular Patches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Area (\text{mm}^2)</td>
</tr>
<tr>
<td>Length (mm)</td>
</tr>
<tr>
<td>Width (mm)</td>
</tr>
</tbody>
</table>

4.6.2 CIRCULAR PATCH

Using the formulae (4-8(a)) the radii are as in table 3

<table>
<thead>
<tr>
<th>Table 3 Dimension of Circular Patches</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
</tr>
<tr>
<td>Area (\text{mm}^2)</td>
</tr>
<tr>
<td>Radius (mm)</td>
</tr>
</tbody>
</table>
4.6.3 CROSS SHAPED PATCH

Using the dimension of figure 15

Table 4 Dimension of Cross Shaped Patches

<table>
<thead>
<tr>
<th></th>
<th>Original</th>
<th>Reduction by 10%</th>
<th>Increase by 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (mm²)</td>
<td>1,812.7354</td>
<td>1,631.4619</td>
<td>1,994.0090</td>
</tr>
<tr>
<td>a(mm)</td>
<td>18.5668</td>
<td>17.6140</td>
<td>19.4730</td>
</tr>
<tr>
<td>b(mm)</td>
<td>24.4083</td>
<td>23.1558</td>
<td>25.5997</td>
</tr>
<tr>
<td>c(mm)</td>
<td>6.3627</td>
<td>6.0361</td>
<td>6.6732</td>
</tr>
</tbody>
</table>

4.6.4 BOW-TIE PATCH

Using the formulae (4-9(a)) to find the value of (b) and (4-10(a)) to find the value of (h).

Table 5 Dimensions of Bow-Tie Patches

<table>
<thead>
<tr>
<th></th>
<th>Original</th>
<th>Reduction by 10%</th>
<th>Increase by 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Area (mm²)</td>
<td>1,665.2837</td>
<td>1,498.7553</td>
<td>1,831.8121</td>
</tr>
<tr>
<td>a(mm)</td>
<td>43.8509</td>
<td>41.6006</td>
<td>45.9912</td>
</tr>
<tr>
<td>h(mm)</td>
<td>37.9760</td>
<td>36.0272</td>
<td>39.8296</td>
</tr>
</tbody>
</table>
CHAPTER 5
RESULTS AND DISCUSSION:

5.1 Introduction
This chapter gives the simulation results, experimental results and discussions of the work carried out. Simulation results were obtained from High Frequency Structure Simulator (HFSS) software, and for experimental results, the microstrip patch antenna was connected to the spectrum analyzer, a horn antenna was used to transmit a signal at a given frequency from the signal generator, the antenna under test produced a signal through the spectrum analyzer at a frequency similar to the one simulated. The value of gain of simulated and fabricated antenna was ascertained and found to be close to each other.

5.2 SET 1: AREA (1,857.1826 mm²)

5.2.1.1 RETURN LOSS Vs FREQUENCY

Fig 5.1 Graph of Return Loss Vs Frequency of a Rectangular Patch MSA

Fig 5.1 shows the Return loss against frequency of a Rectangular microstrip antenna, the reflection coefficient is lowest at a frequency of 6.9940GHz, at
this frequency we have low power loss as compared to the other frequencies of oscillation, and 2.8900GHz has the highest power loss.

**Fig 5.2 Graph of Return Loss Vs Frequency of a Circular patch MSA**

Fig 5.2 gives the lowest frequency of oscillation compared to the other four shapes, at a frequency of 3.4840GHz the coefficient of reflection is very high hence most power is reflected back to the transmission line, but at 8.5600GHz we have the best matching.

**Fig 5.3 Graph of Return Loss Vs Frequency of a Cross Shaped Patch MSA**
Fig 5.3 has a Return loss of greater than -9.54 at 3.3760GHz, 5.7520GHz and 8.2540 GHz which is greater than the recommended maximum, at this frequency most of the power is reflected back to the feed line hence the antenna cannot be commercially viable at this frequencies.

Fig 5.4 Graph of Return loss Vs Frequency of a Bow-Tie Patch MSA

Fig 5.4 has the lowest return loss of the four shapes at a frequency of 9.3112 GHz; the coefficient of reflection is lowest at this frequency hence better matching than the other three shapes, but at a frequency of 2.0872GHz and 5.4808GHz the coefficient of reflection is higher than recommended maximum.

\[ M_i, \text{ where } i = 1, 2, 3, \text{ etc, are oscillation frequency} \]

**Table 6 Lowest Operating Frequency for SET1**

<table>
<thead>
<tr>
<th>Shape</th>
<th>Frequency(GHz)</th>
<th>Return Loss(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.8640</td>
<td>-20.1557</td>
</tr>
<tr>
<td>Circular</td>
<td>1.7380</td>
<td>-24.9439</td>
</tr>
<tr>
<td>Cross Shaped</td>
<td>2.1520</td>
<td>-9.5902</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>3.6328</td>
<td>-16.3852</td>
</tr>
</tbody>
</table>
Circular patch registered the lowest operating frequency followed by Rectangular, Cross Shaped and finally Bow-Tie, return loss of circular patch is lowest and for cross shaped highest.

Table 7 Optimum Operating Frequency SET 1

<table>
<thead>
<tr>
<th>Shape</th>
<th>Frequency (GHz)</th>
<th>Return Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>6.9940</td>
<td>-28.2359</td>
</tr>
<tr>
<td>Circular</td>
<td>8.5600</td>
<td>-28.4646</td>
</tr>
<tr>
<td>Cross Shape</td>
<td>9.5680</td>
<td>-31.6279</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>9.3112</td>
<td>-43.3030</td>
</tr>
</tbody>
</table>

Rectangular patch has the lowest optimum frequency followed by circular, Bow-tie and finally Cross shaped. However, Bow-tie has the lowest return loss followed by cross-shaped, then, circular and finally rectangular. The minimum recommended return loss of an antenna is -9.54, but in some cases the antennas have a return loss higher than this, it shows that the coefficient of reflection is greater than recommended hence the antenna is not suitable for use commercially at those frequencies.
5.2.1.2 SMITH CHART
Figure 5.5 shows the smith chart of a rectangular patch MSA.

Fig5.5 Smith Chart of a Rectangular Patch MSA
Fig 5.5 shows the impedance matching of the Rectangle, the nearer the circular curve is to one the better the matching, the antenna exhibits inductive and capacitive reactance in some cases and both inductive and capacitive reactance in others.

Figure 5.6 shows the smith chart of circular patch MSA

Fig5.6 Smith Chart of Circular Patch MSA
Figure 5.7 shows the smith chart of a cross shaped MSA

Fig 5.7 Smith Chart of a Cross Shaped Patch MSA

Figure 5.8 shows a smith chart of a bow-tie patch MSA

Fig 5.8 Smith Chart of Bow-Tie Patch MSA

The smith chart in the figures above shows that the antennas are operating at frequencies more than one hence the many circular curves. It also shows that at some frequencies the antenna patches exhibit inductive or capacitive reactance, and in others both capacitive and inductive reactance, hence the antenna is non resonant.
5.2.1.3 RADIATION PATTERN

Figure 5.9 shows the radiation pattern of a rectangular patch MSA

![Figure 5.9 Radiation Pattern of a Rectangular Patch MSA](image)

Fig 5.9 Radiation Pattern of a Rectangular Patch MSA

Figure 5.9 Rectangular MSA shows that it directs its energy in one direction, hence a good antenna for picking small signal.

Figure 5.10 radiation pattern of a circular patch MSA

![Figure 5.10 Radiation Pattern of Circular Patch MSA](image)

Fig 5.10 Radiation Pattern of Circular Patch MSA

Figure 5.10 shows the radiation pattern of a circular shaped MSA is in one direction, this antenna can be used to communicate in only one direction.
Figure 5.11 shows radiation pattern of a cross shaped patch MSA.

**Fig5.11 Radiation Pattern of a Cross-Shaped Patch MSA**

Figure 5.11 shows that this antenna directs its power in one direction at $0^0$, this antenna can receive or radiate in one direction only.

Figure 5.12 shows radiation pattern of a bow-tie patch MSA

**Fig 5. 12 Radiation Pattern of a Bow-Tie Patch MSA**

The radiation pattern of the first three shapes namely Rectangular, Circular and Cross shaped radiate at an angle of $\Theta = 0^0$ and in one direction perpendicular to the patch but the Bow-tie radiates at $\Theta = 50^0$ and $\Theta = -50^0$, bow-tie can receive or radiate in two different directions hence an intermediate radiator.
5.2.1.4 3D POLAR

Figure 5.13 shows the radiation pattern in 3D of a rectangular patch MSA.

**Fig 5. 13 Radiation Pattern in 3D polar of Rectangular Patch MSA**

Figure 5.14 Shows the Radiation Pattern of a Circular Patch MSA.

**Fig 5.14 Radiation Pattern in 3D Polar of a Circular Patch MSA**

This antenna in fig 5.15 radiates along the z axes with maximum energy.

Figure 5.15 shows the Radiation Pattern in 3D Polar of a Cross Shaped MSA.
Figure 5.15 shows that the antenna radiates its power just like rectangular and circular MSA in a given direction.

Figure 5.16 shows the radiation pattern in 3D polar of a bow-tie MSA.

Figure 5.16 shows that the bow-tie patch radiates in two different directions which is neither end fire nor broadside.

Rectangular, Circular and Cross shaped radiate along the Z axis(0°) hence end fire radiator but the Bow tie radiate along the -50° and 50° hence an intermediate radiator.
5.2.1.5 GAIN

1) Graph of Gain Vs Theta of a Rectangular Patch MSA

Fig 5.17 Graph of Gain against Theta of a Rectangular patch MSA

Graph of Gain against theta of a Circular patch MSA

5.18 Graph of Gain of a Circular Patch MSA

Graph of Gain against theta of a Cross shaped patch MSA
Fig 5.19 Graph of Gain of a Cross shaped Patch MSA

Graph of Gain against theta of Bow-tie patch MSA

Fig 5.20 Graph of Gain of a Bow-Tie Patch MSA

Rectangular MSA has the highest gain of 1.0063, followed by Cross shaped with a gain of 0.8256, Circular with 0.0.7891 and finally Bow-Tie with a gain Of 0.2446. This means that Rectangular MSA would be able to pick weaker signal than any of the other 3 designs because of its higher gain. The higher the gain the better an antenna is in peaking weak signals.
5.2.1.6 DIRECTIVITY
Graph of Directivity against Theta of Rectangular MSA

Fig 5.21 Graph of Directivity of a Rectangular MSA
Graph of Directivity against theta of Circular patch MSA

Fig 5.22 Graph of Directivity of a Circular MSA
Graph of directivity against theta of a Cross shaped patch MSA
**Fig 5.23 Graph of Directivity of a Cross shaped patch MSA**

Graph of directivity against theta of a Bow-tie patch MSA.

**Fig 5.24 Graph of Directivity of a Bow-Tie patch MSA**

Rectangular has the highest directivity of 1.9642, followed by Circular 1.6610, Cross shaped 1.4957 and finally Bow-tie 1.306.

Rectangular patch MSA has the best directivity showing that as a transmitter or receiver it would direct most of its power in a given direction, so for an antenna...
than is unidirectional Rectangular patch would be the best for this kind of an antenna.

5.2.1.7 VSWR Vs FREQUENCY
Graph of VSWR Vs Frequency of a rectangular patch MSA

Fig 5.25 Graph of VSWR Vs Frequency of a Rectangular Patch MSA

Graph of VSWR Vs Frequency of a circular patch MSA

Fig 5.26 Graph of VSWR against Frequency of a Circular Patch MSA

Graph of VSWR Vs Frequency of a Cross Shaped MSA
Fig 5.27 Graph of VSWR Vs Frequency of Cross Shaped Patch MSA

Graph of VSWR Vs Frequency of a Bow-tie MSA

Fig 5.28 Graph of VSWR Vs Frequency of Bow-Tie Patch MSA

Bow –tie has the lowest VSWR of 1.0138 followed by Cross shaped at 1.0538, Circular at 1.0784 and finally Rectangular with the most at 1.0806.

The nearer the VSWR of an antenna is to one the better the matching. An ideal antenna has a VSWR of one, a commercially viable antenna should have a VSWR of between one and two.
5.2.1.8 SET 1

Table 8 Antenna Parameters for set 1

<table>
<thead>
<tr>
<th>SET 1</th>
<th>Frequency (GHz)</th>
<th>Return Loss</th>
<th>Bandwidth</th>
<th>Gain</th>
<th>Directivity</th>
<th>Radiation Pattern</th>
<th>Best VSWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.8640</td>
<td>-21.1483</td>
<td>0.1092</td>
<td>6.02</td>
<td>1.0063</td>
<td>1.9642</td>
<td>7.5608</td>
</tr>
<tr>
<td></td>
<td>6.9940</td>
<td>-28.2359</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0806</td>
</tr>
<tr>
<td></td>
<td>9.8200</td>
<td>-25.1170</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>circular</td>
<td>1.7380</td>
<td>-24.9439</td>
<td>0.1227</td>
<td>6.83</td>
<td>0.7891</td>
<td>1.6610</td>
<td>4.0942</td>
</tr>
<tr>
<td></td>
<td>8.5600</td>
<td>-28.4646</td>
<td>0.512</td>
<td>6.11</td>
<td></td>
<td></td>
<td>1.0784</td>
</tr>
<tr>
<td>Cross shaped</td>
<td>2.1520</td>
<td>-9.5902</td>
<td>0.0195</td>
<td>2.95</td>
<td>0.8256</td>
<td>1.4957</td>
<td>4.0149</td>
</tr>
<tr>
<td></td>
<td>9.5680</td>
<td>-31.6279</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0538</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>3.6328</td>
<td>-16.3852</td>
<td>0.1710</td>
<td>4.72</td>
<td>0.2450</td>
<td>1.3066</td>
<td>2.0859</td>
</tr>
<tr>
<td></td>
<td>8.9248</td>
<td>-31.6965</td>
<td></td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>9.3112</td>
<td>-43.3030</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0138</td>
</tr>
</tbody>
</table>

The bandwidth of Circular and Bow-tie patch is highest at 0.512GHz and 0.1710GHz respectively. Rectangular and Cross shaped patches cannot be ascertained fully because their bandwidth goes beyond 10GHz upper limit. The higher the bandwidth the better is the antenna because it can be able to capture signal from a wide range within the bandwidth.
5.2 SET2 (Area = 1812.7360mm²)

5.2.2.1 RETURN LOSS VS FREQUENCY
Graph of Return loss Vs Frequency of a Rectangular patch MSA

Fig 5.29 Graph of Return loss Vs Frequency of a Rectangular Patch MSA

Fig 5.29 shows that at a frequency of 5.7700GHz the antenna wastes a lot of power, but at 7.0660GHz the antenna reflects most is the power hence the lowest return loss, but all frequencies are within acceptable commercial limits of a return loss of -9.5.
Graph of Return loss Vs Frequency of a circular patch MSA

Fig 5.30 Return loss Vs Frequency of a Circular patch MSA

In Figure 5.30 all frequencies except 3.538GHz are within commercially acceptable limits in terms of return loss which is -9.5.

Graph shows Return loss Vs Frequency of a cross shaped patch MSA

Fig 5.31 Graph of Return loss Vs Freq of a Cross Shaped Patch MSA

The Return loss in the frequency 3.3940GHz shows that the loss of the antenna surpasses the acceptable limit, but can operate at all other frequencies.
Fig 5.32 Graph of Return Loss Vs Frequency of a Bow-Tie Patch

Figure 5.32 shows that this Bow-tie antenna has the best operating frequency of 6.0400GHz where the wasted power is very low, and the worst operating frequency is 2.1160GHz where the power wastage is very high, hence at this frequency the antenna is not viable commercially.

<table>
<thead>
<tr>
<th>Shape</th>
<th>Frequency(GHz)</th>
<th>Return Loss(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.8820</td>
<td>-23.1643</td>
</tr>
<tr>
<td>Circular</td>
<td>1.7560</td>
<td>-22.8263</td>
</tr>
<tr>
<td>Cross Shaped</td>
<td>2.1700</td>
<td>-10.6310</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>3.6640</td>
<td>-15.4353</td>
</tr>
</tbody>
</table>

Circular patch registered the lowest operating frequency of 1.7560GHz followed by Rectangular at 1.8820GHz, Cross Shaped at 2.1700GHz and finally Bow-Tie at 3.6640GHz, Return loss of Rectangular patch is lowest at -23.1643 and Cross shaped highest at -10.6310.
Table 10 Optimum Operating Frequency for SET 2

<table>
<thead>
<tr>
<th>Shape</th>
<th>Frequency (GHz)</th>
<th>Return Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>7.0660</td>
<td>-30.4761</td>
</tr>
<tr>
<td>Circular</td>
<td>8.6860</td>
<td>-33.5349</td>
</tr>
<tr>
<td>Cross Shape</td>
<td>5.4280</td>
<td>-36.7637</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>6.0400</td>
<td>-49.0997</td>
</tr>
</tbody>
</table>

Cross shaped patch has the lowest optimum frequency followed by Bow-tie, Rectangular and finally Circular. Return loss for Bow-tie MSA is lowest and Rectangular highest. Return loss represents the antenna power lose in terms of reflection to the feed line due to poor impedance matching, the lower the Return loss the better the antenna since most of the power will be delivered to the antenna for radiation. For Optimum frequency Bow-tie has the best impedance matching.

5.2.2.2 SMITH CHART

Fig 5.33 Smith Chart of a Rectangular Patch MSA
The antenna is either capacitive or inductive in some frequencies, and both inductive and capacitive in others frequencies.

Fig 5.34 Smith Chart of a Circular Patch MSA

Fig 5.35 Smith Chart of a Cross Shape Patch MSA
At some frequencies the antenna patch is both inductive and capacitive and at others it is either inductive or capacitive. This antenna is a non resonant antenna because it is not purely resistive.

### 5.2.2.3 RADIATION PATTERN

Fig 5.36 Smith Chart of the Bow-Tie Patch MSA

Fig 5.37 Radiation Pattern of a Rectangular Patch MSA
Fig 5.38 Radiation Pattern of a Circular Patch MSA

Fig 5.39 Radiation Pattern of a Cross Shaped Patch MSA
Fig 5.40 Radiation Pattern of a Bow-Tie Patch MSA

The Rectangular, Circular and Cross shaped are end fire radiators but Bow-tie is intermediate radiator, Rectangular Patch has the highest radiation pattern.

5.2.2.4 3D POLAR

Fig 5.41 3D Polar of a Rectangular Patch MSA
Fig 5.42 (d) 3D Polar of a Circular Patch MSA

Fig 5.43 3D Polar of a Cross Shaped Patch MSA
Fig 5.44 3DPolar of a Bow-Tie Patch MSA

Rectangular, Circular and Cross shaped radiate in one direction at $0^0$ but Bow-tie radiates in two different directions at $-50^0$ and $50^0$.

The first three namely Rectangular, Circular and Cross-shaped are end fire radiators, but Bow-tie is neither end fire nor broadside.

5.2.2.5 GAIN

Fig 5.45 Graph of Gain of a Rectangular Patch MSA
The Gain of the Rectangular patch MSA is highest at 1.0292, followed by Cross shaped MSA at 0.8963, third is Circular patch MSA at 0.8150 and finally Bow-tie at 0.2207. Bow-tie has the lowest gain because the same energy as in the other three shapes is directed into two different directions. In terms of picking low signals Bow-tie would be the worst and Rectangular the best. The higher the gain the better the picking of low signals.

5.2.2.6 DIRECTIVITY

![Graph of Directivity of a Rectangular Patch MSA](image1)

![Graph of Directivity of a Circular Patch MSA](image2)
The directivity of Cross shaped MSA is the highest at 2.0766, followed by Rectangular at 2.0263, Circular at 1.7189 and finally Bow-tie at 1.2903.
5.2.2.7 VSWR VS FREQUENCY

Best match is when operating frequency is 7.0660GHz where the VWSR is approximately one.

Fig 5.53 Graph of VSWR Vs Frequency of a Rectangular patch MSA

Fig 5.54 Graph of VSWR Vs Frequency of a Circular Patch MSA
The VSWR of Bow-tie is the lowest at 1.0070 followed by Cross shaped MSA at 1.0292, Circular at 1.0430 and finally Rectangular at 1.0610.
The closer the VSWR is to one the better the matching, when input impedance is equal to output impedance there is maximum power transfer to load (antenna) leading to low power wastage.

### 5.2.2.8 Set2

**Table 11 Antenna Parameters for SET2**

<table>
<thead>
<tr>
<th>SET 2</th>
<th>Frequency GHz</th>
<th>Return Loss</th>
<th>Bandwidth %</th>
<th>Gain</th>
<th>directivity</th>
<th>Radiation pattern</th>
<th>Best VSWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.8820</td>
<td>-23.1643</td>
<td>0.1136</td>
<td>6.04</td>
<td>1.0292</td>
<td>2.0053</td>
<td>7.5769</td>
</tr>
<tr>
<td></td>
<td>3.6100</td>
<td>-29.8084</td>
<td>0.2913</td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>3.7180</td>
<td>-21.9537</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td></td>
<td>7.0660</td>
<td>-30.4761</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0610</td>
</tr>
<tr>
<td>Circular</td>
<td>1.7560</td>
<td>-22.8263</td>
<td>0.1199</td>
<td>6.83</td>
<td>0.8150</td>
<td>1.7016</td>
<td>4.2659</td>
</tr>
<tr>
<td></td>
<td>8.6860</td>
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<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0430</td>
</tr>
<tr>
<td></td>
<td>9.4240</td>
<td>-18.2131</td>
<td>0.5725</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross shaped</td>
<td>2.1700</td>
<td>-10.6310</td>
<td>0.0898</td>
<td>4.14</td>
<td>0.8963</td>
<td>2.0766</td>
<td>3.8773</td>
</tr>
<tr>
<td></td>
<td>5.4280</td>
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<td></td>
<td></td>
<td></td>
<td></td>
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</tr>
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<td>9.8560</td>
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</tr>
<tr>
<td>Bow-Tie</td>
<td>3.6640</td>
<td>-15.4353</td>
<td>0.1586</td>
<td>4.33</td>
<td>0.2207</td>
<td>1.2903</td>
<td>2.0125</td>
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<tr>
<td></td>
<td>6.0400</td>
<td>-49.0997</td>
<td></td>
<td></td>
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<td>1.0070</td>
</tr>
<tr>
<td></td>
<td>9.1000</td>
<td>-37.8488</td>
<td>0.9542</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Rectangular, Circular and Bow-tie patch give the highest Bandwidth of 0.2913GHz, 0.5725GHz and 0.9542GHz respectively. Cross shaped patch highest bandwidth cannot be fully ascertained because it goes beyond 10GHz limit.
5.2 SET 3: (AREA 1,735.4485MM²)

5.2.3.1 RETURN LOSS VS FREQUENCY

Fig 5.57 Graph of Return Loss Vs Freq of a Rectangular Patch MSA

All the oscillation frequencies are within acceptable limits of below -9.5, the best frequency with the lowest Return loss is given by 7.2460GHz.

Fig 5.58 Graph of Return loss Vs Frequency of a Circular Patch MSA

The best frequency with lowest Return loss is given by 1.7984GHz. The worst is 3.5936GHz; at this frequency the power wastage is highest.
The lowest return loss is given by a frequency of 9.7120GHz at this frequency the antenna has the lowest power wastage, and at a frequency of 3.4840GHz the wastage is highest.

A frequency of 9.3520GHz gives the best return loss hence power wastage is lowest at this frequency and highest at a frequency of 2.1520GHz.
Table 12 Lowest Operating Frequency for SET3

<table>
<thead>
<tr>
<th>Shape</th>
<th>Frequency (GHz)</th>
<th>Return Loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.9180</td>
<td>-24.5771</td>
</tr>
<tr>
<td>Circular</td>
<td>1.7984</td>
<td>-21.8352</td>
</tr>
<tr>
<td>Cross Shaped</td>
<td>2.1700</td>
<td>-9.6799</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>3.7540</td>
<td>-14.6255</td>
</tr>
</tbody>
</table>

Circular patch registered the lowest operating frequency followed by Rectangular, Cross Shaped and finally Bow-Tie. Return loss of circular patch is lowest and for cross shaped highest.

Table 13 Optimum Operating Frequency SET 3

<table>
<thead>
<tr>
<th>Shape</th>
<th>Frequency (GHz)</th>
<th>Return Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>7.2460</td>
<td>-26.9579</td>
</tr>
<tr>
<td>Circular</td>
<td>1.7984</td>
<td>-21.8352</td>
</tr>
<tr>
<td>Cross Shape</td>
<td>9.7120</td>
<td>-30.1791</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>9.3520</td>
<td>-40.7017</td>
</tr>
</tbody>
</table>

Circular patch has the lowest optimum frequency followed by Rectangular, Bow-tie and finally Cross shaped. Return Loss of Bow-tie is the lowest and Circular has the highest. The power accepted for this Optimum frequency by the antenna in a Bow-tie would therefore be higher than in the other 3 shapes at the Optimum frequency.
5.2.3.2 SMITH CHART

The antenna can operate with more than one frequency, this is due to the many circular curves.

Fig 5.61 Smith Chart of a Rectangular Patch MSA

Fig 5.62 Smith Chart of a Circular Patch MSA
The Circular patch MSA operates with more than one frequency.

**Fig 5.63 Smith chart of a Cross shaped patch MSA**
The Cross-shaped MSA oscillates with more than one frequency, hence the many circular curves like the other shapes.

**Fig 5.64 Smith Chart of a Bow-Tie Patch MSA**
The antenna can operate at more than one frequency, the antenna patch at some oscillating frequencies are capacitive or inductive, and others frequencies both capacitive and inductive.
5.2.3.3 RADIATION PATTERN

The radiation of this antenna is directed towards the z direction, its radiation is in one direction hence its best use would be as a unidirectional antenna.

Fig 5.65 Radiation Pattern of a Rectangular Patch MSA

Fig 5.66 Radiation Pattern of a Circular Patch MSA

This antenna is also unidirectional as the Rectangular but its radiation pattern is shorter than that of a rectangular shaped MSA.
Fig 5.67 Radiation Pattern of Cross Shaped Patch MSA

The radiation pattern of this antenna is lower than for the other two discussed before, hence coverage area is also low.

Fig 5.68 Radiation Pattern of a Bow-Tie Patch MSA

Rectangular, Circular and Cross shaped are end fire radiators and radiate at 0° but Bow-tie is intermediate radiator and Radiates at -50° and 50° theta. Bow-tie covers the shortest area due to small radiation hence it would be poorest in detecting weak signal. But for communication with two stations which are apart Bow-tie would be the most ideal.
5.2.3.4 3D POLAR

Figure 5.3.1(d) shows the 3D polar for rectangular MSA.

The total radiated power is in one direction hence the antenna would be ideal for use where a unidirectional antenna is needed.

Fig 5.69 3D Polar for Rectangular Patch MSA

The antenna is also unidirectional but weaker than the Rectangular patch MSA.

Fig 5.70 3D Polar for Circular Patch MSA
Fig 5.71 3D Polar for a Cross Shaped Patch MSA

Fig 5.72 3D Polar for a Bow-Tie Patch MSA

Rectangular MSA has the highest radiation pattern and Bow-tie the lowest, the first three antennas namely Rectangular, Circular and Cross shaped radiate in the same direction, they can be used as a unidirectional antenna.
5.2.3.5 GAIN

Fig 5.73 Gain of a Rectangular Patch MSA

Fig 5.74 Gain of a Circular Patch MSA
The gain of Rectangular MSA is highest at 1.0270, followed by Cross shaped at 0.8671, Circular at 0.8389 finally for Bow-tie the lowest at 0.1890.
5.2.3.6 DIRECTIVITY

Fig5.77 Directivity of a Rectangular Patch MSA

Fig5.78 Directivity of a Circular Patch MSA
The directivity of Cross shaped patch is greater at 2.0930 than for Rectangular 2.0807, Circular at 1.7497, Bow-tie MSA the lowest at 1.2740.
5.2.3.7 VSWR Vs FREQUENCY

The best matching is achieved at a frequency of 7.2460GHz because this is where the VSWR is nearest to one.

Fig 5.81 Graph of VSWR Vs Frequency of a Rectangular Patch MSA

Fig 5.82 Graph of VSWR Vs Frequency of a Circular Patch MSA.
The best Return loss is achieved at 1.7984 GHz, this is where the least power is wasted in this Circular shaped patch MSA.

![Graph of VSWR Vs Frequency of a Cross Shaped Patch MSA](image1)

**Fig 5.83 Graph of VSWR Vs Frequency of a Cross Shaped Patch MSA**

The lowest return loss is at a frequency 9.7120GHz, this frequency provides the best matching of this Cross-shaped patch MSA.

![Graph of VSWR Vs Frequency of a Bow-Tie Patch MSA](image2)

**Fig 5.84 Graph of VSWR Vs Frequency of a Bow-Tie Patch MSA**

The best frequency of this antenna with low power wastage is 9.3520GHz,
Bow-tie has the lowest Return loss at 1.0186 followed by Cross shaped at 1.0639, Rectangular at 1.0980 and last one is Circular at 1.1762. When all the four shapes are compared bow-tie patch MSA provides the best matching and circular patch MSA has the worst wastage.

### 5.2.3.8 Set3

#### Table 14 Antenna Parameters for SET 3

<table>
<thead>
<tr>
<th>Set3</th>
<th>Frequency (GHz)</th>
<th>Return Loss</th>
<th>Bandwidth</th>
<th>% Bandwidth</th>
<th>Gain</th>
<th>Directivity</th>
<th>Radiation pattern</th>
<th>Best VSWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.9180</td>
<td>-24.5771</td>
<td>0.1174</td>
<td>6.12</td>
<td>1.0270</td>
<td>2.0807</td>
<td>7.2460</td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.2460</td>
<td>-26.9579</td>
<td>0.4721</td>
<td>6.52</td>
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<td></td>
<td></td>
<td>1.0940</td>
</tr>
<tr>
<td>Circular</td>
<td>1.7984</td>
<td>-21.8353</td>
<td>0.1233</td>
<td>6.86</td>
<td>0.8389</td>
<td>1.7497</td>
<td>5.0035</td>
<td>1.1762</td>
</tr>
<tr>
<td></td>
<td>9.7363</td>
<td>-18.0591</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross shaped</td>
<td>2.1700</td>
<td>-9.6799</td>
<td>0.0452</td>
<td>2.08</td>
<td>0.8671</td>
<td>2.0930</td>
<td>3.5923</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.7120</td>
<td>-30.1791</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>1.0639</td>
</tr>
<tr>
<td>Bow-Tie</td>
<td>3.7540</td>
<td>-14.6255</td>
<td>0.1568</td>
<td>4.18</td>
<td>0.1890</td>
<td>1.2740</td>
<td>1.7295</td>
<td></td>
</tr>
<tr>
<td></td>
<td>9.3520</td>
<td>-40.7017</td>
<td>0.7634</td>
<td>8.16</td>
<td></td>
<td></td>
<td></td>
<td>1.0186</td>
</tr>
</tbody>
</table>

For rectangular patch a frequency of 7.2460 gives the highest bandwidth of 0.4721GHz and the Bow-tie patch at frequency of 9.3520 gives the highest bandwidth of 0.7634GHz. for Circular and Cross shaped patch the bandwidth extends beyond 10GHz which was the upper limit of the study so the exact value cannot be ascertained.
5.2 SET 4 (AREA=1,665.2798MM²)

5.2.4.1 RETURN LOSS VS FREQUENCY

All the oscillation frequency in graph 5.4.1(a) are within the acceptable range because the Return loss is lower than -9.5, the best frequency with the lowest Return loss is 7.3720GHz.

Fig 5.85 Graph of Return Loss Vs Frequency of Rectangular Patch MSA

Fig 5.86 Graph of Return Loss Vs Frequency of Circular Patch MSA
One of the frequency 3.6640GHz of this antenna in graph 5.4.2(a) has a higher Return loss than the recommended, but all other frequencies are good, the best is 7.6780GHz.

Fig 5.87 Graph of Return Loss Vs Freq of Cross Shaped Patch MSA
Four Oscillating frequencies are beyond the highest recommended Return loss, with the best Operating frequency at 5.6620GHz.

Fig 5.88 Graph of Return Loss Vs Freq of Bow-Tie Patch MSA
Two Operating frequencies have a Return loss beyond the highest recommended, best matching is provided by a frequency of 9.5140GHz.

**Table 15 Lowest Operating Frequency for SET4**

<table>
<thead>
<tr>
<th>Shape</th>
<th>Frequency(GHz)</th>
<th>Return Loss(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.9720</td>
<td>-24.8265</td>
</tr>
<tr>
<td>Circular</td>
<td>1.8280</td>
<td>-18.2797</td>
</tr>
<tr>
<td>Cross Shaped</td>
<td>4.0780</td>
<td>-14.3004</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>3.8260</td>
<td>-14.3718</td>
</tr>
</tbody>
</table>

Circular patch registered the lowest operating frequency, second Rectangular, Bow-Tie and finally Cross Shaped, Return loss of Rectangular patch is lowest and for cross shaped highest.

**Table 16 Optimum Operating Frequency (SET 4)**

<table>
<thead>
<tr>
<th>Shape</th>
<th>Frequency (GHz)</th>
<th>Return Loss(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>7.3720</td>
<td>-43.2712</td>
</tr>
<tr>
<td>Circular</td>
<td>7.6780</td>
<td>-21.1879</td>
</tr>
<tr>
<td>Cross Shape</td>
<td>5.6620</td>
<td>-20.5779</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>9.5140</td>
<td>-36.5021</td>
</tr>
</tbody>
</table>

Cross shaped patch has the lowest Optimum frequency followed by Rectangular, Circular and finally Bow-tie. Rectangular has the lowest Return loss, followed by Bow-tie, Circular and finally Cross shaped. The lower the Return loss the better the matching hence the antenna which has lowest power wastage is the Rectangular patch MSA at the Optimum frequency.
5.2.4.2 SMITH CHART

Fig 5.89 Smith Chart of a Rectangular Patch MSA

The antenna operates at more than one frequency.

Fig 5.90 Smith Chart of a Circular Patch MSA

This antenna is oscillating and operates at more than one frequency.
Fig 5.91 Smith Chart of a Cross Shaped Patch MSA

This is a multi frequency operating antenna.

Fig 5.92 Smith Chart of a Bow-Tie Patch MSA

This antenna just like the other three shapes operates at more than one frequency, hence a multi frequency operator. The antennas operates at several frequencies, some operating frequency are both capacitive and inductive and others either capacitive or inductive.
5.2.4.3 RADIATION PATTERN

Figure 5.93 shows radiation pattern for Rectangular MSA

Fig 5.93 Radiation Pattern for Rectangular Patch MSA

The Rectangular patch radiates in one direction, at an angle of $0^0$.

Figure 5.94 shows the radiation pattern for Circular patch MSA.

Fig 5.94 Radiation Pattern for Circular Patch MSA

This Circular patch shape radiates along the z axis, but its radiation is weaker than for the Rectangular patch MSA.
Figure 5.95 shows radiation pattern for Cross shaped patch MSA.

Fig 5.95 Radiation Pattern for Cross Shaped Patch MSA

Likewise the Cross-shape also radiates in the $0^\circ$ direction but its radiation is weaker than for Rectangular and Circular.

Figure 5.96 shows radiation pattern for Bow-tie MSA.

Fig 5.96 Radiation Pattern for Bow-Tie Patch MSA

Rectangular, Circular and Cross shaped are end fire radiators and radiate at $0^\circ$, but Bow-tie is an intermediate radiator and radiates at $-50^\circ$ and $50^\circ$ theta.
5.2.4.4 3D POLAR

Figure 5.97 3D polar for Rectangular patches MSA.

Fig 5.97 3D Polar for Rectangular Patch MSA

The power in this antenna is directed in one direction, and in the z direction.

Fig 5.98 3D Polar for Circular Patch MSA

This antenna patch also directs its power towards the same direction as the Rectangular patch MSA.
Fig 5.99 3D Polar of Rectangular Patch MSA

The Cross-shaped patch directs its power perpendicular to the patch surface.

Fig 5.100 3D Polar for Rectangular Patch MSA

Rectangular Circular and Cross shaped are radiating in one direction at 0° but Bow-tie radiates in two different directions at -50° and 50° Theta.
5.2.4.5 GAIN

Fig 5.101 Gain of a Rectangular Patch MSA

Fig 5.102 Gain of a Circular Patch MSA
Fig 5.103 Gain of a Cross Shaped Patch MSA

Fig 5.104 Gain of a Bow-Tie Patch MSA

Rectangular patch has the highest gain 1.0064 followed by Circular at 0.8432, Cross shaped at 0.8115 and finally Bow-tie at 0.1579 the higher the gain the better the antenna in terms of picking low signals.
5.2.4.6 DIRECTIVITY

Fig 5.105 Directivity of a Rectangular Patch MSA

Fig 5.106 Directivity of a Circular Patch MSA
Rectangular patch has the highest directivity at 2.1143 followed by Cross shaped at 2.0544, Circular at 1.7345 and finally Bow-Tie at 1.2229. Rectangular patch energy covers a longer length than the other shapes because of its geometric dimension.
5.2.4.7 VSWR Vs FREQUENCY

VSWR of this Rectangular patch MSA is best at a frequency of 7.3720GHz.

The VSWR of 1.1911 is the best, given by a frequency of 7.6780 GHz.
This shape gives the best VSWR of 1.2064 at a frequency of 5.6620GHz.

Bow-tie has the best matching of VSWR at 1.0304. Rectangular patch has the lowest VSWR at 1.0138 followed by Bow-tie at 1.0304, Circular at 1.1911 and finally Cross shaped at 1.2064. This shows that the best impedance matching is
by Rectangular MSA for this set4, when there good matching most power is delivered to the antenna for radiation.

5.2.4.8 Set4

<table>
<thead>
<tr>
<th>SET4</th>
<th>Frequency GHz</th>
<th>Return Loss</th>
<th>Bandwidth (%)</th>
<th>Bandwidth Gain</th>
<th>directivity</th>
<th>Radiation pattern</th>
<th>Best VSWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.9720</td>
<td>-24.8265</td>
<td>0.1180</td>
<td>5.98</td>
<td>1.0064</td>
<td>2.1143</td>
<td>6.0511</td>
</tr>
<tr>
<td></td>
<td>7.3720</td>
<td>-43.2712</td>
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<td></td>
<td>1.0138</td>
</tr>
<tr>
<td></td>
<td>5.8420</td>
<td>-19.9280</td>
<td>0.2913</td>
<td>4.99</td>
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<td></td>
<td></td>
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<tr>
<td>circular</td>
<td>1.828</td>
<td>-18.2797</td>
<td>0.1213</td>
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<td>0.8432</td>
<td>1.7345</td>
<td>5.6789</td>
</tr>
<tr>
<td></td>
<td>7.6780</td>
<td>-21.1879</td>
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<td>1.1911</td>
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<td>8.8120</td>
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<td>0.4122</td>
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<tr>
<td>Cross shaped</td>
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<td>3.80</td>
<td>0.8115</td>
<td>2.0544</td>
<td>3.1831</td>
</tr>
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<td></td>
<td>5.6620</td>
<td>-20.5779</td>
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<td></td>
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<td>1.2064</td>
</tr>
<tr>
<td></td>
<td>9.7840</td>
<td>-14.8986</td>
<td>-----</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bow-tie</td>
<td>3.8260</td>
<td>-14.3718</td>
<td>0.1564</td>
<td>4.09</td>
<td>0.1579</td>
<td>1.2229</td>
<td>1.4821</td>
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<tr>
<td></td>
<td>9.5140</td>
<td>-36.5021</td>
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<td></td>
<td></td>
<td></td>
<td>1.0304</td>
</tr>
</tbody>
</table>

Circular patch and Rectangular patch have the highest Bandwidth of 0.4122GHz and 0.2913GHz respectively but for Cross shaped and Bow-tie the bandwidth goes beyond the range of (1-10) GHz.
5.2. SET 5: (AREA=1,615.4509MM²)

5.2.5.1 RETURN LOSS VS FREQUENCY

Fig 5.113 Graph of Return Loss Vs Freq of a Rectangular Patch MSA

All the frequencies in this case operate at acceptable limits, with the best at frequency of 1.9900GHz.
5.114 Graph of Return Loss Vs Frequency of a Circular Patch MSA

Two frequencies have a Return loss higher than recommended; hence the antenna cannot be used commercially at this frequency. The best frequency with lowest Return loss is 8.7940GHz.

5.115 Graph of Return Loss Vs Freq of a Cross Shaped Patch MSA
Fig 5.116 Graph of Return Loss Vs Frequency of a Bow-tie Patch MSA.

Table 18 Lowest Operating Frequency for SET5

<table>
<thead>
<tr>
<th>Shape</th>
<th>Frequency (GHz)</th>
<th>Return Loss (dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.9900</td>
<td>-38.0959</td>
</tr>
<tr>
<td>Circular</td>
<td>1.8640</td>
<td>-17.7106</td>
</tr>
<tr>
<td>Cross Shaped</td>
<td>4.1500</td>
<td>-13.9102</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>3.8800</td>
<td>-13.8239</td>
</tr>
</tbody>
</table>

Circular patch registered the lowest operating frequency followed by Rectangular, Bow-Tie and finally Cross Shaped. Return loss of Rectangular patch is lowest and for Bow-Tie highest.

Table 19 Optimum Operating Frequency SET 5

<table>
<thead>
<tr>
<th>Shape</th>
<th>Frequency (GHz)</th>
<th>Return Loss</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.9900</td>
<td>-38.0959</td>
</tr>
<tr>
<td>Circular</td>
<td>8.7940</td>
<td>-21.0045</td>
</tr>
<tr>
<td>Cross Shape</td>
<td>5.7520</td>
<td>-19.7813</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>6.3820</td>
<td>-32.1494</td>
</tr>
</tbody>
</table>
Rectangular patch has the lowest optimum frequency followed by Cross shaped, Bow-tie and Circular finally. However, Return loss of Rectangular patch is the lowest followed by Bow-tie, Circular and finally Cross shaped.

5.2.5.2 SMITH CHART

Fig 5.117 Smith Chart of a Rectangular Patch MSA

This antenna patch operates at more than one frequency.

Fig 5.117 Smith Chart of a Circular Patch MSA

This antenna also operates at more than one frequency.
Fig 5.119 Smith Chart of a Cross Shaped Patch MSA

This antenna oscillates with more than one frequency.

Fig 5.120 Smith Chart of a Bow-Tie Patch MSA

The antenna operates at several frequencies, in some frequency the antenna is both capacitive and inductive and in other frequencies its either capacitive or inductive.
5.2.5.3 RADIATION PATTERN

Fig 5.121 Radiation Pattern of a Rectangular Patch MSA

Fig 5.122 Radiation pattern of a Circular patch MSA
The radiation pattern of the first three namely Rectangular, Circular and Bow-tie are directed along 0° but for Bow-tie are directed along -50° and 50° theta.
5.2.5.4 3D POLAR

Fig 5.125 3D Polar of a Rectangular Patch MSA

Fig 5.126 3D Polar of a Circular Patch MSA
Rectangular, Circular and Cross shaped are End fire radiators, they radiate in one direction along 0° but Bow-tie radiates in two directions along -50° and 50° theta. Radiation pattern of the antenna is dictated by the geometry, the fields die off as 1/r, so the antenna with an extended dimension would have its field travelling the shortest distance.
5.2.5.5 GAIN

Fig 5.129 Gain of a Rectangular Patch MSA

Fig 5.130 Gain of a Circular Patch MSA
The Gain of Rectangular patch is highest at 0.9801 followed by Circular at 0.9047, Cross shaped at 0.9045 and finally Bow-tie at 0.2396. The gain of the rectangular patch is highest showing that in comparison to the other shapes in this set, it can pick the weakest signals.
5.2.5.6 DIRECTIVITY

Fig 5.133 Directivity of a Rectangular Patch MSA

Fig 5.134 Directivity of a Circular Patch MSA
The highest directivity is given by Cross shaped patch at 2.2809, followed by Rectangular at 2.1244, Circular at 1.8731 and finally Bow-tie at 1.4354. Except Bow-tie the other three shapes can be used as a unidirectional antenna because of their pattern of radiation.
5.2.5.7 VSWR Vs FREQUENCY

Fig 5.137 Graph of VSWR Vs Frequency of a Rectangular Patch MSA

Fig 5.138 Graph of VSWR Vs Frequency of a Circular Patch MSA
Fig 5.139 Graph of VSWR Vs Frequency of a Cross Shaped Patch MSA.

Rectangular patch has the lowest VSWR at 1.0252 followed by Bow-tie at 1.0506, Circular at 1.1949 and finally Cross shaped at 1.2285.
### 5.2.5.8 Set5

**Table 20 Antenna Parameters for SET 5**

<table>
<thead>
<tr>
<th>SET 5</th>
<th>Frequency GHz</th>
<th>Return Loss</th>
<th>Bandwidth (%)</th>
<th>Gain</th>
<th>Directivity</th>
<th>Radiation pattern</th>
<th>Best VSWR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.9900</td>
<td>-38.0959</td>
<td>0.1195</td>
<td>6.01</td>
<td>0.9801</td>
<td>2.1244</td>
<td>5.4530</td>
</tr>
<tr>
<td></td>
<td>3.826</td>
<td>-19.4360</td>
<td>0.2454</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>Circular</td>
<td>1.864</td>
<td>17.7106</td>
<td>0.1235</td>
<td>6.63</td>
<td>0.9047</td>
<td>1.8731</td>
<td>6.2332</td>
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<tr>
<td></td>
<td>8.7940</td>
<td>-21.0045</td>
<td>-----</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cross shaped</td>
<td>4.1500</td>
<td>-13.9102</td>
<td>0.1546</td>
<td>3.73</td>
<td>0.9045</td>
<td>2.2809</td>
<td>3.7124</td>
</tr>
<tr>
<td></td>
<td>5.7520</td>
<td>-19.7813</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>7.8220</td>
<td>-14.3409</td>
<td>0.3730</td>
<td>4.77</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Bow-tie</td>
<td>3.8800</td>
<td>-13.8239</td>
<td>0.1555</td>
<td>4.01</td>
<td>0.2396</td>
<td>1.4354</td>
<td>1.3433</td>
</tr>
<tr>
<td></td>
<td>6.3820</td>
<td>-2.1494</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td></td>
<td>9.6400</td>
<td>-29.2573</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The highest Bandwidth for Rectangular and Cross shaped is 0.2454GHz and 0.3730 GHz respectively however, for Circular and Bow-tie patches the Bandwidths cannot be ascertained because they extend beyond the frequency of consideration between (1-10) GHz.
5.6 BEAMWIDTH OF FABRICATED MICROSTRIP ANTENNA PATCHES

Fig 5.141 Beamwidth of Fabricated Rectangular Patch

Fig 5.142 Beamwidth of Fabricated Circular Patch
Fig 5.143 Beamwidth Fabricated Cross-Shaped Patch

Fig 5.144 Beamwidth of Fabricated Bow-Tie Patch

Bow-tie has the highest beamwidth of 174.1261°, followed by Circular with a beamwidth of 150.7534°, Cross-shaped has a beamwidth of 149.6109° and finally Rectangular shape with 147.2692°.
Bow-tie Microstrip antenna has widest range which can receive or transmit radiation due to its large beamwidth and Rectangular the shortest.

**Table 21 Area of the Four Shapes against Return Loss of Optimum Frequency**

<table>
<thead>
<tr>
<th>SET NO</th>
<th>Area(mm$^2$)</th>
<th>Optimum operating frequency return loss</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Rectangular</td>
<td>Circular</td>
</tr>
<tr>
<td>Set 1</td>
<td>1,857.18</td>
<td>-28.24</td>
</tr>
<tr>
<td>Set 2</td>
<td>1812.74</td>
<td>-30.48</td>
</tr>
<tr>
<td>Set 3</td>
<td>1735.45</td>
<td>-26.96</td>
</tr>
<tr>
<td>Set 4</td>
<td>1665.28</td>
<td>-43.27</td>
</tr>
<tr>
<td>Set 5</td>
<td>1615.45</td>
<td>-38.10</td>
</tr>
</tbody>
</table>
The graph in figure 5.145 shows comparison of area of the four simulated Microstrip antenna patches against the optimum Return loss.

**Fig 5.145 Graph of Return Loss of Optimum Frequency (dB) Against Area (mm²)**

Between an areas of ≈1615mm² to ≈1665mm² the return loss decreases for all the four shapes this shows that impedance matching is improved, between ≈1665 and ≈1735 the Return loss of the Rectangular patch increases but for the other three shapes namely Circular, Cross shaped and Bow-tie reduces, between ≈1735 and ≈1812 the Return loss of all the four shapes improves and from ≈1812 to ≈1857 the Return loss increases for all the three shapes, except Rectangular patch Microstrip antenna all other shapes namely Circular, Cross shaped and Bow-tie have the best Return loss for their shapes between (1-10) GHz.
5.7 RESULTS OF VARIATION OF AREA (set 6)

The area of the fabricated set (original) was increased by 10% and decreased by 10% and the results are as shown follows.

5.7.1 RECTANGULAR PATCH

Fig 5.146 Graph of Return Loss Vs Frequency

Fig 5.147 Graph of Return Loss against Frequency of Reduced Area by 10% (Area 1,631.4619mm²)
Fig 5.148 Graph of Return Loss against Frequency Increasing Area by 10% (Area 1,994.0090mm²)

5.7.2 CIRCULAR PATCH

Fig 5.149 Graph of Return Loss against Frequency of Original Area (Area 1,812.7354mm²)
Fig 5.150 Graph of Return Loss against Frequency of Reduced Area by 10% (Area 1,631.4619mm²)

Fig 5.151 Graph of Return Loss against Frequency of Increased Area by 10% (Area 1,994.0090mm²)
5.7.3 CROSS SHAPED PATCH

Fig 5.152 Graph of Return Loss against Frequency of Original Area (Area 1,812.7354mm$^2$)

Fig 5.153 Graph of Return Loss against Frequency of Reduced Area by 10% (Area 1,631.4619mm$^2$)
Fig 5.154 Graph of Return Loss against Frequency of Increased Area 10% (Area 1,994.0090mm²)

5.7.4 BOW-TIE PATCH

Fig 5.155 Graph of Return Loss against Frequency of Original Area (1,665.2837mm²)
Fig 5.156 Graph of Return Loss against Frequency of Reduced Area by 10% (Area1, 498.7553mm²)

Fig 5.157 Graph of Return Loss against Frequency of Increased Area 10% (Area1, 831.8121mm²)
### Table 22 Comparison of 1st Frequency and Optimum Frequency

<table>
<thead>
<tr>
<th>SHAPE</th>
<th>Frequency considered</th>
<th>Original area</th>
<th>Area reduced by 10%</th>
<th>Area increased by 10%</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>frequency</td>
<td>Return loss</td>
<td>frequency</td>
<td>Return loss</td>
</tr>
<tr>
<td>Rectangle</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; OF</td>
<td>1.8820</td>
<td>21.1483</td>
<td>1.9900</td>
</tr>
<tr>
<td></td>
<td>Optimum</td>
<td>7.0480</td>
<td>-25.8825</td>
<td>7.4350</td>
</tr>
<tr>
<td>Circular</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; OF</td>
<td>1.7560</td>
<td>22.8263</td>
<td>1.8640</td>
</tr>
<tr>
<td></td>
<td>Optimum</td>
<td>8.6860</td>
<td>-33.5349</td>
<td>7.7500</td>
</tr>
<tr>
<td>Cross</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; OF</td>
<td>2.1520</td>
<td>-10.6194</td>
<td>4.1500</td>
</tr>
<tr>
<td>Shaped</td>
<td>optimum</td>
<td>5.4280</td>
<td>36.7637</td>
<td>5.7520</td>
</tr>
<tr>
<td>Bow-Tie</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; OF</td>
<td>3.8260</td>
<td>-14.3718</td>
<td>4.0240</td>
</tr>
</tbody>
</table>

**KEY**: OF – Operating Frequency

The frequency under consideration is acceptable frequencies with a return loss below -9.5. Circular patch had the best return loss for the original patch 1<sup>st</sup> frequency at -22.8263, and Cross shape for the Optimum frequency at -36.7637.
5.7.6 **Area Reduced by 10%**
1st frequency of the Rectangular patch had the lowest return loss at -30.9155 and bow-tie best for the optimum frequency at -37.4566.

5.7.8 **Area Increased by 10%**
The Circular patch has the lowest return loss for both 1st and optimum frequency at -27.7388 and -32.5424 respectively.

5.8 **EXPERIMENTAL RESULTS**
The signal generator was made to generate one of the frequencies of the simulated antenna. The fabricated antenna was able to detect, though with slight variation, this was due to slight variation in measurement of the fabricated antenna.

5.8.1 **RECTANGULAR MSA**

![Graph of Return Loss Vs Frequency](image)

**Fig 5.158** Graph of Return Loss against Frequency of Rectangular Patch

(Simulated)
Fig 5.159 Measured Gain And Frequency of Rectangular MSA

5.8.2 CIRCULAR MSA

Fig 5.160 Graph of Return Loss against Frequency of Circular Patch (Simulated)
Fig 5.161 Measured Gain and Frequency of Circular Patch MSA

5.8.3 CROSS SHAPED MSA

Fig 5.162 Graph of Return Loss against Frequency of a Cross-Shape (Simulated)
Fig 5.163 Measured Gain and Frequency of Cross Shaped MSA

5.8.4 BOW-TIE MSA

Fig 5.164 Graph of Return Loss against Frequency of Bow-Tie MSA (Simulated)
Table 23 COMPARISON OF SIMULATED AND MEASURED RESULTS

<table>
<thead>
<tr>
<th>Shapes</th>
<th>Simulated Frequency(GHz)</th>
<th>Gain(dB)</th>
<th>Measured Frequency(GHz)</th>
<th>Gain(dB)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rectangular</td>
<td>1.8820</td>
<td>-29.937</td>
<td>1.88403</td>
<td>-34.17</td>
</tr>
<tr>
<td>circular</td>
<td>1.7560</td>
<td>-30.888</td>
<td>1.75213</td>
<td>-32.17</td>
</tr>
<tr>
<td>Cross shaped</td>
<td>2.1520</td>
<td>-37.235</td>
<td>2.15217</td>
<td>-41.67</td>
</tr>
<tr>
<td>Bow-tie</td>
<td>3.8260</td>
<td>-38.016</td>
<td>3.8260</td>
<td>-37.83</td>
</tr>
</tbody>
</table>

From table 23 the frequency of operation of the fabricated Microstrip antenna is comparable to the simulated frequency hence the antenna is operating at the designed frequency. The operating frequency considered has a Return loss of below -9.5 dB.
5.9 DISCUSSION

5.9.1 Oscillating Frequency

Microstrip antenna is sensitive in terms of resonant length any small change in length will give a different frequency, the small difference between the simulated results and the experimental results is due to the slight variation in dimension when fabricating the antenna.

5.9.2 Gain and Bandwidth

The greater the bandwidth of an antenna the lower the gain, the rectangular shape patch has the highest gain but the lowest bandwidth, for bow-tie it has the highest bandwidth but the lowest gain, the price to pay for higher bandwidth is reduced gain.

5.9.3 Return Loss

The return loss of an antenna is determined by impedance matching, the lower the return loss the better the impedance matching, in this research the antenna are non resonant because they possess both inductive and capacitive reactive, unlike a resonant antenna which is purely resistive at some frequency the percentage power reflected is very high hence making the antenna unviable for commercial purposes, a resonant antenna is purely resistive and its coefficient of reflection is 0 since no power is reflected back to the transmitter. A non resonant antenna can be made resonant by adding an external circuitry of capacitors and inductors.
5.9.4 Gain and Directivity

The antennas in this research just like any other gadget are not 100% efficient, hence directivity and gain is different for all the shapes and sets of antennas. Directivity higher than gain since gain is a product of directivity and efficiency, Gain =efficiency x directivity.

5.9.5 Voltage Standing Wave Ratio

Is a measure of how much power is delivered to the antenna, though the antenna does not radiate all the power it receives. VSWR measures the potential to radiate, when the VSWR is between 2 and 1, the antenna match is considered good and very little would be gained by impedance matching as VSWR increases two main problems arise.

1) The power is reflected from the antenna and therefore not transmitted.

2) As VSWR increases more power is reflected to the transmitter, large amounts of reflected power can damage the transmitter in addition to transmitting incorrect information. The crosser the VSWR is to 1 the better the matching, in this research the VSWR ranges from 1.0070 to 1.2285 showing that the power delivered to the antenna is a very high percentage compared to the power reflected. These antennas are commercially viable because of their voltage standing wave ratio of less than 1.5.
5.9.6 Smith Chart

The smith chart in this study shows many resonant modes over a range of frequency (1-10) GHz, optimum frequency provides the best frequency of transmission because the return loss is lowest and the VSWR closest to 1, hence most of power will be radiated.

5.9.7 Optimum Frequency

The optimum frequency of the original size of shapes namely rectangular, circular, cross shaped and bow-tie is between the optimum frequencies when the shaped are reduced by 10% and when increased by 10%, optimum frequency of reduced size is highest and for increased size lowest.
CHAPTER 6
CONCLUSIONS AND RECOMMENDATION.

CONCLUSION

6.1 Introduction
In this research it was found that despite the different shapes having similar surface area they oscillated at different frequencies, the best optimum frequency was given by Bow-tie patch.

6.2 Radiation Pattern
Rectangular, Circular and Cross shaped MSA radiates its Energy in one direction (end fire Radiator) but Bow-Tie Radiation is in two directions which is neither end-fire nor broad side radiations and can be used to transmit or receive a signal in two different directions.

6.3 Directivity
Best directivity was given by Cross shaped MSA, this is because it has shorter length than any other shape and the worst by Bow-tie MSA due to its longer length than any other shape.

6.4 Miniaturization
For a specific frequency Circular MSA provided the smallest size/surface area followed by Rectangular MSA, Cross shaped and Bow-tie had the biggest.
6.5 Bandwidth
Circular MSA has the largest %ge Bandwidth of the four shapes followed by Rectangular MSA, Bow-tie and finally Cross shaped. The bandwidth (2-8) % is approximate to the one in the open literature of about (2-5) % for transmission line feed.

6.6 Lowest Operating Frequency
Circular patch Microstrip antenna had the lowest operating frequency followed by Rectangular MSA, Cross shaped MSA and finally Bow-tie MSA.

6.7 Optimum Operating Frequency
The optimum operating frequency of rectangular and circular MSA is the same in some cases as the lowest operating frequency within the range of (1-10) GHz, but different for the other three shapes.

6.8 Beamwidth
Bow-tie provides the largest beamwidth, it operates on a wider angle than the other 3 shapes hence the most suitable in case high bandwidth transmission is required.

6.9 RECOMMENDATION
Different method of feeding can be used (coaxial probe, proximity coupling, aperture coupling). Different shapes other than the ones used in this research
such as square, elliptical, semi circular, quarter circle etc can also be studied. The shapes used in this research can be slotted maintaining the surface area of the shapes to be compared. These antennas are suitable for application where high directivity is not necessary like in mobile phones. The substrate used FR4 substrate gives poor gain, different substrate(s) can be used for these shapes or other shapes to be considered by the researcher such as Rt-Duroid5880, alumina, glass epoxy, silicon etc which give a higher gain. Use of higher dielectric constant material like silicon with a dielectric constant of 11.9 will reduce the size of the antenna. Making an array of antenna patches should be considered because it improves the overall gain of the antenna.
REFERENCES


Cellular devices, M.sc Thesis. Florida state university, USA.


Appendix I

Signal detection from a spectrum analyser

Antenna not connected  Antenna connected

In (a) antenna is not connected, the signal line is straight showing no detection of signal.

In (b) antenna is connected, there is a shoot at the middle showing detection of signal.