DESIGN AND TESTING OF A COMPACT CIRCULARLY POLARIZED MICROSTRIP ANTENNA FOR FUTURE WIRELESSAPPLICATIONS

DISSERTATION-II

Submitted in partial fulfillment of
the Requirement for the award of the
Degree of

MASTER OF TECHNOLOGY
IN
Electronics and Communication Engineering

By

Gagan Deep Singh (11605285)

Under the Guidance of
Gurpreet Kumar
Assistant Professor

School of Electronics and Electrical Engineering
Lovely Professional University
Phagwara, Punjab
December 2017

CERTIFICATE

This is to certify that Gagan Deep Singh bearing Registration no. 11605285 have completed Base Paper implementation of the thesis titled, “Design and testing of a compact circularly polarized microstrip antenna for future wireless applications” under my guidance and supervision. To the best of my knowledge, the present work is the result of his original investigation and study. No part of the thesis has ever been submitted for any other degree at any university.

Gurpreet Kumar
Assistant Professor
School of Electronics and Electrical Engineering
Lovely Professional University
Phagwara, Punjab
Date: 22-11-2017

ACKNOWLEDGEMENT

First and foremost, I would like to express my sincere gratitude and appreciation to my guide Gurpreet Kumar**,** for his whole-hearted and invaluable guidance, inspiring discussions, encouragement, and support throughout my work. I found him always sincere in helping me even during his busiest hours of the day. His ardor and earnestness for studies are respected and will never be forgotten. Without his sustained and sincere effort, this report would not have taken this shape.

We are also in debited to all authors of the research papers and books referred to, which have helped us in carrying out the research work.

Gagan Deep Singh
Reg. No: 11605285

DECLARATION

I, Gagan Deep Singh, a student of M. Tech under Department of Electronics and Communication of Lovely Professional University, Punjab, hereby declare that all the information furnished in this Dissertation-II report is based on my own intensive research and is genuine.

This report does not to the best of our knowledge, contain part of my work which has been submitted for the award of my degree either of this University or any other University without proper citation.

Gagan Deep Singh
Reg no. 11605285

ABSTRACT

Circularly polarized antenna reduces the effect of multipath reflections, enhances weather penetration and allows for the mobility of both the transmitter and the receiver. Circularly polarized radiation field achieved with the combination of both radiation fields of microstrip patch and slots. The orientation of the slots on the ground plane can be dynamically changed and polarization state can be switched from RHCP to LHCP This work shows the design of broadband and circularly polarized radiations from an open slot antenna. This antenna has an open slot at the ground plane and a coaxial feeding provides high bandwidth and improves circular polarization characteristics. The ground plane has an open slot L-shaped conducting strip asymmetrically connected to it. Impedance bandwidth provided by this antenna is nearly 2.06 GHz with a 3 dB axial ratio bandwidth of 3.07 GHz. The bandwidth range of this antenna covers WIFI, GPS, and WLAN spectrums.

LIST OF ABBREVIATIONS

RHCP	Right-hand circular polarized
LHCP	Left-hand circular polarized
CP	circular polarization
RL	return loss
HPBW	half power beam width
FNBW	full null beam width
mm	millimetre
dB	decibel
WIFI	wireless fidelity
WLAN	wireless local area network
GPS	global positioning system
VSWR	voltage standing wave ratio
3D	3 dimensional
E-field	Electric field
H-field	magnetic field
AR	axial ratio
CPW	coplanar waveguide
LTE	long-term evolution
CST	computer simulation technology
S- parameters	scattering parameters

TABLE OFCONTENTS

TitlePage **PageNo.**

PAC **i**

CERTIFICATE **ii**

ACKNOWLEDGEMENT **iii**

DECLARATION **iv**

ABSTRACT **v**

LIST OFABBREVIATIONS **vi**

LISTOFFIGURES **ix**

LIST OF TABLES **xi**

CHAPTER 1: INTRODUCTION **1-5**

1.1 Parameters of antenna 1
1.2 Radiation pattern 1
1.3 Return loss 2
1.4 Gain 2
1.5 Beamwidth 3
1.6 VSWR 3
1.7 Efficiency 4
1.8 Radiation intensity 4
1.9 Radiation power density 5
1.10 Directivity 5
1.11 Axial ratio 5

CHAPTER 2: MICROSTRIP ANTENNA **7-11**

2.1 Microstrip patch 7
2.2 Dielectric substrate 8
2.3 Ground plane 8
2.4 Feeding techniques 8
2.4.1 Microstrip line feeding 8
2.4.2 Coaxial feeing 9
2.4.3 Aperture coupled feed 10
2.4.4 Proximity coupled feeding 11

CHAPTER 3: MICROSTRIP CIRCULAR POLARIZED ANTENA 12-17

3.1 Polarization 12
3.2 Types of polarization 12
3.2.1 Linear polarization 12
3.2.2 Elliptical polarization 13
3.2.3 Circular polarization 13
3.2.3.1 LHCP/RHCP 14
3.3 Circular polarized antenna 14
3.4 Techniques for circular polarization 14
3.4.1 Dual feed circular polarized antenna 14
3.4.2 Single feed circular polarized antenna 14
3.5Design of circularly polarized antenna 15
3.6 Design of antenna on CST 17

CHAPTER 4: REVIEW OF LITERATURE 19-22

CHAPTER 5: OBJECTIVE 23

CHAPTER 6: PROPOSED METHODOLOGY 24

CHAPTER 7: RESULTS AND DISCUSSIONS 25-35

6.1 S_{11} Parameters and VSWR results 25
6.2 Far-field results 30
6.3 Axial ratio results 34

CHAPTER 8: CONCLUSION AND FUTURE SCOPE 36

REFERENCES 37-40

LIST OFFIGURES

Figure	Caption	PageNo.
Figure1.1	Radiation pattern of antenna	2
Figure 1.2	Different lobes of antenna	3
Figure 1.6	Trace of E-field vector	6
Figure 2.1	Basic microstrip antenna	7
Figure 2.2	Types of microstrip patches	7
Figure 2.3	Microstrip line feed	8
Figure 2.4	Coaxial feed line	9
Figure 2.5	Aperture coupled patch	10
Figure 2.6	Proximity coupled feed	11
Figure 3.1	Linear polarize waves	12
Figure 3.2	Elliptically polarized wave	13
Figure 3.3	Circularly polarized wave	13
Figure 3.4	Dual feed	14
Figure 3.5	Single feed CP antenna	15
Figure 3.6 (a)	Open slot antenna (top view)	16
Figure 3.6 (b)	Open slot antenna (side view)	17
Figure 3.7 (a)	Prototype antenna front side	17
Figure 3.7 (b)	Prototype antenna ground plane	17
Figure 3.8 (a)	Asymmetry design front side	17
Figure 3.8 (b)	Asymmetry design ground plane	17
Figure 3.9 (a)	Bent feeding front side	18
Figure 3.9 (b)	Bent feeding ground plane	18
Figure 3.10 (a)	CP antenna with patch front side	18
Figure 3.10 (b)	CP antenna with patch ground plane	18
Figure 7.1 (a)	S_{11} parameters at 1.55 GHz	24

Figure 7.1 (b)	VSWR at 1.55 GHz	25
Figure 7.2 (a)	S_{11} parameter at 2 GHz	26
Figure 7.2 (b)	VSWR at 2 GHz	26
Figure 7.3 (a)	S_{11} parameters at 2.79 GHz	26
Figure 7.3 (b)	VSWR at 2.79 GHz	27
Figure 7.4 (a)	S_{11} parameter at 3.67 GHz	27
Figure 7.4 (b)	VSWR at 3.67 GHz	27
Figure 7.5 (a)	Combined S_{11} parameters for all designs	28
Figure 7.5 (b)	Combined VSWR results for all designs	28
Figure 7.6 (a)	far field pattern at 1.5 GHz	28
Figure 7.6 (b)	Far field at 1.55 GHz (polar plot)	29
Figure 7.7 (a)	far field pattern at 2 GHz	30
Figure 7.7 (b)	Far field at 2 GHz (polar plot)	30
Figure 7.8 (a)	far field pattern at 2.79 GHz	31
Figure 7.8 (b)	Far field at 2.79 GHz (polar plot)	31
Figure 7.9 (a)	far field pattern at 3.6 GHz	32
Figure 7.9 (b)	Far field at 3.68 GHz (polar plot)	32
Figure 7.10	Axial ratio parameters for prototype antenna	33
Figure 7.11	Axial ratio parameters for asymmetric design	34
Figure 7.12	Axial ratio parameters for bent feeding	34
Figure 7.13	Axial ratio parameters with patch design	34
Figure 7.14	Axial ratio parameters for combined design	35

LIST OFTABLES

Table No.	**Caption**	**Page No.**
Table 1.1	Parameter values	16

CHAPTER 1

INTRODUCTION

In general wireless communication if the gain of the antenna is increased then it consequences the decrease of errors, decreases the battery consumption, increases the bit error rate and also increases the coverage. One of the main factors in increasing this gain is matching the polarization of the transmitting and receiving antenna. For the polarization matching, both receiver and transmitter should have same axial ratio. Circularly polarized antennas could be matched in a wide range of orientations because the radiated waves oscillate in a circle that is perpendicular to the direction of propagation.

For circular polarization microstrip antenna [20] is most commonly used an antenna. Microstrip antennas do not generate circular polarization on their own. Circular polarization is achieved in microstrip antenna by either feeding the antenna with dual feed equal in magnitude but having 90° phase shift or by introducing a perturbation segment to a basic single fed microstrip antenna. In this thesis, we focus on achieving polarization through the introduction of a perturbation to a basic circular microstrip patch. This chapter presents a background of microstrip antennas, circular polarization and feeding techniques to generate circular polarization.

1.1 Parameters of antenna

To understand the performance of the antenna is necessary to understand the parameters of the antenna. Parameters may be independent or dependent on each other. There are some important parameters need to be considered that characterize all antenna designs. There is the radiation bandwidth, return loss, gain, pattern, VSWR, half – power beamwidth and antenna efficiency.

1.2 Radiation pattern

The radiation pattern is defined as the power radiated or received by an antenna in a function of the angular position and radial distance from the antenna. It detects the energy radiation of the antenna. The Fig. 1.1 shows a 3D representation of the radiation from an antenna (top) and one form of radiation pattern (bottom). The pattern consists of several minor lobes and the main lobe. With all antennas (except monopoles and dipoles), side lobe and backlobes can be obtained, and they are always undesirable because they represent wasted energy for transmitting antennas.

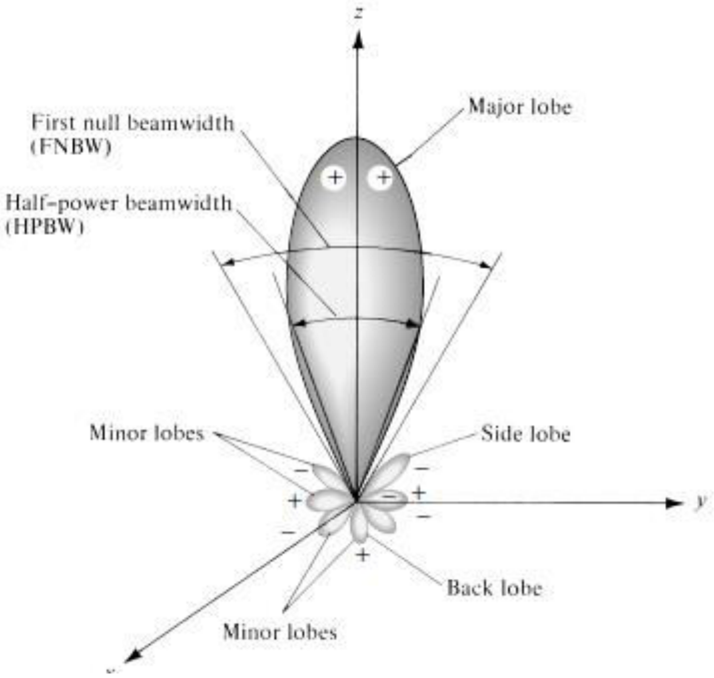


Fig.1.1 Radiation pattern of antenna [33]

1.3 Return loss

It shows that how much power is reflected back on the transmitted port of the antenna. Generally, it is measured in logarithmic scale. Very less reflected power is desirable.

$$RL = -20 \log |\Gamma| \ (dB) \qquad (1.1)$$

Where,

$|\Gamma|$ = reflection coefficient

1.4Gain

Gain is defined as the ratio of intensity in the given direction to the ratio of theintensity of isotropic antenna. The antenna gain describes the antenna's ability to radiate power in a certain direction when connected to a power source. Gain is usually calculated in the direction of maximum radiation. Gain is given by referencing the antenna under test against a standard antenna. This is technically known as the gain transfer technique. The two most common reference antennas are the isotropic antenna. The isotropic antenna radiates equally well in "all" directions. Real isotropic antennas do not exist, but they provide useful and simple theoretical antenna patterns with which to compare real antennas.

Gain can be obtained by using Equation

$$G = \eta \times D \qquad (1.2)$$

$$G = 4\pi \frac{U(\theta, \emptyset)}{Pin} \qquad (1.3)$$

Where,

η = efficiency

D = directivity

Pin =input power

U $(\theta, \emptyset)$= Radiation intensity

1.5 Beamwidth

The beamwidth of a radiation pattern is defined as angular separation between the same points on opposite side of themaximum pattern. It is an important parameter which follows inverse relation with the side lobe if beamwidth increases side lobes decreases. The important beamwidths are:

Half power beamwidth(HPBW): It is defined as the angular separation between two opposite points in the direction of themaximum beam where radiation intensity is one half the value of the beam.

First Null Beamwidth(FNBW): It is defined as the angle between the first nulls of theradiation pattern.

$$HPBW = \frac{FNBW}{2} \qquad (1.4)$$

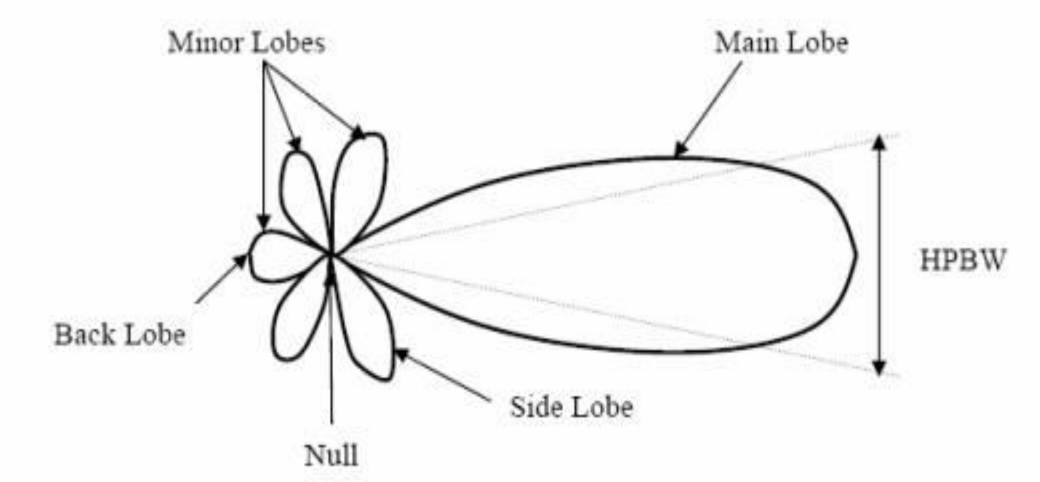


Fig.1.2 Different lobes of antenna [34]

1.6 VSWR

The VSWR (ratio of maximum voltage to the minimum voltage along the line) expresses the degree of match between the transmission line and the antenna. When the VSWR is 1 to 1 (1:1) the match is perfect and all the energy is transferred to the antenna prior to being radiated. By definition, VSWR can never be less than 1.

1.7 Efficiency

Efficiency is used to expresses the ratio of the total power radiated by an antenna (and the power dissipated in the antenna structure as heat) to the net power accepted by the antenna from the connected transmitter. Efficiency is defined as

$$e=\frac{prad}{pt} \qquad (1.5)$$

p_{rad}= Radiated power

p_t = transmitted power

1.8 Radiation intensity

Radiation intensity in a given direction is defined as "the power radiated from an antenna per unit solid angle." The radiation intensity is a far-field parameter, and it can be obtained by simply multiplying the radiation density by the square of the distance. In mathematical form it is expressed as

$$U=r^2 Wrad \qquad (1.6)$$

Where

U = radiation intensity (W/unit solid angle)

Wrad = radiation density (W/m^2)

r = radial distance (m)

It can also be defined as power radiated by an antenna per unit solid angle. It denotes a far-field parameter. It is given by the equation:

$$Prad=\oiint U \sin\theta \, d\theta d\varphi = \oiint Uod\omega$$
$$=Uo\oiint d\omega= 4\pi Uo \qquad (1.7)$$

Where

Uo=average power intensity

1.9 Radiation power density

Electromagnetic waves are used to transport information through a wireless medium or a guiding structure, from one point to the other. It is then natural to assume that power and energy are associated with electromagnetic fields. The quantity used to describe the power associated with an electromagnetic wave is the instantaneous Poynting vector defined as

$$W = E \times H \qquad (1.8)$$

W = instantaneous Poynting vector (W/m^2)
E= instantaneous electric-field intensity (V/m)
H= instantaneous magnetic-field intensity (A/m)

Since the Poynting vector is a power density, the total power crossing a closed surface can be obtained by integrating the normal component of the Poynting vector over the entire surface. In equation form

$$P=\oiint w.ds \qquad (1.9)$$

P = instantaneous total power (W)

1.10 Directivity

The directivity of the antenna is defined as the ratio of radiation intensity in given direction to averaging of radiation intensity over all the directions. Its mathematical expression can be given as:

$$\text{Directivity}=\frac{\text{maximum radiation intensity}}{\text{average radiation intensity}}=\frac{Umax}{\text{Uo}}=\frac{4\pi Umax}{prad} \qquad (1.10)$$

1.11 Axial ratio

It is the ratio of major axis to the minor axial lengths of an electric field vector [2]. The electric field has its two components E_x and E_y.

$$\text{AR}=\frac{OA}{OB} \qquad (1.11)$$

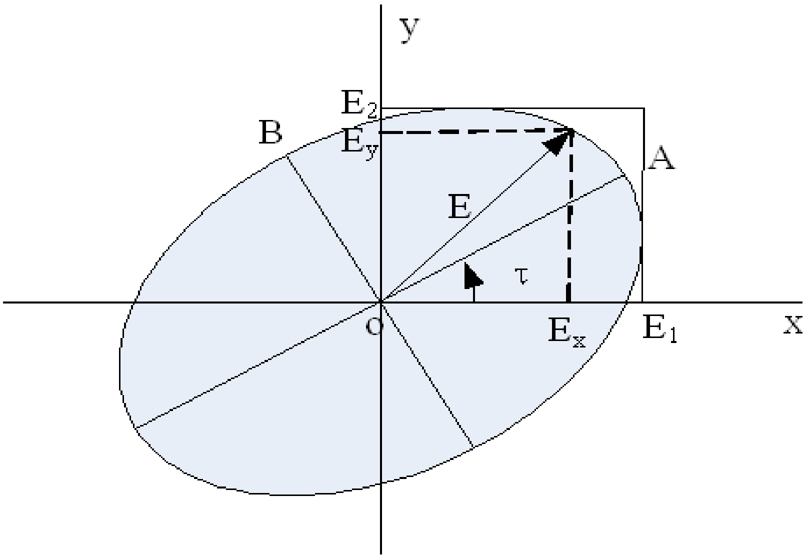


Fig. 1.3 Trace of E-field vector [35]

If the length of major axis is equal to the length of minor axis or AR=1, then the antenna is circularly polarized. Practically for circular polarize antenna AR is taken up to 3 dB.

If AR is greater than 1 dB then the antenna is elliptically polarized. If AR value is very large or (AR=∞) then the antenna is linearly polarized.

CHAPTER 2

MICROSTRIP ANTENNA

The microstrip antenna is having low cost, low weight, compact size and having the ease of fabrication. Basically, it contains four parts which are a patch, substrate, ground plane and feeding. In figure 2.1 L is the patch length, w is the width of the patch, h is the height of dielectric substrate and Ɛr is relative permittivity.

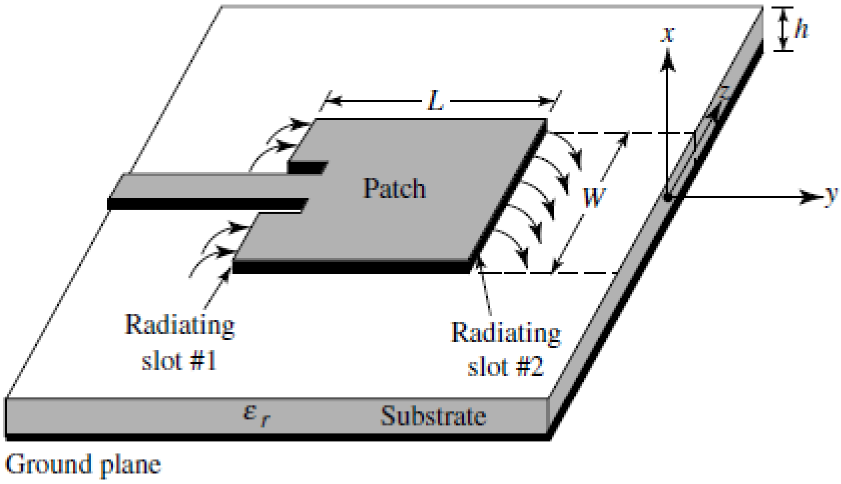


Fig. 2.1 Basic microstrip antenna [36]

2.1 Microstrip patch

It is a thin conducting strip mounted on the dielectric substrate [5]. Microstrip patch can be of any size. It may be rectangular, circular, triangular, square etc. Rectangular and circular patches are mostly used. Every shape has its own characteristics and designed to meet specific requirements. Fig. 2.2 shows some types of patches

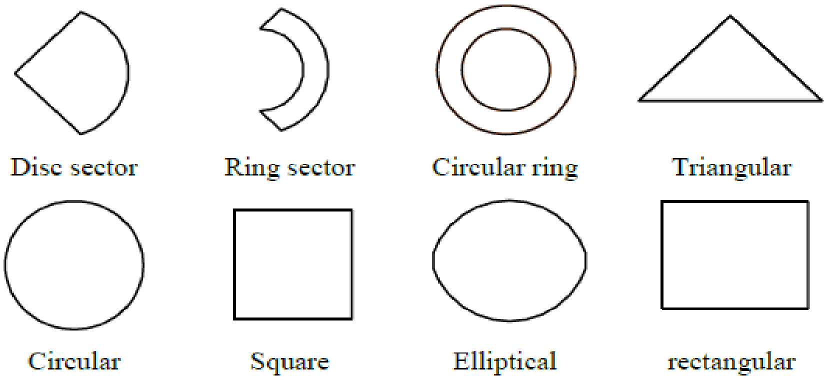


Fig. 2.2 Types of microstrip patches [37]

2.2 Dielectric substrate

It is a dielectric layer between the ground plane and the patch. The substrate can be of different dielectric materials but it can be chosen between $2.2 < \mathcal{E}r < 12$ for good antenna performance. If the $\mathcal{E}r$ value increases the antenna size will get smaller. The thick substrate with a low dielectric constant is used to improve efficiency, radiation, and bandwidth.

2.3 Ground Plane

It is a metallic part below the substrate. By inserting shapes and slots into the ground plane certain performance of the antenna can be enhanced.

2.4 Feeding Techniques

Feeding provides an input power to initiate the antenna. Basically, the antenna has four feeding techniques which are illustrated below

2.4.1 Microstrip Line Feeding

The microstrip line consists of a conducting strip connected to the patch [14]. The microstrip line has often the same thickness as the patch but the width is smaller. To obtain good impedance matching an inset cut can be made. The length of the inset controls the impedance matching. The figure shows how to use microstrip as feed technique.

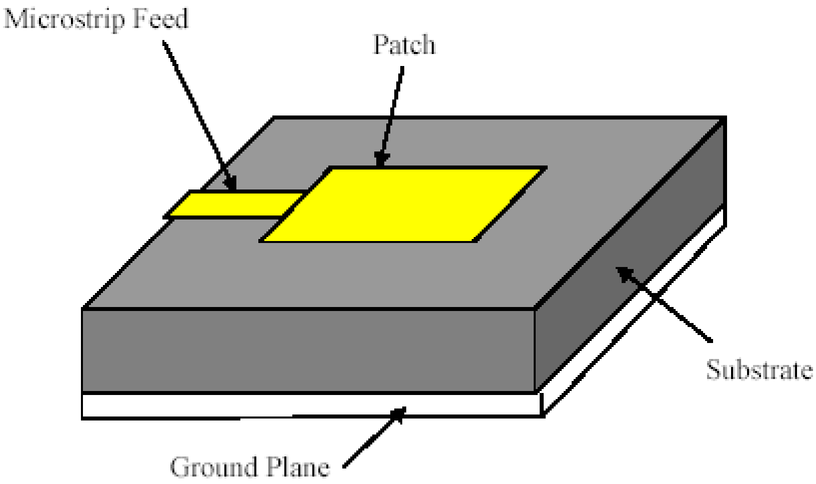


Fig. 2.3. Microstrip line feed [38]

Advantages of microstrip feed are:

- One of the easiest methods to fabricate.
- Easy to match by controlling inset length.

Disadvantages with microstrip feed are:

- Make the patch larger.
- Bandwidth decreases when the thickness of the substrate increases.

2.4.2 Coaxial Feeding

The coaxial feed method is one of the most common feed techniques. The inner conductor of the coaxial goes through the substrate from the ground to the patch and the outer conductor are connected to the ground plane. The figure shows how to use the coaxial probe as feed technique.

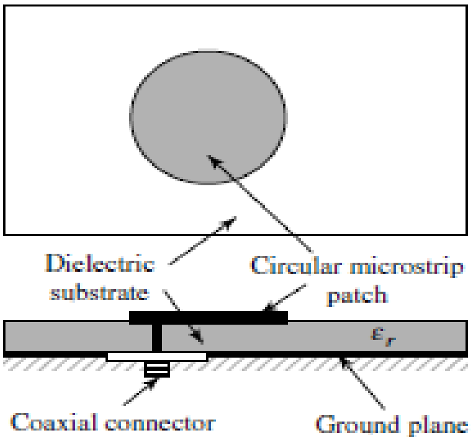


Fig. 2.4 Coaxial feed line

Advantages of coaxial probe feed are:

- Easy to fabricate.
- Easy to match because the feed position can be placed anywhere to the patch to get impedance matching.
- Wide bandwidth.

Disadvantages with coaxial probe feed are:

- For thicker substrates, the increased probe length makes the input impedance more inductive which lead to a matching problem.
- Difficult to model especially for the thick substrate.
- May reduce efficiency.
- Can be difficult to design, depending on the substrate. Not difficult with air.

2.4.3 Aperture-coupled feeding

Below the patch are there two layers of the substrate. The ground plane is between the two substrates. The feed line is given below the lower substrate. The ground plane has a slot cut of any size to enhance the antenna parameters. Figure below shows how to use the aperture-coupled patch as feeding technique.

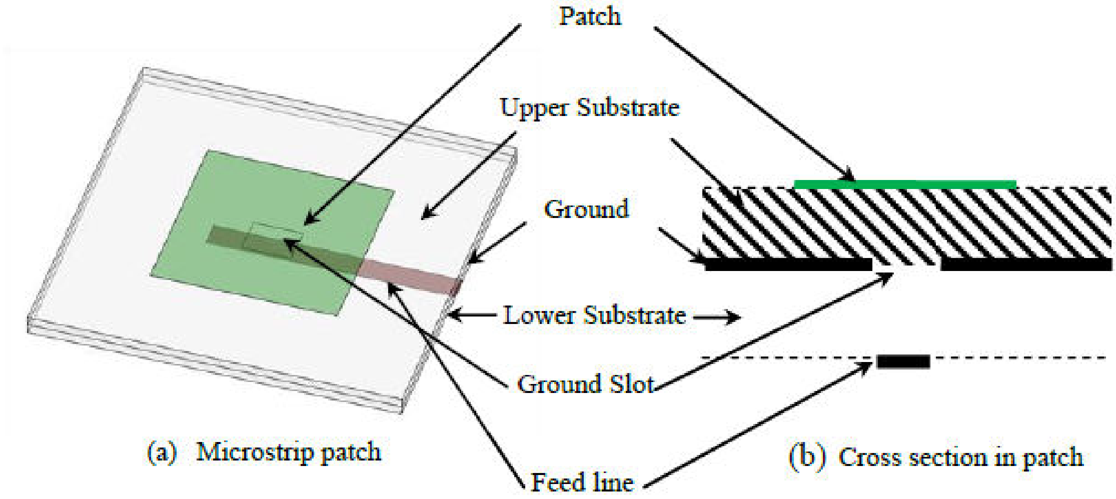


Fig. 2.5 aperture coupled patch [39]

Advantages of the aperture-coupled patch feed are:

- Many parameters to choose between to match the antenna as the height of substrate, width, length, and position of the slot.
- Purifier polarization since the feed is isolated by the ground plane between the substrates.

Disadvantages with the aperture-coupled patch feed are:

- Difficult to fabricate.
- Narrow bandwidth.

2.4. 4 Proximity Coupled Feed

This type of technique is also called as the electromagnetic coupling scheme. It has no ground plane. As shown in Figure below, two dielectric substrates are used such that the feed line is between the two substrates and the radiating patch is on top of the upper substrate.

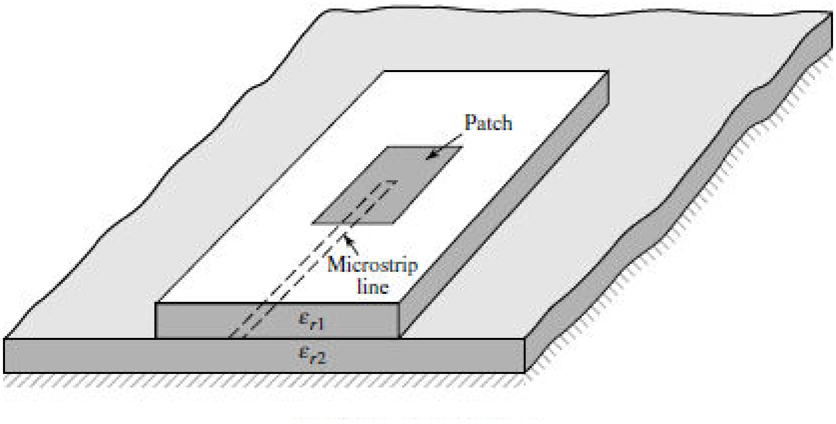


Fig. 2.6 proximity coupled feed [40]

Advantages of proximity coupled feeding

- Low spurious feed radiations
- Highest bandwidth

Disadvantages of proximity coupled feeding

- Difficult to fabricate due to alignment requirements

CHAPTER 3

MICROSTRIP CIRCULAR POLARIZED ANTENNA

3.1 Polarization

It is defined as the rotation of electric or magnetic field vector at a fixed point in the space. Because electric and magnetic field vectors both are elated according to the Maxwell's equation so it is enough to specify one of them. Basically, for wave polarization, we consider only the orientation of electric field vector. In other words, Counter drawn by the tip of electric field vector is referring to wave polarization. Polarization is a very important term for antenna propagation. For maximum power transfer polarization of polarization of receiving antenna should be same as the polarization of transmitting antenna. Losses will be high in the polarization mismatch condition.

3.2 Types of polarization

Polarizations are of three types as linear, elliptical and circular polarization.

3.2.1 Linear polarization

If the electric or magnetic field vector has only one component of its magnitude or two components with a phase difference of 0° or 180°.

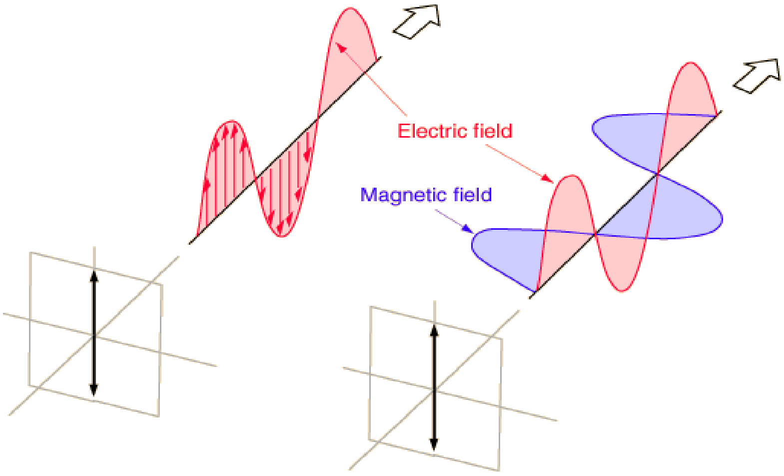


Fig. 3.1 Linear polarize waves [41]

3.2.2 Elliptical polarization

If the electric or magnetic field vector of a wave having unequal amplitude or may have equal amplitude along with a phase difference of any value except 0°, 180°, 90°.

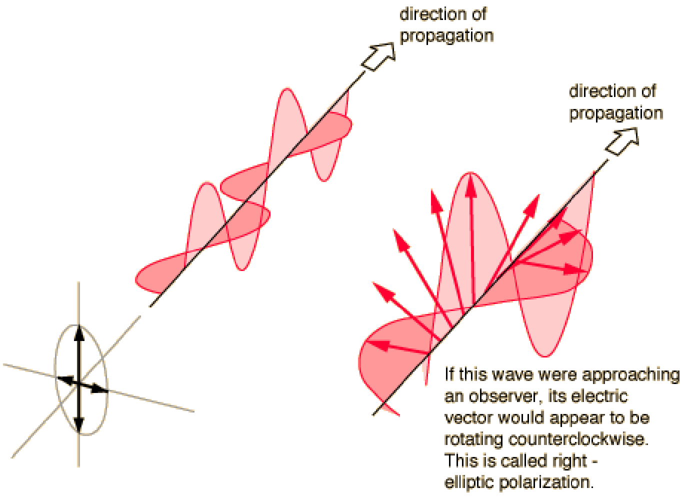


Fig. 3.2 Elliptical polarized wave [42]

3.2.3 Circular polarization

When electric or magnetic field vector has two components of the same magnitude with a phase difference of 90° then the tip of electric field traced in space is circular in nature. It is called as circular polarization.

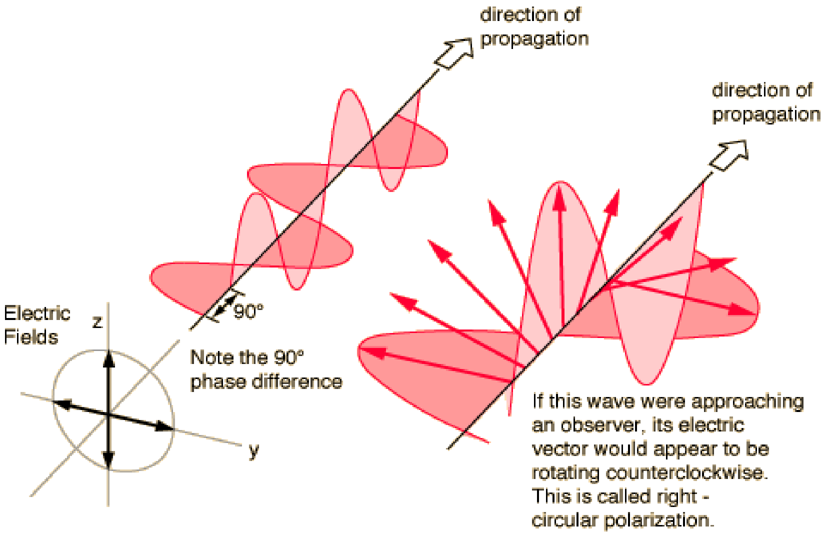


Fig. 3.3 Circular polarized wave [43]

3.2.3.1 Left-hand circular polarization/ right-hand circular polarization

Circular polarization may be referred to as right-hand circular polarization (RHCP) [23] or left-hand circular polarization (LHCP) and clockwise or anti-clockwise, depending on the direction in which the electric field vector rotates [31].

3.3 Circular polarized antenna

Circular polarization referred by an antenna makes it circular polarize (CP) [1]. The CP antenna is very effective in combating multi-path interferences or fading [15]. CP antenna is vastly used nowadays. It provides more flexibility in transmitting and receiving antenna orientations so it eliminates the mismatching of polarizations. The main disadvantage of CP antenna is that it is difficult to design.

3.4 Techniques for circular polarization

Circularly polarized microstrip antennas can be classified according to the number of feeding points required to produce circularly polarized waves. The most commonly used feeding techniques in circular polarization generation are dual feed and single feed.

3.4.1 Dual feed circular polarized antenna

It is an easy way to produce circular polarize configuration of an antenna. Two ports at of the same amplitude and a phase difference of 90° are fed to the patch as shown in fig. 3.3.

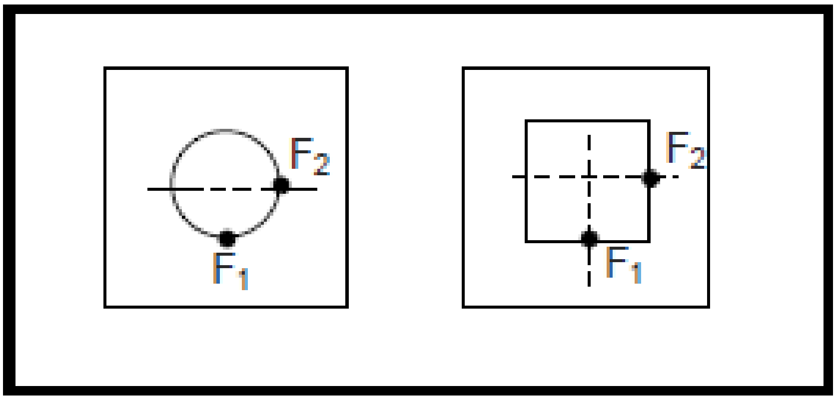


Fig. 3.4 Dual feed [44]

3.4.2 Single feed circular polarized antenna

The operational principle of this antenna is based on the fact that the generated mode can be separated into two orthogonal modes by the effect of a perturbation segment such as a slot or other truncated segment. Consequently, by setting the perturbation segment to the edge of the patch, the generated mode is separated into two orthogonal modes 1 and 2.

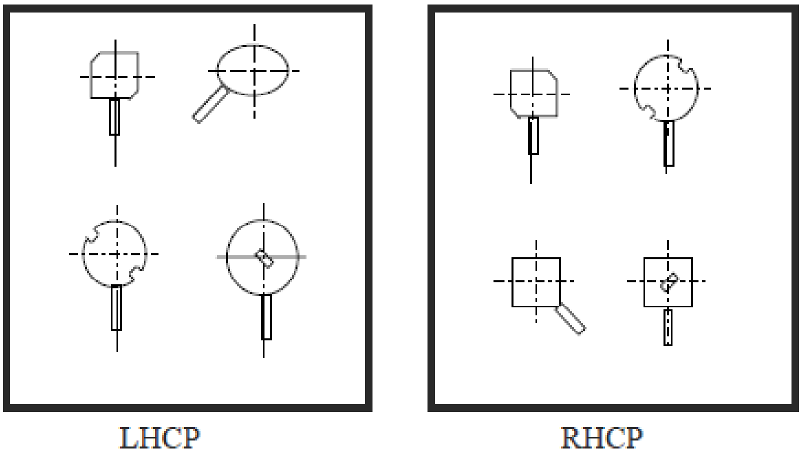


Fig. 3.5 Single feed CP antenna [45]

3.5 Design of circular polarize antenna

Fig. 3.6 shows the configuration of the proposed open-slot antenna. The proposed antenna is fabricated on an FR4 microwave substrate with a thickness of 0.8 mm, a relative permittivity of 4.4, and a loss tangent of 0.02. The antenna structure consists of an open slot located at the edge of the ground plane and a microstrip patch-protruded feeding line. The length of the open slot is determined by approximately a quarter-wavelength corresponding to the operating frequency of 2.3 GHz. This makes the antenna dimension compact, with a total size of 0.29 λo (width) × 0.20 λo (length) with respect to 1.32 GHz. A bent feeding structure is used as a power-injection element for the improvement of impedance matching and circular polarization. To further reduce the lower operating frequency band, a patch is designed for the feeding structure. Finally, a finger strip is added for fine-tuning to improve the impedance matching condition around 4 GHz. Table I lists the dimensional parameters of the open-slot antenna after optimization of the frequency characteristics, such as the impedance and AR bandwidths.

Table 1 Parameter values

Parameters	(mm)	Parameters	(mm)
L	30	W_g	66
L_g	10.25	W_f	1.5
L_1	9	W_1	1.5
L_2	5	W_2	1.5
L_3	2	W_3	23
L_4	8	W_4	11
L_5	4.5	W_5	7.5
L_6	1.5	L_7	8

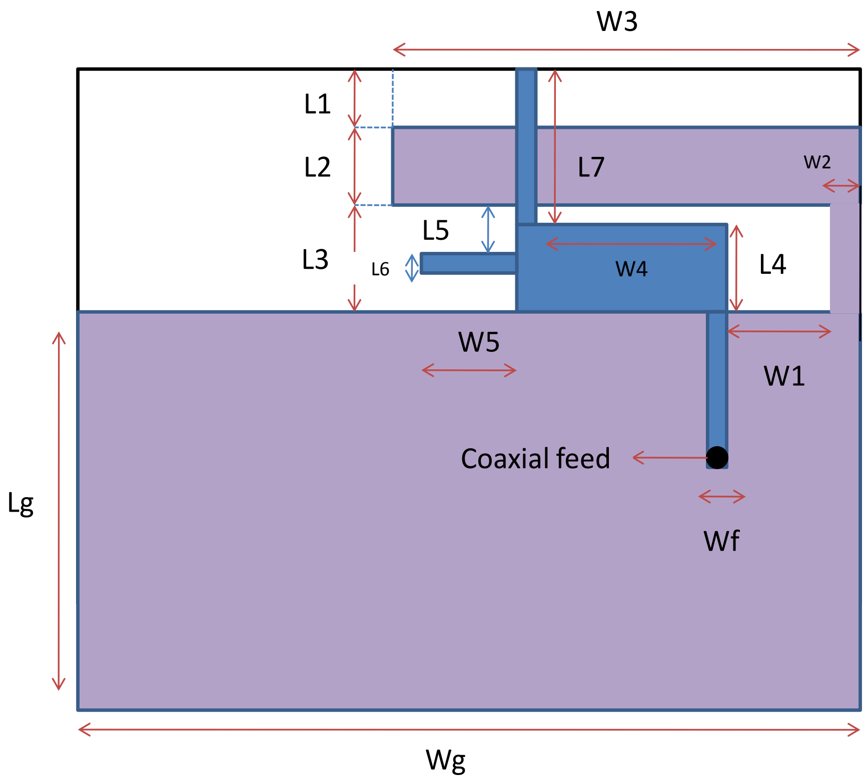


Fig. 3.6 (a) Open slot antenna (top view)

Fig. 3.6 (b) Open slot antenna (side view)

3.6 Design of antenna on CST microwave studio

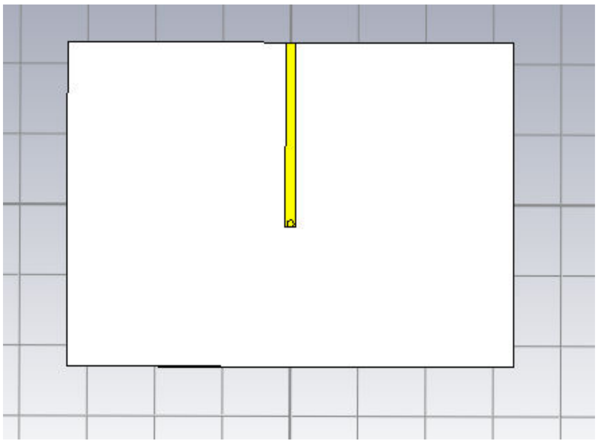


Fig. 3.7 (a) Prototype antenna front side

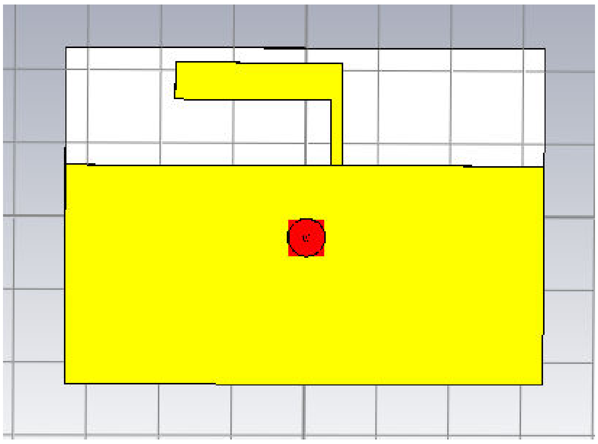


Fig. 3.7 (b) Prototype antenna ground plane

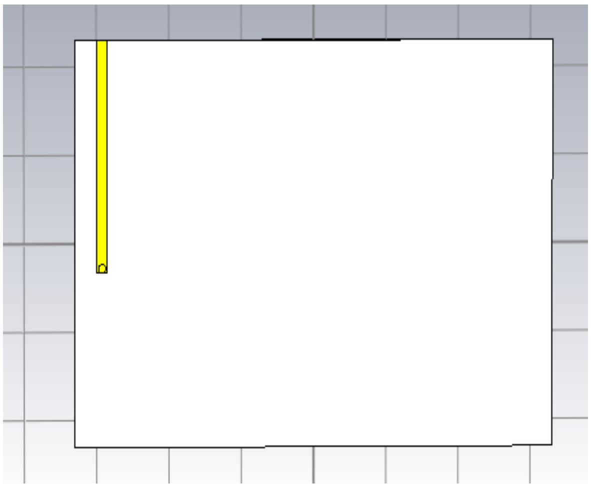


Fig .3.8 (a) Asymmetry design front side

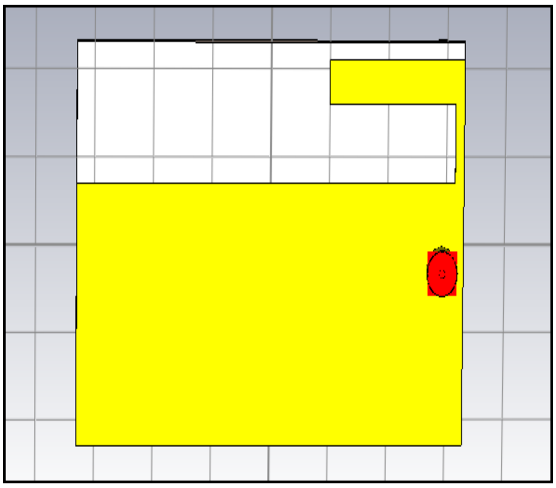


Fig. 3.8 (b) Asymmetry design ground plane

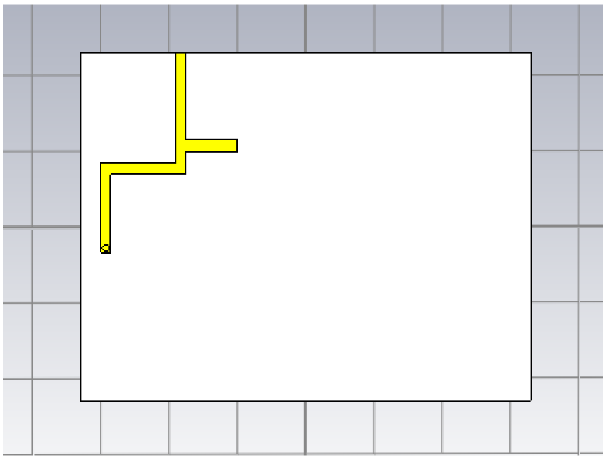


Fig. 3.9 (a) Bent feeding front side

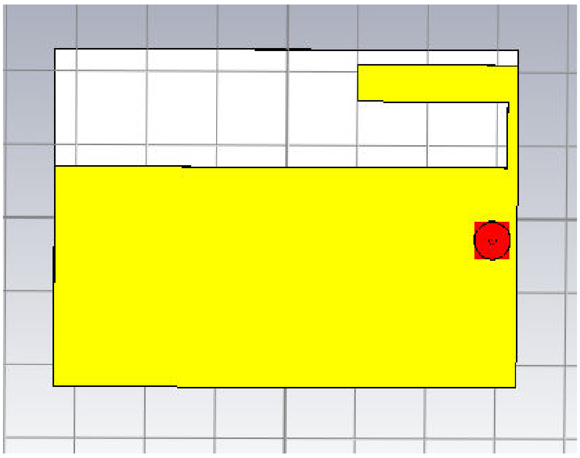


Fig. 3.9 (b) Bent feeding ground plane

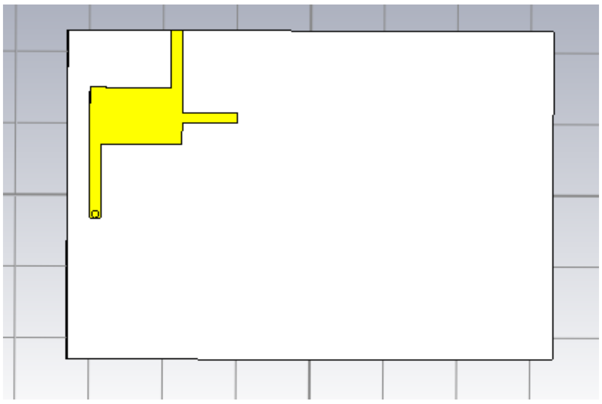


Fig. 3.10 (a) CP antenna with patch front side

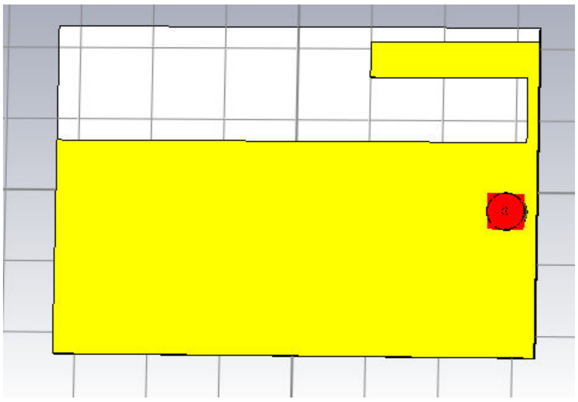


Fig. 3.10 (b) CP antenna with patch ground plane

CHAPTER 4

REVIEW OF LITERATURE

This chapter provides the overview regarding the “circular polarized” antenna. Out of the papers read by me, some of them are represented below. All the papers presented below are from various journals and conferences both national as well as international.

karmakar et al. [3] proposed a paper with circular polarized (CP) aperture coupled circular patch antenna. This antenna consists a single-feed patch with perturbation segments, a single feed stacked patch with perturbation segments, and a dual-feed patch with a 3-dB branch line coupler as an external polarizer is considered to obtain the wide impedance bandwidth. These antennas provide more than 9 dBi gain and production cost is low.

Satish et al. [4] proposed across CP stacked microstrip antenna having single aperture coupled feed. The frequency range for LHCP and RHCP is 3.224 GHz and 3.714 GHz. It consists two patches. The lower patch is of square shape (40 mm × 40 mm) and the upper patch is rectangular in shape (36 mm × 38 mm). The maximum gain is 9.71 dB and 8.30 dB for both the frequencies. The 3 dB axial ratio bandwidth is 48.65 MHz and 24.32 MHz for LHCP and RHCP respectively.

Padhi et al. [6] presented a circular patch antenna having a C- shaped linear coupling slot with aperture feeding structure. Slots are symmetrically oriented about the vertical diameters of the patch. This antenna provides a maximum gain of 7.6 dB and a 3 dB beamwidth of 70 degrees. This antenna provides a high gain, wide beamwidth, low cross polarization and used for RF applications in C-band.

Rafi et al. [7] proposed a 4-elements sequentially rotated patches and a V-shaped slot cut on each element and having a coaxial feeding. Every element has a 90-degree phase difference between adjacent elements. Impedance bandwidth provided by the antenna is 36.5 %.

Chair et al. [8] composed polarized dielectric resonator antenna (DRA) which is excited by a cross-shaped slot with two orthogonal ports. A U shaped stub is added to optimize the matching. Two ports provide more than 30 dB isolation. Impedance bandwidth achieved by port 1 and port 2 is 20 % and 21 % respectively. Average gain of more than 7 dB is obtained.

Lee et al. [9] presented an antenna having corner truncated square patch, a probe feed, and a ground plane. Size of the antenna is 200 mm × 200 mm. Impedance bandwidth obtained is 23 MHz. Peak gain obtained by the antenna is 10.8 dBi and provided average gain is 9.7 dB. This antenna is used as an RFID reader.

Tong et al. [10] present a square ring patch antenna. The square ring is used for the simplicity of the design. FR4 with a dielectric constant of 4.4 is used for the substrate. The impedance bandwidth provided by the antenna is 4.2 % and a 3 dB axial ratio bandwidth is about 1 %. The maximum gain provided by the antenna is 7.7 dB.

Kim et al. [11] designed an antenna having stacked structure, an air gap and a coaxial probe for feeding structure. FR-4 with a dielectric constant of 4.4 is used as the substrate. Size of the bottom patch of the antenna is 19 mm × 19 mm and size of the top patch is 16 mm × 16 mm having truncated corners. Impedance bandwidth and axial ratio bandwidth provided by the antenna are 66.26 % and 20.2 % respectively. Maximum gain obtained from the antenna is 7.6 dB. This antenna is designed at 5 GHz frequency band used in wireless local area network (WLAN).

Malekabadi et al. [12] proposed an antenna having two rectangular patches with two orthogonal slots at the center of each patch. Coaxial feeding is provided to the lower patch. Impedance bandwidth and axial ratio bandwidth of the antenna are 17 % and 13 % respectively.

Tong et al. [13] presented an antenna having a U-shaped microstrip line structure with proximity feeding. RT/Duriod with a dielectric constant of 2.2 is used substrate. The antenna is designed to operate at 2.9 GHz frequency. The 3 dB axial ratio bandwidth and impedance bandwidth of the proposed antenna is 19.4 % and 20.1 % respectively. The maximum gain provided by the antenna is 3.5 dB.

Mousavi et al. [16] composed a circular polarized L-shape monopole slot antenna having a single C-shaped feed. This antenna provides an impedance bandwidth of 30 % and an axial ratio bandwidth of 23 %. The overall gain of the antenna varies between 1.8 and 2.45 dBi and having efficiency greater than 90 %. This antenna is used for GPS applications.

Lee et al. [17] proposed a planar monopole antenna. It is formed by four simple monopole antenna elements to enhance the performance of circular polarization. RF35 with a dielectric constant of 3.5 is used for the substrate. Impedance bandwidth and axial ratio bandwidth provided by the antenna are 87.3 % and 95 % respectively. The antenna provides a maximum gain of 4.02 dB.

Seyyedrezaei et al. [18] designed a CPW-fed antenna having two square slots around both sides of the feed. The size of the antenna is 40 mm × 30 mm. Circular polarization is obtained at 2.385 GHz frequency with an axial ratio bandwidth of 3.77 % and impedance bandwidth of 13.39 %. This antenna is used for WiMAX/WLAN applications.

Falade et al. [19] presented a single feed stacked patch CP antenna. The substrate contains five layers. All the layers are made up of Roger R04003. RHCP pattern achieved is greater by 15 dB than the LHCP pattern. Beamwidth achieved at 3 dB axial ratio is 150 degree. The minimum axial ratio obtained is 0.56 dB which make it suitable for mobile and satellite applications.

Falade et al. [21] composed a compact broadband annular ring slot and a slotted ground plane antenna. The antenna is fed by a microstrip line. Impedance bandwidth provided by the antenna is 1.239 GHz and an axial ratio bandwidth of 1.01 GHz. This antenna design is cost effective and useful for mobile applications.

Khan et al. [24] proposed a multilayer dual-port dual CP antenna. The design is based on a truncated corner square ring slot configuration. This antenna is designed to use in KU-band. Due to high isolation and high efficiency, the antenna can be used for satellite applications also.

Jan et al. [25] designed a broadband microstrip line fed CP circular slot antenna. CP operation can be achieved by embedding a spur slot into the circular slot. The axial ratio bandwidth provided by the antenna is 14.5 %. This antenna has the applications in WLAN 2.4 GHz band.

Deshmukh et al. [26] designed a thinner substrate, notch cut CP antenna. VSWR and axial ratio bandwidth provided by the antenna are 60 and 50 MHz respectively and also provide a gain of more than 5 dB over axial ratio bandwidth.

Prasitha et al. [27] presented a CP microstrip antenna for compass navigation system. It holds two circular substrate and two rectangular stubs. The antenna is designed at 2.292 GHz. Half power beam width (HPBW) could be widening by adding a parasitic ring.

Wang et al. [28] proposed a planar antenna having two CP. By using different feeding ports antenna can radiate RHCP or LHCP. The antenna has a substrate integrated waveguide (SIW) design and a single grounded coplanar waveguide (GCPW) as a feeding element. Impedance bandwidth calculated from the design is 120 MHz and 3dB axial ratio bandwidth is 40 MHz. The maximum simulated gain is 8.5 dB within the axial ratio bandwidth.

Tushar et al. [29] implemented a metamaterial wideband CP antenna. The antenna has a U-shaped ground plane and meanders shape parasitic patch. The fr4 material is used for the substrate with a dielectric constant of 4.4 and thickness of the substrate is 1.5mm. The antenna is designed for C and X band. Impedance bandwidth provides the antenna is 7.3 GHz. This antenna is used for the RADAR system.

Lu et al. [30] designed a planer CP circular antenna with clover slot used for ultra high frequency (UHF) radio frequency identification (RFID). Patch is embedded with a four-leaf clover slot and fed by a microstrip line. FR4 material with a dielectric constant of 4.4 is used a substrate. Simulation provides an impedance bandwidth of 99 MHz and an axial ratio bandwidth of 60 MHz. The maximum gain provided by the antenna is 6.2 dBic with 90 % radiation efficiency.

Liu et al. [32] presented compact size CP broadband antenna based on microstrip to CPW fed rectangular slot antenna. FR4 material with a dielectric constant of 4.4 is used as a substrate. Impedance and 3dB axial ratio bandwidths provided by simulations are 74.4 % and 70.8 % respectively. Simulated peak gain obtained is 7.8 dB. This antenna has applications in 2G/3G/LTE wireless communication system.

CHAPTER 5

OBJECTIVE

The objective of the paper is to design a new circularly polarized single feed microstrip antenna.

1. To do the comparative analysis of the various antenna designs related to the circular polarization in the literature.
2. To design a new compact circularly polarized microstrip antenna for future wireless applications.
3. To do fabrication and testing of the designed circular polarization antenna.

CHAPTER 6

PROPOSED METHODOLOGY

In this chapter, steps the procedure of the complete antenna design using CST studio suite are shown. The following procedure was followed for the completion of the antenna design:

1. First of all review of literature is done on the circularly polarized antenna. A Literature review has many techniques for the circularly polarized antenna like a truncated corner, truncated patch, dual feeding, open slot etc.
2. Then from literature review, we selected a base paper on the circular polarized antenna with an open slot. This design consists four designs by varying the positions of the slot in ground plane and patch on the top.
3. After selecting the base paper, it is implemented in the computer simulation technology (CST) microwave studio.
4. After successfully implementing the base paper on CST microwave studio results like S-parameters, VSWR, far-field and axial ratio are calculated.
5. As results obtained are appropriate, then we compared the results with base paper.

CHAPTER 7

RESULTS AND DISCUSSIONS

The simulation of the proposed antenna was carried out using CST microwave studio with the units being set to GHz for frequency and mm for length. There are four designs of the antenna that are implemented are a prototype, asymmetry, bent feeding and final design with the patch. The simulation settings in CST (mesh shells properties, frequency range, accuracy etc.) affect the simulations result a little, special the *S*11 parameter. Therefore the *S*11 parameter looks a bit different depending on which settings are used. The report presents four different simulation results (*S*11 parameter, far-field pattern, axial ratio).

*S*11 parameter (return loss) describes the relationship between the input power and reflected power to the system for a two ports network. The transmission line and load (antenna) are better matched if the S11 is lower. A lower S11 means also that less power is reflected.

The far-field pattern shows how good the antenna radiates in the far field region for different angles from the antenna. The antenna radiates with higher power for those angles in the far field pattern there is red, radiates with lower power at those angles in the far field pattern there is yellow and radiates with no power at the angels there the far field pattern is blue. For the simulation results, the far field pattern is given with the absolute value.

The Axial ratio shows the polarization for the antenna. It is circularly polarized if the pattern is green (0 dB) and linearly polarized where the pattern is red. The radiation efficiency is the ratio between the radiated power and input power.

6.1 S_{11} parameter and VSWR results

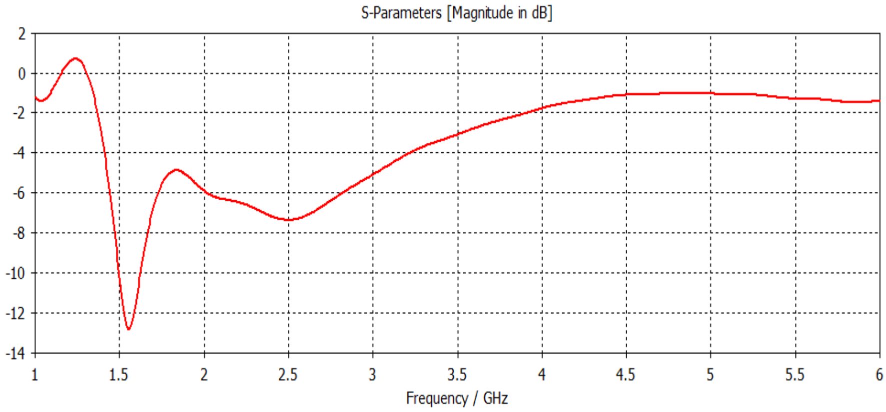


Fig. 6.1 (a) S_{11} parameter for prototype antenna at 1.55 GHz

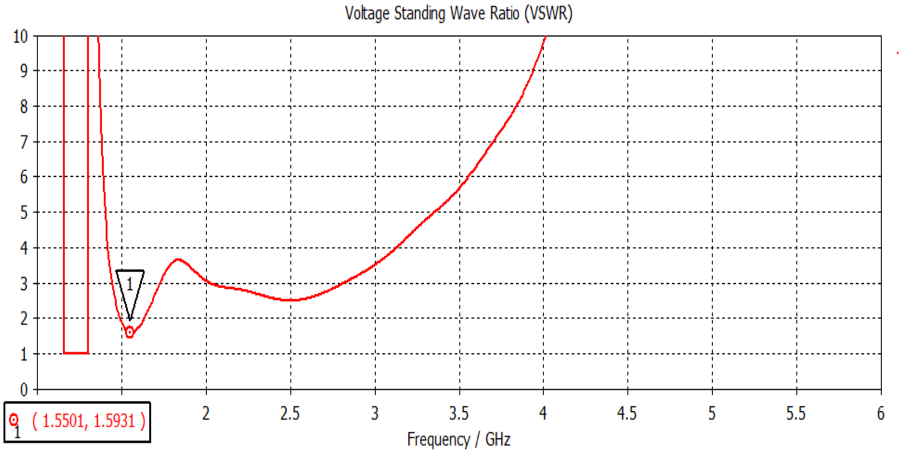


Fig. 6.1 (b) VSWR result for frequency 1.55 GHz

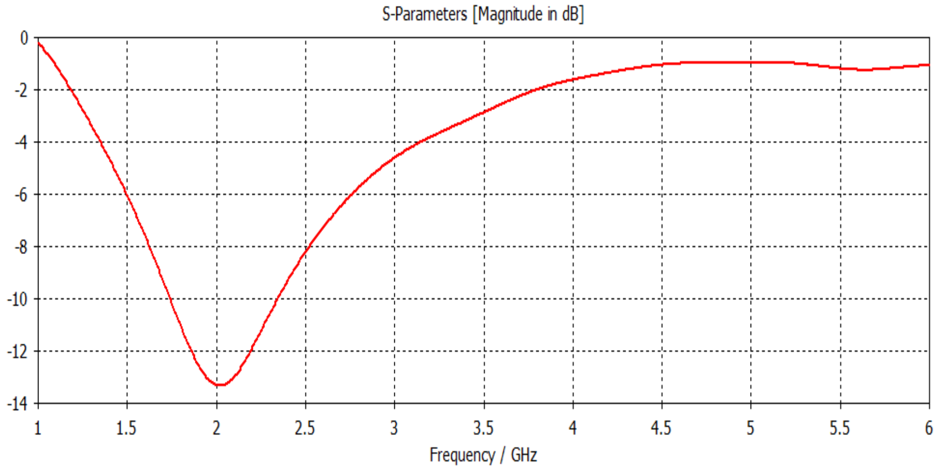


Fig. 6.2. (a) S_{11} parameter for asymmetry design for frequency 2 GHz

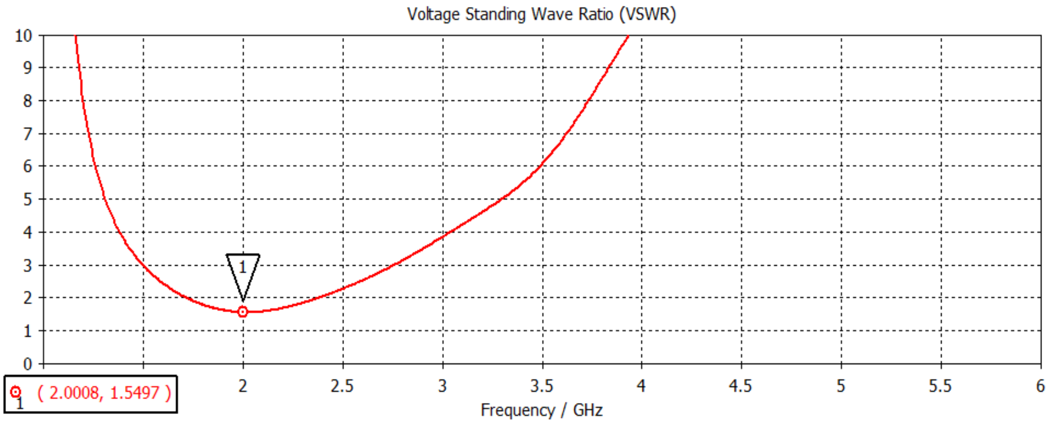


Fig. 6.2 (b) VSWR for asymmetry design for frequency 2 GHz

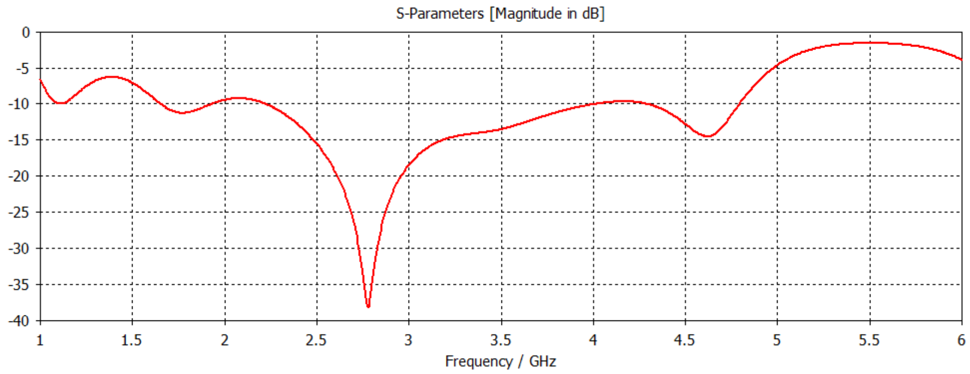


Fig. 6.3 (a) S_{11} parameter for bent feeding design for frequency 2.79 GHz

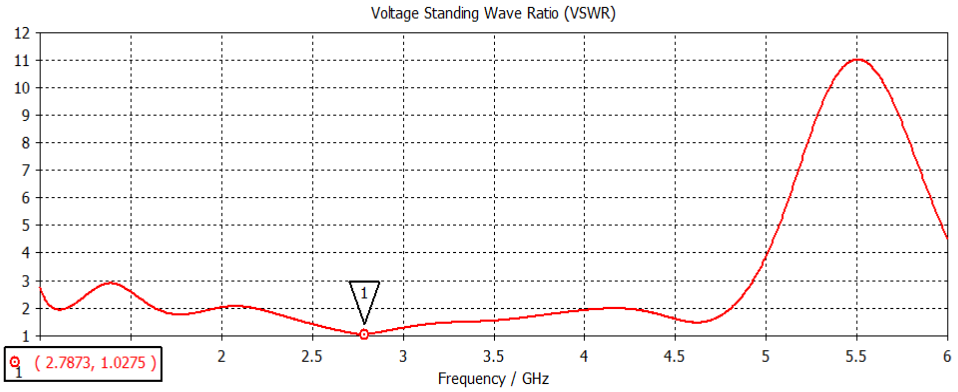


Fig. 6.3 (b) VSWR for bent feeding design for frequency 2.79 GHz

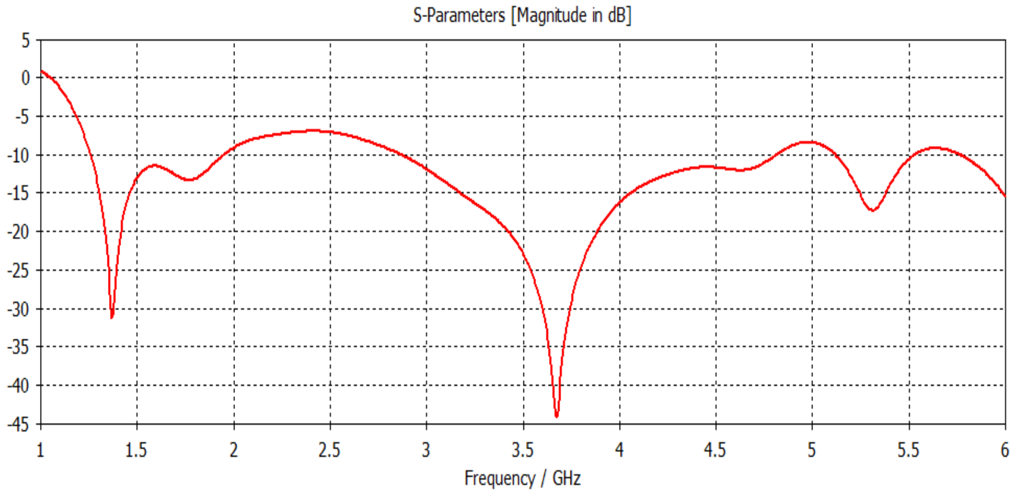


Fig.6.4 (a) S_{11} parameter for bent feeding with patch design for frequency 3.67 GHz

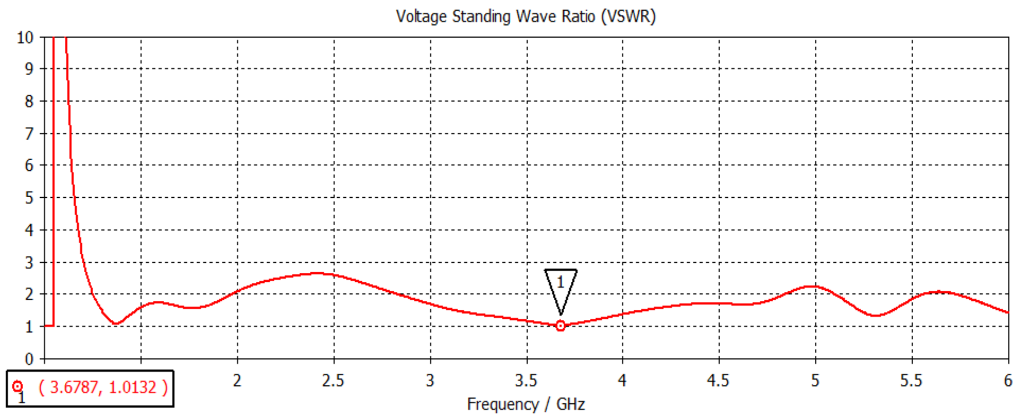


Fig. 6.4 (b) VSWR for bent feeding with patch design for frequency 3.67 GHz

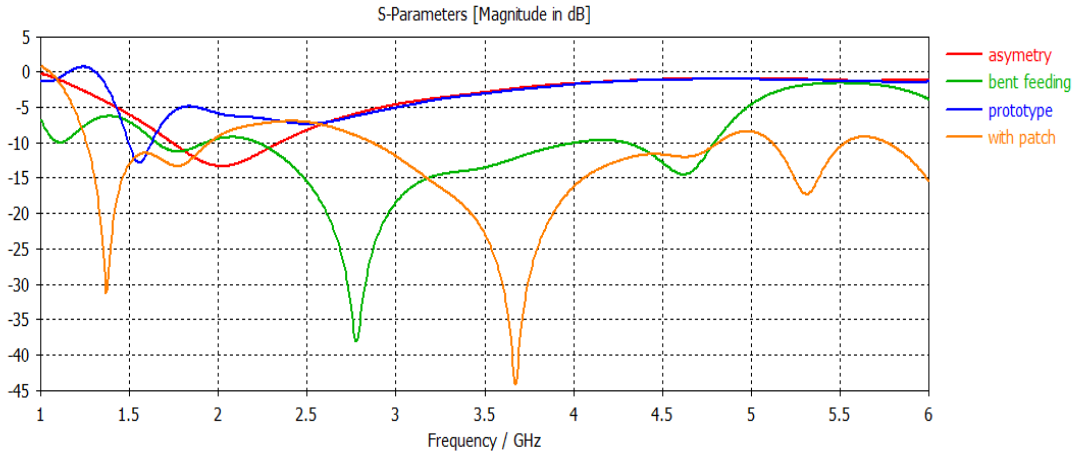


Fig. 6.5 (a) Combined S_{11} parameters for all designs

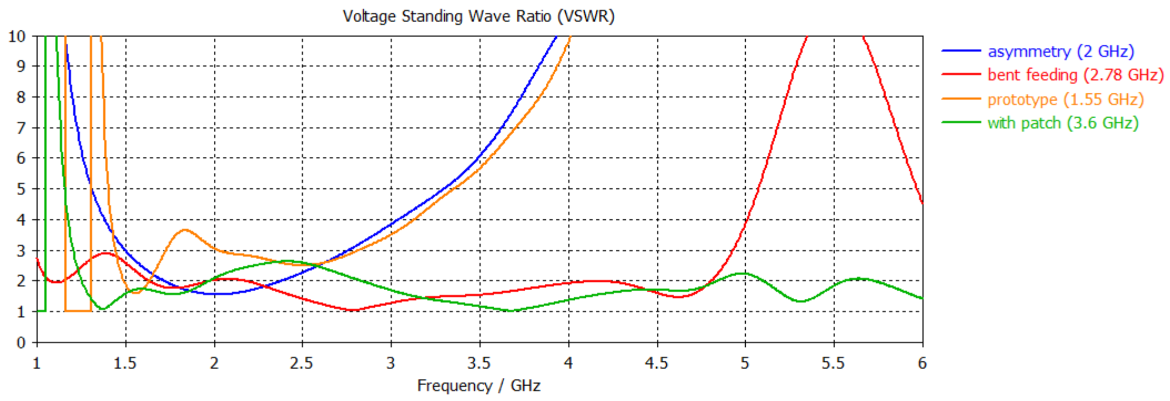


Fig. 6.5 (b) Combined VSWR results for all designs

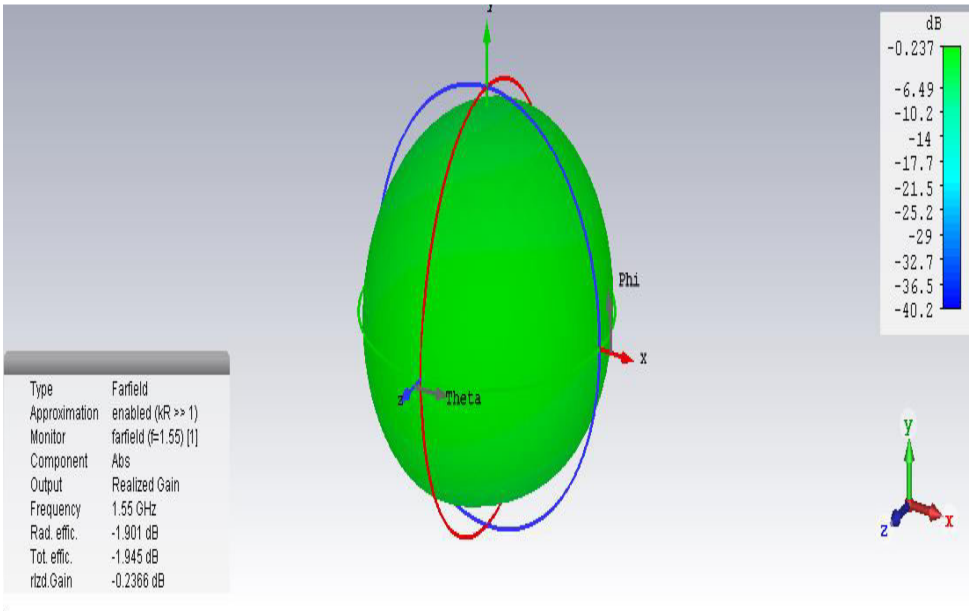
In Fig. 6.1 for an open slot antenna, which is located at the center of the ground plane, provides a return loss of -12.81 dB and having the operating resonant frequency is 1.55 GHz and the 10 dB impedance bandwidth is 129 MHz. VSWR value at obtained is 1.59 at 1.55 GHz.

In fig. 6.2 the open slot moved to the right side of the ground plane (Asymmetry), provides return loss of -13.32 dB and having operating frequency is 2 GHz and impedance bandwidth is increased to 608.5 MHz. VSWR value at obtained is 1.54 at 2 GHz.

In fig. 6.3 the antenna with bent feeding line provides return loss of -37.9dB and having an operating resonant frequency of 2.78 GHz and an impedance bandwidth for center frequency is 2.06 GHz and having two notches bandwidth of 316.8 MHz and 719.7 MHz. VSWR value at obtained is 1.02 at 2.78 GHz.

In Fig. 6.4 then antenna including bent feeding having a return loss of -43.84 dB and a patch provide a resonant frequency of 3.68 GHz and provide a large bandwidth of 1.94 GHz and having two more notches of bandwidth including 685.1 GHz and 302.8 MHz for a lower and higher resonant frequency of 1.3 GHz and 5.3 GHz. VSWR value at obtained is 1.01 at 3.68 GHz.

6.2 Far-field results



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=1.55) [1]
Component	Abs
Output	Realized Gain
Frequency	1.55 GHz
Rad. effic.	-1.901 dB
Tot. effic.	-1.945 dB
rlzd.Gain	-0.2366 dB

Fig. 6.6 (a) far-field pattern at frequency 1.5 GHz

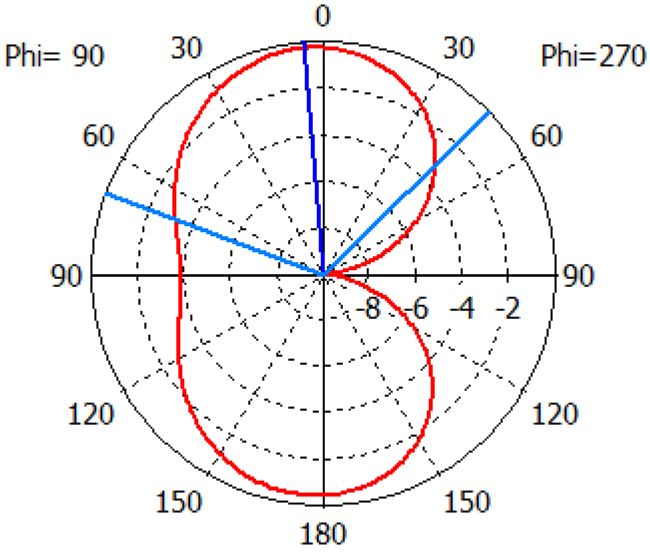
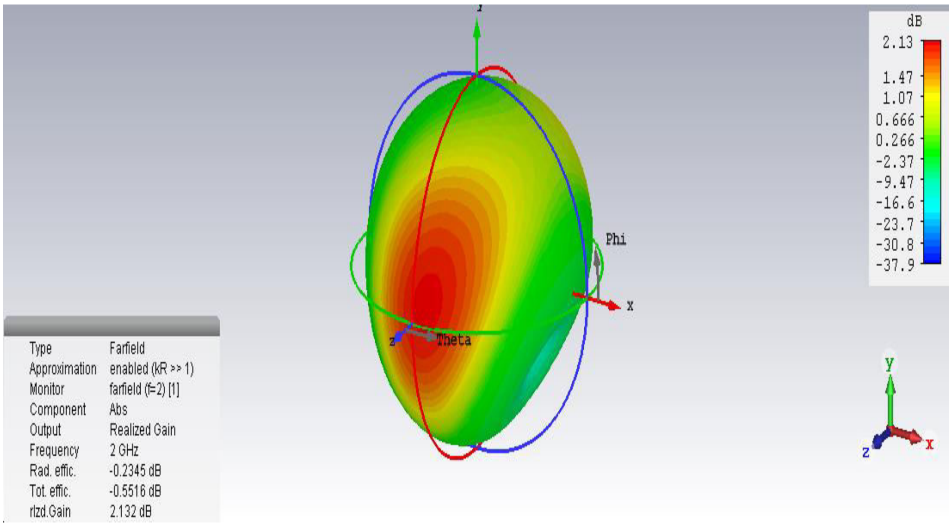


Fig. 6.6 (b) far-field pattern at frequency 1.5 GHz (polar plot)

Fig. 6.6 (a) shows the far-field pattern for 1.5 GHz. The radiation efficiency is – 1.901 dB, the total efficiency is -1.954 dB and the directivity is 1.708 dBi with Realized gain is -0.2366.

Fig. 6.6 (b) shows the main lobe gain magnitude is -0.267 dB and direction is 5 deg. 3 dB angular width is 115.4 degree.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2) [1]
Component	Abs
Output	Realized Gain
Frequency	2 GHz
Rad. effic.	-0.2345 dB
Tot. effic.	-0.5516 dB
rlzd.Gain	2.132 dB

Fig. 6.7 (a) Far-field pattern at 2 GHz

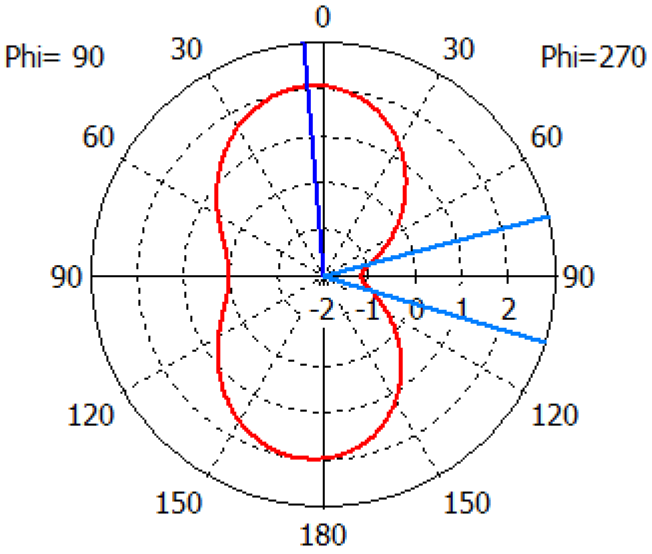
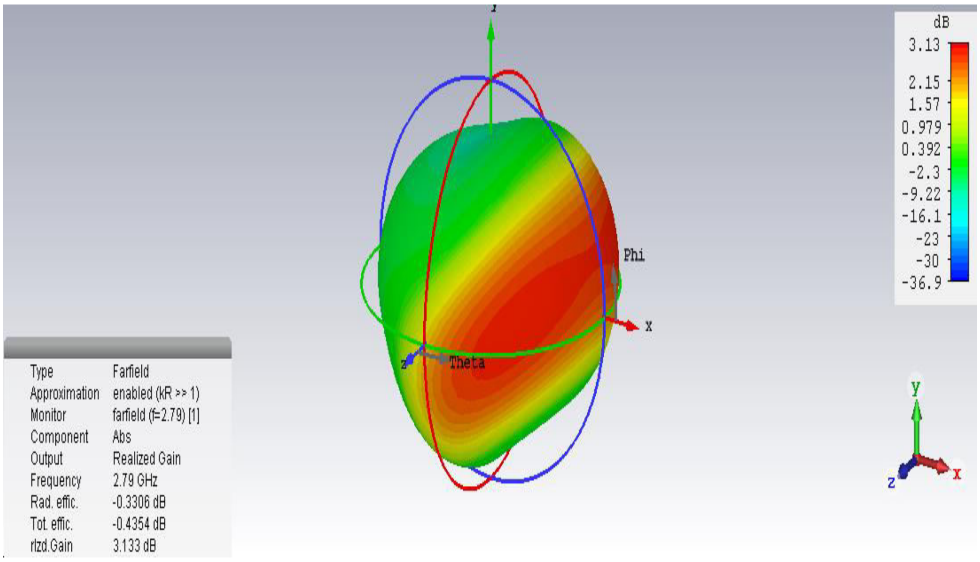


Fig. 6.7 (b) Far field pattern at 2 GHz

Figure 6.7 (a) shows the far-field pattern for 2 GHz. The radiation efficiency is –0.2345 dB, the total efficiency is -0.5516 dB and the directivity is 2.684 dBi with Realized gain is -2.132.

Fig. 6.7 (b) shows the main lobe gain magnitude is 2.07 dB and direction is 5 deg. 3 dB angular width is 328.6 degree.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=2.79) [1]
Component	Abs
Output	Realized Gain
Frequency	2.79 GHz
Rad. effic.	-0.3306 dB
Tot. effic.	-0.4354 dB
rlzd.Gain	3.133 dB

Fig. 6.8 (a) Far field pattern at 2.78 GHz

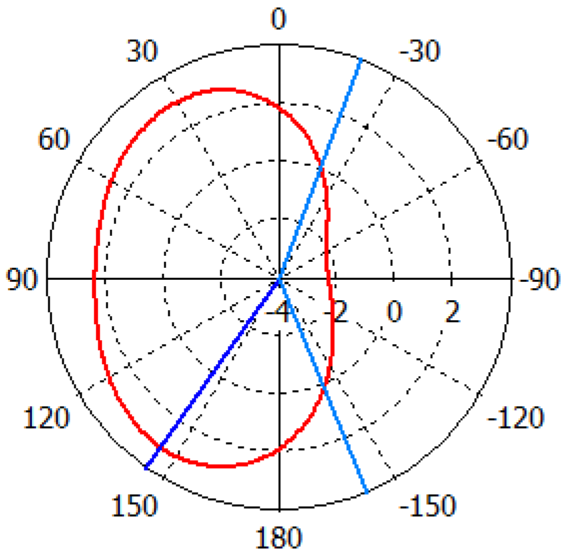
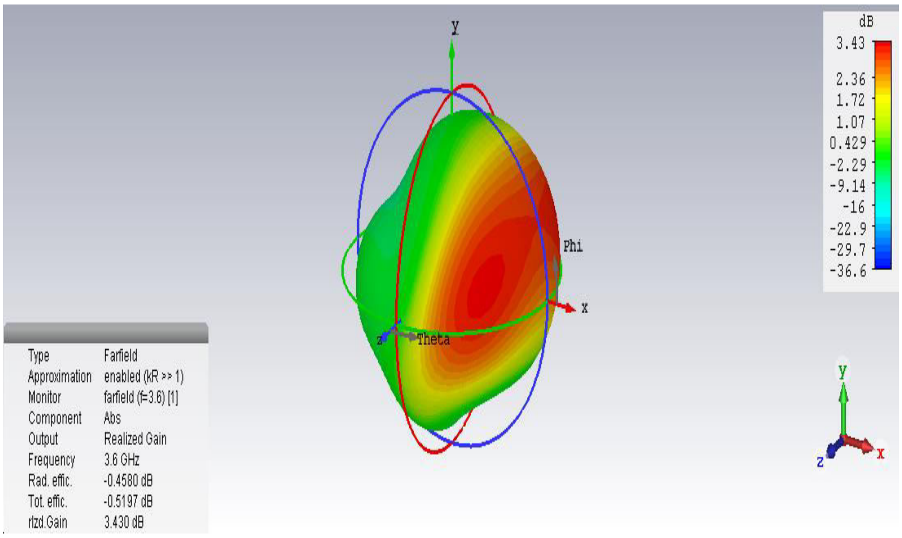


Fig.6.8 (b) far field pattern at 2.79 GHz (polar plot)

Figure 6.8 (a) shows the far-field pattern for 2.79 GHz. The radiation efficiency is –0.3306 dB, the total efficiency is -0.4354 dB and the directivity is 3.568 dBi with Realized gain is 3.133. Fig. 6.8 (b) shows the main lobe gain magnitude is 3.08 dB and direction is 145 deg. 3 dB angular width is 222.9 degree.



Type	Farfield
Approximation	enabled (kR >> 1)
Monitor	farfield (f=3.6) [1]
Component	Abs
Output	Realized Gain
Frequency	3.6 GHz
Rad. effic.	-0.4580 dB
Tot. effic.	-0.5197 dB
rlzd.Gain	3.430 dB

Fig. 6.9 (a) Far-field at 3.68 GHz

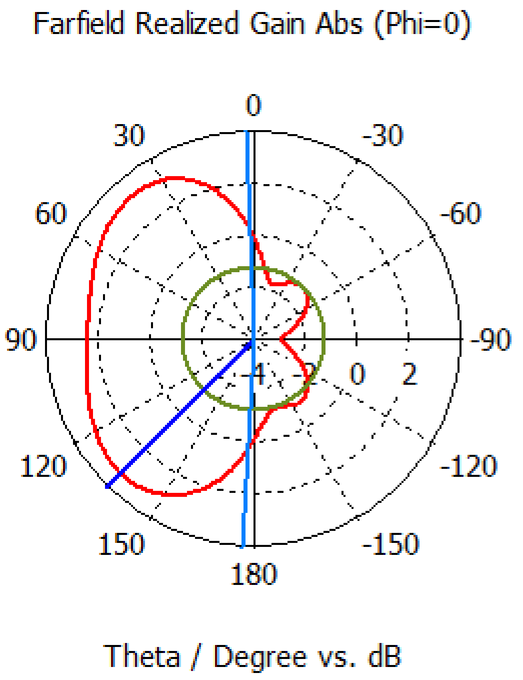


Fig. 6.9 (b) Far-field at 3.68 GHz (polar plot)

Figure 6.9 (a) shows the far-field pattern for 3.68 GHz. The radiation efficiency is – 0.4590 dB, the total efficiency is -0.5197 dB and the directivity is 3.950 dBi with Realized gain is 3.430. Fig. 6.9 (b) shows the main lobe gain magnitude is 0.842 dB and direction is 24 deg. 3 dB angular width is 116.3 degree and side lobe -2.6 dB.

As we moving the slot to the edge of the ground plane both the directivity and gain increases and as we further add the finger strip and patch to the antenna it shows better far-field results and directivity and gain also enhanced.

6.3 Axial ratio results

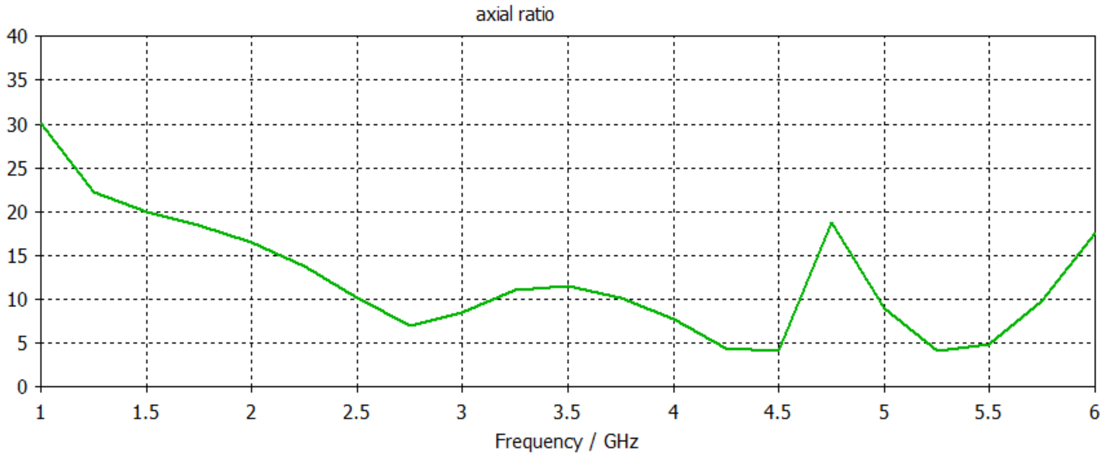


Fig. 6.10 Axial ratio parameters for prototype antenna

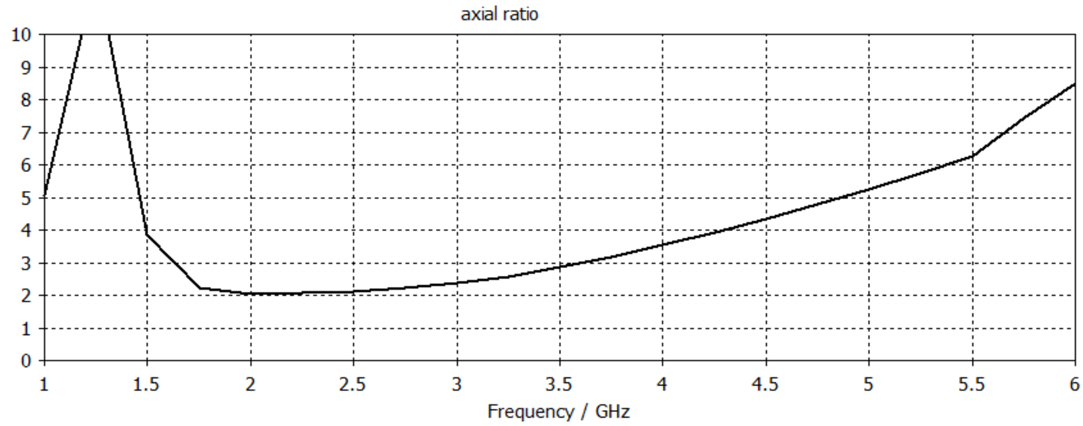


Fig. 6.11 Axial ratio parameters for asymmetry design

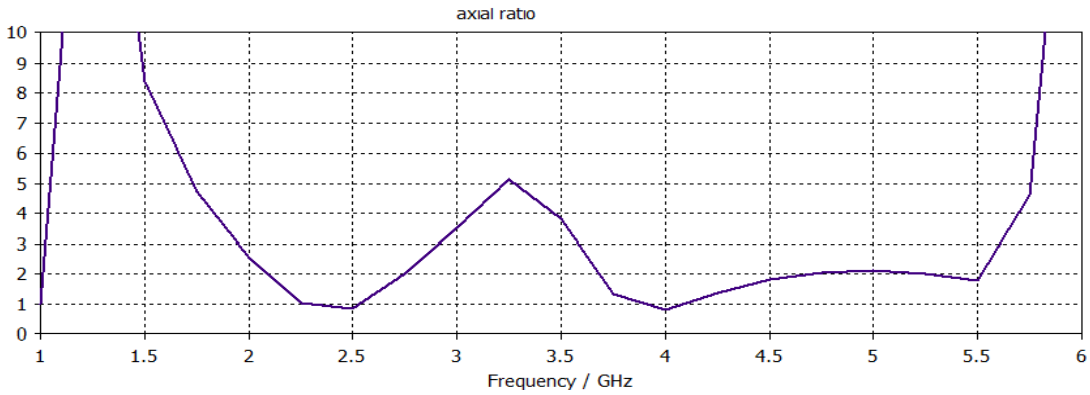


Fig. 6.12 Axial ratio parameters for bent feeding design

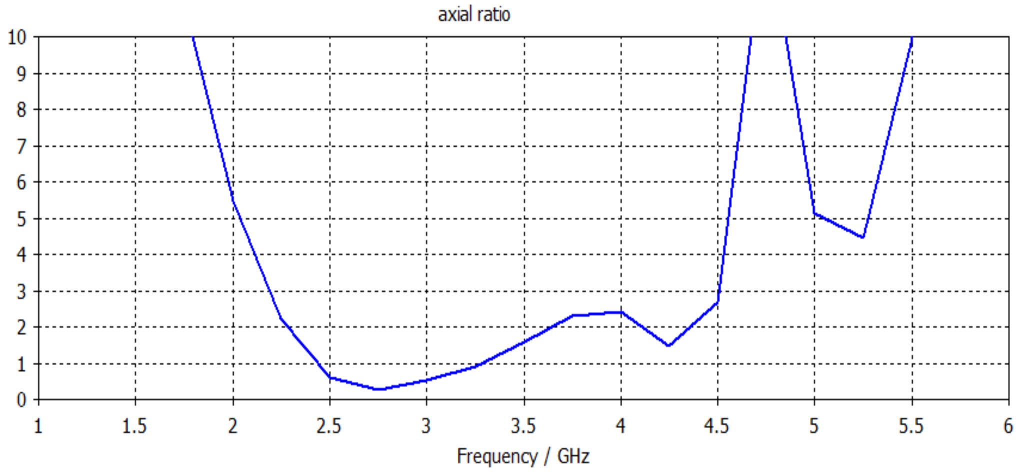


Fig. 6.13 Axial ratio parameters for with patch design

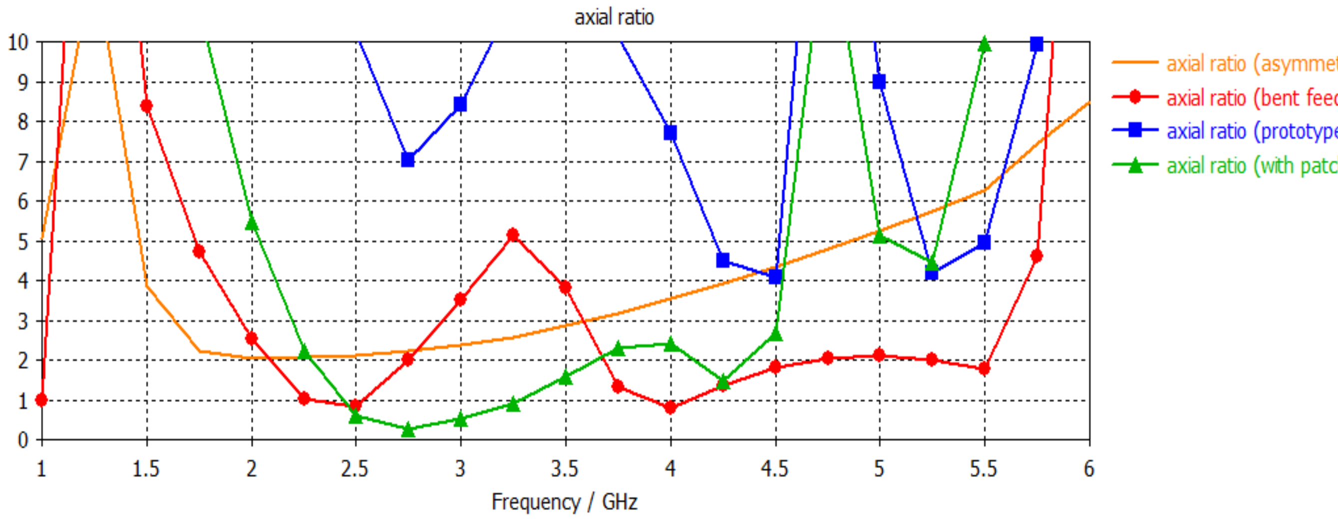


Fig .6.14 Axial ratio parameters for all antenna designs

Fig. 6.10 shows the axial ratio curve for prototype antenna. From the design, it can be illustrated that prototype antenna is failed to achieve 3 dB axial ratio for a frequency band of 1-6 GHz. So this antenna is not properly circular polarized. To make this antenna circular polarized we shift the open slot on the ground plane to the right side to achieve the asymmetry design.

Fig. 6.11 illustrates the axial ratio curve for the asymmetry design. The minimum axial ratio obtained in this design is 2 dB. 3 dB axial ratio bandwidth obtained in this plot is 1.98 GHz it shows that this design hasgood circular polarized characteristics.

Fig. 6.12 Indicates the axial ratio curve for bent feeding design. The minimum value of axial ratio obtained in this design is 1 dB and 3 dB axial ratio bandwidth is 3.07 GHz along with 2 notches of 1.03 GHz and 2.04 GHz. This design is an improvement of circular polarization pattern than previous designs.

Fig. 6.13 Depicts the axial ratio curve of a full design with the patch. The minimum value of axial ratio obtained in this design is 0.2 dB which indicates that antenna is highly circular polarized. 3 dB axial ratio bandwidth obtained in this design is 2.31 GHz.

CHAPTER 7

CONCLUSION AND FUTURE WORK

There is various type of microstrip antenna that is able to excite a circular polarization. For this base paper, the open slot circular polarization microstrip antenna is chosen. Four design versions were presented. The proposed antenna, which consists of an open slot and a coaxial feeding topology, provides a large bandwidth, which covers the operation bandwidth of a satellite digital audio radio (SDAR) service system. The main objective of the designs was to provide high impedance bandwidth along with maximum axial ratio bandwidth. The maximum impedance obtained from the design is 2 GHz with a maximum value of axial ratio bandwidth is nearly 3 GHz. For the design of bent feeding with patch min value of axial ratio obtained is less than 1 dB which indicates highly circular polarized characteristics of the antenna. Furthermore, the wideband circular polarization is also effectively excited for the application of the SDAR system. The attractive performance of the proposed antenna makes it a candidate for multi-functional integration of wireless communication systems. The impedance bandwidth of a reflection coefficient < -10 dB ranges from 1.55 to 3.67 GHz, which covers most commercial wireless communication systems, such as GPS, DCS, PCS, IMT-2000, WLAN, LTE 2600, WiMAX, and WiFi.

One of the main advantages of a single fed microstrip antenna is that it can be used in the production of the antenna array. This work can be extended by investigating the design of an antenna array that uses the antenna presented as its unit element. The future array structure should investigate the use of the 3 feeding techniques presented as well. It should also investigate the arrangement of the array elements.

Therefore, in future work, both for single feed and dual feed, a different type of circular polarization can be designed and studied, so that, comparisons can be made to the antennas, thus better microstrip antenna that excites circular polarization can be obtained.

Some more work can be done in the following area-

Reducing the size of microstrip element

- Improving cross-polar to co-polar levels.
- Designing the feed network which avoids unwanted radiations.
- Designing the feed network which will not affect the polarization of the antenna even if it is used in an array.
- Designing the feed network having minimum losses.

REFERENCES

1. M. Fleury and E. Philippouci, "Design of a circularly polarized dielectric resonator antenna," *Electrical and Computer Engineering, 1997. Engineering Innovation: Voyage of Discovery. IEEE 1997 Canadian Conference on*, St. Johns, Nfld., 1997, pp. 716-719 vol.2.
2. A. Ittipiboon, A. Petosa and M. Cuhaci, "Effects of inter-feed coupling on the axial ratio performance of circular polarized microstrip antennas," *1998 Symposium on Antenna Technology and Applied Electromagnetics*, Ottawa, Canada, 1998, pp. 209-212.
3. N. C. Karmakar and M. E. Bialkowski, "Circularly polarized aperture-coupled circular microstrip patch antennas for L-band applications," in *IEEE Transactions on Antennas and Propagation*, vol. 47, no. 5, pp. 933-940, May 1999.
4. S. K. Sharma and L. Shafai, "Aperture coupled dual band dual circularly polarized stacked microstrip antenna," *Symposium on Antenna Technology and Applied Electromagnetics [ANTEM 2000]*, Winnipeg, Canada, 2000, pp. 41-44.
5. Yi Qin, E. G. Lim and E. Korolkiewicz, "Design of microstrip offset feed circular polarised nearly square patch antenna operating at 2.45 GHz," in *Electronics Letters*, vol. 38, no. 16, pp. 844-845, 1 Aug 2002.
6. S. K. Padhi, N. C. Karmakar, C. L. Law and S. Aditya, "A dual polarized aperture coupled circular patch antenna using a C-shaped coupling slot," in *IEEE Transactions on Antennas and Propagation*, vol. 51, no. 12, pp. 3295-3298, Dec. 2003.
7. G. Z. Rafi and L. Shafai, "Wideband circular polarized microstrip antennas with V-slot," *2004 10th International Symposium on Antenna Technology and Applied Electromagnetics and URSI Conference*, Ottawa, Canada, 2004, pp. 1-4.
8. R. Chair, A. A. Kishk and K. F. Lee, "Wideband dual polarized dielectric resonator antennas at X-band," *2005 IEEE Antennas and Propagation Society International Symposium*, 2005, pp. 214-217 vol. 4B.
9. Jong Moon Lee, Nae Soo Kim and Cheol Sig Pyo, "A Circular Polarized Metallic Patch Antenna for RFID Reader," *2005 Asia-Pacific Conference on Communications*, Perth, WA, 2005, pp. 116-118.
10. Kin-Fai Tong, "A new single-feed proximity coupled circularly polarized square ring antenna," *2006 Asia-Pacific Microwave Conference*, Yokohama, 2006, pp. 69-72.
11. S. M. Kim and W. G. Yang, "Single feed wideband circular polarised patch antenna," in *Electronics Letters*, vol. 43, no. 13, pp. 703-704, June 21 2007.

12. S. A. Malekabadi, A. R. Attari and M. M. Mirsalehi, "Compact and broadband circular polarized Microstrip Antenna with wideband Axial-Ratio bandwidth," *2008 International Symposium on Telecommunications*, Tehran, 2008, pp. 106-109.

13. K. F. Tong and G. Lacotte, "Novel single-feed proximity coupled wideband circularly polarized slot antenna," *2008 Asia-Pacific Microwave Conference*, Macau, 2008, pp. 1-4.

14. A. E. Popugaev and R. Wansch, "A novel miniaturization technique in microstrip feed network design," *2009 3rd European Conference on Antennas and Propagation*, Berlin, 2009, pp. 2309-2313.

15. M. Matsunaga and T. Matsunaga, "A New Design of Circular Polarized Planar Antennae," *2010 International Conference on Broadband, Wireless Computing, Communication and Applications*, Fukuoka, 2010, pp. 612-615.

16. P. Mousavi, B. Miners and O. Basir, "Wideband L-Shaped Circular Polarized Monopole Slot Antenna," in *IEEE Antennas and Wireless Propagation Letters*, vol. 9, pp. 822-825, 2010.

17. W. S. Lee, S. Y. Cha and J. W. Yu, "Wideband planar monopole antenna with circular polarized radiation," *Asia-Pacific Microwave Conference 2011*, Melbourne, VIC, 2011, pp. 1957-1960.

18. S. F. Seyyedrezaei, H. R. Hassani and S. M. A. Nezhad, "A novel small size CPW-fed circular polarized antenna," *2011 Loughborough Antennas & Propagation Conference*, Loughborough, 2011, pp. 1-4.

19. O. P. Falade, X. Chen, Y. Alfadhl and C. Parini, "Quad band circular polarized antenna," *2012 Loughborough Antennas & Propagation Conference (LAPC)*, Loughborough, 2012, pp. 1-4.

20. L. Peng, K. Sun, X. Jiang, S. M. Li and C. L. Ruan, "EZR-MZR Resonators for Compact Low-Profile Omnidirectional Circular-Polarized Antenna Design," in *IEEE Photonics Journal*, vol. 9, no. 4, pp. 1-15, Aug. 2017.

21. O. P. Falade, X. Chen and C. Parini, "Broadband circular polarized antenna for mobile communication applications," *2013 International Workshop on Antenna Technology (iWAT)*, Karlsruhe, 2013, pp. 51-54.

22. N. Usami and A. Hirose, "Proposal of wideband reconfigurable circular-polarized single-port antenna," *2014 Asia-Pacific Microwave Conference*, Sendai, Japan, 2014, pp. 34-36.

23. Y. Liu, H. Xiao and G. Lu, "Design of a High Gain Circular Polarized Radial Line Slot Antenna," *2014 Seventh International Symposium on Computational Intelligence and Design*, Hangzhou, 2014, pp. 490-493.

24. M. Khan, Z. Yang and K. Warnick, "Dual-Circular-Polarized High-Efficiency Antenna for Ku-Band Satellite Communication," in *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 1624-1627, 2014.

25. J. Y. Jan, G. J. Wu, C. Y. Pan and H. M. Chen, "Broadband microstrip-line-fed circularly-polarized circular slot antenna," *2014 IEEE International Workshop on Electromagnetics (iWEM)*, Sapporo, 2014, pp. 58-59.

26. A. A. Deshmukh, S. A. Shaikh, A. A. Desai, K. A. Lele and S. Nagarbowdi, "Design of Notch Cut Circularly Polarized Circular Microstrip Antenna," *2015 Fifth International Conference on Advances in Computing and Communications (ICACC)*, Kochi, 2015, pp. 266-269.

27. Prasitha M and Yogeshwaran A, "Densed circular polarised microstrip antenna for telecommunication," *2015 International Conference on Computation of Power, Energy, Information and Communication (ICCPEIC)*, Chennai, 2015, pp. 0350-0353.

28. H. H. Wang, Z. C. Hao and X. M. Liu, "A planar antenna having two realizable circular polarizations," *2015 Asia-Pacific Microwave Conference (APMC)*, Nanjing, 2015, pp. 1-3.

29. T. Mhuskey and P. Gour, "Metamaterial wideband circular polarized microstrip antenna for C and X band," *2015 International Conference on Computer, Communication and Control (IC4),* Indore, 2015, pp. 1-5.

30. J. H. Lu and H. M. Chin, "Planar circularly polarized circular antenna with clover slot for RFID system," *2016 International Symposium on Antennas and Propagation (ISAP)*, Okinawa, 2016, pp. 420-421.

31. D. A. Buhtiyarov and A. P. Gorbachev, "The linearly polarized ends-fed magnetic dipole antenna excited by circular waveguide," *2016 11th International Forum on Strategic Technology (IFOST)*, Novosibirsk, 2016, pp. 290-293.

32. H. Liu, Y. Liu, S. Gong and T. Wan, "A broadband microstrip-CPW fed circular-polarized antenna," *2016 International Conference on Electromagnetics in Advanced Applications (ICEAA)*, Cairns, QLD, 2016, pp. 616-619.

33. Constantine A. Balanis, “ANTENNA THEORY: ANALYSIS AND DESIGN, 3RD ED,” 2009 John Wiley & Sons, pp. 812.

34. Constantine A. Balanis, “ANTENNA THEORY: ANALYSIS AND DESIGN, 3RD ED,” 2009 John Wiley & Sons, pp. 813.
35. Constantine A. Balanis, “ANTENNA THEORY: ANALYSIS AND DESIGN, 3RD ED,” 2009 John Wiley & Sons, pp. 812.
36. B. G. Hakanoglu and M. Turkmen, "An inset fed square microstrip patch antenna to improve the return loss characteristics for 5G applications," *2017 XXXIInd General Assembly and Scientific Symposium of the International Union of Radio Science (URSI GASS)*, Montreal, QC, Canada, 2017, pp. 1-4.
37. Constantine A. Balanis, “ANTENNA THEORY: ANALYSIS AND DESIGN, 3RD ED,” 2009 John Wiley & Sons, pp. 814.
38. Constantine A. Balanis, “ANTENNA THEORY: ANALYSIS AND DESIGN, 3RD ED,” 2009 John Wiley & Sons, pp. 815.
39. Constantine A. Balanis, “ANTENNA THEORY: ANALYSIS AND DESIGN, 3RD ED,” 2009 John Wiley & Sons, pp. 815.
40. Y. Noh, Y. Shin, M. J. Lee and S. Pyo, "Perpendicularly-fed microstrip antenna with crossed ground slot for GPS application," *2017 14th International Conference on Electrical Engineering/Electronics, Computer, Telecommunications and Information Technology (ECTI-CON)*, Phuket, 2017, pp. 463-464.
41. Zhang Ri-rong, "The analysis about three types of polarization correctors for satellite communication with frequency reuse systems," *1980 Antennas and Propagation Society International Symposium*, Quebec, Canada, 1980, pp. 686-688.
42. A. V. Uzlenkov, "Potential properties of radar signals formed by some types of polarization modulation," *2011 21st International Crimean Conference "Microwave & Telecommunication Technology"*, Sevastopol, 2011, pp. 1104-1105.
43. P. Bienias, G. Budzyń and E. Beres-Pawlik, "Set partitioning type modulation utilising polarization-maintaining fibers," *2017 19th International Conference on Transparent Optical Networks (ICTON)*, Girona, 2017, pp. 1-4
44. S. Garg and S. Yadav, "A novel polarization independent transmissive type frequency selective surface for WiFi, WiMax & WLAN applications," *2017 International Conference on Computer, Communications and Electronics (Comptelix)*, Jaipur, 2017, pp. 216-220.
45. S. Bharadwaj *et al*., "High-temperature p-type polarization doped AlGaN cladding for sub-250 nm deep-UV quantum well LEDs by MBE," *2017 75th Annual Device Research Conference (DRC)*, South Bend, IN, 2017, pp. 1-2