A CPW Feed Orthogonal Quad-Port Conformal MIMO Antenna for Satellite Applications

A Project report submitted in partial fulfillment of the requirements for

The award of the degree of

BACHELOR OF TECHNOLOGY

IN

ELECTRONICS AND COMMUNICATION ENGINEERING

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DEPARTMENT OF ELECTRONICS AND COMMUNICATION ENGINEERING

ANIL NEERUKONDA INSTITUTE OF TECHNOLOGY AND SCIENCES

(*Permanently Affiliated to AU, Approved by AICTE and Accredited by NBA & NAAC with 'A' Grade*)

Sangivalasa, Bheemili Mandal, Visakhapatnam dist. (A.P)

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CERTIFICATE

This is to certify that the project report entitled **"A CPW Feed Orthogonal Wideband Quad-port Conformal MIMO Antenna for Satellite Applications"** submitted by in partial fulfillment of the requirements for the award of the degree of **Bachelor of Engineering K.S.R.PRAVEEN(318126512L01),R.ABHISHEK(318126512L08),V.SARVARI(317126512057), K.ANISHA KEERTHI(317126512033)** in **Electronics & Communication Engineering** of Andhra University, Visakhapatnam is a record of bonafide work carried out under my guidance and supervision.

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ABSTRACT

The project proposes four-element wideband monopole MIMO antenna for mobile devices. This antenna configuration has four identical CPW-fed elements. It has better bandwidth and simulated peak gain. The applications of these antennas are WLAN, WiMAX and various satellite band applications. It has well improved isolation characteristics for the operational bandwidth of the antenna. These are achieved without having too much trade-off with the foot print of the antenna. This configuration has simple structure with the size 50 x 50 mm2. This proposed antenna also provides the good impedance matching, low mutual coupling and good diversity throughout a wide-range of frequencies over 2GHz in simulation and measurement of the fabricated prototype.

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MIMO : Multiple input multiple output

VSWR : Voltage Standing Wave Ratio

WLAN : Wireless Local Area Network

WIMAX : Worldwide Interoperability for Microwave Access

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1. ANTENNA FUNDAMENTALS

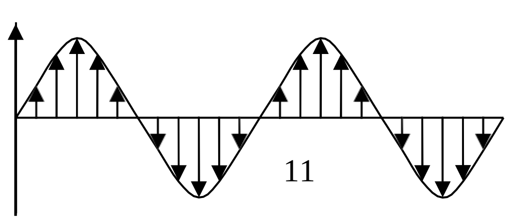
In this chapter, the basic concept of an antenna is provided and its working is explained. Next, some critical performance parameters of antennas are discussed. Finally, some common types of antennas are introduced.

1.1 Introduction:

Antennas are metallic structures designed for radiating and receiving electromagnetic energy. An antenna acts as a transitional structure between the guiding device (e.g. waveguide, transmission line) and the free space. The official IEEE definition of an antenna as given by Stutzman and Thiele follows the concept: “That part of a transmitting or receiving system that is designed to radiate or receive electromagnetic waves”.

How an Antenna radiates?

In order to know how an antenna radiates, let us first consider how radiation occurs. A conducting wire radiates mainly because of time-varying current or an acceleration (or deceleration) of charge. If there is no motion of charges in a wire, no radiation takes place, since no flow of current occurs. Radiation will not occur even if charges are moving with uniform velocity along a straight wire. However, charges moving with uniform velocity along a curved or bent wire will produce radiation. The radiation from an antenna can be explained with the help of Figure 1.1 which shows a voltage source connected to a two conductor transmission line. When a sinusoidal voltage is applied across the transmission line, an electric field is created which is sinusoidal in nature and these results in the creation of electric lines of force which are tangential to the electric field. The magnitude of the electric field is indicated by the bunching of the electric lines of force. The free electrons on the conductors are forcibly displaced by the electric lines of force and the movement of these charges causes the flow of current which in turn leads to the creation of a magnetic field.



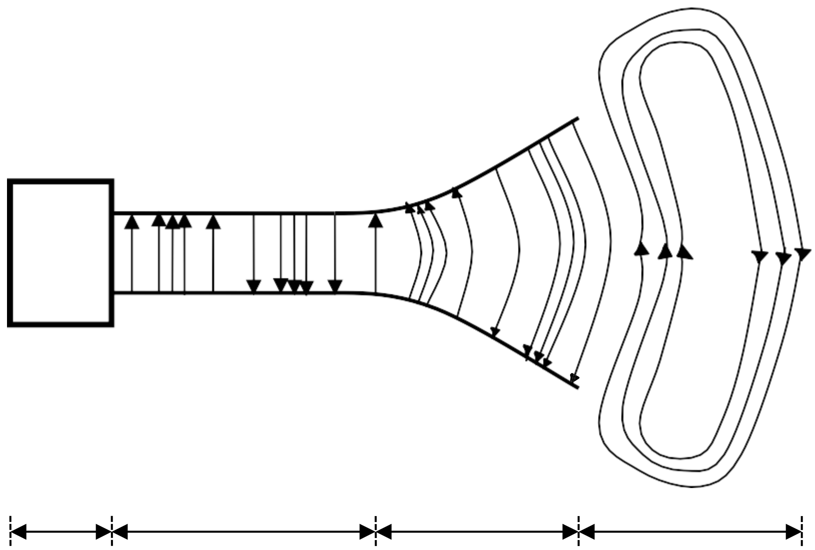


Figure 1.1: Radiation from an antenna

Due to the time varying electric and magnetic fields, electromagnetic waves are created and these travel between the conductors. As these waves approach open space, free space waves are formed by connecting the open ends of the electric lines. Since the sinusoidal source continuously creates the electric disturbance, electromagnetic waves are created continuously and these travel through the transmission line, through the antenna and are radiated into the free space. Inside the transmission line and the antenna, the electromagnetic waves are sustained due to the charges, but as soon as they enter the free space, they form closed loops and are radiated.

1.2 Antenna Performance Parameters:

The performance of an antenna can be gauged from a number of parameters. Certain critical parameters are discussed below.

1.2.1 Radiation Pattern:

The radiation pattern of an antenna is a plot of the far-field radiation properties of an antenna as a function of the spatial co-ordinates which are specified by the elevation angle and the azimuth angle. More specifically it is a plot of the power radiated from an antenna per unit solid angle which is nothing but the radiation intensity. Let us consider the case of an isotropic antenna. An isotropic antenna is one which radiates equally in all directions.

The radiation pattern plot of a generic directional antenna is shown in Figure 1.2.

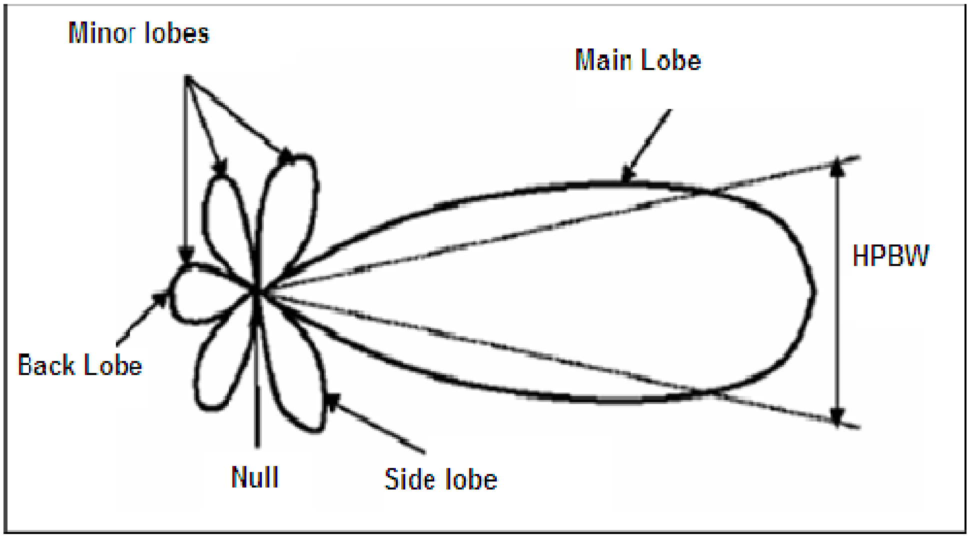


Figure 1.2: Radiation pattern of a generic directional antenna

Figure 1.2 shows the following:

HPBW: The half power beam width (HPBW) can be defined as the angle subtended by the half power points of the main lobe.

Main Lobe: This is the radiation lobe containing the direction of maximum radiation.

Minor Lobe: All the lobes other than the main lobe are called the minor lobes. These lobes represent the radiation in undesired direction.

1.2.2 Directivity:

The directivity of an antenna has been defined by as "the ratio of the radiation intensity in a given direction from the antenna to the radiation intensity averaged over all directions". In other words, the directivity of a non-isotropic source is equal to the ratio of its radiation intensity in a given direction, over that of an isotropic source. Sometimes, the direction of the directivity is not specified.

Directivity is a dimensionless quantity, since it is the ratio of two radiation intensities. Hence, it is generally expressed in db. The directivity of an antenna can be easily estimated from the radiation pattern of the antenna. An antenna that has a narrow main lobe would have better directivity, then the one which has a broad main lobe, hence it is more directives

1.2.3 Input Impedance:

The input impedance of an antenna is defined by as "the impedance presented by an antenna at its terminals or the ratio of the voltage to the current at the pair of terminals or the ratio of the appropriate components of the electric to magnetic fields at a point". Hence the impedance of the antenna can be written as:

$$Z_{in} = R_{in} + jX_{in}$$

Where, R_{in} is the antenna resistance at the terminals

X_{in} is the antenna reactance at the terminals

The imaginary part, X_{in} of the input impedance represents the power stored in the near field of the antenna. The resistive part, R_{in} of the input impedance consists of two components,

The radiation resistance R_r and the loss resistance R_L. The power associated with the radiation resistance is the power actually radiated by the antenna, while the power dissipated in the loss resistance is lost as heat in the antenna itself due to dielectric or conducting losses.

1.2.4 Return Loss (RL):

The Return Loss (RL) is a parameter which indicates the amount of power that is "lost" to the load and does not return as a reflection. As explained in the preceding section, waves are reflected leading to the formation of standing waves, when the transmitter and antenna.

1.2.5 Bandwidth (BW):

The bandwidth of an antenna is defined by as “the range of usable frequencies within which the performance of the antenna, with respect to some characteristic, conforms to a specified standard.” The bandwidth can be the range of frequencies on either side of the center frequency where the antenna characteristics like input impedance, radiation pattern, beamwidth, polarization, side lobe level or gain, are close to those values which have been obtained at the center frequency. The bandwidth of a broadband antenna can be defined as the ratio of the upper to lower frequencies of acceptable operation.

1.2.6 Antenna Gain:

The term **Antenna Gain** describes how much power is transmitted in the direction of peak radiation to that of an isotropic source. **Antenna gain** is more commonly quoted than directivity in an antenna's specification sheet because it takes into account the actual losses that occur.

A transmitting antenna with a gain of 3 dB means that the power received far from the antenna will be 3 dB higher (twice as much) than what would be received from a lossless isotropic antenna with the same input power. Note that a lossless antenna would be an antenna with an antenna efficiency of 0 dB (or 100%). Similarly, a receive antenna with a gain of 3 dB in a particular direction would receive 3 dB more power than a lossless isotropic antenna.

Antenna Gain is sometimes discussed as a function of angle. In this case, we are essentially plotting the radiation pattern, where the units (or magnitude of the pattern) are measured in antenna gain. An example of the radiation pattern plotted in terms of gain is shown in Figure 1:

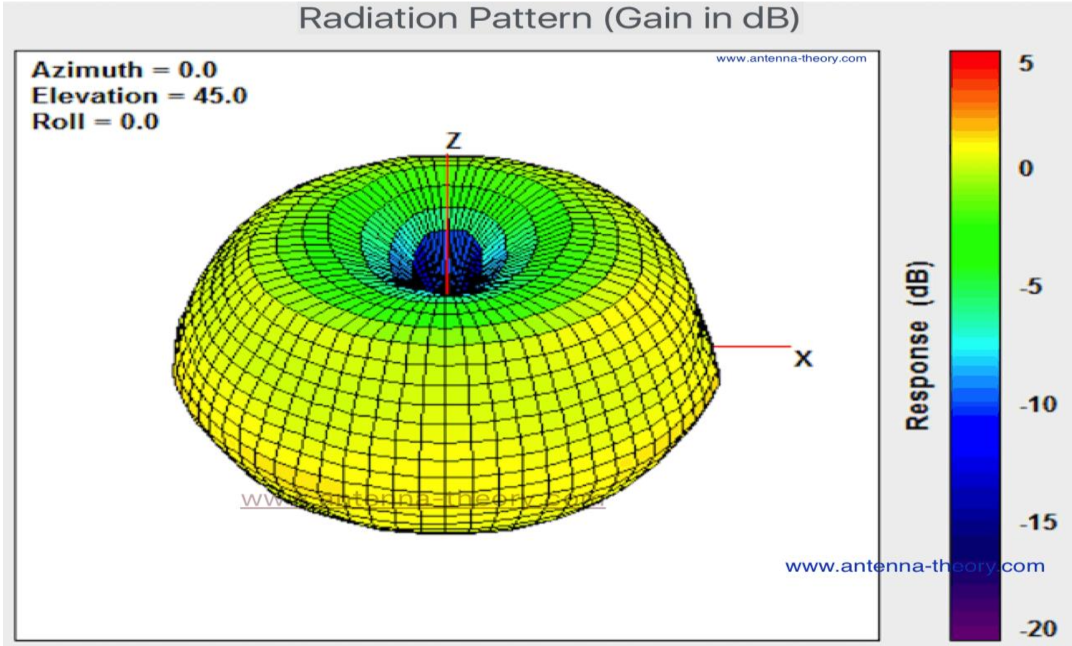


Figure 1.3 Example Gain Pattern for an Antenna (source:internet/googleimages)

1.3 Types of Antennas:

Antennas come in different shapes and sizes to suit different types of wireless applications. The characteristics of an antenna are very much determined by its shape, size and the type of material that it is made of. Some of the commonly used antennas are briefly described below.

1.3.1 Half Wave Dipole:

The length of this antenna is equal to half of its wavelength as the name itself suggests. Dipoles can be shorter or longer than half the wavelength, but a tradeoff exists in the performance and hence the half wavelength dipole is widely used.

To make it crystal clear, if the antenna is to radiate at 600 MHz, what size should the half-wavelength dipole be?`

One wavelength at 600 MHz is = c / f = 0.5 meters. Hence, the half-wavelength dipole antenna's length is 0.25 meters.

The half-wave dipole antenna is as you may expect, a simple half-wavelength wire fed at the center as shown in Figure 1:

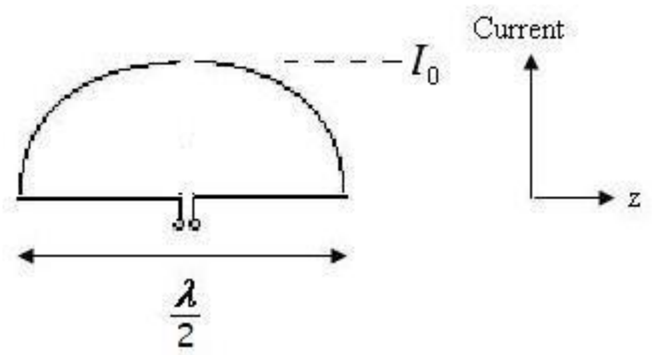


Figure 1.4 Electric Current on a half-wave dipole antenna.

The input impedance of the half-wavelength dipole antenna is given by Zin = 73 + j42.5 Ohms. The fields from the half-wave dipole antenna are given by:

$$E_\theta = \frac{jnI_o e^{-jkr}\cos(\frac{\Pi cos\theta}{2})}{2\Pi r sin\theta}$$

$$H_o = \frac{E_\theta}{\eta}$$

The directivity of a half-wave dipole antenna is 1.64 (2.15 dB). The HPBW is 78 degrees.

In viewing the impedance as a function of the dipole length in the section on dipole antennas, it can be noted that by reducing the length slightly the antenna can become resonant. If the dipole's length is reduced to 0.48λ, the input impedance of the antenna becomes Zin = 70 Ohms, with no reactive component. This is a desirable property, and hence is often done in practice. The radiation pattern remains virtually the same.

The above length is valid if the dipole is very thin. In practice, dipoles are often made with fatter or thicker material, which tends to increase the bandwidth of the antenna. When this is the case, the resonant length reduces slightly depending on the thickness of the dipole, but will often be close to

0.47λ.

1.3.2 Monopole Antenna:

The monopole antenna, shown in Figure 1.5, results from applying the image theory to the dipole. According to this theory, if a conducting plane is placed below a single element of length L / 2 carrying a current, then the combination of the element and its image acts identically to a dipole of length L except that the radiation occurs only in the space above the plane as discussed by Saunders.

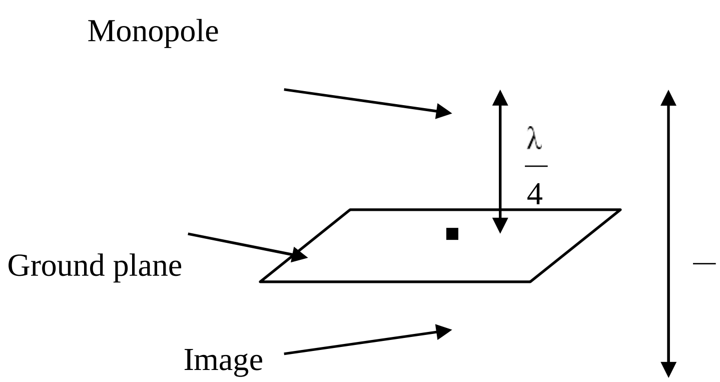


Figure 1.5: Monopole Antenna

For this type of antenna, the directivity is doubled and the radiation resistance is halved when compared to the dipole. Thus, a half wave dipole can be approximated by a quarter wave monopole. The monopole is very useful in mobile antennas where the conducting plane can be the car body or the handset case. The typical gain for the quarter wavelength monopole is 2-6dB and it has a bandwidth of about 10%. Its radiation resistance is 36.5 Ω and its directivity is 3.28 (5.16dB) . The radiation pattern for the monopole is shown below in Figure 1.6.

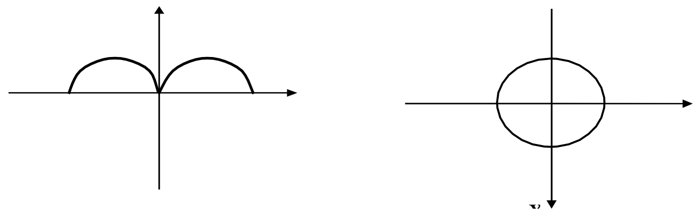


Figure 1.6 Radiation pattern for the Monopole Antenna

1.3.3 Loop Antennas:

As loop antennas get larger, they become better antennas. A loop antenna will be resonant (with purely real impedance) as the perimeter of the loop approaches one wavelength in size. Hence, a 300 MHz loop antenna should have a perimeter of 1 meter or larger; a 2.4 GHz loop antenna will only need to be about 12 centimeters in perimeter.

The one-wavelength perimeter loop antenna behaves like a folded dipole antenna, with impedance that is higher than that of a half-wavelength dipole antenna.

Robustness of Loop Antennas to the Body

Loop antennas have a very desirable property related to robustness in performance near the human body. To explain this, note that the human body tends to have a large value for permittivity and a bit of conductivity. The permittivity acts on the Electric Field and tends to tune the response of the antenna down in frequency. The conductivity of the body acts as a lossy material and absorbs energy from the antenna; this can severely degrade the antenna efficiency.

The human body affects dipole antennas particularly strongly. This is because in the near field (very close to the antenna), the Electric Fields are particularly strong. The interesting thing though, is the body isn't really magnetic. Hence, the magnetic fields don't really see the body as much, and hence aren't affected like the electric fields are. And because the loop antenna is somewhat the "dual" of the dipole as discussed earlier, the magnetic fields are strong in the near field of the loop antenna. These magnetic fields ultimately give rise to the antenna radiation, and since they are somewhat immune to the human body, loop antennas tend to be much more robust in terms of performance when they are placed near a human. As a result, antennas in hearing aids and other "wearable antennas" are often loop antennas. This property makes loop antennas extremely useful.

Loop Antenna Shapes

It turns out the loop antenna does not need to be a perfect circle (as in Figure 1), or a tight rectangle as in the folded dipole case. The main parameter of interest is the perimeter length, which should be about a wavelength. Therefore, the enclosed loop area is not as important a parameter as the perimeter length. One note: it is not a great idea to meander the loop to increase the length. This causes the current to somewhat cancel and introduces capacitance to the loop, which degrades the efficiency and bandwidth of the antenna. A loop antenna designer may try to shrink the size of the loop antenna by meandering. This is illustrated in Figure 1.7:

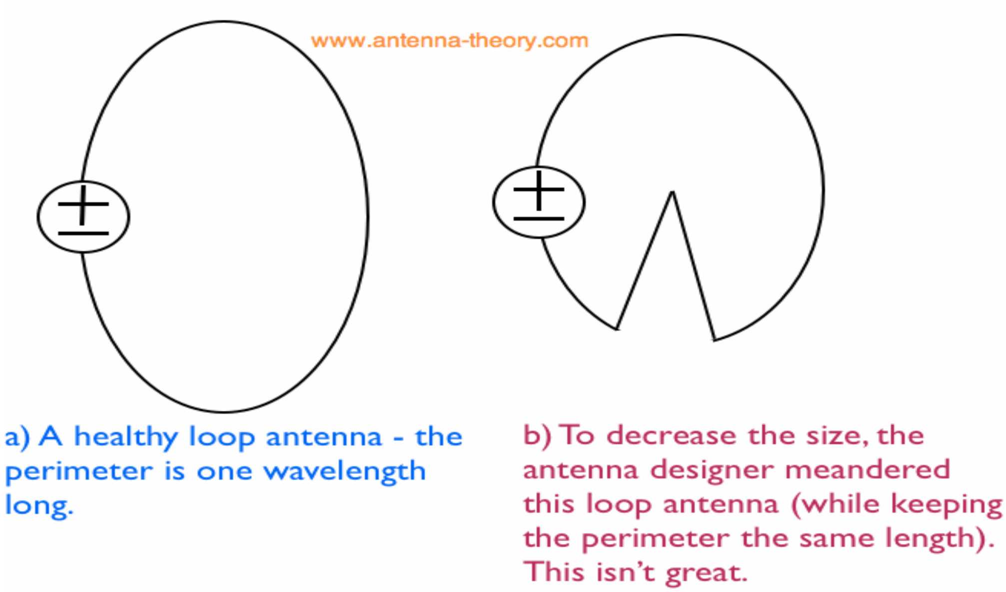


Figure 1.7 Loop Antenna Shapes - Meandering is bad.

1.3.4 Helical Antennas:

Helix antennas (also commonly called **helical antennas**) have a very distinctive shape.

The most popular helical antenna (helix) is a travelling wave antenna in the shape of a corkscrew that produces radiation along the axis of the helix antenna. These helix antennas are referred to as axial-mode helical antennas. The benefits of this helix antenna are it has a wide bandwidth, is easily constructed, has real input impedance, and can produce circularly polarized fields. The basic geometry of the helix antenna shown in Figure 1.8

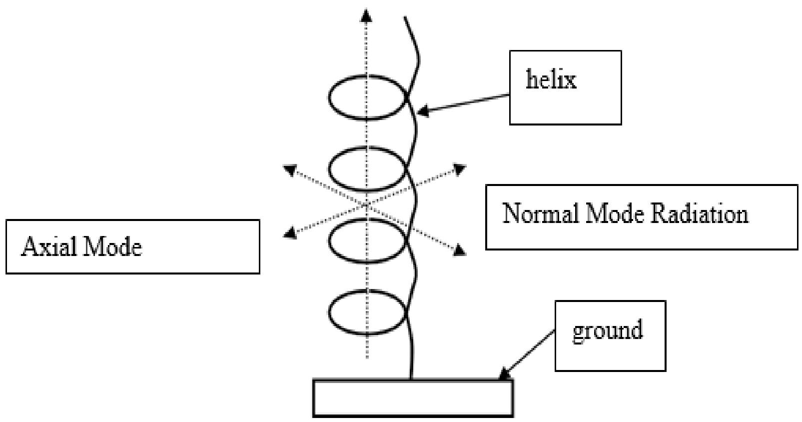


Figure 1.8 Helix Antenna

The parameters of the helix antenna are defined below.

- D - Diameter of a turn on the helix antenna.
- C - Circumference of a turn on the helix antenna (C=pi*D).
- S - Vertical separation between turns for helical antenna.
- α - pitch angle, which controls how far the helix antenna grows in the z-direction per turn, and is given by $\alpha = \tan^{-1}\left(\frac{s}{c}\right)$
- N - Number of turns on the helix antenna.

The antenna in Figure 1 is a left handed helix antenna, because if you curl your fingers on your left hand around the helix your thumb would point up (also, the waves emitted from this helix antenna are Left Hand Circularly Polarized). If the helix antenna was wound the other way, it would be a right handed helical antenna.

The radiation pattern will be maximum in the +z direction (along the helical axis in Figure 1). The design of helical antennas is primarily based on empirical results, and the fundamental equations will be presented here.

Helix antennas of at least 3 turns will have close to circular polarization in the +z direction when the circumference *C* is close to a wavelength:

$$\frac{3\lambda}{4} \le C \le \frac{4\lambda}{3}$$

Once the circumference *C* is chosen, the inequalities above roughly determine the operating bandwidth of the helix antenna. For instance, if *C*=19.68 inches (0.5 meters), then the highest frequency of operation will be given by the smallest wavelength that fits into the above equation,

or λ=0.75*C*=0.375 meters, which corresponds to a frequency of 800 MHz The lowest frequency of operation will be given by the largest wavelength that fits into the above equation, or λ =1.333*C*=0.667 meters, which corresponds to a frequency of 450 MHz. Hence, the fractional BW is 56%, which is true of axial helical antennas in general.

The helix antenna is a **travelling wave** antenna, which means the current travels along the antenna and the phase varies continuously. In addition, the input impedance is primarily real and can be approximated in Ohms by:

$$Z_{in} = 140\frac{C}{\lambda}$$

The helix antenna functions well for pitch angles (α) between 12 and 14 degrees. Typically, the pitch angle is taken as 13 degrees.

The normalized radiation pattern for the E-field components is given by:

$$E_\theta \infty E_\phi \infty \sin\left(\frac{\pi}{2N}\right)\cos\left(\frac{\sin\left(\frac{N\Omega}{2}\right)}{\sin\left(\frac{\Omega}{2}\right)}\right)$$

$$\Omega = KS(\cos(\theta) - 1) - \Pi(2 + \frac{1}{N})$$

For circular polarization, the orthogonal components of the E-field must be 90 degrees out of phase. This occurs in directions near the axis (z-axis in Figure 1) of the helix. The axial ratio for helix antennas decreases as the number of loops *N* is added, and can be approximated by:

$$AR = \frac{2N + 1}{2N}$$

The gain of the helix antenna can be approximated by:

$$G = \frac{6.2C^2NS}{\lambda^3} = \frac{6.2C^2Nf^3}{c^3}$$

In the above, *c* is the speed of light. Note that for a given helix geometry (specified in terms of *C, S, N*), the gain increases with frequency. For an *N*=10 turn helix, that has a 0.5 meter circumference as above, and a pitch angle of 13 degrees (giving *S*=0.13 meters), the gain is 8.3 (9.2 dB).

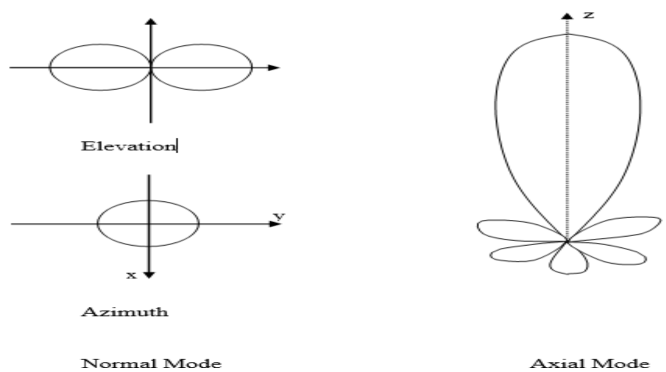


Figure 1.9 Radiation Pattern of Helix Antenna

1.3.5 Horn Antennas:

Horn antennas are used typically in the microwave region (gigahertz range) where waveguides are the standard feed method, since horn antennas essentially consist of a waveguide whose end walls are flared outwards to form a megaphone like structure.

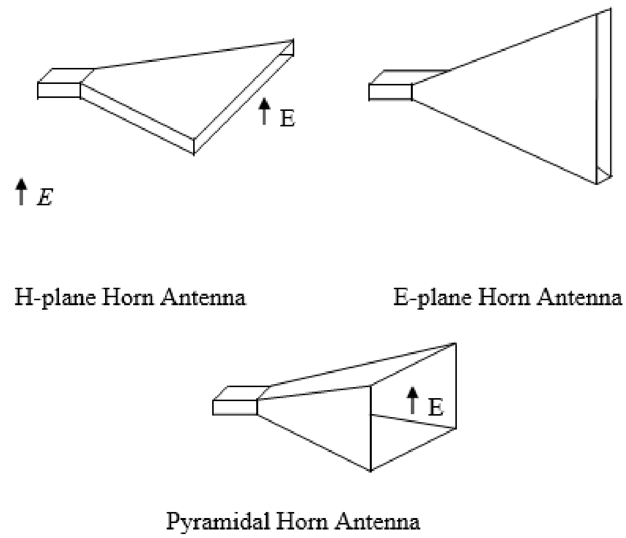


Figure 1.10 Types of Horn Antenna

Horns provide high gain, low VSWR, relatively wide bandwidth, low weight, and are easy to construct. The aperture of the horn can be rectangular, circular or elliptical. However, rectangular horns are widely used. The three basic types of horn antennas that utilize a rectangular geometry are shown in Figure. These horns are fed by a rectangular waveguide which have a broad horizontal well as shown in the figure. For dominant waveguide mode excitation, the E-plane is vertical and H-plane horizontal. If the broad wall dimension of the horn is flared with the narrow wall of the waveguide being left as it is, then it is called an H-plane sectorial horn antenna as shown in the figure. If the flaring occurs only in the E-plane dimension, it is called an E-plane sectorial horn antenna. A pyramidal horn antenna is obtained when flaring occurs along both the dimensions. The horn basically acts as a transition from the waveguide mode to the free-space mode and this transition reduces the reflected waves and emphasizes the traveling waves which lead to low VSWR and wide bandwidth. The horn is widely used as a feed element for large radio astronomy, satellite tracking, and communication dishes. In the above sections, several antennas have been discussed. Another commonly used antenna is the Microstrip patch antenna. The aim of this thesis is to design a compact microstrip patch antenna to be used in wireless communication and this antenna is explained in the next chapter.

2. Microstrip Patch Antenna

In this chapter, an introduction to the Microstrip Patch Antenna is followed by its advantages and disadvantages. Next, some feed modeling techniques are discussed. Finally, a detailed explanation of Microstrip patch antenna analysis and its theory are discussed, and also the working mechanism is explained.

2.1 Introduction

In its most basic form, a Microstrip patch antenna consists of a radiating patch on one side of a dielectric substrate which has a ground plane on the other side as shown in Figure 2.1. The patch is generally made of conducting material such as copper or gold and can take any possible shape. The radiating patch and the feed lines are usually photo etched on the dielectric substrate.

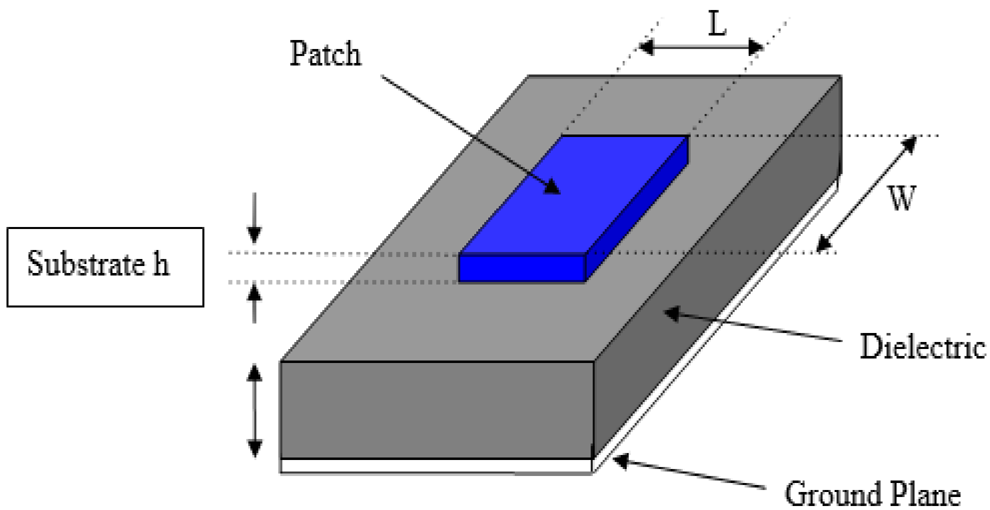


Figure 2.1 Structure of a Microstrip Patch Antenna

In order to simplify analysis and performance prediction, the patch is generally square, rectangular, circular, triangular, and elliptical or some other common shape as shown in Figure 3.2.

- For a rectangular patch, the length L of the patch is usually 0.3333
- $\lambda_o < L < 0.5\lambda_o$, where λ_o is the free-space wavelength.
- The patch is selected to be very thin such that $t << \lambda_o$(patch thickness).
- The height h of the dielectric substrate is usually $0.003\ \lambda_o \leq h \leq$0.0 $0.05\lambda_o$.
- The dielectric constant of the substrate (ε_r) is typically in the range $2.2 \leq \varepsilon_r \leq 12$.

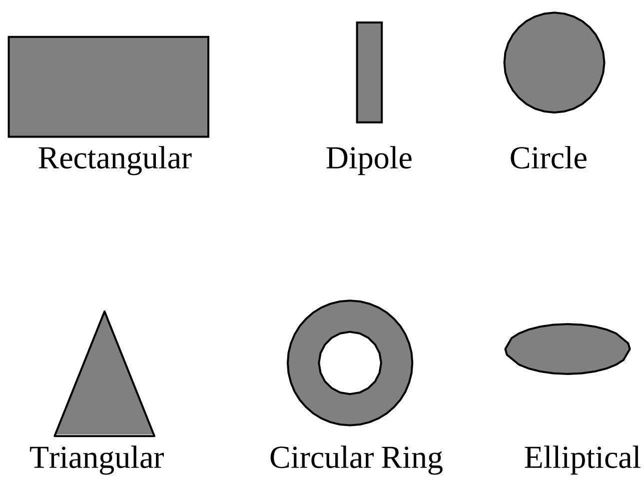


Figure 2.2 Common shapes of microstrip patch

Microstrip patch antennas radiate primarily because of the fringing fields between the patch edge and the ground plane. For good antenna performance, a thick dielectric substrate having a low dielectric constant is desirable since this provides better efficiency, larger bandwidth and better radiation. However, such a configuration leads to a larger antenna size. In order to design a compact Microstrip patch antenna, higher dielectric constants must be used which are less efficient and result in narrower bandwidth. Hence a compromise must be reached between antenna dimensions and antenna performance.

2.2 Advantages and Disadvantages

Microstrip patch antennas are increasing in popularity for use in wireless applications due to their low-profile structure. Therefore they are extremely compatible for embedded antennas in handheld wireless devices such as cellular phones, pagers etc... The telemetry and

Communication antennas on missiles need to be thin and conformal and are often Microstrip patch antennas. Another area where they have been used successfully is in Satellite communication. Some of their principal advantages discussed by and Kumar and Ray are given below:

- Light weight and low volume.
- Low profile planar configuration which can be easily made conformal to host surface.
- Low fabrication cost, hence can be manufactured in large quantities.
- Supports both, linear as well as circular polarization.
- Can be easily integrated with microwave integrated circuits (MICs).
- Capable of dual and triple frequency operations.
- Mechanically robust when mounted on rigid surfaces.

Microstrip patch antennas suffer from a number of disadvantages as compared to conventional antennas. Some of their major disadvantages discussed by and Garg et al are given below:

- Narrow bandwidth

- Low efficiency
- Low Gain
- Extraneous radiation from feeds and junctions
- Poor end fire radiator except tapered slot antennas
- Low power handling capacity.
- Surface wave excitation

Microstrip patch antennas have a very high antenna quality factor (Q). Q represents the losses associated with the antenna and a large Q leads to narrow bandwidth and low efficiency. Q can be reduced by increasing the thickness of the dielectric substrate. But as the thickness increases, an increasing fraction of the total power delivered by the source goes into a surface wave. This surface wave contribution can be counted as an unwanted power loss since it is ultimately scattered at the dielectric bends and causes degradation of the antenna characteristics. However, surface waves can be minimized by use of photonic band gap structures as discussed by Qian et al. Other problems such as lower gain and lower power handling capacity can be overcome by using an array configuration for the elements.

2.3 Applications:

After a number of limitations due to the several advantages microstrip antenna found very useful in different applications. Microstrip antenna widely used in the defense systems like missiles, aircraft, satellites and rockets. Now a day's microstrip antenna is used in commercial sectors due to its inexpensiveness and easy to manufacture benefit by advanced printed circuit technology. Due to the development and ongoing research in the area of microstrip antenna it is expected that in future after some time most of the conventional antenna will be replaced by microstrip antenna. Some of the major applications of microstrip antennas are:

- **Mobile Communication:**

Antenna used in mobile applications should be light weight, small size. Microstrip antenna possesses this entire requirement. The most of mobile applications are handheld gadgets or pocket size equipment, cellular phones, UHF pagers and the radar applications in vehicles like car, planes, and ships. Various types of designs are made and used for radar applications like marine radar, radar for surveillance and for remote sensing.

- • **Satellite Communication:**

In satellite communication antenna should have the circular polarization. One of the major benefit of microstrip antenna is that one can easily design an antenna with require polarization by using dual feed networks and different techniques. Parabolic antennas are used in satellite communication to broadcasting from satellite. A flat microstrip antenna array can be used in the place of parabolic reflector.

- • **Global Positioning System:**

Initially the satellite based GPS system are used for only in military purposes but now a day's GPS found a large application in everyone's life and now used commercially. GPS found an essential requirement in vehicles, ships and planes to track the exact location and position. 24 satellites are working in GPS encircling the earth in every 12 hours at altitude 20,200 km. GPS satellite using two frequencies in L-band to transmit the signal which is received by thousands of receivers on earth. The receiver antenna should be circularly polarized. An omnidirectional microstrip antenna has wide beam and low gain can be easily design with dual frequency operation in L-band.

- • **Direct Broadcast Satellite System**:

In many countries direct broadcasting system is used to provide the television services. A high gain (~33db) antenna should be used at the ground by the user side. A parabolic reflector antennas are generally used are bulky requires space and affected by snow and rain. An array of circularly polarized microstrip antenna can be used for direct broadcasting reception. Which are easy to install, has less affect from snow and rain and cheaper also.

- • **Antenna for Pedestrian**:

For pedestrian applications antenna should be as small as possible due to space constraints. Low profile, light weight and small structure antennas are generally used in the handheld pocket equipment. Microstrip antenna is the best candidate for that. Various types of techniques can be used to reducing the size of antenna like short circuiting the patch or using the high dielectric constant material. But it has a drawback that smaller antenna leads to poorer efficiency.

- **Radar Applications**:

Radar application such as Manpack radar, Marine radar and Secondary surveillance radar requires antenna with appropriate gain and beamwidth. An array of microstrip antenna with desired gain and desired beamwidth can be used. For some application such as sensing the ocean wave speed and direction and for determining the ground soil grades Synthetic Aperture radar method is used. Two arrays of patch antennas separated by a proper distance are used in this system.

- **Application in Medical Science**:

In medical science for treating the malignant tumors microwave energy is used to induce hyperthermia. The microwave energy radiator used for this should be adaptable to the surface being treated and should be light weight. Microstrip patch antenna is the only one that can fulfill that requirement. Annular ring and circular disk microstrip antenna are some examples.

2.4 Feed Techniques:

Microstrip patch antennas can be fed by a variety of methods. These methods can be classified into two categories- contacting and non-contacting. In the contacting method, the RF power is fed directly to the radiating patch using a connecting element such as a microstrip line. In the non-contacting scheme, electromagnetic field coupling is done to transfer power between the microstrip line and the radiating patch. The four most popular feed techniques used are the microstrip line, coaxial probe (both contacting schemes), aperture coupling and proximity coupling (both non-contacting schemes).

2.4.1 Microstrip Line Feed:

In this type of feed technique, a conducting strip is connected directly to the edge of the microstrip patch as shown in Figure 2.3. The conducting strip is smaller in width as compared to the patch and this kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure.

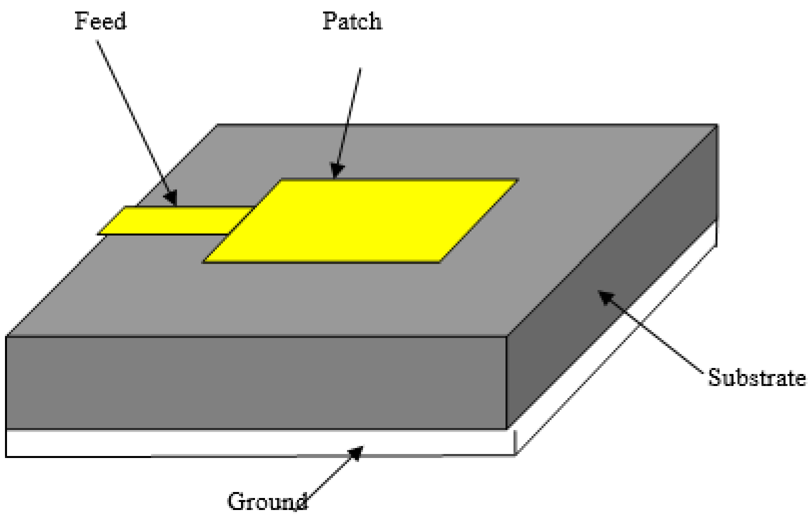


Figure 2.3 Microstrip Line Feed

The purpose of the inset cut in the patch is to match the impedance of the feed line to the patch without the need for any additional matching element. This is achieved by properly controlling the inset position. Hence this is an easy feeding scheme, since it provides ease of fabrication and simplicity in modeling as well as impedance matching. However as the thickness of the dielectric substrate being used, increases, surface waves and spurious feed radiation also increases, which hampers the bandwidth of the antenna. The feed radiation also leads to undesired cross polarized radiation.

2.4.2 Coaxial Feed:

The Coaxial feed or probe feed is a very common technique used for feeding Microstrip patch antennas. As seen from Figure 3.4, the inner conductor of the coaxial connector extends through the dielectric and is soldered to the radiating patch, while the outer conductor is connected to the ground plane.

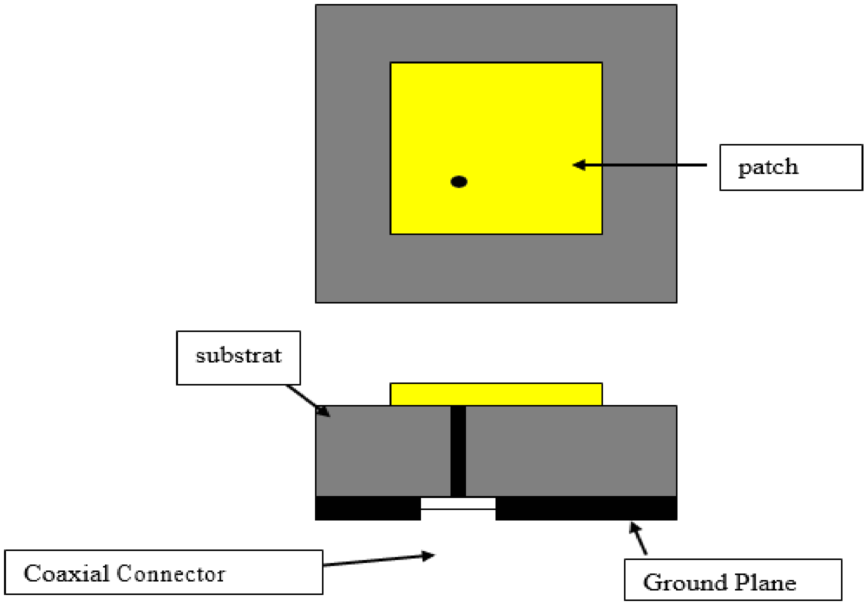


Figure 2.4 Probe fed Rectangular Microstrip Patch Antenna

The main advantage of this type of feeding scheme is that the feed can be placed at any desired location inside the patch in order to match with its input impedance. This feed method is easy to fabricate and has low spurious radiation. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled in the substrate and the connector protrudes outside the ground plane, thus not making it completely planar for thick substrates ($h > 0.02\lambda_o$). Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. It is seen above that for a thick dielectric substrate, which provides broad bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages. The non-contacting feed techniques which have been discussed below, solve these problems.

2.4.3 Aperture Coupled Feed:

In this type of feed technique, the radiating patch and the microstrip feed line are separated by the ground plane as shown in Figure 2.5. Coupling between the patch and the feed line is made through a slot or an aperture in the ground plane.

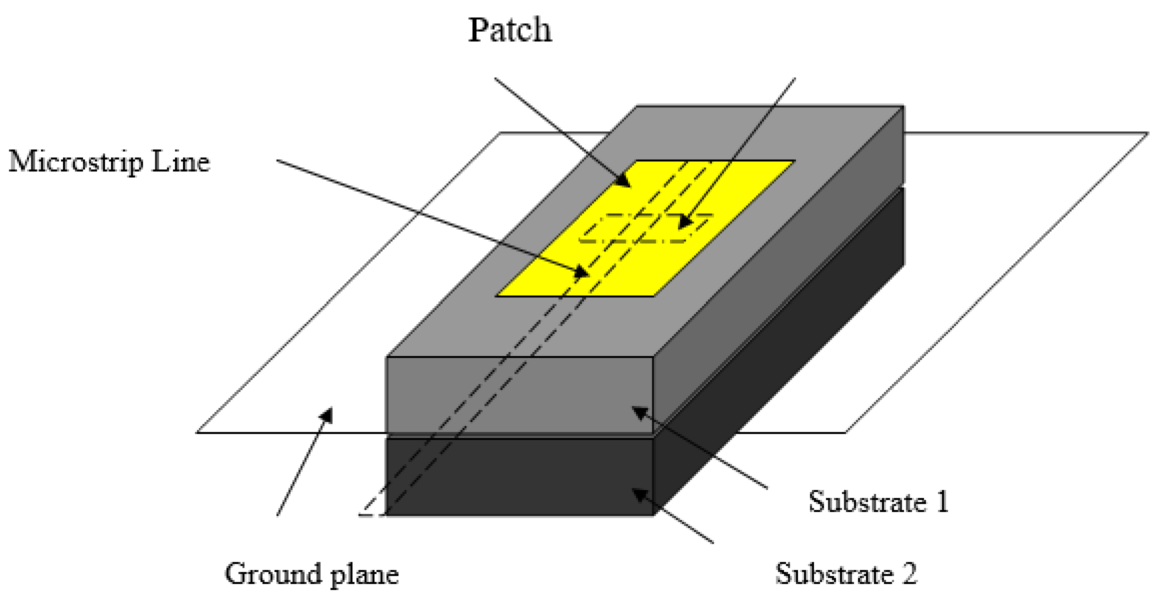


Figure 2.5 Aperture-coupled feed

The coupling aperture is usually centered under the patch, leading to lower cross- polarization due to symmetry of the configuration. The amount of coupling from the feed line to the patch is determined by the shape, size and location of the aperture. Since the ground plane separates the patch and the feed line, spurious radiation is minimized. Generally, a high dielectric material is used for the bottom substrate and a thick, low dielectric constant material is used for the top substrate to optimize radiation from the patch. The major disadvantage of this feed technique is that it is difficult to fabricate due to multiple layers, which also increases the antenna thickness. This feeding scheme also provides narrow bandwidth.

2.4.4 Proximity Coupled Feed:

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 3.6, 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. The main advantage of this feed technique is that it eliminates spurious feed radiation and provides very high bandwidth (as high as 13%) , due to overall increase in the thickness of the microstrip patch antenna. This scheme also provides choices between two different dielectric media, one for the patch and one for the feed line to optimize the individual performances.

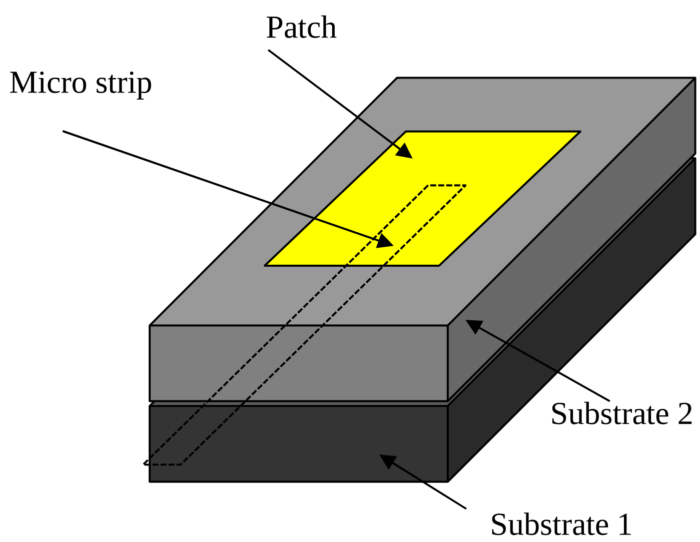


Figure 2.6 Proximity-coupled Feed

Matching can be achieved by controlling the length of the feed line and the width-to-line ratio of the patch. The major disadvantage of this feed scheme is that it is difficult to fabricate because of the two dielectric layers which need proper alignment. Also, there is an increase in the overall thickness of the antenna. Table 2.1 below summarizes the characteristics of the different feed techniques.

Table 2.1 comparing the different feed techniques

Characteristics	Microstrip Line Feed	Coaxial Feed	Aperture coupled Feed	Proximity coupled Feed
Spurious feed radiation	More	More	Less	Minimum
Reliability	Better	Poor due to soldering	Good	Good
Ease of fabrication	Easy	Soldering and drilling needed	Alignment Required	Alignment Required
Impedance Matching	Easy	Easy	Easy	Easy
Bandwidth (achieved with impedance matching)	2-5%	2-5%	2-5%	13%

3. Ansys HFSS

3.1 3D Electromagnetic Field Simulator for RF and Wireless Design

Ansys HFSS is 3D electromagnetic (EM) simulation software for designing and simulating high-frequency electronic products such as antennas, antenna arrays, and RF or microwave components, high-speed interconnects filters, connectors, IC packages and printed circuit boards. Engineers worldwide use Ansys HFSS to design high-frequency, high-speed electronics found in communications systems, radar systems, advanced driver assistance systems (ADAS), satellites, internet-of-things (IoT) products and other high-speed RF and digital devices.

HFSS (High Frequency Structure Simulator) employs versatile solvers and an intuitive GUI to give you unparalleled performance plus deep insight into all your 3D EM problems. Through integration with Ansys thermal, structural and fluid dynamics tools, HFSS provides a powerful and complete multiphysics analysis of electronic products, ensuring their thermal and structural reliability. HFSS is synonymous with gold standard accuracy and reliability for tackling 3D EM challenges by virtue of its automatic adaptive meshing technique and sophisticated solvers, which can be accelerated through high performance computing (HPC) technology.

The Ansys HFSS simulation suite consists of a comprehensive set of solvers to address diverse electromagnetic problems ranging in detail and scale from passive IC components to extremely large-scale EM analyses such as automotive radar scenes for ADAS systems. Its reliable automatic adaptive mesh refinement lets you focus on the design instead of spending time determining and creating the best mesh. This automation and guaranteed accuracy differentiates HFSS from all other EM simulators, which require manual user control and multiple solutions to ensure that the generated mesh is suitable and accurate. With Ansys HFSS, the physics defines the mesh rather than the mesh defining the physics.

Ansys HFSS is the premier EM tool for R&D and virtual design prototyping. It reduces design cycle time and boosts your product’s reliability and performance. Beat the competition and capture your market with Ansys HFSS.

ANSYS simulation technology enables you to predict with confidence that your products will thrive in the real world. Customers trust our software to help ensure the integrity of their products and drive business success through innovation.

Industry Standard Full Wave, Electromagnetic Field Simulation HFSS sets the gold-standard for accuracy, advanced solver and high-performance computing technology, making it the ‘go to’ tool for engineers designing high-frequency and high-speed electronics found in communication systems, radar systems, satellites, smart phones and tablet devices.

Rigorous Validation Sign-off quality high-frequency EM results that allow customers to simulate and go straight to manufacturing. With HFSS, engineers can extract parasitic parameters (S, Y, Z), visualize 3D electromagnetic fields (near- and far-field) and generate Full-Wave SPICE™ models that link to circuit simulations.

Easy to Use, Versatile and Fast Features such as automatic adaptive meshing, versatile design entry and advanced high-performance computing technology put analyst-quality solvers in the hands of the designer.

3.2 Ansys HFSS for Antenna Design

This application brief describes antenna design using Ansys HFSS, the industry leading 3D electromagnetic (EM) simulation tool for high frequency and high speed electronic components. It highlights several antenna-related applications with emphasis on antennas on or around other structures.

With multiple simulation technologies and powerful automated adaptive mesh refinement providing gold standard accuracy, HFSS can help antenna designers who are constantly challenged with implementing designs across more and more frequency bands inside a smaller and smaller footprint.

With these additional technical challenges along with the ever shrinking time to market, simulation with HFSS is a must-have in the antenna design and integration process.

3.3 DESIGN EQUATIONS FOR MICROSTRIP ANTENNA ARE

The width of the patch is calculated using the following equation:

$$W = \frac{c}{2f_r\sqrt{\frac{\epsilon_r+1}{2}}}$$

Where, W = Width of the patch C= Speed of light

εr= value of the dielectric substrate. The value of the effective dielectric constant (ϵ_{reff}) is calculated using the following equation:

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2}$$

The actual increase in length (ΔL) of the patch is to be calculated using the following equation:

$$\Delta L = 0.412h\frac{(\epsilon_{reff} + 0.33)(\frac{W}{h} + 0.264)}{(\epsilon_{reff} - 0.258)(\frac{W}{h} + 0.8)}$$

Where 'h'=height of the substrate.

The length (L) of the patch is now to be calculated using the below mentioned equation:

$$L_{eff} = \frac{c}{2f\sqrt{\epsilon_{reff}}}$$

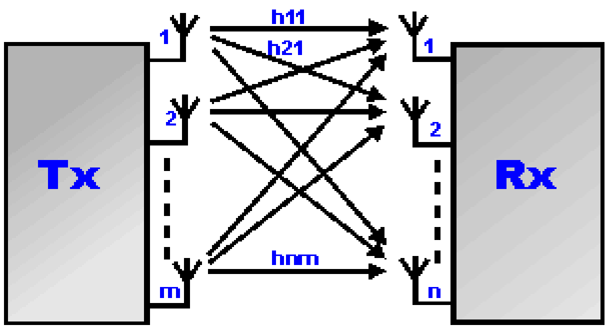
$L=L_{eff}-2\Delta L$

4 A Compact Four-Element MIMO Antenna for WLAN/WiMAX/Satellite Applications (base paper work)

4.1 INTRODUCTION

MIMO (multiple input multiple output):

This wireless technology can immensely improve data rate, capacity, and link safety of wireless systems by multipath data communication. These systems conduct the power through multiple antennas at the transmitter and receiver in that enhancing the channel capacity without the use of supplementary bandwidth or power. These systems are at present engaged in 4G user material and are a rising technology for service in the eventual 5G mobile terminals.



MIMO – Technology

The rapid progress in wireless communication requires a single RF device such as antenna to operate in a multi-band scheme. To meet these requirements, compact high-performance multiband planar antennas with good radiation characteristics are needed. At the same time, a great interest in coplanar waveguide (CPW) has been presented because of their many features, such as simplest structure of a single metallic layer and easy integration with active devices or MMICs .

4.2 ANTENNA DESIGN

This section contains the evolution of the antenna design from a single wideband monopole antenna to a four-element MIMO antenna with improved isolation characteristics using the single element antenna as its fundamental element. The various steps involving antenna design are given as follows:

SINGLE-ELEMENT ANTENNA

A simple CPW-fed wideband antenna operating from 4.30 to 6.45 GHz is designed as shown in Figure 3.1. The antenna mainly covers the C band, which includes INSAT, WLAN, WiMAX, and Wi-Fi applications. The return loss (in dB) is well below −10 dB over the entire range of operation as shown in Figure 3.2, and minimum return loss is observed at 5.3 GHz, which is about −34 dB. Using this design, an approach towards MIMO structures are studied by placing two identical elements and four identical elements.

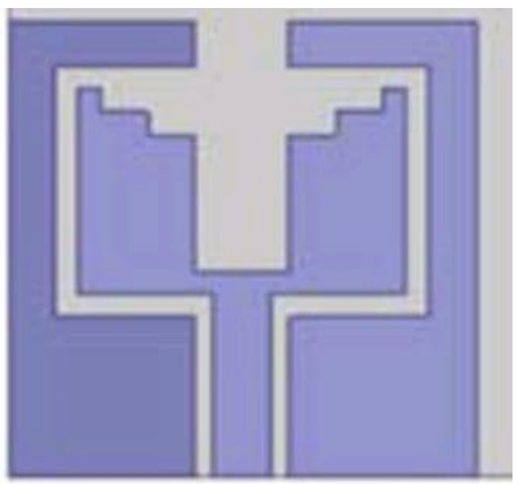


Figure 3.1 Single element antenna design

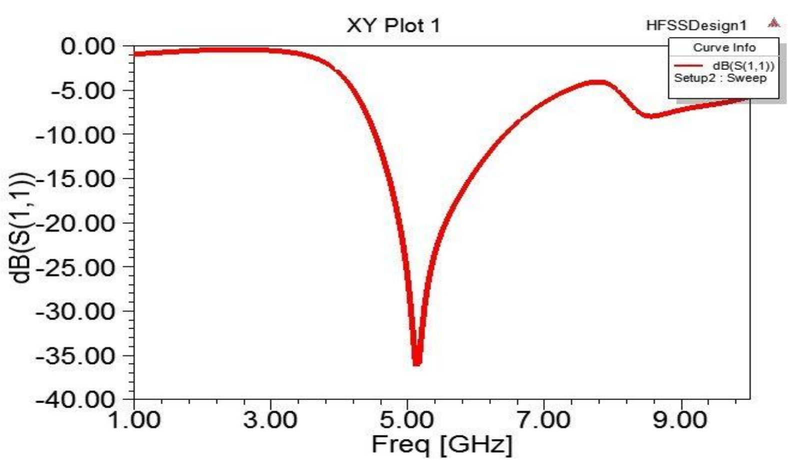


Figure 3.2 S11 characteristics of single element antenna

FOUR-ELEMENT MIMO ANTENNA

The four-element antenna is designed using four single-element antennas. This structure is built on a flexible FR4 epoxy dielectric material with a dielectric constant of 4.4. The height of the flexible FR4 epoxy dielectric material is taken to be 1.6 mm. To utilize this structure for C-Band applications to cover the frequency range of 4.3 to 6.5 GHz. All the parameters related with the antenna is optimized to get the desired results. The spacing between the symmetric orthogonal arrangements of the four antenna elements is considered as λ / 3. This arrangement is made on a substrate of 50 × 50 mm2 . The final configuration of the four-element antenna is presented in Figure 3.3.

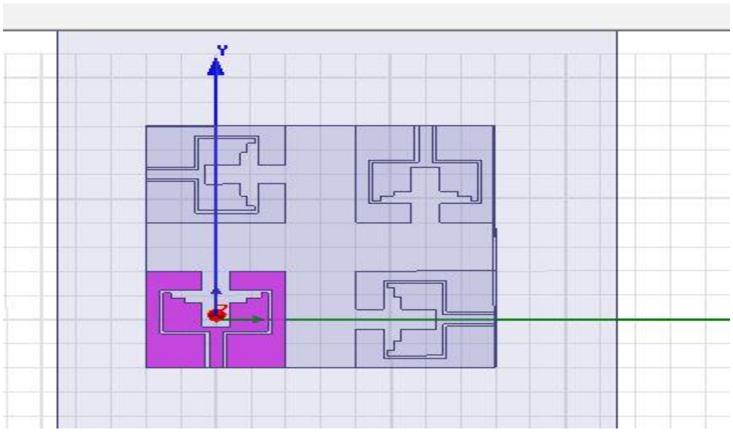


Figure 3.3 Four element antenna design

Figure 3.4 shows the return loss (in dB) of the four antennas. It can be visually perceived that all the four antennas have bandwidth ranging from 4.3 to 6.5 GHz, thereby making each element a wideband antenna.

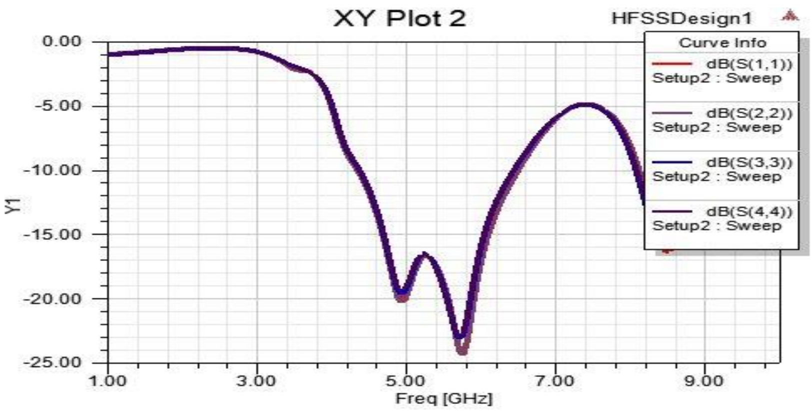


Figure 3.4 The reflection coefficients of four element MIMO antenna

4.3RESULTS AND DISCUSSION

The proposed MIMO antenna configuration has significantly improved isolation characteristics as presented in Figure 3.6. It is visible from Figure 11 that the isolation characteristics are significantly lower than −20 dB for the operational bandwidth of the antenna. These characteristics are achieved without sacrificing too much in terms of the overall footprint of the antenna.

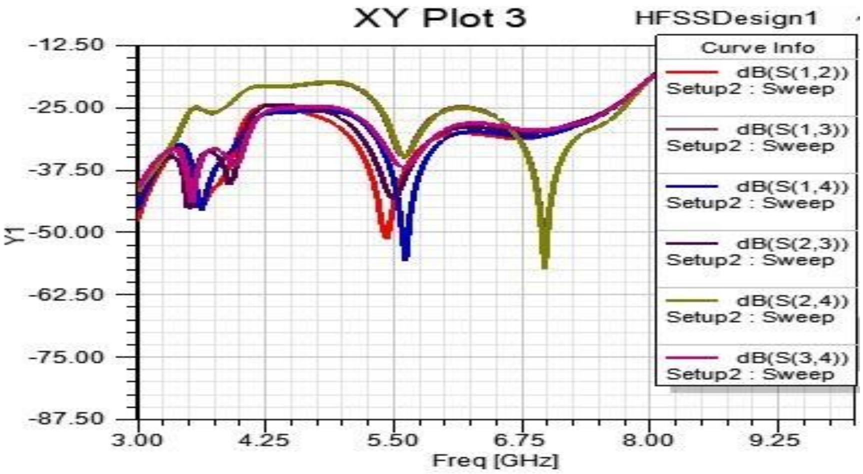


Figure 3.5 The isolation characteristics of the proposed MIMO antenna

The Mean Effective Gain (MEG) is calculated among individual 2 antenna elements is shown in Figure 3.6. The MEG1, MEG2 define the mean effective gain calculation among 1 and 2 antenna elements. Similarly, MEG3 and MEG4 for 1 and 3 elements and finally MEG5 and MEG6 for 1 and 4 antenna elements. The difference between these mean effective gains should be less than 3 dB as per the standards. From the MEG plot it is evident that the values a re well within the standards.

The TARC versus frequency plot is shown in Figure 3.7. The standard limit should be less than -10 dB and the plot shows that the entire operating range of frequencies of the MI MO antenna is less than -10 dB in the operating bandwidth region. The TARC value is as low as close to -20dB in-between frequency ranges from 5 to 6 GHz.

Figure 3.8 deals with the ECC versus frequency plot. From the plot, it is conformed that the value of the ECC is less than 0.05 for the entire frequency range of 4.5 to 6.35 GHz. Generally, the ECC limit is 0.5 it is considered to be satisfactory and if the ECC value is less than 0.3, then it is good for the MIMO applications

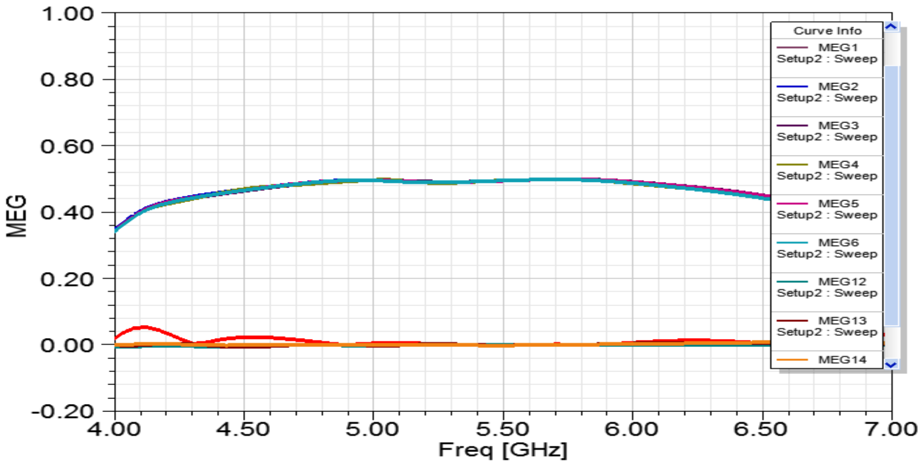


Figure 3.6 MEG versus frequency plot

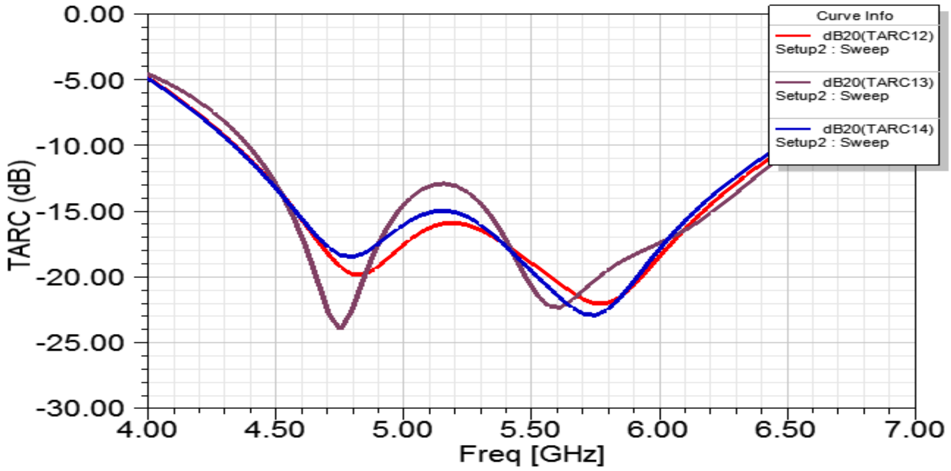


Figure 3.7 TARC versus frequency plot

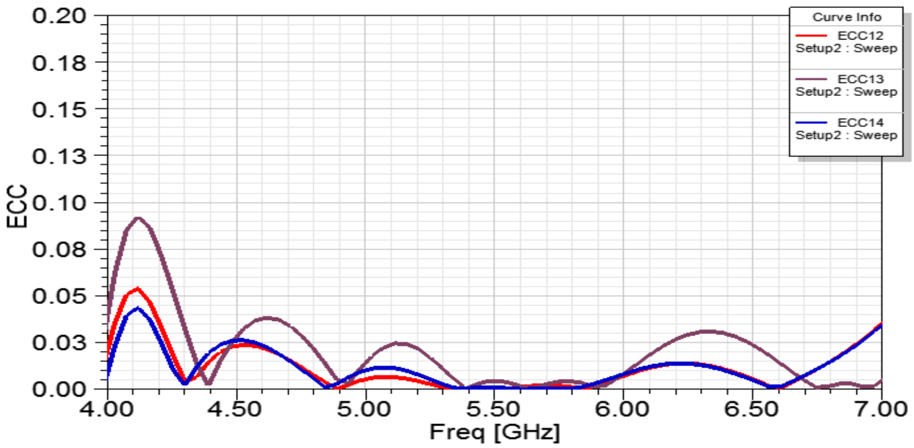
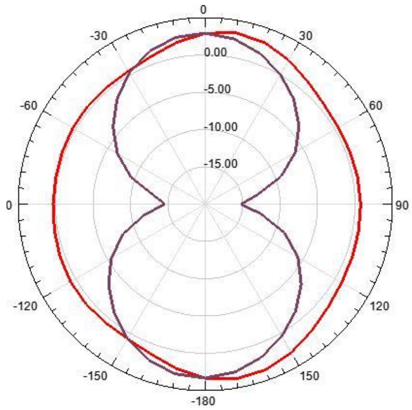


Figure 3.8 ECC versus frequency plot

The radiation pattern of the proposed MIMO configuration is presented in Figure 3.9, 3.10 and 3.11. It is visible from the plot that the antenna is displaying a copolarized omnidirectional pattern at φ = 0o (H-plane) and a bidirectional pattern at φ = 90o (E-plane). The cross-polarization at both the place (E and H plane) is well below −15 dB as measured at 4.5, 5.4, and 6GHz



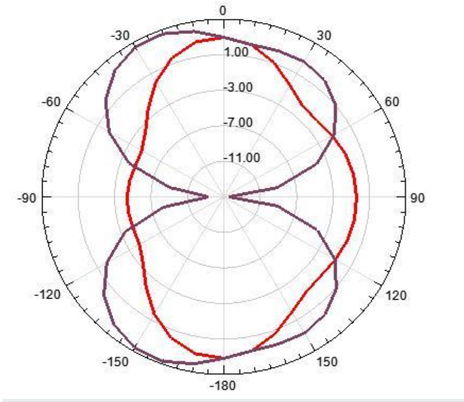


Figure 3.9

Measured radiation pattern at 4.5GHz

Figure 3.10

Measured radiation pattern at 5.4GHz

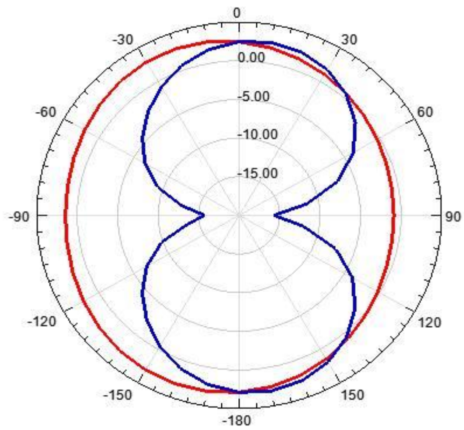


Figure 3.11

Measured radiation pattern at 6GHz

The analysis of four-element MIMO antenna is presented in this paper. First, a two-element wideband antenna with operating range of 4.3 to 6.65 GHz is designed. In order to include the MIMO technology, we add two more single-element wideband antennas in such way that they result in minimum insertion loss. The four-element MIMO antenna has operating range of 4.35 6.5 GHz and average peak gain of 5.5 dBi. The proposed configuration is fabricated to, and its S-parameters are validated. So, this makes the antenna suitable for WLAN and Wi-Fi applications.

5. A CPW Feed Orthogonal Quad-Port Conformal MIMO Antenna for Satellite Applications (extension paper)

ABSTRACT

In this proposed paper, a four-element C band monopole conformal MIMO antenna is designed. This antenna configuration has four similar CPW-fed elements of size 10x15 mm. It is a conformal antenna supported with malleable FR4 epoxy dielectric material. It is having the relative permittivity of 4.4 and a loss tangent of 0.02. It has achieved the impedance bandwidth in concern with the -10dB reference line in the frequency ranges of 4.5 GHz to 7.5 GHz which covers C band applications. The good isolation characteristics are achieved which are less than -20 dB with the help of orthogonal arrangement of the four mono-pole antennas. For the excellent working of MIMO some of the characteristics like Mean Effective Gain, Total Active Reflection, Envelope Correlation Coefficient are considered as important and they are investigated and found that they are following the standards as MEG<3dB and ECC<0.5. The entire work is done with the help of ANSYS High-Frequency Structure Simulator (HFSS) Software.

5.1 Introduction

Nowadays in modern wireless systems, the wide band and ultra-wideband technology plays a crucial role since it meets the requirement of high data rate in a limited range. [1]. Wideband and UWB techniques gained required attention due to advantages such as wide bandwidth, high data rate, and less expensive [2].

Multiple input multiple output systems are becoming more prominent these days when considering the requirement for high data rates in wireless and mobile communication systems [3]. Planar antennas in the recent past are being widely used to address wideband technology which form the part of large number of wireless applications. [4].

The next generation of high-speed transmission over wireless communications will make full use of the merits of reduced multipath fading and increased channel capacity inherent in MIMO RF architectures [5].There are number of techniques used to minimize the size of antenna, such as implementing a shorting pin in a micro strip patch, using short circuit and cutting slots in radiating patch [6].

In [7] A 2 x 2 meta-material compact -MIMO antenna is designed. The proposed antenna was suitable for WLAN applications. The MIMO structure is obtained by placing side by side a couple of meta-material antennas which were built based on the changed composite right/left-handed (CRLH) model. In [8] a measured bandwidth of (2.20–2.51 GHz) is obtained to cover the LTE 2300/ISM2.45 GHz operation and isolation of above 16 dB is achieved. In [9] to improve impedance matching and multi band operation, a pair of inverted L-shaped mono-poles are printed in the circular slot of the ground plane.

The single element design is duplicated along the diameter of the circular slot of the ground plane. A strip is utilized between the two radiators in order to decrease the mutual coupling effect and improve the impedance matching at operating bandwidths. In [10] A MIMO microstrip antenna is proposed for frequency ranges from 800-2600 MHz. The MIMO microstrip antenna elements had an antenna gain of 2 to 5 dB and mutual coupling is less than -20 dB.

In this research paper, an improved T-shaped slot conformal MIMO antenna is proposed to cover satellite applications of C band range. Important MIMO parameters such as TARC, MEG and ECC are computed and other important antenna parameters such reflection coefficient, isolation and gain are studied.

5.2Antenna design

A modified micro-strip patch antenna structure is designed a s shown in Figure 4.1. The structure of the antenna is constructed in a step by step modification process with overall antenna dimensions of 20 x 20 mm and patch dimensions to be 15 x 10 mm (width x length). The antenna is designed to work at 6 to 7 GHz. Dimensions were calculated using the formulas mentioned.

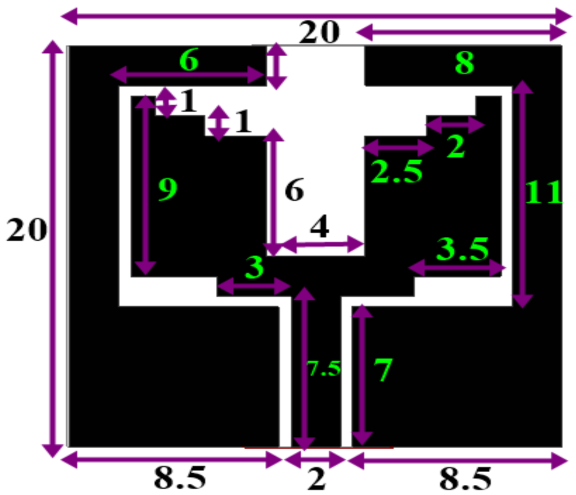


Figure 4.1 Single element antenna design

After this design, the antenna is duplicated and made as a quad element MIMO antenna shown in figure 4.2. These antenna elements are designed to obtain maximum isolation. This structure is built on a flexible FR4 epoxy dielectric material with a dielectric constant of 4.4. The height of the flexible FR4 epoxy dielectric material is taken to be 1.6 mm. To utilize this structure for C-Band applications to cover the frequency range of 4 to 7 GHz. All the parameters related with the antenna is optimized to get the desired results. The spacing between the symmetric orthogonal arrangements of the four antenna elements is considered as λ / 3.

The designing and the analysis of the proposed structure are done with the help of ANSYS HFSS software using the design equations as mentioned.

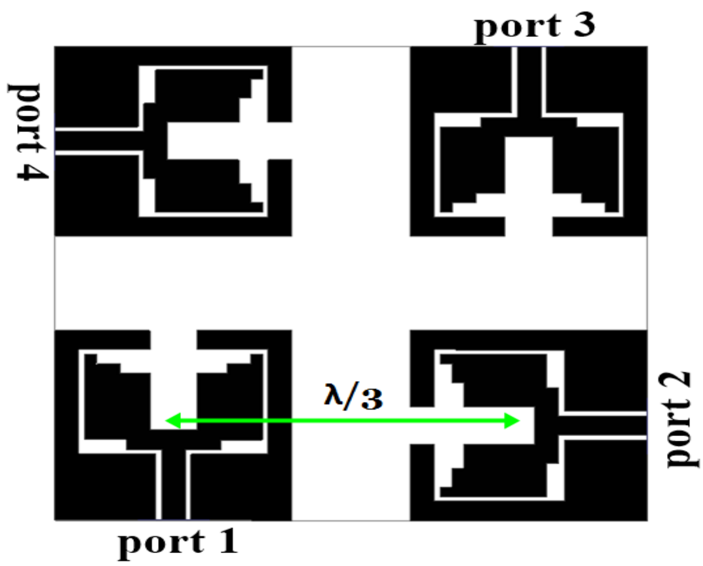
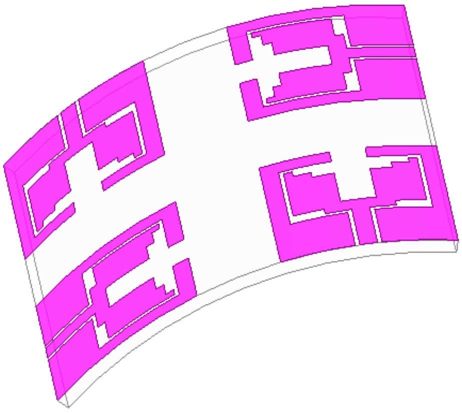


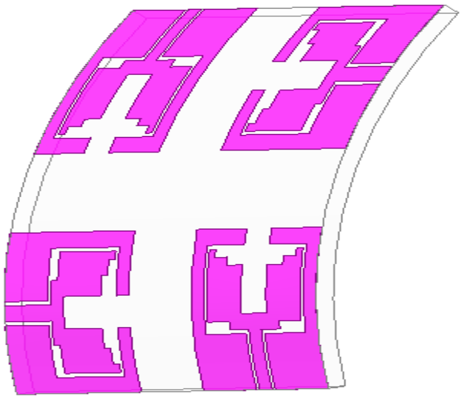
Figure 4.2 Four element antenna design

The MIMO antenna proposed is converted to conformal shape for accessibility to be mounted on the body surface for different satellite applications. The merits of the conformal arrangement is that it helps to design any entity without modifying its physical. Figure 4.3 shows conformal arrangement of proposed MIMO antenna with the flexible FR4 epoxy substrate.

Conformal geometry of proposed work



1) $\mathbf{20^0}$**bend**



2) $\mathbf{25^0}$**bend**

Figure 4.3 Conformal arrangement of the proposed MIMO antenna with 1) $\mathbf{20^0}$ **bend 2)** $\mathbf{25^0}$ **bend angles.**

6. Results and Discussions

The return loss (in dB) is well below −10 dB over the entire range of operation as shown in Figure 5.1, and minimum return loss is observed at 6.3 GHz, which is about −34 dB. Using this design, an approach towards MIMO structures are studied by placing two identical elements and four identical elements. Figure 5.2 shows the reflection coefficient for all the four MIMO antenna elements. It is evident from the figure that, all the 4 antenna elements impedance bandwidth pertaining to -10 dB is well achieved from 4.5 GHz to 7.5 GHz.

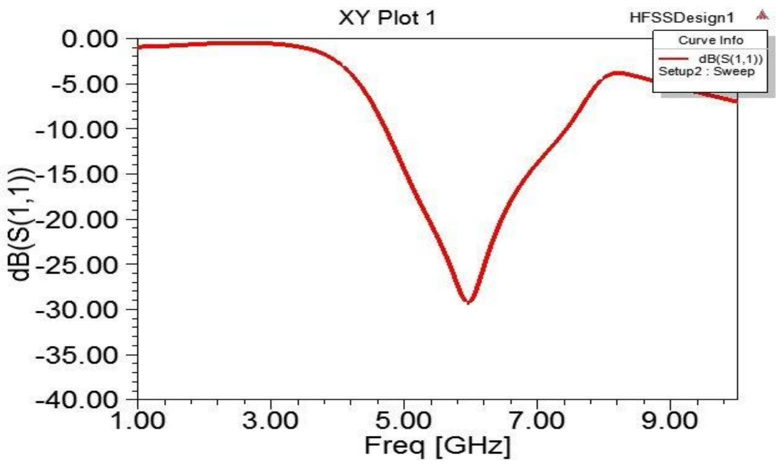


Figure 5.1 S11 characteristics of single element antenna

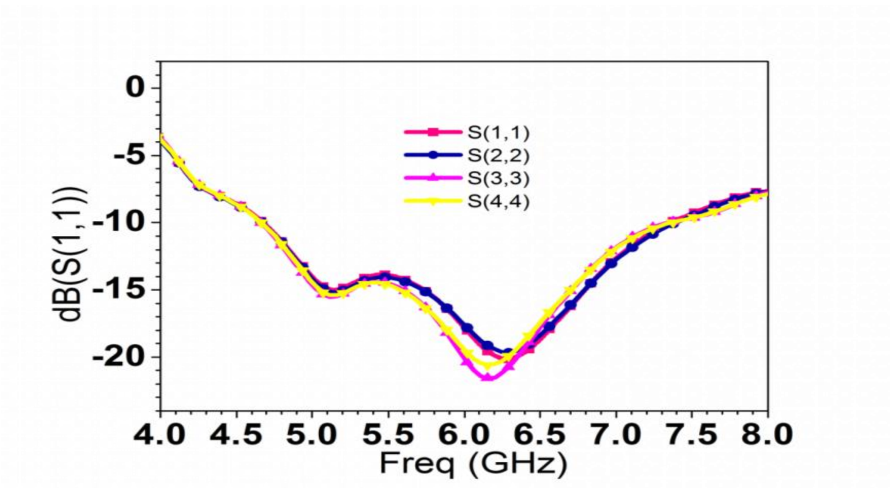


Figure 5.2 The reflection coefficients of four element MIMO antenna

Figure 5.3 give necessary information regarding the mutual coupling from port 1 and all other ports also. It is to be particularly noted that the isolation or transmission coefficients from Figure 5.3 is less than -20 dB for the entire working impedance bandwidth of 4.5 GHz to 7.5 GHz.

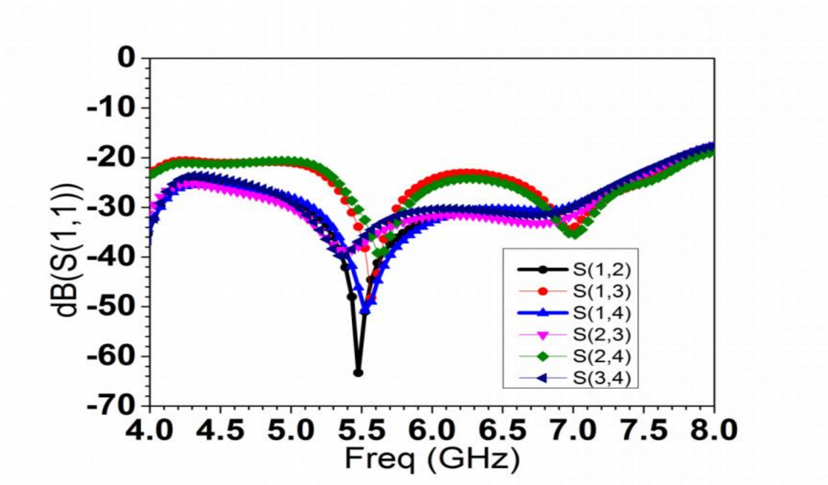


Figure 5.3 The isolation characteristics of the proposed MIMO antenna

Figure 5.4 shows the Mean Effective Gain (MEG) is calculated among individual 2 antenna elements. The MEG1, MEG2 define the mean effective gain calculation among 1 and 2 antenna elements. Similarly, MEG3 and MEG4 for 1 and 3 elements and finally MEG5 and MEG6 for 1 and 4 antenna elements. The difference between these mean effective gains should be less than 3 dB as per the standards. From the MEG plot it is evident that the values a re well within the standards.

The TARC versus frequency plot is shown in Figure 5.5. The standard limit should be less than -10 dB and the plot shows that the entire operating range of frequencies of the MI MO antenna is less than -10 dB in the operating bandwidth region. The TARC value is as low as close to -20dB in-between frequency ranges from 6 to 7 GHz.

Figure 5.6 deals with the ECC versus frequency plot. From the plot, it is conformed that the value of the ECC is less than 0.05 for the entire frequency range of 4.5 to 7.5 GHz. Generally, the ECC limit is 0.5 it is considered to be satisfactory and if the ECC value is less than 0.3, then it is good for the MIMO applications.

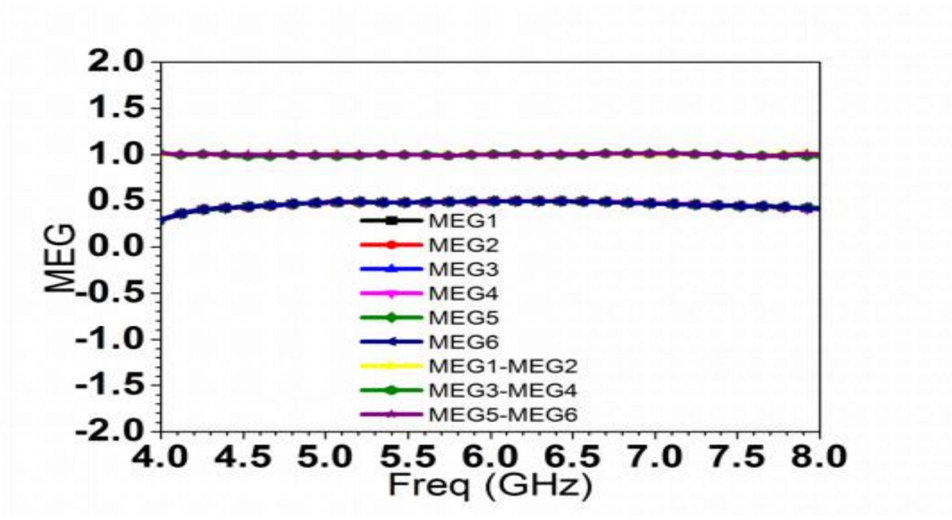


Figure 5.4 MEG vs Frequency plot

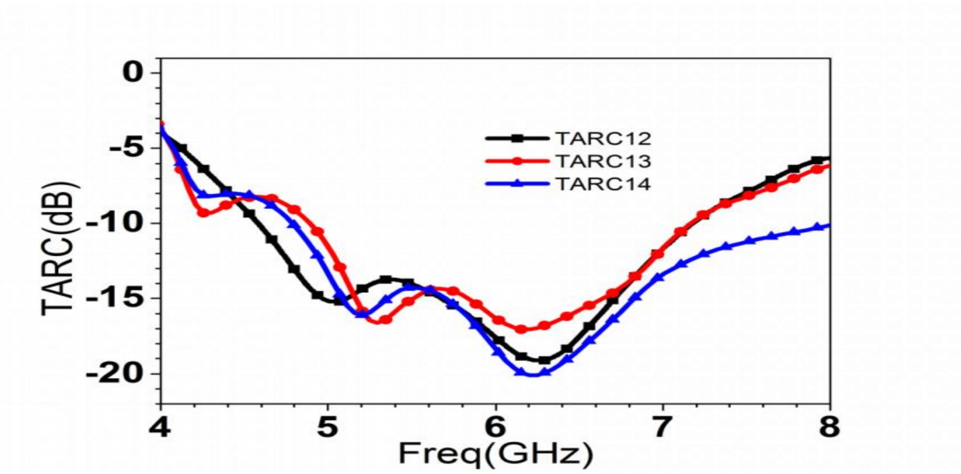


Figure 5.5 TARC vs Frequency plot

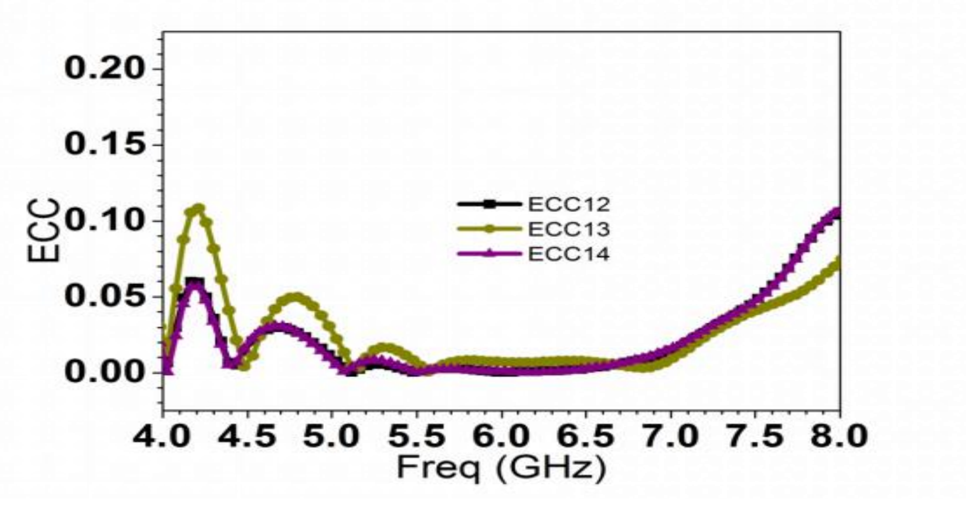


Figure 5.6 ECC vs Frequency plot

Figure 5.7 shows the radiation pattern of the proposed MIMO configuration. It is visible from the plot that the antenna is displaying a copolarized omnidirectional pattern at φ = 0o (H-plane) and a bidirectional pattern at φ = 90o (E-plane). The cross-polarization at both the place (E and H plane) is well below −15 dB as measured at 4.8, 5.7, 6.5 and 7 GHz.

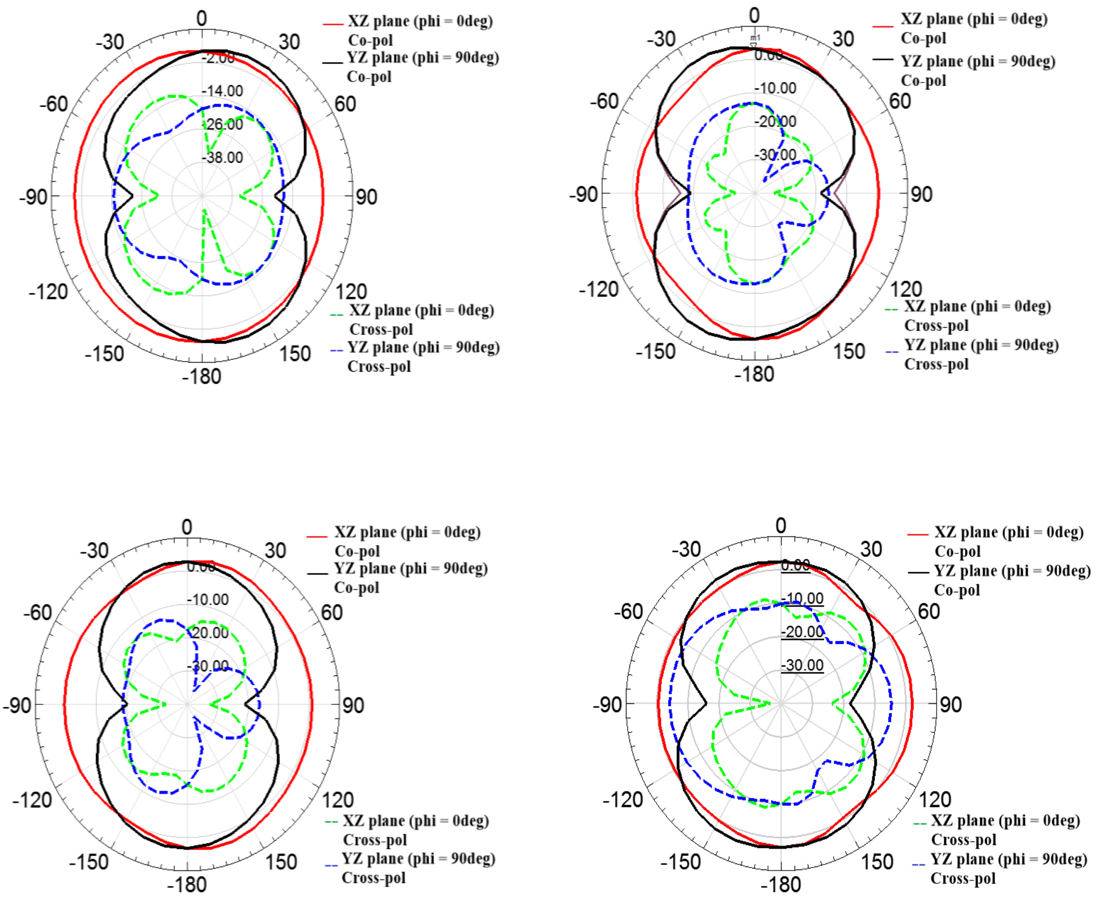


Figure 5.7 simulated radiation Pattern for the proposed Configuration at 4.8, 5.7, 6.5 and 7 GHz

Figures 5.8 and 5.9 gives the related simulation results for the conformal arrangement of the antenna. Two bend angles of 20^0 and 25^0 are investigated. Isolation characteristics are studied. The conformal MIMO antennas are analysed to get good isolation properties being less than -15dB within whole region discussed operating bandwidth region of C band range. Thus, on an overall note conformal quad-port MIMO antenna arrangement also showed lower mutual coupling effect and better isolation.

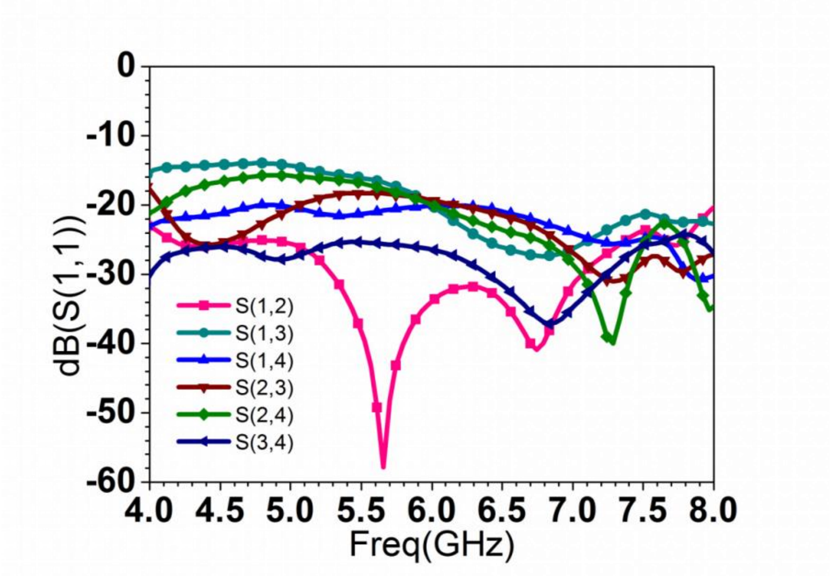


Figure 5.8 S-Parameters plot depicting the isolation or transmission coefficients information with 20^0 bend angle

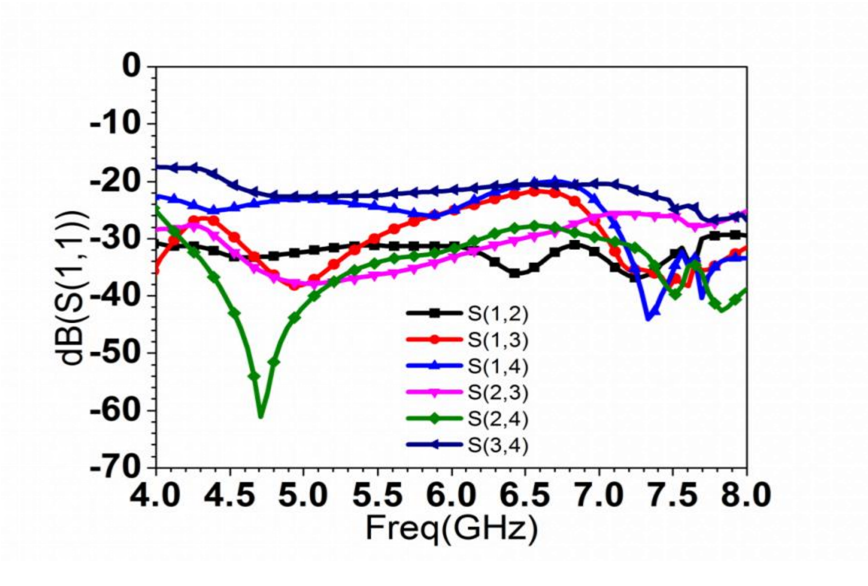


Figure 5.9 S-parameters plot depicting the isolation or transmission coefficients information with 25^0 bend angle

7. Conclusion

A quad-port wide band conformal MIMO antenna with modified micro-strip patch antenna elements in orthogonal arrangement is employed in this model. The MIMO antenna is achieved wide band range of 4.5 to 7.56GHz with 3.06 GHz impedance bandwidth. MIMO performance in terms of isolation, Envelope Correlation Coefficient (ECC), Mean Effective Gain (MEG) and, Total Active Reflection Coefficient (TARC) is also analyzed which resulted in isolation less than -15 dB, ECC < 0.5, MEG < 3dB , and TARC < -10 dB for the required operating frequency range. The Co-polarization and Cross-polarization for the proposed antenna are good with difference of -15dB. The proposed antenna also exhibited a satisfactory gain of 2 to 3.5 dB in the mentioned operating range. The MIMO antenna is extended to its conformal variant with 20 and 25 bend angles to study the isolation parameters which were found to be in good agreement pertaining to less than -10dB. Therefore the proposed quad-port conformal MIMO antenna is a useful candidature for the satellite applications.

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9.Published Paper

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A CPW Feed Orthogonal Wideband Quad-Port Conformal MIMO Antenna for Satellite Applications

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***Abstract*—In this proposed paper, a quad-port C band conformal MIMO antenna is designed. This antenna configuration has four similar CPW-fed elements of size 10x15 mm. It is supported with flexible FR4 epoxy dielectric material with relative permittivity of 4.4 and a loss tangent of 0.02. The proposed antenna achieved an impedance bandwidth in accordance with the -10dB reference from frequency ranges of 4.5 GHz to 7.56 GHz which covers C band satellite applications. Good isolation characteristics are achieved which is less than -15 dB with the help of the orthogonal arrangement of the four MIMO antennas. For the excellent working of MIMO, some of the characteristics like Mean Effective Gain, Total Active Reflection, Envelope Correlation Coefficient are considered as important and they are investigated and found that they are within the standards as MEG < 3dB and ECC < 0.5. The entire work is done with the help of ANSYS High-Frequency Structure Simulator (HFSS) software.**

Keywords*— *MIMO; conformal antenna; C band applications; Mean Effective Gain; Total Active Reflection; Envelope Correlation Coefficient; Satellite Applications

I. INTRODUCTION

Nowadays in modern wireless systems, wideband and ultra-wideband technology plays a crucial role since it meets the requirement of high data rate in a limited range. [1]. Wideband and UWB techniques gained required attention due to advantages such as wide bandwidth, high data rate, and less expensive [2]. Multiple input multiple output systems are becoming more prominent these days when considering the requirement for high data rates in wireless and mobile communication systems [3]. Planar antennas in the recent past are being widely used to address wideband technology which forms the part of a large number of wireless applications. [4]. The next generation of high-speed transmission over wireless communications will make full use of the merits of reduced multipath fading and increased channel capacity inherent in MIMO RF architectures [5]. There are a number of techniques used to minimize the size of the antenna, such as implementing a shorting pin in a micro-strip patch, using a short circuit, and cutting slots in radiating patch [6]. In [7] A 2 x 2 meta-material compact -MIMO antenna is designed. The proposed antenna was suitable for WLAN applications. The MIMO structure is obtained by placing side by side a couple of meta-material antennas which were built based on the changed composite right/left-handed (CRLH) model. In [8] a measured bandwidth of (2.20–2.51 GHz) is obtained to cover the LTE 2300/ISM2.45 GHz operation and isolation of above 16 dB is achieved. In [9] to improve impedance matching and multi-band operation, a pair of inverted L-shaped mono-poles are printed in the circular slot of the ground plane. The single element design is duplicated along the diameter of the circular slot of the ground plane. A strip is utilized between the two radiators in order to decrease the mutual coupling effect and improve the impedance matching at operating bandwidths. In [10] A MIMO microstrip antenna is proposed for frequency ranges from 800-2600 MHz. The MIMO microstrip antenna elements had an antenna gain of 2 to 5 dB and mutual coupling is less than -20 dB.

In this research paper, an improved T-shaped slot conformal MIMO antenna is proposed to cover satellite applications of the C-band range. Important MIMO parameters such as TARC, MEG, and ECC are computed and other important antenna parameters such as reflection coefficient, isolation, and gain are studied.

II. ANTENNA DESIGN STRUCTURE

A modified microstrip patch antenna structure is designed as shown in Fig. 1a. The structure of the antenna is constructed in a step-by-step modification process with overall antenna dimensions of 20 x 20 mm and patch dimensions to be 15 x 10 mm (width x length). The antenna is designed to work at 6 to 7 GHz. Dimensions were calculated using the formulas mentioned.

$$W = \frac{c}{2 f_r \sqrt{\frac{\epsilon_r + 1}{2}}} \quad (1)$$

$$\epsilon_{reff} = \frac{\epsilon_r + 1}{2} + \frac{\epsilon_r - 1}{2}\left[1 + 12\frac{h}{W}\right]^{-1/2} \quad (2)$$

$$L_{eff} = \frac{c}{2 f \sqrt{\epsilon_{reff}}} \quad (3)$$

$$\Delta L = 0.412h \frac{(\epsilon_{reff} + 0.33)\left(\frac{W}{h} + 0.264\right)}{(\epsilon_{reff} - 0.258)\left(\frac{W}{h} + 0.8\right)} \quad (4)$$

$$L = L_{eff} - 2\Delta L \quad (5)$$

The above equations represent the general microstrip patch antenna equations used for calculating the dimensions.

The microstrip patch antenna is given CPW feed with a strip-line of length 8 mm and width 2 mm. Multiple slots with dimensions as mentioned in Fig. 1a are cut to achieve improved bandwidth and gain. All the parameters related to the antenna are optimized to get the desired results. A close version of the proposed final structure with different dimensions, element spacing, extra slots, and different operating range is discussed in [11]. Once this initial stage of design is completed, it is extended to quad-port MIMO design. The orthogonal combination is considered to obtain maximum isolation. This structure is built on a flexible FR4 epoxy dielectric material with a dielectric constant of 4.4 and a height of 1.6 mm. The spacing between the symmetric orthogonal arrangements of the four antenna elements is considered as λ/3.

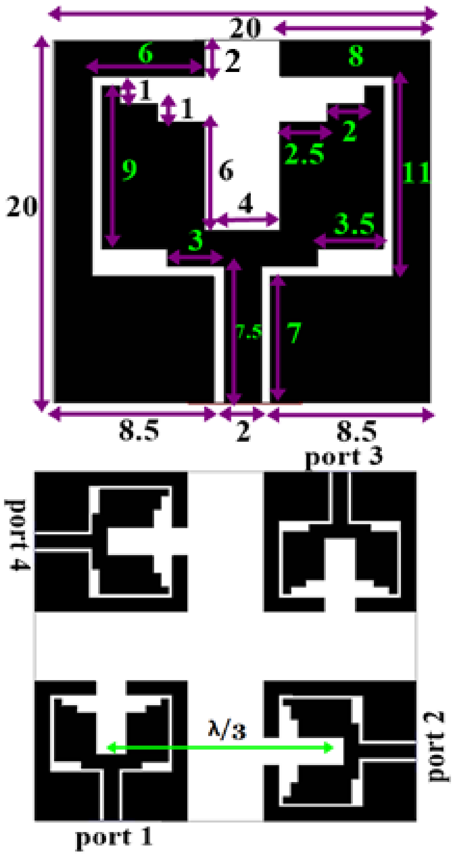


Fig. 1a) Single element 1b) Proposed MIMO structure

The designing and the analysis of the proposed structure is carried out in ANSYS HFSS software.

III. Analysis of Proposed Antenna

The S-parameters are analyzed for the MIMO antenna. Fig. 2 shows the reflection coefficient for all the four MIMO antenna elements. It is evident from the figure that, all the 4 antenna elements impedance bandwidth pertaining to -10 dB is well achieved from 4.5 GHz to 7.56 GHz (3.06 GHz bandwidth).

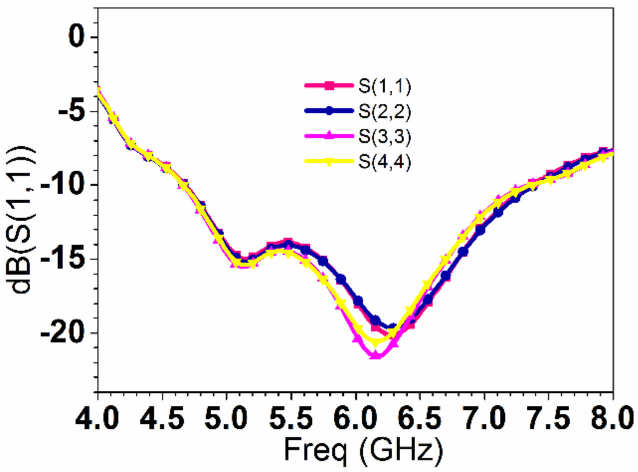


Fig. 2 S-parameters for the quad-port MIMO antenna – Reflection coefficients.

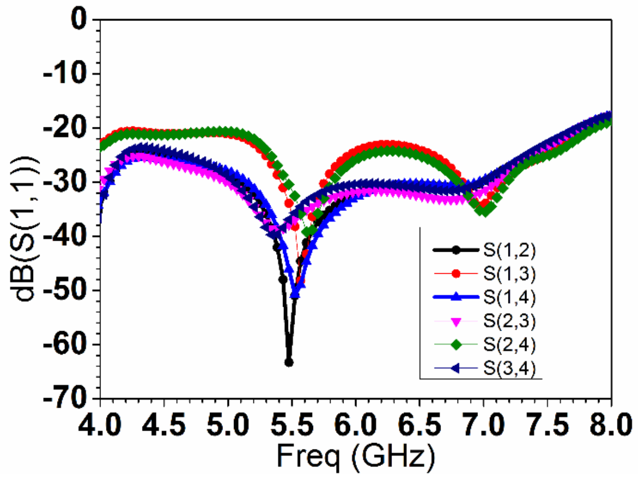


Fig. 3 S-parameters for the quad-port MIMO antenna.

The effect of mutual coupling which is a critical factor in the design of the MIMO antenna system is also examined. This factor is simulated when excitation is given at port 1 and all other ports are terminated with 50 ohms characteristic impedances. Fig. 3 gives necessary information regarding the mutual coupling from port 1 and all other ports also. It is to be particularly noted that the isolation or transmission coefficients from Fig. 3 is less than -20 dB for the entire working impedance bandwidth of 4.5 GHz to 7.5 GHz. The S12 or S21 has peak isolation of nearly -65 dB in the range of 5 to 6 GHz. The S14 or S41 has an isolation of -50 dB, for the range of 5.5 to 6.5 GHz. For S23 or S32 the isolation is given as -40 dB within the ranges of 5 to 5.5 GHz. S24 or S42 has peak isolation of nearly -40 dB in the range of 5 to 5.75 GHz.

And for S34 or S43. the isolation is achieved to be -40 dB within the ranges of 5 to 5.5 GHz.

The diversity capabilities of the MIMO antenna are characterized by the computation of the Envelope Correlation Coefficient (ECC), Total Active Reflection Coefficient (TARC), and Mean Effective Gain (MEG). These parameters are calculated using the formulas given by

$$ECC = \frac{\left|S^{*}_{pp}S_{pq} + S^{*}_{qp}S_{qq}\right|^2}{(1-\left|S_{pp}\right|^2 - \left|S_{pq}\right|^2)(1-\left|S_{qp}\right|^2 - \left|S_{qq}\right|^2)^{*}} \quad (6)$$

$$TARC = -\sqrt{\frac{(S_{pp}+S_{pq})^2 + (S_{qp}+S_{qq})^2}{2}} \quad (7)$$

Fig. 5 deals with the ECC versus frequency plot. From the plot, it is confirmed that the value of the ECC is less than 0.05 for the entire frequency range of 4.5 to 7.5 GHz. Generally, the ECC limit is 0.5 it is considered to be satisfactory and if the ECC value is less than 0.3, then it is good for the MIMO applications.

The Mean Effective Gain (MEG) as mentioned in [12] is calculated among individual two antenna elements as shown in Fig. 6. The MEG1, MEG2 define the mean effective gain calculation among 1 and 2 antenna elements. Similarly, MEG3 and MEG4 for 1 and 3 elements and finally MEG5 and MEG6 for 1 and 4 antenna elements. The difference between these mean effective gains should be less than 3 dB as per the standards. From the MEG plot, it is evident that the values are well within the standards.

The TARC versus frequency plot is shown in Fig. 7. The standard limit should be less than -10 dB and the plot shows that the entire operating range of frequencies of the MIMO antenna is less than -10 dB in the operating bandwidth region. The TARC value is as low as close to -20dB in-between frequency ranges from 6 to 7 GHz.

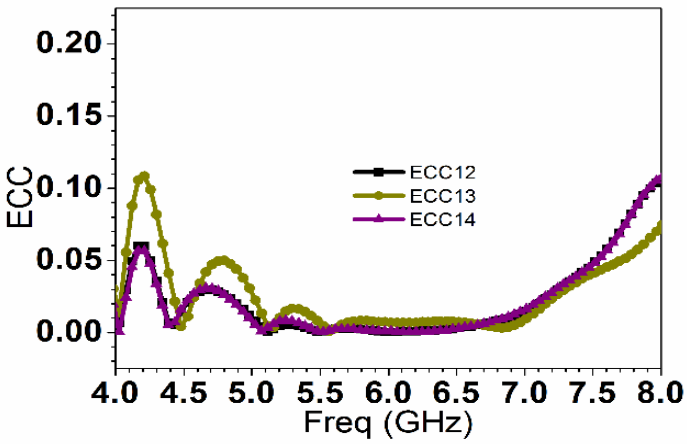


Fig. 5 Envelope Correlation Coefficient V/S frequency plot

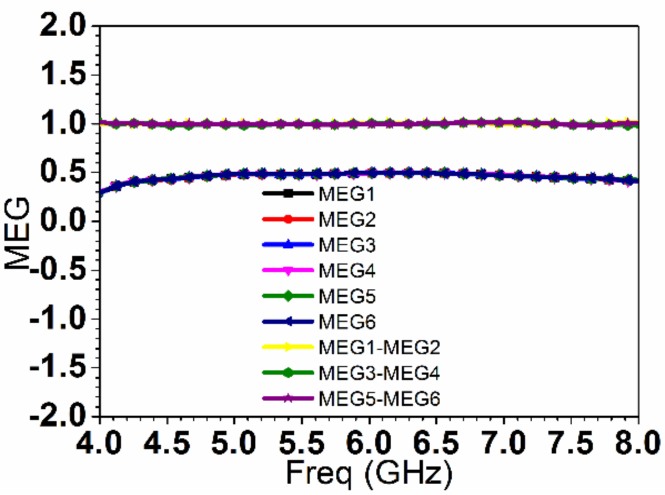


Fig. 6 Mean effective gain V/S frequency plot

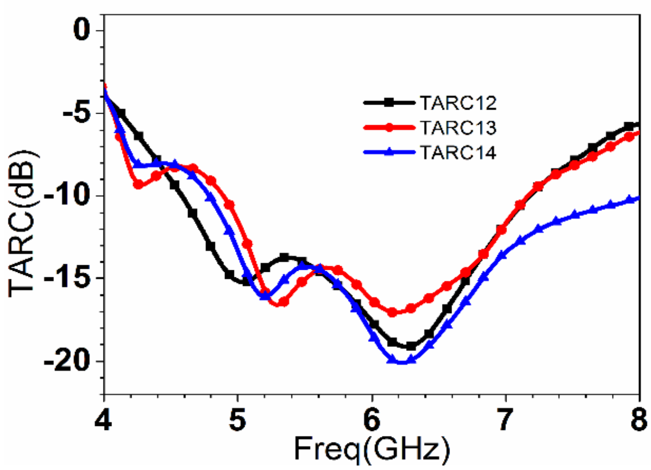
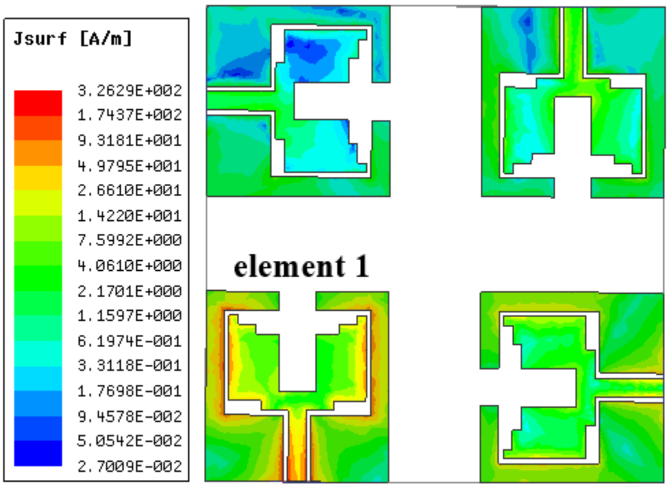


Fig. 7 Total active reflection Coefficient V/S frequency plot

The surface current distribution for individual port excitation is shown in Fig. 8. The values are computed when each of the ports is separately excited at the centre frequency of 6.7 GHz. These stand at 326 A/m and 425 A/m when ports 1 and 2 are separately excited and 341 A/m and 365 A/m when the rest to ports, 3 and 4 are excited individually.



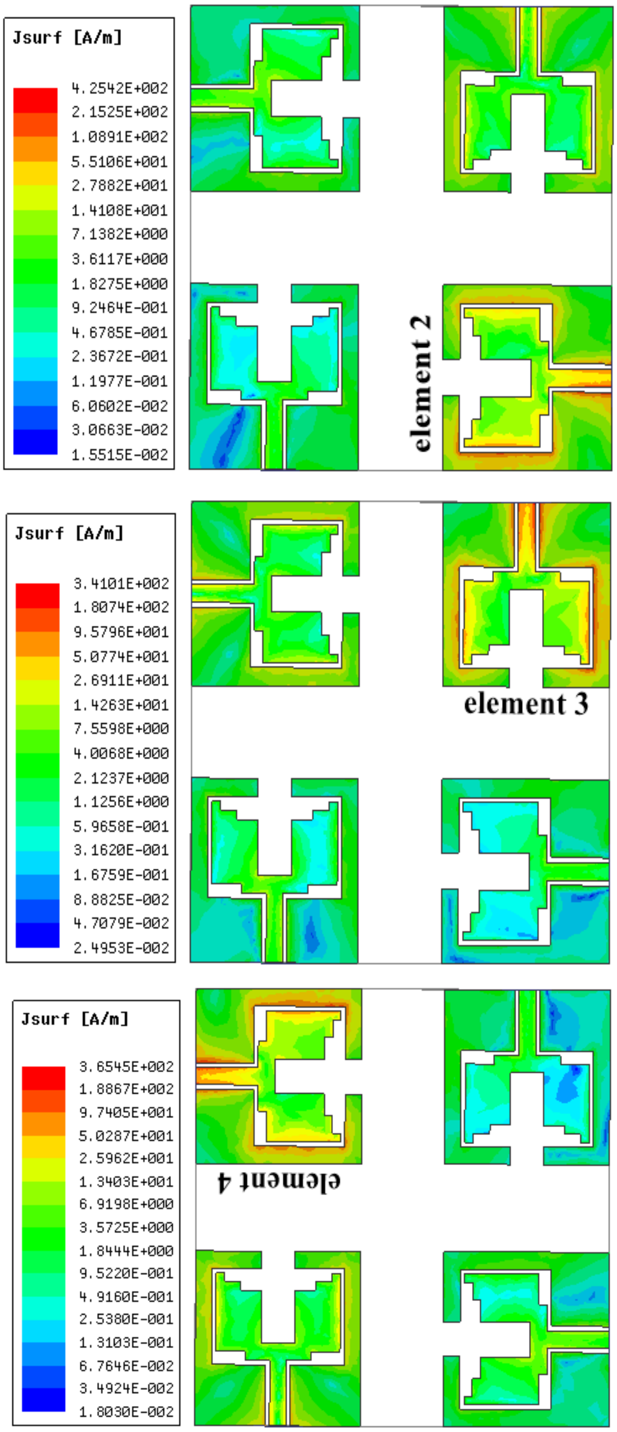


Fig. 8 Surface currents distribution for different port excitations

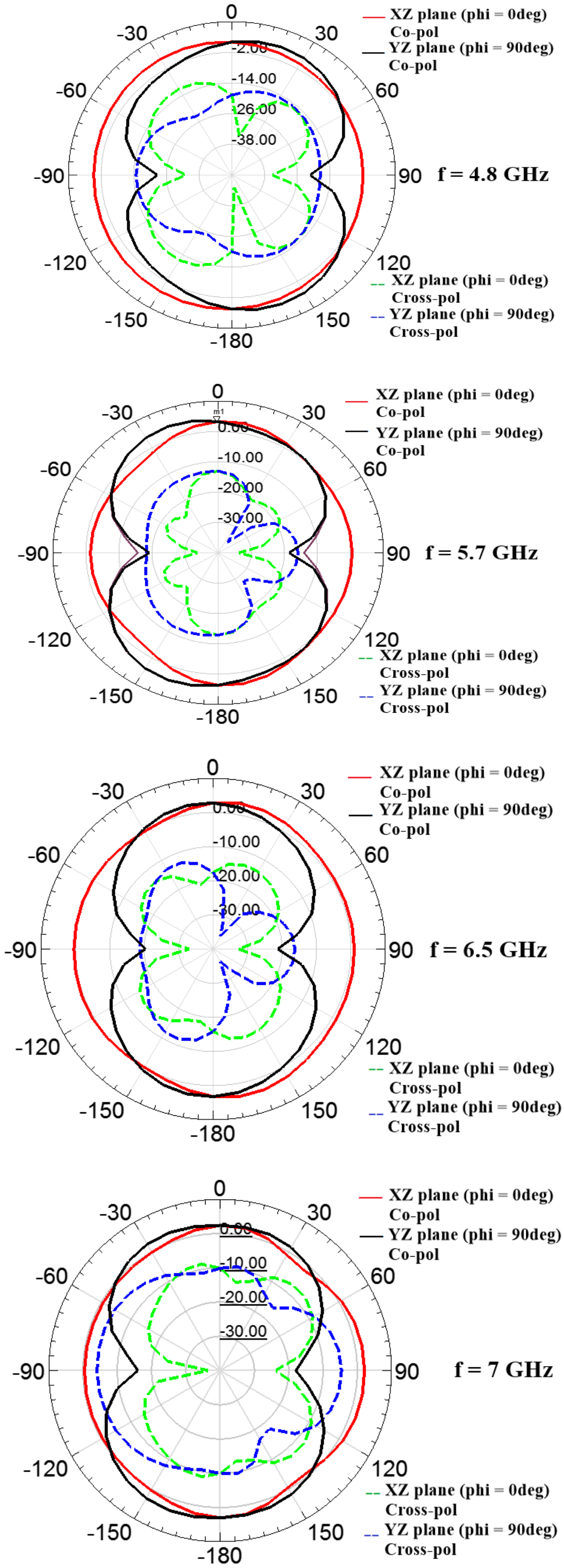


Fig. 9 Radiation pattern plots for different frequencies

Fig. 9 represents the radiation pattern plots at different frequencies. It is particularly noted that the difference between Co-polarization and cross-polarization is greater than -15 dB which is a satisfactory parameter. The proposed antenna achieved an overall gain of 2 to 3.5 dB in the working bandwidth region of 4.5 to 7.56 GHz with a peak gain of 3.5dB at 6.7 GHz frequency.

The MIMO antenna proposed is converted to a conformal shape for accessibility to be mounted on the body surface for different satellite applications. The merits of the conformal arrangement are that it helps to design any entity without modifying its physical. Fig. 10 shows the conformal arrangement of the proposed MIMO antenna with the flexible FR4 epoxy substrate.

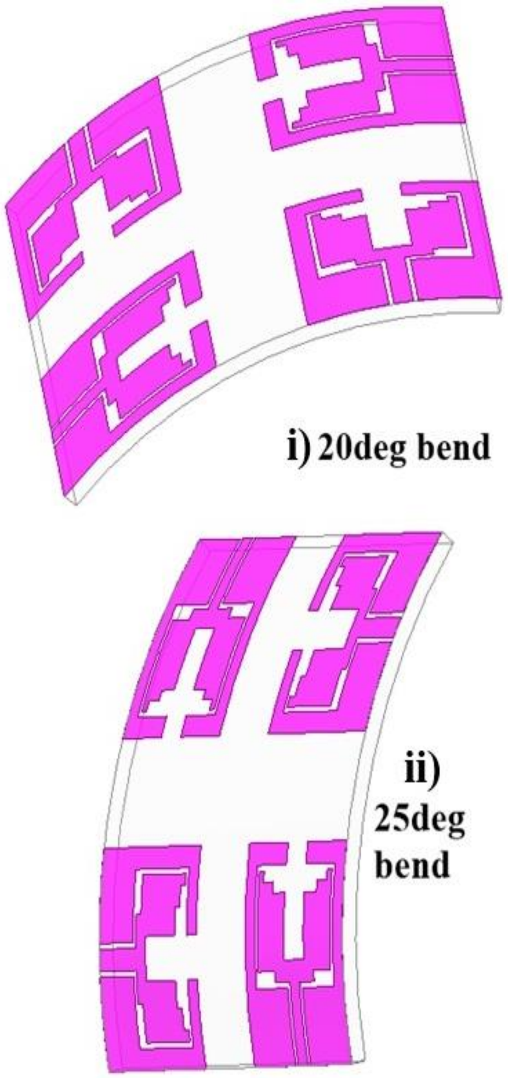


Fig.10 Conformal arrangement of the proposed MIMO antenna with i) 20^0 bend ii) 25^0 bend angles.

Figs. 11 and 12 give the related simulation results for the conformal arrangement of the antenna. Two bend angles of 20^0 and 25^0 are investigated. Isolation characteristics are studied.

The conformal MIMO antennas are analysed to get good isolation properties being less than -15dB within the whole region discussed operating bandwidth region of C band range. Thus, on an overall note conformal quad-port MIMO antenna arrangement also showed a lower mutual coupling effect and better isolation.

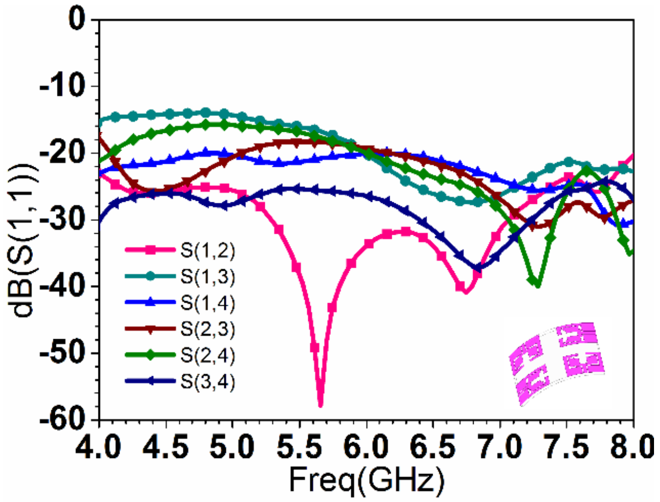


Fig.11 S-Parameters plot depicting the isolation or transmission coefficients information with 20^0 bend angle

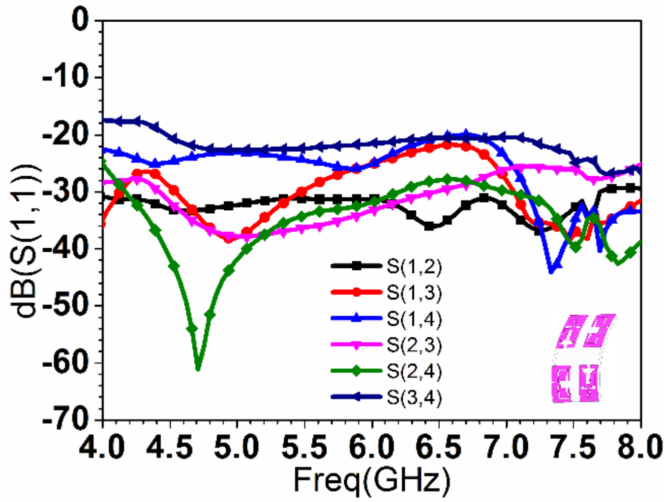


Fig.12 S-parameters plot depicting the isolation or transmission coefficients information with 25^0 bend angle

IV. CONCLUSION

A quad-port wide-band conformal MIMO antenna with modified microstrip patch antenna elements in the orthogonal arrangement is employed in this model. The MIMO antenna is achieved wideband range of 4.5 to 7.56 GHz with 3.06 GHz impedance bandwidth. MIMO performance in terms of isolation, Envelope Correlation Coefficient (ECC), Mean Effective Gain (MEG) and, Total Active Reflection Coefficient (TARC) is also analyzed which resulted in isolation less than -15 dB, ECC < 0.5, MEG < 3dB, and TARC < -10 dB for the required operating frequency range. The Co-polarization and Cross-polarization for the proposed antenna are good with a difference of -15dB. The proposed antenna also exhibited a satisfactory gain of 2 to 3.5 dB in the mentioned operating range. The MIMO antenna is extended to its conformal variant with 20^0 and 25^0 bend angles to study the isolation parameters which were found to be in good agreement pertaining to less than -10dB. therefore, the proposed quad-port conformal MIMO antenna is a useful candidature for satellite applications.

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