Wearable Dual-port MIMO antenna for On-body 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 **"Wearable Dual-port MIMO antenna for On-body applications"** submitted by in partial fulfillment of the requirements for the award of the degree of Bachelor of Technology **G.RAMESH(317126512078), P.PAVAN KUMAR(317126512100), R.VINAY SAI(317126512104), B.GIRI PRASAD(317126512068)** 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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CONTENT

ABSTRACT

In this chapter, a conformal MIMO circular patch antenna structure is proposed. Two elements with individual port excitations are presented for obtaining the MIMO arrangement. The antenna is backed by a Jean cloth substrate with relative permittivity 1.6 and a loss tangent of 0.02. The impedance bandwidth concerning -10 dB is achieved from frequency ranges 2.3 GHz to 2.85 GHz covering ISM band (2.4 to 2.5GHz) for On body applications. The center frequency is 2.58 GHz and the impedance bandwidth observed is 550 MHz. In the proposed antenna structure a double H-shaped stub is introduced on ground plane for better impedance matching. Important parameters such as Total Active Reflection Coefficient, Mean Effective Gain, Envelope Correlation Coefficient which are responsible for the efficient working of the MIMO are also investigated and are found to be well within the standards with TARC < -10dB, MEG < 3 dB and ECC < 0.5. Also, Specific Absorption Rate analysis is carried out by creating the homogenous 3-layer human body model consisting of skin, fat, and muscle layers. The work is carried out using ANSYS High Frequency Structure Simulator Software(HFSS).

LIST OF FIGURES

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LIST OF ABBREVATIONS

WLAN : Wireless Local Area Network

WIMAX : World wide Interoperability for Microwave Access

VSWR : Voltage Standing Wave Ratio

DGS : Defected ground structure

1.ANTENNA FUNDAMENTALS

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

1.1 INTRODUCTION:

An antenna is an array of conductors , electrically connected to the receiver or transmitter. Antennas can be designed to transmit and receive radio waves in all horizontal directions equally (omnidirectional antennas), or preferentially in a particular direction (directional, or high-gain, or “beam” antennas).

1.1.1 EVOLUTION OF ANTENNA:

Antennas have been around now for nearly 125 years. In those 125 years wireless communication has become increasingly important. Personal mobile communication applications are putting huge constraints on the antennas that need to be housed in limited spaces. Therefore the common practice of wireless engineers to consider the antenna as a black-box component is not valid anymore. The modern wireless engineer needs to have a basic understanding of antenna theory. Before we dive into the derivation of antenna characteristics, however, we will in this chapter present a brief overview of antenna history and the mechanisms of radiation. Thus, a solid foundation will be presented for understanding antenna characteristics and their derivations. When James Clerk Maxwell, in the 1860s, united electricity and magnetism into electromagnetism, he described light as and proved it to be an electromagnetic phenomenon. He predicted the existence of electromagnetic waves at radio frequencies, that is at much lower frequencies than light. In 1886, Maxwell was proven right by Heinrich Rudolf Hertz who without realizing it himself1 created the first ever radio system, consisting Of a transmitter and a receiver.

1.1.2 HOW DOES AN ANTENNA WORK:

Suppose you're the boss of a radio station and you want to transmit your programs to the wider world. How do you go about it? You use microphones to capture the sounds of people's voices and turn them into electrical energy. You take that electricity and, loosely speaking, make it flow along a tall metal antenna . As the electrons in the electric current wiggle back and forth along the antenna, they create invisible electromagnetic radiation in the form of radio waves. These waves travel out at the speed of light , taking your radio program with them .The radio waves you sent flow through the metal antenna and cause electrons to wiggle back and forth. That generates an electric current a signal that the electronic components inside my radio turn back into sound I can hear.

Transmitter and receiver antennas are often very similar in design. For example, if you're using something like a satellite phone that can send and receive a video-telephone call to any other place on Earth using space satellites , the signals you transmit and receive all pass through a single satellite dish a special kind of antenna shaped like a bowl . Often, though, transmitters and receivers look very different. TV or radio broadcasting antennas are huge masts sometimes stretching hundreds of meters/feet into the air, because they have to send powerful signals over long distances. But you don't need anything that big on your TV or radio at home: a much smaller antenna will do the job fine.

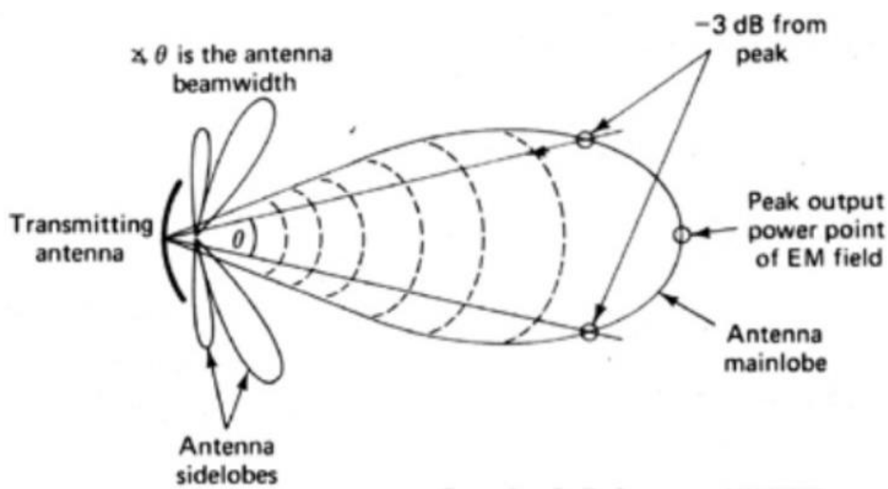

Figure 1.1: Antenna radiation

1.2 Antenna Performance Parameters:

1.2.1.RadiationPattern

In the field of antenna design the term radiation pattern refers to the directional dependence of the strength of the radio waves from the antenna or other source.

Radiation Pattern of Antenna

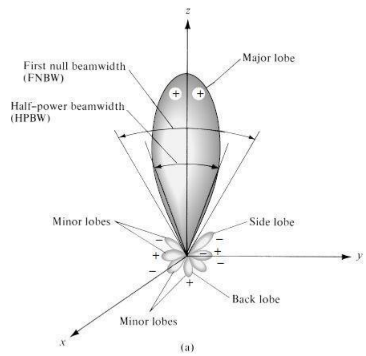

Figure 1.2

the radiation pattern has main lobe, side lobes and back lobes.

The major part of the radiated field, which covers a larger area, is the main lobe or major lobe. This is the portion where maximum radiated energy exists. The direction of this lobe indicates the directivity of the antenna.

The other parts of the pattern where the radiation is distributed side wards are known as side lobes or minor lobes. These are the areas where the power is wasted.

There is other lobe, which is exactly opposite to the direction of main lobe. It is known as back lobe, which is also a minor lobe. A considerable amount of energy is wasted even here.

*Minor lobes usually represent radiation in undesired directions, and they should be minimized. Side lobes are normally the largest of the minor lobes.

*The level of minor lobes is usually expressed as a ratio of the power den- sity, often termed the side lobe ratio or side lobe level.

*In most radar systems, low side lobe ratios are very important to mini- mize false target indications through the side lobes (e.g., -30 dB)

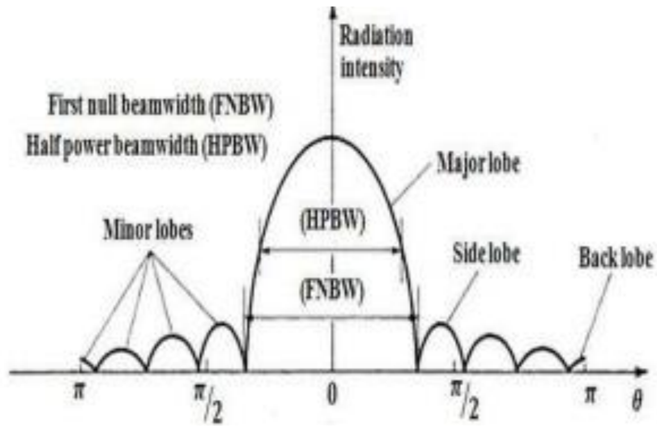

Figure 1.3: Linear plot of power patterns and respective lobes

Components in the Amplitude Pattern:

There would be, in general, three electric-field components (E_r ,E_θ, E_φ) at each observation point on the surface of a sphere of constant radius.

In the far field, the radial E_r component for all antennas is zero or vanishingly small.

Some antennas, depending on their geometry and also observation distance, may have only one, two, or all three components.

1.Isotropic antenna: The antenna which radiates equally in all directions is called isotropic antenna. The radiation pattern of this antenna is called spherical.

2.Directional antenna: Radiates more in a particular direction and less in other direction

3.Omni directional antenna: The antenna which radiates power only in one direction is called omni directional antenna.

EXAMPLES:

Isotropic – Sun, Bulb antenna

Directional – Dipole antenna, Folded dipole antenna.

Omni directional – Horn antenna, Yagi-guda antenna.

1.2.2.Directivity:

Directivity is the measure of the concentration of an antenna's radiation pattern in a particular direction. Directivity is expressed in dB. The higher the directivity, the more concentrated or focused is the beam radiated by an antenna. A higher directivity also means that the beam will travel further.

An antenna that radiated equally well in all directions would be omni-directional and have a directivity of 1 (0 dB).

$$\textbf{Antenna gain} = \textbf{directivity} * \textbf{antenna efficiency} \quad \textbf{(1.1)}$$

Gain is the product of directivity and efficiency. Where efficiency accounts for the losses on the antenna such as manufacturing faults, surface coating losses, dielectric, resistance, VSWR, or any other factor. A high directivity is not always better, for example, many applications like mobile devices require omni-directional antennas and thus require antennas with a low/no directivity. High-directivity antennas are used in permanent installations such as satellite television, wireless backhaul etc. as they need to transmit and receive information over longer distances, in a particular direction.

1.2.3 Input Impedance:

The input impedance of antenna is basically the impedance offered by the antenna at its terminals. It is defined as the ratio of voltage to the current across the two input terminals of the antenna. Generally, the antenna impedance is given as:

$$Z_A = R_A + JX_A \quad (1.2)$$

We have already discussed in our previous article that antennas are used in wireless communication in order to transmit the signal in the form of waves. It is designed to change electrical energy into the electromagnetic signals at the transmitting end. While electromagnetic signal back to electrical one at the receiving end. So, it basically integrates the electric field and magnetic field in order to generate voltage and current so as to actuate electrical devices. Thus the antenna impedance at a point is also given as the ratio of electric field to the magnetic field at that particular point. Hence we can say that the impedance provided by the antenna at its input terminal is known as antenna impedance. We know that when a certain voltage is provided to any transmitting antenna then it generates current by following ohm's law.

$$V = I * R \quad (1.3)$$

Here R represents the resistance of the input terminal of the antenna. Further on considering the imaginary part, we will have

$$E = I * Z \quad (1.4)$$

So, if we have a transmitting antenna that is radiating some power then impedance Z will be present behind it. This is known as the impedance of the antenna.

This impedance is a merger of resistance and reactance thereby forming a complex value.

1.2.4 Return Loss (RL):

Return loss is the measure of how small the "return" or reflection/echo is. We want a small return, so a large loss on the return "echo" is good. Smaller return loss is bad, and means less energy is going into our antenna. RF engineers often measure return loss on a "dB" logarithmic scale

1.2.5 Bandwidth (BW):

Bandwidth of an antenna is an important concept. The bandwidth of an antenna refers to the range of frequencies over which the antenna satisfies a particular parameter specification. The parameters generally specified are gain, radiation pattern, the VSWR etc. Most commonly, the VSWR is chosen as the parameter for bandwidth considerations and this bandwidth is called the impedance bandwidth. The lower and upper frequencies conforming to the desired VSWR set the frequency band over which the antenna meets the VSWR specification. A VSWR specification commonly adopted is a 2:1 VSWR, which means that the range of frequencies over which the VSWR is less than 2 is chosen as the bandwidth of operation.

1.2.6. Antenna Gain:

Antenna gain is a measure of the maximum effectiveness with which the antenna can radiate the power delivered to it by the transmitter towards a target. Antenna gain is typically given the symbol *G*, and is defined as the maximum radiation intensity produced by the antenna compared to that given by a lossless isotropic radiator supplied with the same level of power. If an antenna's gain is 2 (3 dB), it means that twice the amount of effective power will be sent in the direction of a target than from an isotropic radiator, and so has the equivalent effect of doubling the power of the transmitter in that particular direction. In practice, the gain of a ship's radar antenna will be around 30 dB (1000 times). By definition, the gain of an isotropic radiator is 0 dB (unity).

1.3TYPES 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 dipole antenna is cut and bent for effective radiation. The length of the total wire, which is being used as a dipole, equals half of the wavelength (i.e., $l = \lambda/2$). Such an antenna is called as half-wave dipole antenna. This is the most widely used antenna because of its advantages. It is also known as Hertz antenna.

Frequency range:

The range of frequency in which half-wave dipole operates is around 3KHz to 300GHz. This is mostly used in radio receivers.

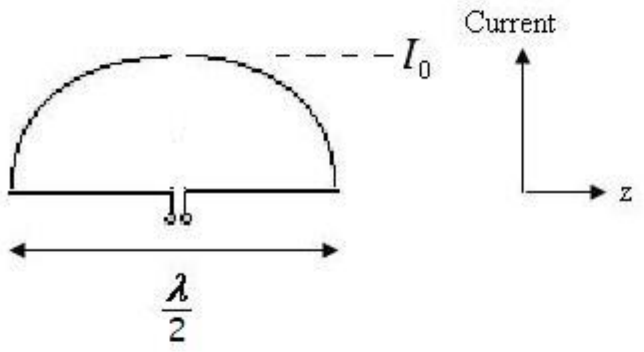

Figure 1.4 : Half Wave Dipole

The above figure shows the current distribution in half wave dipole. The directivity of half wave dipole is 2.15dB, which is reasonably good. Where, 'i' represents the isotropic radiation.

Radiation Pattern:

The radiation pattern of this half-wave dipole is Omni-directional in the H-plane. It is desirable for many applications such as mobile communications, radio receivers etc.

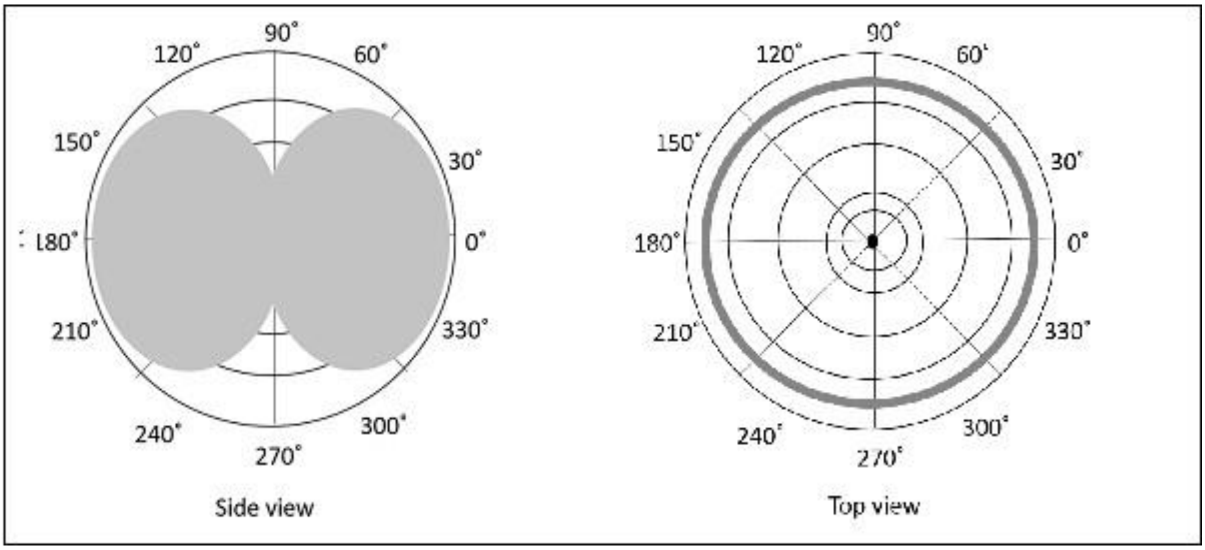

Figure 1.5: Radiation Pattern for half wave dipole

The above figure indicates the radiation pattern of a half wave dipole in both H-plane and V-plane.

The radius of the dipole does not affect its input impedance in this half wave dipole, because the length of this dipole is half wave and it is the first resonant length. An antenna works effectively at its resonant frequency, which occurs at its resonant length.

Advantages:

The following are the advantages of half-wave dipole antenna −

- Input impedance is not sensitive.
- Matches well with transmission line impedance.
- Has reasonable length.
- Length of the antenna matches with size and directivity.

Disadvantages:

The following are the disadvantages of half-wave dipole antenna −

- Not much effective due to single element.
- It can work better only with a combination.

Applications:

The following are the applications of half-wave dipole antenna −

- Used in radio receivers.
- Used in television receivers.
- When employed with others, used for wide variety of applications.

1.3.2.MONOPOLE ANTENNA:

Monopole antennas, as shown in Figure, constitute a group of derivatives of dipole antennas. Here, only half of the dipole antenna is needed for operation. A metal ground plane (ideally of infinite size) is used, with respect to which the excitation voltage is applied to the half structure. The half structure for a regular dipole antenna is called a monopole antenna, in reference to the presence of only one physical side. A similar half structure for a folded dipole antenna is called a folded monopole antenna. The presence of the ground plane allows the monopole antenna to operate as electrically equivalent to a dipole antenna. The ground plane equivalently replaces the lower half by an imaging principle, similar to creating an optical image through a mirror. Notice in Figure1.5 that for the currents in the monopole and dipole structures to be the same, one needs the source voltage of the equivalent dipole antenna to be twice that of the monopole antenna. As a result, the input impedance of the monopole structure is half that of the corresponding dipole structure:

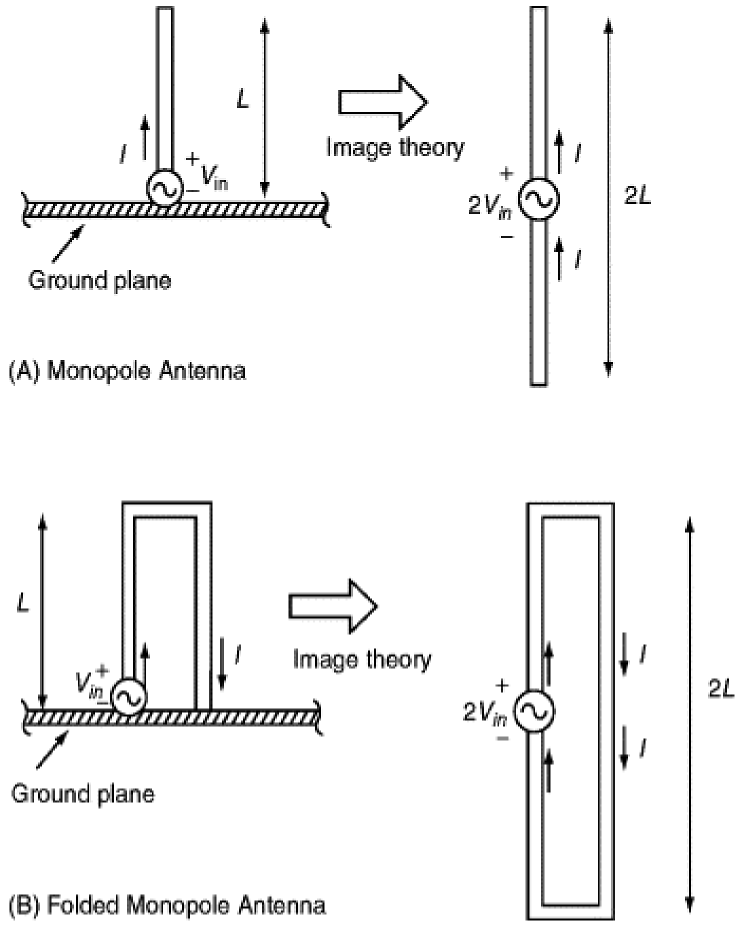

Figure 1.6 : MONOPOLE ANTENNA

1.3.3.LOOP ANTENNA:

An RF current carrying coil is given a single turn into a loop, can be used as an antenna called as loop antenna. The currents through this loop antenna will be in phase. The magnetic field will be perpendicular to the whole loop carrying the current.

Frequency Range:

The frequency range of operation of loop antenna is around 300MHz to 3GHz. This antenna works in UHF range.

A loop antenna is a coil carrying radio frequency current. It may be in any shape such as circular, rectangular, triangular, square or hexagonal according to the designer's convenience.

Loop antennas are of two types.

- Large loop antennas
- Small loop antennas

Large loop antennas:

Large loop antennas are also called as resonant antennas. They have high radiation efficiency. These antennas have length nearly equal to the intended wavelength.

$$L=\lambda L=\lambda \qquad (1.5)$$

Where,

- **L** is the length of the antenna
- **λ** is the wavelength

The main parameter of this antenna is its perimeter length, which is about a wavelength and should be an enclosed loop. It is not a good idea to meander the loop so as to reduce the size, as that increases capacitive effects and results in low efficiency.

Small loop antennas:

Small loop antennas are also called as magnetic loop antennas. These are less resonant. These are mostly used as receivers .These antennas are of the size of one-tenth of the wavelength.

$$L=\lambda/10 \qquad (1.6)$$

Where,

- **L** is the length of the antenna
- **λ** is the wavelength

The features of small loop antennas are :

- A small loop antenna has low radiation resistance. If multi-turn ferrite core constructions are used, then high radiation resistance can be achieved.
- It has low radiation efficiency due to high losses.
- Its construction is simple with small size and weight.

Due to its high reactance, its impedance is difficult to match with the transmitter. If loop antenna have to act as transmitting antenna, then this impedance mis-match would definitely be a problem. Hence, these loop antennas are better operated as receiver antennas.

Radiation Pattern

The radiation pattern of these antennas will be same as that of short horizontal dipole antenna.

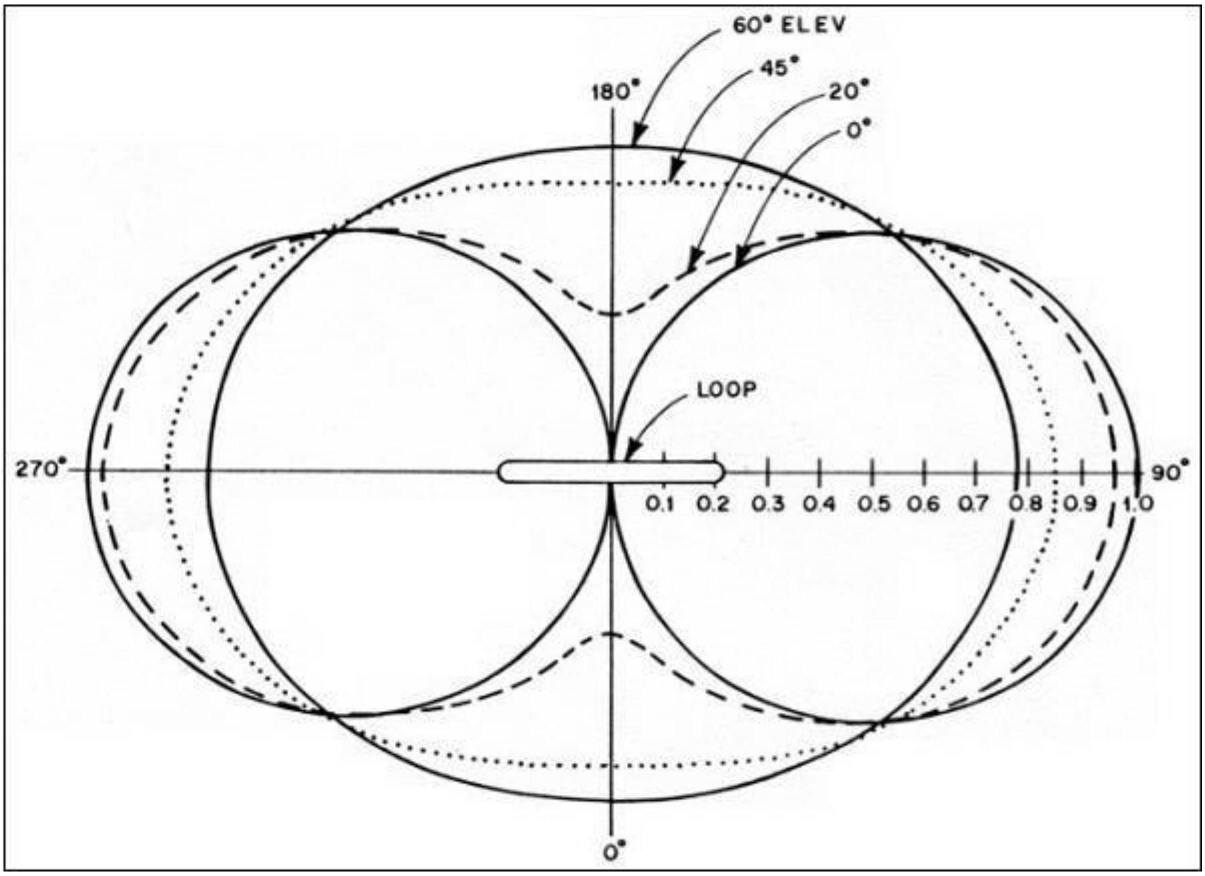

Figure 1.7 : Radiation pattern for LOOP ANTENNA

The radiation pattern for small, high-efficiency loop antennas is shown in the figure given above. The radiation patterns for different angles of looping are also illustrated clearly in the figure. The tangent line at 0° indicates vertical polarization, whereas the line with 90° indicates horizontal polarization.

Advantages

The following are the advantages of Loop antenna :

- Compact in size
- High directivity

Disadvantages

The following are the disadvantages of Loop antenna :

- Impedance matching may not be always good
- Has very high resonance quality factor

Applications

The following are the applications of Loop antenna :

- Used in RFID devices
- Used in MF, HF and Short wave receivers
- Used in Aircraft receivers for direction finding
- Used in UHF transmitters

1.3.4 HELICAL ANTENNA:

Helical antenna is an example of wire antenna and itself forms the shape of a helix. This is a broadband VHF and UHF antenna.

Frequency Range :

The frequency range of operation of helical antenna is around 30MHz to 3GHz. This antenna works in VHF and UHF ranges. Helical antenna or helix antenna is the antenna in which the conducting wire is wound in helical shape and connected to the ground plate with a feeder line. It is the simplest antenna, which provides circularly polarized waves. It is used in extra-terrestrial communications in which satellite relays etc., are involved. It consists of a helix of thick copper wire or tubing wound in the shape of a screw thread used as an antenna in conjunction with a flat metal plate called a ground plate. One end of the helix is connected to the center conductor of the cable and the outer conductor is connected to the ground plate. The radiation of helical antenna depends on the diameter of helix, the turn spacing and the pitch angle.

Pitch angle is the angle between a line tangent to the helix wire and plane normal to the helix axis.

$$\alpha = \tan^{-1}(S\pi D) \quad \textbf{(1.7)}$$

where,

- **D** is the diameter of helix.
- S is the turn spacing (centre to centre).
- α is the pitch angle.

Advantages

The following are the advantages of Helical antenna −

- Simple design
- Highest directivity
- Wider bandwidth
- Can achieve circular polarization
- Can be used at HF & VHF bands also

Disadvantages

The following are the disadvantages of Helical antenna −

- Antenna is larger and requires more space
- Efficiency decreases with number of turns

Applications

The following are the applications of Helical antenna −

- A single helical antenna or its array is used to transmit and receive VHF signals
- Frequently used for satellite and space probe communications
- Used for telemetry links with ballastic missiles and satellites at Earth stations
- Used to establish communications between the moon and the Earth
- Applications in radio astronomy

1.3.5 HORN ANTENNA:

To improve the radiation efficiency and directivity of the beam, the wave guide should be provided with an extended aperture to make the abrupt discontinuity of the wave into a gradual transformation. So that all the energy in the forward direction gets radiated. This can be termed as Flaring. Now, this can be done using a horn antenna.

Frequency Range

The operational frequency range of a horn antenna is around 300MHz to 30GHz. This antenna works in UHF and SHF frequency ranges.

Sectoral horn

This type of horn antenna, flares out in only one direction. Flaring in the direction of Electric vector produces the sectorial E-plane horn. Similarly, flaring in the direction of Magnetic vector, produces the sectorial H-plane horn.

Pyramidal horn

This type of horn antenna has flaring on both sides. If flaring is done on both the E & H walls of a rectangular waveguide, then pyramidal horn antenna is produced. This antenna has the shape of a truncated pyramid.

Conical horn

When the walls of a circular wave guide are flared, it is known as a conical horn. This is a logical termination of a circular wave guide.

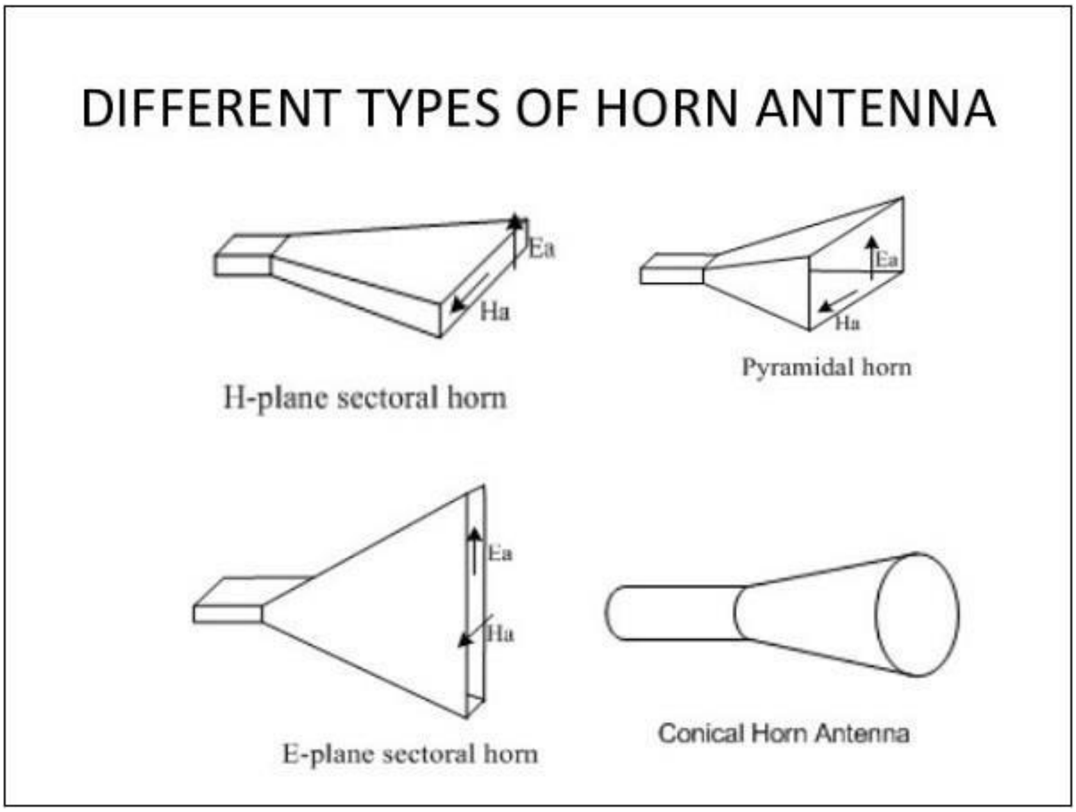

Figure 1.8: Different types of Horn Antenna

The above figures show the types of horn configurations, which were discussed earlier.

Radiation Pattern

The radiation pattern of a horn antenna is a Spherical Wave front. The following figure shows the radiation pattern of horn antenna. The wave radiates from the aperture, minimizing the diffraction of waves. The flaring keeps the beam focussed. The radiated beam has high directivity.

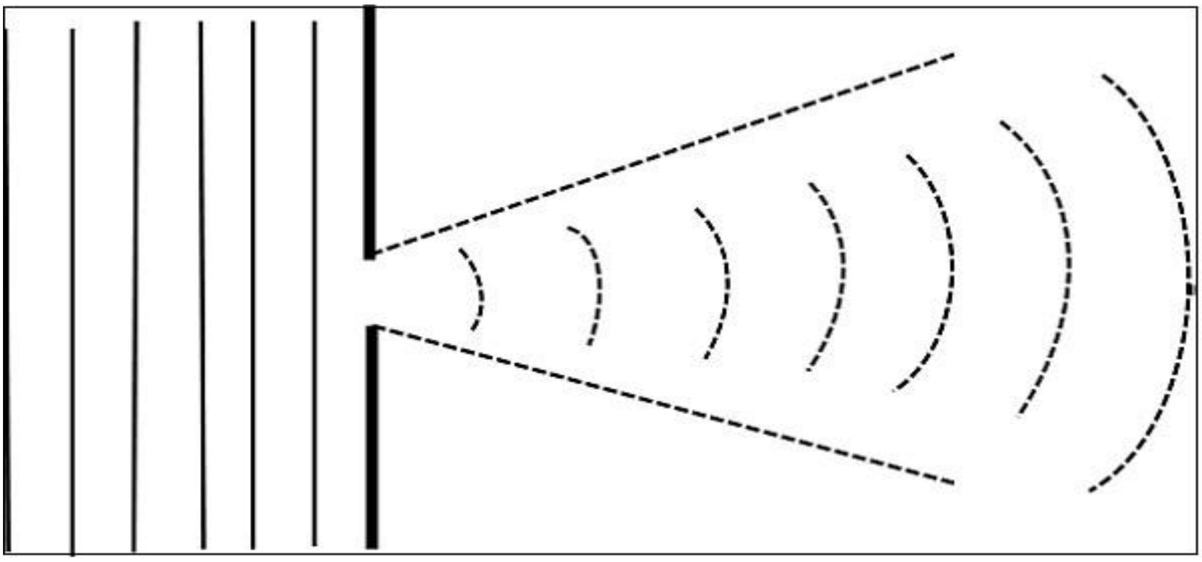

Figure 1.9 : Radiation pattern of horn antenna

Advantages

The following are the advantages of Horn antenna :

- Small minor lobes are formed
- Impedance matching is good
- Greater directivity
- Narrower beam width
- Standing waves are avoided

Disadvantages

The following are the disadvantages of Horn antenna :

- Designing of flare angle, decides the directivity
- Flare angle and length of the flare should not be very small

Applications

The following are the applications of Horn antenna :

- Used for astronomical studies
- Used in microwave application

2.MICRO STRIP PATCH ANTENNA AND MIMO ANTENNA

In this chapter, an introduction to the Microstrip Patch Antenna and mimo 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:

The idea of microstrip patch antennas arose from utilizing printed circuit technology not only for the circuit components and transmission lines but also for the radiating elements of an electronic system. It was first proposed by Deschamps. However, little attention was paid to his idea until the 1970's. Since then, this class of antennas has been the subject of intensive research and development. There are several thousand papers published on the subject, as well as a number of books. A list of books, review articles, and handbook chapters are given in the references . The basic structure of the microstrip patch antenna consists of area of metallization supported above a ground plane by a thin dielectric substrate and fed against the ground at an appropriate location. The patch shape can in principle be arbitrary; in practice, the rectangle, the circle, the equilateral triangle and the annular-ring are common shapes. Four feeding methods are: coaxial probe feed, microstrip line feed, aperture-coupled feed and proximity feed. Electromagnetic energy is first guided or coupled to the region under the patch, which acts like a resonant cavity with open circuits on the sides. Some of the energy leaks out of the cavity and radiates into space, resulting in an antenna.

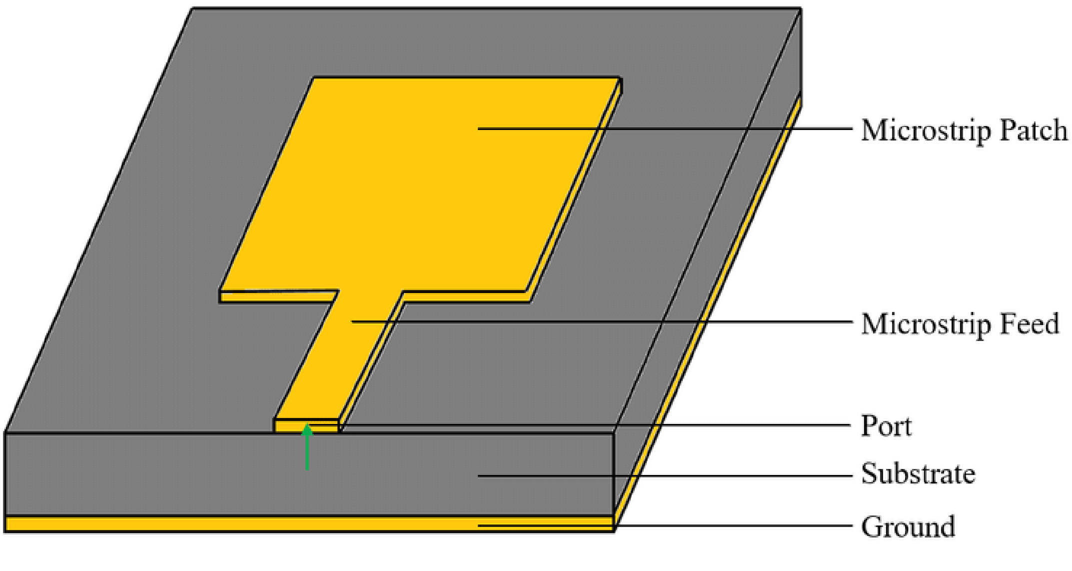

Figure 2.1: Basic Structure of microstrip patch antenna

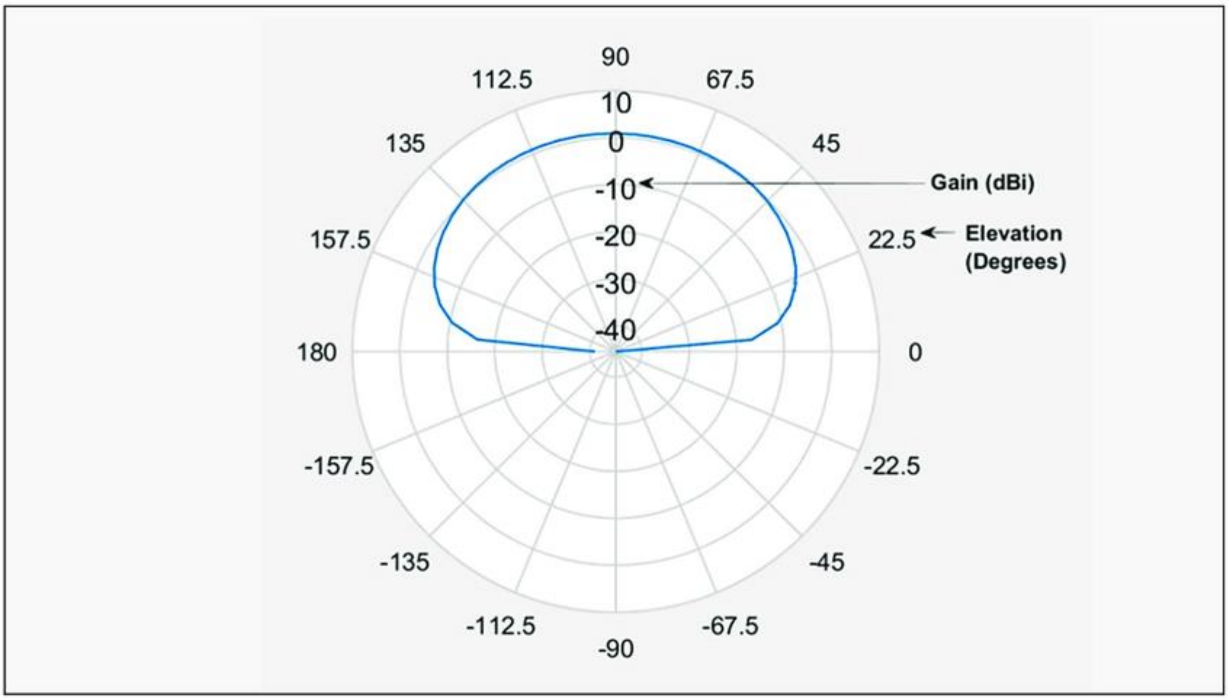

Figure 2.2: Microstrip patch antenna radiation pattern

2.1.1 COMMON SHAPES OF MICRO STRIP PATCH ANTENNA:

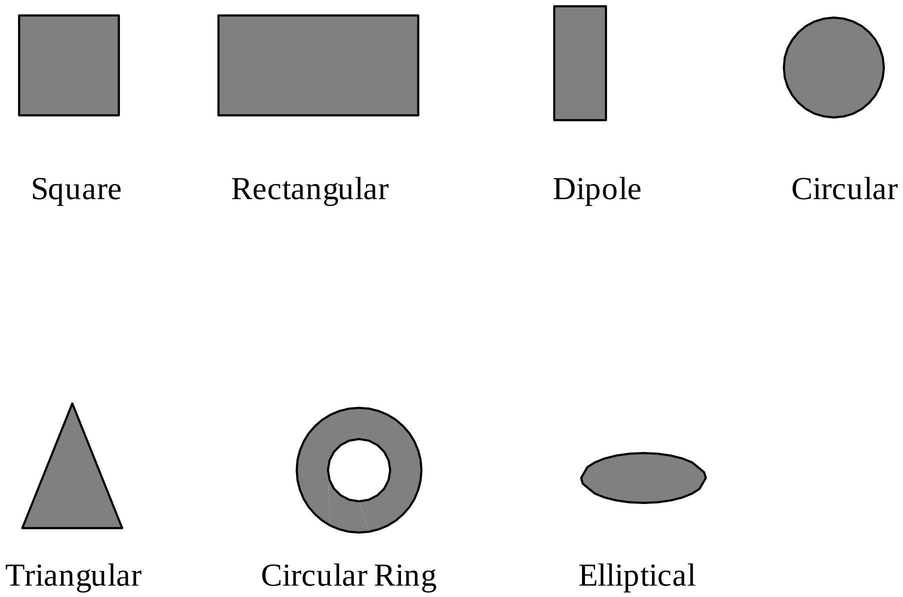

Figure 2.3: Microstrip patch elements shapes

2.2. Introduction to MIMO antenna:

Many modern telecommunications standards, particularly in the consumer space, have adopted multiple antenna (MIMO) technology because of the significant advantages it provides over similar system utilizing single antenna transceivers (SISO). MIMO stands for Multiple-In Multiple-Out, referring to the fact that when a packet is transmitted into the channel it transmitted on more than one antenna and when it comes out of the channel it is received on multiple antennas. This is in contrast to a Single-In Single-Out system with one antenna on both ends of the link, or a SIMO system which would include some types of radios that use diversity combining at the receive end but still transmit over only a single antenna.

Figure 2.4: SISO antenna

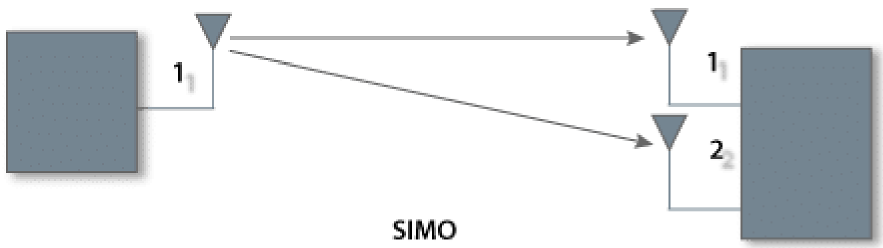

Figure 2.5: SIMO antenna

Multiple antennas at the transmitter and receiver introduces signaling degrees of freedom that were absent in SISO systems. This is referred to as the spatial degree of freedom. The spatial degrees of freedom can either be exploited for "diversity" or "multiplexing" or a combination of the two. In simple terms, diversity means redundancy. A simple example of diversity is multiple antennas trying to receive the same signal. The received signal on the two antennas is corrupted by noise that is uncorrelated between antennas, therefore by combining the two signals a better quality signal can be reconstructed. The analogy here is that by looking at the same object from two different vantage points, richer information on the object can be obtained. Diversity can also be achieved using multiple transmit antennas by using Space Time Coding (STC) techniques. The second major MIMO technique is Spatial Multiplexing. Spatial multiplexing enables a MIMO transmitter/receiver pair to increase its throughput without increasing bandwidth usage or transmit power. Multiplexing increases throughput linearly with the number of transmit or receive antennas, whichever is lower. The transmitter sends signals carrying different bit streams from each of its antennas. Each receiver antenna receives a linear combination of the transmitted signals. The wireless channel is a matrix that is a function of transmit/receive antenna array geometry and the scatters/reflectors present in the environment. When a MIMO transmitter/receiver pair operates in an environment rich in scattering, the channel matrix becomes invertible, thus enabling the receiver to decode all the different signals transmitted from the various transmit antenna apertures, resulting in multiplexing gain. There is a trade off between the amount of diversity and multiplexing gain a MIMO system can provide. A typical MIMO transmitter/receiver pair automatically finds an operating point on the diversity-multiplexing trade off curve based on instantaneous wireless channel conditions.

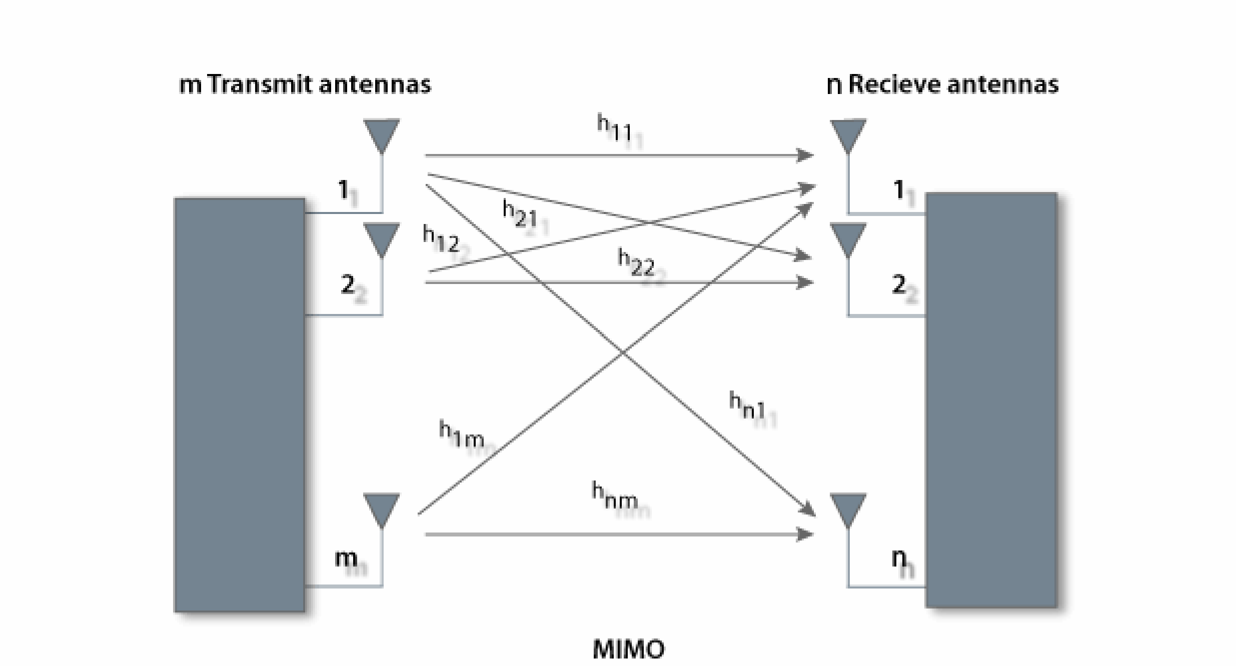

Figure 2.6: MIMO antenna design

2.3. Applications of microstrip antenna

2.3.1. Communication based applications:

Mobile communication requires small, low-cost, low-profile antennae. In some mobile handsets, semiconductor-based diodes or detectors are used as antennae. They are much like p-n diode photo-detectors but work at microwave frequency. Many times omnidirectional antenna is used in mobile phones. There are different kinds of antennae like planar inverted-F antenna, folded inverted conformal antenna and mono pole. Also retractable whip antenna is commonly used in handsets. The phone is subdivided into roughly 60 components, each consisting of hundreds or even thousands of individual facets.

2.3.2. Medical application:

Implantable medical devices are used to perform a wide variety of diagnostic and therapeutic function. With the help of biotelemetry and integrated implantable antenna full duplex communication is made possible between implantable antennas with on body receiver antennas for in-body communication system. Also wireless communication makes inroads into every aspect of human life. Designing an antenna for implanted application is difficult because of different electrical properties of human tissue. Also size of antenna at low frequency is a very crucial factor. Implantable medical devices can communicate wirelessly with an external device. Biomedical telemetry can be both real time and stored physical signals can also be communicated to the receiver. As per the commendation of FCC, Medical Implant communication Services (MICS) band of 402-406 MHz is recommended for implantable antennas. MICS band has replaced previous low frequency inductive link, which suffers from slow data rate, short range communication. The maximum transmit power requirement at this band is very low, about 25 microwatt. This reduces the risk of interference with other users of the same band. The maximum used bandwidth at a time is 300 KHz, which makes it a low bit rate system compared with Wi-Fi or Bluetooth. Implanted devices are inserted into human body and implantable antenna ensures wireless bio-telemetry. Therefore the antenna design is very crucial part in implantable device. Microstrip patch antenna is preferred as it is a narrowband, wide-beam antenna. These are fabricated by etching the antenna element pattern in metal trace bonded to an insulating dielectric substrate, such as a printed circuit board, with a continuous metal layer bonded to the opposite side of the substrate which forms a ground plane. Ground plane acts as reflector for radiation or it prevents radiation towards human body. Common microstrip antennas are designed in shapes like square, rectangular, circular and elliptical, but any continuous shape is possible. Some patch antennas do not use a dielectric substrate, instead they are made of a metal patch mounted above a ground plane using dielectric spacers; the resulting structure is less rugged but has a wider bandwidth.

2.3.3 Textile antenna:

Recently, many researchers are focusing in the study of wireless body area network (WBAN). WBAN links various electronic devices in and on the human body. The application of WBAN has been intensifying in various fields including medical, military, navigation, entertainment, and sport. Several frequency bands have been assigned for WBAN systems, such as the Medical Implant Communication System band (MICS: 400 MHz), the Industrial Scientific Medical band (ISM: 2.40 GHz and 5.80 GHz), and the Ultra-wideband (UWB: 3.00-10.00 GHz), respectively. In WBAN, portable devices and sensors must have a persistent ubiquitous network connection to communicate with each other. A key technology to achieve this obtrusive requirement is wearable electronics and antennas. Considering the convenience of users, wearable antennas need to be flexible, hidden and lightweight. Therefore textile wearable antennas have become the focus of many antenna research efforts due to their flexibility, durability, and suitability for various applications . It is important to focus the properties of textile material, which directly affect a wearable antenna radiation performance . In this study, a wearable microstrip patch antenna is being designed, fabricated, and integrated to clothing. The main distinction of a wearable patch antenna from a regular patch antenna is that a wearable antenna substrate is made of textile fabrics. Textile fabric with a low dielectric constant or relative permittivity, can reduce the surface wave loss, which is tied to guided wave propagation within substrates. As a consequence, this will improve impedance bandwidth. For any wearable antenna, wider impedance bandwidth is required to have a larger tolerance to cope with a resonant frequency, fr shift due to changing shape and environment.

2.4 FEEDING 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. Feeding technique is governed by the factor of efficient power transfer between the radiation structure, feeding structure and their impedance matching .

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. The conducting strip is smaller in width as compared to the patch. This kind of feed arrangement has the advantage that the feed can be etched on the same substrate to provide a planar structure. An inset cut can be incorporated into the patch in order to obtain good impedance matching without the need for any additional matching element. This is achieved by properly controlling the inset position.

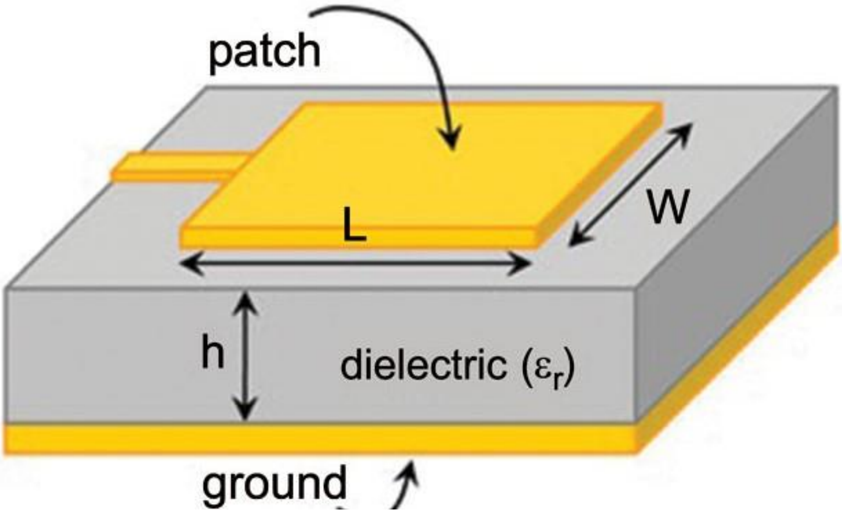

Figure 2.7 : Microstrip Line Feed

2.4.2. Coaxial Feed

The Coaxial feed or probe feed is one of the most common techniques used for feeding microstrip patch antennas. 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. Coaxial feed The main advantage of this type of feeding scheme is that the feed can be placed at any desired position inside the patch in order to obtain impedance matching. This feed method is easy to fabricate and has low spurious radiation effects. However, its major disadvantage is that it provides narrow bandwidth and is difficult to model since a hole has to be drilled into the substrate. Also, for thicker substrates, the increased probe length makes the input impedance more inductive, leading to matching problems. By using a thick dielectric substrate to improve the bandwidth, the microstrip line feed and the coaxial feed suffer from numerous disadvantages such as spurious feed radiation and matching problem. The non-contacting feed techniques which have been discussed below, solve these problems.

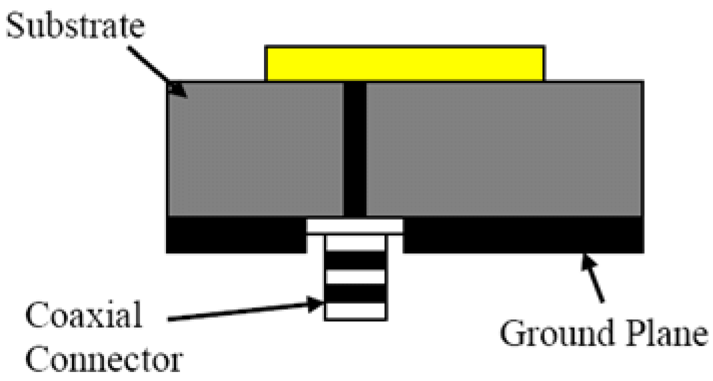

Figure 2.8 : Coaxial Feed

2.4.3. Aperture Coupled Feed

In aperture coupling as shown in figure 1.4 the radiating microstrip patch element is etched on the top of the antenna substrate, and the microstrip feed line is etched on the bottom of the feed substrate in order to obtain aperture coupling. The thickness and dielectric constants of these two substrates may thus be chosen independently to optimize the distinct electrical functions of radiation and circuitry. 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

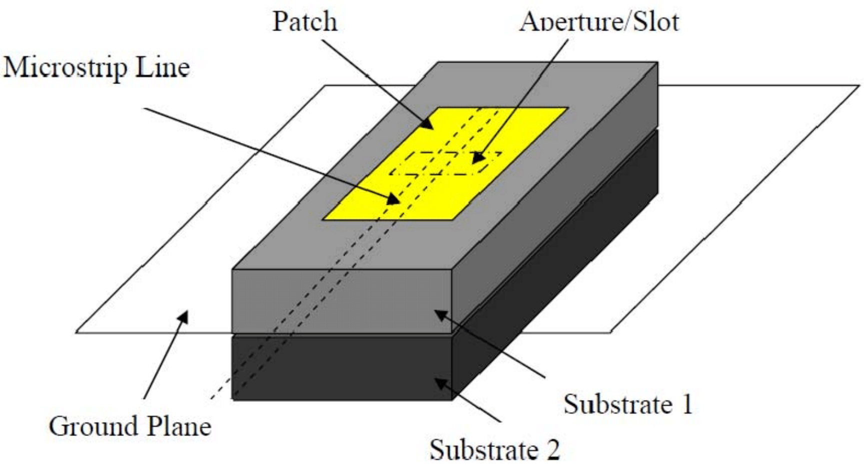

Figure 2.9 : Aperture-coupled feed

2.4.4.Proximity Coupled Feed

This type of feed technique is also called as the electromagnetic coupling scheme. As shown in Figure 14 and Figure 15 respectively. 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%) [5], due to overall increase in the thickness of the microstrip patch antenna [17]. 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

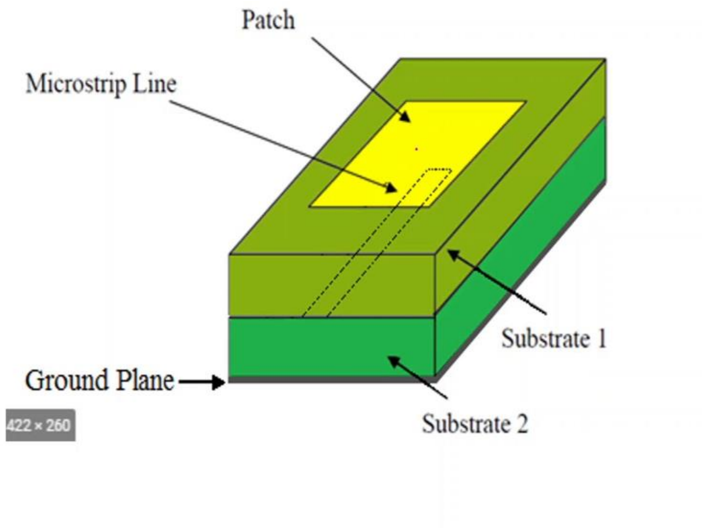

Figure 2.10 : Proximity-coupled Feed

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%

Table 2.1 Comparing the different feed techniques

3. A Compact Wideband MIMO Antenna With Very Low Mutual Coupling For Wireless Applications (Base Paper)

3.1 INTRODUCTION

Recently, there has been an enormous demand of high-performance compact antenna for wearable devices. The idea of these wearable antennas has widespread in the arenas of rescue in urgent crisis condition, monitoring of health, medical assistance, and physical training applications. The demanding high data rate needs additional antenna elements that may increase the functional capability for the multiple frequency applications. On the other hand, recent wireless devices also require the system miniaturization along with the multi-antenna arrangements. Therefore, researchers should take care for the design of the recent wireless gadgets. In this perspective, wide band MIMO antennas are found to be essential because of their less power requirement, ability to provide extraordinary data rate and exclusion from the interferences of other schemes. The design of a wearable antenna is really challenging due to its operation in human-body that consists of a lossy intermediate with a high value of permittivity. The efficiency of the antenna may be degraded by this property. Therefore, special precaution is to be set due to its textile integrated wearable design. Different real-world circumstances such as folding, twisting, and washing disputes are also possible for the wearable on-body antenna performance. Insertion of EBG, SRR, different stubs, slots, DGS into the MIMO antenna could advance the antenna performances such as gain improvement, broaden of bandwidth and mutual coupling (MC) reduction between the elements. MIMO antenna can increase the transmission ability as well improve the spectral efficiency. It also simplifies the layers of the multiple accesses and upturns the robustness along with the reduction of the air interface potential. Reduction of mutual coupling is one of the major constraints in MIMO antenna design. It is also desired that the envelope correlation coefficient (ECC) should be very low along with higher diversity gain (DG) for a good MIMO antenna system

3.2 ANTENNA DESIGN

The project deals with the design of a compact wide band wearable MIMO antenna with very low mutual coupling (VLMC). The proposed antenna composed of jean cloth substrate with relative permittivity 1.6. Two “I” shaped stubs are connected in series and are employed on the ground plane between the two patches separated by 0.048λ to increase isolation characteristics of the antenna port.

The antenna is designed to cover frequency spectrum from 2 GHz to 8 GHz (about 125.5%). The envelope correlation coefficient (ECC) of the MIMO antenna which should be less than 0.5 is examined and also other parameters such as diversity gain, total active reflection coefficient which should be less than -10 dB for the operating band of frequencies are examined. The proposed antenna is geometrically symmetric along the x axis so as to maintain a low cross polarization. The electromagnetic software HFSS was used for simulation, and the final dimensions of the proposed antenna are given in Table 1.

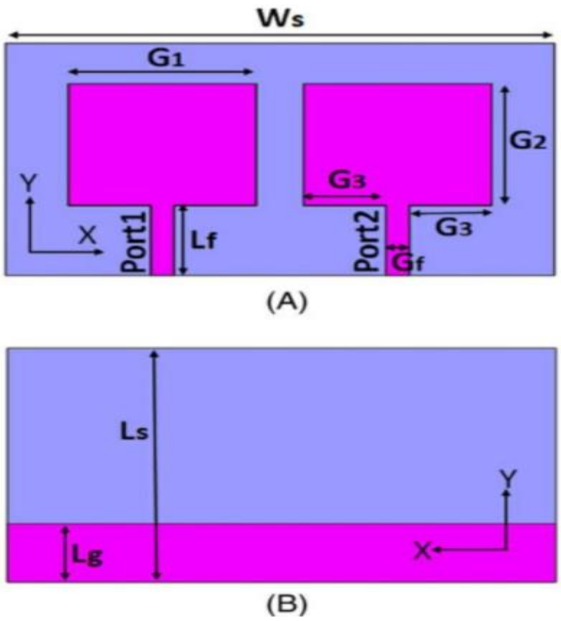

Figure 3.1

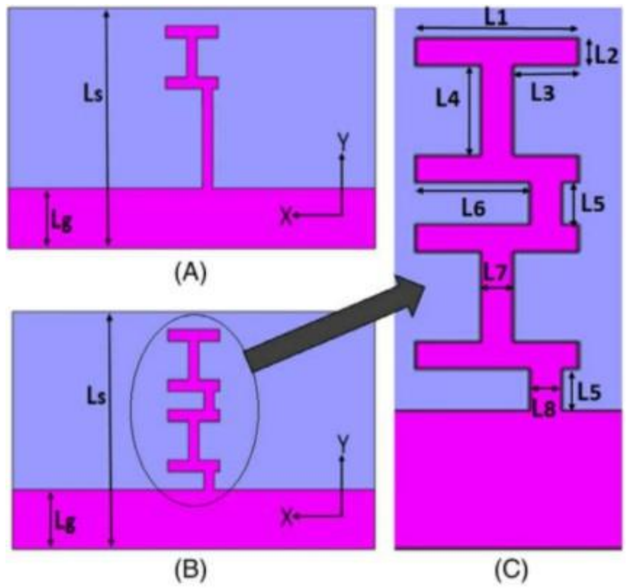

Figure 3.2

Figure 3.1: Arrangement of the MIMO antenna (A) top view and (B) bottom view

Figure 3.2: Bottom layer of MIMO antenna with (A) single 'I' stubs, (B) double 'I' stub, and (C) structure of the double 'I' stub

Parameters	Dimension (mm)	Parameters	Dimension (mm)
G_1	24	L1	10
G_2	21	L2	2
G_3	10.5	L3	4
G_f	3	L4	6.5
L_f	12	L5	3
Ws	70	L6	7
Lg	10	L7	2
Ls	40	L8	2
d	6	h	1

Table 3.1: Parameter dimension of the proposed MIMO antenna

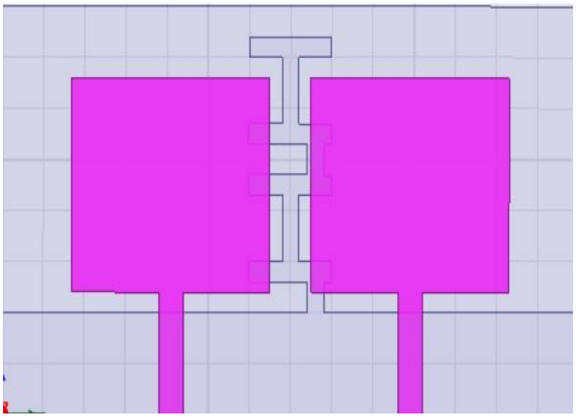

Figure 3.3 : Top View of MIMO Antenna

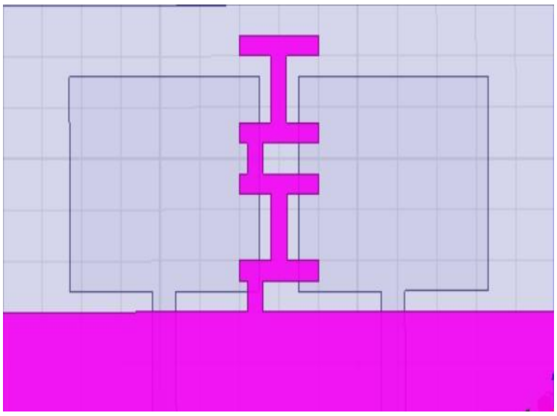

Figure 3.4: Bottom View of MIMO Antenna

MIMO PARAMETERS :

The diversity capabilities with respect to any MIMO antenna are analysed by the computation of Mean Effective Gain (Mean),Total Active Reflection Coefficient (TARC), and Envelope Correlation Coefficient (ECC).These parameters are calculated using the formulas given as mentioned below

$$ECC = \frac{\left|s_{pp}^{*}s_{pq} + s_{qp}^{*}s_{qq}\right|^{2}}{\left(1 - \left|s_{pp}\right|^{2} - \left|s_{pq}\right|^{2}\right)\left(1 - \left|s_{qp}\right|^{2} - \left|s_{qq}\right|^{2}\right)^{*}} \tag{3.1}$$

$$TARC = -\sqrt{\frac{\left(s_{pp} + s_{pq}\right)^{2} + \left(s_{qp} + s_{qq}\right)^{2}}{2}} \tag{3.2}$$

3.3 RESULTS AND DISCUSSION

MIMO Parameters:

Envelope Correlation Coefficient (ECC):

Envelope Correlation Coefficient tells us how independent two antennas' radiation patterns are. So if one antenna was completely horizontally polarized, and the other was completely vertically polarized, the two antennas would have a correlation of zero. Similarly, if one antenna only radiated energy towards the sky, and the other only radiated energy towards the ground, these antennas would also have an ECC of 0. Hence, Envelope Correlation Coefficient takes into account the antennas' radiation pattern shape, polarization, and even the relative phase of the fields between the two antennas.

MEAN EFFECTIVE GAIN (MEG):

The mean effective gain is one of the most important parameters for the characterization of antennas in wireless channels. An analysis of some fundamental properties of the MEG is provided and corresponding physical interpretations are given.

Total Active Reflection Coefficient (TARC):

From the graph, it is evident that the ECC vs frequency plot is far less than 0.5 which satisfies the standard condition. Also the difference between the meg vs frequency plots is almost equal to 0.1

which is less than 3dB thereby satisfies the standard condition. TARC vs frequency plot shows that the plot obtained was below -10dB over the range of our operating frequency range which also satisfied the standard conditions. All these plots shows that our antenna would work efficiently.

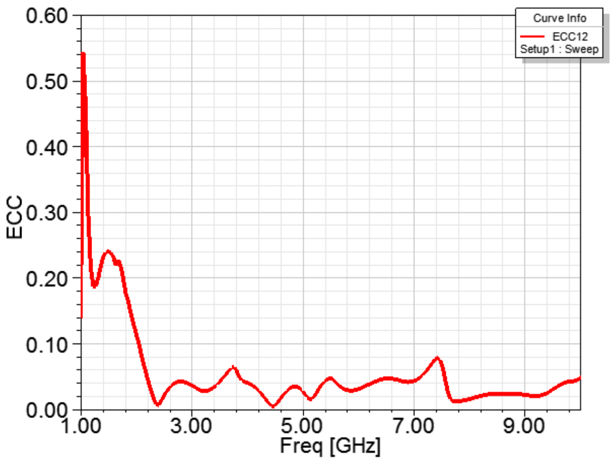

Figure 3.5 : Envelope Correlation Coefficient plot

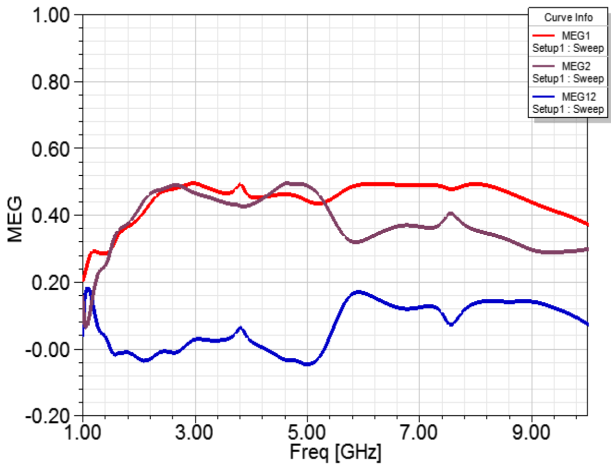

Figure 3.6 : Mean Effective Gain plot

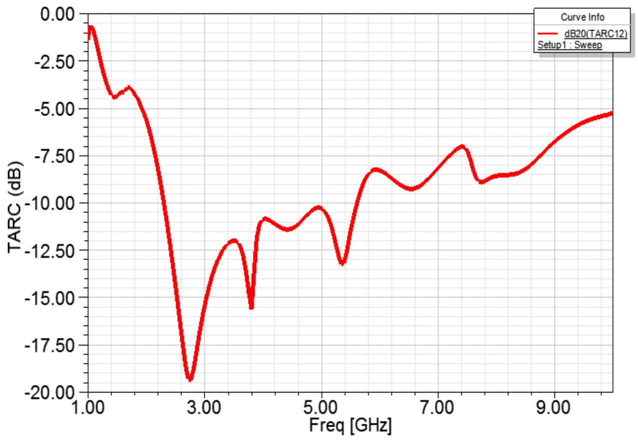

Figure 3.7 : Total Active Reflection Coefficient plot

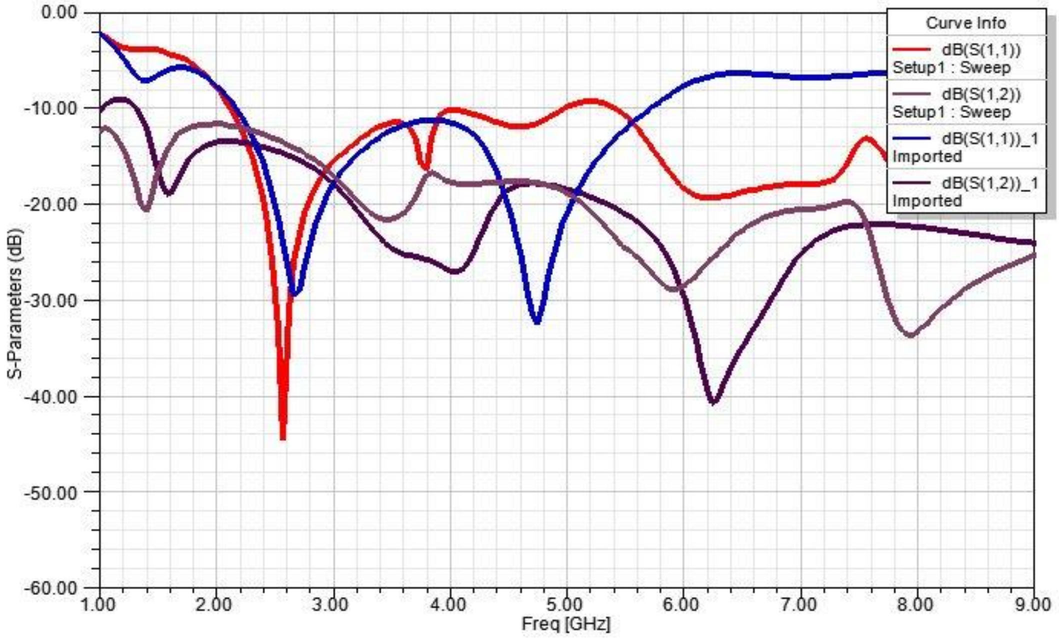

Figure 3.8 : S-Parameters Obtained for MIMO antenna

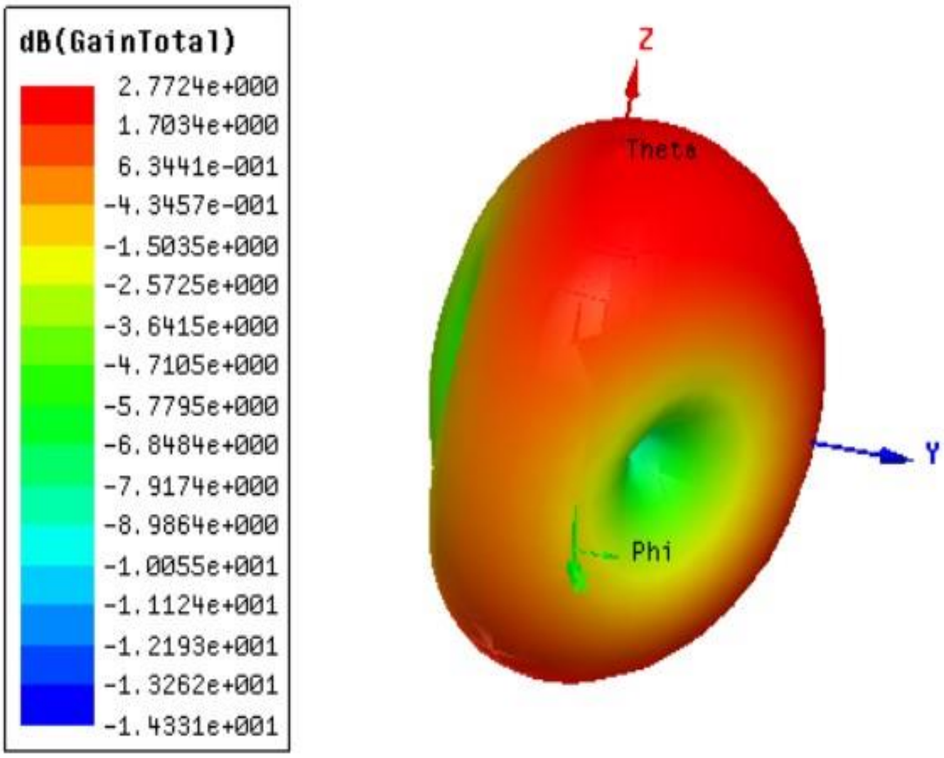

Figure 3.9 : 3D Figure of Radiation Pattern at 5 GHz

CONCLUSION:

A compact wideband MIMO antenna with very low mutual coupling is obtained with the two 'I' shaped stubs on the ground plane and with two rectangular patch antennas on the dielectric substrate. The antenna will be working over the frequency range of 2 to 8 GHz. Also the MIMO parameters like envelope correlation coefficient which is less than 0.5 and mean effective gain less than 3dB and the total active reflection coefficient is less than -10dB which satisfies the standard conditions.

4. Wearable Dual-port MIMO antenna for On-body applications (extension work)

ABSTARCT:

In this chapter, a conformal MIMO circular patch antenna structure is proposed. Two elements with individual port excitations are presented for obtaining the MIMO arrangement. The antenna is backed by a Jean cloth substrate with relative permittivity 1.6 and a loss tangent of 0.02. The impedance bandwidth concerning -10 dB is achieved from frequency ranges 2.3 GHz to 2.85 GHz covering ISM band (2.4 to 2.5GHz) for On body applications. The center frequency is 2.58 GHz and the impedance bandwidth observed is 550 MHz. In the proposed antenna structure a double H-shaped stub is introduced on ground plane for better impedance matching. Important parameters such as Total Active Reflection Coefficient, Mean Effective Gain, Envelope Correlation Coefficient which are responsible for the efficient working of the MIMO are also investigated and are found to be well within the standards with TARC < -10dB, MEG < 3 dB and ECC < 0.5. Also, Specific Absorption Rate analysis is carried out by creating the homogenous 3-layer human body model consisting of skin, fat, and muscle layers. The work is carried out using ANSYS High Frequency Structure Simulator (HFSS) software.

4.1 Introduction

Present-day wireless communication systems must give both channel capacity and good reliability. Multiple-input-multiple output technology is the best way to obtain such targets. Dissimilar contemporary communication devices like mobile phones, USB dongles, and laptops use MIMO technology [1]. MIMO antenna technology is largely used in contemporary wireless units. The data rate is enhanced by multiple antennas without the use of more power levels and bandwidth [2]. The main advantage of MIMO technology is permitting different users to use multiple utilities in sequence and at the same time giving further advancement in the channel ca pacity and the transmission quality of wireless communication technologies [3]. For wideband systems in multi-path domains have difficulties with signal diminishing. MIMO technology is designed to improve the communication quality therefore this technology can be used to regulate the multipath fading problem in wideband systems [4]. Data-rate needs f or future services are too high and high data rates are achieved by wideband and UWB considerations. Higher data rates achieved using is MIMO technology in UWB systems is discussed in [5].In [6] a dual compact MIMO antenna with planar monopole antenna as the antenna element for ISM and LTE2300 operations is discussed. This system covered a 310 MHz (2.20–2.51 GHz) operating bandwidth. I n [7] a four element wideband monopole MIMO antenna is mentioned. At first, a single-element wideband CPW-fed antenna is designed to work on the scale of 4.30 to 6.45 GHz, and later the design is extended to MIMO .In [8] a cylindrical dielectric resonator antenna with a four-element, eight-port structure is proposed capable of multidirectional pattern applicable for applications involving wireless access point .In this, two different feeding methods are discussed to create two concurrent orthogonal patterns. In [9] a dual-port multiple-input multiple-output antenna, operating in ultrawideband (UWB) frequency band communication is mentioned. In [10] A thick 2×2 metamaterial-MIMO antenna for WLAN applications is discussed where two single metamaterial antennas are placed alongside each other to design a MIMO antenna. They are built on the altered composite right/left-handed model. In this research paper, a circular patch antenna with a double H-shaped ground stub is proposed for ISM band (2.4 to 2.5GHz) On-body applications. The design is later extended to conformal geometry where it is bent to study the isolation parameters. Important MIMO parameters such as TARC, MEG, and ECC are computed and other important antenna parameters such as reflection coefficient, isolation, and ga in are studied. SAR analysisis carried out in the final stage.

4.2 Antenna Design Structure

The antenna is designed with two circular patches as shown in Fig.1a etched top of the dielectric substrate and a double H-shaped stub on the ground plane. The radii of the circular patches are 10mm.The double H-shaped stub is placed on the ground plane with optimized dimensions as shown in Fig. 1b. The dimensions of the dielectric are 70 x 40 (width x length) and height is considered to be 1mm. Symmetry is maintained between the two patches with the help of optimized measurements. The dielectric used is Jean cloth with relative permittivity is 1.6. The loss tangent for this material is found to be 0.02. The ground plane on the other side is considered with the following dimensions 70 x 5mm (width x length). The radius of the patch is calculated using the general circular patch antenna equations mentioned in [11]. The modelling and analysis of the proposed antenna is done in ANSYS HFSS software.

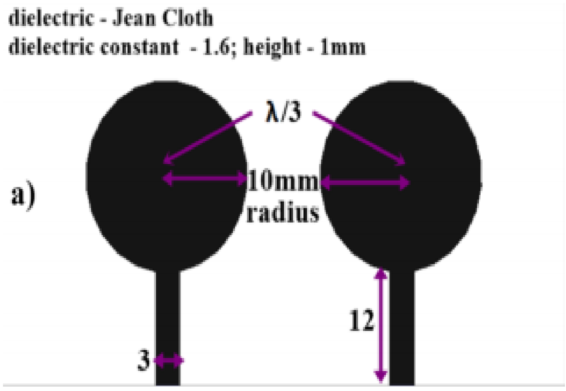

Figure 4.1 : Front view of proposed antenna

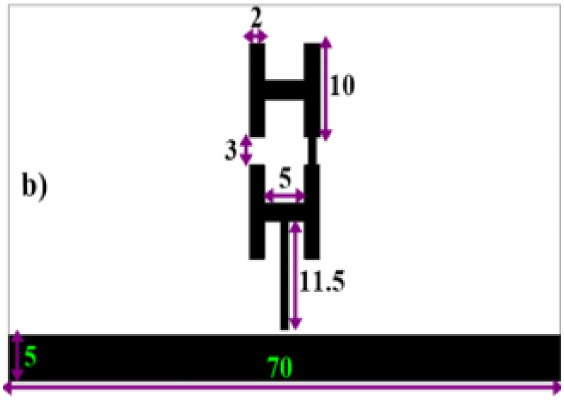

Figure 4.2 : Back view of propose antenna

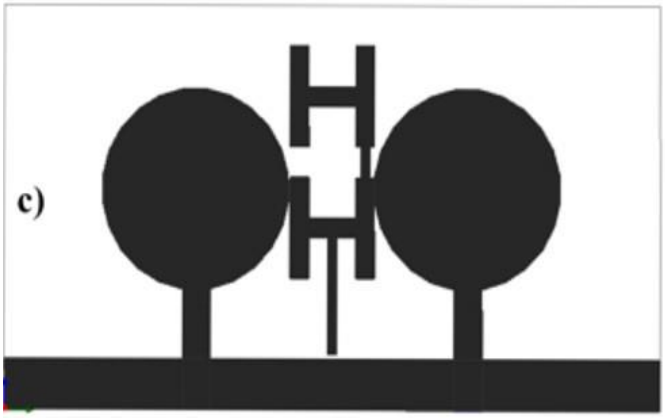

Figure 4.3 : Overall view of proposed antenna

The proposed antenna is further subjected to conformal geometry as shown in Fig.7 to study the effect on isolation characteristics upon bending. Two bend angles are considered with angles of 15^0

and 25^0. Fig.8 shows the simulation results for s-parameters of the conformal arrangement of the proposed antenna. For both the cases taken (15^0 and 25^0 bend angles), the proposed MIMO antenna maintained a good ref lection coefficient and isolation properties with less than -20dB for the entire operating bandwidth range. Therefore, the conformal MIMO antenna arrangement sho wed an overall satisfactory MIMO performance indicating good isolation or lower mutual coupling effect.

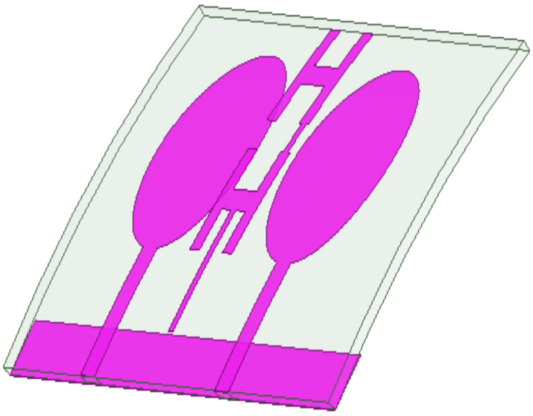

Figure 4.4 : Conformal design with 15^0 bend

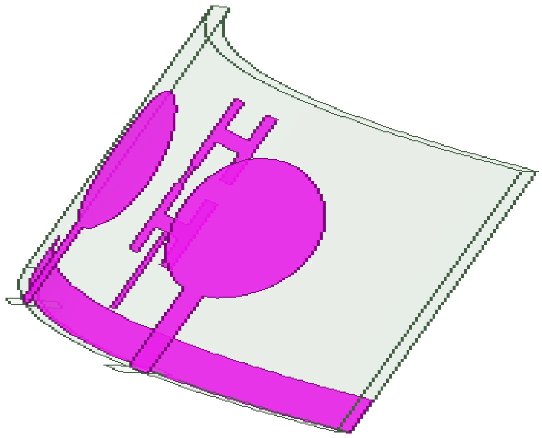

Figure 4.5 : Conformal design with 25^0 bend

MIMO PARAMETERS :

The diversity capabilities with respect to any MIMO antenna are analysed by the computation of Mean Effective Gain (MEG),Total Active Reflection Coefficient (TARC), and Envelope Correlation Coefficient (ECC).These parameters are calculated using the formulas given as mentioned below

$$\boldsymbol{ECC = \frac{\left|s_{pp}^{*}s_{pq} + s_{qp}^{*}s_{qq}\right|^{2}}{\left(1 - \left|s_{pp}\right|^{2} - \left|s_{pq}\right|^{2}\right)\left(1 - \left|s_{qp}\right|^{2} - \left|s_{qq}\right|^{2}\right)^{*}}} \quad \textbf{(4.1)}$$

$$\boldsymbol{TARC = -\sqrt{\frac{\left(s_{pp} + s_{pq}\right)^{2} + \left(s_{qp} + s_{qq}\right)^{2}}{2}}} \quad \textbf{(4.2)}$$

By using the above equations the S-parameters are obtained and the MIMO antenna is simulated on the HFSS software.

5. Results and Discussions

The Simulations are done stage by stage in order to observe the improvement in the S11 plot. The simulations are carried in High Frequency Structure Simulator (HFSS) software.

5.1 Analysis of proposed antenna:

The S-parameters are analyzed for the proposed MIMO antenna. Fig 2 shows the reflection coefficient plot. It is evident from the figure that both the design structure impedance bandwidth pertaining to -10 dB is well achieved from 2.3 GHz to 2.85 GHz (bandwidth of 550MHz) with the center frequency around 2.58 GHz. One of the critical and crucial factors to consider while designing a MIMO antenna is the effect of mutual coupling. When port 1 is excited with all other ports are terminated using a characteristic impedance of 50ohms this factor is calculated. Fig.2 gives necessary information regarding the mutual coupling information from port 1. It is to be particularly noted that the isolation or transmission coefficients from Fig.2 are less than -15 dB for the entire working impedance bandwidth of 2.3 GHz to 2.85 GHz. From Fig.3 the radiation pattern of the proposed antenna is analysed . The antenna obtained a peak gain of 3.81 dB in the principle direction. It is to be particularly noted that the difference between co-polarization and cross-polarization is greater than -15dB which defines satisfactory radiation properties of the antenna. The diversity capabilities with respect to any MIMO antenna are analysed by the computation of Mean Effective Gain (Mean), Total Active Reflection Coefficient (TARC), and Envelope Correlation Coefficient (ECC) .These parameters are calculated using the formulas given as mentioned below.

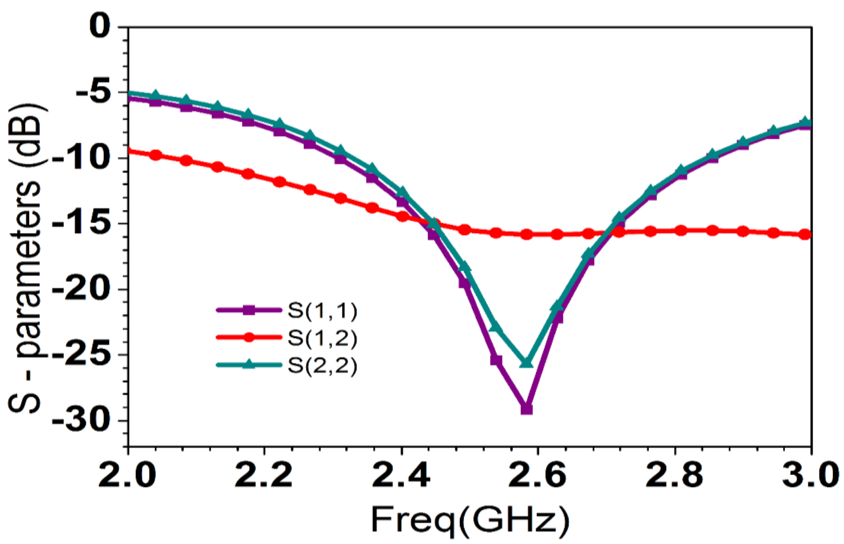

Figure 5.1 : S-Parameters for Proposed MIMO Antenna

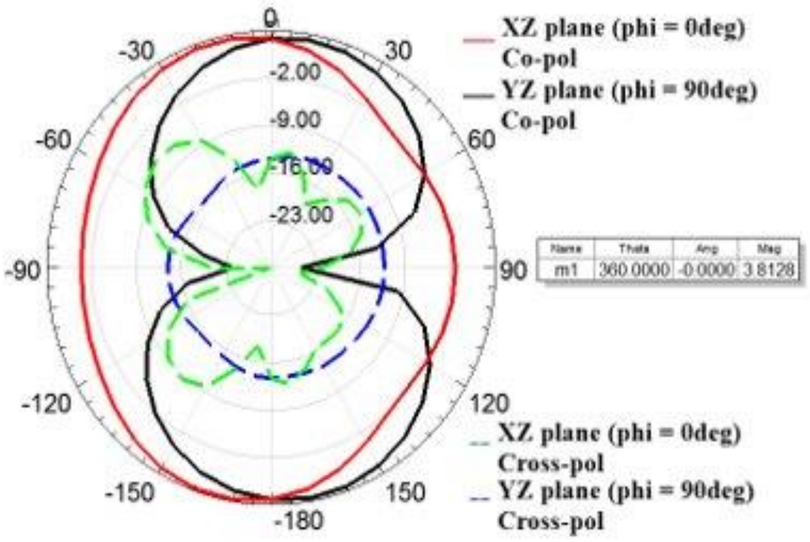

Figure 5.2 : Radiation Pattern for Proposed MIMO Antenna

Fig.4 deals with the ECC versus frequency plot. From the figure, it is evident that the value of the ECC is limited to less than 0.17 for the entire operating frequency range of 2.3 to 2.85 GHz. In general, for MIMO applications ECC is said to be satisfactory if it is limited to less than 0.5 and considerably good if it is less than 0.3. The proposed MIMO antenna system is well within the standard limit and is as low as < 0.17.

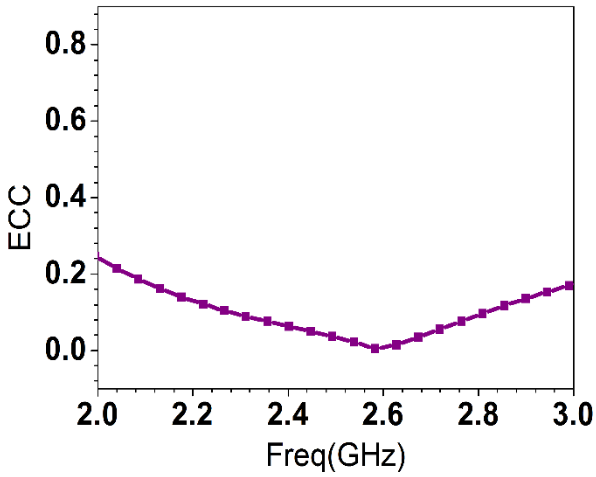

Figure 5.3 : Envelope Correlation Coefficient plot

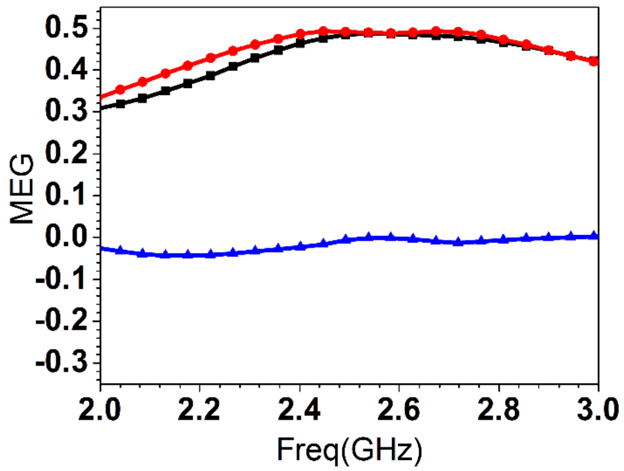

Figure 5.4 : Mean Effective Gain plot

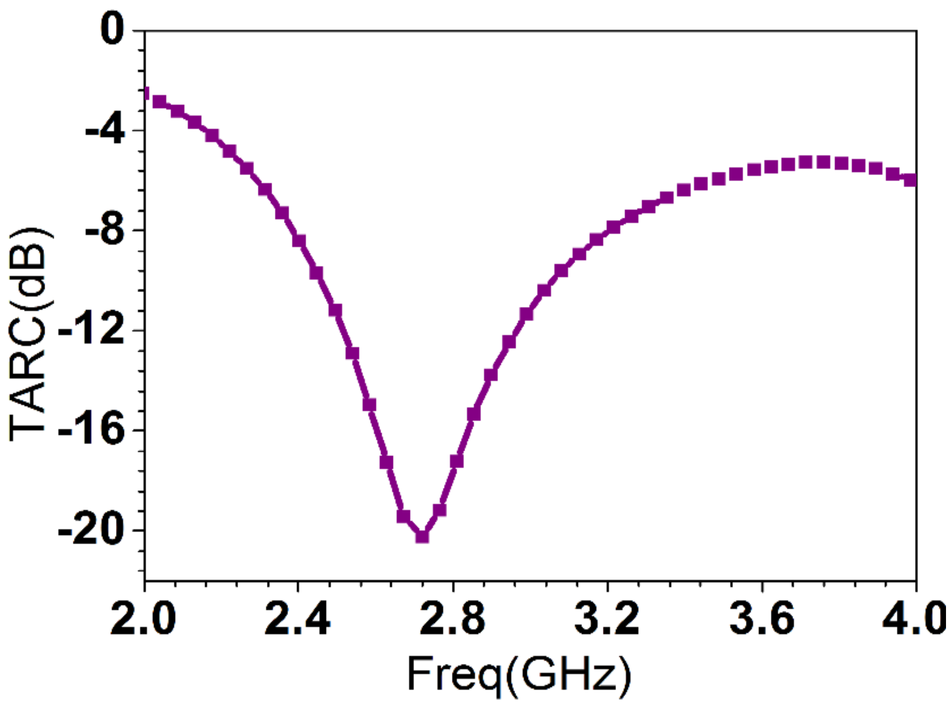

Figure 5.5 : Total Active Reflection Coefficient plot

Fig. 5 shows the Mean Effective Gain (MEG) plot calculated between two antenna elements as mentioned in [12]. The difference between the mean effective gain of any two antenna should be less than 3 dB as per the standards. As seen from the graph the difference is less than 1 dB which satisfies the standards. Fig. 6 shows the TARC against frequency plot which depicts that the TARC obtained is as low as -21 dB and well within the standard (the less than -10dB) f or the entire operating range of the proposed antenna. Fig.8 shows the simulation results for s-parameters of the conformal arrangement of the proposed antenna. For both the cases taken (15^0 and 25^0 bend angles), the proposed MIMO antenna maintained a good ref lection coefficient and isolation properties with less than -20dB f or the entire operating bandwidth range. Therefore, the conformal MIMO antenna arrangement showed an overall satisfactory MIMO performance indicating good isolation or lower mutual coupling effect.

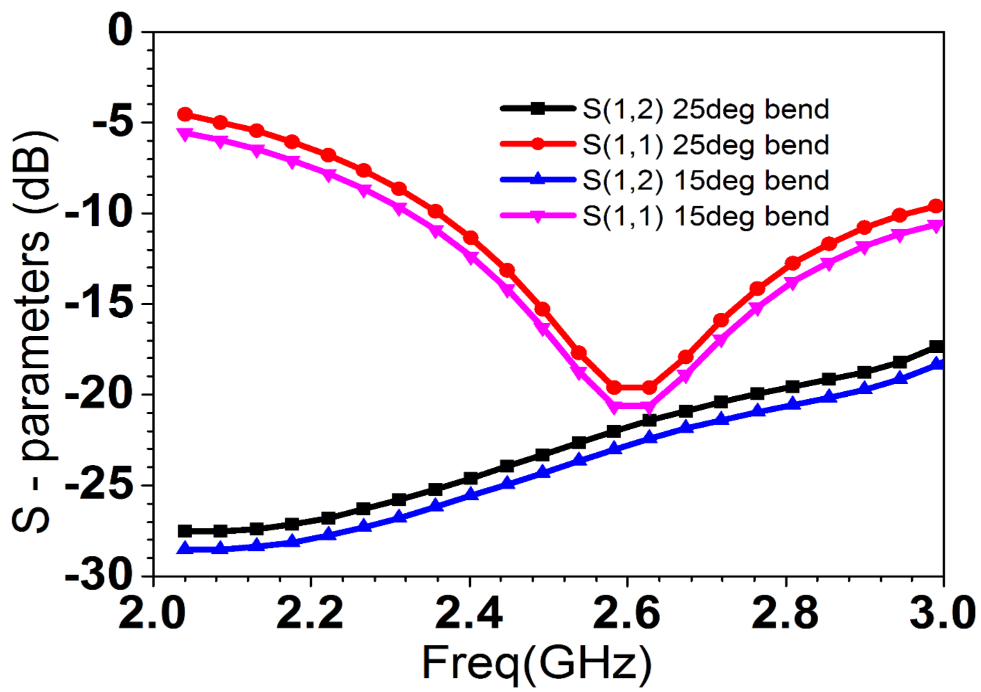

Figure 5.6 : S-Parameters For Conformal Design.

5.2 Specific absorption rate analysis :

Once, the MIMO parameters are calculated and analyzed, SAR analysis is carried out as a final stage. In general, the mathematical relation using which SAR is calculated is given by

$$SAR = \sigma \frac{|E^2|}{\rho} \quad \textbf{(5.1)}$$

where 'σ' is the conductivity (s/m), E defines the electric field (V/m) and 'ρ' is taken as the biological tissue's mass density often usually represented in (kg/m^3). A three-layer homogenous human body model with skin, fat, and muscle a s shown in Fig.9 is modelled. Each of these layers has a different mass and permittivity as discussed in [13]. The SAR analysis is carried out to check the proposed antenna compliance level with the FCC recommended standard of 1.6 Watts/Kg .The below Fig. 10 shows the SAR values against the skin, fat, and muscle for 1g of tissue. Table 1 represent the SAR analyses for different types of power input values against both 1g and 10g of tissue. The values suggest the proposed MIMO antenna complies with FCC set standards as all the values were well below 1.6 Watts/Kg.

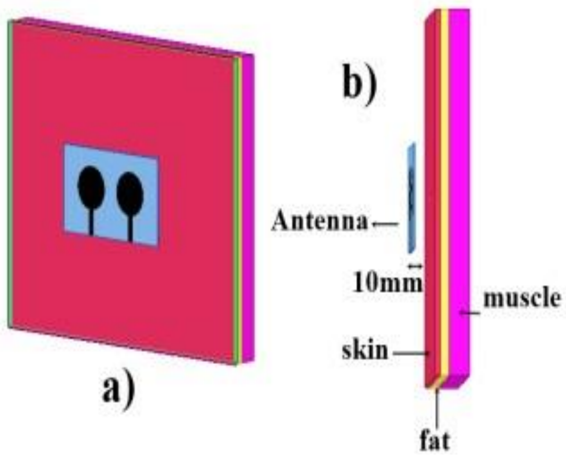

Figure 5.6 : Proposed MIMO antenna
Arrangment against 3-layer homogenous human
body model

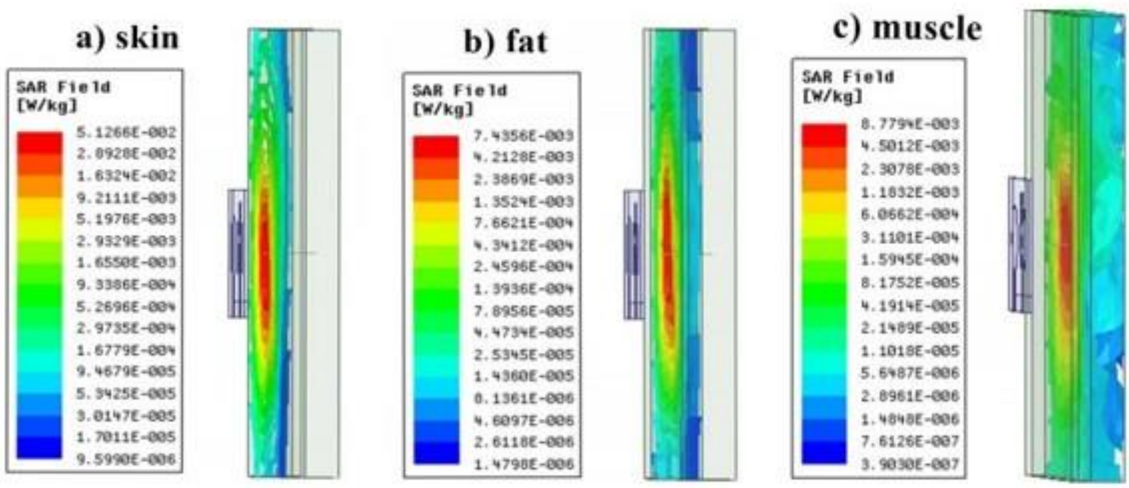

Figure 5.7 : SAR values of proposed MIMO antenna against 3-layer homogeneous human body model(1 g tissue)

Mass of the Tissue = 1g	SAR value (w/kg)		
Input power	**Skin**	**Fat**	**Muscle**
1mW	0.0512	0.00743	0.00877
25mW	1.281	0.185	0.219
Mass of the Tissue = 10g	**SAR value (w/kg)**		
Input power	**Skin**	**Fat**	**Muscle**
1mW	0.0136	0.00307	0.00348
25mW	0.3224	0.0768	0.0871
50mW	0.684	0.153	0.174

Table 5.1 : SAR values against the 3-layer homogeneous human body model

6. Conclusion

A wearable circular MIMO antenna with H shaped ground stub is proposed in this chapter. The MIMO antenna designed covered the frequency range of 2.3 GHz to 2.85 GHz with a n impedance bandwidth of 550 MHz. The intention to target ISM band of (2.4 to 2.5 GHz) for On-body applications is achieved. The proposed MIMO antenna also achieved good isolation of greater than –15 dB for the entire operating bandwidth. MIMO performance in terms of Envelope Correlation Coefficient (ECC), Mean Effective Gain (MEG) and, Total Active Reflection Coefficient (TARC) is also computed which showed ECC < 0.17, MEG difference below 3dB, and TARC < -10 dB for the mentioned bandwidth range. The conformal arrangement of the proposed structure with two bend angles also showed good isolation characteristics. Finally, SAR analysis is carried out to check the conformity with FCC standards and is found to be within the set limit of 1.6 watts/kg for both 1g and 10g tissue against different input power levels. Therefore, the proposed MIMO antenna can be a prime candidate for On-body applications targeting the ISM band.

7. References

[1]. Ssorin, V., Artemenko, A., Maltsev, A., Sevastyanov, A. and Maslennikov, R., 2012. Compact MIMO microstrip antennas for USB dongle operating in 2.5–2.7 GHz frequency band. International Journal of Antennas and Propagation, 2012.

[2]. Yang, L., Li, T. and Yan, S., 2015. Highly compact MIMO antenna system for LTE/ISM applications. International Journal of Antennas and Propagation, 2015.

[3]. Ali, W.A. and Ibrahim, A.A., 2017. A compact double-sided MIMO antenna with an improved isolation for UWB applications. AEUInternational Journal of Electronics and Communications, 82, pp.7-13.

[4]. Mohammad Saadh, A.W., Khangarot, S., Sravan, B.V., Aluru, N., Ramaswamy, P., Ali, T. and Pai, M.M., 2020. A compact four-element MIMO antenna for WLAN/WiMAX/satellite applications. International Journal of Communication Systems, 33(14), p.e4506.

[5]. Quddus, A., Saleem, R., Shabbir, T., ur Rehman, S. and Shafique, M.F., 2016, August. Dual port UWB-MIMO antenna with ring decoupling structure. In 2016 Progress in Electromagnetic Research Symposium (PIERS) (pp. 116-119). IEEE.

[6]. Yang, L., Li, T. and Yan, S., 2015. Highly compact MIMO antenna system for LTE/ISM applications. International Journal of Antennas and Propagation, 2015.

[7]. Mohammad Saadh, A.W., Khangarot, S., Sravan, B.V., Aluru, N., Ramaswamy, P., Ali, T. and Pai, M.M., 2020. A compact four-element MIMO antenna for WLAN/WiMAX/satellite applications. International Journal of Communication Systems, 33(14), p.e4506.

[8]. Chaudhary, P., Kumar, A., Kumar, P., Patel, K. and Verma, A.K., 2020. Circularly Polarized Wideband MIMO Rectangular Antenna in Cube Form for X-Band with Pattern and Polarization Diversity. Progress In Electromagnetics Research, 94, pp.103-108.

[9]. Quddus, A., Saleem, R., Shabbir, T., ur Rehman, S. and Shafique, M.F., 2016, August. Dual port UWB-MIMO antenna with ring decoupling structure. In 2016 Progress in Electromagnetic Research Symposium (PIERS) (pp. 116-119). IEEE.

[10]. Kiem, N.K., Phuong, H.N.B., Hieu, Q.N. and Chien, D.N., 2015. A novel metamaterial MIMO antenna with high isolation for WLAN applications. International Journal of Antennas and Propagation, 2015.

[11]. Tewari, M., Yadav, A. and Yadav, R.P., 2017, March. Polarization reconfigurable circular patch antenna: Parasitic stub. In 2017 international conference on wireless communications, signal processing and networking (WiSPNET) (pp. 1083-1086). IEEE.

[12]. Nasir, J., Jamaluddin, M.H., Khalily, M., Kamarudin, M.R., Ullah, I. and Selvaraju, R., 2015. A reduced size dual port MIMO DRA with high isolation for 4G applications. International Journal of RF and Microwave Computer-Aided Engineering, 25(6), pp.495-501.
[13]. Yadav, A., Kumar Singh, V., Kumar Bhoi, A., Marques, G., GarciaZapirain, B. and de la Torre Díez, I., 2020. Wireless body area networks: UWB wearable textile antenna for telemedicine and mobile health systems. Micromachines, 11(6), p.558.

8.Published Paper

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Wearable Dual-port MIMO antenna for On-body applications

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***Abstract*— In this chapter, a conformal MIMO circular patch antenna structure is proposed. Two elements with individual port excitations are presented for obtaining the MIMO arrangement. The antenna is backed by a Jean cloth substrate with relative permittivity 1.6 and a loss tangent of 0.02. The impedance bandwidth concerning -10 dB is achieved from frequency ranges 2.3 GHz to 2.85 GHz covering ISM band (2.4 to 2.5GHz) for On-body applications. The center frequency is 2.58 GHz and the impedance bandwidth observed is 550 MHz. In the proposed antenna structure a double H-shaped stub is introduced on the ground plane for better impedance matching. Important parameters such as Total Active Reflection Coefficient, Mean Effective Gain, Envelope Correlation Coefficient which is responsible for the efficient working of the MIMO are also investigated and are found to be well within the standards with TARC < -10dB, MEG < 3 dB, and ECC < 0.5. Also, Specific Absorption Rate analysis is carried out by creating the homogenous 3-layer human body model consisting of skin, fat, and muscle layers. The work is carried out using ANSYS High-Frequency Structure Simulator (HFSS) software.**

Keywords*— *Wearable antenna; MIMO; circular; conformal antenna; ISM band; Mean Effective Gain; Total Active Reflection; Envelope Correlation Coefficient; On-body Applications

I. INTRODUCTION

Present-day wireless communication systems must give both channel capacity and good reliability. Multiple-input-multiple-output technology is the best way to obtain such targets. Dissimilar contemporary communication devices like mobile phones, USB dongles, and laptops use MIMO technology [1]. MIMO antenna technology is largely used in contemporary wireless units. The data rate is enhanced by multiple antennas without the use of more power levels and bandwidth [2]. The main advantage of MIMO technology is permitting different users to use multiple utilities in sequence and at the same time giving further advancement in the channel capacity and the transmission quality of wireless communication technologies [3]. For wideband systems in multi-path domains have difficulties with signal diminishing. MIMO technology is designed to improve the communication quality therefore this technology can be used to regulate the multipath fading problem in wideband systems [4]. Data-rate needs for future services are too high and high data rates are achieved by wideband and UWB considerations. Higher data rates achieved using is MIMO technology in UWB systems is discussed in [5]. In [6] a dual compact MIMO antenna with planar monopole antenna as the antenna element for ISM and LTE2300 operations is discussed. This system covered a 310 MHz (2.20–2.51 GHz) operating bandwidth. In [7] a four-element wideband monopole MIMO antenna is mentioned. At first, a single-element wideband CPW-fed antenna is designed to work on the scale of 4.30 to 6.45 GHz, and later the design is extended to MIMO. In [8] a cylindrical dielectric resonator antenna with a four-element, eight-port structure is proposed capable of multidirectional pattern applicable for applications involving wireless access point. In this, two different feeding methods are discussed to create two concurrent orthogonal patterns. In [9] a dual-port multiple-input multiple-output antenna, operating in ultra wideband (UWB) frequency band communication is mentioned. In [10] A thick 2×2 metamaterial-MIMO antenna for WLAN applications is discussed where two single metamaterial antennas are placed alongside each other to design a MIMO antenna. They are built on the altered composite right/left-handed model.

In this research paper, a circular patch antenna with a double H-shaped ground stub is proposed for ISM band (2.4 to 2.5GHz) On-body applications. The design is later extended to conformal geometry where it is bent to study the isolation parameters. 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. SAR analysis is carried out in the final stage.

II. ANTENNA DESIGN STRUCTURE

The antenna is designed with two circular patches as shown in Fig.1a etched top of the dielectric substrate and a double H-shaped stub on the ground plane. The radii of the circular patches are 10mm. The double H-shaped stub is placed on the ground plane with optimized dimensions as shown in Fig. 1b. The dimensions of the dielectric are 70 x 40 (width x length) and height is considered to be 1mm. Symmetry is maintained between the two patches with the help of optimized measurements. The dielectric used is Jean cloth with relative permittivity is 1.6. The loss tangent for this material is found to be 0.02. The ground plane on the other side is considered with the following dimensions 70 x 5mm (width x length). The radius of the patch is calculated using the general circular patch antenna equations mentioned in [11]. The modelling and analysis of the proposed antenna is done in ANSYS HFSS software.

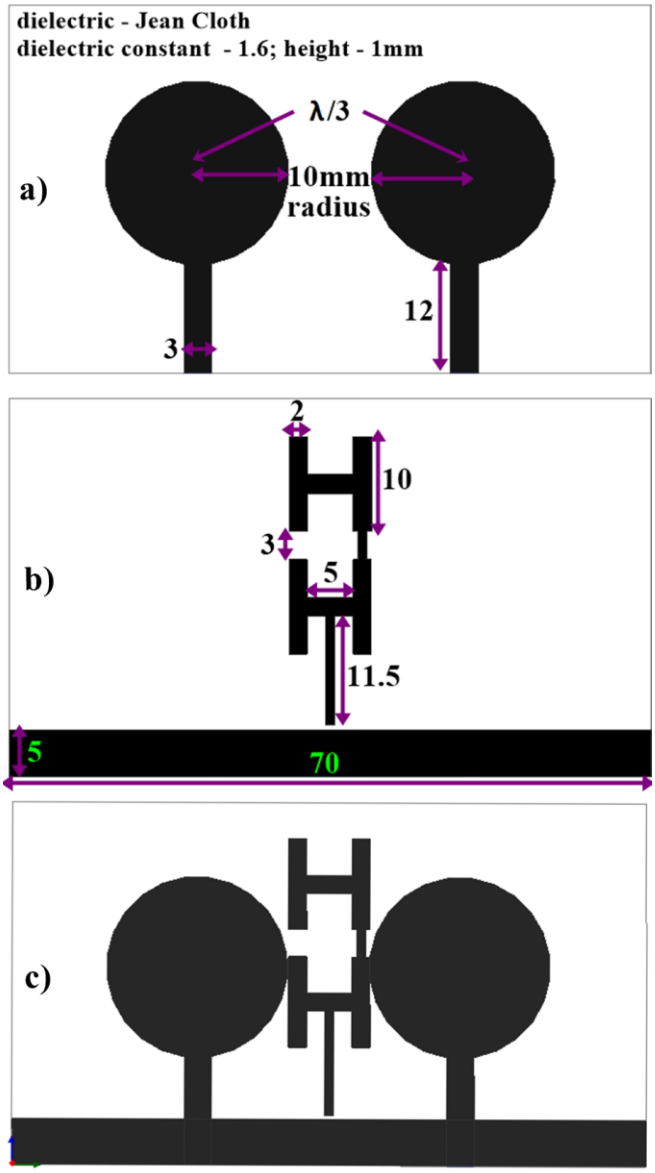

Fig. 1 Front, back and overall view of the proposed MIMO antenna

III. ANALYSIS OF PROPOSED ANTENNA

The S-parameters are analyzed for the proposed MIMO antenna. Fig 2 shows the reflection coefficient plot. It is evident from the figure that both the design structure impedance bandwidth pertaining to -10 dB is well achieved from 2.3 GHz to 2.85 GHz (bandwidth of 550 MHz) with the center frequency around 2.58 GHz.

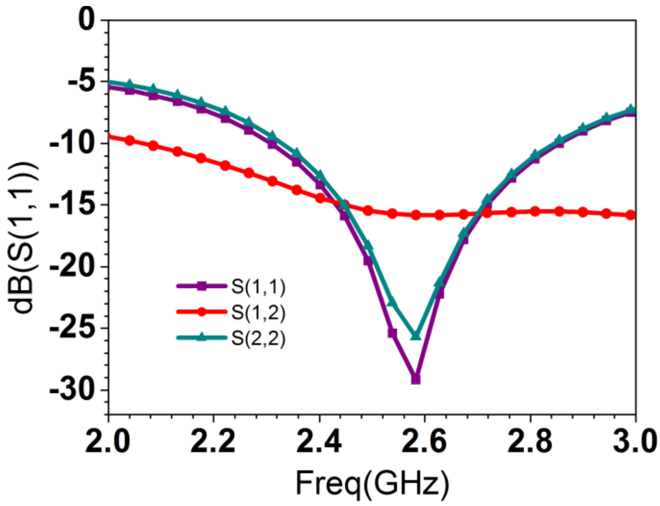

Fig. 2 Reflection coefficient parameters plot for the proposed antenna

One of the critical and crucial factors to consider while designing a MIMO antenna is the effect of mutual coupling. When port 1 is excited with all other ports are terminated using a characteristic impedance of 50ohms this factor is calculated. Fig.2 gives necessary information regarding the mutual coupling information from port 1. It is to be particularly noted that the isolation or transmission coefficients from Fig.2 are less than -15 dB for the entire working impedance bandwidth of 2.3 GHz to 2.85 GHz.

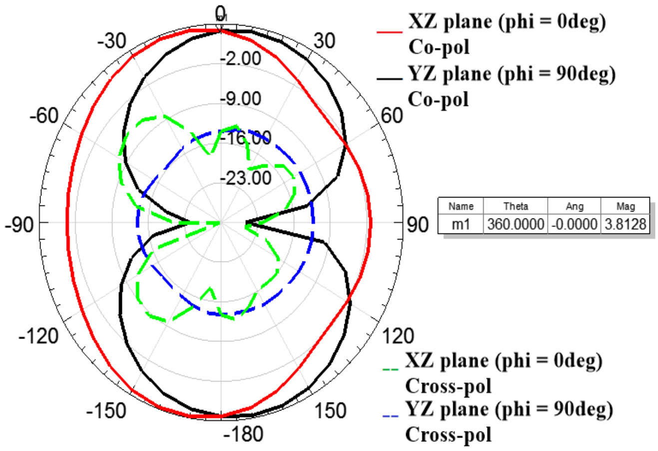

Fig.3 Radiation pattern plot at the center frequency 2.58 GHz

From Fig.3 the radiation pattern of the proposed antenna is analysed. The antenna obtained a peak gain of 3.81 dB in the principle direction. It is to be particularly noted that the difference between co-polarization and cross-polarization is greater than -15dB which defines satisfactory radiation properties of the antenna.

The diversity capabilities with respect to any MIMO antenna are analysed by the computation of Mean Effective Gain (Mean), Total Active Reflection Coefficient (TARC), and Envelope Correlation Coefficient (ECC). These parameters are calculated using the formulas given as mentioned below.

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

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

Fig.4 deals with the ECC versus frequency plot. From the figure, it is evident that the value of the ECC is limited to less than 0.17 for the entire operating frequency range of 2.3 to 2.85 GHz. In general, for MIMO applications ECC is said to be satisfactory if it is limited to less than 0.5 and considerably good if it is less than 0.3. The proposed MIMO antenna system is well within the standard limit and is as low as < 0.17.

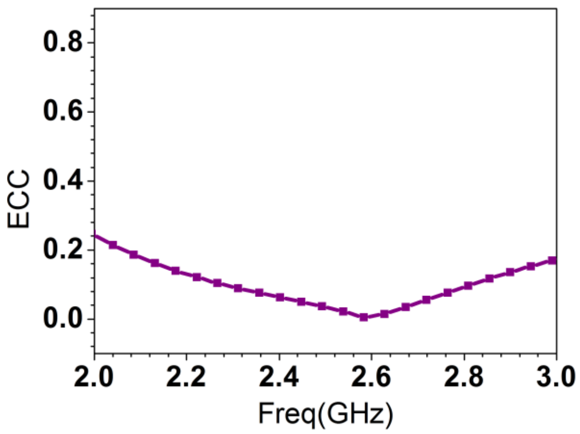

Fig. 4 ECC versus frequency plot

Fig. 5 shows the Mean Effective Gain (MEG) plot calculated between two antenna elements as mentioned in [12]. The difference between the mean effective gain of any two antenna should be less than 3 dB as per the standards. As seen from the graph the difference is less than 1 dB which satisfies the standards. Fig. 6 shows the TARC against frequency plot which depicts that the TARC obtained is as low as -21 dB and well within the standard (the less than -10dB) for the entire operating range of the proposed antenna.

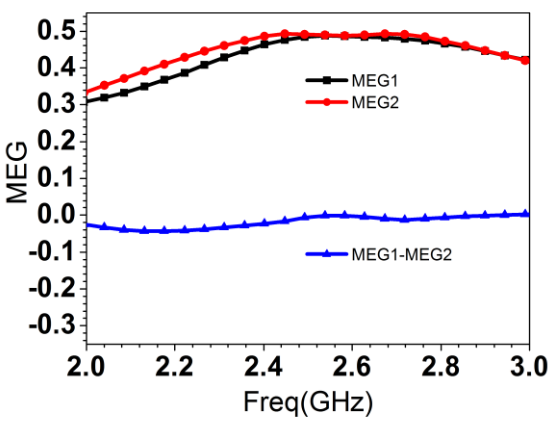

Fig. 5 Mean Effective Gain versus frequency plot

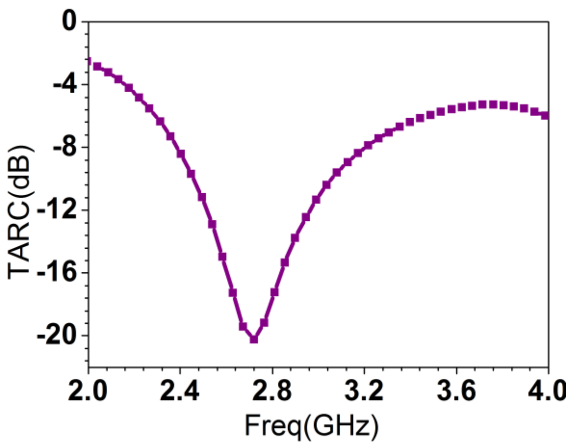

Fig. 6 Total Active Reflection Coefficient versus frequency plot

The proposed antenna is further subjected to conformal geometry as shown in Fig.7 to study the effect on isolation characteristics upon bending. Two bend angles are considered with angles of 15^0 and 25^0. Fig.8 shows the simulation results for s-parameters of the conformal arrangement of the proposed antenna. For both the cases taken (15^0 and 25^0 bend angles), the proposed MIMO antenna maintained a good reflection coefficient and isolation properties with less than -20dB for the entire operating bandwidth range. Therefore, the conformal MIMO antenna arrangement showed an overall satisfactory MIMO performance indicating good isolation or lower mutual coupling effect.

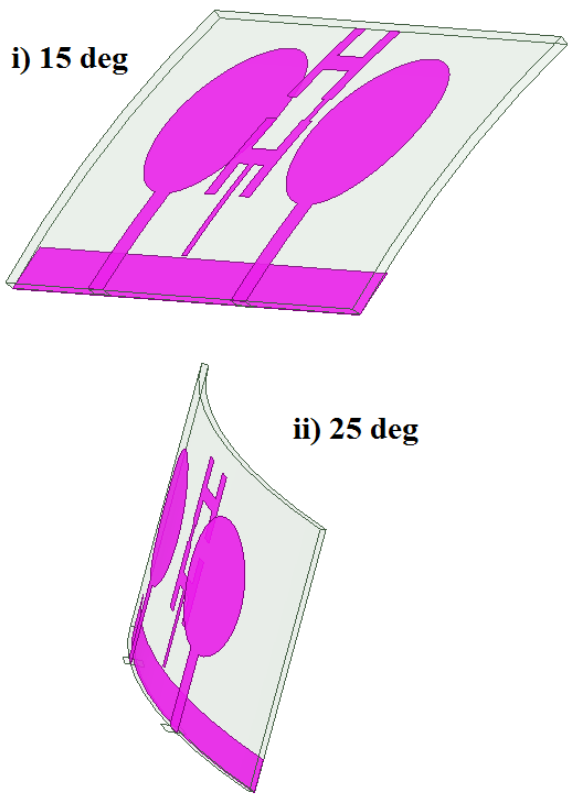

Fig. 7 Conformal arrangement with i) 15^0deg and ii) 25^0deg bend angles

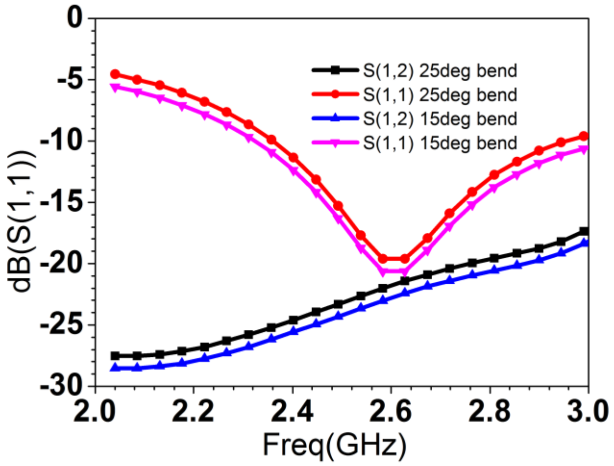

Fig. 8 S-parameters plot for the conformal arrangement of the proposed MIMO antenna

IV. SPECIFIC ABSORPTION RATE ANALYSIS

Once, the MIMO parameters are calculated and analyzed, SAR analysis is carried out as a final stage. In general, the mathematical relation using which SAR is calculated is given by

$$SAR = \sigma \frac{|E|^2}{\rho} \tag{3}$$

where 'σ' is the conductivity (s/m), **E** defines the electric field (V/m) and 'ρ' is taken as the biological tissue's mass density often usually represented in (kg/m^3). A three-layer homogenous human body model with skin, fat, and muscle as shown in Fig.9 is modelled. Each of these layers has a different mass and permittivity as discussed in [13].

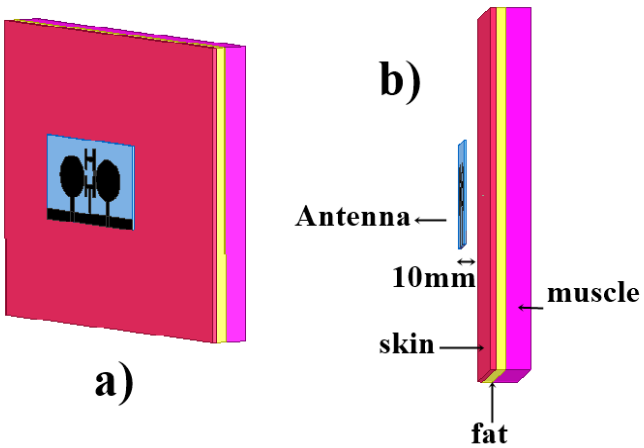

Fig. 9 Proposed MIMO antenna arrangement against 3-layer homogenous human body model

The SAR analysis is carried out to check the proposed antenna compliance level with the FCC recommended standard of 1.6 Watts/Kg. The below Fig. 10 shows the SAR values against the skin, fat, and muscle for 1g of tissue.

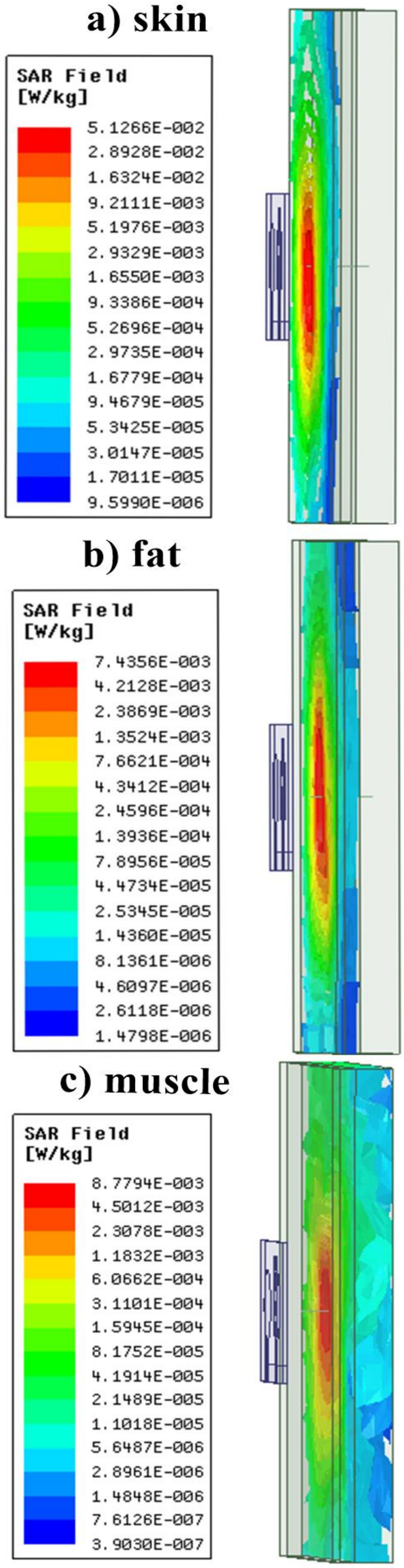

Fig. 10 SAR values of proposed MIMO antenna against the 3-layer human body value (1g tissue)

Table 1 represent the SAR analyses for different types of power input values against both 1g and 10g of tissue. The values suggest the proposed MIMO antenna complies with FCC set standards as all the values were well below 1.6 Watts/Kg.

TABLE1 SAR values against the 3-layer homogenous human body model

Mass of the tissue = 1g	**SAR value (W/kg)**		
Input Power	**Skin**	**Fat**	**Muscle**
1mW	0.0512	0.00743	0.00877
25mW	1.281	0.185	0.219
Mass of the tissue = 10g	**SAR value (W/kg)**		
Input Power	**Skin**	**Fat**	**Muscle**
1mW	0.0136	0.00307	0.00348
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50mW	0.684	0.153	0.174

V. CONCLUSION

A wearable circular MIMO antenna with H shaped ground stub is proposed in this chapter. The MIMO antenna designed covered the frequency range of 2.3 GHz to 2.85 GHz with an impedance bandwidth of 550 MHz. The intention to target ISM band of (2.4 to 2.5 GHz) for On-body applications is achieved. The proposed MIMO antenna also achieved good isolation of greater than –15 dB for the entire operating bandwidth. MIMO performance in terms of Envelope Correlation Coefficient (ECC), Mean Effective Gain (MEG) and, Total Active Reflection Coefficient (TARC) is also computed which showed ECC < 0.17, MEG difference below 3dB, and TARC < -10 dB for the mentioned bandwidth range. The conformal arrangement of the proposed structure with two bend angles also showed good isolation characteristics. Finally, SAR analysis is carried out to check the conformity with FCC standards and is found to be within the set limit of 1.6 watts/kg for both 1g and 10g tissue against different input power levels. Therefore, the proposed MIMO antenna can be a prime candidate for On-body applications targeting the ISM band.

REFERENCES

[1]. Ssorin, V., Artemenko, A., Maltsev, A., Sevastyanov, A. and Maslennikov, R., 2012. Compact MIMO microstrip antennas for USB dongle operating in 2.5–2.7 GHz frequency band. International Journal of Antennas and Propagation, 2012.

[2]. Yang, L., Li, T. and Yan, S., 2015. Highly compact MIMO antenna system for LTE/ISM applications. International Journal of Antennas and Propagation, 2015.

[3]. Ali, W.A. and Ibrahim, A.A., 2017. A compact double-sided MIMO antenna with an improved isolation for UWB applications. AEU-International Journal of Electronics and Communications, 82, pp.7-13.

[4]. Mohammad Saadh, A.W., Khangarot, S., Sravan, B.V., Aluru, N., Ramaswamy, P., Ali, T. and Pai, M.M., 2020. A compact four-element MIMO antenna for WLAN/WiMAX/satellite applications. International Journal of Communication Systems, 33(14), p.e4506.

[5]. Quddus, A., Saleem, R., Shabbir, T., ur Rehman, S. and Shafique, M.F., 2016, August. Dual port UWB-MIMO antenna with ring decoupling structure. In 2016 Progress in Electromagnetic Research Symposium (PIERS) (pp. 116-119). IEEE.

[6]. Yang, L., Li, T. and Yan, S., 2015. Highly compact MIMO antenna system for LTE/ISM applications. International Journal of Antennas and Propagation, 2015.

[7]. Mohammad Saadh, A.W., Khangarot, S., Sravan, B.V., Aluru, N., Ramaswamy, P., Ali, T. and Pai, M.M., 2020. A compact four-element MIMO antenna for WLAN/WiMAX/satellite applications. International Journal of Communication Systems, 33(14), p.e4506.

[8]. Chaudhary, P., Kumar, A., Kumar, P., Patel, K. and Verma, A.K., 2020. Circularly Polarized Wideband MIMO Rectangular Antenna in Cube Form for X-Band with Pattern and Polarization Diversity. Progress In Electromagnetics Research, 94, pp.103-108.

[9]. Quddus, A., Saleem, R., Shabbir, T., ur Rehman, S. and Shafique, M.F., 2016, August. Dual port UWB-MIMO antenna with ring decoupling structure. In 2016 Progress in Electromagnetic Research Symposium (PIERS) (pp. 116-119). IEEE.

[10]. Kiem, N.K., Phuong, H.N.B., Hieu, Q.N. and Chien, D.N., 2015. A novel metamaterial MIMO antenna with high isolation for WLAN applications. International Journal of Antennas and Propagation, 2015.

[11]. Tewari, M., Yadav, A. and Yadav, R.P., 2017, March. Polarization reconfigurable circular patch antenna: Parasitic stub. In *2017 international conference on wireless communications, signal processing and networking (WiSPNET)* (pp. 1083-1086). IEEE.

[12]. Nasir, J., Jamaluddin, M.H., Khalily, M., Kamarudin, M.R., Ullah, I. and Selvaraju, R., 2015. A reduced size dual port MIMO DRA with high isolation for 4G applications. *International Journal of RF and Microwave Computer-Aided Engineering*, *25*(6), pp.495-501.

[13]. Yadav, A., Kumar Singh, V., Kumar Bhoi, A., Marques, G., Garcia-Zapirain, B. and de la Torre Díez, I., 2020. Wireless body area networks: UWB wearable textile antenna for telemedicine and mobile health systems. *Micromachines*, *11*(6), p.558.