DUAL BAND 8 ELEMENT MIMO ANTENNA FOR 5G MOBILE COMMUNICATION

By

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A thesis submitted to the faculty of Electrical Engineering Department, Military College of Signals, National University of Sciences & Technology, Pakistan in partial fulfillment of the requirements for the degree of MS in Electrical (Telecom)

August, 2022

Declaration

I certify that this research work titled *"Dual Band 8 Element MIMO Antenna for 5G Mobile Communication"* is my own work. The work has not been presented elsewhere for assessment. The material that has been used from other sources it has been properly acknowledged / referred.

Syed Irfan Ali Shah

Signature of Student

2018-NUST-MS-EE-24

Copyright Statement

Acknowledgements

I am thankful to my Creator Allah Subhana-Watala to have guided me throughout this whole research work. I am profusely thankful to my beloved parents who raised me when I was not capable of walking and continued to support me in every step of my life.

I would also like to express special thanks to my supervisor Dr. Abdul Wakeel for his help throughout my thesis as my research supervisor and course instructor. His teaching skills and cooperative attitude towards me has always motivated me to keep working hard to achieve my desired research goals.

I would also like to pay special thanks to Dr. Zeeshan for his tremendous support and cooperation. Each time I got stuck in something, he came up with the solution. Without his help I wouldn't have been able to complete my thesis. I appreciate his patience and guidance throughout the whole thesis.

Finally, I would like to express my gratitude to all the individuals who have rendered valuable assistance to my study.

Dedicated to my exceptional parents and adored siblings whose tremendous support and cooperation led me to this wonderful accomplishment. In addition, this accomplishment would not be possible without the guidance and knowledge shared by my professors.

Abstract

The 5G communication technology is seen as a breakthrough in wireless communications, as current smart phones demand a very wide band width. This rapid transformation motivates researchers in communication technologies, whether in software or hardware. Additionally, antenna design is regarded as a fundamental topic that requires ongoing development to serve 5th Generation wire-less communication networks. The major objective of the thesis is to advance a dual band multiple input multiple output MIMO antenna that can serve 3G and 5G mobile communication systems while including all the essential features of modern wireless communication systems. It is pertinent to note that this thesis emphasis on 8×8 MIMO antenna model with explanation about the chronological growth, basic factors and the sorts of antennas which are applied in 5G mobile phones. Mobile phones antenna design section consists of two antennas namely Upturned U-Shaped and Upturned F-Shaped. Inverted U-shaped design operates at 3.5 GHz while the Inverted F-shaped design generates resonance at 5.5 GHz frequency. The return loss of 3.5 GHz band and 5.5 GHz bands are -29.5 dB and -41 dB separately. The impedance bandwidth at both bands is 1700 MHz and 700 MHz respectively. The efficiency of the antennas are 95 percent. The simulations of 8×8 MIMO Antenna are performed in CST. The simulation meets with measured results showing the validation of design.

Keywords: Massive MIMO, Envelope Correlation Coefficient, Radiation pattern, S parameters, isolated dual band shared radiated MIMO Antenna Mobile Communications

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List of abbreviations

MIMO	Multiple Inputs Multiple Outputs
PIFA	Planar inverted F (type) Antenna
SAR	Specific Absorption Rate
GSM	Global System for Mobiles
WLAN	Wireless local area network
DCS	Distributed control system
UMTS	Universal Mobile Telecommunications System
DECT	Digital Enhanced Cordless Telecommunications
IoT	the Internet of Things
NIE	National Institute of Electronics
RIMMS	Research Institute of Microwave and Millimeter-wave Studies
PCB	Printed Circuit Boards
1G	1^{st} Generation of wireless cellular technology
2G	2^{nd} Generation of wireless cellular technology
3G	3^{rd} Generation of wireless cellular technology
4G	4^{th} Generation of wireless cellular technology
5G	5^{th} Generation of wireless cellular technology
LTE	Long term evolution
VSWR	Voltage standing wave ratio
NR	New Radio
3GPP	3^{rd} Generation Partnership Project
EU	European Union
mm	millimeter
SVD	Synthetic Vector Dipole
TL	Transmission Line

Chapter 1

Background

1.1 Introduction

The massive growth of the handsets has expanded recently with the evolution of high frequency and the users are expecting for Nano devices with enhanced features which deliver feasible signal performance utilized by the users using small mobile phones around the whole world. It is require reducing the risk affecting human beings while using mobile phones that receive radiation. The antenna in the past was located on the top of which radiation emits directly on the body while some radiations are reflected and absorbed the human body results in poor efficiency. Currently antenna used in the mobile's phones are printed inside rather than external and its main reason is its SAR having good relationship with antenna. Furthermore, the size of the user handsets becomes smaller.

Moreover, there are various types of internal antennas embedded on PCB namely PIFA antennas, Slot antennas, Monopole Antenna covering several bands from single band to multiband. Slot and planer inverted antennas are used widely in handsets. The advantage of these antennas is its low absorption rate in human body and are not greatly affected by environment. However, the main problem of PIFA antenna is its narrow bandwidth that can be solved by using defected ground planes on the back of PCB. The design of planer inverted antennas is easy for WLAN, GSM, 3G/4G and 5G with multiple bands simultaneously.

1.1.1 Problem Statement

The requirements of modern world are fulfilled by keeping up the technology with it. Data communication has converted the strength for growth. Fifth generation (5G) network for mobile communication highlight on data rate and higher spectrum which is needed for upcoming communication network. Mobile Antennas designed for 5G handsets have been reported in the literature. 8 Elements antenna for LTE 42 band has been designed with a measurement of channel capacity. However, all antenna elements are positioned along the 4 edges of PCB and no space has been left for other antennas i.e., 2G/3G/4G. Some Massive MIMO antennas has designed for smartphone with a narrow bandwidth which is non-sufficient to cover up the LTE 46 band for the future 5G mobile phones applications. Moreover, the enough space at the two corners which is set aside for 2G/3G/4G MIMO antennas, and the other two corners are not fully demoralized for MIMO procedure.

Therefore, it is still challenging for antenna engineers to design a massive MIMO antenna that can cover more sub- 6GHz bands, which include LTE bands 42, 43 and 46 to achieve desirable inter-element isolation and antenna efficiency. The techniques presented in the literature provide better isolation between antenna elements; however, the antennas are single band. A novel MIMO antenna configuration will design for smartphone applications. In literature review, the proposed 8x8 MIMO antenna achieves single 3.5 band using single strip which could be improved upon changing the design parameters slightly to get dual band using single strip, making the design to be novel. Each antenna element will locate in an inverted U-shaped and an inverted F-shaped arrangement to give dual band characteristics. The antenna will cover both 3.5 GHz and 5.5 GHz bands. Dual band proposed model can easily be integrated in cell phones for both 3G and 5G mobile applications. Moreover, decoupling strip with defected ground plane will be used for enhanced isolation.

1.1.2 Thesis Motivation

The work in this thesis is inspired by the requirement to examine antenna configurations which are embedded in today's user's handsets. There is a space limitation inside mobile phones. The advantage of low-profile multiband MIMO antennas quickly increases that's in response to the enormous expansions of mobile phone devices both in function and size. The other inspiration is to examine and develop a single element antenna and then convert to 4-Element antennas. In general, the disadvantage of planer inverted F-Shaped antennas is its narrow bandwidth, however in this case the bandwidth is wide and having low profile and easily embedded in mobile phones. These features made this antenna best candidate for mobile phones. A lot of literature is there that discuss the narrow bandwidth of PIFA antenna, however in dual band antennas, the narrow bandwidth vanishes. There are some frequency bands which have not designed for handsets. So, this thesis grants a revision of a proposed wideband 4 element antenna with enhanced bandwidth, high gain, and high efficiency for 5G handsets.

1.1.4 Objectives of the Thesis

This thesis comprises of four parts: (i) To design and simulate monopole with strip for mobile application at 3.5 GHz and 5.5 GHz (ii) Convert single element in to 4 element antenna (iii) Convert the4 element in to 8 elements antenna (iv) The fabrication of antenna has done in NIE and its testing in RIMMS, NUST. (v) Judgements of the simulated and calculated results for authentication.

1.1.5 Scope

This study focuses on designing a monopole strip antenna with inverted U shaped and inverted F shaped strips. The main scope of my thesis is to 4 element antennae for 5G mobile applications. The antenna is located on each corner of the PCB and a copper is used as ground plane fixed on the towards the back on the side of the PCB. The antenna can also be applicable for future 5G IoT devices.

1.1.6 Research Methodology

In this thesis, a low profile 4 element antenna for 5G handsets application is analyzed at bual band with the help of CST software. Low profile antennas such as strip antenna have small configuration as related to the entire structure. The impedance matching is achieved by ground clearance while its frequency bands are obtained by inverted U-Shaped and Inverted PIFA. Return loss, bandwidth, gain pattern, Efficiency and envelope correlation coefficient are displayed in simulation. The substrate used is FR4 having dielectric constant of 4.4 with 0.003 tangent loss and a dimension 150 mm × 80 mm.

1.1.7 Methodology

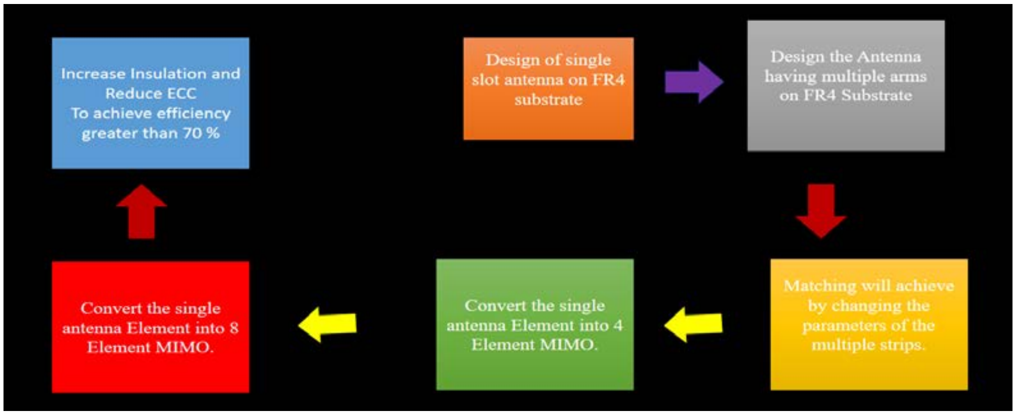

Fig 1. 1 Design Methodology

1.1.8 Thesis Organization

The thesis has been organized as follows: Chapter 2 describes the basics related to the various parameters of the mobile phone antennas. Chapter 3 presents the background and literature reviews. Chapter 4 presents design of dual bands antennas with a focus on 4 Element MIMO antennas with simulation. 8 Element MIMO antennas are discussed in chapter 5 with simulated results. Chapter 5 while conclusion and future work has discussed in chapter 6.

Chapter 2

Basic Principles of Smart Phones Antennas

2.1 The Growth of Mobile Phone Antennas

The 1St generation of mobile was operated at 800 MHz frequency and was called analog system. The length of the 1st antenna was lambda by 4 which is 9.3 cm. Motorola DynaTAC8000X was the first handset with a dipole antenna at the top as shown in the Fig. 2.1. It is not used in nowadays handsets, however still used in wireless modem and routers. At resonance, length of dipole antenna is one-half of its wavelength and having efficient radiation pattern. With reducing the size of mobile phones and its growth, there is no need for a dipole antenna matched with the modern handsets.

Fig 2. 1 Sleeve dipole antenna used by Motorola DynaTAC8000X

2G was launched in 1990 and its offered services are audio call and text messages which are operated at 900 MHz for GSM and 1800 MHz for DCS system. In 90s era only text messages were served by

2G, and it was working at 900 MHz However, 1800 MHz band was designed rather than 1G that uses two antennas operating at single band as shown earlier in the Figure 2.1.

Fig 2. 2 Nokia 1011 use GSM

Fig 2. 3 Motorola use 1800

Motorola created a mobile phone named Motorola mr601 in 1997. It supports both bands i-e GSM 900 and DCS 1800 band used two antenna one was sleeve dipole and the other was helix antenna produced a circular polarized travelling waves by helix and dipole antenna that radiates in two direction. That’s classical phone presented the capacity to contact the cellular services in more than 70 countries at the end of 1977.

Prof. Peter Hall invented PIFA Antenna with dual band features i-e GSM 900 and DCS 1800 in 1996. The first Planer Inverted antenna was designed having dual bands produced by slots in the ground plane. The growing stage of handsets has certain important stages when Nokia designed Nokia 3210 in 1998 as depicted in the following snap. The first handset supports both GSM 900 and DCS 1800 bands with the antenna integrated inside mobile phone and was one of the most widespread handset having 160 million users [2].

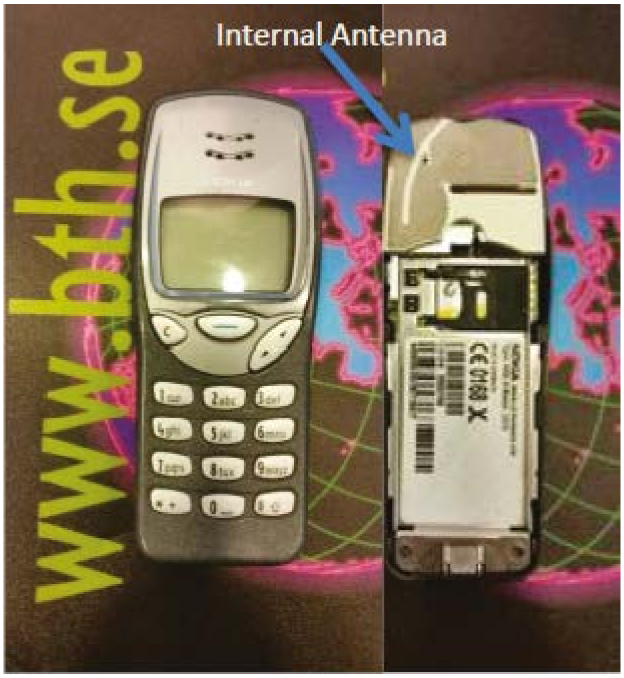

Fig 2. 4 Nokia 3210 with dual band antenna

Hutchison Telecommunication launched the first 3G network branded as a 3G in June 2003 while Nokia designed Nokia 6630 in 2004 as depicted in the Fig. 2.5. These mobile phones allow global roaming and having triband antenna covering both GSM 900, 1800 and UMTS 2100 bands.

Fig 2. 5 Nokia 6630 with its internal Antennas

Year	1900	1950	1970	1990	2000	2010
Frequency	< 10 kHz	< 30 MHz	< 800 MHz	< 1.9 GHz	< 2 GHz	3 GHz 5 GHz
System	Telegraph / telephone for train, ship, police cars	Vehicle and portable systems for business, Pager	Mobile phones (analog), cordless phones, pagers, GPS	Mobile phones (digital),aircraft (voice and data) personal phone	Mobile phones (multimedia), Wireless access, Bluetooth	Mobile phones (high data rate), Ultra wideband,
Antenna	Monopole dipole, whip,	Blades, ferrite coil, helical antenna	Corner reflector, PIFA, helix	Meander line, normal mode helix, ceramic chip, adaptive array	Wideband, multiband built-in antennas, adaptive array, MIMO	Small compact functional antennas, implant antennas

Table 2. 1 Evolution of Mobile phones based on Frequency and Antenna Geometry

Table 2.1 shows the development of mobile phones based on the frequency and antenna geometry. The mobile phones used 6 GHz band for 4G/LTE. The Navigation system gives by the Cordless phones have contributed intensely to the growth of designing antennas. Moreover, multichannel access system also contributed to the growth of antenna design. Hybrid system uses small antenna for their needs, dual band GSM handset of multiband merged with DECT for example.

Low profile, compact and lightweight are the specifications of the handset small antennas that led to enhance and design the antennas and its modified form is PIFA antenna that has varied, and its distinguishing is very hard as an original PIFA. GSM 900 handset used the modified PIFA antenna which has become more popular in various mobile terminals. Normal PDC used mode helical and monopole antennas for its operation. In advanced handsets, we have summarized the design procedure in the following manner: Multiband mostly antenna in the chip is needed for modern communication. Due to the low profile, Nano antennas i-e radio frequency ID and microwave sensors are used for smart watches and handsets. Mobile terminals used printed antennas having the small dimension and low profile comparing with the other small integrated antennas. These antennas appropriate a low size, efficient radiation pattern and high gain.

2.1. Parameters of Smart Phones Antennas

In this section, we will discuss in detail about basic antenna parameters which are used in mobile phones. This section is sub divided into further sections in which each parameter is discussed separately so that one can understand basic operations of mobile phone antennas in more elaborate way.

2.1.1 Radiation pattern

Radiation pattern is the power emitting from an antenna, depending on direction which can also be represented by the mathematical or graphical function of radiation properties. Two types of radiation patterns are presented: one is radiated power while the other is filed pattern. The power emitted by the antenna with respect to the position of spherical coordinates whereas field pattern concern with the position of spherical coordinates w.r.t the magnetic and electric field. Moreover, the field region is divided in to three regions. The nearest field of the antenna which is known as Reactive near field that controls the energy and standing waves. The region between the near and far field which controls the radiation field is known as radiation field. The 3rd is far field which is away from the antenna as shown in the following Fig. 2.6

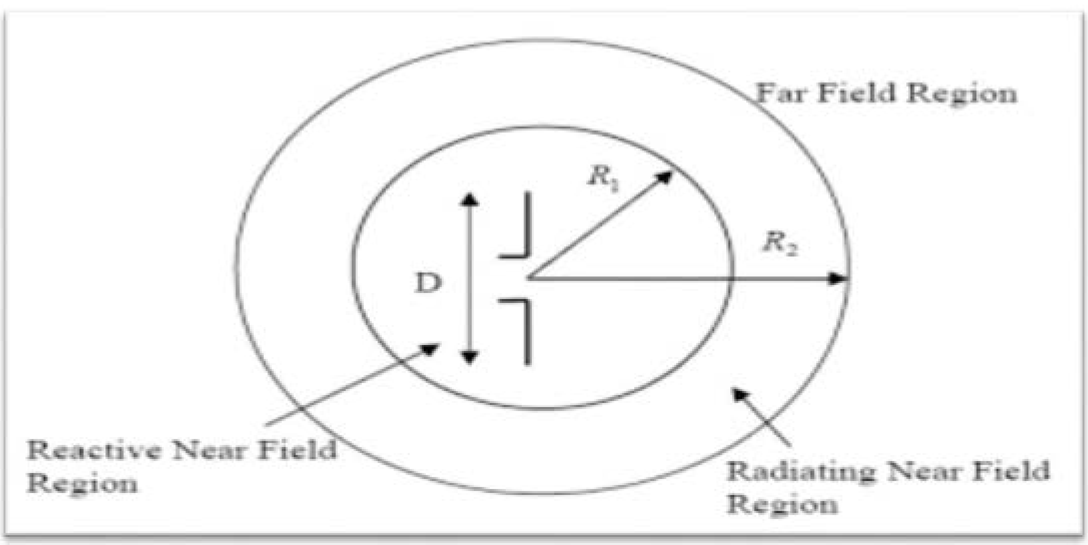

Fig 2. 6 Radiation pattern and field regions

Three types of radiation patterns are:

Isotropic radiation is the radiation which is same in all direction. This is the ideal case which is not presented till now. Directional pattern gives the radiation in only one direction. The 3rd one is the plan pattern which consists of E-field pattern and H-field pattern. E-field pattern shows the electric field vector in the direction in which the radiation is maximum whereas H plane pattern is the magnetic field vector in which the radiation along the H plane is maximum. Main lobe is the radiation which goes in the maximum radiation along the E plane, whereas sides lobes are the radiation of the main lobe with worst pattern. Back lobe is the radiation in the opposite direction of main lobe. The angular width between the half power point and the beam width which is equal to -3 dB is said to be Half Power Beam Width. The angular separation between the 1st zero and the other side lobe is known as First Null Beamwidth as depicted in the Fig. 2.7:

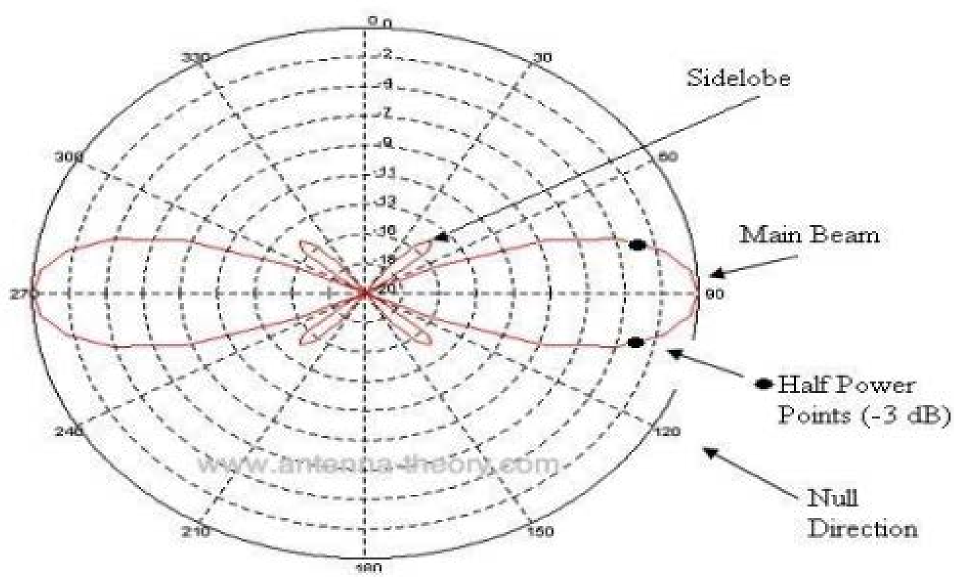

Fig 2. 7 Polar patterns of antenna

2.1.2. Directivity

Directivity is the antenna parameter that measures the radiation direction. We can also calculate the gain and efficiency through Directivity. Radiation intensity can also be determined through directivity and the power radiated. To calculate the directivity, we must determine the maximum value of the magnitude of the power emitting, the average power radiated in all direction as given by:

$$D = \frac{1}{\frac{1}{4\pi}\int_0^{2\pi}\int_0^{\pi}|F(\theta,\emptyset)|^2 sin\ \theta d\theta d\varphi} \qquad \text{Eq. 2. 1}$$

Where D is the directivity, theta is the azimuth between the z-axis and the vector from the origin and Phi is the azimuth between the a-axis and the vector in the x-y plane. Smart phones have low directivity because it receives and transmit radiation from all direction while Base station has high directivity due its beam forming.

2.1.3 Polarization

It is one of the features for any types of antennas is the orientation of the electrical field vector of the electromagnetic wave. The divisions of electromagnetic wave depend on the E-Field, which is at right angles with the H-field. Three types of polarization are defined as:

- Linear polarization is the type of polarization in which the electric filed is propagated along the plane wave's direction. Linear polarization has two types.

The type of linear polarization in which electric field is parallel to the x-axis and the H-field is orthogonal to the y-axis is said to be horizontally polarized whereas vertical polarization is a type in which the H-field is parallel to the y-axis and E-field is orthogonal to the x-axis. Both type of polarization is depicted in the following figures 2.8 .

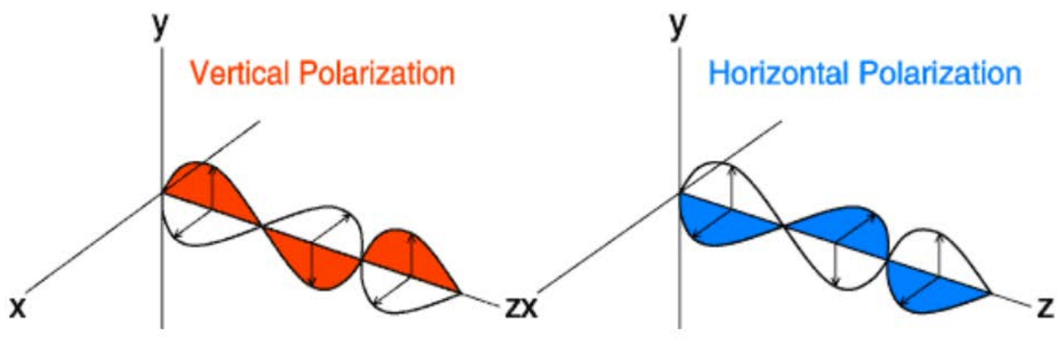

Fig 2. 8 Horizontal and Vertical Polarization

- Circular Polarization is the type of polarization in which the magnitude of the E-field vector and M-field vector are same and having a 90° phase difference. Circular polarization has two kinds. Right Hand Circular Polarization: in which the orientation of both vectors is along the clockwise direction.

- Left Hand Circular Polarization: in which the orientation of both vectors is along the antilock wise direction.

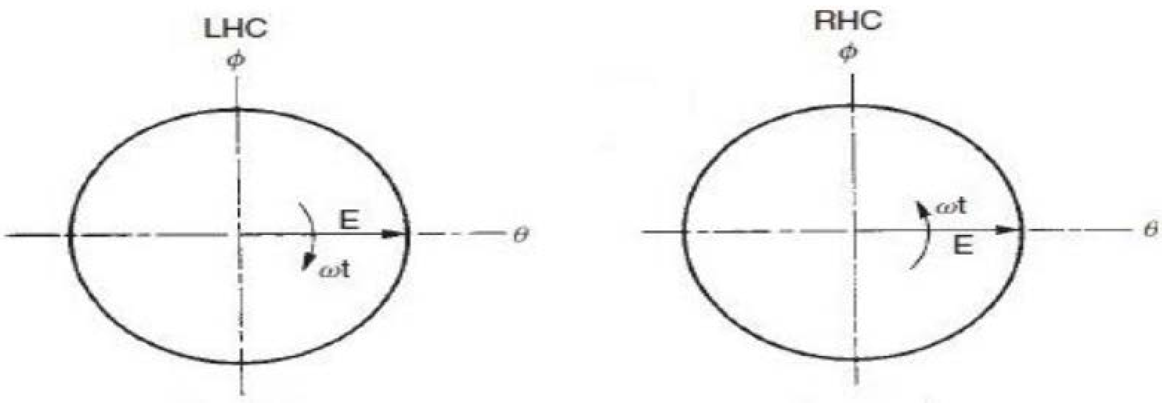

Fig 2. 9 LHCP and RHCP

- Elliptical polarization is a polarization in which the E-Field propagates in a elliptical shape depends on the E-Filed direction. Right Elliptical Polarization having clock wise direction and Left Elliptical Polarization having anti clock wise direction as shown in the Fig. 2.10.

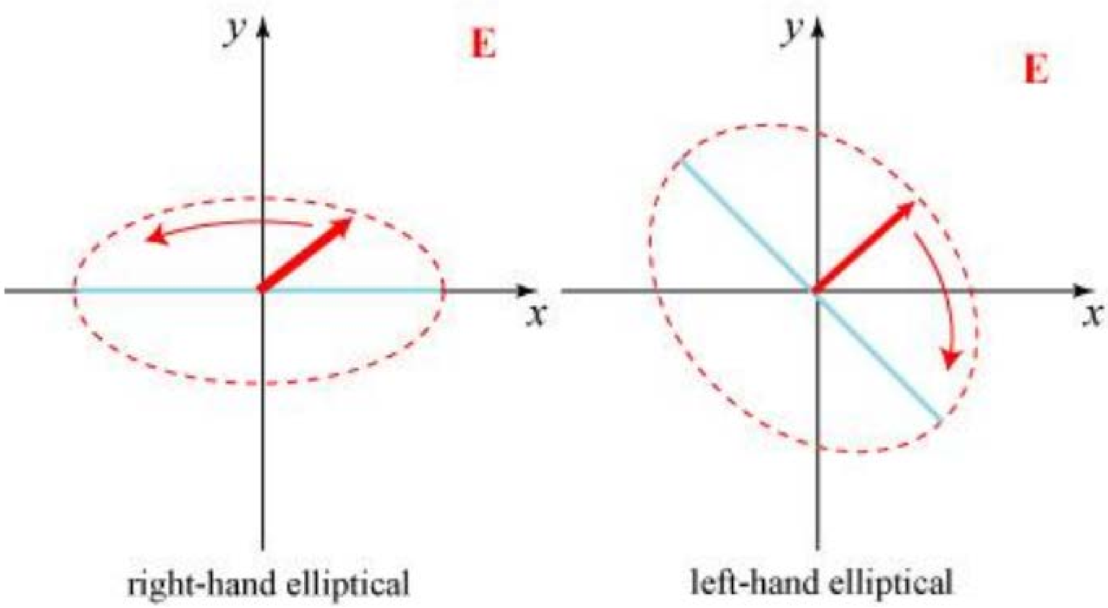

Fig 2. 10 Elliptical Polarization

2.1.4 Impedance

It is the ratio of voltage and current. It consists of real and imaginary parts; the R_r (Radiation Resistance) describes the power radiated or absorbed whereas the JX_L (Reactance) explains the energy stored in the near field of transmission line. To take power losses in transmission line, impedance depends on the input current and voltage. The advantage of knowing the impedance is to choose the best transmission line for the antenna. The transmission line impedance must be matched with the antenna impedance. Once the antenna is matched, there will be no power and standing waves reflected from the load which shows that the antenna resonates. According to maximum power transfer theorem, Source impedance must be equal to antenna impedance.

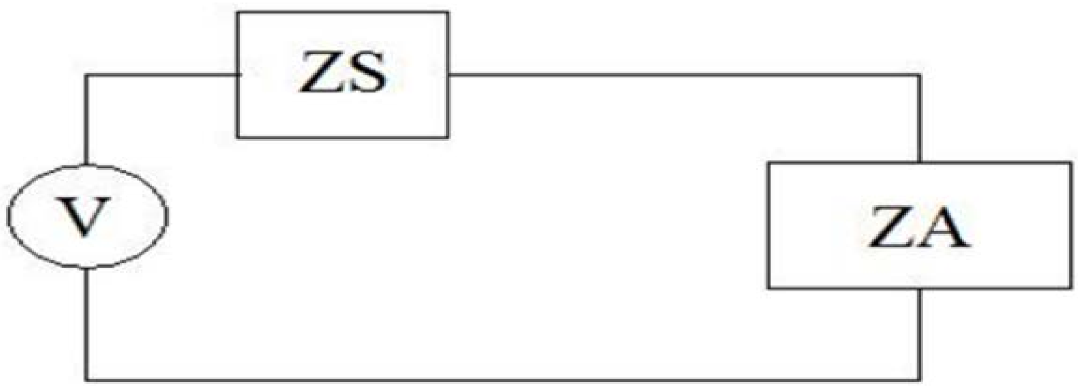

Fig 2. 11 Antenna circuit and its TL

2.1.5 Antenna Gain

Gain is another parameter of antenna which the product of antenna efficiency and directivity. Gain explains the transmission power to the peak radiation. The gain and directivity will be equal when the efficiency is 100 percent. Mathematically, Gain is defined as:

$$\mathbf{G=\varepsilon \times D} \qquad \text{Eq. 2. 2}$$

2.1.6 Antenna Efficiency

Gain divided by directivity gives efficiency. It is the relation to the input power of antenna and the transmission losses i-e the dissipated losses and reflection losses. Mathematically, Efficiency is defined as

$$\varepsilon_R = P_{R/P_{in}}$$ Eq. 2. 3

2.1.7 Antenna Beam width

Beam width the angular separation between half power points of the radiation pattern. It is a half power and is inverse relation with directivity. High directivity will lead to small beam width and vice versa. It can be found by knowing the two points on the radiation pattern.

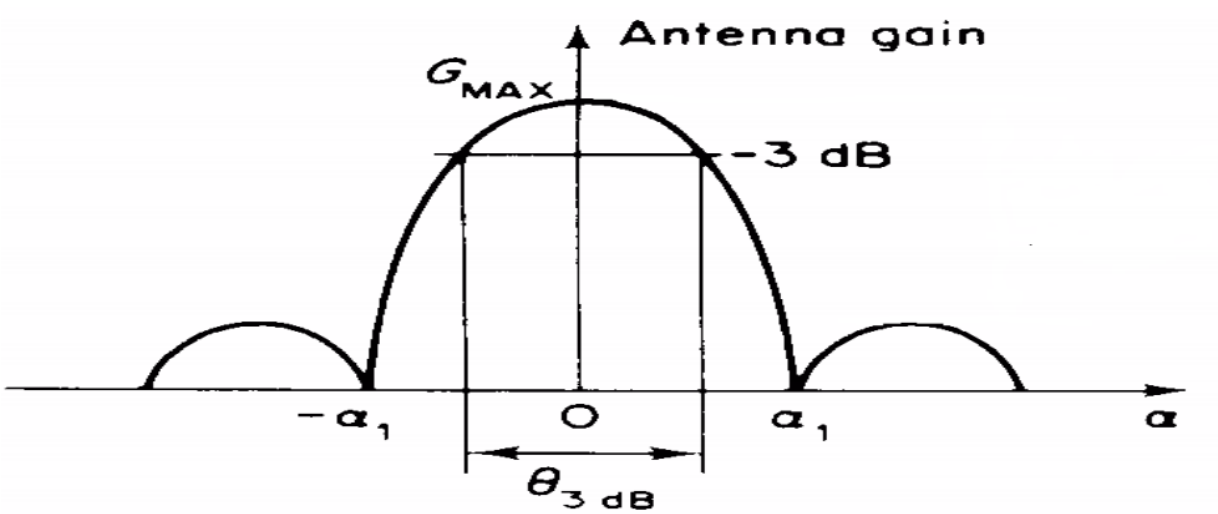

Fig. 2. 7 Beam width (half power) of antenna

2.1.8 Effective Area

Transmission power is the product of power density and effective area. Transmission power is calculated by knowing how much power loss is due to the relationship between effective area and power density in the plane wave as given by

$$P_{t=P\times A_e}$$ Eq. 2. 4

Effective area can be calculated by knowing the gain of antenna. Mathematically effective area can be written as:

$$A_e = \frac{\lambda^2}{4\pi} G \qquad \text{Eq. 2. 5}$$

2.1.9 Bandwidth

It is the range of frequencies within the operating band. To show the impedance matching in the given band, bandwidth is a key parameter which is the inverse of Q-factor. High the bandwidth, low will be the Q-factor. In mobile antennas, the bandwidth is high due to low Q-factor of other IC embedded in the PCB. The percentage bandwidth is mathematically given by:

$$\text{Bandwidth \%} = \frac{f_{max} - f_{min}}{f_{center}} \times 100 \qquad \text{Eq. 2. 6}$$

Various type of antenna with different bandwidth is given in the following Table 2.2:

Reference	Bandwidth (GHz)	Efficiency (%)	Ground size (mm^2)	ECC	Peak channel capacity (bps/Hz)	MIMO order
Proposed	3.4–3.8, 5.15–5.925 (–6 dB)	41–82 (low band) and 47–79 (high band)	150 × 80	Lower than 0.15 (low band) and 0.1 (high band)	37 (8 × 8, 20-dB SNR) and 29.5 (6 × 6, 20-dB SNR)	8 (low band) and 6 (high band)
[12]	3.4–3.6 (–6 dB)	59–72	120 × 60	Not mentioned	15 (2 × 8, 20-dB SNR)	8
[13]	3.4–3.8 (–6 dB)	40–57	140 × 70	Lower than 0.1	47 (10 × 10, 20-dB SNR)	10
[15]	3.4–3.6 (–6 dB)	30–53	150 × 75	Lower than 0.3	72 (16 × 16, 20-dB SNR)	16
[17]	3.4–3.6 (–10 dB)	62–78	140 × 70	Lower than 0.2	39 (8 × 8, 20-dB SNR)	8
[14]	2.55–2.65 (–10 dB)	48–63	136 × 68	Lower than 0.15	40 (8 × 8, 20-dB SNR)	8
[19]	3.4–3.6 (–6 dB)	40–52	150 × 75	Lower than 0.15	35 (8 × 8, 20-dB SNR)	8

Table 2. 2 Various type of antenna with different bandwidth

2.1.10 VSWR

VSWR or S11 is the reflected power from the load due to the mismatching. The threshold for VSWR is 1.3, more than 1.3 lead to mismatching and the antenna will not radiate.

Mathematically, VSWR can be written as

$$VSWR = \frac{1+\Gamma}{1-\Gamma} \qquad \text{Eq. 2. 7}$$

VSWR occurs due to bending of feed line, dust and water entering the transmission line. Small value of VSWR mean that the transmission power will deliver to antenna, however it doesn't mean that all the time power radiated are fully delivered. VSWR shows the antenna radiation properties describing the impedance matching and the return loss along with reflection coefficient. Antenna will not radiate all the power; some power will be reflected to the source creates mismatching. More VSWR will cause damage to the port of the transmission line.

2.2 Antenna Types

2.2.1 Dipole Antenna

In practice, dipole antenna is widely used in radio communication due to its easy shape. Dipole antenna consists of two wires having identical conductive elements radiated by giving a feed energy. A change in current and voltage creates electromagnetic waves as shown in the Fig. 2.2.1

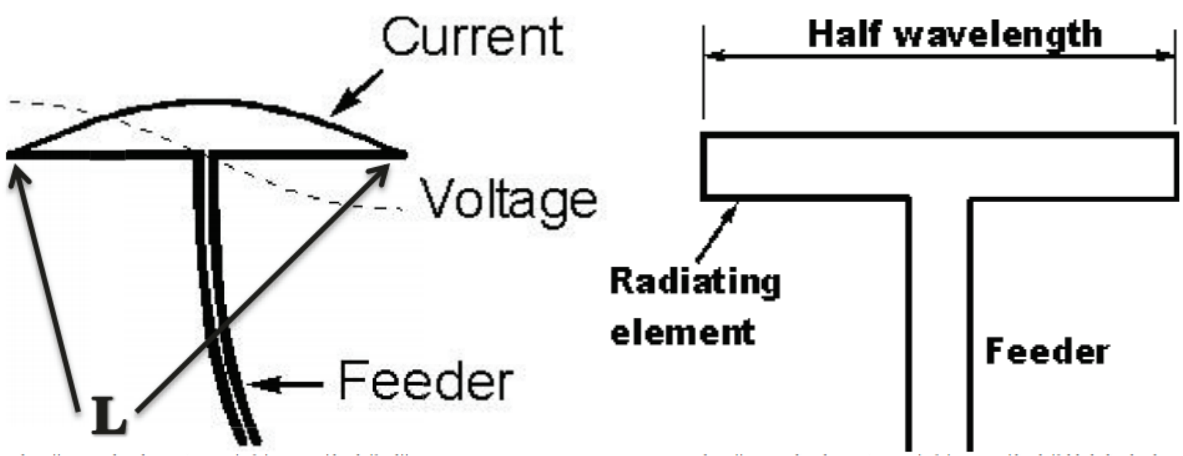

Fig 2.2. 1 Dipole antennas

2.2.2 Dipole Antennas Classification

Dipole antenna has various types in which half wave dipole antenna is one of them. A dipole antenna in which its wire is shorter than half wave dipole antenna, then it is called short dipole antenna. A dipole antenna in which there are two wires having a quarter wavelength and the feeding point is connected to both wires are called half wave dipole antenna. Other dipole antennas which are mostly used in WLAN are having multiple half dipole antennas and folded dipole antennas.

2.2.3 Monopole Antenna

Monopole antenna used straight wire and is printed over a conductive surface as depicted in the Fig. 2.2.2. The feeding is given at lower end of monopole antenna in the vicinity ground plane showing reflector characteristics. Dipole antenna will have same efficiency as monopole antenna if having if having a conductive ground plane with a valid size.

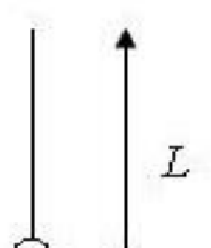

Fig 2.2. 2 Monopole antenna

Whip, helical, T-antenna and mast radiator are the types of the monopole antenna. Radiation pattern of monopole antennas are omnidirectional. Monopole antennas are used in mobile phones having Omni directional pattern. These antennas are also used in airplanes, shopping centers and mobile communication having a size of quarter wavelength. Monopole antennas are suitable for MIMO wireless communication system because of its low angle radiation and minimized ground plane.

2.2.4 PIFA Antenna

PIFA is a planer inverted-F shaped antenna used in nowadays mobile phones for GSM, DCS and 3G/4G communication. Its geometry is like a microstrip antenna; however, its size is small comparatively. Moreover, PIFA antennas are embedded on the edges of the substrate/PCB produces quarter wavelength. The following Fig. shows the geometry and dimension of PIFA antenna in which L represent the length, W1 shows the width, h is height, W2 represent the short pin and D is the space between the feed point and short pin.

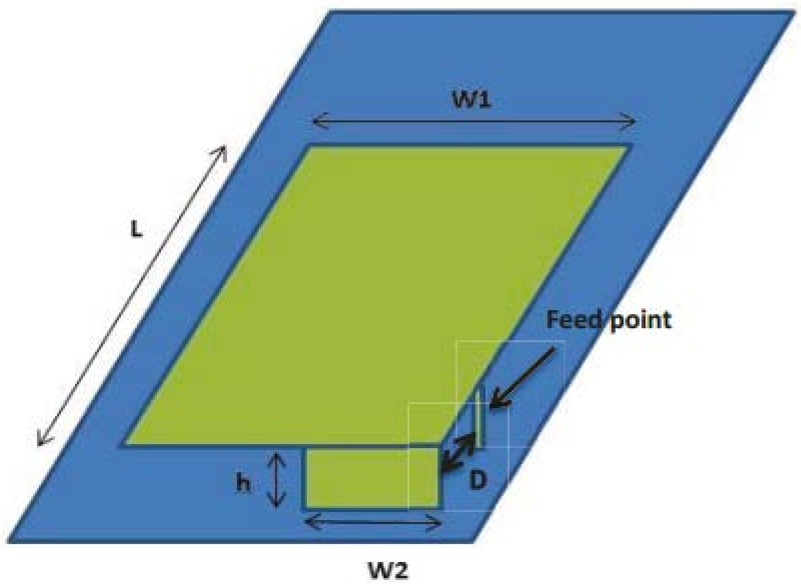

Fig 2.2. 3 PIFA antenna and its parameters

PIFA antennas are designed for single band, dual band and multiple band frequencies.

2.2.5 Advantages of PIFA antenna

- Handsets have PIFA antenna due its small geometry.
- Due to its high gain for both vertical and horizontal polarization: it receives radiation from different direction.
- PIFA antenna receives a low radiation due to which it doesn’t affect human health.
- Its fabrication is easy and having low cost.

2.2.6 Fractal Antenna

To reduce the size further and get rid of narrow band antennas, Fractal antennas are used in mobile phones. Its size is small and having wide bandwidth. The following Fig. shows the fractal antenna:

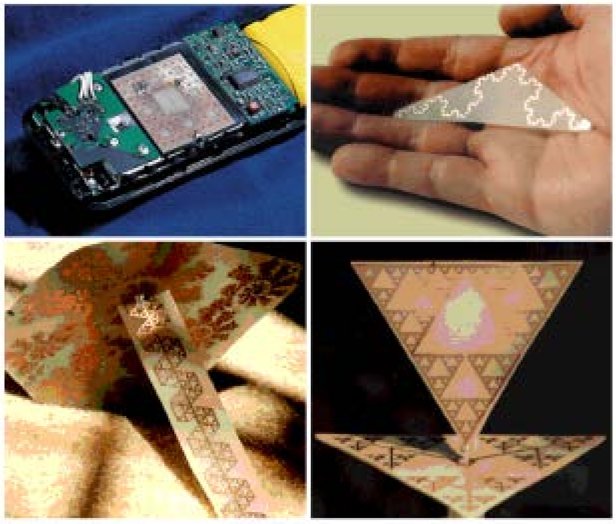

Fig 2.2. 4 fractal antennas

The design of fractal antennas solves the narrow bandwidth issues and can efficiently work well at one quarter of wavelength as compared to other types of antennas.

2.3 Issues in Smart Phones Antennas

The process of designing mobile phone antennas is very complicated. A lot of critical consideration will consider while design a mobile phone antenna; the place where the antenna is embedded in the mobile phone chassis. Moreover, different frequencies band will be used for 2G/3G/4G/5G. It may be single band or having multiple bands depends on the geometry of the antenna and the IC.

2.3.1 Radiation Efficiency

The shape, size and ground plane of antenna affect the performance of mobile phone antenna. By inserting the antenna element in the middle of the mobile chassis, its efficiency will be affected as there are IC mostly embedded in the center of the ground plane. Moreover, there is a high circuit density in the mobile phone ground plane, so there is a space limitation which is a critical problem for mobile antennas. Some mobile phones have low efficiency, low input resistance and reactance thus causes the antenna to be mismatched. To make the efficiency better, mostly monopole antennas are designed having a large space between each element. To maximize the radiation for electrically small antennas, Wheeler developed a method by the analysis of various experiments among one is in free space while the other is in loop with a particular radius, depicted in the Figure. 3.3.1. Wheeler determined that two types of resistances during antenna resonance are produced, one is radiation resistance, and the other is loss resistance. Mathematically the radiation efficiency of small antennas is defined as

$$\eta_{rad} = \frac{R_{rad}}{R_{rad+R_L}} \qquad \text{Eq. 2. 8}$$

The current distribution has a small space in electrically small antennas, making antenna like a capacitor inducing a zero current resulting in no radiation power. To get the radiated power by a small antenna, we must make impedance matching network. Due to weak radiation, the small antenna radiation resistance becomes small. The system efficiency of antenna is given by the antenna and its matching network. It is the product of matching efficiency and radiated efficiency. High efficiency will be obtained by taking maximum radiation resistance, low value of loss resistance and lower mismatch network.

2.3.2 Bandwidth

Bandwidth is the measure of frequency difference in a specified range and is determined by the impedance of all frequencies. However, bandwidth depends on other factors in small antennas. The real input impedance of small antennas is low nearly equal to zero and high reactive impedance cause a mismatch network. The bandwidth depends on Q-factor, reflection coefficient and impedance.

Bandwidth=1/Q

Higher the bandwidth, lower will be the Q-factor.

The radiation power had defined by Wheeler in 1947. Based on the Wheeler concept, Mclean published a paper in 1996 on Q-factor for linearly polarized antennas as given below

$$Q_{LP} = \frac{1}{k^3a^3} + \frac{1}{ka} \qquad \text{Eq. 2. 9}$$

Chapter 3

Literature Study

3.1. Literature Review

The quality of wireless communication is increased day by day; as a result, the 5th generation mobile communication technology gives a promising high data rate transmission, low profile, small latency, high capacity, and more connection density. A good deal of Multiple Input and Multiple Output 5G antennas have been recognized for 5G mobile phones and base-stations [1-5]. However, there is a limited space in mobile phones the integration of antennas with extreme-level isolation and minimal ECC is a challenging task. The system capacity and multimode communication has expanded by a dual band four ports MIMO. Different isolation methods have been applied in the direction of lower the mutual coupling [3–14]. The mutual coupling is reduced by using the rectangular slots of microstrip-lines and defected ground plane in [3]. In [4], straight up patch is used to compensate the coupling in the middle of the antennas and neighboring elements. A T-shaped dissociating stub connected to ground plane and a little modification in T-shaped decoupling stub is joined amongst the two reflected twin-arrays of antennas to improve the separation in [5].

When two short T-shaped strips and a π-shaped strip were introduced, the mutual coupling between antenna elements are lowered [6]. Mutual coupling is reduced in inverted planer F shaped antenna [7]. Moreover, Neutralization line [8,9], filters which are high pass [10], diversity of pattern [11], decoupling of self [12], ground structure which is defected [13] and structure having meta material [14] are presented. One of the 5G mobile phone spectrums used 3.5 GHz frequency band was introduced in the World Radio communication Conference 2015. A 3.30 to 3.60 GHz and 4.80 to 5 GHz as the sub 6 GHz 5^{th} generations frequency bands were accepted by China's ministry of IT. Furthermore, A phased array mm - wave antenna which operates at 28 GHz frequency are also expected from 5G mobile phones except for the sub-6-GHz [15]. Nowadays, mostly research is set out on sub 6 GHz band for 5G application. In [16] 4 Elements MIMO antenna has been presented that used sub 6GHz band where a circular arc shaped radiator and a rectangular feed line is used for resonance. A 4×4 MIMO upturned monopole antenna which is L shaped has presented [18] where bandwidth, enhanced by using symmetric MIMO configuration in the frequency ranging from 2.7 GHz to 4.96 GHz. A dual polarized 4 port VSD antenna has been proposed for 5G wireless applicable in [19]. A dual band polarized 8 element massive MIMO antennas has been presented [20]. Moreover a 10 ×10 MIMO antenna with dual polarization and 8 Elements MIMO array for 5^{th} Generations smart phone applications have been presented in [21] and [22]. To meet the requirement of 5G, MIMO technology has deployed to achieve the latency, bandwidth for the growing of mobile demands in [23-24]. A base station antenna is used to increase the capacity and utilization of required bandwidth [25]. The testing and evolution of MIMO BSs antenna for 5G communication systems have been proposed in [26]. A 4-element antenna for 5G base station with dual polarization has presented in [27] and the author use the magnetic conductor to achieve the required isolation.

Numerous mobile phone antenna designs with MIMO systems have been proposed recently [10–26]. However, all of the antennas operates at either 3.5 GHz or 5.5 GHz band and some antennas occupy a larger space in the main printed circuit board. The 5G handset antenna designs introduced in [10-16] only cover a lower single frequency band i-e 3.5 GHz and dual band has presented in [17-26]. In modern times of Wi-Fi networking, the MIMO antenna is especially necessary. Within the subject of the MIMO antenna, a cluster of studies enterprise has been accomplished in the last decade. Here distinctive MIMO antennas and their specs are discussed. This survey shipping remembers to boot discusses various MIMO antennas jointly with wonderful factors and their results regarding reducing MIMO antenna problems, comprehensive of a full heap cross-polarization and reciprocal composition amongst blow arrays. (1Kausar Parveen, Mohammad Sabir, Surbhi Mehta, 2019)

The acronym of MIMO is Multiple input multiple output. Whereas it includes several technologies, MIMO can simply be defined as any wireless network that permits the transmission and receiving of over single data signal simultaneously over the constant radio channel usually uses a distinct antenna for the transmitting and receiving of every signal. But the 5G has large traffic and addresses the massive traffic and addresses this limitation of data rate responsibility and potency. Recently, a technology familiar as large MIMO has been planned, that uses tons of or perhaps thousands of antennas at rock bottom station, and it'll serve tens of users at constant time. 5G communications aim at encouraging endless capacity of networking, vast system of measurement information measure intensive signal coverage thus as to provide an honest vary of prime quality customized essential services to the highest users. Towards this aim, 5G communications will incorporate multiple existing advanced knowledges with innovative new methods. (Aishwarya Patila, Dr. Raghunath S. Bhadade, 2021)

3.2 MIMO Antennas-a survey

A comprehensive analysis performed on MIMO antennas with an applicable uncoupling method for several applications is presented here. One is a Murkowski technique which is mentioned by K. Vasu male person and B. Amerada, in which four-sided slots of assorted sizes as well as types are halted on one or the other side of the patch. The antenna presents multi-band resonant frequencies in the 2.8 GHz band on a measurement of 60 x 40 mm^2. A little mutual coupling as realized from S12=54 dB is because of surface current division, because of different cut-offs at intervals of the patch fringes. Huge MIMO technology in 2010, Marzetta, an person in Bell laboratory, proposed the sense of major MIMO within the framework of several cell and telecommunication devices for deaf scenarios. Thus, some totally separate options for restricted quantity of antennas in the one cell were realized. Massive MIMO knowledge describes there to the bottom station is presented with an oversized quantity of antennas, typically 100 or several hundred antennas, which are numerous orders of scale over the quantity of antennas in the current communication system. It operates multiple users at the same time on identical time-frequency resources, and mobile terminals usually assume the transmission method of one antenna receiving. (Jiarui Wu, 2018)

Literature study within the written metal structure Due to the use of multiple antennas, the performance is plagued by the mutual coupling of the antennas. To break the coupling, a cylindrical material resonator antenna (CDRA) is inserted into the paper. In this document, the focus is on the multi-frequency extension of the CDRA by two completely different micro strip feeds. Two methods are studied to achieve multiband throughout a cylindrical resonator antenna. This is the first to cut and crimp a radiant element, and the second is semi-sanded. This study presents an 8-element MIMO antenna compatible with 5G connectivity. Two spit-ring resonators with a C-shaped arrangement structure the antenna. Four-liner grooves are in groups and are cut between the centers of two members to reinforce the gap. To promote the separation of groups, four linear slits are projected and inscribed between the centers of two elements.

The isolation is fourteen dB which meets the wants of a mobile communication application. The subsequent document shows the vaulted 2 × 2 MIMO monopole configuration with branching parts. Within the ground plane, 2 comb holes are used to get twin band reaction from the antenna. Frequency bands cowl LTE, WIFI/WLAN, Bluetooth, and WiMAX applications. To attain high isolation, a T-shaped piece with a ground plane is employed. A spider-shaped MIMO antenna is used for applications reminiscent of Bluetooth, Wi-Fi, WiMAX, and WLAN. This antenna consists of two spider-shaped radiation spots moving one when the opposite on a micro strip feedline and associating an elongated sub-ground plane stuffed with a formed backplane, within the form of a spider, permitting multi-band operation. Because of the fully different bands of the antenna, poor correlation between the radiators is achieved. This text analyzes and addresses the performance of MIMO antenna parameters.it is meant for a local area network application. The elongated line has been integrated into the first part compared to the triangular design. It had been placed in a very rectangular frame. Within the third and last phase, the math of 2 half-curves was developed. (Aishwarya Patila, Dr. Raghunath S. Bhadade, 2021)

5G technology has number of benefits over 4G communication systems, such as Band width higher transfer rates and lower latency periods. To see the increasing requirements of 5G transmission, MIMO methods could be a likely technology in antenna model. In sub 6 band rate 5G operation, high isolation, high gain, and low computer code MIMO antenna systems must attain a high transmission rate and vast network capacity. Various 5G MIMO antenna system have recently been designed in recent times. To have a better understanding of the data measurement response, a variety of new radiators has been introduced, such as upturned F-shaped, Yagi-designed, π-designed, Y-shaped, T-shaped, and linked with a collapsible shape. A folded monopole and a space coupled-loop branch are modeled to see a noticeable reduction in mutual coupling. Due to compact size of the smart mobile phones, the approach to style MIMO antenna array with sensible separation operation remains to be an essential task. In numerous reportable antennas, varied ways are projected to boost isolation between antenna components. In a literature, 4 sets of orthogonal antennas are positioned symmetrically on the corners of modern mobile phones to increase separation between antennas.

A well-adjusted slotted antenna is intended that can provide a neutral slotted pattern to improve the separation operation. That antenna which relates the orthogonal monopole or dipole methods inside the lower band can increase isolation performance whereas victimization the orthogonal slot and open slot approaches in the higher band to make a high-level isolation all over the full band. The 3GPP has confirmed that 5G NR includes 3 sub-6 GHz operating bands, i.e., N77 (3.3

to 4.2 GHz), N78 (3.3 to 3.8 GHz), and N79 (4.4 to 5 GHz). Various countries and territories can choose their personal 5G running bands from 3 bands which is mentioned above. For instance, the usage of 3.3 to 3.6 GHz and 4.8 to 5GHz bands have been adopted officially across China, Another frequency band from 3.6 GHz to 4.2 GHz and from 4.4 GHz to 4. 9 GHz has been adopted Japan, another frequency band 3.4 GHz to 3.8 GHz has been followed by EU. For antenna designers, it is difficult for them to achieve larger bandwidth in both bands, thus it is difficult endeavors to achieve good results. The loop-shape antennas can significantly reduce the size as well as efficiency.

Normally, 0.5λ, 1.0λ, and 1.5λ modes are the key 3 modes of resonance of all loop type antennas. Furthermore, an open slot, a fine-tuning phase, and a parasitic phase on the opposite surface be able to in addition, improve the bandwidth. In another paper in a literature, a unique ring-type antenna for packages of 5th generations mimo antenna gadgets in cellular terminals is suggested. The arrays of antennas incorporate an open-loop which is ring type resonator and a T-shaped emitting components. Different radiators were proposed and investigated for the proposed small 4 Element antenna mimo device. The functionality of suggested 4 Elements antenna mimo device, validated repetitively through for each simulation and measurement. (Huang, Jianlin; Dong, Guiting; Cai, Qibo; Chen, Zhizhou; Li, Limin., 2021. Table 3.1 shows comparison of various antennas operating on 5G bands.

References	Operating Band (GHz)	Isolation in dB	ECC	Efficiency (%)	Size (mm3)
[3]	2.45-2.65, 3.4-3.75,5.6-6	11	< 0.01	40-65, 50-70 60-80	20.5 × 6.5 × 0.8
[4]	3.3 - 6	11	<0.1	40-71	15 × 6 × 3
[5]	3.3-3.6, 4.8-5.0	10	<0.15	>60	7 × 15.5 × 0.8
[10]	3.3-6.0	12	<0.11	>50	9 × 7 × 2
[13]	3.4-3.6, 4.8-5	16.5	<0.02	>70	14.9 × 7 × 0.8
[18]	3.4-3.6	17	<0.01	58	25 × 3.5 × 0.8
Proposed	3.4-3.6, 5.4-5.6	10	<0.12	>60	150×40×0.035

Table 3. 1 Comparison of Different antennas

The geometries of the antennas are shown in the following Figure 3.1, 3.2, 3.3, and 3.4:

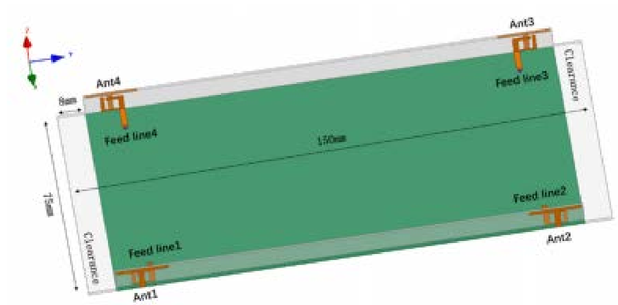

Fig 3. 1 4-Element dual band Antenna

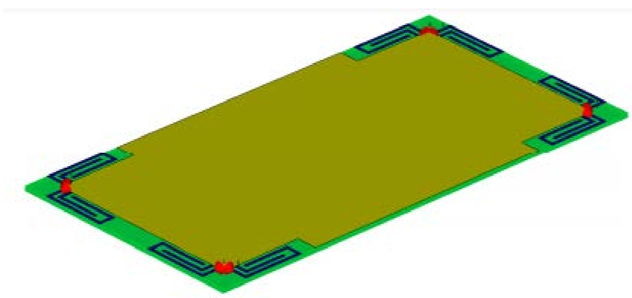

Fig 3. 2 8-Element dual band Antenna

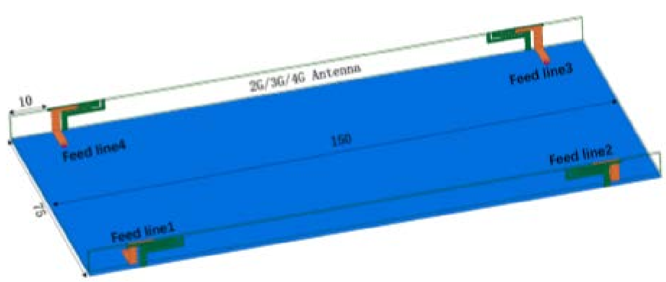

Fig 3. 3 4 Element MIMO Antenna

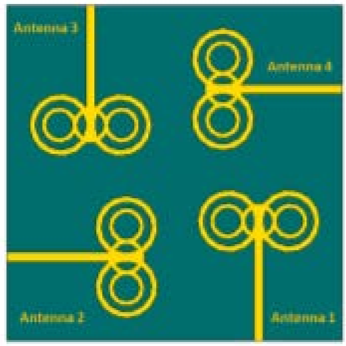

Fig 3. 4 MIMO Antenna for 5G applications

Chapter 4

Antenna Design

4.1 Design of dual band antenna

This section is about designing of dual band single element antenna. The antenna will work operates on two bands that is 3G and 5G band with better isolation between both antenna after converting into more elements.

4.1.1 Single element Antenna configuration

The design of single element antenna is shown in the Fig 4.1.1. One antenna is designed on FR4 as a substrate having a dimension of 140 mm × 70 mm × 0.8 mm. On the back side of the FR4 substrate, a copper (h=0.035 mm) used as a ground plane is printed. The single element is designed on the left edge of the substrate. Two strips have been used: one is U shaped strip and the other as shown in the Fig. 4.1 (b) is an inverted F shaped strip. The vertical strip on the left side is taken as a feeding point. Both ground plane and FR4 have same dimension; however the ground plane is cut below the antenna structure with a dimension of 15 mm × 7 mm as shown in the following Figure 4.1.1

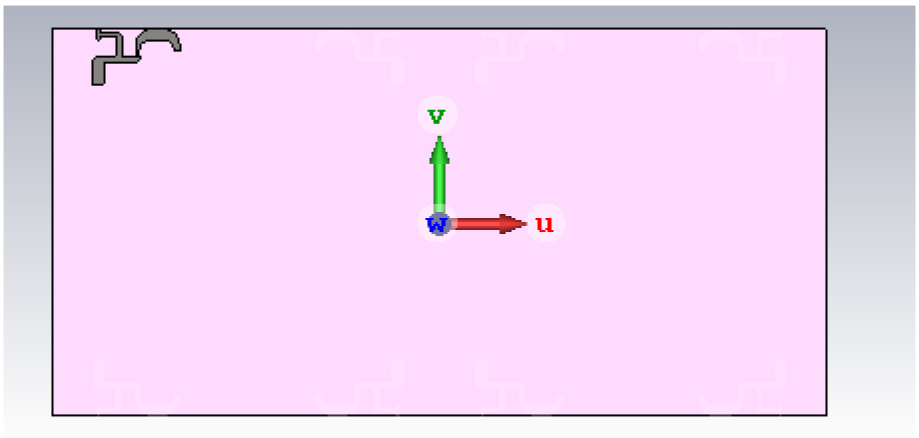

Fig 4. 1 1 Single element antenna

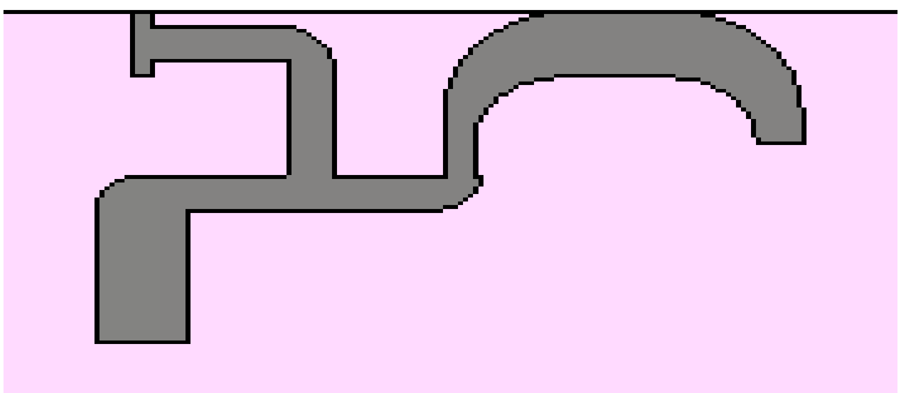

Fig 4. 2 Single element antenna Zoomed Image

4.1.2 Antenna parameters

The Figure 4.3 shows the dimensions length (L) and width (w) of the single element antenna. The measurement unit is millimeter (mm) and complete parameters of the antenna is depicted in table 4.1

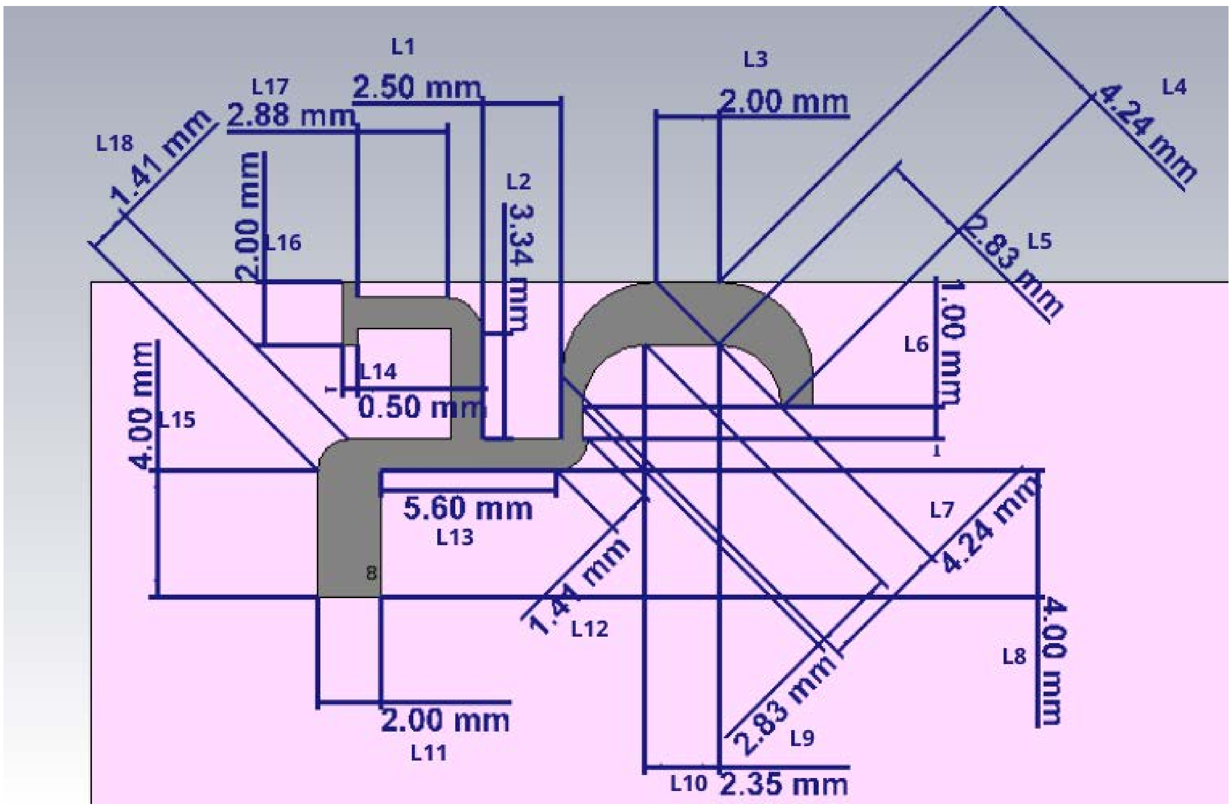

Fig 4. 3 Dimensions of Single Element Antenna

L1	L2	L3	L4	L5	L6	L7	L8	L9
2.50	3.34	4.6	4.24	2.83	1.0	4.24	4.00	2.83
L10	L11	L12	L13	L14	L15	L16	L17	L18
2.35	2.00	1.44	5.60	0.50	4.00	2.00	2.88	1.41

Table 4. 1 Parameters of Single Element Antenna in millimeters (mm)

4.2 Simulating Results

4.2.1 Return Loss

Return loss is the matching of an antenna. It shows how much antenna is matched. High value of return loss shows good matching resulting in good radiation pattern. The return loss in lower band is -26.76 dB and -21.9 dB in the high band, respectively. The return loss is measured at 3.28 GHz and 5.287 GHz bands. The frequency shifting is controlled by cutting the copper along with the movement of strips towards left side. The antenna consists of two strips: one is U-shaped strip while the other is inverted F-shaped strip. The lower band is achieved by U-shaped strip while the high band is achieved by the inverted F-shaped strip. The following Fig. 4.2.1 shows the return loss at 3.28 GHz

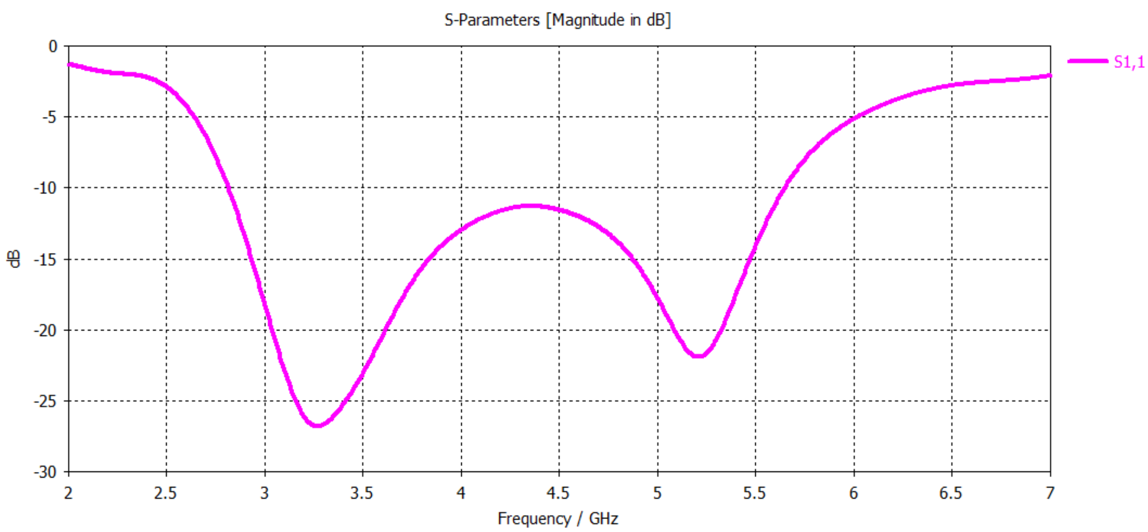

Fig 4.2. 1 The return loss of Antenna at 3.28 GHz

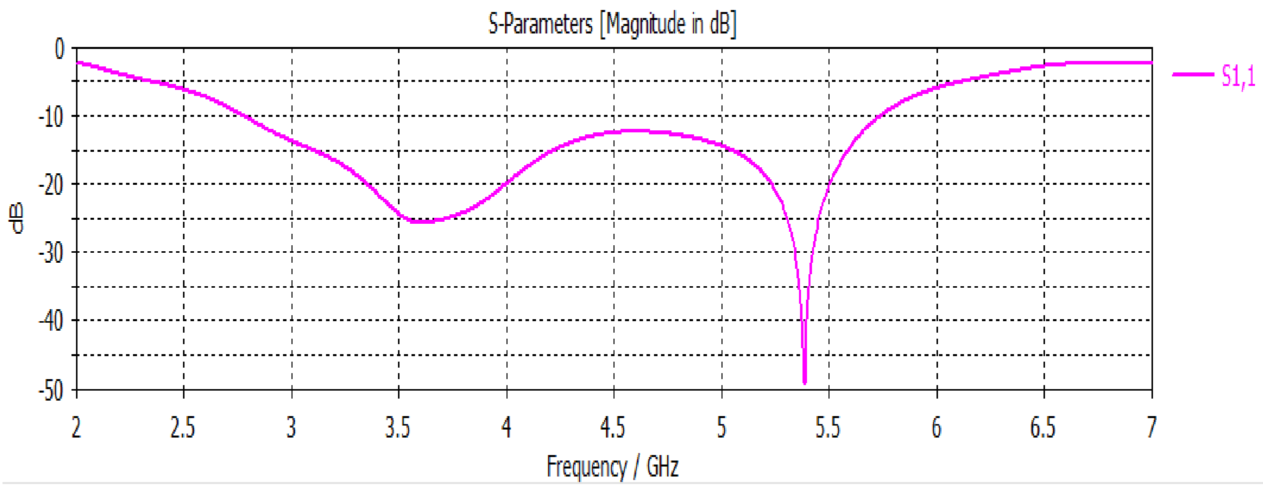

Fig 4.2. 2 The return loss of Antenna at 5.28 GHz

4.2.2 VSWR

VSWR shows the reflecting power back from the load. High VSWR resulting in no radiation pattern. The threshold for VSWR is 1.3 which implies that the values within the range of 1.3 will give an applicable radiation pattern. When dust particle or water enters in the port of antenna, VSWR appears on antenna. VSWR at both resonant frequencies is given in the Fig. 4.2.3 and Fig. 4.2.4 respectively.

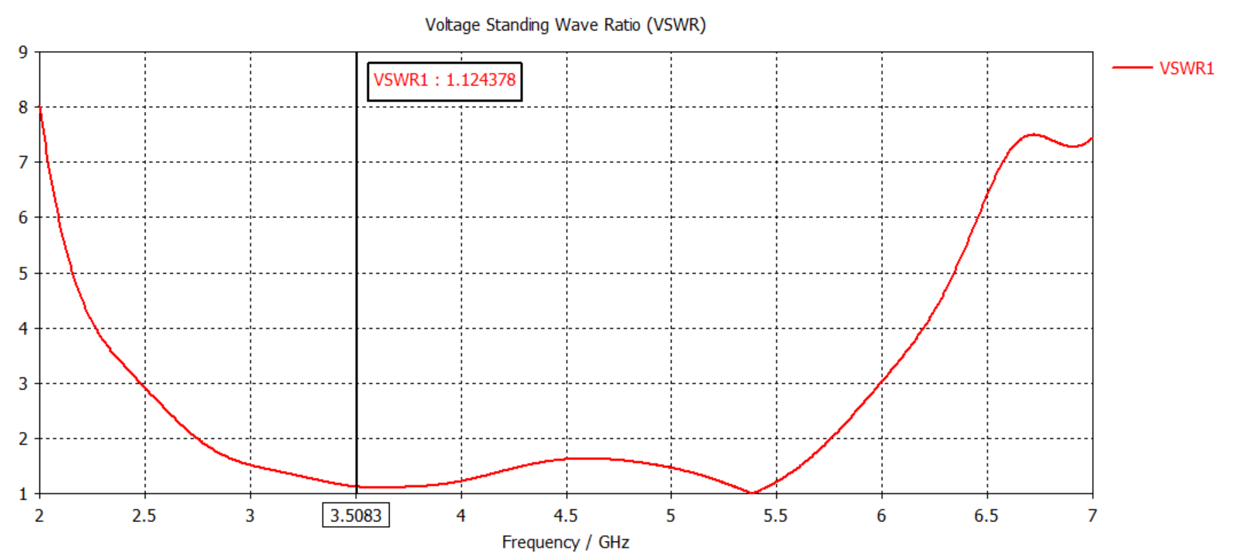

Fig 4.2. 3 VSWR at 3.5 GHz

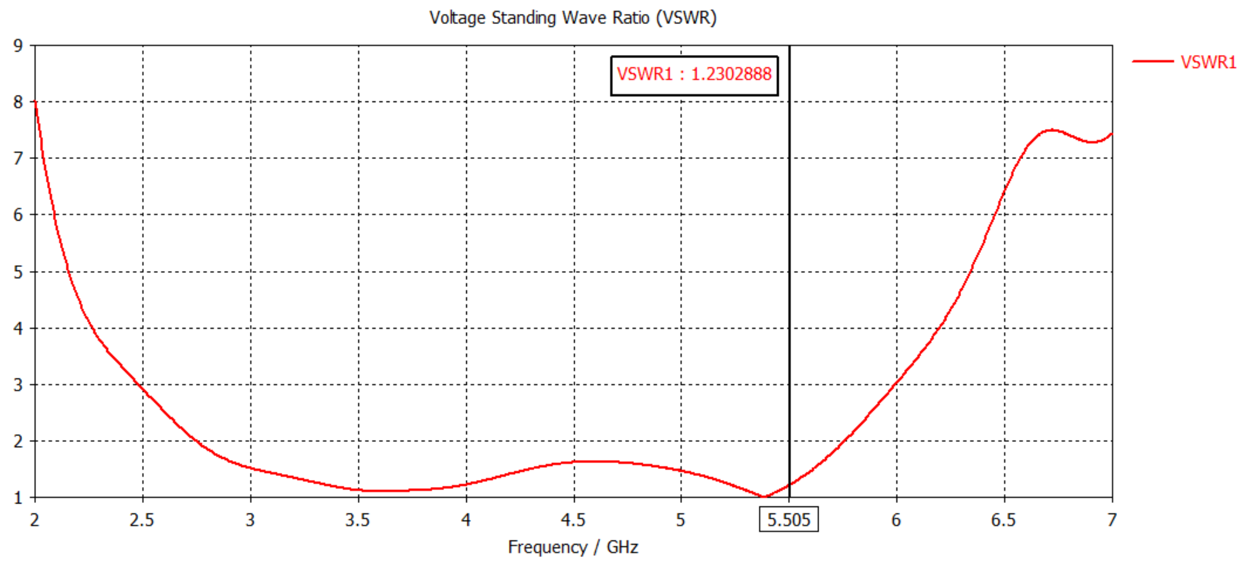

Fig 4.2. 4 VSWR at 5.5 GHz

4.2.3 Impedance Matching

While designing antennas, to minimize input and output Impedance of an antenna or to maximize transmission power of an antenna is said to be impedance matching. Impedance matching of the antenna is controlled by changing the length and the breadth of U-shaped and Inverted F-shaped strips. It is also controlled by cutting the ground plane near the corners. The impedance bandwidth at both frequencies is 1.5 GHz and 0.5 GHz, respectively. The impedance bandwidth for both frequencies is represented as.

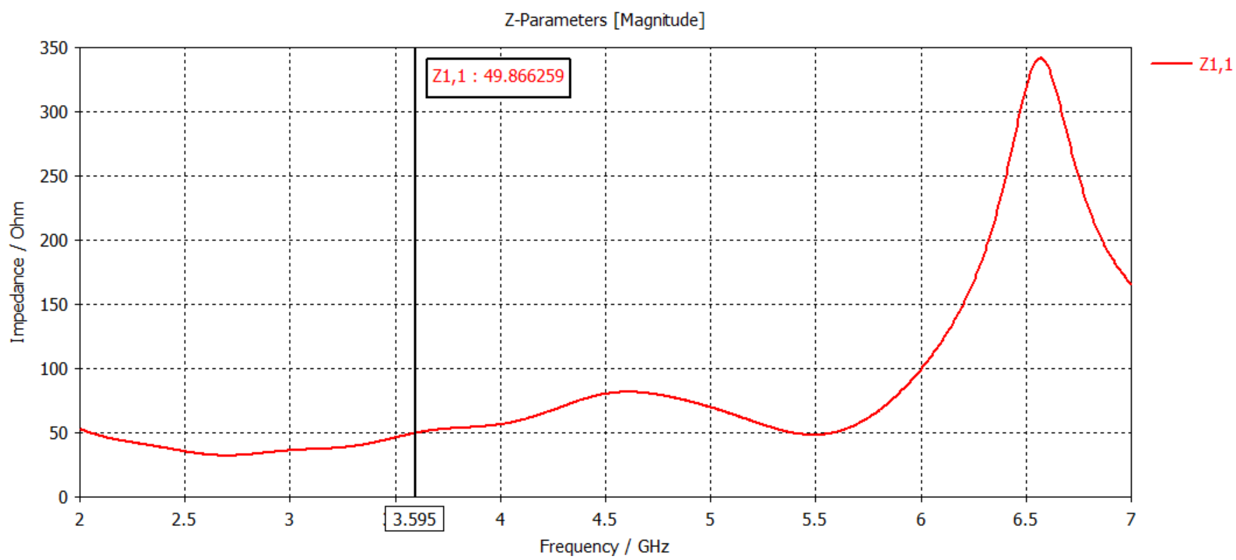

Fig 4.2. 5 Impedance Bandwidth at 3.5 GHz

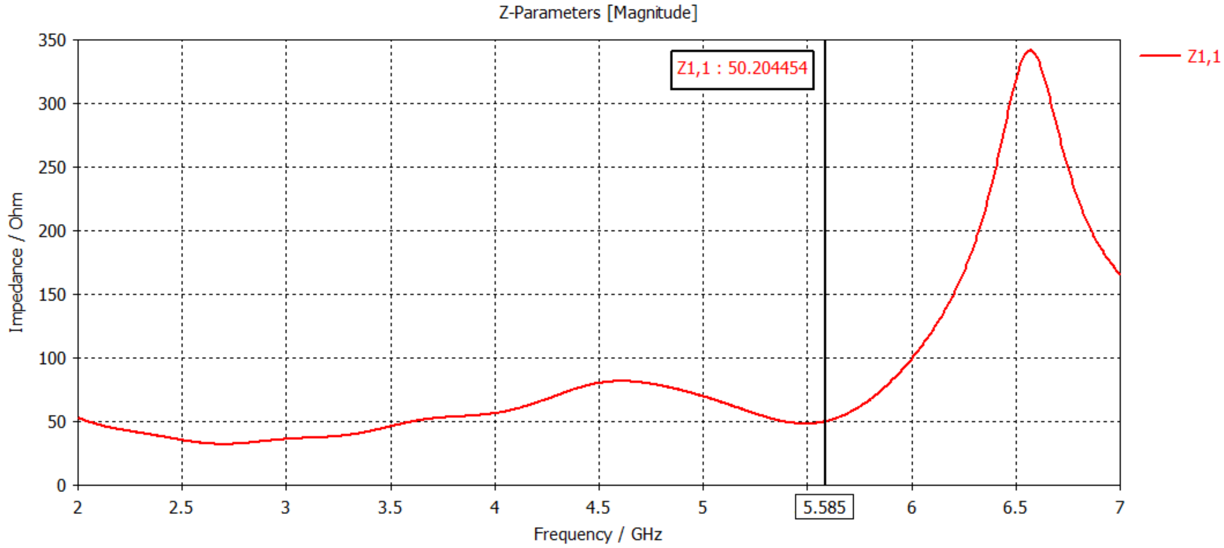

Fig 4.2. 6 Impedance Bandwidth at 5.5 GHz

4.2.4. 3D Radiation Pattern

3D Radiation pattern is representation of pattern in 3 dimensions representing the transmission or reception of wave front. The gain of single element antenna is 2.3 dB which is applicable for smart phone antennas. The 3D and polar-radiation patterns at resonance are given in the Fig. 4.2.7 as:

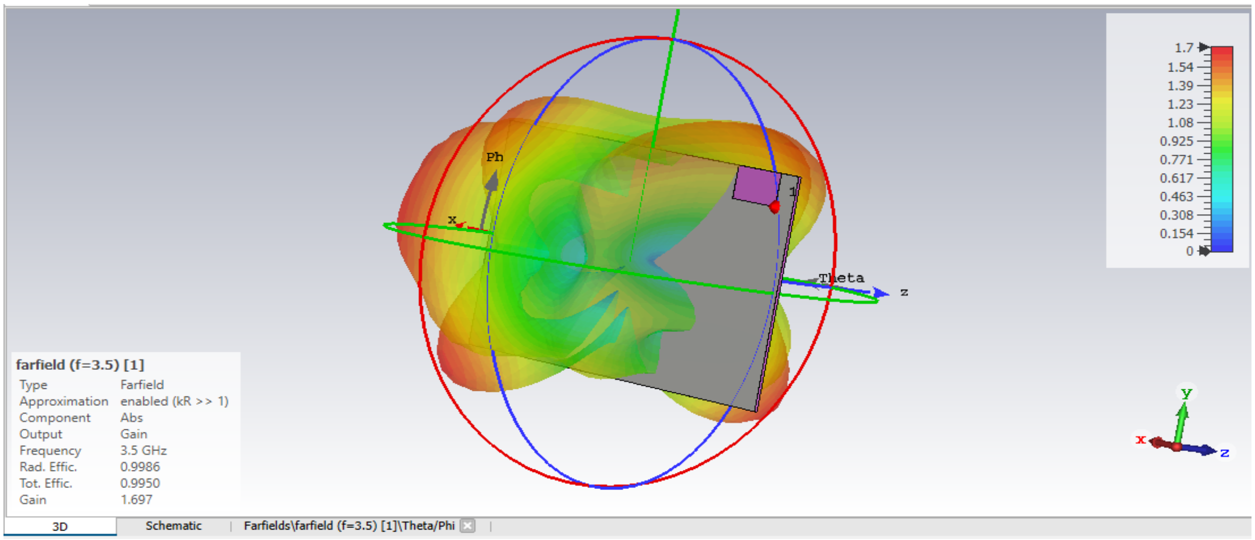

Fig 4.2. 7 3D Radiation pattern of antenna 1 at 3.5 GHz

The radiation efficiency of the antenna at 3.5 GHz is 99 percent and the gain is 1.697 at 3.5 GHz frequency. The overall efficiency is 99 percent.

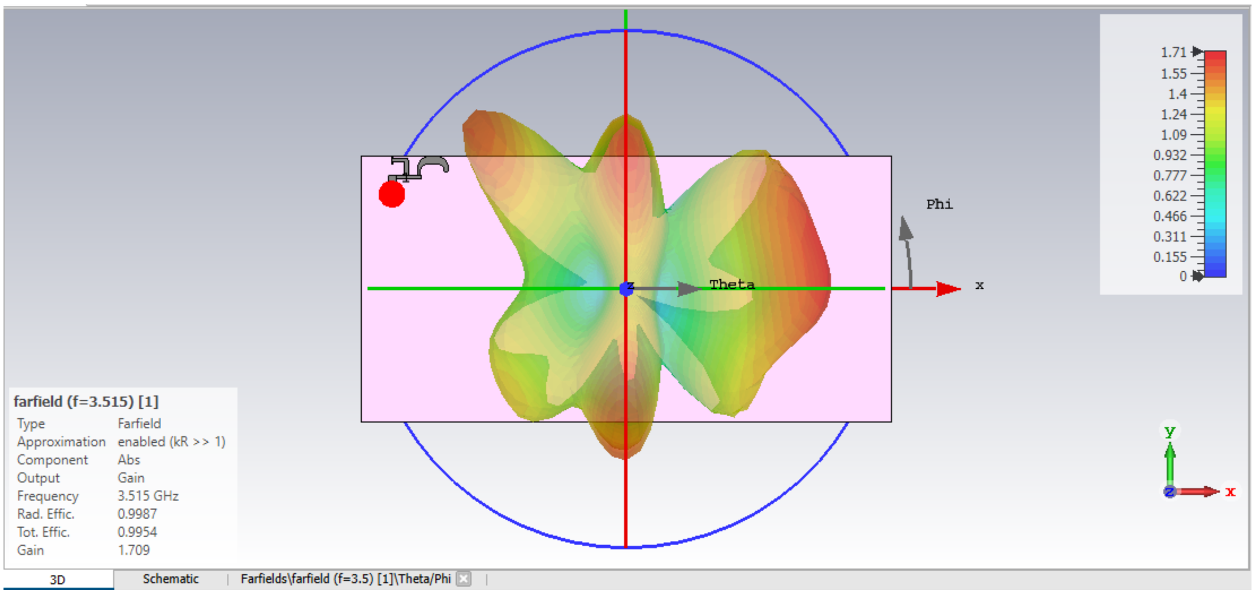

Fig 4.2. 8 3D radiation patterns of antenna 1 at 3.5 GHz

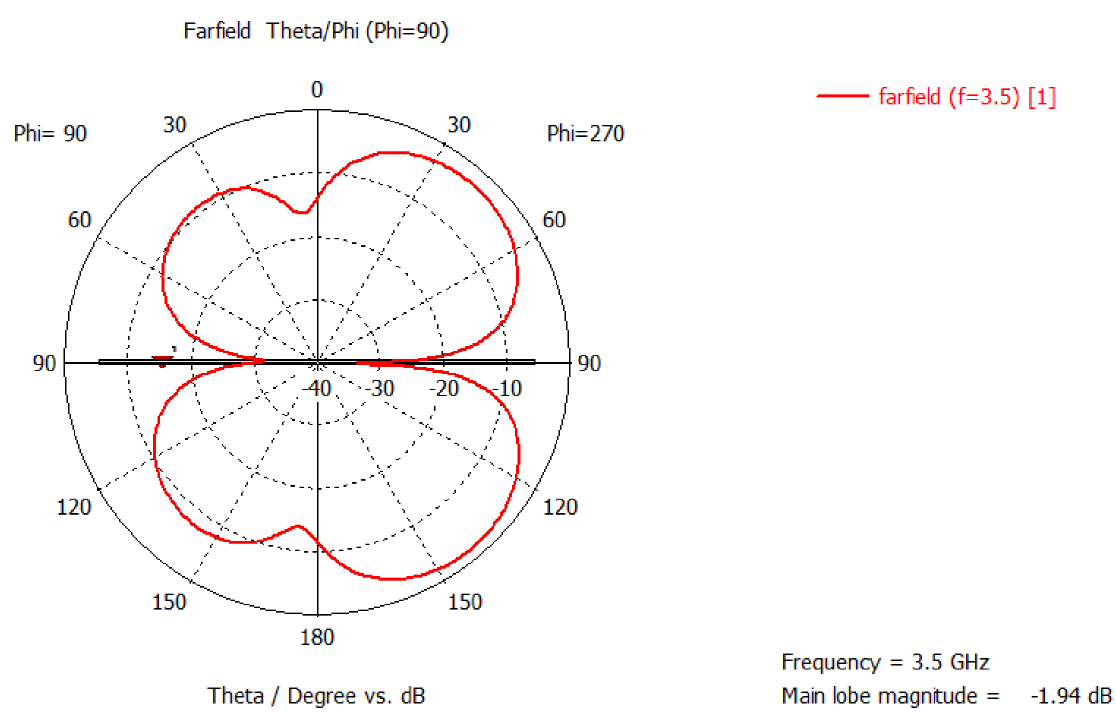

Fig 4.2. 9 E field Pattern at 3.5 GHz

The main lobe in Omni direction antenna shows back radiation pattern while the front lobe shows the useful radiations.

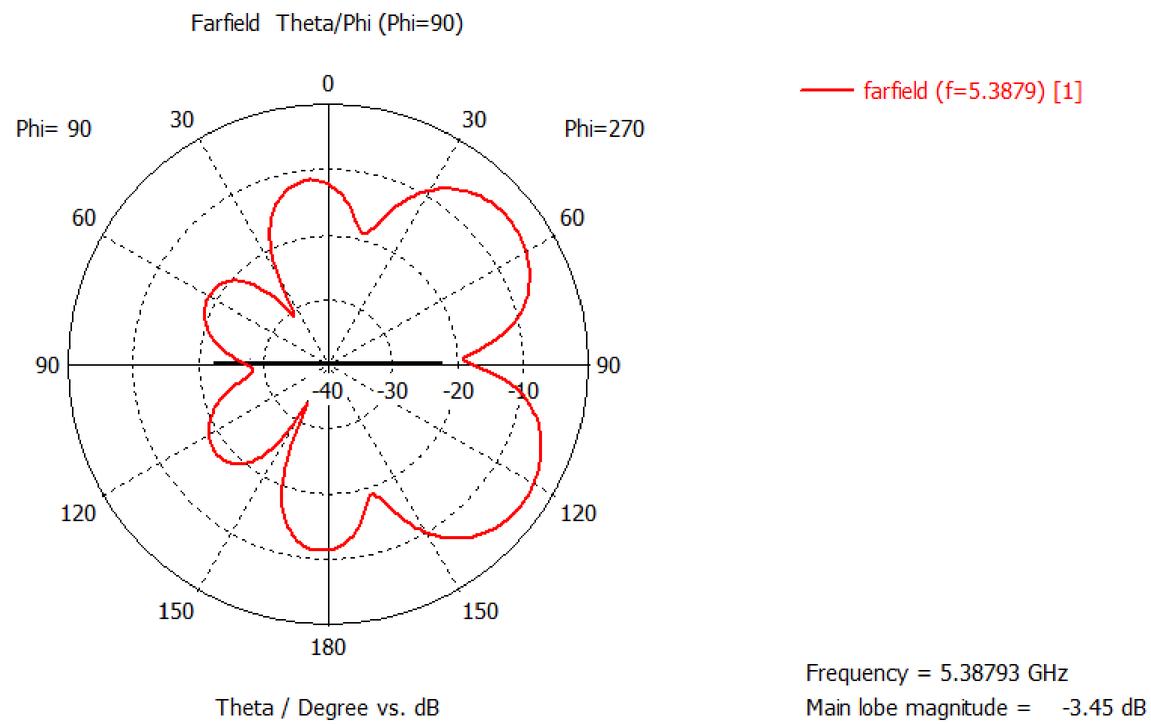

Fig 4.2. 10 E field pattern at 5.3 GHz

4.2.5. Efficiency of Single Element Antenna

Efficiency shows that how much input power is converted into radiation power and is the ratio of gain to the directivity. The total radiation efficiency of the single element antenna at 3.5 GHz and 5.5 GHz are 99 %, respectively as represented in the following snap.

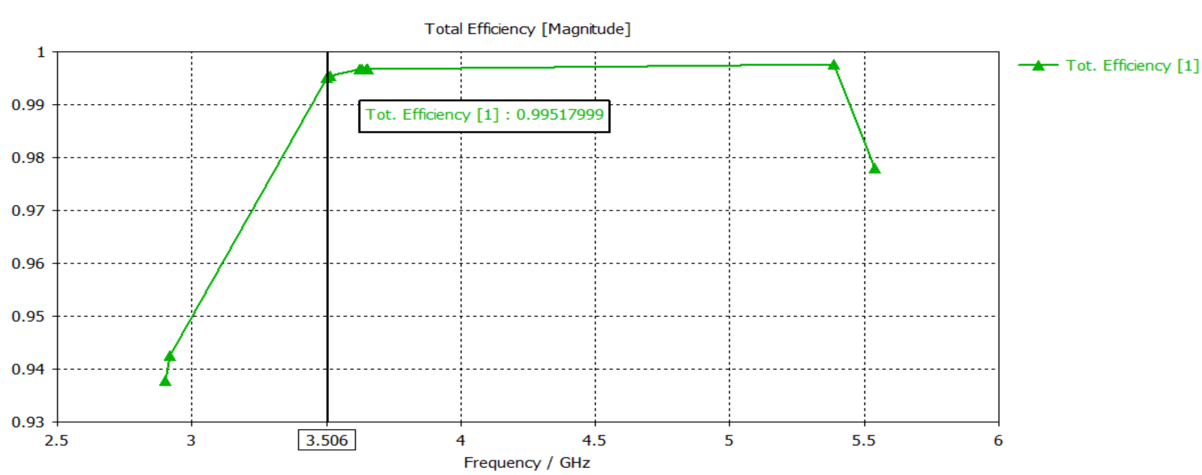

Fig 4.2. 11 Radiation efficiency of the single element antenna at 3.5 GHz

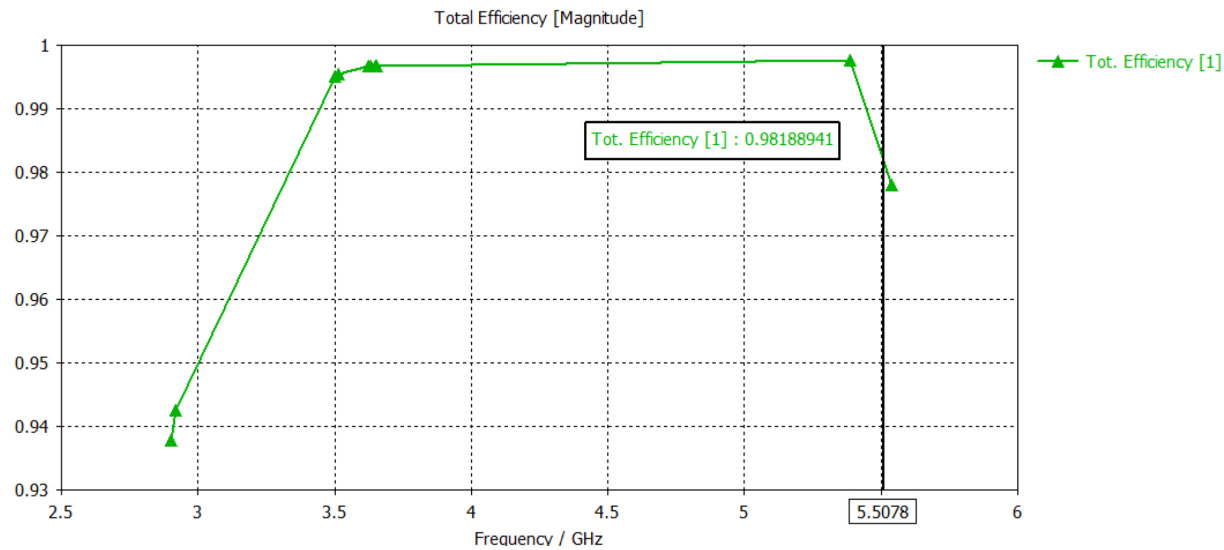

Fig 4.2. 12 Radiation efficiency of the single element antenna at 5.5 GHz

4.3. Design of 4×4 MIMO Antennas

The single element antenna as shown earlier in the Fig. 4.1. 4 is converted into 4 element MIMO antenna by translated the first antenna element into every corner of the FR4 substrate. In Fig. 4.3.1, the shifting of frequency is done via ground clearance.

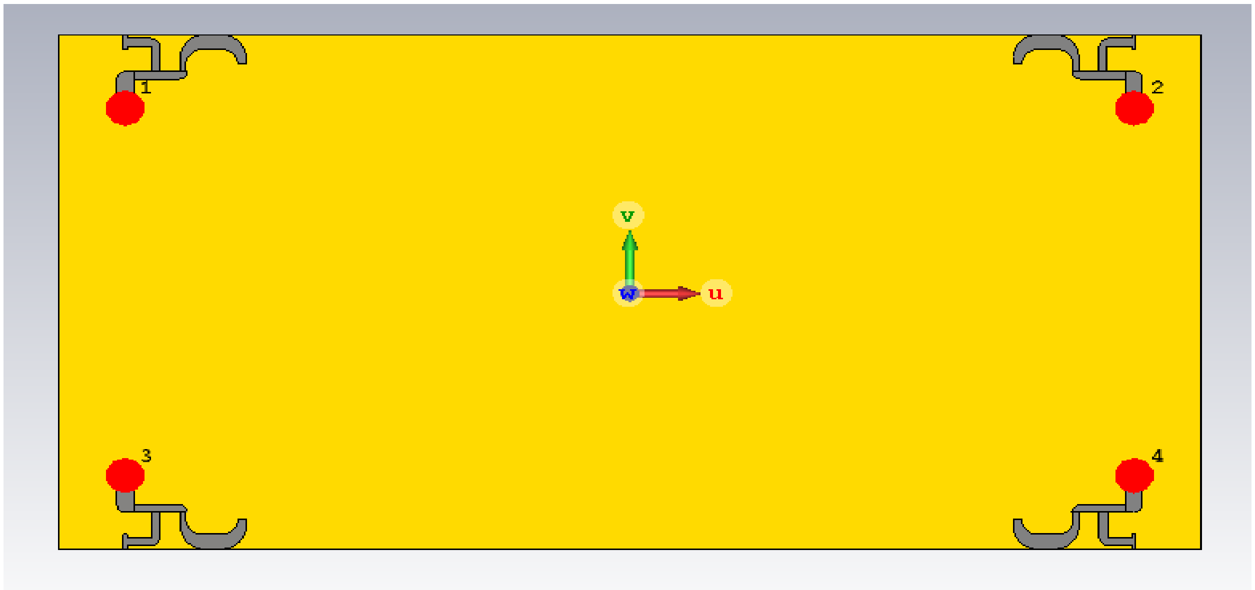

Fig 4.3. 1 The geometry of 4 element MIMO antenna:

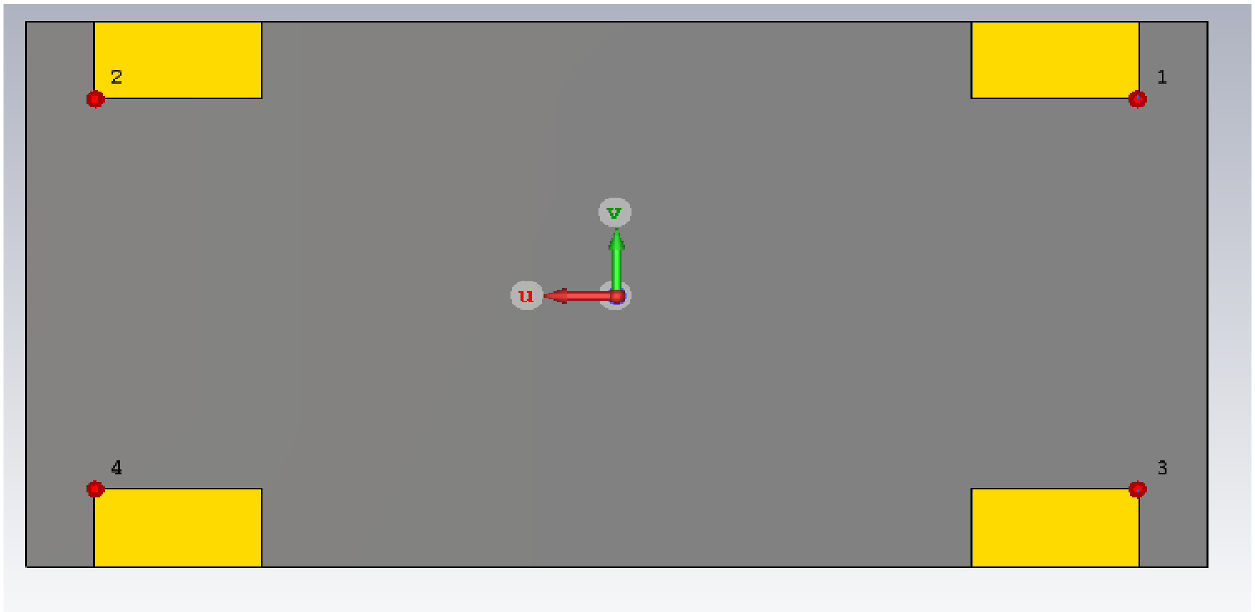

Fig 4.3. 2 Ground Plane with clearance

4.3.1. Return Loss and Mutual Coupling

The return loss and mutual coupling of the 4×4 MIMO antenna at both resonances is indicated in the Figure 4.3.3 and Figure 4.3.4 separately. There is a large distance between each antenna element; therefore, isolation between each antenna element is greater than -10 dB which is applicable for mobile antennas.

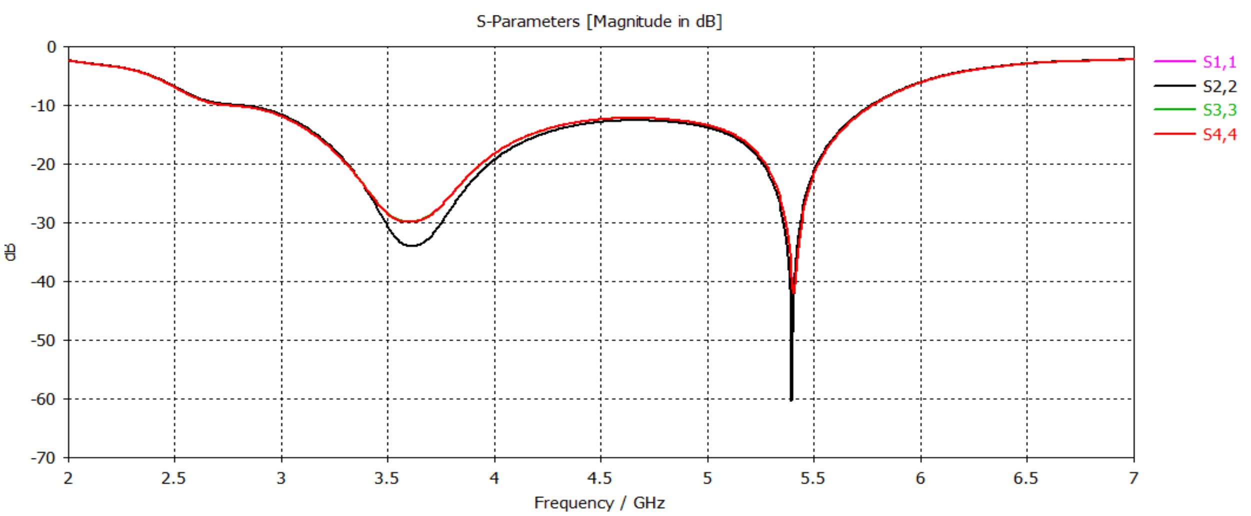

Fig 4.3. 3 Return Loss

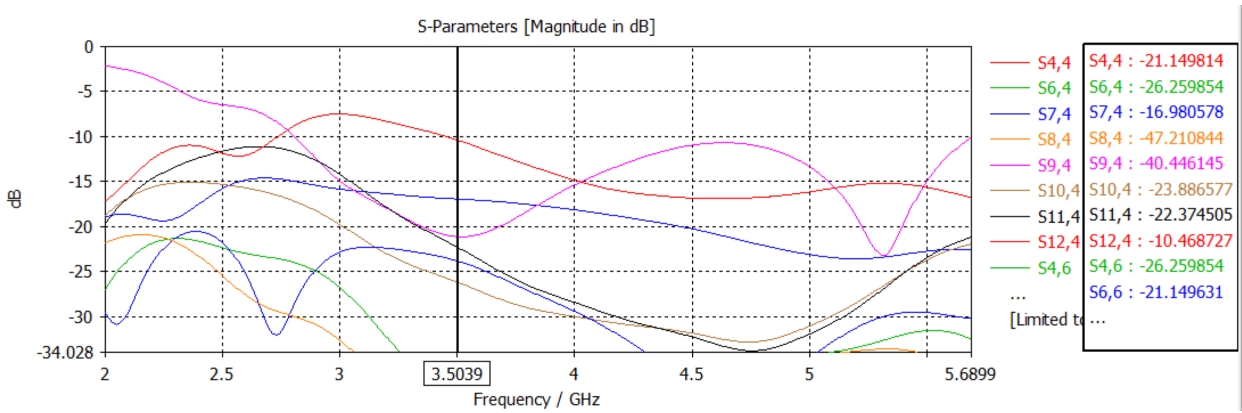

Fig 4.3. 4 Mutual coupling

4.3.2. VSWR

The VSWR of the 4×4 MIMO antenna at 3.5 GHz and 5.5 GHz bands are shown in the Fig 4.3.5. and Fig. 4.3.6 respectively. The acceptable value of VSWR is less than 1.5, and in our design, it lies in the range.

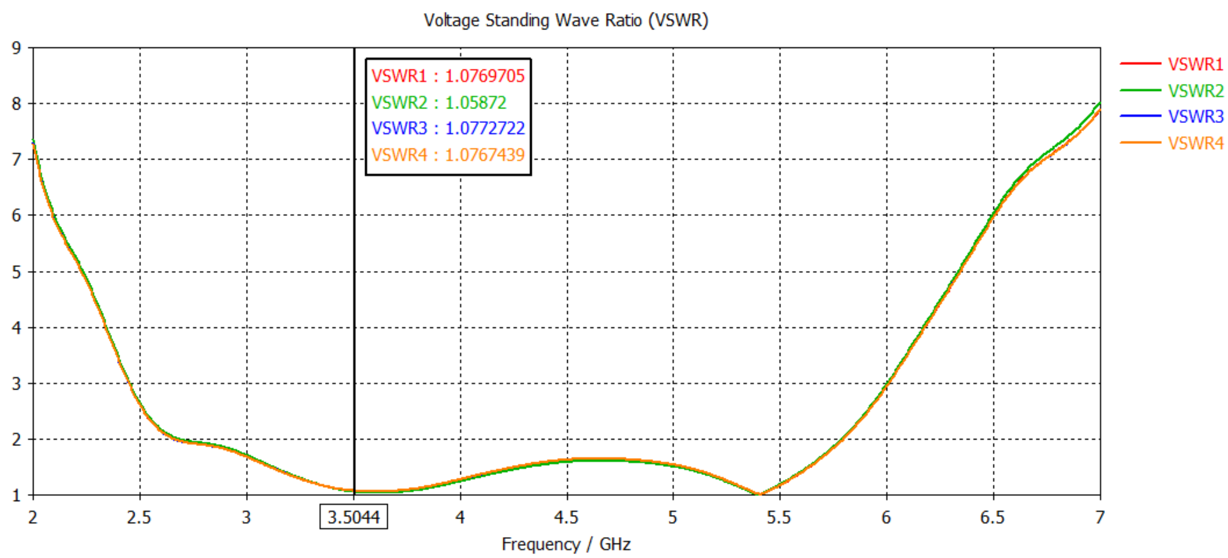

Fig 4.3. 5 VSWR of the 4×4 MIMO antenna at 3.5 GHz

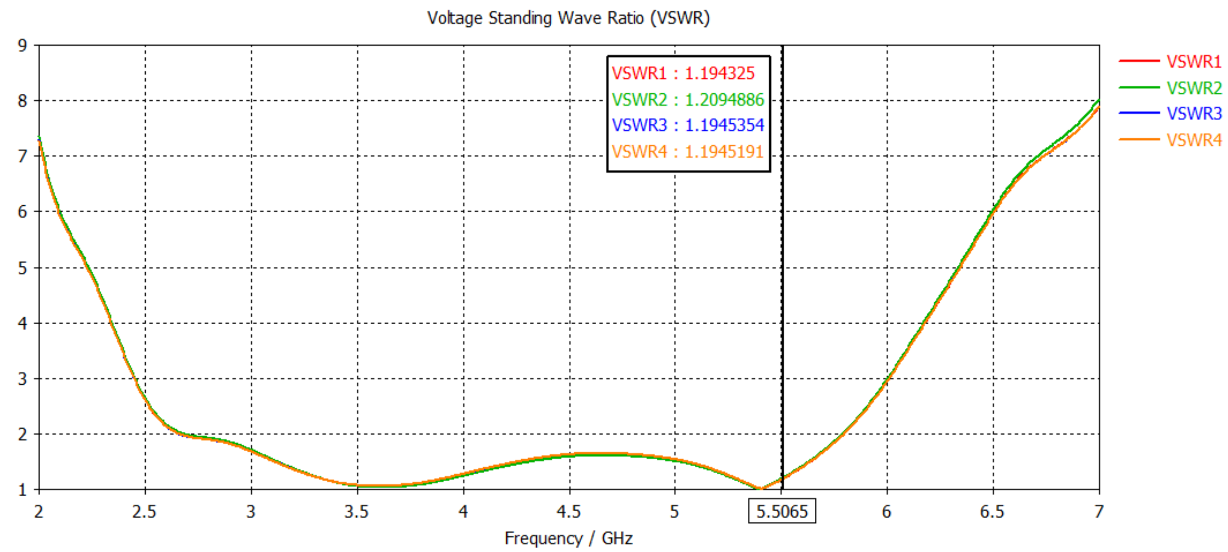

Fig 4.3. 6 VSWR of the 4×4 MIMO antenna at 5.5 GHz

4.3.3. Impedance Matching

Impedance matching is the process of reducing an antenna's input and output impedance or increasing its transmission power when designing it. The impedance matching of the 4×4 MIMO antenna at 3.5 GHz and 5.5 GHz bands are shown in the Fig. 4.3.7 and 4.3.8 separately.

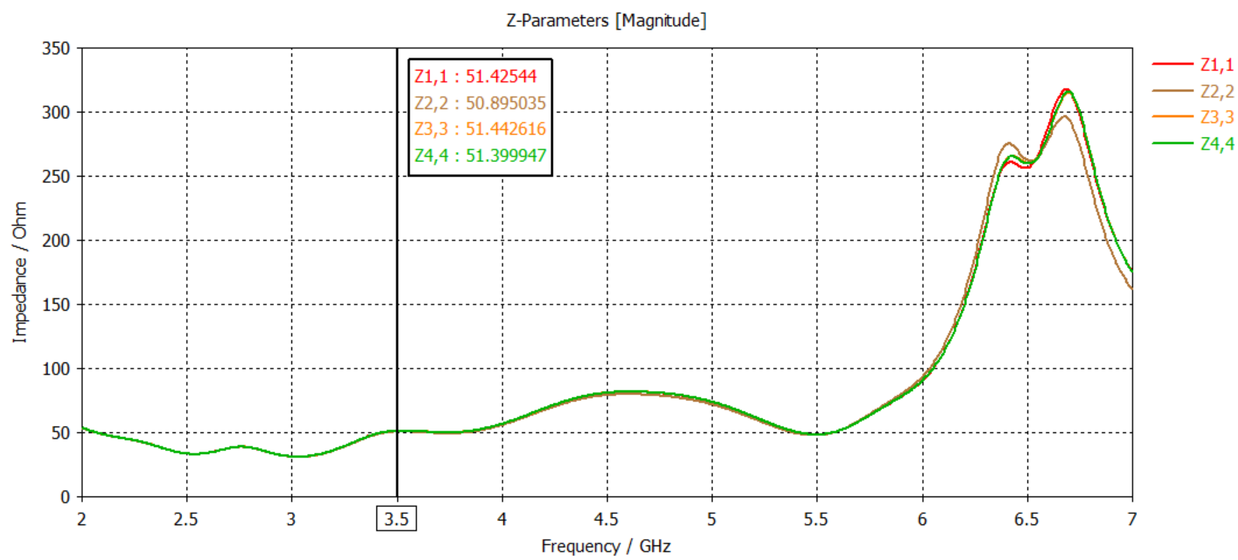

Fig 4.3. 7 Impedance matching of the 4×4 MIMO antenna at 3.5 GHz

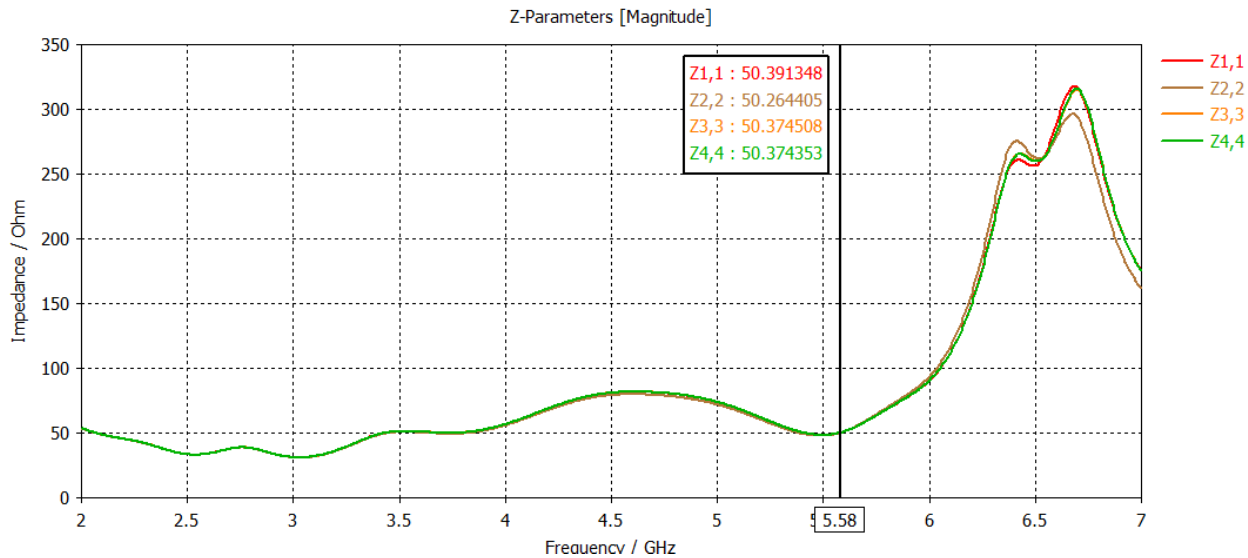

Fig 4.3. 8 Impedance matching of the 4×4 MIMO antenna at 5.5 GHz

4.3.4. 3D Radiation and Polar Pattern

The 3D radiations and polar pattern of the 4×4 MIMO antenna at 3.5 GHz and 5.5 GHz bands are depicted in the Fig. 4.3.9 and 4.3.10. The gain of each antenna at 3.5 GHz and 5.5 GHz are 2.1 dB and 2.7 dB, separately.

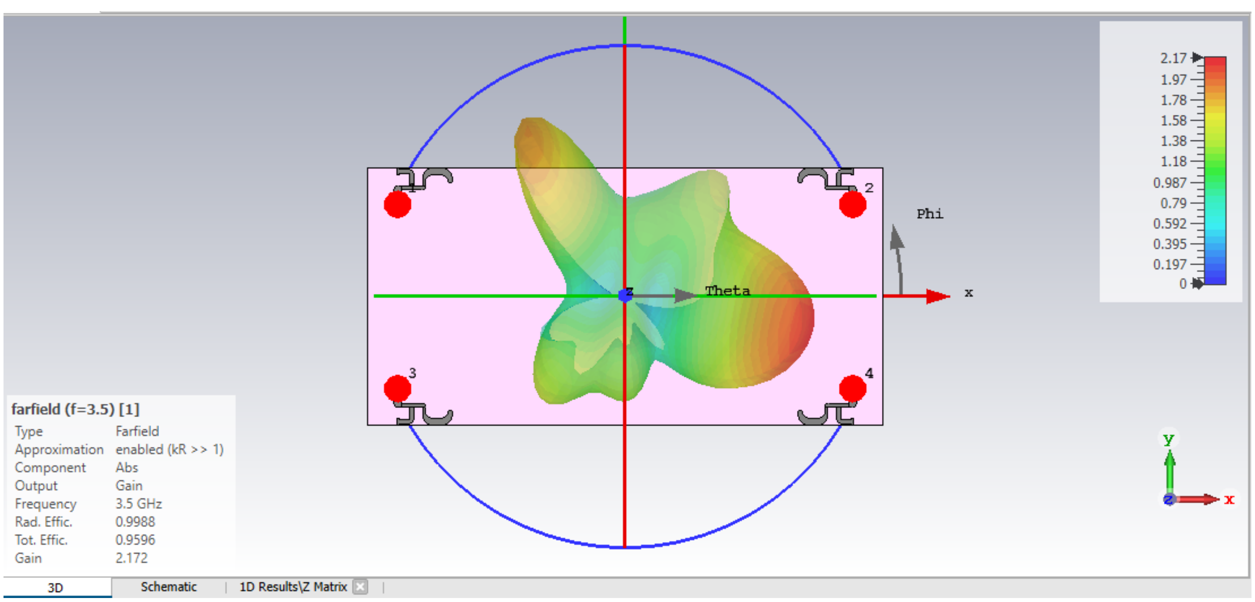

Fig 4.3. 9 3D radiation pattern of antenna 1 at 3.5 GHz

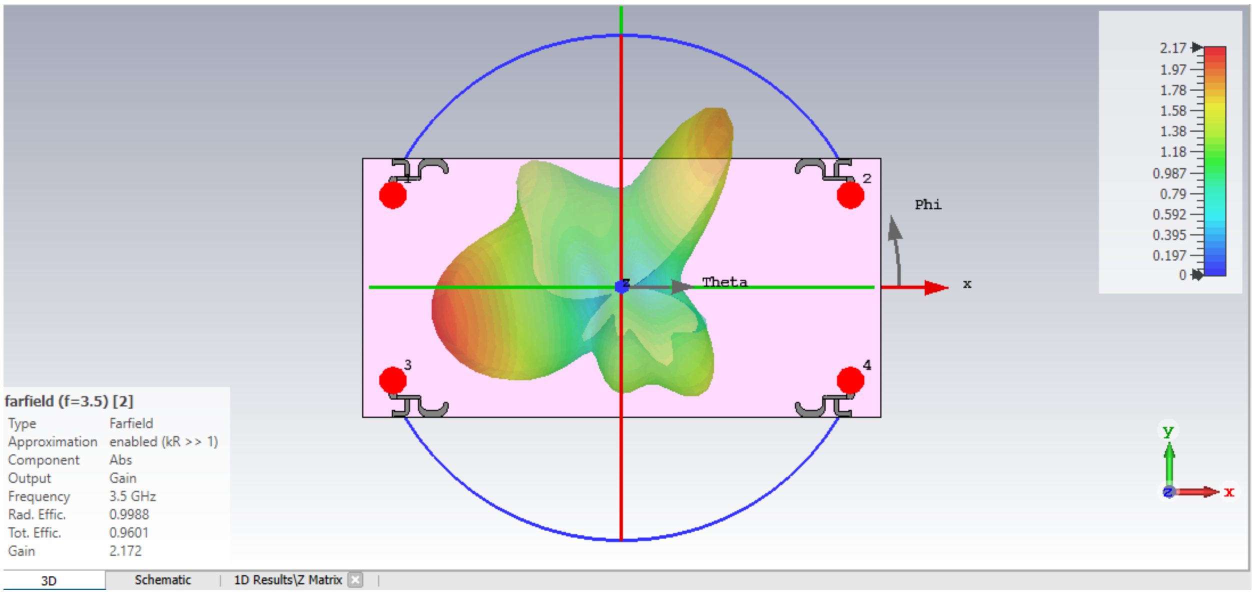

Fig 4.3. 10 3D radiation pattern of antenna 2 at 3.5 GHz

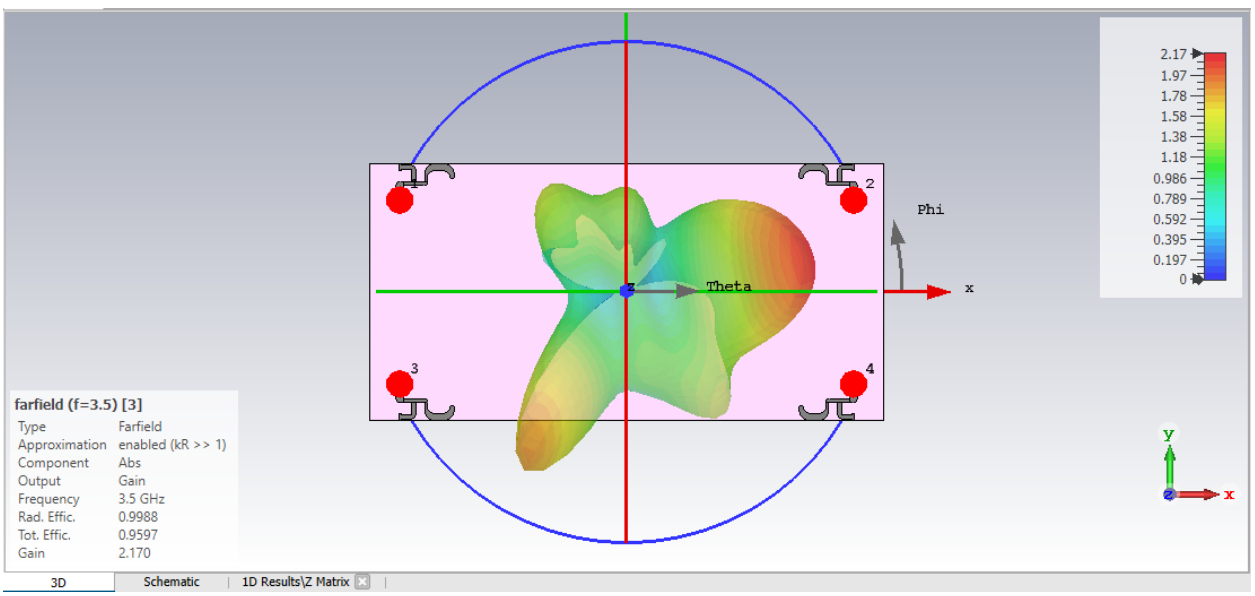

Fig 4.3. 11 3D radiation pattern of antenna 3 at 3.5 GHz

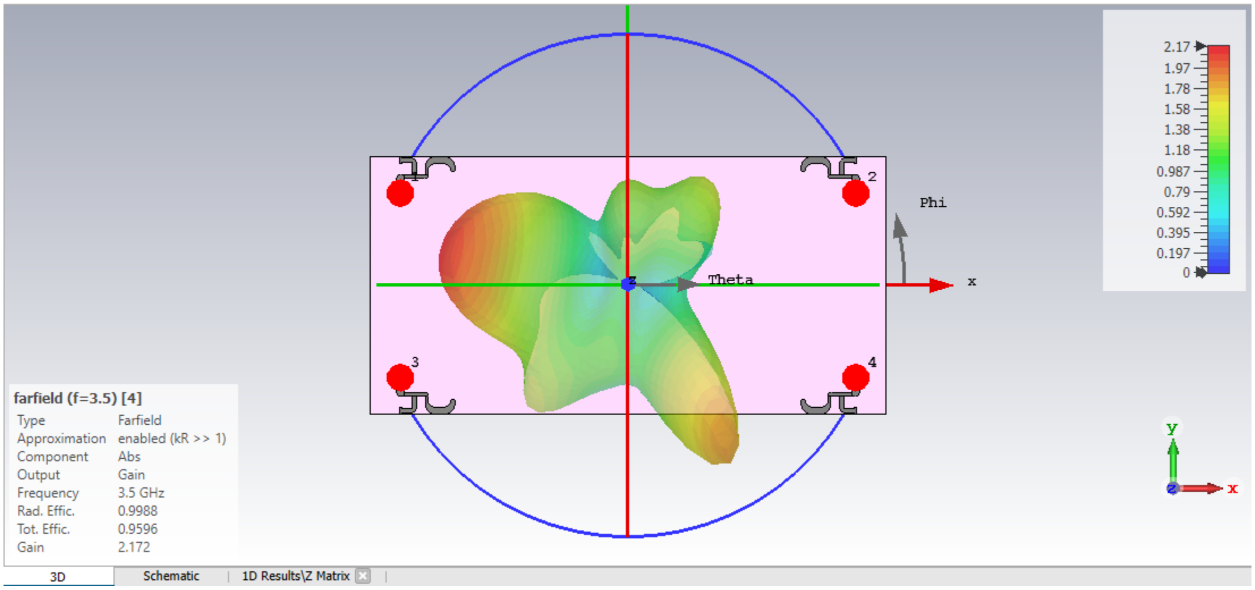

Fig 4.3. 12 3D radiation pattern of antenna 4 at 3.5 GHz

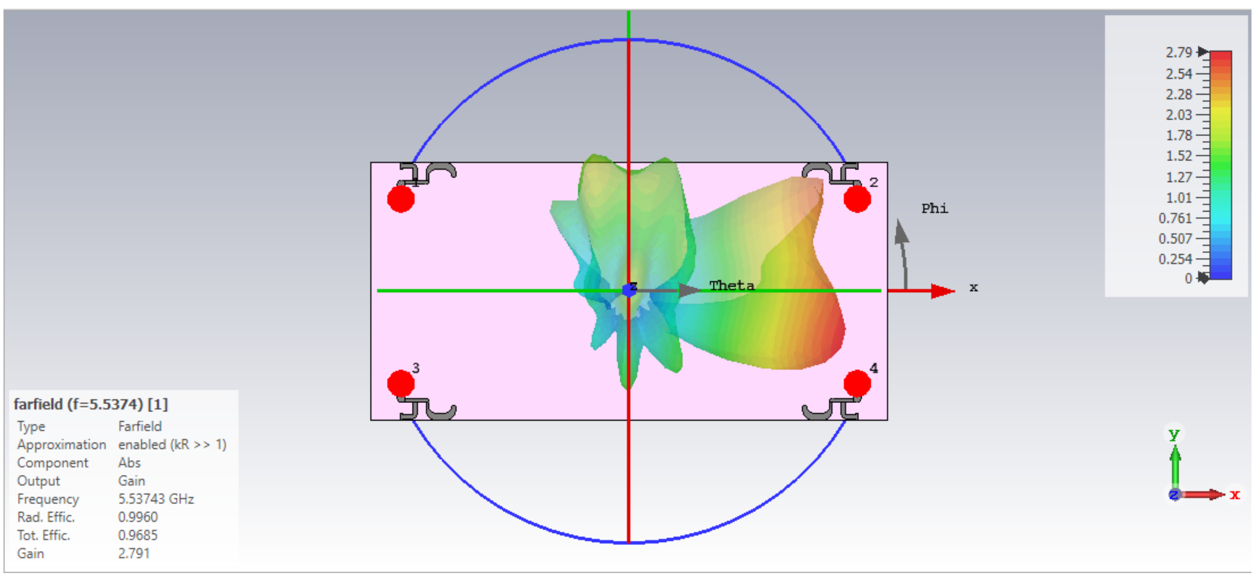

Fig 4.3. 13 3D radiation and polar pattern at 5.5 GHz

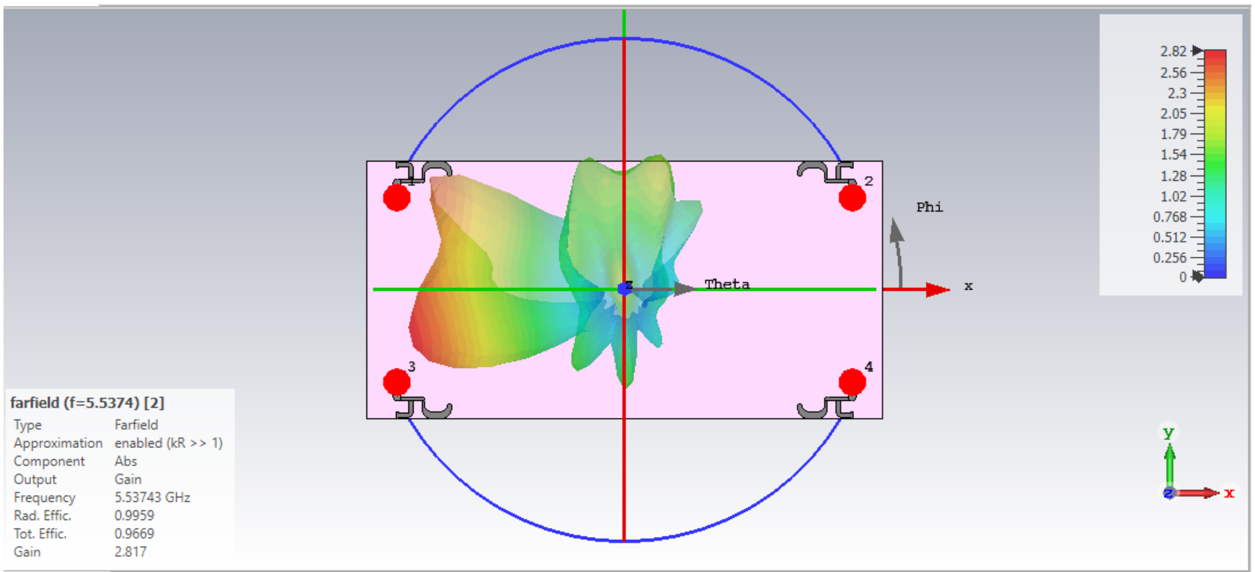

Fig 4.3. 14 3D radiation and polar pattern at 5.5 GHz

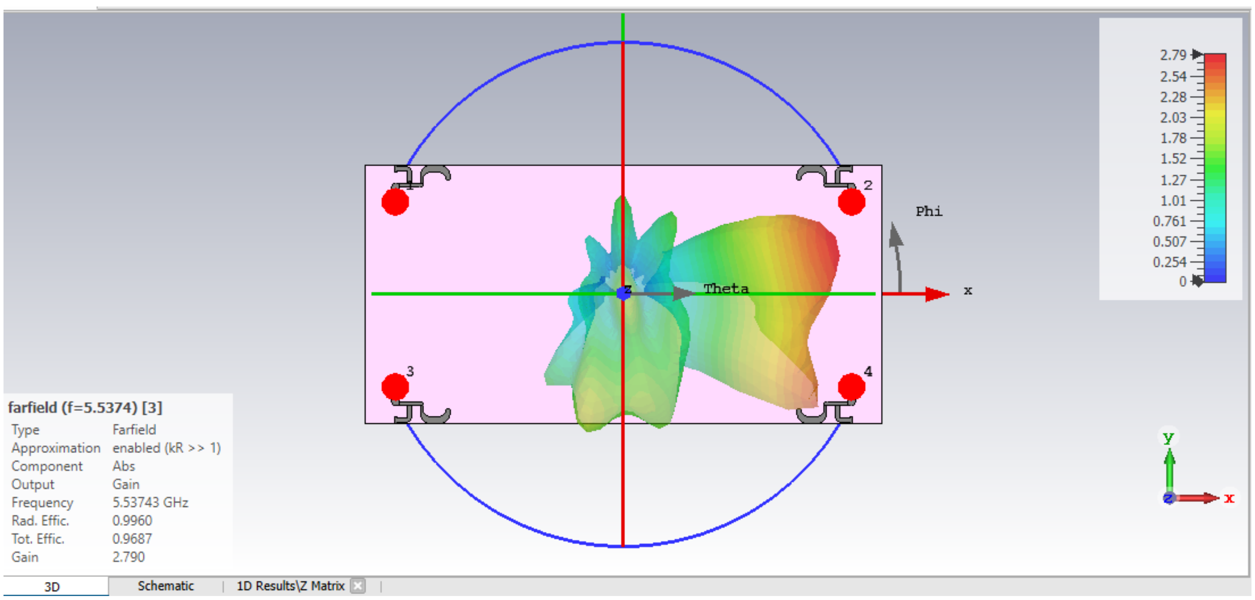

Fig 4.3. 15 3D radiation and polar pattern at 5.5 GHz

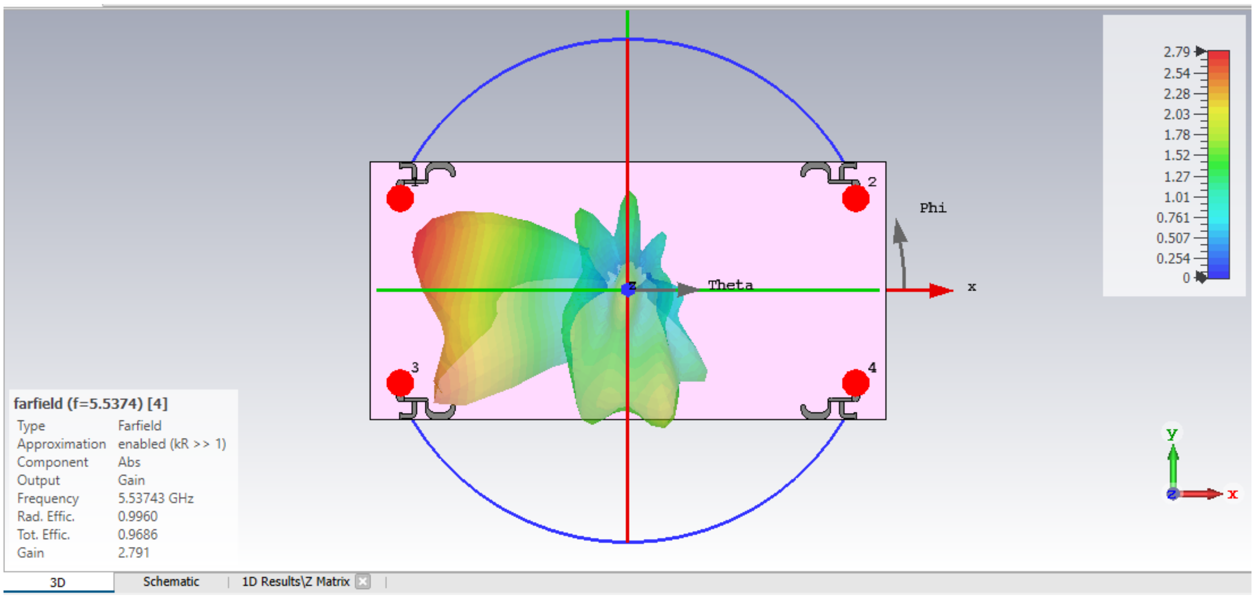

Fig 4.3. 16 3D radiation and polar pattern at 5.5 GHz

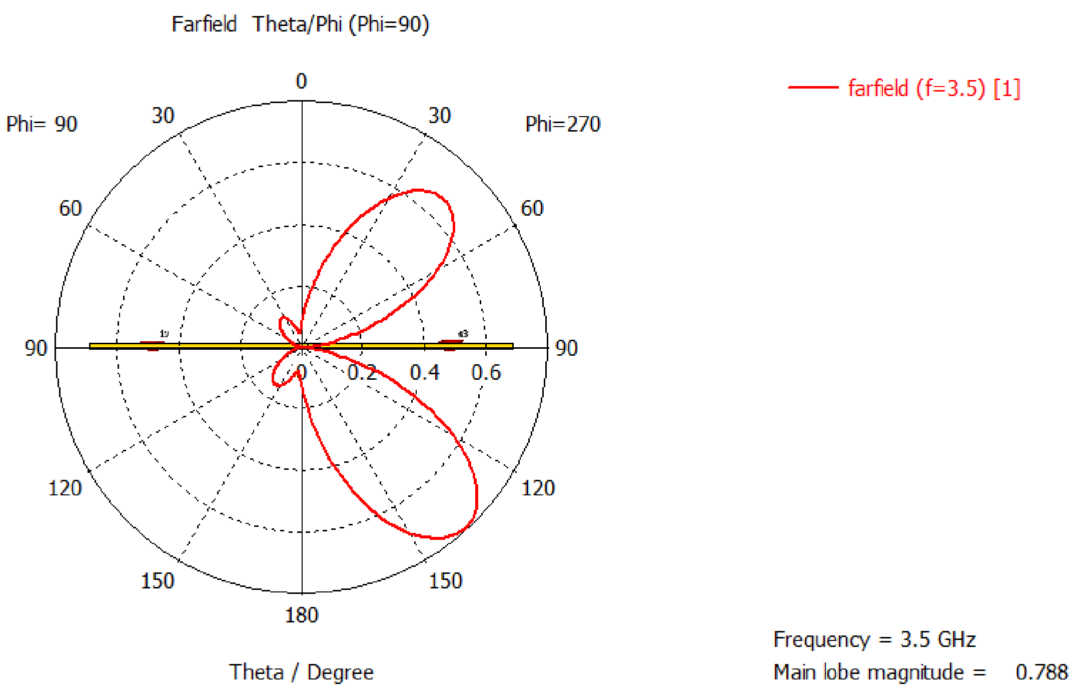

Fig 4.3. 17 Radiation direction of antenna at 3.5 GHz

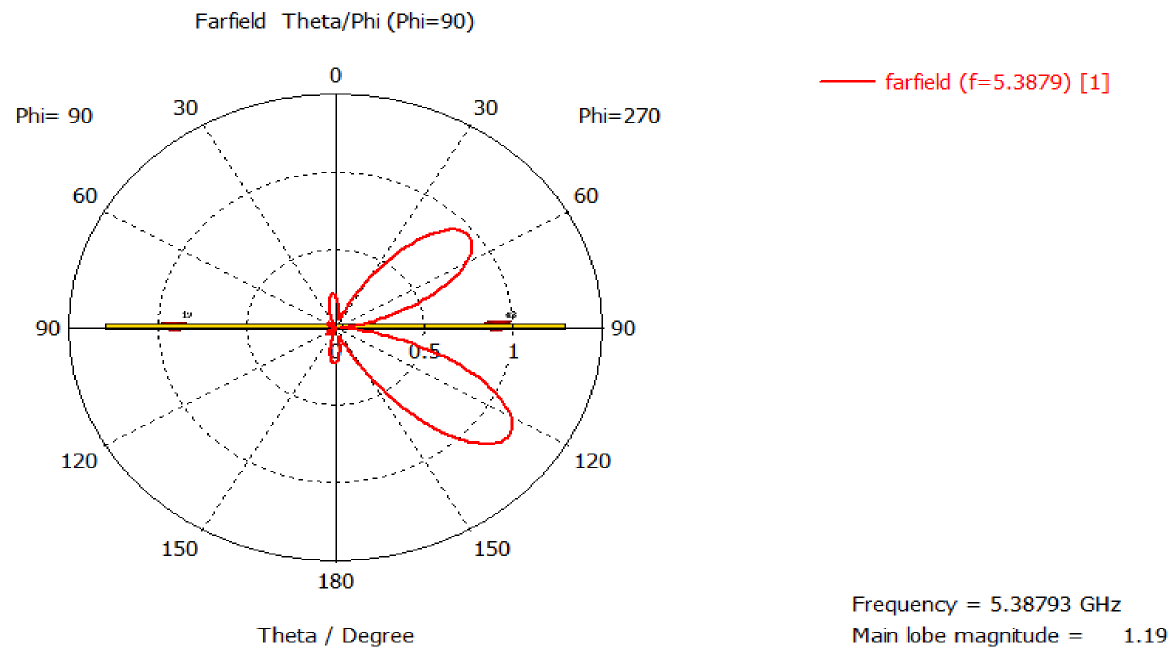

Fig 4.3. 18 Radiation direction of antenna at 5.3 GHz

4.3.5. Efficiency 4×4 MIMO antenna

The total and radiation efficiency of the 4×4 MIMO antenna at 3.5 GHz and 5.5 GHz bands are 99 % and 95 %, respectively. Fig. 4.3.19 shows the radiation and total efficiencies.

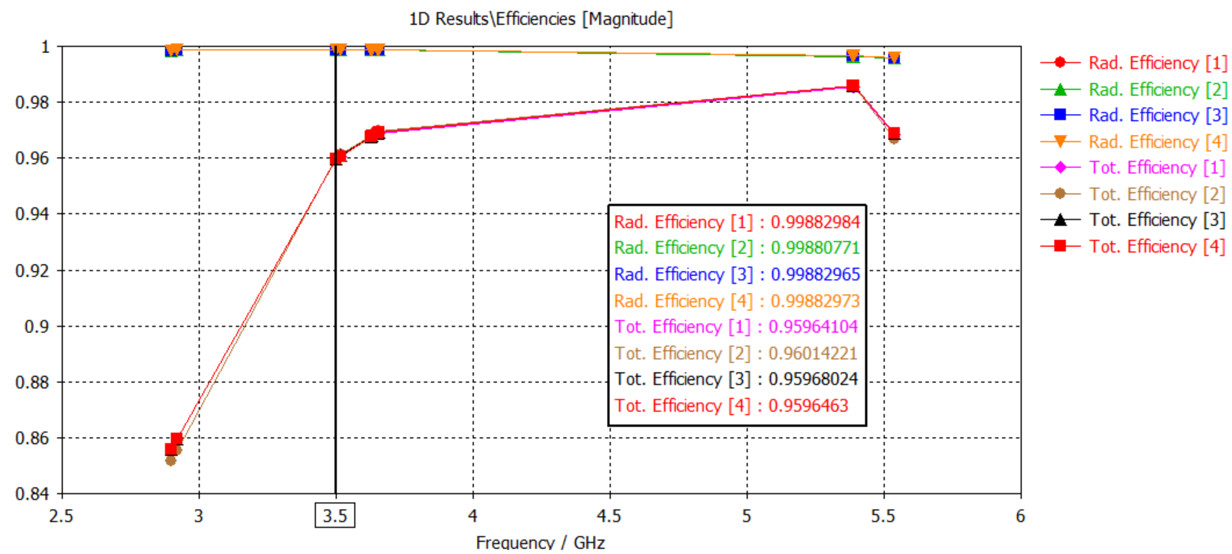

Fig 4.3. 19 Total and Radiation Efficiencies

4.4. Design of 8×8 MIMO Antennas

The configuration of 8×8 MIMO antennas embedded on FR4 substrate with a ground level is shown in the Fig. 4.3.20. The space between each antenna is 14.6 mm having greater than -15 dB isolation which is valid for mobile antennas. There is enough space between each antenna element resulting in high isolation.

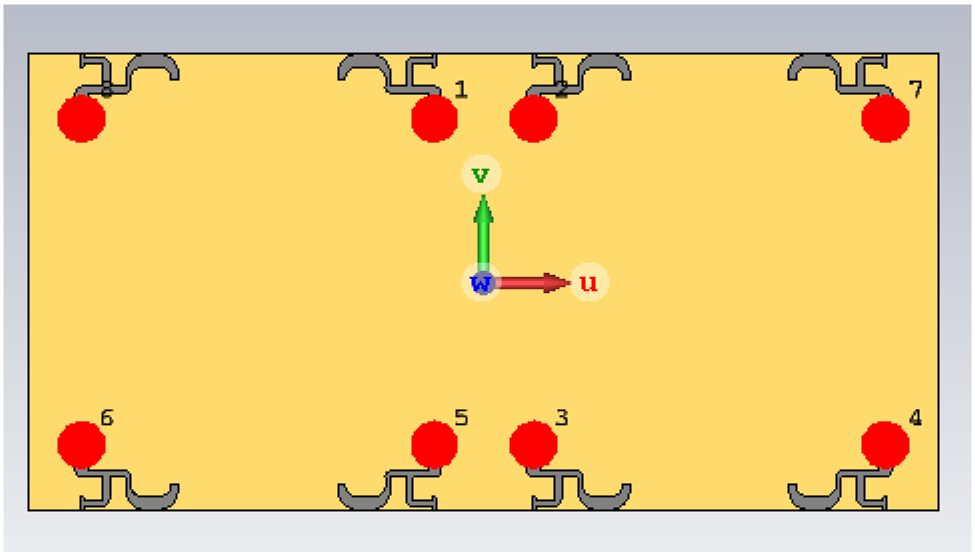

Fig 4.3. 20 8 Element MIMO Antenna Configurations

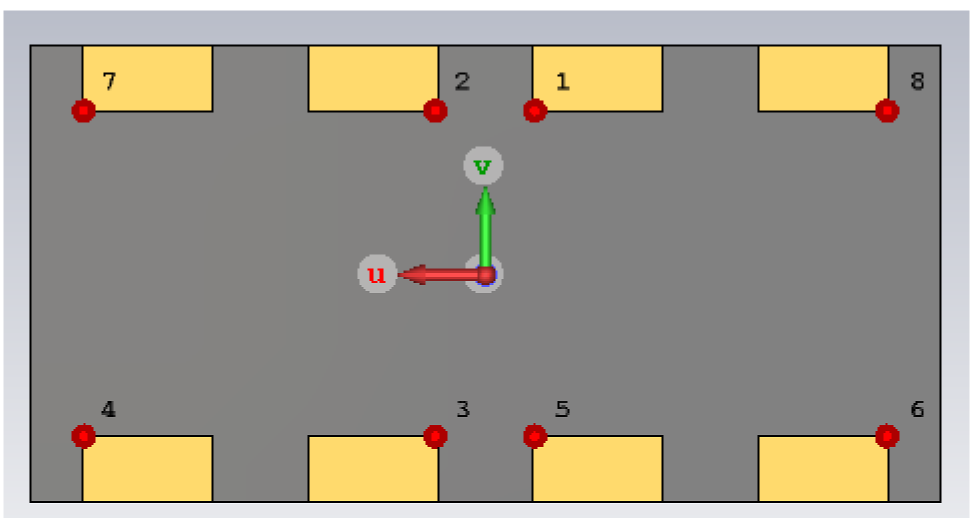

Fig 4.3. 21 8 Element MIMO Antenna with Ground Clearance

4.4.1. Return Loss and Mutual Coupling

The return loss and mutual coupling of the 8×8 MIMO antenna at both resonances are shown in the Fig. 4.15. There is a large distance between each antenna element; therefore the mutual coupling between each antenna element is greater than -15dB which is applicable for mobile antennas.

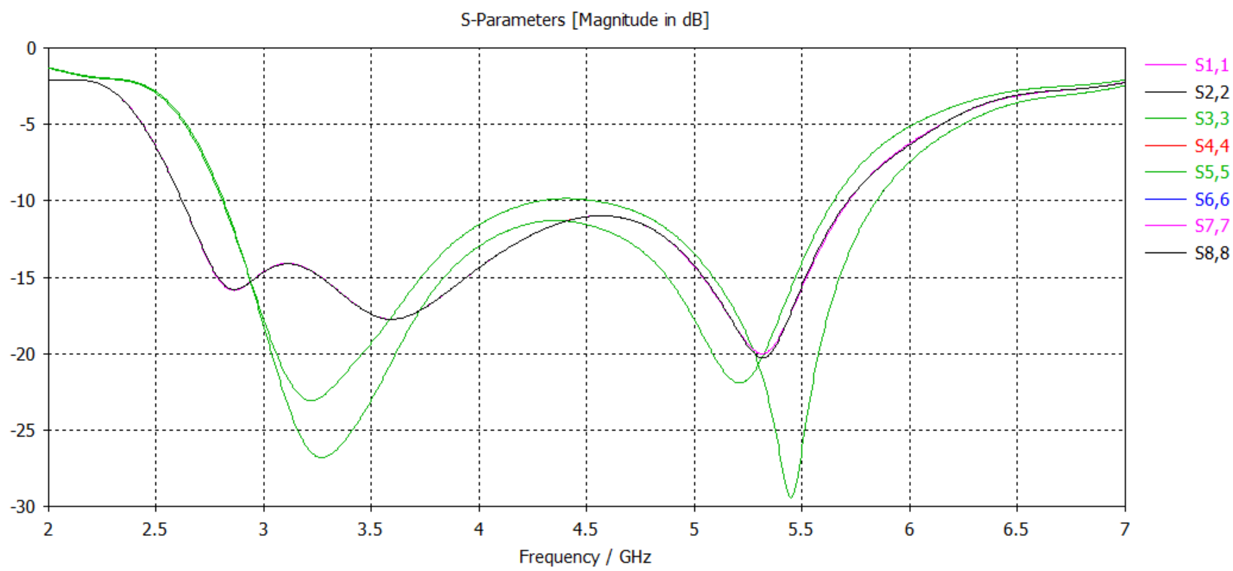

Fig 4.3. 22 Return loss at 3.5 GHz and 5.5 GHz

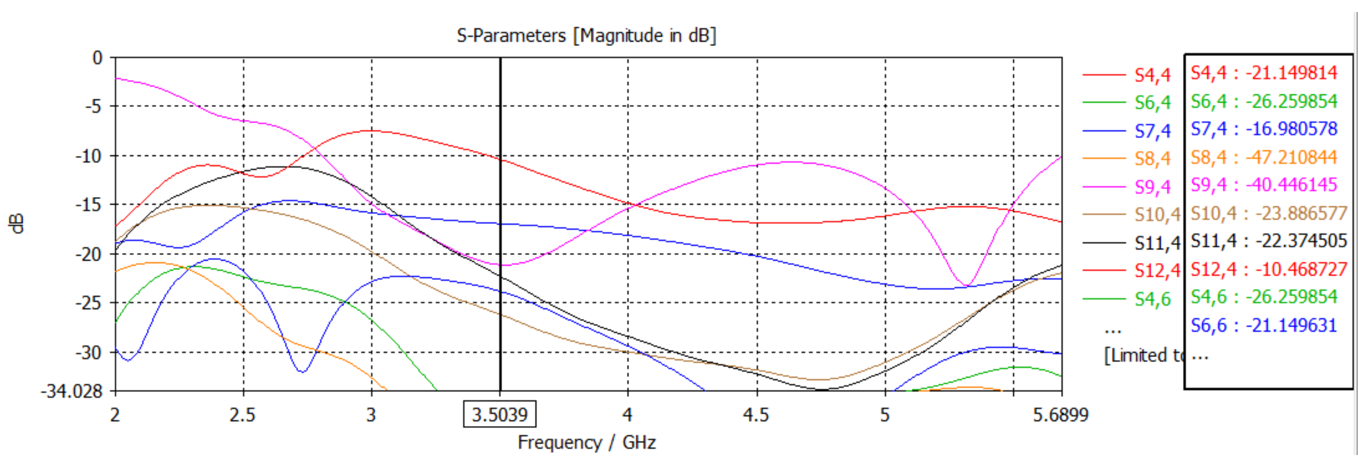

Fig 4.3. 23 Mutual coupling at 3.5 GHz and 5.5 GHz

4.4.2. VSWR

The VSWR of the 8×8 MIMO antenna at 3.5 GHz and 5.4 GHz bands are depicted in the Fig. 4.3.24 and Fig. 4.3.25 respectively.

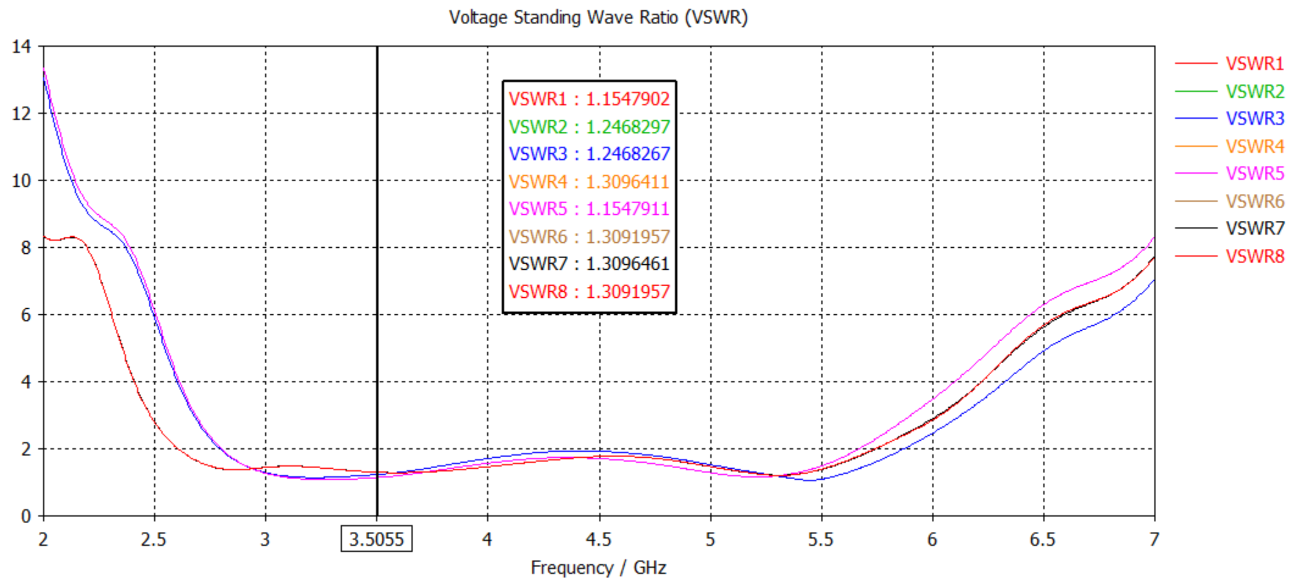

Fig 4.3. 24 VSWR at 3.5 GHz

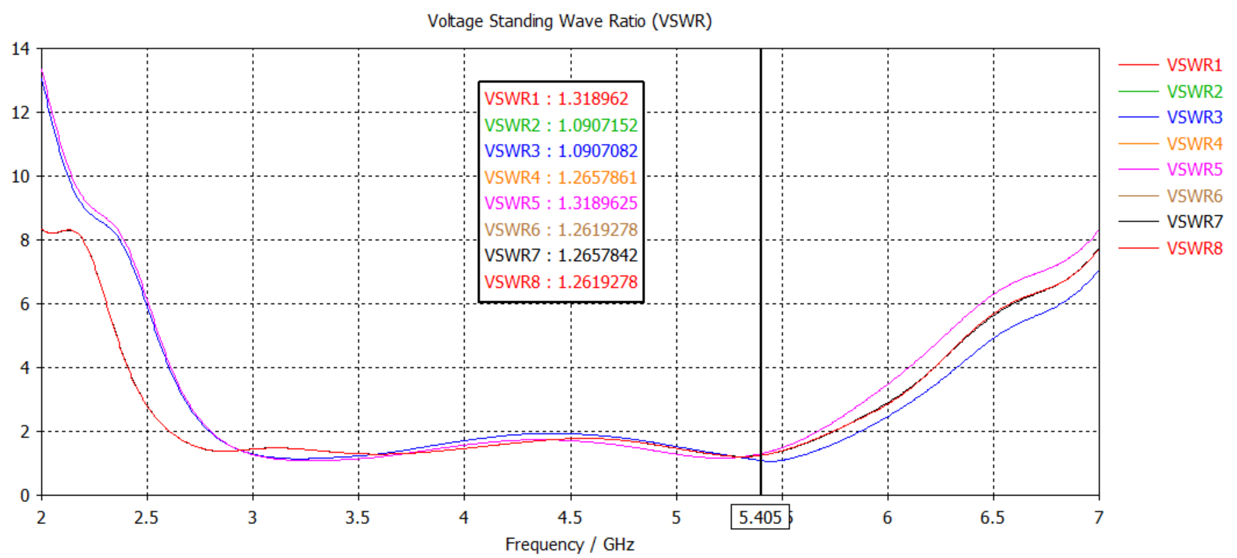

Fig 4.3. 25 VSWR at 5.4 GHz

4.4.3. Impedance Matching

The impedance matching of the 8×8 MIMO antenna at 3.5 GHz and 5.5 GHz bands are depicted in the Fig. 4.3.26 and Fig. 4.3.27 respectively.

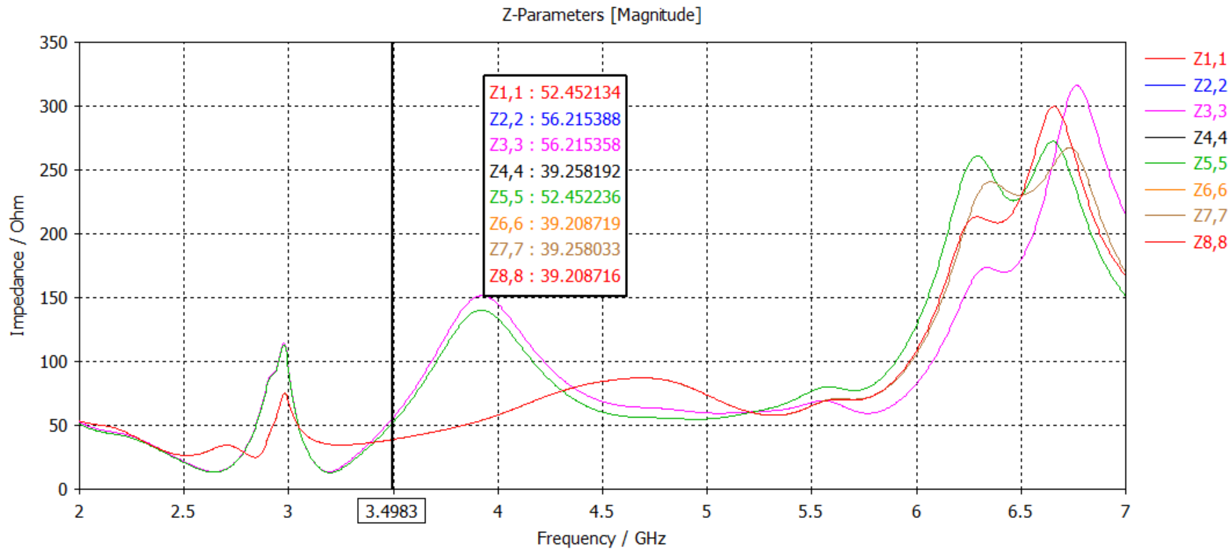

Fig 4.3. 26 Impedance matching at 3.5 GHz

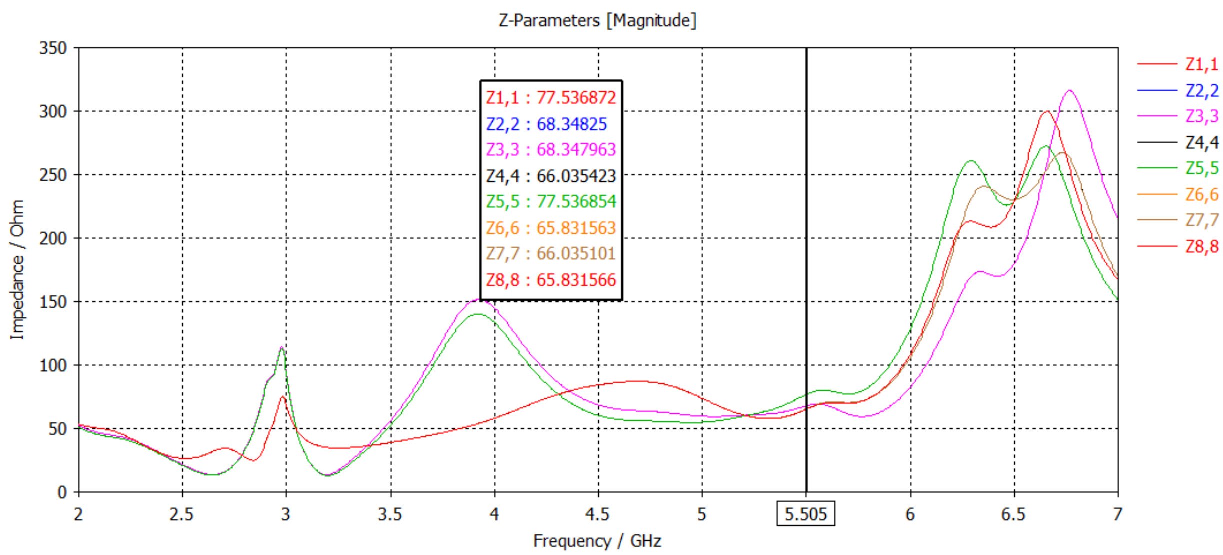

Fig 4.3. 27 Impedance matching at 5.5 GHz

4.4.4. 3D Radiation

The 3D radiation of the 8×8 MIMO antenna at 3.5 GHz and 5.5 GHz bands are depicted in the Fig. 4.3.28 and 4.3.29 respectively. The gain of each antenna at 3.5 GHz and 5.5 GHz are 2.1 dB and 2.7 dB, respectively.

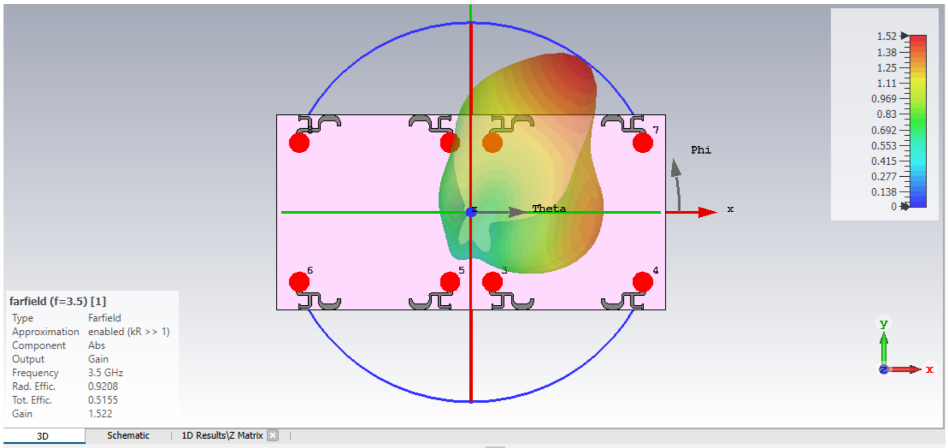

Fig 4.3. 28 Radiation pattern of antenna 1 at 3.5 GHz

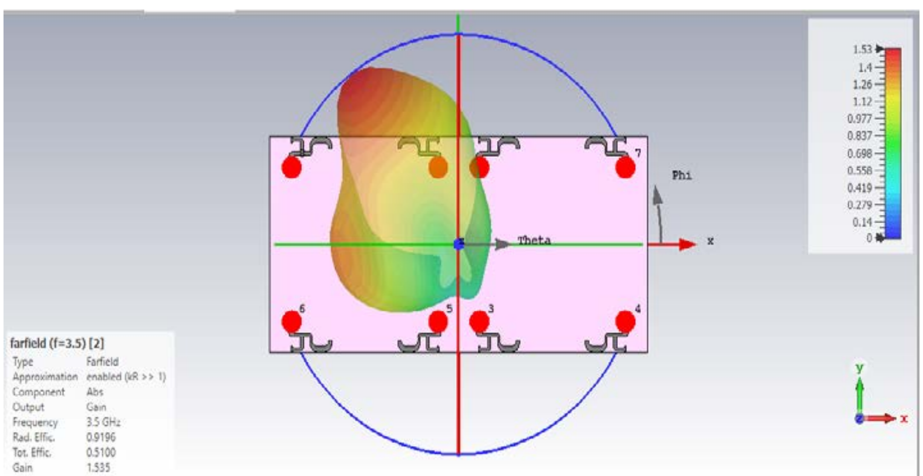

Fig 4.3. 29 Radiation pattern of antenna 2 at 3.5 GHz

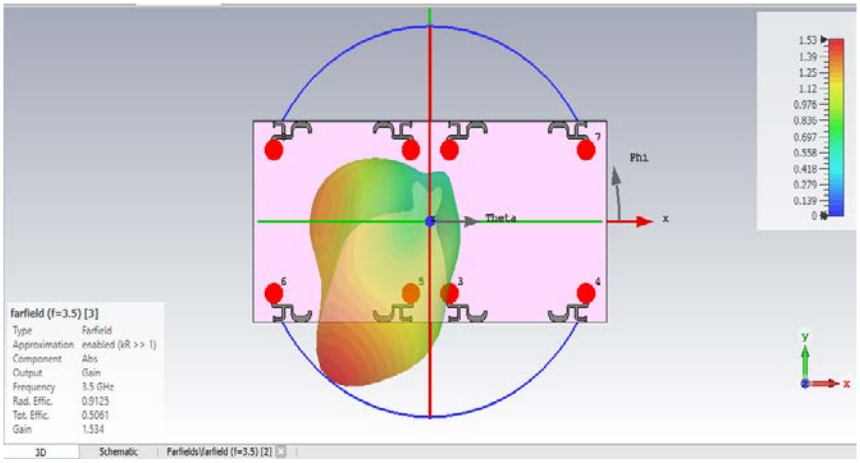

Fig 4.3. 30 Radiation pattern of antenna 3 at 3.5 GHz

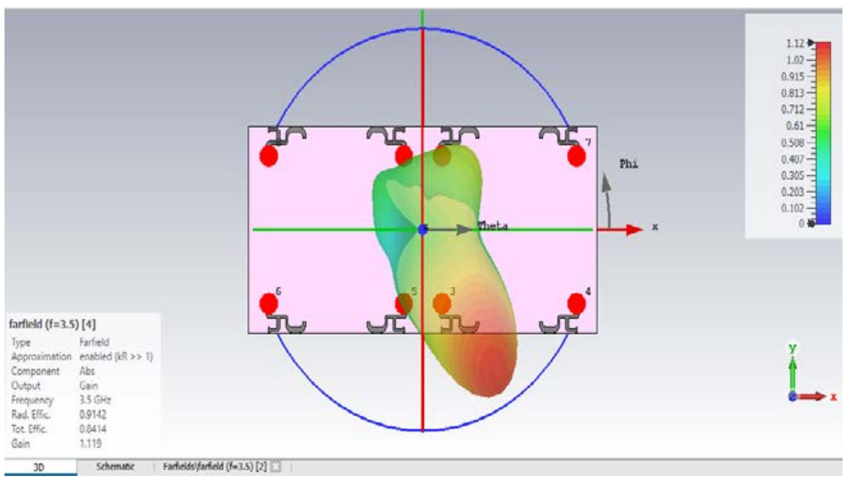

Fig 4.3. 31 Radiation pattern of antenna 4 at 3.5 GHz

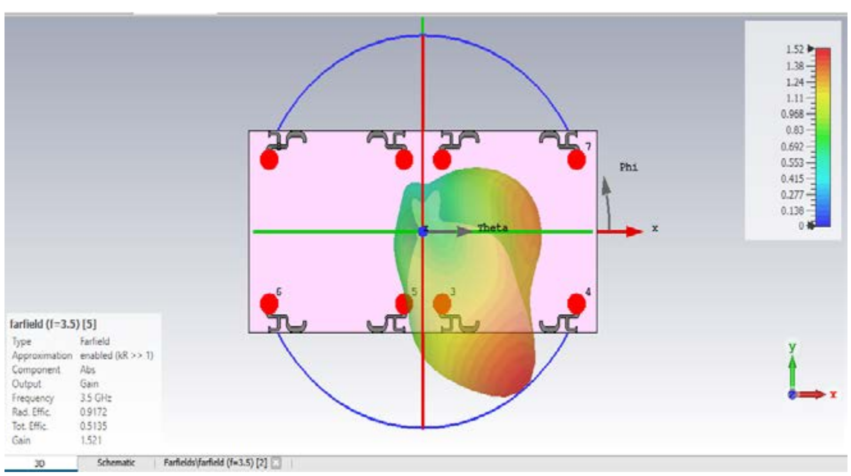

Fig 4.3. 32 Radiation pattern of antenna 5 at 3.5 GHz

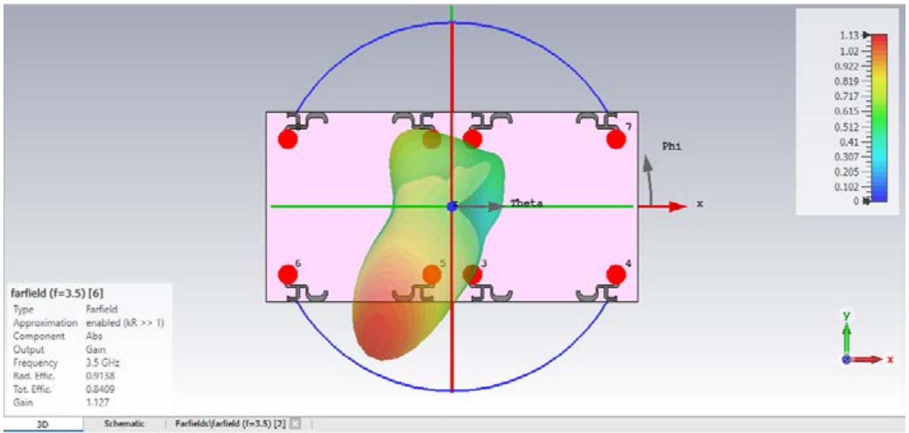

Fig 4.3. 33 Radiation pattern of antenna 6 at 3.5 GHz

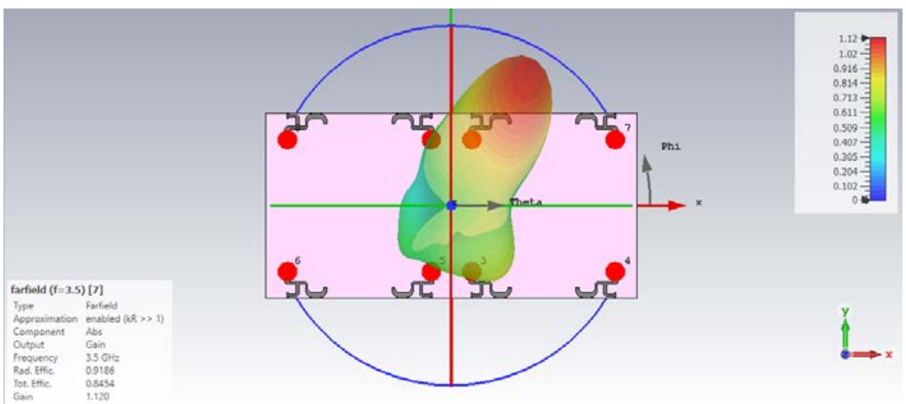

Fig 4.3. 34 Radiation pattern of antenna 7 at 3.5 GHz

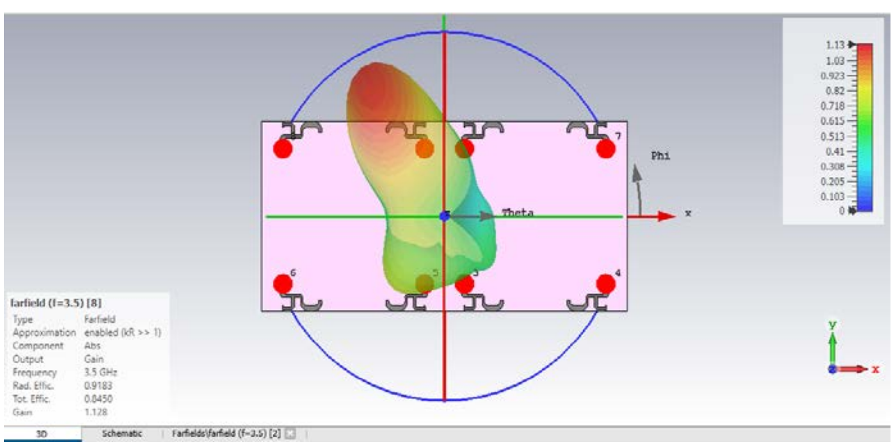

Fig 4.3. 35 Radiation pattern of antenna 8 at 3.5 GHz

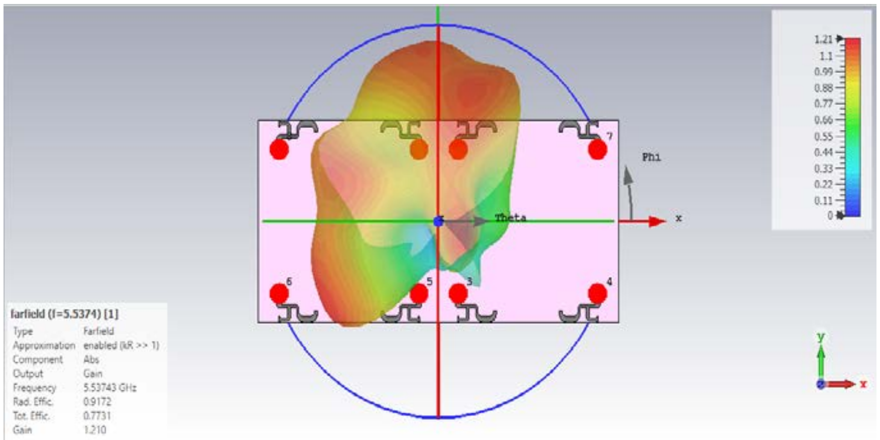

Fig 4.3. 36 Radiation pattern of antenna 1 at 5.5 GHz

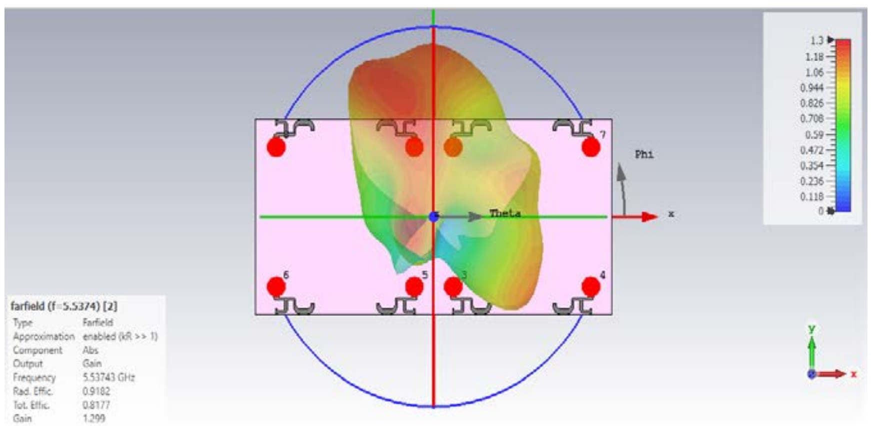

Fig 4.3. 37 Radiation pattern of antenna 2 at 5.5 GHz

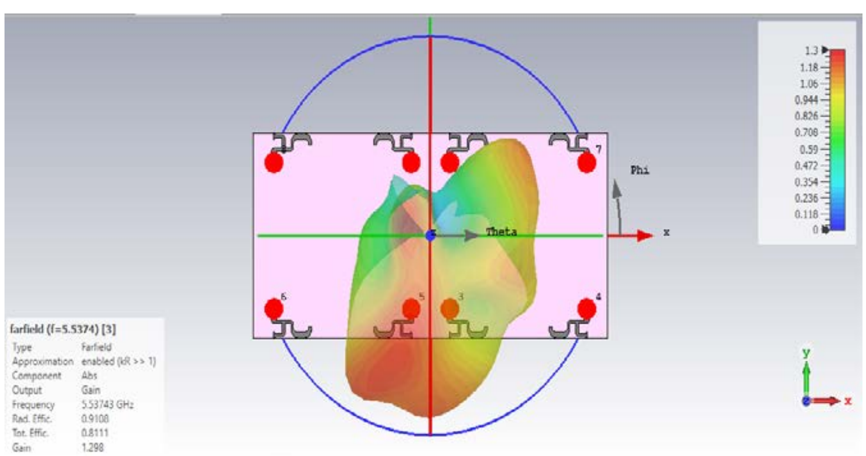

Fig 4.3. 38 Radiation pattern of antenna 3 at 5.5 GHz

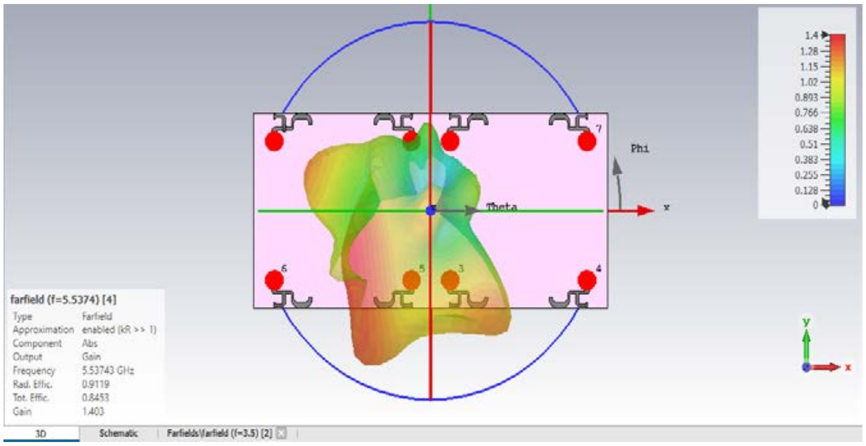

Fig 4.3. 39 Radiation pattern of antenna 4 at 5.5 GHz

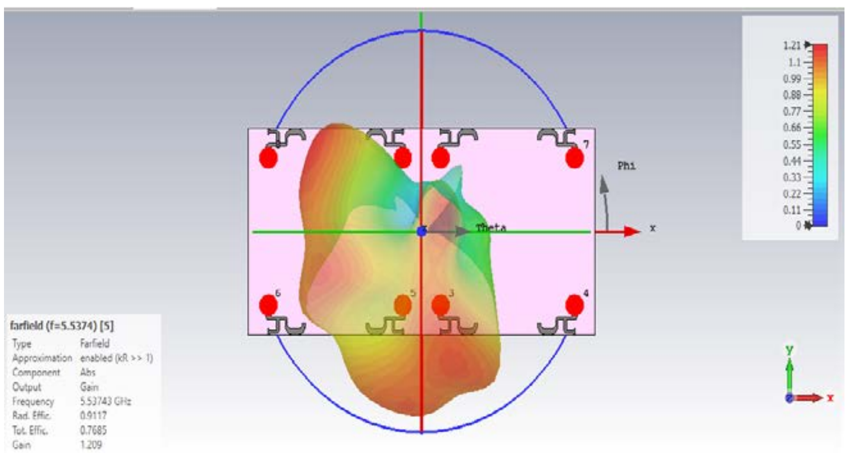

Fig 4.3. 40 Radiation pattern of antenna 5 at 5.5 GHz

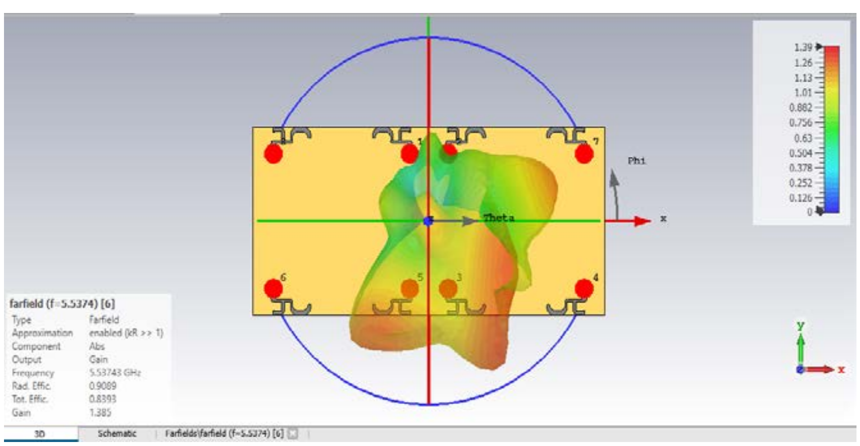

Fig 4.3. 41 Radiation pattern of antenna 6 at 5.5 GHz

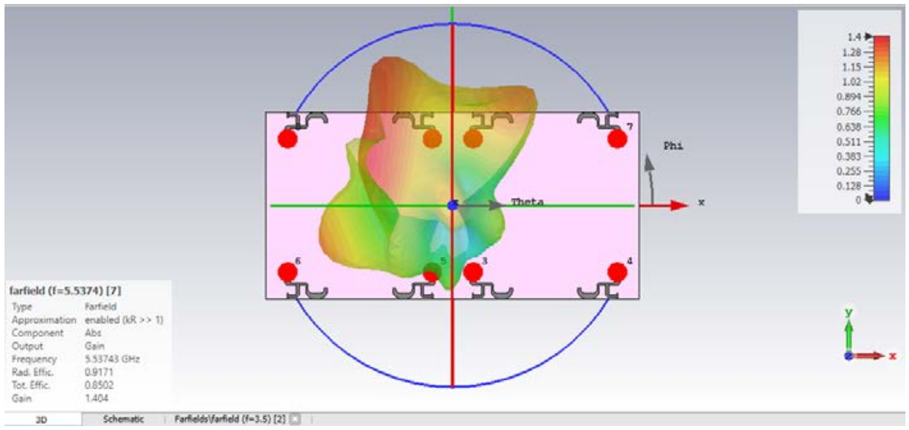

Fig 4.3. 42 Radiation pattern of antenna 7 at 5.5 GHz

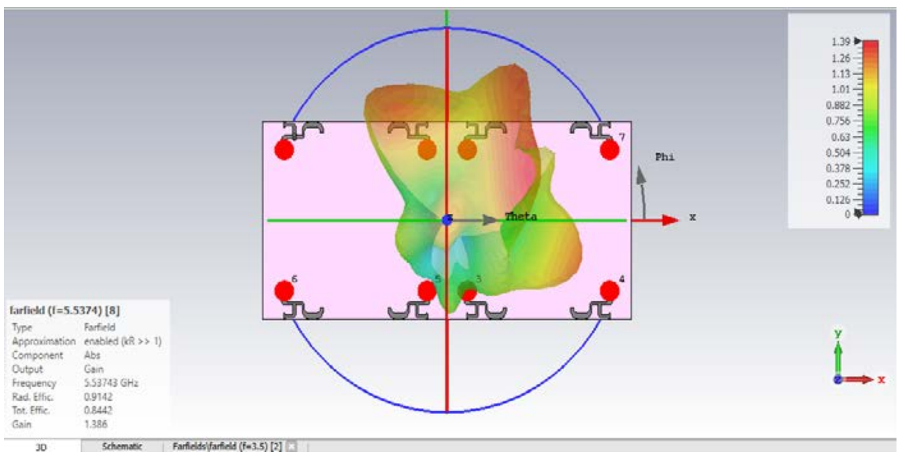

Fig 4.3. 43 Radiation pattern of antenna 8 at 5.5 GHz

4.4.5. 1D Radiation

The 1D radiation of the 8×8 MIMO antenna at 3.5 GHz and 5.5 GHz bands are depicted in the Fig. 4.3.44 and 4.3.45 respectively.

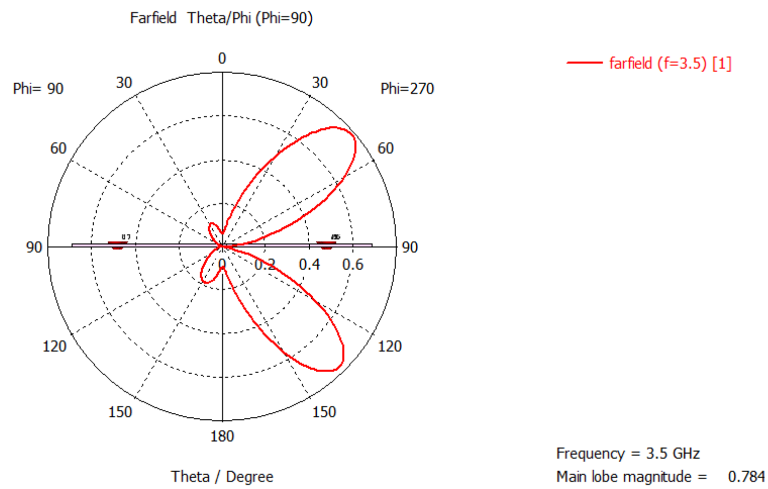

Fig 4.3. 44 E field pattern of Antenna 1 at 3.5 GHz

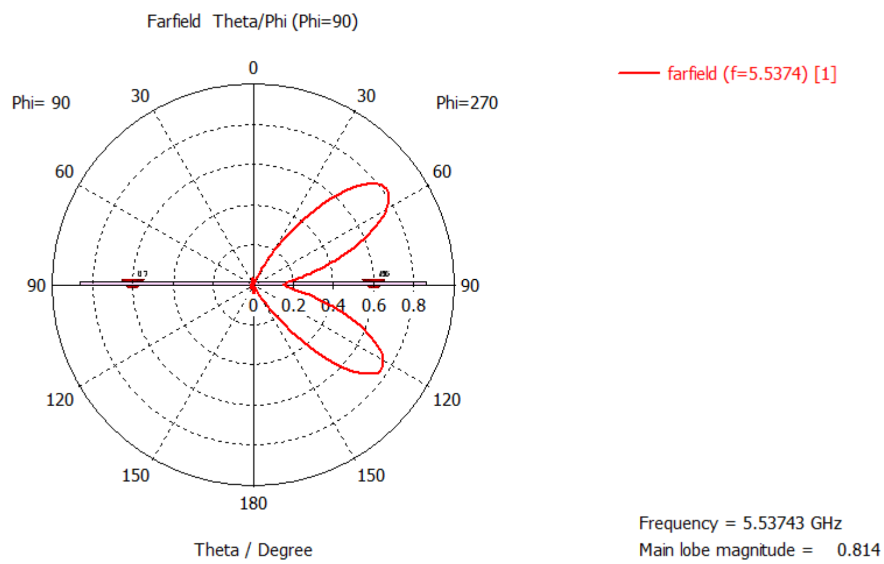

Fig 4.3. 45 E field pattern of Antenna 1 at 3.5 GHz

Chapter 5

Design of 8 Element Antennas with Metal Frame

5.1. Design of 8×8 MIMO Antennas

The configuration of 8×8 MIMO antennas embedded on FR4 substrate with a ground plane is shown in the Fig. 5.1 and 5.2. The space between each antenna is 14.6 mm having greater than -10 dB isolation which is valid for mobile antennas. There is enough space between each antenna element resulting in high isolation.

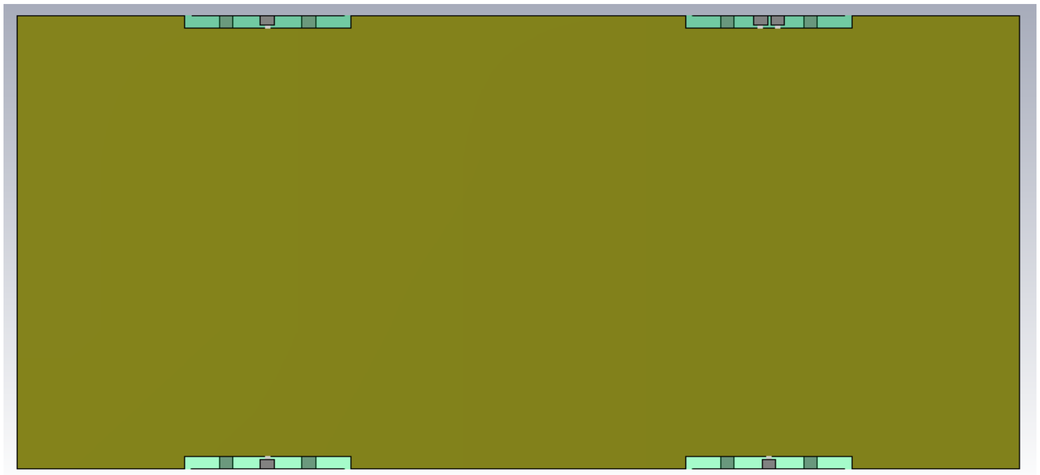

Fig 5. 1 8×8 MIMO antenna configuration

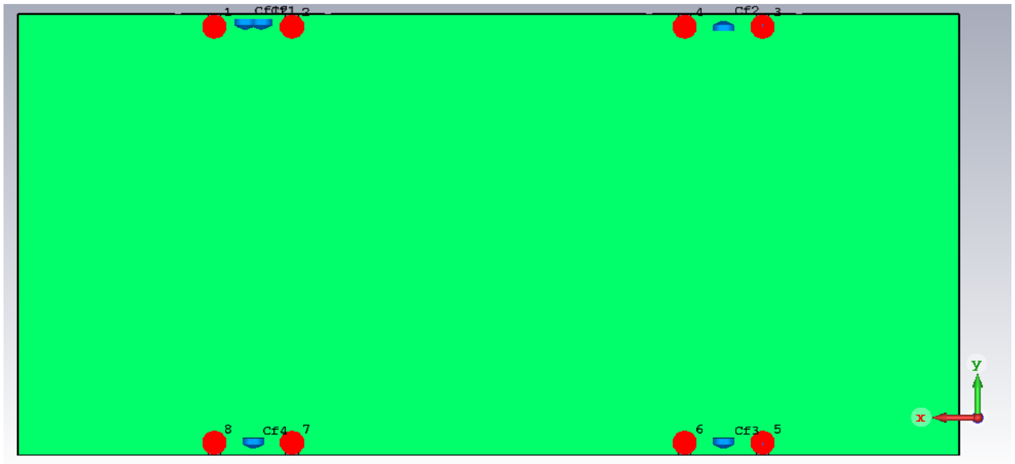

Fig 5. 2 8×8 MIMO antenna configuration

5.2. Return Loss and Mutual Coupling

The return loss and mutual coupling of the 8×8 MIMO antenna at both resonances is shown in the Fig. 5.3 and 5.4 respectively. There is a large distance between each antenna element; therefore, the mutual coupling between each antenna element is greater than -10 dB which is applicable for mobile antennas.

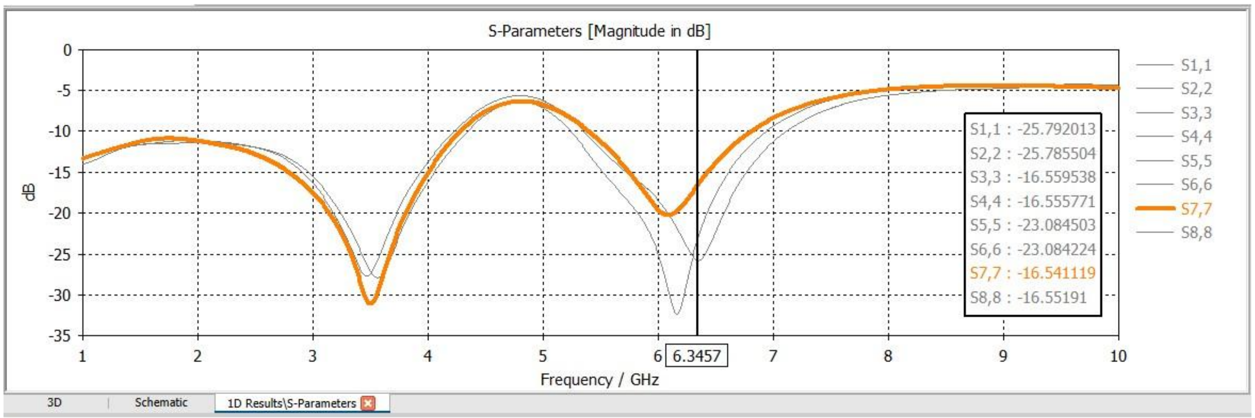

Fig 5. 3Return Loss

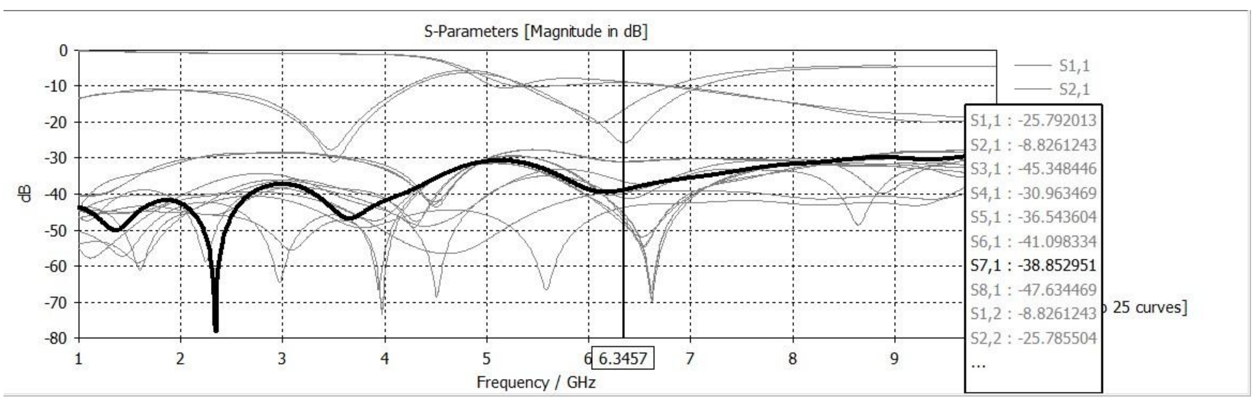

Fig 5. 4 Mutual Coupling

5.3. VSWR

The VSWR of the 8×8 MIMO antenna at 3.5 GHz and 5.5 GHz bands are depicted in the Figure 5.5 and Figure 5.6 respectively.

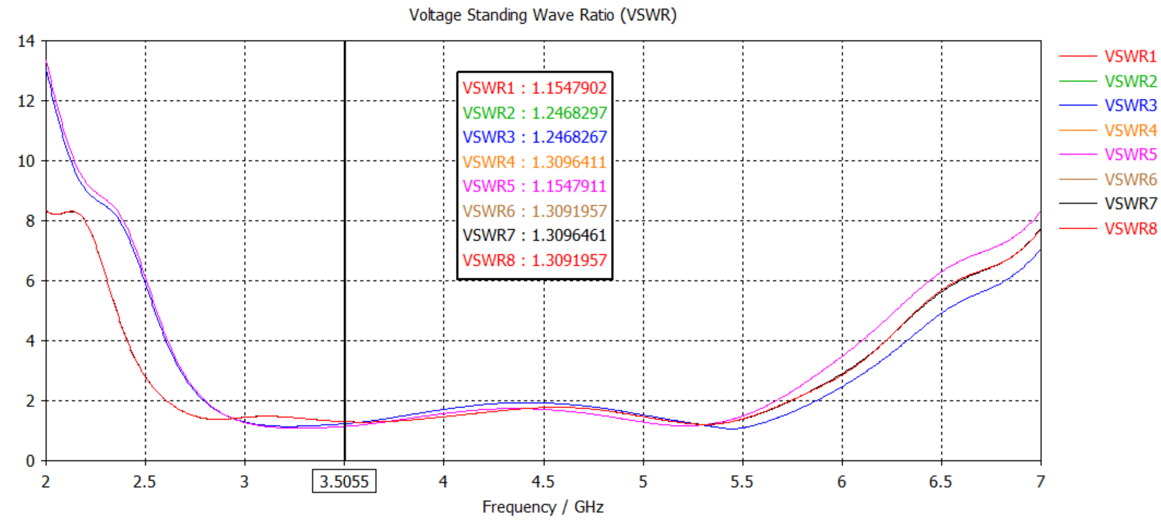

Fig 5. 5 VSWR at 3.5 GHz

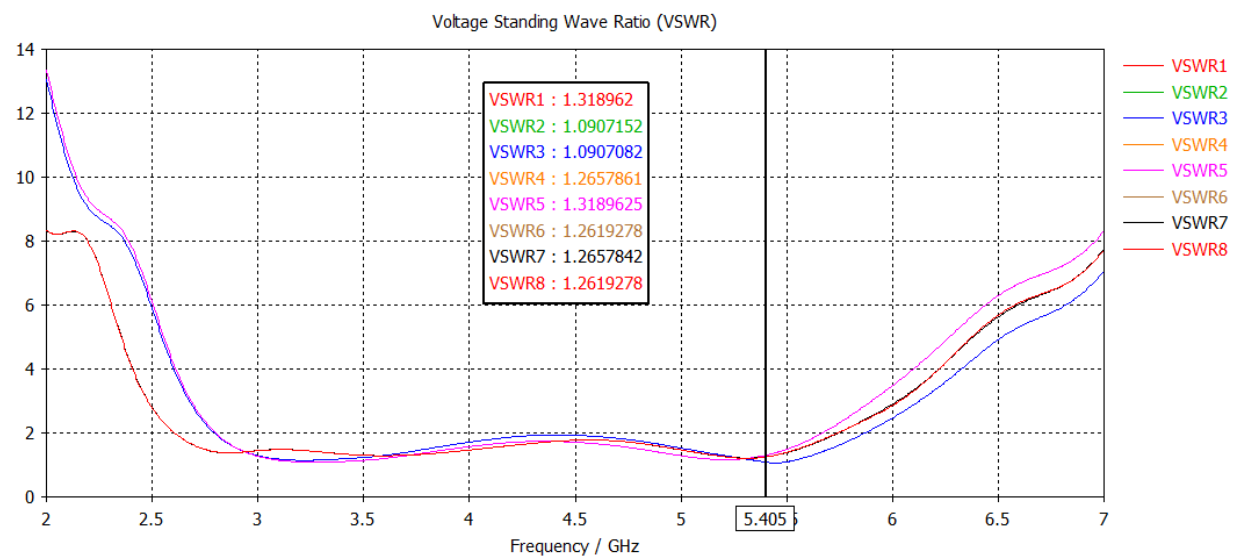

Fig 5. 6 VSWR at 5.4 GHz

5.4. Impedance Matching

The impedance matching of the 8×8 MIMO antenna at 3.5 GHz and 5.5 GHz bands are depicted in the Figure 5.7 and 5.8 respectively.

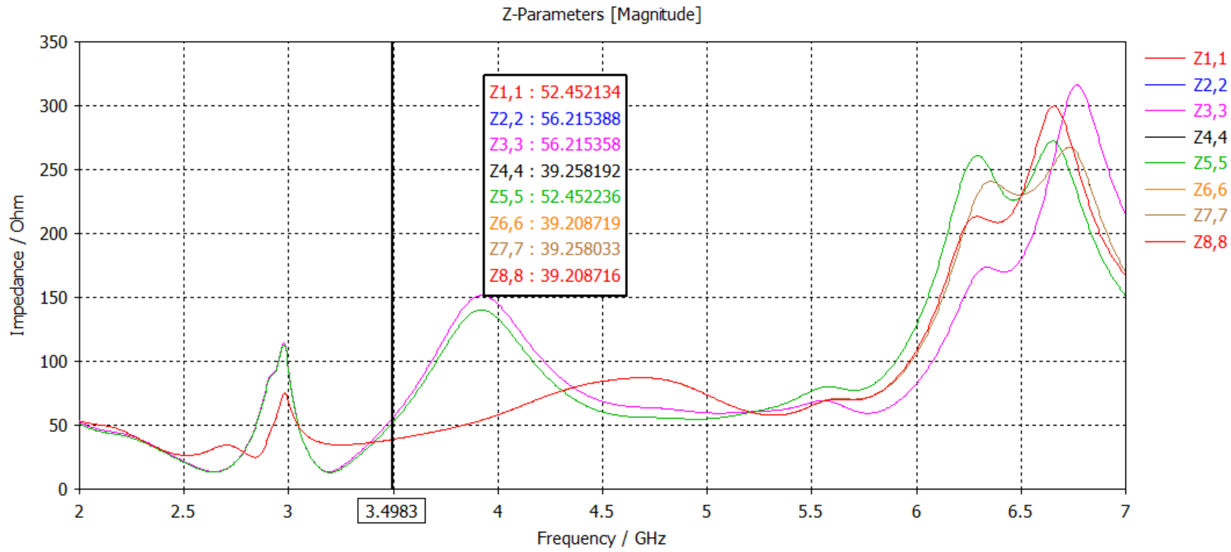

Fig 5. 7 Impedance Matching at 3.5 GHz

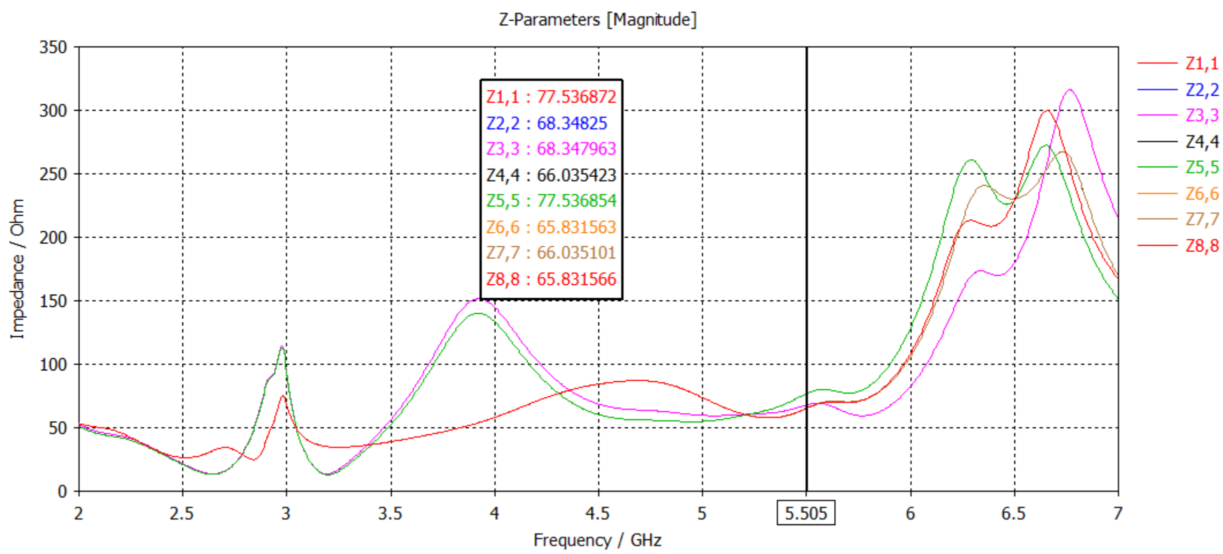

Fig 5. 8 Impedance Matching at 5.5 GHz

5.5. 3D Radiation

The 3D radiation of the 8×8 MIMO antenna at 3.5 GHz and 5.5 GHz bands are depicted in the Fig. 5.9 and 5.10 respectively. The gain of each antenna at 3.5 GHz and 5.5 GHz are 4.2dB and 4.1 dB, respectively.

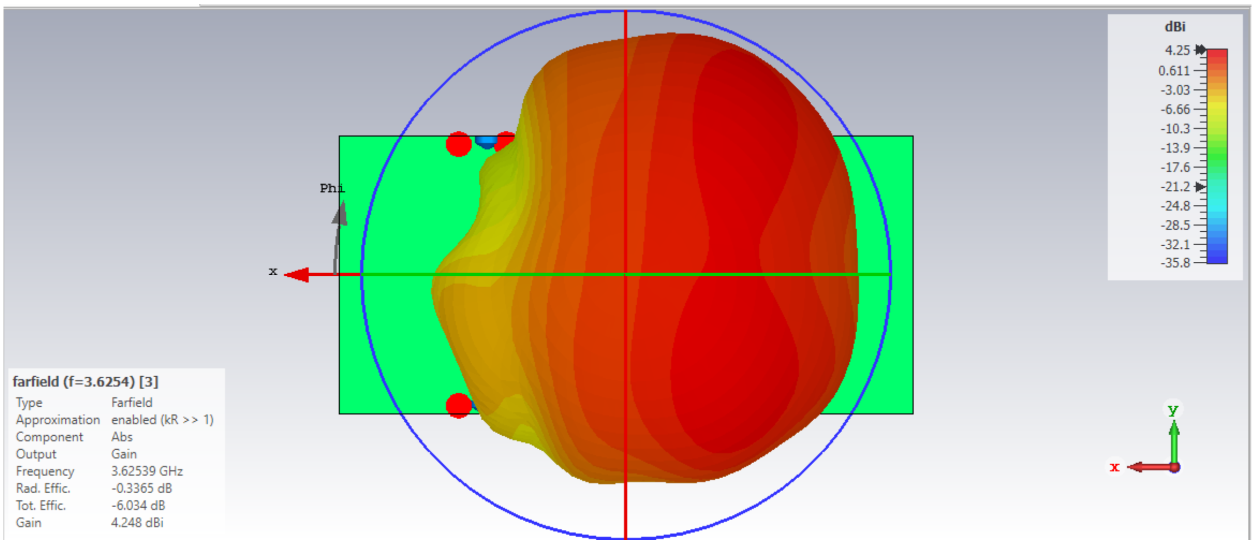

Fig 5. 9 3D Radiations at 3.5 GHz

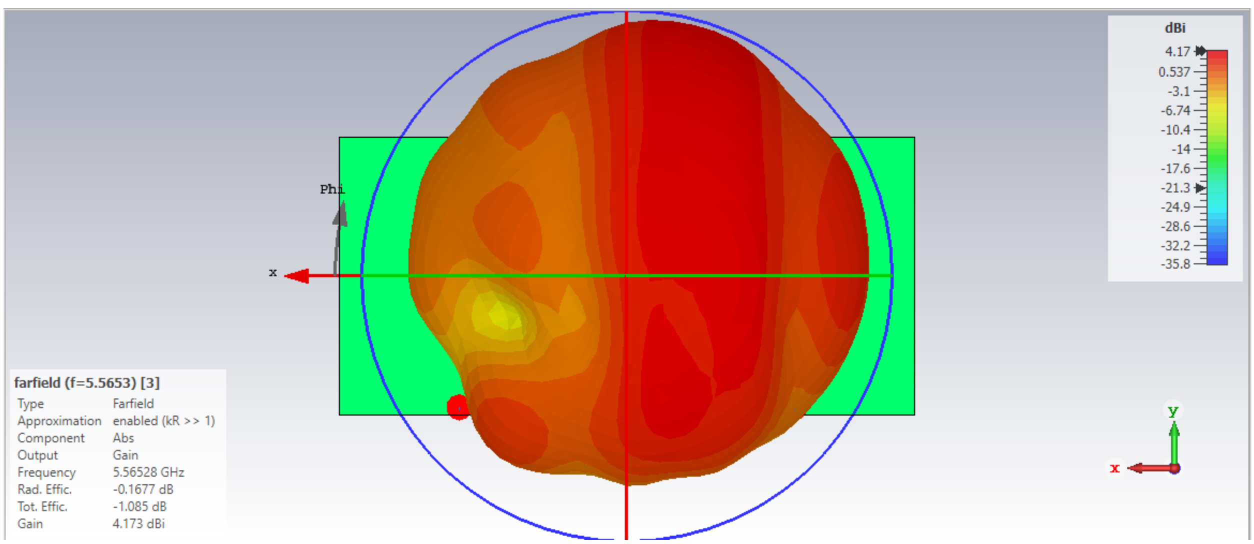

Fig 5. 10 3D Radiations at 5.5 GHz

5.6. 1D Radiation

The 1D radiation of the 8×8 MIMO antenna at 3.5 GHz and 5.5 GHz bands are depicted in the Figure 5.11. and Figure 5.12 respectively.

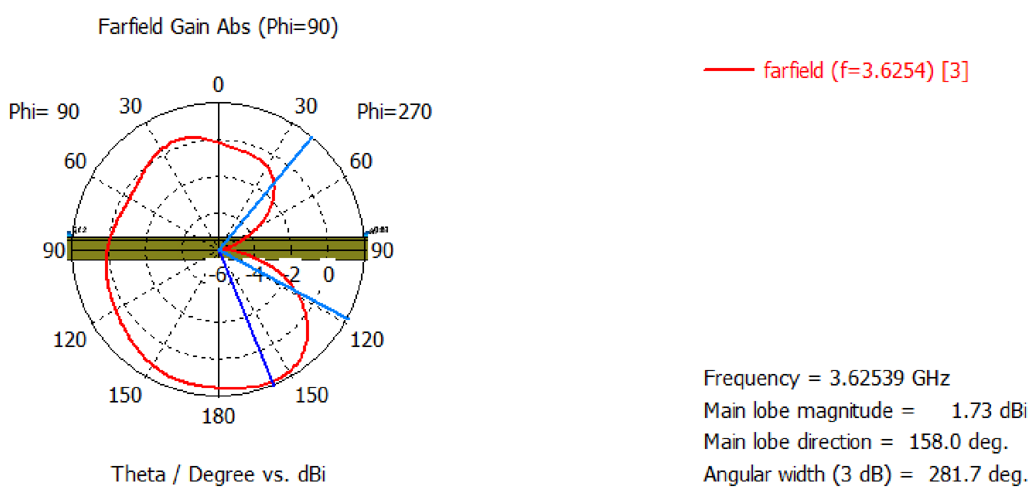

Fig 5. 11 1D Radiation at 3.5 GHz

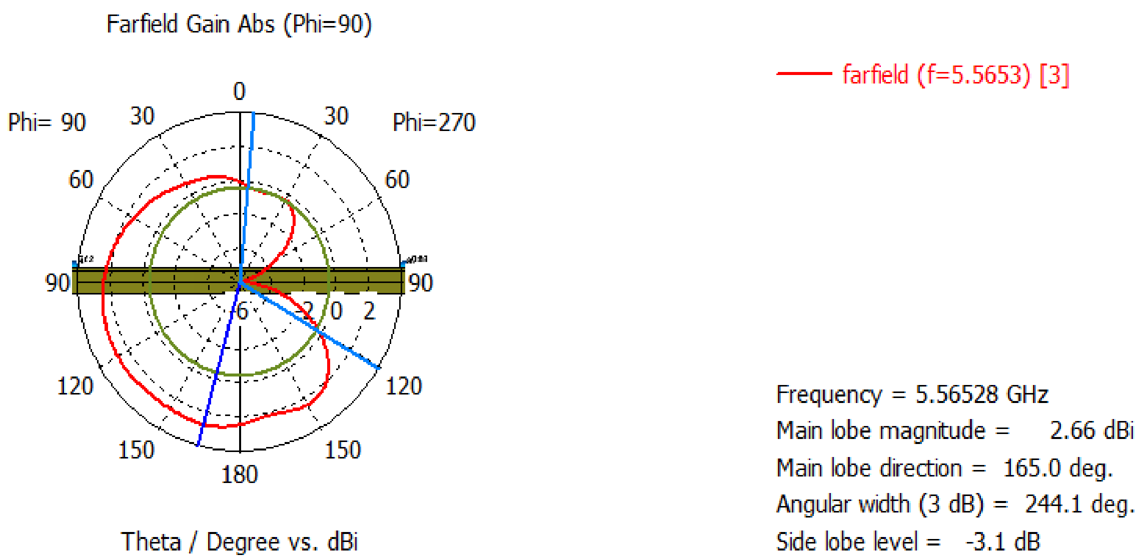

Fig 5. 12 1D Radiation at 5.5 GHz

Chapter 6

6.1 Summary and Conclusion

Mobile phone antennas have several major drawbacks such as the symmetrical dimensions and their substrates which are applied in design, and the ground plane of the antenna. These all parameters are gone through their optimization method. The fast development of mobile phones devices improves further demands on optimizations of the antennas. In this thesis, an eight element MIMO antenna for smartphone is designed. The dimension of the designed antenna is 140 mm × 70 mm × 0.8 mm. An isolation of -15dB is achieved due to an enough space among antenna elements. The impedance bandwidth and frequency shifting is achieved by the ground clearance and the shifting of monopole strip. Mobile phones antenna model part entails of two antennas namely Inverted U-Shaped and Inverted F-Shaped. Inverted U-shaped design operates at 3.5 GHz while the Inverted F-shaped design generates resonance at 5.5 GHz frequency. The return loss of 3.5 GHz band and 5.5 GHz bands are -29.5 dB and -41 dB separately. The impedance bandwidth at both bands is 1700 MHz and 700 MHz respectively. The gain and the efficiency of the antennas are 2.2 dB and 70 percent which is applicable for mobile phone applications. These all parameters are gone through their optimization process. The simulations of 8×8 MIMO Antenna are performed in CST. The simulation meets with measured results showing the validation of design.

6.2 Future Work

Antenna can be made compact in size. The isolation further can be improved using any decoupling method such as defected ground structure (DGS), neutralization line, grounded branches, microstrip lines. Ground clearance can be reduced.

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