A MASSIVE MIMO ANTENNA FOR 4G AND 5G COMMUNICATION

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in partial fulfillment for the requirements of B.E Degree in Electrical Engineering.

2nd July 2021

CERTIFICATE OF CORRECTIONS & APPROVAL

Certified that work contained in this thesis titled "***A Massive MIMO Antenna for 4G and 5G Communication***", carried out by ***Capt. Ahsan Ali Farooqi, Capt. Irfan Haider, Capt. Muhammad Abdullah Sohail and Capt. Ali Zain Amjad*** under the supervision of ***Lecturer Maryam Rasool*** for partial fulfillment of Degree of Bachelor of Electrical Engineering, in Military College of Signals, National University of Sciences and Technology, Islamabad during the academic year 2020-2021 is correct and approved. The material that has been used from other sources it has been properly acknowledged / referred.

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ACKNOWLEDGEMENTS

We are grateful to Allah Almighty and extend our gratitude to our supervisor and lecturer Maryam Rasool and, all our teachers for their priceless support throughout this research even in the middle of pandemic. We would also like to thank our faculty of EE department, our friends from Military College of Signals, our batch seniors and lab researchers since without their motivation and help we would not have achieved all this.

Dedicated to our loving parents and dedicated teachers whose tremendous support, cooperation and motivation led us to this marvelous accomplishment.

ABSTRACT

Massive multiple-input multiple-output (MIMO) is the most recent advancement in the field of mobile communication, along with millimeter-wave with duplex transmission and small cell architecture such as femtocell and picocell, which led the world to the development of the next generation of 5G cellular networks. Quality of services (QoS) and quality of experience (QoE) are the primary target areas required by the consumers for a 5G network. Superior mobile broadband (eMBB) is the principle 5G network which is expected to coincide the requirements of high data rate-based applications like city applications, smart industrial application, smart industrial application, smart house, high-definition video streaming and diverse data rate needs of mobile users. High-speed mobile date rate capacity demand of the population is met by MIMO technology which places multiple antenna elements closely together in a compact case, both at base station and user mobile utilizing multipath rich propagation environment but due to the modern slimmer and thinner designs, Multiple antenna elements must be accommodated in 5G devices while avoiding severe electro-magnetic coupling. In this thesis, for compact and thin 5G user device, we designed an 8 element MIMO system and analyzed the system performance for various parameters for any likely degrading.

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ABBREVIATIONS LIST

HSDPA - High-Speed Downlink Packet Access

GPRS - General Packet Radio Service

EDGE – Enhanced Data Rates for GSM Evolution

HSDPA - High-Speed Downlink Packet Access

HSPA - High-Speed Packet Access

IoT - Internet of Things

WISDOM - Wireless System for Dynamic Operating Mega Communication

WWWW - World-Wide Wireless Web

MMIMO - Massive-MIMO

WLAN - Wireless Local Area Network

SNR - Signal to Noise Ratio

WBAN - Wireless Body Area Networks

WPAN - Wireless Personal Area Network

WLAN - Wireless Local Area Networks

WMAN - Wireless Metropolitan Area Networks

WWAN - Wireless Wide Area Networks

NLOS - Non-Line-Of-Sight

ITU - International Telecommunication Union

LOS - Line-Of-Sight

SISO - Single Input Single Output

CHAPTER 1

INTRODUCTION

1.1 Evolution in 5G Communication

Routine use of cellular services has increased the use of mobile data globally for services such as online gaming, video calling, and social media applications such as Instagram, Facebook, and Twitter. The proficiency of third(3G), fourth(4G), and fifth(5G) networks, which include features such as high data rate and lower latency, has significantly improved our lives.

Another milestone of cellular technology is the addition of 5G wireless communication, which will give best services to the various end systems such as vehicular network, smart city, smart industries, and video surveillance. Figure 1.1 indicates the new paradigm of important pillars of 5G that will provide tremendous opportunities for communities, users, homes, and businesses. Important features are:

- eMBB will ensure provision of enhanced capacities to the industrial users and mobile network customers along with providing benefit to B2C, media and entertainment.
- Critical mission applications (e.g., industry automation, remote surgical operation, and autonomous driving). will be supported by low latency communication and ultra-reliable.
- Industry players will be connected to the numbers of the devices with desired connectivity needs by using Massive Machine-type Communications (mMTC) in sectors like manufacturing, logistics and utilities.

Due to the wide range of business and technological prospects created by 5G network paradigms, it connects equipment vendors, mobile network operators, and other industry stakeholders more efficiently than previous generations.

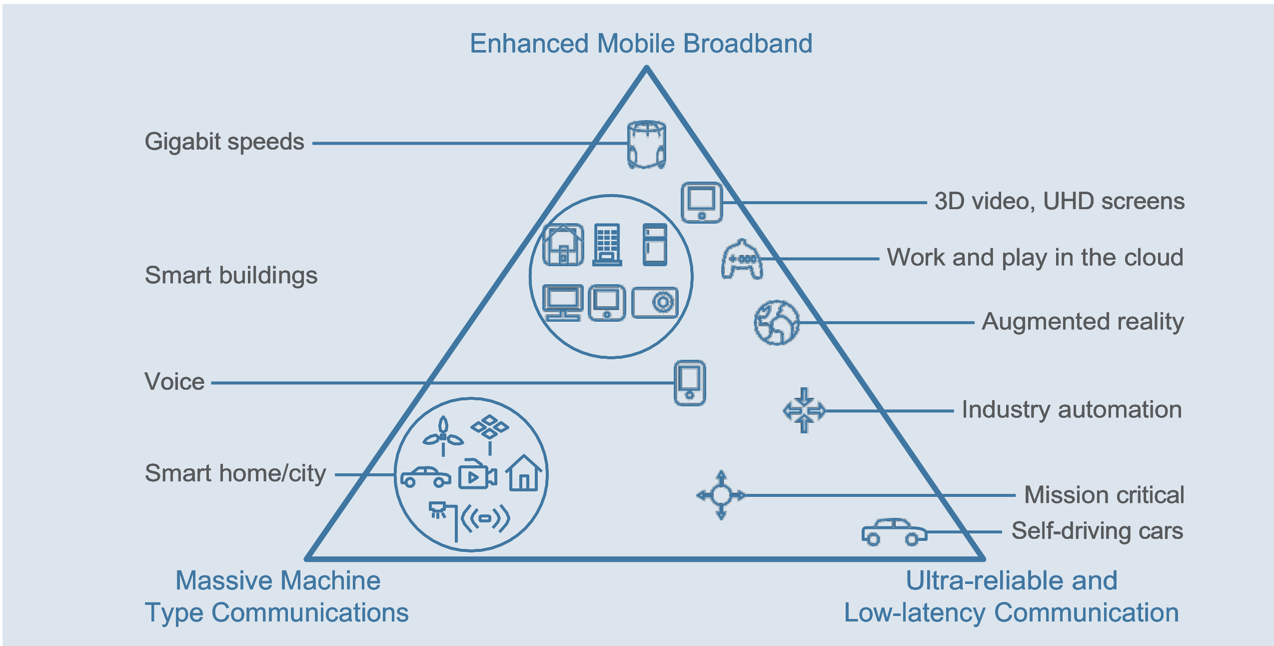

Figure 1.1: Pillars of 5th Generation [3]

By 2035, 5G is predicted to produce USD 12 trillion in income, with around 80% of telecom revenues (services, gear, and bandwidth) tied to 5G. It is expected to eliminate disparities by improving the access and decreasing the cost of critical facilities such as education and healthcare. By broadening the breadth of wireless technologies through autonomous devices. It will minimize carbon emissions and save natural resources as well as boost employment rates across the board.

1.1.1 Network Till 4G

Network users need mobile connectivity essentially for daily usage. Advancement in information technology needs to provide safer, faster, and smarter wireless networks along with vehicular communication also known as vehicle to everything, industrial setup, and smart cities. Now the networks are also advanced as they have grown from the first digital generation (GSM or Global System for Mobile Communications) to the latest generation network connectivity 4G (LTE or Long-Term Evolution). The general technology of mobile communications include frequency, speed, and system numerical generation such as 1G, 2G, and 3G. Whether it is 4G or 5G, each generation has its own set of technologies that define it. 1G emerged in Japan in 1979, before its use in other countries such as the USA (1980), and the UK, (1985) [8]. The analogue radio signals were used by 1G (which has frequency 150 MHz), the voice of a call was not encoded to digital signals rather modulated to a higher frequency r. Analogue signals degrade the voice quality over time within a call.

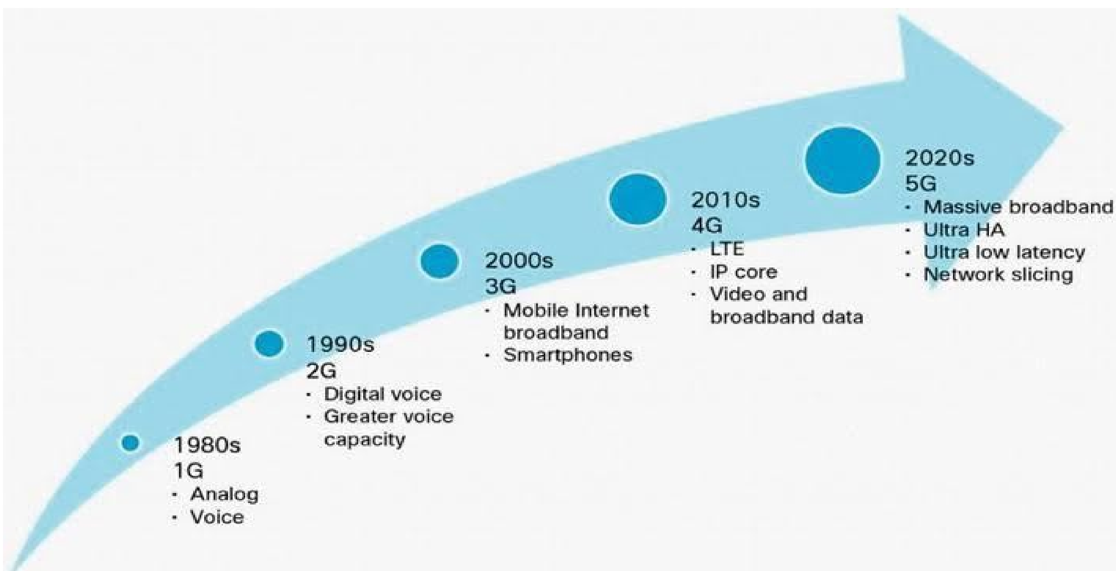

Figure 1.2: Evolution of Mobile Communication

In **2G** there was advancement of feature such as text messaging service by digital phone communication. It introduced GSM in early 90's as a standard technology which permitted the users to travel and data and digital voice to be sent over the network. It used mobile station authentication, data confidentiality, and signaling to ensure that calls were more secure and private. International roaming around the world, SMS, call hold, conference calls, and pricing based on services, such as costs for long distance calls and real-time pricing, were all introduced with the advancement of technology from 1G to 2G. Between the years 2000 and 2003, a packet network called 2.5G emerged, which enabled high-speed internet and data transfer up to 384 kbps and had standards of GPRS in addition to EDGE, with GPRS maintaining easy data transmission rates. So, service providers charged for the amount of data instead of their connection time. 3G evolved in 2001 at commercial level and supported multimedia techniques which enhanced the technique of information transmission rates. Increased voice and data capacity were the goals of the 3G mobile communications which will support a broader application range and decreased the cost of the greater data transmission. Video calls, chatting, and conferencing, as well as mobile TV, navigation maps, email, music, digital services, and mobile gaming were all possible. Network Access, Domain Security, and Application Security were all improved with 3G. It is now used as a backup for 4G. For increase in data rates of 3G services, HSUPA, HSDPA, and HSPA+ were added to it, and the networks with such qualities are known as 3.5G networks, and they give up to 2 Mbps but are expensive and compatibility with 2G is difficult [11].

4G is more dependable and provides higher data quality than 3G, and its modification provides high-speed internet access based on LTE, as well as increased security and bandwidth. With a speed of 100 Mbps, 4G is an improved version of 3G (with features such as increased video streaming, multimedia, worldwide access). It provides stationary users with fast mobile internet of up to one gbps, which helps with HD recording, HQ video conferencing, and gaming.

4G is based on IP and provides users with high-quality, thrilling speed, and capacity multimedia, voice, as well as Internet over IP, with increased security and lower costs. It also provides flawless handover for UMTS (universal mobile telecommunications service), data, and voice to GSM and CDMA2000 technologies as an advancement. Because voice calls in CDMA, UMTS, and GSM were circuit-switched before the introduction of LTE, service providers had to re-develop their voice call network. Although LTE failed to meet the criteria, its successor, LTE-Advanced, did (Adrio Communications Ltd.). The 4G networks provided 1Gb/s peak data transmission by using over 40 frequency bands around the world by using techniques such as MIMO and carrier collection.

1.1.2 5G Network

5G is being developed to address the world's expectations and needs for high-speed connectivity, allowing the use of IoT based applications. In the form of true wireless as the world-wide wireless web (WWWW), 5G evolved in 2020 and is still in the development phase. 5G is a mix of 4G and WISDOM, which is a new concept for wireless communication Figure- 1.3. shows vision of 5G.

30GHz to 300GHz is the frequency range of 5G which allows communication over short distances and with bandwidth greater than 1Gbps. This increased connectivity is beneficial as it has plugged the underlying selling point of 5G that increases connectivity to let seamless integration of devices. It runs at new su-6 GHz bands for M-MIMO operation along with mm-wave frequency bands for higher capacity and increased data rate. The smart homes, mobile health, industrial control, internet of vehicles and environmental monitoring which are the future applications of the IoT will initiate the quick growth and the date generated will be the base and Cloud will be storage and processing.

The existing technologies and evaluation systems are increased to meet the requirements of 5G systems. The important technologies of 5G are:

- **M2M Communications and Industry 4.0:** Helps many low-rate devices at very low latency data-transfer.
- **Cloud-Based Radio Access Network (C-RAN)**: separates baseband units (BBU) from remote radio heads (RRHs). Different RRHs are connected to a centralized cloud with the entire signal processing.
- **mmW:** A gold mine of spectrum and contiguous blocs of bandwidths.
- **Device Centric Architecture**: Small cells (micro, femto) in a heterogeneous network (HETNETs), traffic offload better coverage, etc.

- **Massive MIMO**: Allows the densification of base station (BS) or access points by deploying massive Tx arrays that enable multiplexing number of user equipment in the same time-frequency resource. It is a cutting-edge technology with ability of filling the gap for many 5G systems requirements by raising system capacity of new wireless systems .

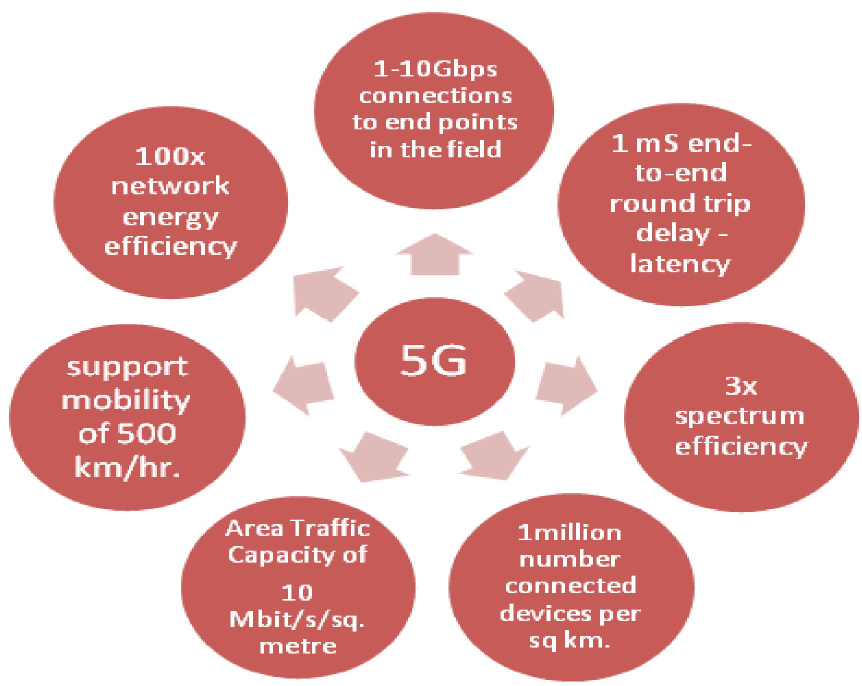

Figure 1.3: Future Visions for the 5G Mobile Communications

Beneficial points of 5G are:

- **Data Rate:** It offers up to 10 Gbps data rate, which is better than 4G.
- **User Experience:** It improves artificial intelligence and virtual, augmented reality.
- **Spectral Efficiency:** It delivers a ten-time improvement in spectral and network progression in comparison to 4G.
- **Energy Efficiency:** It offers 90 % more proficient network energy's consumption in comparison to 4G.
- **Latency:** 4G network provide 10ms latency whereas 5G provide latency as low as 1ms.

- **Ubiquitous Connection:** It gives broadcasting data that supports more than 65,000 connections, which is hundred times better than 4G.
- **Battery life:** For low power IoT devices, it delivers 10 years battery life.

Challenges faced by 5G technologies are:

- ❖ **Frequency Bands:** 300 GHz frequency bands are required for 5G networks for which wireless carriers need to pay millions in order to obtain this high frequency, thus it is costly.
- ❖ **Coverage:** The wavelength of the high-frequency wave is shorter and unable to travel a long distance and requires more BS in a smaller area that ultimately increases the complexity and the cost of the overall network.
- ❖ **Cost:** 5G not only just add an extra layer to the 4G network but the cost for building the system is huge.
- ❖ **Device Support:** Current mobiles do not assist 5G infrastructure, and thus, it would be a problem for device developer to develop phones which not only assist 5G but is also pocket friendly.
- ❖ **Security and Privacy:** Because 5G relies on authentication and a Key Agreement mechanism, it is still vulnerable to intermediary attacks, location monitoring, and eavesdropping.
- ❖ **Availability:** M2M and IoT will result in network overload and congestion. These radio access networks will make it a problem for everyone to access the network.
- ❖ **Cybercrime:** It will increase Cybercrime so; strict Cyber laws would be required to prevent these attacks.

1.2 MIMO- Enabling Technology For 5G

To achieve excellent performance and energy efficiency, MIMO systems are employed. New MIMO technologies for example, network MIMO, single-user MIMO and multi-user MIMO were developed but these are not sufficient to put up the increasing demands because the number of consumers has increased who millions of data points that must be handled professionally and accurately. There are several IoT devices with health care, smart home, and smart energy applications that boost data flow. In the years 2020-2021, it is expected that there will be over 50 billion linked devices.

The massive MIMO makes use of more transmitters and receivers to communicate more data instantly. Massive MIMO is the new version of modern MIMO system that make use of 1000s of antennas connected to a BS to enhance spectral efficiency which enables speed and higher capacity for the incoming 5G. The massive MIMO has large number of antennas but 4G BS have dozen ports for antennas to keep in check all circular traffic whereas 5G BS supports 100 ports, which means that a single array can compensate more antennas to send and receive signals from magnanimous users in one time. This led to an increased capacity of users by a factor of 2 and more. The importance of massive MIMO technology is:

- **Energy Efficiency:** Because the antenna array is altered in a tiny region, it requires very little emerging power and reduced energy requirements in larger MIMO systems.
- **High Data Rate:** Greater MIMO improves the capacity and throughput of data for wireless networks by increasing array gain and spatial multiplexing.
- **Spectral Efficiency:** It aids in the concentration of narrow beams in direction of a user and improves spectral efficiency tenfold over conventional 4G/LTE MIMO systems.
- **Reliability**: It boosts link reliability by providing diversity gain.
- **Low Complex Linear Processing:** It makes the system's simple signal detectors and pre-coders perfect.

- **User Tracking:** User tracking becomes more exact and trustworthy because of this.
- **Low Power Consumption:** It assists in the removal of bulky electronic equipment from the system, resulting in a significant reduction in power usage.
- **Less Fading:** Massive MIMO is resistant to fading due to the employment of a greater number of antennas at the receiver.
- **Low Latency:** in air interface, it reduces latency.
- **Robustness:** These systems are resistant to unintentional interference and internal jamming, as well as reducing antenna failure.
- **Enhanced Security:** Because of the orthogonal mobile station channels and narrow beams, it provides stronger physical security.

MIMO technology was first utilized in China and Japan in 2016, and in 2017, Vodafone and Huawei collaborated to test Massive MIMO systems in the real world, achieving a speed of 717 Mb per second. In 2018, Nokia released the Reef Shark chipset, which is a large MIMO antenna design. It reduces the size of enormous MIMO antennas to half their original size, making it a potential technique for Massive MIMO implementation. Samsung also deployed huge MIMO, which allows for rapid high-speed video broadcasting even in a busy stadium in South Korea. Sprint Mobile used the 3GPP 5G New Radio communication to make the world's 1st 5G data call in 2019, using Massive MIMO. In 2020, Singhwal and colleagues proposed circular polarization (CP) agility in DRA-based MIMOs for 5G network in the Sub-6 GHz band, which they regulate by implanting various cylindrical shells inside ring-type DRAs.

It offers compactness as compared to earlier DRA-based MIMOs operating in the same spectrum. It has the benefit of being simple. As Hassan and coworkers worked on a sort of 2-elements MIMO antenna with frequency reconfigurable features for 5G applications, antenna frequency is an important factor that reduces problems. They also looked into improving the isolation and compactness of MIMO antennas, and came up with a novel type of MIMO antenna array for wideband applications using a 5.5 GHz WLAN that included a parasitic decoupler. Simulation and measurement findings are used to determine band notch characteristics. A list of key technological characteristics of massive MIMO is:

1. **Channel Hardening:** Channel fading is the term for the variation in channel gain. When fluctuations in gain have no influence on the transmitted data, the channel hardens, which eliminates channel fading effects.

2. **Fully Digital Processing**: Each antenna has a frequency and the signals emitted from all of the antennas at each BS (due to MIMO) are managed in a coherent manner. On the uplink, digital processing enables channel response measurement and responds fast to changes in the channel.

3. **Computationally Inexpensive Pre-Coding/Decoding**: Every transmitter and receiver have a single Line-of-Sight (LOS) path, but reflection or diffraction may occur from the surrounding atmosphere, and the signals may interfere, resulting in a low SNR at the receiver, preventing data streams from being decoded efficiently. That is why, on the transmission side, pre-coding is used to equalize signal reception across multiple receiver antennas.

The reliance on propagation reciprocity and Time division Duplex (TDD) functioning necessitates previous or structural knowledge of downlink propagation channels, which can be approximated from uplink pilots.

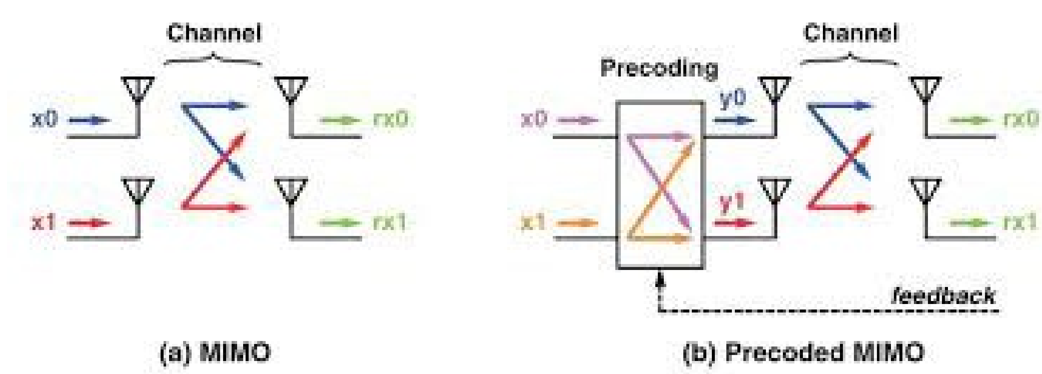

Figure 1.4: Difference between MIMO and Pre-coded MIMO

1.2.1 Characteristics of Wireless Propagation Environment

Scattering, reflection, and diffraction are the three forms of wireless communication channels. WBAN, WPAN, WLAN, WMAN, and WWAN are examples of wireless communication. Reflection happens when a wave collides with an object with dimensions are much larger than the propagating signal's wavelength Diffraction is an example of NLOS communication in wireless channels, which happens when a signal passes through an object with thin edges on its route to the destination. When a propagating wave collides with an object whose dimensions are tiny in contrast to the propagating signal's wavelength, scattering occurs, and reflections run PLC channels.

Quality of received signals in wireless communication channels are judged by Large-scale and small-scale fading. Minor-scale fading assists in determining the received signal characteristics as a consequence of tiny changes in the spatial domain (as tiny as a half wavelength), whereas big-scale fading depicts the variation in the received signal caused by motion across large regions.

✪ **Indoor Deployment**: Homes and offices.

✪ **Outdoor Deployment**: Rural, urban, suburban and so on.

✪ **Electric-Power-System Facility Deployment**: Transmission, distribution, power control rooms and transformation substations are part of this deployment.

According to the study, measurements at roughly 900 MHz and 1.9 GHz are used to model indoor communication situations. Indoor route loss exponent (n) values vary from 1.2 to 6, with values less than 2 suggesting the presence of a waveguide effect in the environment and higher values suggesting substantial attenuation of the transmit signal imposed by walls, ceilings, and floors, among other things. For office contexts, the ITU recommends a shadowing value of 12 dB, as well as a modified indoor route loss expression based on the distance between transmitter and receiver and the number of floors in the transmit signal path. Depending on the parameters of the environment, the usual route loss exponent (n) for outdoor situations ranges from 2.7 to 6.5. For both urban and sub-urban situations, the ITU recommends a value of 4. The value of n is lower in rural areas with flat terrain. 8-10dB is considered shadowing in urban areas, while the ITU considers a standard deviation value of 10 dB to be substantial in both urban and suburban settings.

The research on radio propagation in electric power networks is sparse, however a 500 kV research found that the route loss exponent n varied from 1.45 to 3.55 depending on LOS and NLOS conditions between transmitter and receiver. In these cases, shadowing levels vary from 2.25 to 3.29 decibels. In such a harsher wireless environment, the 5GRAN system supports both radio waves and mm waves-based spectrum; nevertheless, the channel behavior for radio waves and mm waves is different. In this case, MIMO systems will be able to fully benefit from multipath diversity gain.

1.3 Brief Overview of Antenna

SISO According to the literature, antenna can be used in tiny devices where antenna size is critical. SISO multi-element antennas can be used to increase gain and bandwidth. So, with the exception of smart phones, these systems are simple to blend into 5G devices that enable IoT, and MIMO antennas are the greatest choice for this because they aid beamforming. For smart phones and cognitive radios, MIMO multiple patch antennas are simple to design and implement**.** It increases the antenna parameters even more; a multi-element antenna can be employed in MIMO, and basic and higher order resonance frequencies are formed when metal rims are added to MIMO antennas, resulting in increased bandwidth. These metal-rimmed antennas are suitable for smart phones and smart watches, as well as future application in MIMO (massive MIMO), which provides improved efficiency and range proficiency. The different designs of antenna performance techniques are:-

Table 1: Overview Of 5G Antenna Design

Antenna Type	Trivial Points	References
SISO: Single element	◆Design is simple to make. ◆It gives low gain& narrow operating bandwidth. ◆With large sized antenna gain enhancement bandwidth and other parameters can be achieved. ◆The multilayer and corrugation technique can be used for enhancement in gain & bandwidth	[53, 54, 55]
SISO: Multi-element	◆ For single element antenna gain, a multi-element antenna can be employed. ◆ It enhances the antenna's returning loss and hence its bandwidth, resulting in a steadier radiation pattern. ◆ The size of the antenna grows, the feeding network design becomes more complicated, and achieving 50 input impedance becomes a daunting challenge. ◆ An antenna's gain and radiation pattern can be improved by using meta-material and corrugation.	[56, 57, 58]

MIMO: Wideband dual element without metal rim	◆Gives high efficiency. ◆Antenna design is complex. ◆Dielectric Resonator provides Isolation among wideband antenna elements and shares common ground between antenna elements.	[59, 60, 61, 62]
MIMO: Wideband multi-element without metal rim	◆Monopole antenna is used as it is small & easy to design. ◆Difficult thing is Impedance matching. ◆ Orthogonal polarization and polarization variety, respectively, can enhance channel capacity and isolation.	[63, 64]
MIMO: Wideband multi-element with metal rim	◆ It aids antenna miniaturization as well as envelop correlation coefficient and isolation improvements. ◆ Reactance loading and impedance matching allow for a condensed antenna design with broad functioning. ◆The overall efficiency is affected due to user's hand abates isolation. ◆Its orthogonal attribute enhances isolation & gives diverse performance.	[65, 66, 67]

MIMO: Multiband dual element without metal rim	◆ Provides optimal gain, broad bandwidth, high efficiency, and strong isolation in a small package. ◆ The design is complicated by the need for dual polarization. ◆ Meta-surface-based antenna expands the gain & isolation can be achieved with meta-surface-based antenna.	[68, 62]
MIMO: Multiband multi element without metal rim	◆ Low envelop correlation coefficient value gives compact antenna size. ◆ Gives marginal values of isolation. ◆ Improved proficiency and correlation coefficient by slotted ground structure and polarization diversity technique.	[69, 70, 71]
MIMO: Multiband multi element with metal rim	◆ Antenna design is reconfigurable by the use of ON/OFF switches of varactor diode. ◆ Design process is restricted by Device aesthetic properties. ◆ Design is complex because Reconfigurable antenna utilizes switching mechanism. ◆ It enhances data rate.	[72, 73, 74]

1.3.1 Definition of Antenna

It's a gadget that converts a radio frequency signal going down into an electromagnetic wave flowing through free space.

1.3.2 Basics of Antenna

These are discussed as follows:

- **Radiation Pattern:** Although the strength of generating radiations in all directions is unequal, an antenna transmits signals in only one direction when using a radiation pattern. Field Strength depicts the antenna's radiation pattern, which may be assessed using different voltage prints of an electric line.
- **Radiation Intensity:** It is the power per unit solid angle, indicated by the letter U, and is unaffected by the distance between the antennas. Watts per steradian (W/Sr) is the unit of measurement.
- **Beam Efficiency:** It examines an antenna's performance and tells us how much power is transmitted or received in both lobes in the minor to major lobe.
- **Antenna Bandwidth:** It aids antenna efficiency, and for some antenna classes, ratio of allowable upper to lower operation frequencies is defined as bandwidth.
- **Antenna Polarization:** These are electromagnetic wave oscillations in space. Electromagnetic waves have a feature that characterizes the direction and amplitude of the electric field vector as it changes over time. Linear polarization, circular polarization, and elliptical polarization are the three types.
- **Directivity and Gain:** Antennas that are isotropic emit radiation in all directions. Although an isotropic antenna does not exist in reality, if one is considered, its power density will be the same

at all points on the sphere of radiation, and an antenna's average power as a function of radiated power is

$$P_{avg} = P_{rad} / 4r^2 \quad W/m^2$$

- **Input Impedance:** The input impedance of the antenna is matched to the input impedance of the transmission line. If the input impedance does not match, the system degrades over time due to the reflected power.
- **Effective Length:** It is the length of an imaginary linear antenna which is uniformly distributed.
- **Voltage Standing Wave Ratio (VSWR):** According to the Maximum Power Transfer theorem, adequate impedance matching between these two is required for full power transfer from source to the load, and if this is not achieved, a standing wave occurs, representing the amount of power that is not delivered to the load and is returned to the source.
- **Loss of return:** It is the power's amount lost because of the wrong insertion of the device in transmission lines and is expressed in dB.
- **Effective Aperture:** It relates to the receiving antenna and is a measurement of an antenna's capacity to extract energy from an electromagnetic wave.

1.3.3 Types of Antennas

Numerous antenna classifications exist based on types and literature, and a variety of 5G antenna designs have been created in recent years using various technologies. The input and output ports, as well as the antenna types, are used to classify 5G antenna designs.

1.3.3.1 Classification Based on Input Output Ports

The types of antennas are:

1. **Single Input Single Output (SISO):** For 5G applications, it is a single or multi-element antenna. that is used by some researchers since it is simple to create and construct. Integrating it into 5G

communication equipment is straightforward. A single element antenna has a large dimension for good gain. Signal propagation losses and service quality degradation in frequency bands above 6 GHz. A single element antenna must be replaced with a multi-element antenna to ensure consistent and improved performance. Multi-element antennas are commonly used to boost the gain of an antenna at the expense of increased bulk and design complexity.

2. **Multiple Input Multiple Output (MIMO):** MIMO antennas are critical for resolving wireless communication issues since They extend the range of transmission without raising the signal power. In 5G, they are used to achieve low latency, high throughput, and great efficiency. Multiple antennas are used in MIMO to dramatically improve channel capacity. MIMO employs multiband antennas to provide coverage for a wide range of wireless applications. In MIMO antennas, wideband and multiband antennas are divided into multi-element antennas with a metal rim and multi-element antennas without a metal rim.1.3.3.2 Antenna Type Classification. According to these antennas for 5G are as follows:

3. **Monopole Antenna:** It features a straight microstrip line with a length of /4, where is the resonant operating frequency's wavelength. According to the literature, modify the fundamental structure to create other shapes such as conical, spiral, and others as needed. It has advantages including ease of design and manufacture. A multi-element monopole antenna may be turned in any direction with ease. Its downsides include low gain, the need for a wide amount of ground, and poor reaction in severe weather.

4. **Dipole Antenna:** The dipole antenna contains two straight microstrip lines, each of which is 4 feet long, and feeding is given between the two microstrip lines; the dipole antenna's overall length is 2 feet [90]. Its merits include a simple design and the ability to receive balanced signals, while its cons include poor gain, inability to communicate over long distances, and limited bandwidth.

5. **Magneto-Electric (ME) Dipole Antenna**: It has a vertically shorted planar magnetic dipole and a planar electric dipole, with the magnetic dipole supplied from the substrate's bottom side. It has a high front to back ratio, low side lobe and back lobe levels, wide bandwidth, and low cross polarization, yet it is difficult to design and manufacture.

6. **Loop Antenna:** It can be rectangular, square, circle, or any other ring shape with a radius less than the wavelength. It has the advantages of being simple to design and having a large channel capacity. Its downsides are that it cannot meet 5G specifications due to its single element; a multi-element loop antenna is needed, and it has a poor gain.

7. **Antipodal Vivaldi Antenna (AVA):** On opposing sides of the substrate, it has two conductors, one of which is a duplicate of the other. It has an upper conductor that acts as a radiator and a bottom conductor that acts as a ground. Its benefits include increased gain, a wide bandwidth, and a consistent radiation pattern, while its drawbacks include the need for greater area and reduced gain at lower frequencies.

8. **Fractal Antenna:** It is built using an iterative mathematical rule and has several repetitions of the same structure. It can take the form of a rectangle, circle, star, triangle, or leaf [98]. Its benefits include the ability to reduce antenna size, increase bandwidth, improve impedance matching, and give consistent antenna performance over a large working range, while its drawbacks include the complexity of the design and the constraint on fractal design recurrence.

9. **Inverted F antenna (IFA)**: It has one bend in the microstrip line, and feeding is done on the straight section, with the feed point near to the curved section, giving it an inverted F look. It has a small footprint and excellent impedance matching thanks to intermediate feeding; however, it has a limited bandwidth and low gain.

10. **Planar Inverted F Antenna (PIFA):** Because it functions at quarter wavelength and requires minimum space, it is constructed comprised of a patch antenna and a ground plane connected by a shorting pin

and fed from the lower side of the substrate. It has a low profile, superb impedance matching, and a better front-to-back ratio, among other advantages. It has a restricted bandwidth and weak gain, among other flaws.

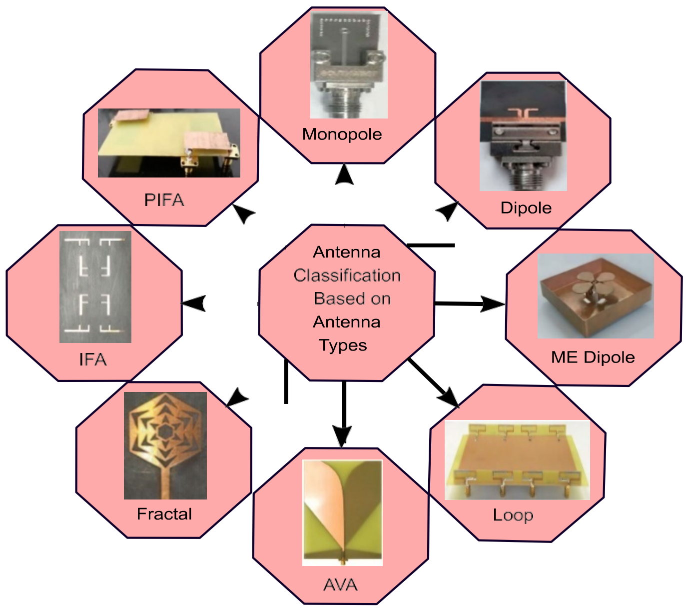

Figure 1.5: 5G Antenna Classification Based on Antenna Types [60, 88, 94]

1.3.4 Why is antenna so important?

Antenna is required for communication and has two complementary functions:

- ❖ It converts electromagnetic waves into the voltage and current that a circuit requires.
- ❖ It converts voltage and current into electromagnetic waves that travel through space.

Electromagnetic waves with electric fields measured in volts per metre and magnetic fields measured in amps per metre transport signals through space. The antenna adopts a certain structure depending on the type of field detected. The antenna has recently become a vital feature of numerous services and technologies. The users and BS are connected via antennas, which are communication equipment.

1.4 Problem Statement

1. Power received at any antenna is given by:

$$P_r = \frac{P_t G_t G_r \lambda^2}{(4\pi R)^2}$$

2. Free space path loss is inversely proportional to gain at transmitting and receiving antenna. So, enhancing the gain reduces the net losses occurred at receiving antenna.

3. Linearly polarized signals are more susceptible to reflectivity, absorption and multi-path fading.

4. It can be seen from formulas that power received, and free space path loss is directly proportional to the gain of transmitting and receiving antenna whereas free space path loss lowers with increase in gain of antenna. Hence concluded that gain of antenna is crucial parameter in increasing the performance of any antenna which is an important part of any rectenna (antenna + rectifier) system.

1.5 Proposed **Solution**

1. Advanced Antenna System.
2. Massive MIMO techniques.
3. Equipped with multiple antennas.
4. Spectrum & Energy Efficiency.
5. High transmission rate.
6. Stable communication.
7. Improve capacity of communication system.
8. Miniaturization of electronic equipment.

1.6 Objectives

The objective of this study is to design a novel massive MIMO antenna targeting the already existing bands of 4G and the sub 6 GHz band of 5G communication.

1.7 Limitations

There are limitations of this study:

1. First, we had to go through the literature to find the suitable antenna design.
2. Then we had to truncate the sides to see its effect on overall gain of antenna.
3. FR4 (FR stands for flame retardant) substrate is the only option available to us as it is comparatively cheap and easily available. But since it's a losy material, it has its own disadvantages as well.
4. Central slot to attain circular polarization has no specific formulas, rather its dimension is adjusted by optimization.
5. After the implementation of a single patch antenna converting, it into 1x4 array antenna while keeping the operating frequency same as that of single patch which was an arduous task.

1.8 Thesis Organization

It is presented as:

- The literature review of the imperative principles presented in this thesis is presented in Chapter 2 along with several developed antenna systems to provide a flow for the readers.
- A system model for designing 8 element small antennas is included in Chapter 3.
- The descriptive evaluation of system performance is the topic of Chapter 4.
- The final notes are presented in Chapter 5 along with a proposal for future work.

CHAPTER 2

LITERATURE STUDY

2.1 Massive MIMO Antenna Design Literature

Mobile data usage has increased by 40% over the last few years, owing to mobile video streaming and IoT integration, which has resulted from a total of 29 billion devices, around 18 billion has been resulted from it, requiring future 5th generation networks to overcome the need for more spectrum in the high frequency range. The availability of frequency spectrum is one of the key obstacles to the creation and deployment of 5G networks before 2022, thus both the higher and lower frequency bands are required for 5G.

Massive MIMO, which uses a huge quantity of antennas at the base station to increase efficiency and energy effectiveness, is a critical technology for 5G. The real problem in integrating a large MIMO system is cramming more antenna elements into a small space while retaining the requisite performance, such as mutual coupling level and input matching. Many large MIMO test beds have been developed, all of which use a single frequency band below 6 GHz with half-wavelength spacing between neighboring antenna units. The mutual coupling effect between parts operating in different bands when they are near together is a difficulty with the dual band antenna, which is designed for wireless communication. High gain and suitable bandwidth are difficult to obtain in dual band array design. For dual/multi frequency bands, coplanar multi-resonator antennas, stacked patches, E-shaped patches, and U-slot cut in a broadband antenna, among other techniques, might be used.

The literature on massive MIMO assisted us in determining which fundamental antenna design we should use for later optimizations. This section focuses on important features such as the number of antennas, mutual coupling, compactness, design approaches, applications, obstacles, and challenges experienced by existing systems. The features and shortcomings of the articles assessed, as well as their designs, are summarized here.

2.2 Compact Dual-Band Antenna Array for Massive MIMO

First, we looked at a published paper by Li and associates, who proposed a small dual band antenna array of 111 elements. At 5.4 GHz, 48 cross patch antennas and 63 square patch antennas provide a uniform planar array layout. The whole array's constructed prototype is 150.8 mm x 178.8 mm in size. (Figures 2.1 & 2.2).

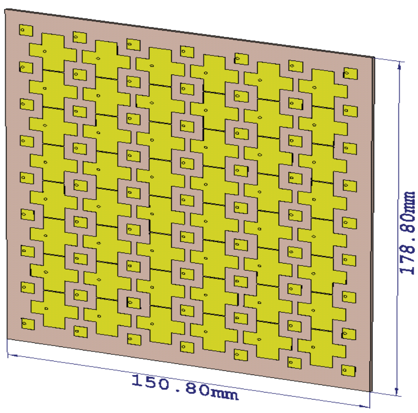

Fig. 2.1 Antenna Array

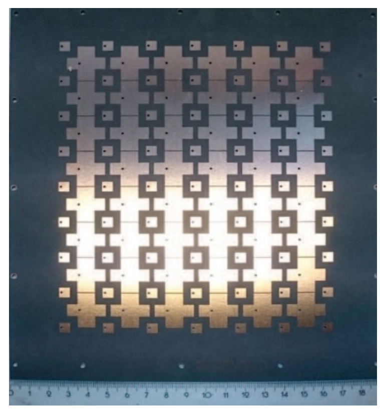

Fig. 2.2 Complete Antenna Array

Mutual coupling between any two ports within the necessary bands is less than 10dB, and the 5.4 GHz patch components provide a matching bandwidth of 300 MHz, while the bandwidth for 15 GHz is more than 2GHz with a reflection coefficient less than -6 dB. When compared to the typical half-wavelength technique, they constructed an antenna array with 1.6 times the number of antenna elements for 5.4 GHz and an additional 63 patch elements for 15 GHz. This array is suited for future compact base stations for wireless communication, such as 5G. For 5.4 GHz patches, dual polarization feeding would be desirable, however the distance between the two feeding ports is inadequate to compensate for two SMA connections in one patch, making it problematic to use with existing Sub Miniature version A (SMA) connections.

The measurements from the entire antenna array are presently being analyzed. The reflection coefficient and mutual coupling level between any two ports can be investigated but examining each feeding port would be unacceptably time-consuming. The problem of determining how to quantify the antenna performance of a huge MIMO array with over 100 feeding ports remains unsolved.

2.3 4-Element Printed Dual Band MIMO System Design

The author proposes a four-element configuration for the antenna system of dual band MIMO. A built four-shaped compact MIMO system is shown in Figure 2.3. The antenna is dual band, with one band covering 760 MHz with 50 MHz bandwidth and second one covering 2.4 GHz with a bandwidth of 150 MHz Because of the close composition of the antennas in a 60 x 100 mm2 smart-phone case, the distance between two neighboring antennas is much smaller, resulting in a lower /15 level in the lower operating band of 50 MHz It restricts the amount of isolation that may be achieved in a design.

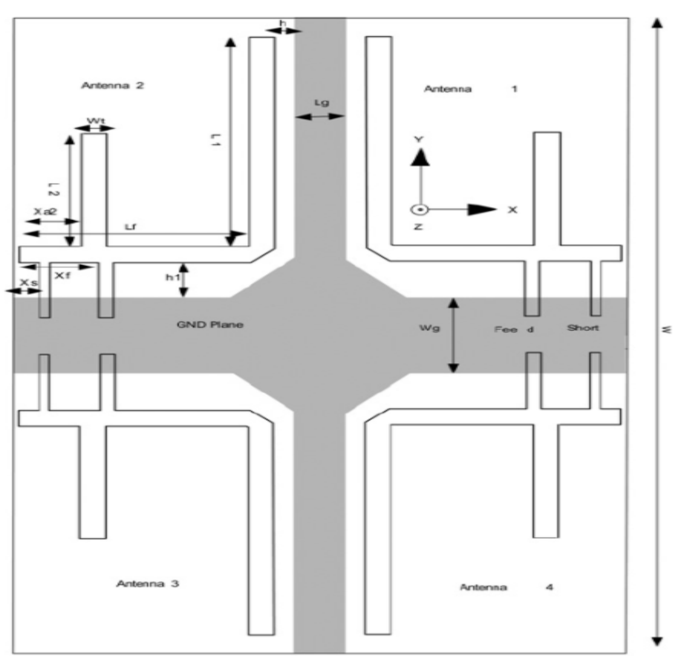

Figure 2.3: Design Of A 4-Element Printed Dual Band MIMO System

The author has created a band-stop filter for enhanced isolation between all antenna parts in the design in order to achieve the goal, which is accomplished by adding a simple defective ground containing induced vertical slits. Due to impedance mismatches and antenna losses ranging from 40% to 70%, proficiency in both bands is reduced.

2.4 Design Of 8 × 8 Dual-Band MIMO Antenna Array For 5G Smartphone Applications

Zou and colleagues introduced a dual-band 8 x 8 antenna array for 5G communication MIMO in the smartphone that operates in the long term evolution (LTE) bands 42 (3400-3600 MHz) and 46 (5150-5925 MHz) (Fig. 2.4). Smartphones have lately gained popularity due to their wide range of features, which include communication, navigation, mobile financial services, and entertainment. As a result, the wireless communication industry's ability to increase smartphone multiband operation and radio signal transmission performance has become a research hotspot.

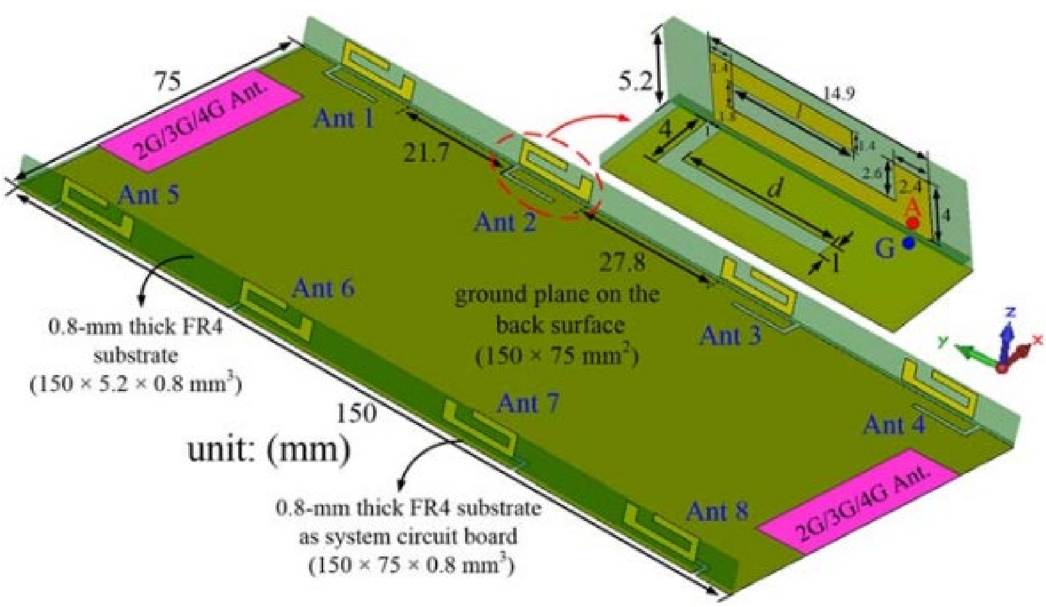

Figure 2.4: Geometry of The Proposed 8-Antenna Array

According to this study, the dual-band antenna array element is made up of an L-shaped open slot antenna and a U-shaped monopole antenna. Across the two desired operation bandwidths, the evaluated results showed acceptable isolation (better than 12 dB) and efficiency (more than 50%), and the proposed antenna array also demonstrated good MIMO performance with an envelope correlation coefficient of less than 0.1 and ergodic channel capacities greater than 38.8 bps/Hz in the operation bands. Hand phantom effects are also investigated, with the results revealing that the proposed antenna array can perform well in terms of radiation and MIMO in both single and dual hand modes.

2.5 Finite Large Antenna Arrays for Massive MIMO: Characterization and System Impact

The effect of mutual coupling in larger arrays on embedded gains, and specifically the impact on system performance in a massive MIMO system, is investigated for the first time in a paper published by Chen and others, both for the more omnidirectional dipole element and the well-known and intensively patch element. It also showed how mutual coupling between closely positioned components and edge effects in finite arrays caused the active gain pattern modification of individual antenna elements in a big gigantic MIMO array. In the simulation-based evaluation, both dipoles and patch antennas are analysed, and real-life experiment data is also provided for the latter. The antenna's specifications

The further detail of the paper is:

- In Section II, researchers presented a huge Model of a MIMO system with an enhanced channel model that takes into account 3-D antenna gain.
- Section III examines the antenna gain fluctuation and directivity of a representative finite large array made up of dipoles or patch antennas using simulations.
- The experimental validation is presented in section IV.

Section V depicts the effect of improvement distinction on spectral efficiency at the system level.

A microstrip patch antenna produces an omnidirectional pattern, while a half wavelength dipol in the H-plane produces a directed pattern. Because their features are ideal for commercial wireless applications, so for antenna design microstrip patch antennas have been selected. They are smaller, lighter, and easier to build; they can be rectangular, square, or triangular in shape, and they can accommodate high-density packaging. The microstrip patch prototype in this study consists of a 31 mm square patch with two 1.4 mm wide merged U-slots. The patch and slot forms were then distorted to polygons utilizing computer simulation technology's optimization technique to cover the frequency bands 2.4-2.62 and 3.4-3.6 GHz. At 2.6 GHz, the primary contrast was done. Figure 4 depicts a single patch. The patch is etched on a 1.6 mm FR4 substrate that is sandwiched between two 1.6 mm FR4 substrates with 5 mm nylon spacers. The antenna is 70 x 70 mm in size. The dipole is approximately 51.3x2 mm in size. Figure 2.5 shows both forms of finite arrays with an element spacing of 71 mm. As illustrated in Figure 2.6, all members in the array are numbered sequentially from the left bottom corner.

The fundamental discovery of the research is that excessive mutual coupling between components can completely destroy the omnidirectional pattern of the dipole. With a finite array, the problem is very different. The edge effect, or the fact that the elements at the margins encounter a different environment than the components in the centre, causes the embedded benefits of the parts to differ. In this work, scientists experimentally demonstrated that the gain patterns of different antenna elements in a limited array vary significantly. This gain pattern shift is caused by mutual coupling and the edge effect,and is heavily impacted by the angle of arrival. On a large MIMO system, a significant gain pattern variation means that not all antennas contribute equally to all users, and the number of effective antennas observed for a single user is reduced.

The zero forcing MIMO detector with up to 20% of patch array has a reduced users rate as a result of this at the system level. Contrary to this, maximum ratio mixing increases user injustice. They suggested that future research look at optimal antenna array topologies and combinations to limit the impact of substantial strength variation effects.

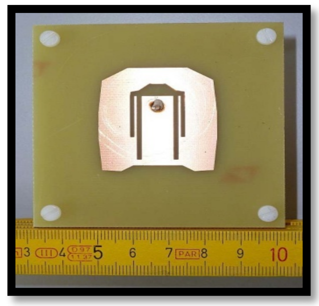

Figure 2.5: View of The Microstrip Patch Antenna

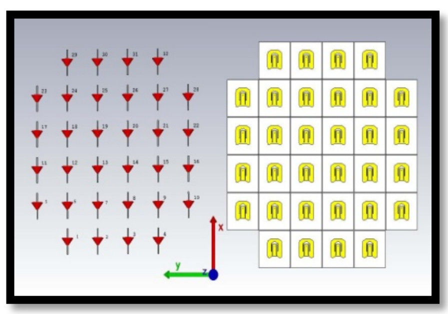

Figure 2.6: 2 Finite 32-Element Antenna Arrays: Dipoles (Left) And Patches (Right).

2.6 For 5G Communication, A Four-Element Microstrip Patch Array Antenna with A Corporate-Series Feed Network

In the year 2020, Korean engineers developed a four-element patch antenna designs using series feed and corporate feed techniques. One of the most important features of microstrip patch antennas is wireless applications is their simple feed mechanism. A single line or numerous lines can be used to feed the microstrip patch elements of an array antenna, depending on the system's requirements. A range of sophisticated feeding techniques are also available A prominent feed approach for microstrip array antennas is corporate feed, sometimes known as corporate-series feed. The power is uniformly dispersed at each junction of the microstrip patch array antenna for uniform distribution in the corporate feed network.

The several feeding systems were merged to create a corporate-series feed network, which was then utilised to propose a microstrip array antenna with a broad bandwidth and end-fire radiation patterns. To boost the antenna's total gain, Yagi components were also integrated into the designs. The geometry of the array antenna with a series feed network is shown in Figure 2.7.

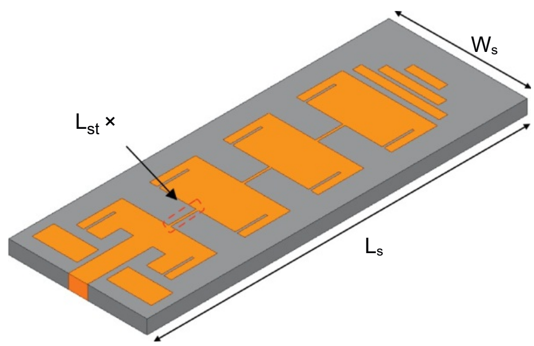

Figure 2.7: Geometry of Series-Fed Microstrip Array Antenna

According to simulation findings, the suggested microstrip array antenna with corporate-series feed approach outperforms series- and corporate-fed array antennas in terms of gain, size, and bandwidth. Figure 2.8 depicts a prototype of the recommended corporate-series-fed microstrip array antenna. The suggested four-element antenna also covers the majority of the higher frequencies necessary for 5G communications. The antenna's greatest peak achievable gain was 9.49 dB over a wide bandwidth of 25.15–30.87 GHz.

Array Antenna: (A) Top View **(B) Bottom View**

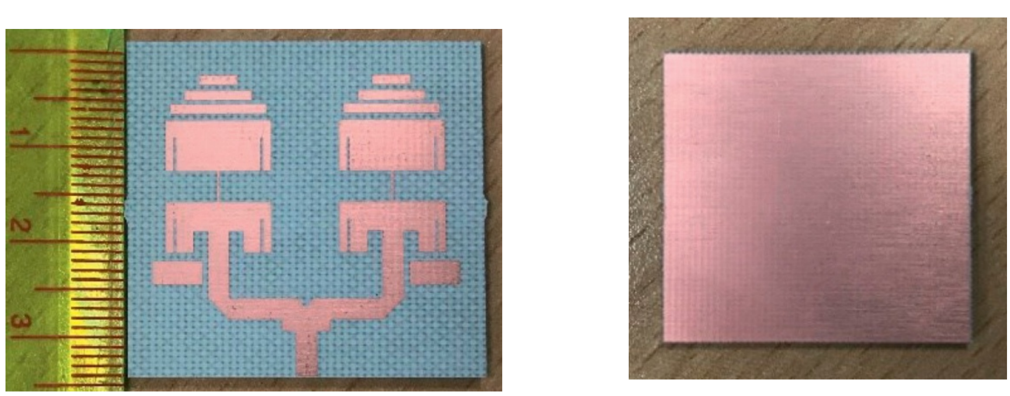

FIGURE2.8. Fabricated Prototype of Proposed Microstrip

2.7 Compact Ultra-Wide Band MIMO Antenna System for Lower 5G Bands

In 2018, Al-Saif and colleagues published a research demonstrating that lower 5G bands are optimal for early deployment due to favorable attributes such as wave propagation and accessible bandwidth. The key spectrum bands between 2GHz and 6GHz are 3.3 GHz and 4.2 GHz, and 4.4 GHz and 4.990 GHz, respectively. In nations like as Europe (3.4-3.8GHz), China (3.4-3.8, 4.4-4.5, 4.8-4.99GHz), Japan (3.6-4.2, 4.4-4.9 GHz), Korea (3.4-3.7 GHz), and the United States (3.1-3.55, 3.7-4.2 GHz), these bands are currently being examined for first 5G network experiments [119].

A revolutionary ultra-wide band (UWB) 2 2 MIMO antenna system has been designed and modelled to tackle this challenge and fulfil current expectations. UWB-enabled wireless communication devices may broadcast over a wide frequency range while using less power [120]. Furthermore, UWB-based devices offer a number of benefits, including fast data rates, increased bandwidth, and cheap cost. The primary challenge in designing these antenna systems is to avoid reciprocal contact between the radiating elements while reducing the bulk of tiny portable devices to a minimum. The 22 MIMO antenna systems were constructed up of two asymmetric "F" type structures with an extremely compact fractured ground plane. The described MIMO antenna system is extremely small, with a total volume of 13 25 0.254 mm3. Figures 2.9(a), 1(b), and 1(c) show the front and back perspectives of the planned antenna system (c). The coupling between two antenna system parts is less than 20 dB across the entire transmission bandwidth, with peak minimum values reaching up to 35 dB. The greatest gain was found to be 4.8 dB, with a gain of 2.8 dB at the middle frequency. In addition, the patterns of radiation are isotropic. The findings of the MIMO antenna system's constructed prototype and its simulated model are in good agreement. The antenna's fractional bandwidth is 143.2 percent, which satisfies its UWB response.

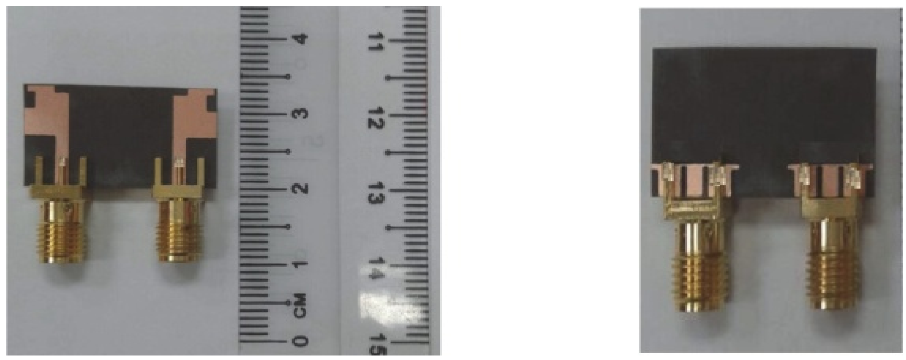

Fig. 2.9 Fabricated antenna

CHAPTER 3

DESIGN AND DEVELOPMENT OF ANTENNA

3.1 Antenna Design Introduction and Development

The MIMO framework, which consists of eight parts, was examined in this final year research. For future 5G services, a compact and narrow eight-element MIMO system was constructed and measured experimentally. At first, only one component of the MIMO system was built and studied. The plan was to cover the upcoming 5G band. The design has been extended to eight components using the symmetry attribute.

Various parameters have an impact on the MIMO system. Mutual coupling is one of the most important factors that affects the performance of a MIMO antenna system. It is one of the most important factors that influences the MIMO system's properties. To achieve results that are closer to the ideal value, it is required to have as low mutual coupling as feasible between the components of the MIMO system. As a result, the pattern diversity property has been imposed in order to achieve low mutual coupling and achieve the required results. Furthermore, the design was made unique by omitting the usage of a decoupler structure. However, good isolation of less than 15dB has been achieved.

3.2 Proposed Eight Element MIMO System Design

A planar structure with a single branch resonating on a single frequency is the single element of the antenna design system. The printing was done on a FR4 Epoxy substrate. It possesses a 4.4 relative permittivity, a 1 relative permeability, and a 0.02 loss tangent. The thickness of the substrate is 1.6mm, while the other two dimensions are 5.9mm and 17mm.

High-Frequency Simulation Software is used to model the single and subsequent parts. The findings of the experiments are recorded in an anechoic chamber at RIMMS. Both measured and modelled findings have shown an excellent match. Figure 3.1(b) depicts the simulated surface current distribution of a single element. The regulation of resonance may be seen in the surface current distribution on the antenna element. Discussed earlier, system consists of similar eight elements shape.

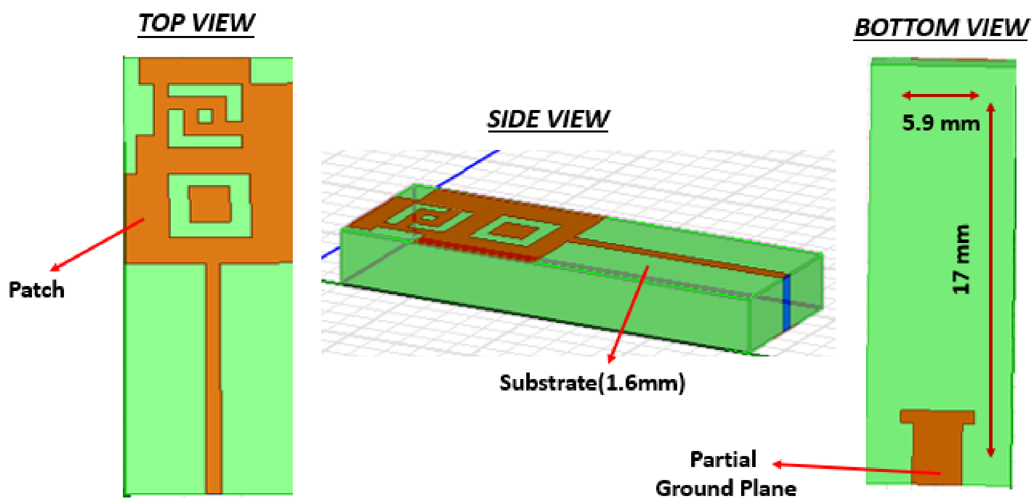

Figure 3.2(a) Different Views Of Single Element Antenna

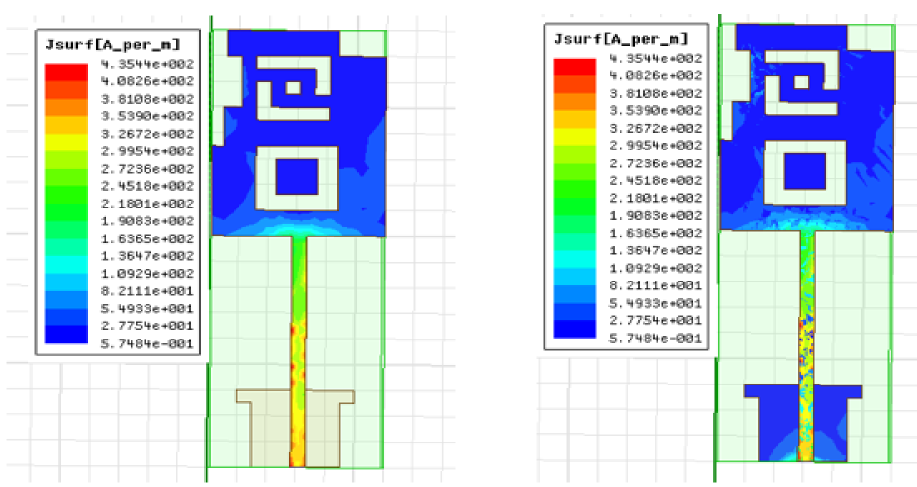

Figure 3.2 (b) Simulated Surface Current Distribution of a Single Element

3.3 Fabricated Antenna Designs

Case 1

In this case four elements are printed in linear fashion on substrate and next four elements are placed perpendicular to each of them. In order to avoid mutual coupling, each element is placed at a separation of 14.1 mm adjacently and 8 mm perpendicularly.

Figure 3.2 (a) shows a built MIMO antenna with input feeds. The front view and back view of the constructed design are all depicted. In the meantime, fig 3.2(b) shows the visuals of system of the planned MIMO, with physical measurements in millimetres.

The Front View **The Back View**

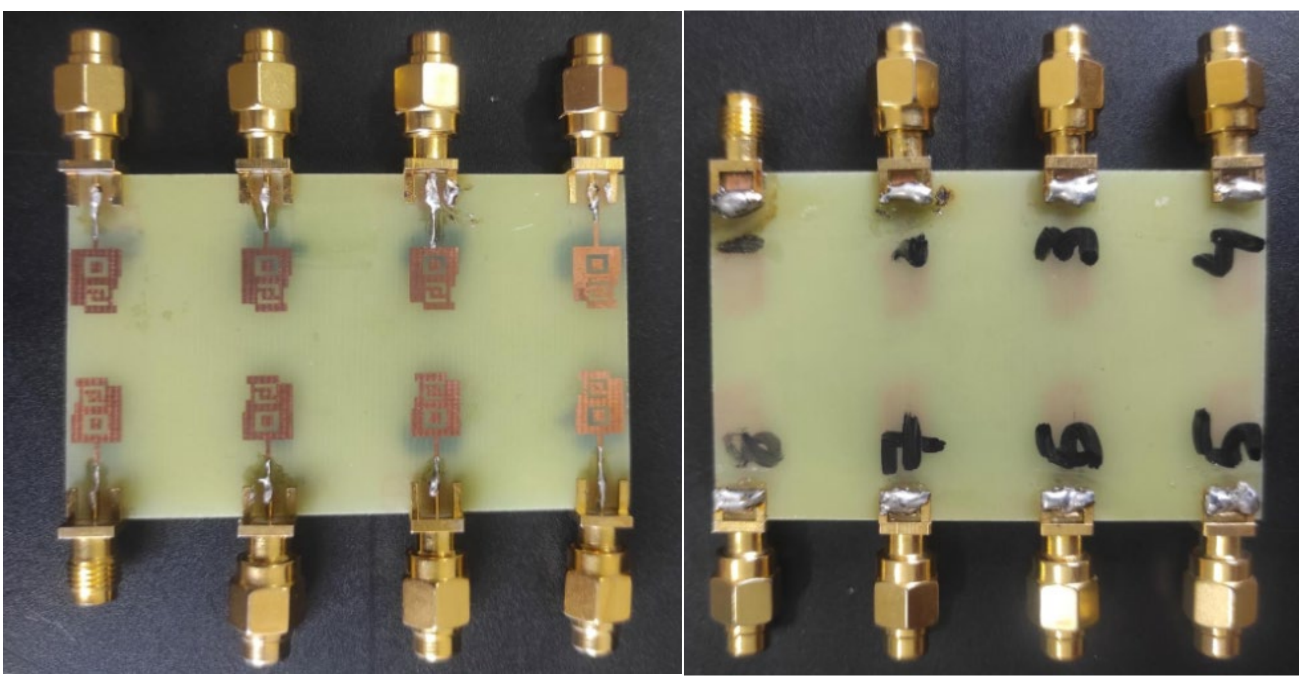

Figure 3.2 (c) MIMO Antenna with Input Feeds

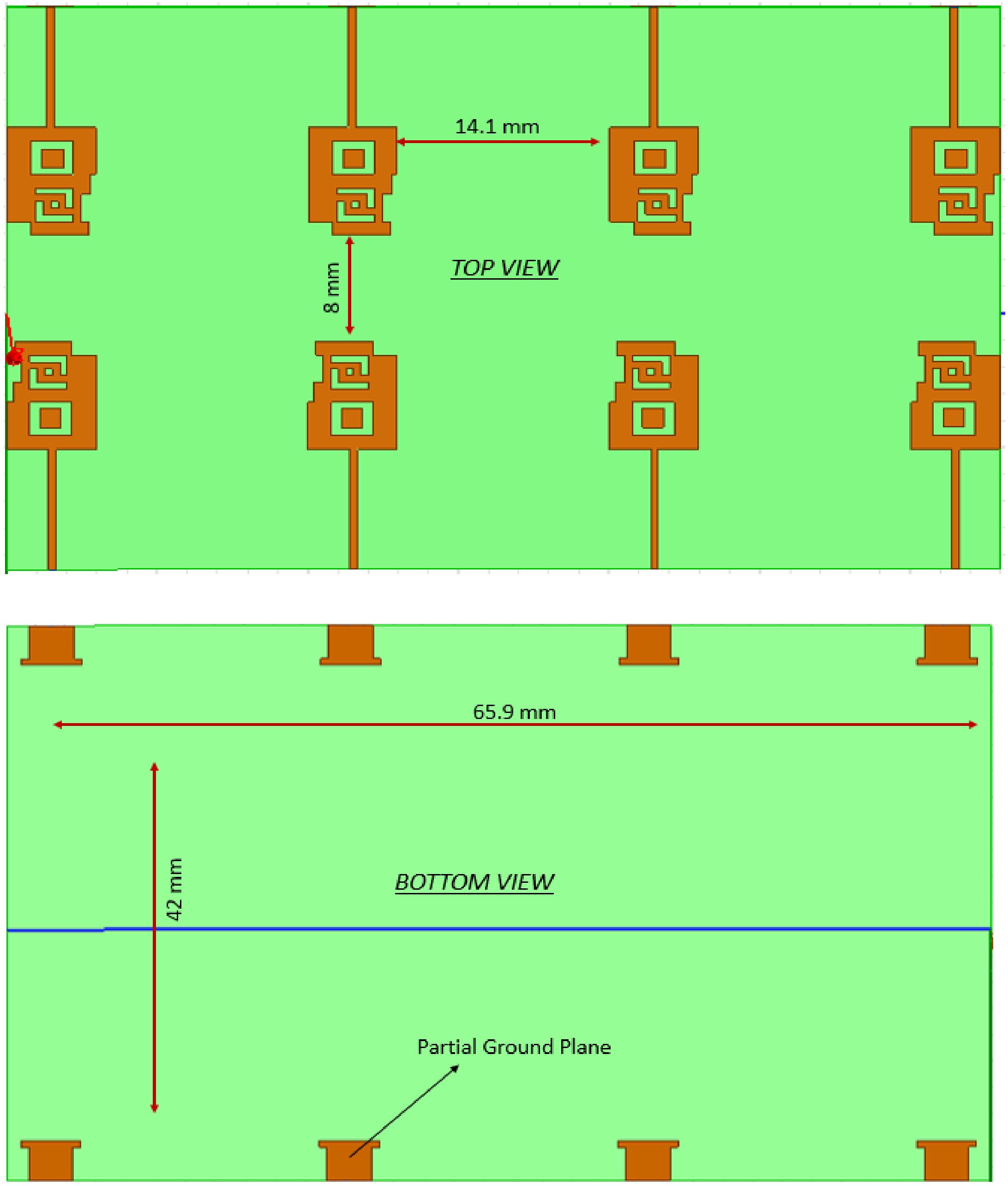

Figure 3.2(d) Schematic Design with Dimensions of a MIMO System

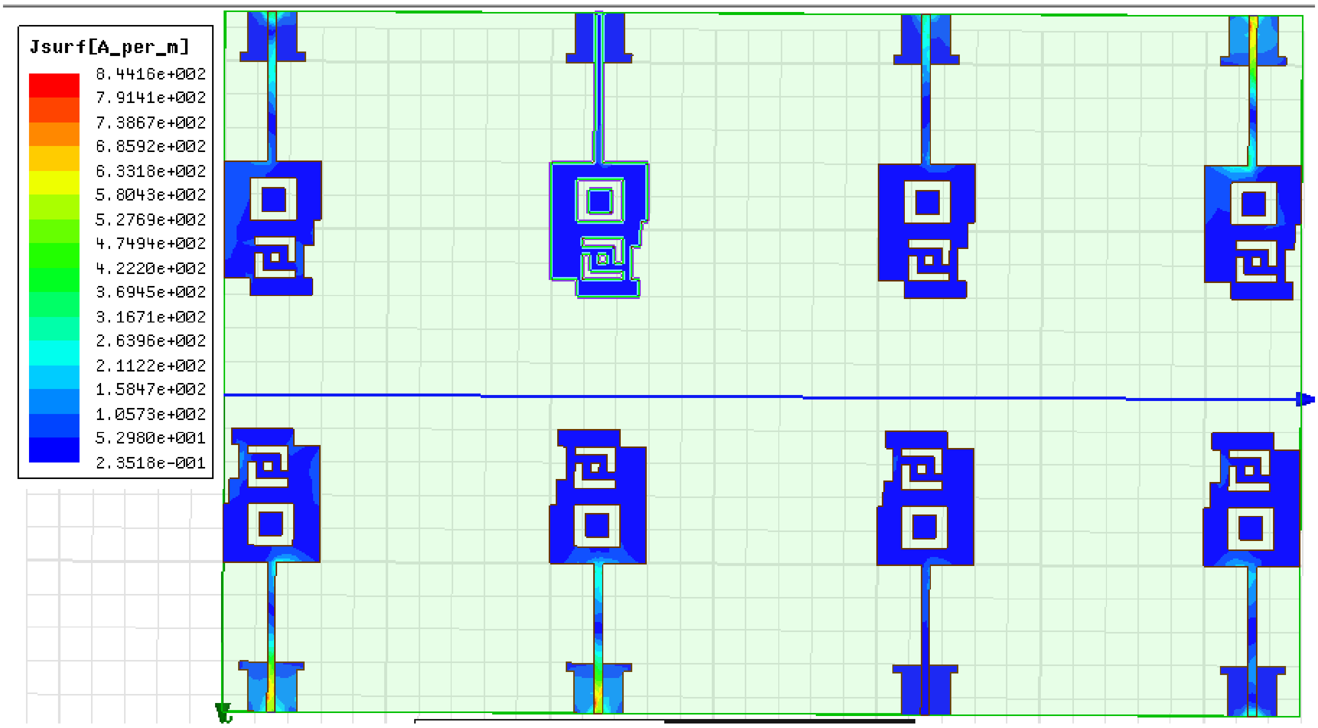

Figure 3.2(e) Current distribution in MIMO System

Case 2

In this case all eight elements are printed in a linear fashion on a substrate with a separation of 14.1mm with each other in order to get low mutual coupling value. Different views of fabricated design with antenna input feeds are shown in Fig.

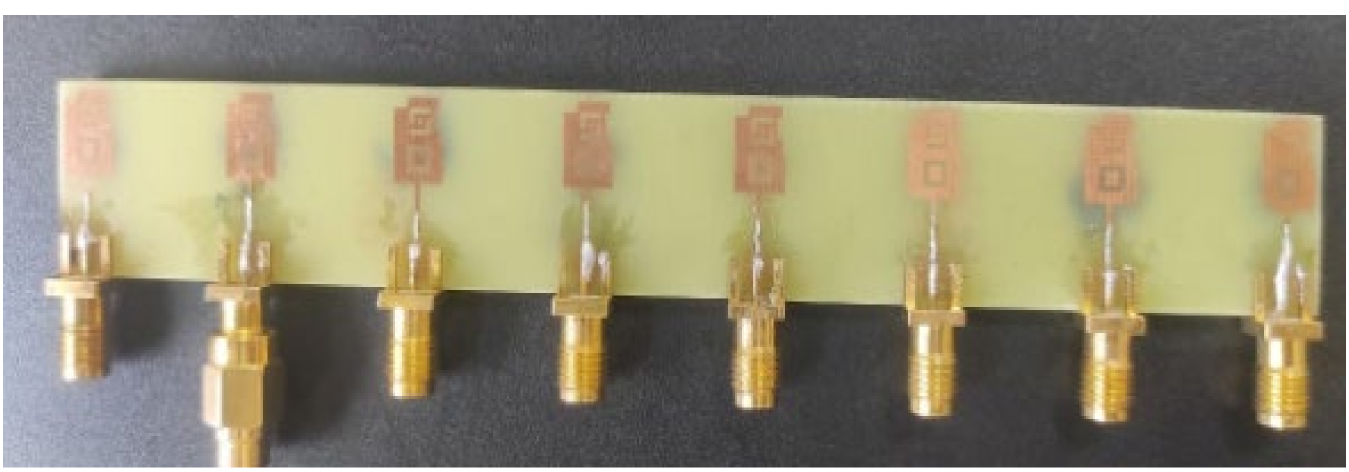

Figure 3.2 (f) Front View of Fabricated Antenna

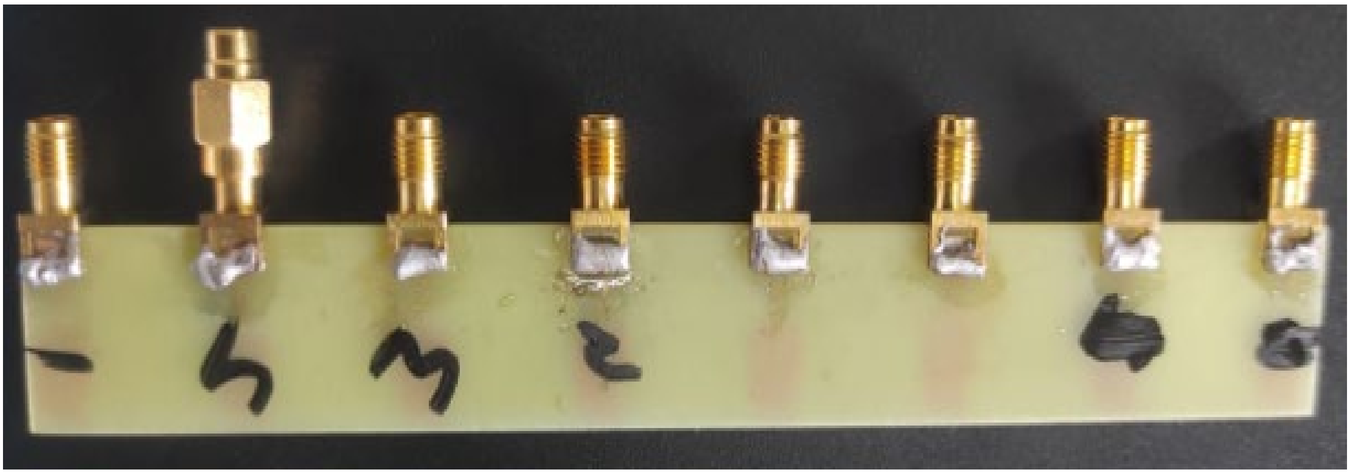

Figure 3.2 (g) Back View of Fabricated Antenna

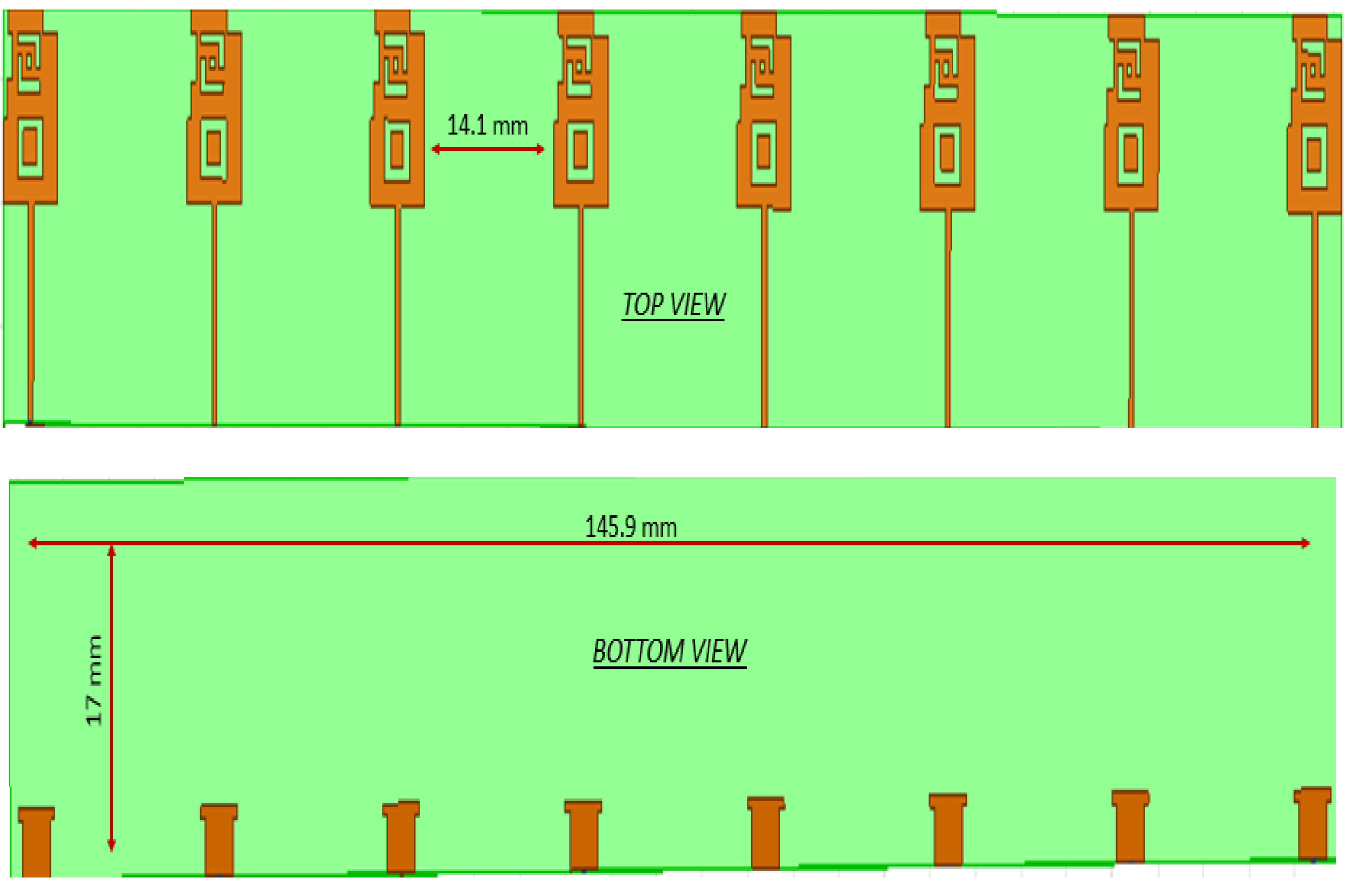

Figure 3.2 (h) MIMO System Schematics with Dimensions of Design

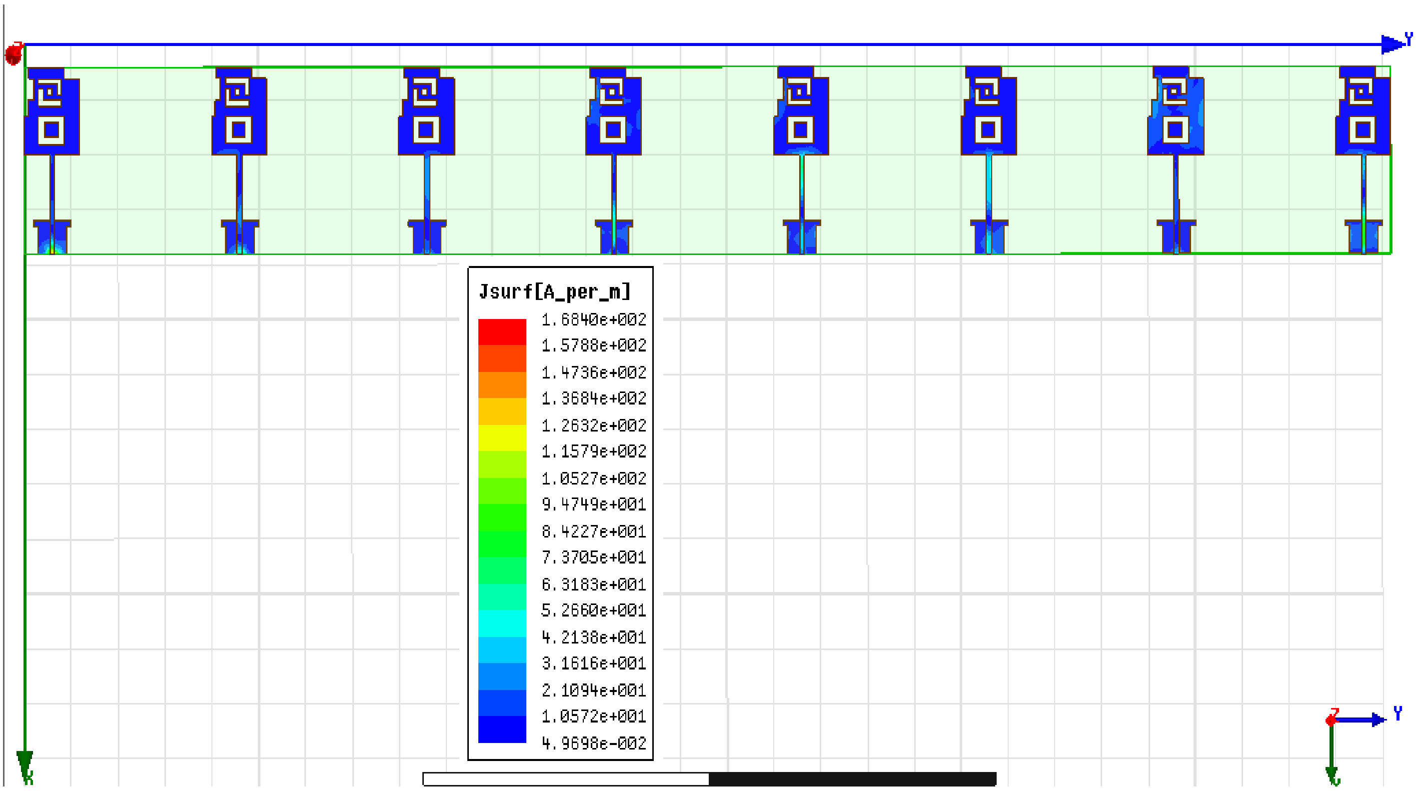

Fig 3.2 (i) Surface Current Distribution

CHAPTER 4

SIMULATED AND MEASURED RESULTS OF ANTENNA SYSTEM

4.1 Single Element

Figure 4.1 depicts the reflection coefficient of a single antenna element (a). The x-axis in the graph below depicts frequency, while the y-axis indicates the single element reflection coefficient. When we look at the value of frequencies that cross the 10dB threshold, we can get a good reflection coefficient value.

Very little power should be reflected from the element. Value should not be larger than -10dB at the optimum operating frequency. If the element's power is reflected more, relatively little power will radiate outward, which is desirable.

If this occurs, no element can reach resonance, which is the opposite of what is sought, and so proper matching between the feeding port and the planned antenna structure is essential. As a result, the simulated results meet the requirements for a good reflection coefficient.

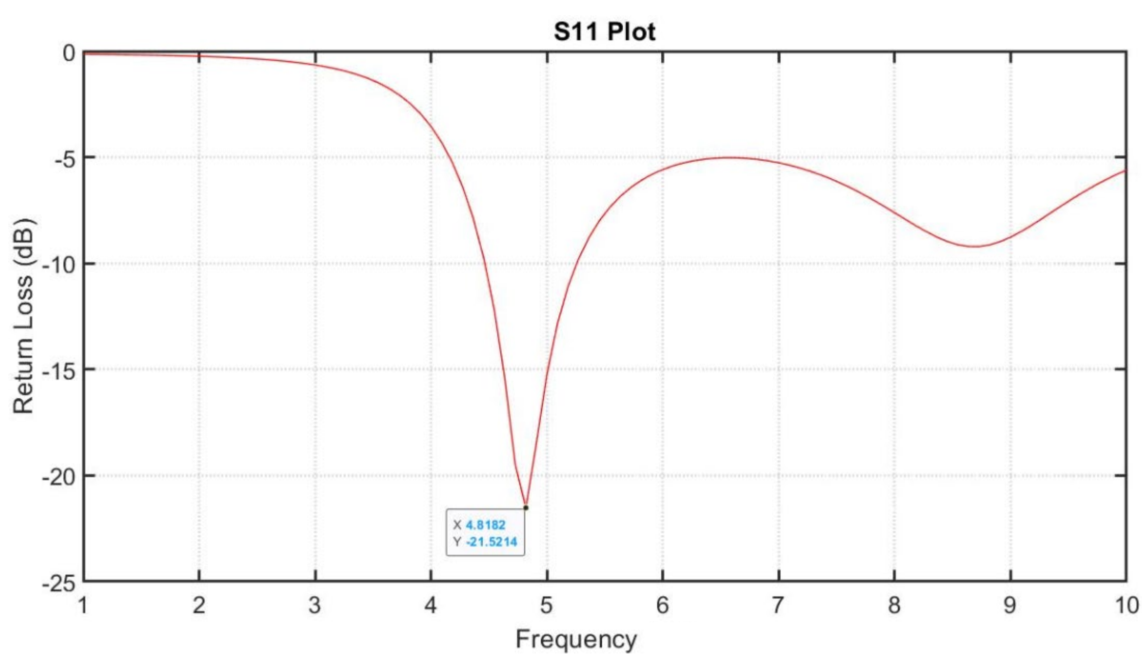

Fig 4.1 (a) Reflection Coefficient of Single Element Antenna

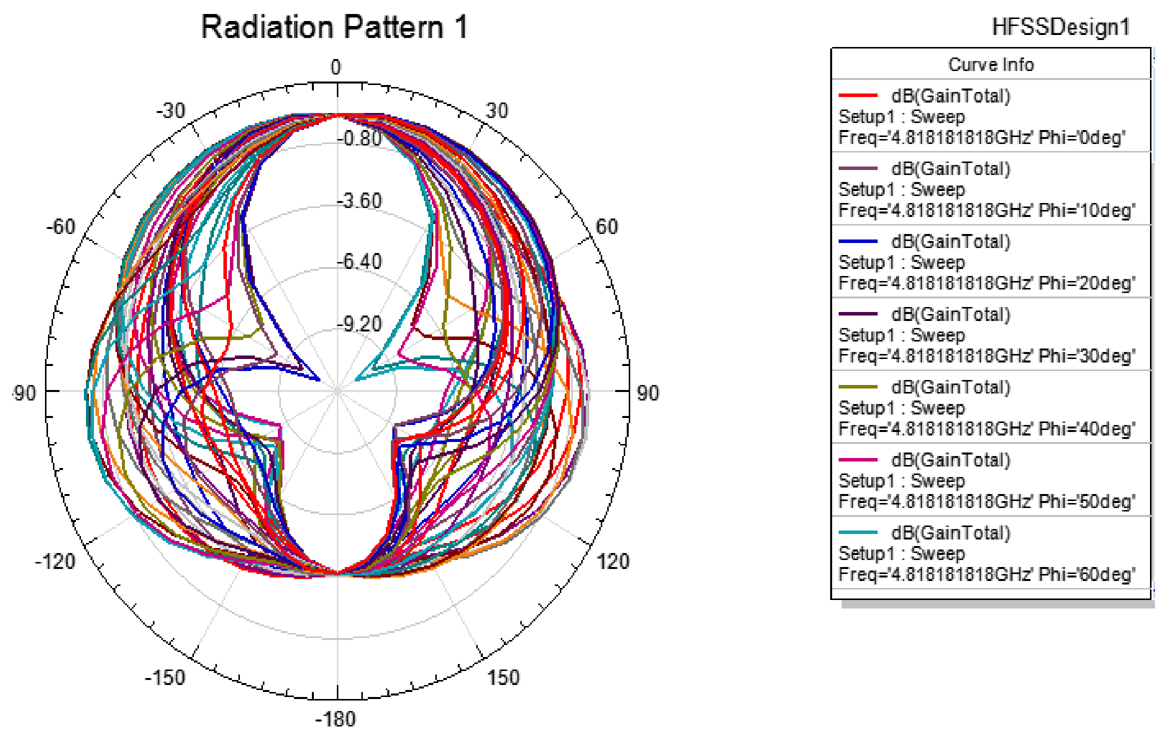

Fig 4.1(b) Radiation Pattern at 4.81 GHz

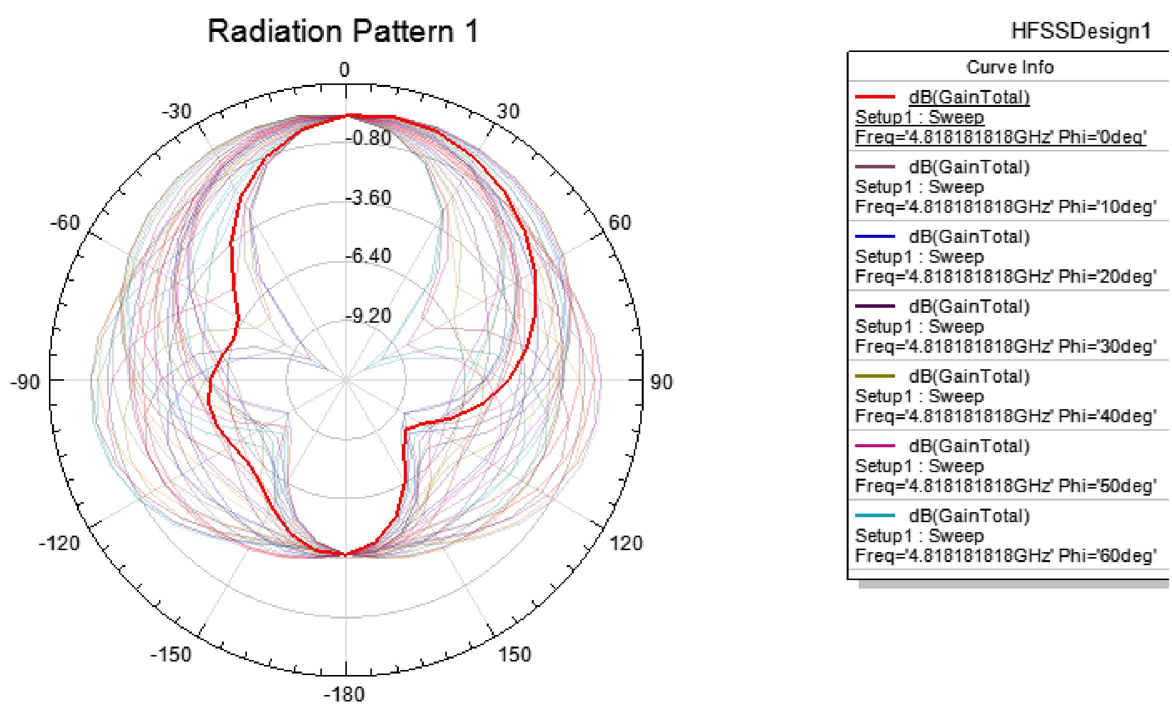

Fig 4.1 (c) Radiation Pattern at Phi = 0^0 With Fixed Theta.

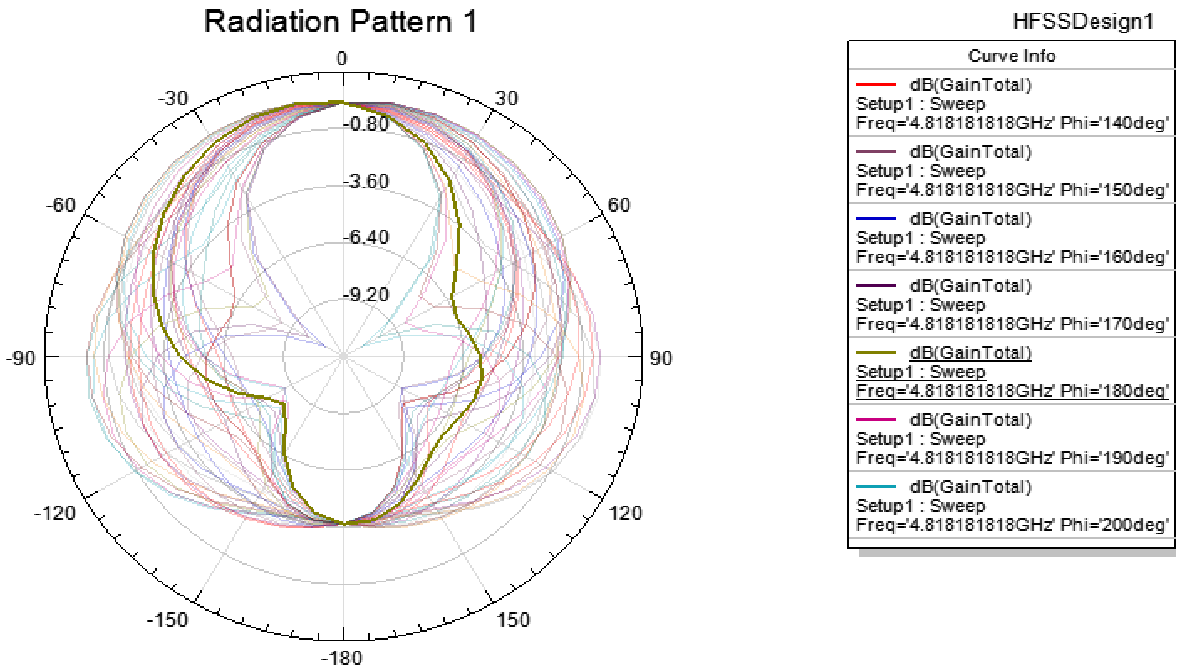

Fig 4.1 (d) Radiation Pattern at Phi = 180^0 With Fixed Theta

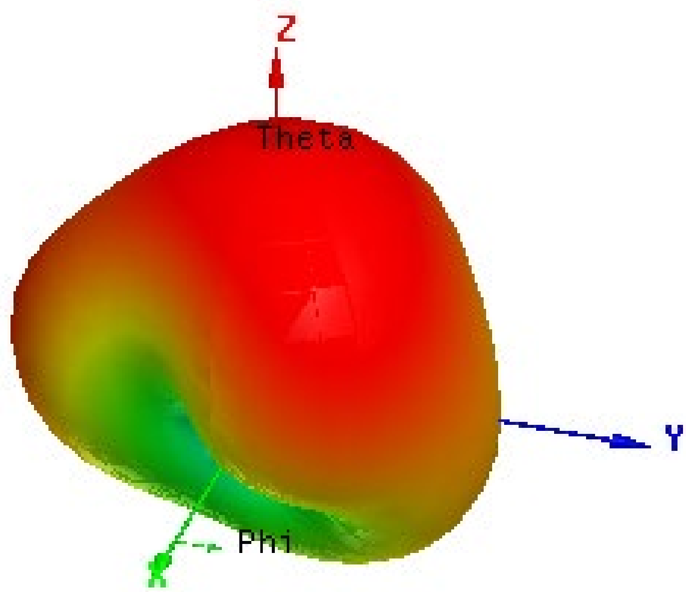

Fig 4.1 (e) Gain of Single Element at 4.81 GHz

4.2: Eight Element MIMO Antenna System

Case I

The all eight members reflection coefficient of MIMO system is shown in Fig. 4.2(a). The MIMO system was created with a single band in mind. In this case we get a return loss of -23.98 dB at center frequency of 4.45 GHz. Reflection Co-efficient plot shows that element's power is reflected more, relatively little power will radiate outward, which is desirable. In the Fig 4.2 (a) S-parameter plot i.e. S11, S22, S33, S44, …….S88 of antenna system has been shown in various colors.

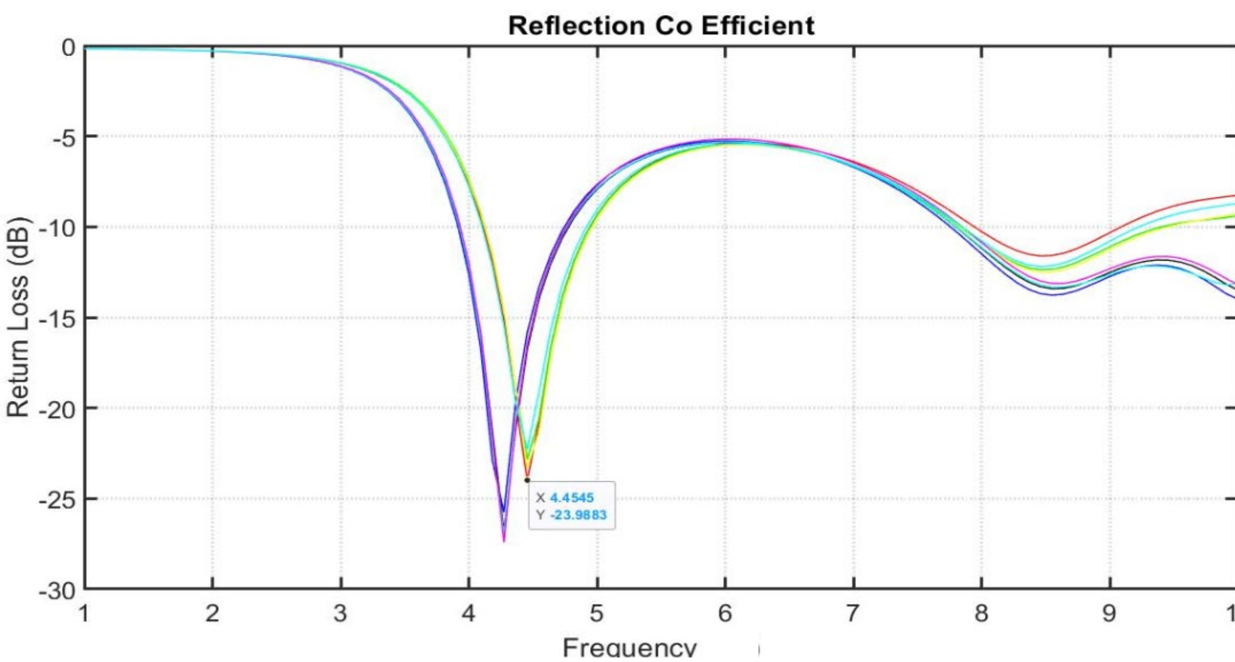

Fig 4.2 (a) Case – I: Reflection Coefficient of 8-Elements of MIMO system

In the MIMO system, it is necessary to validate each element separately in order to measure the accuracy of system. Therefore, in the subsequent figures effect of other elements on one element can be seen. All the figures show us the effect of mutual coupling between the elements. The standard value is -10dB so isolation between the one element to the other should not be greater than the standard value. From the Fig 4.2(b), we can easily see that isolation is -15dB which reflects the good value of impedance matching.

Different colors have been used to show different curves. In the next fig 4.2 (c) all values of curves are crossing the value of -14.86dB which also depicts the good mutual coupling between element 2 with rest of the other elements.

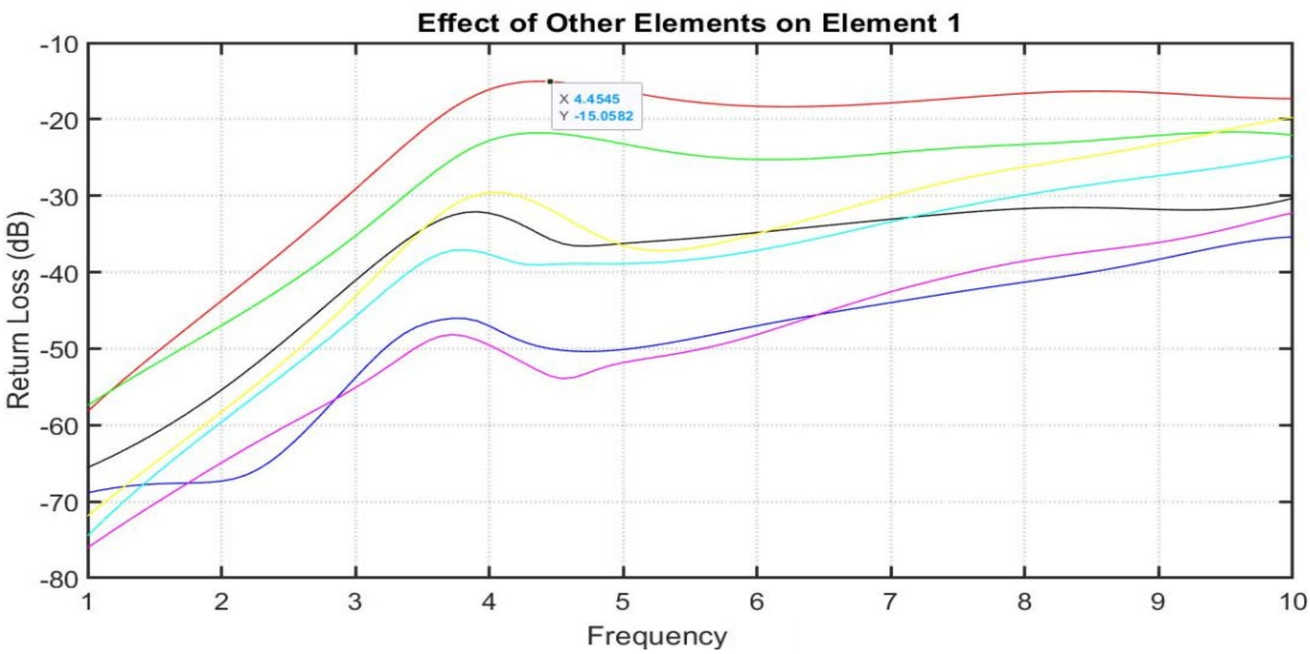

Fig 4.2 (b) Case I - Effects of Other Elements on Element 1

The results will be the same after carefully analyzing the rest of the plots i.e. effects of other elements on one element which clearly shows that antenna system is acquiring good value of reflection coefficient and isolation between the elements. If we follow the same analysis on fig 4.2 (b – j) at a frequency of 4.45GHz, then we would be able to know that antenna system is meeting a standard value.

Fabricated antenna system has been measured in RIMMS – NUST. Fig 4.2(j) is showing the measured results of port 1 and port 4 of the said antenna system which are also nearly meeting the standards.

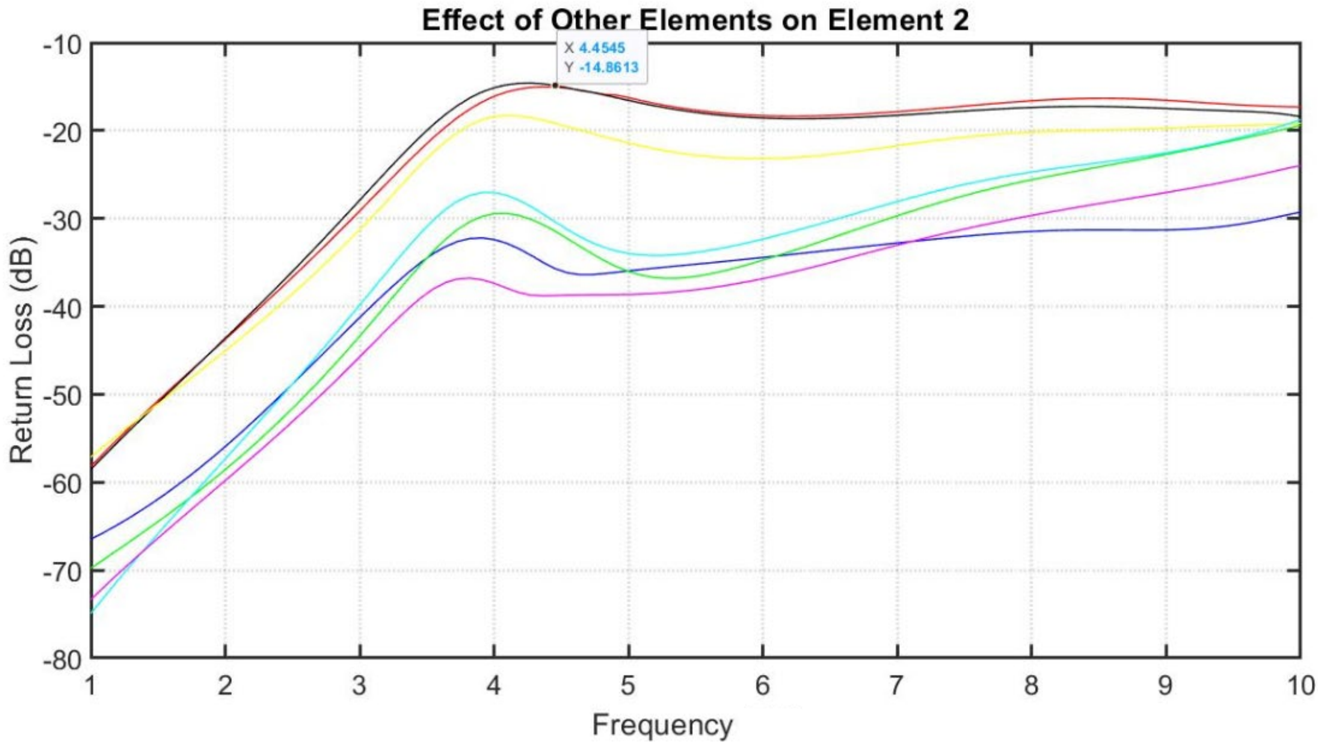

Fig 4.2 (c) Case – I Effects of Other Elements on Element 2

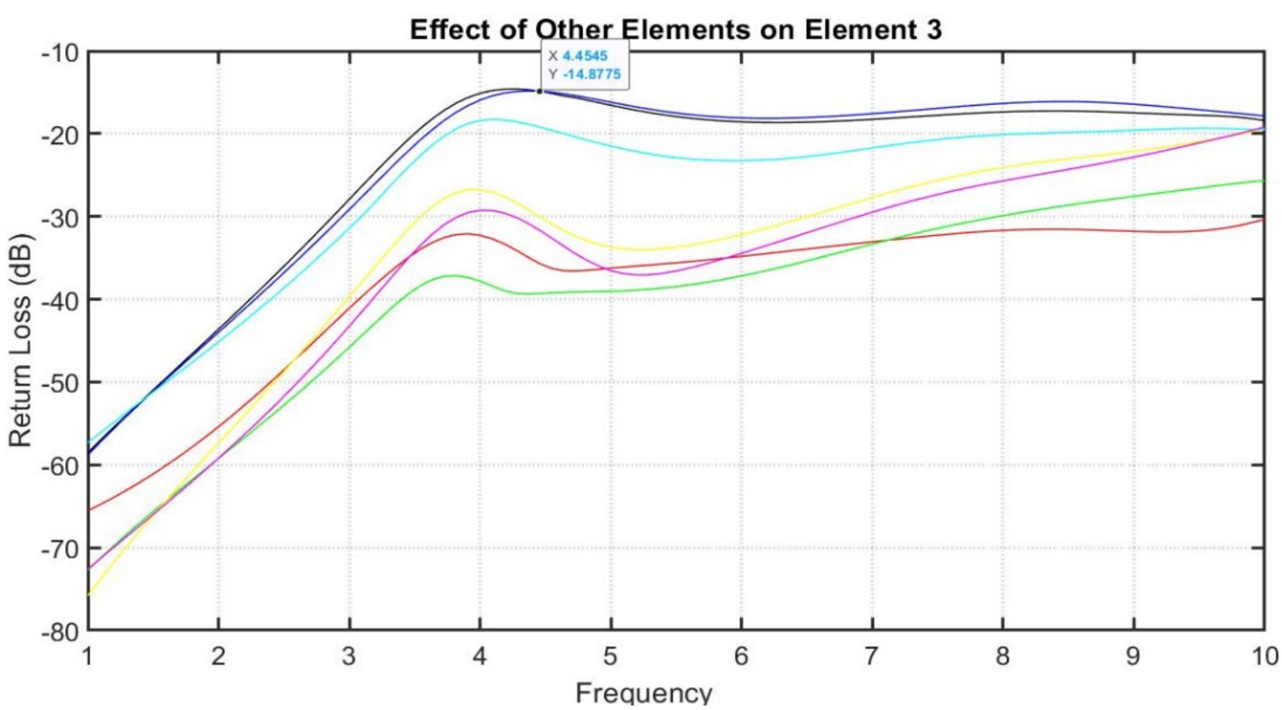

Fig 4.2 (d) Case I - Effects of Other Elements on Element 3

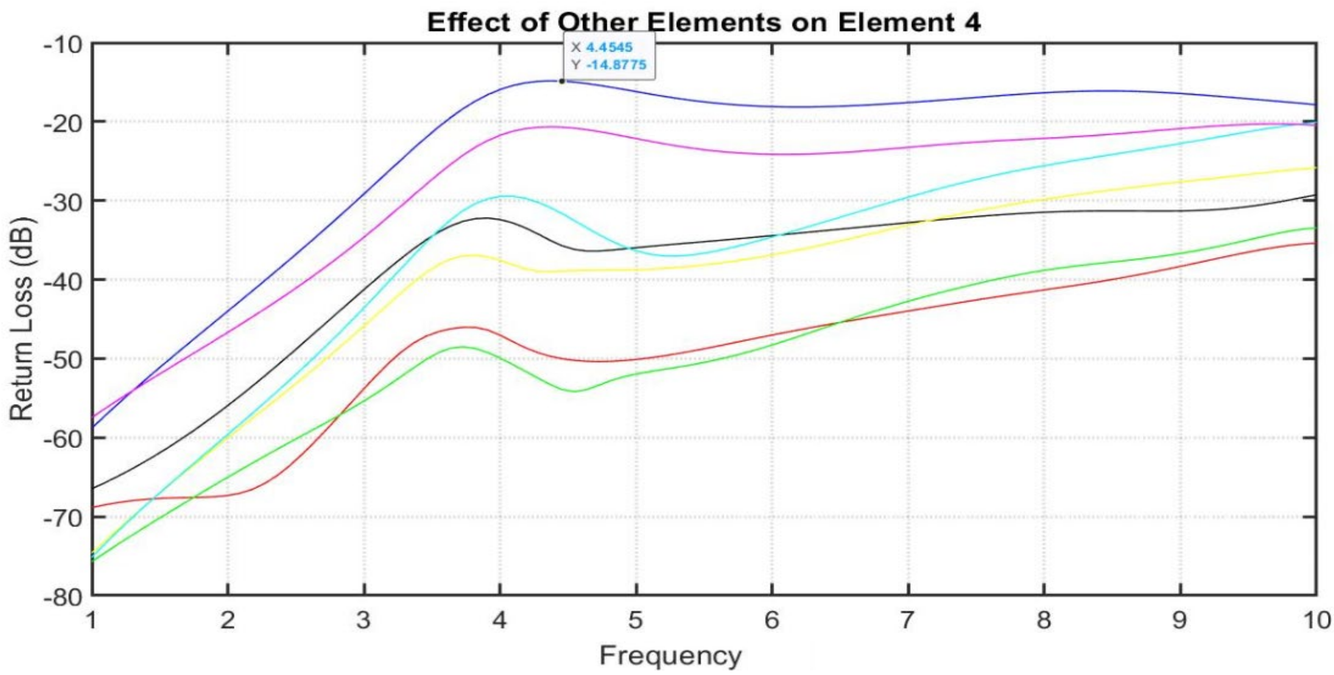

Fig 4.2 (e) Case I - Effects of Other Elements on Element 4

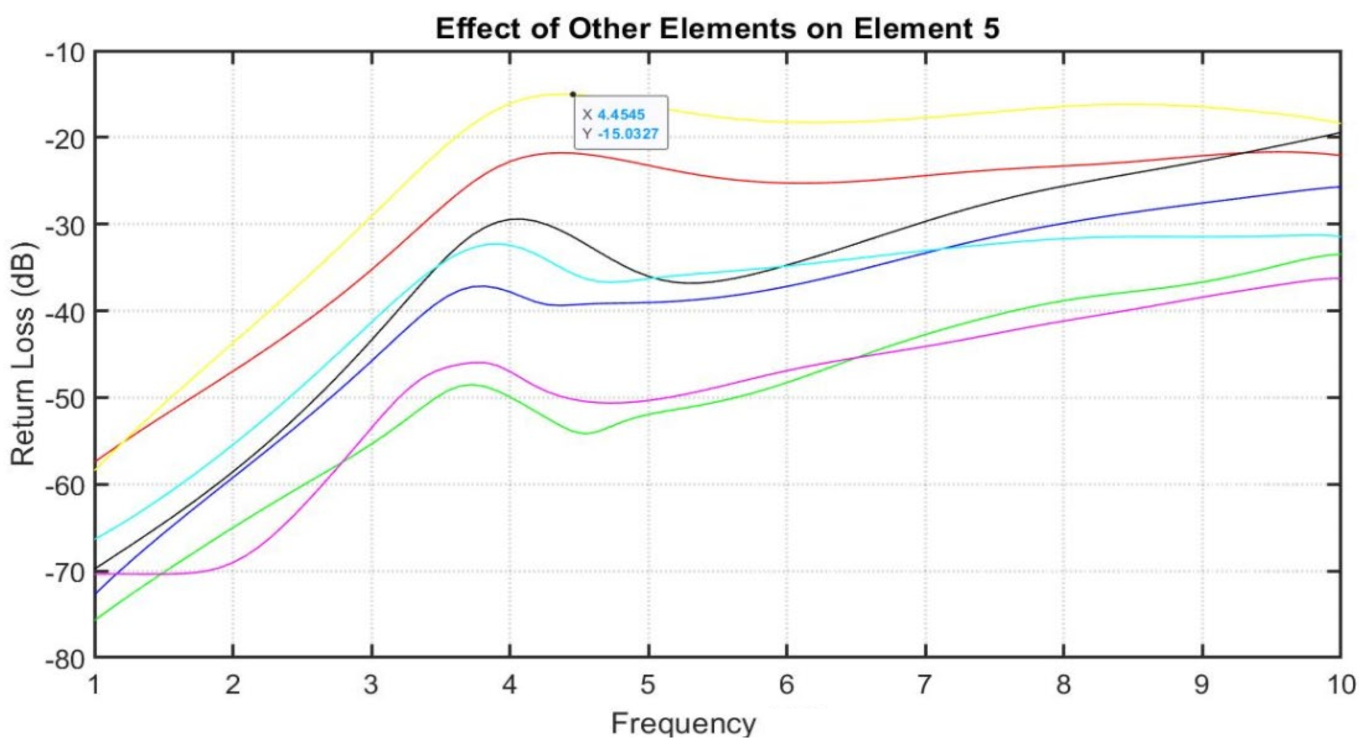

Fig 4.2 (f) Case I - Effects of Other Elements on Element 5

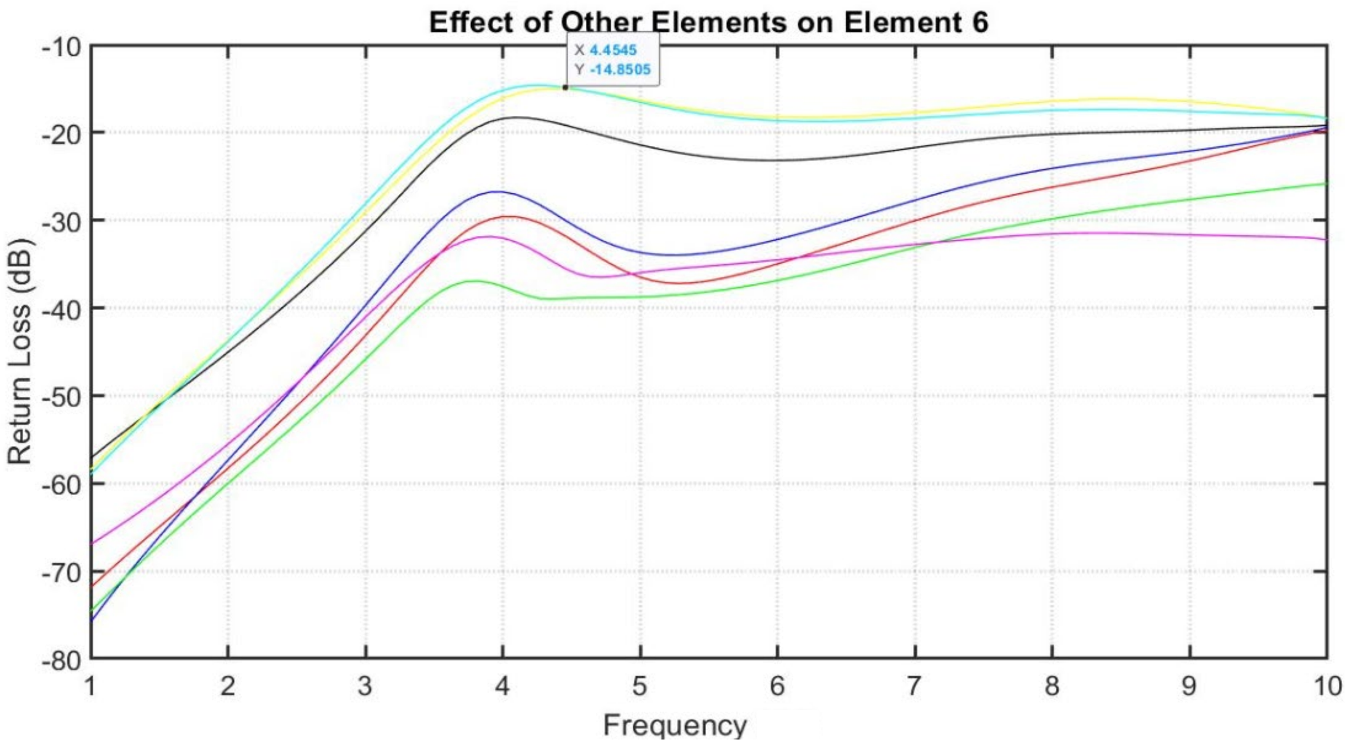

Fig 4.2 (g) Case I - Effects of Other Elements on Element 6

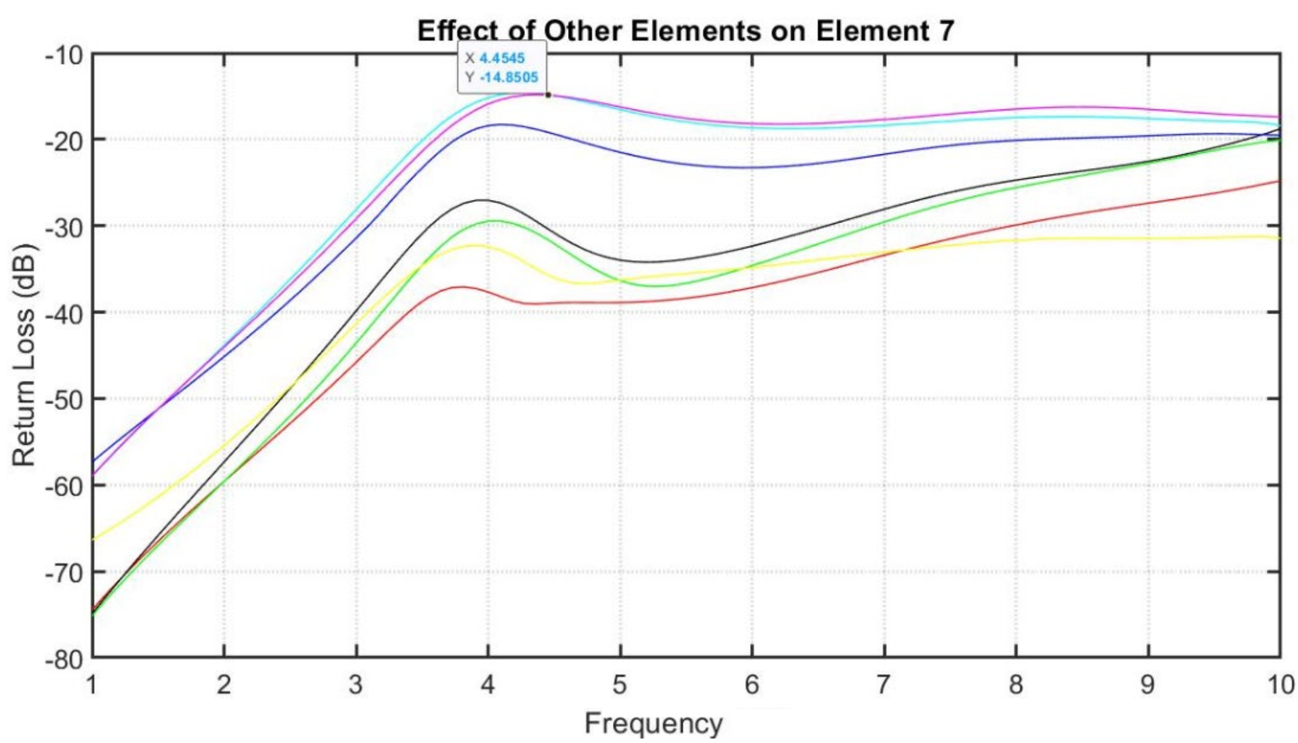

Fig 4.2 (h) Case I - Effects of Other Elements on Element 7

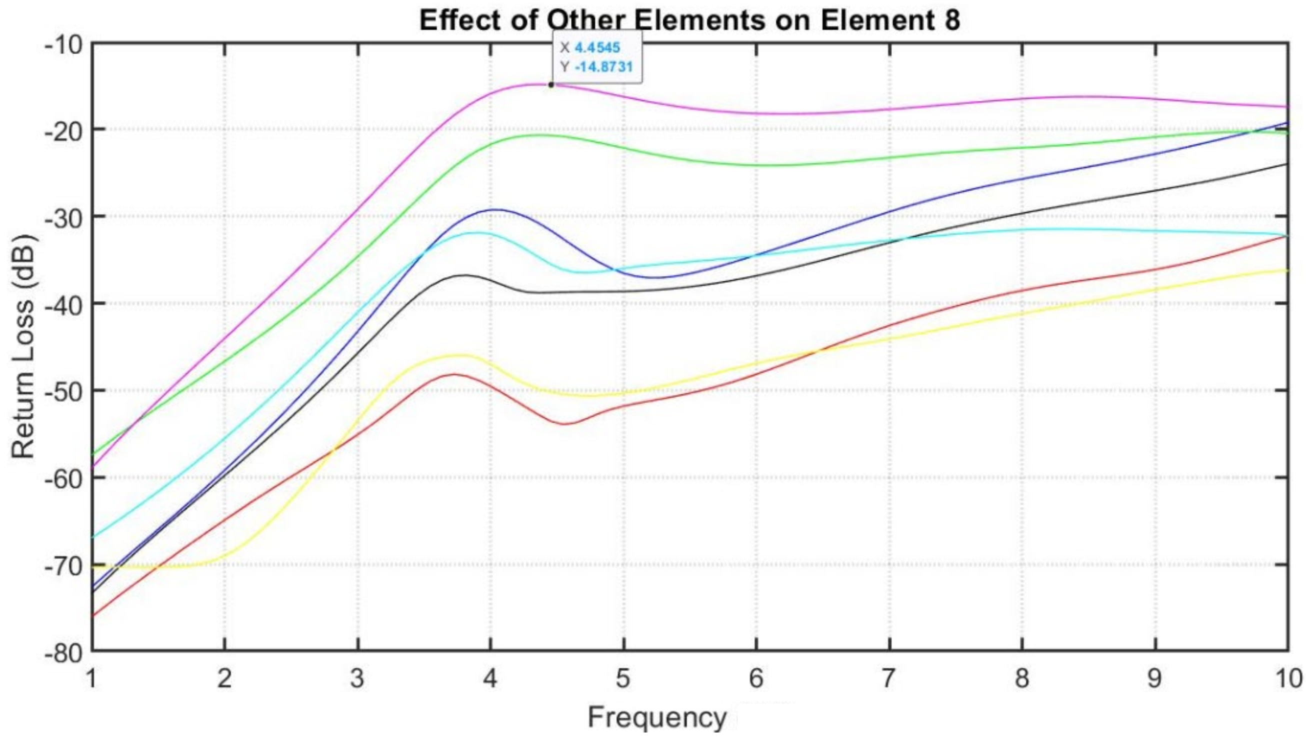

Fig 4.2 (i) Case I - Effects of Other Elements on Element 8

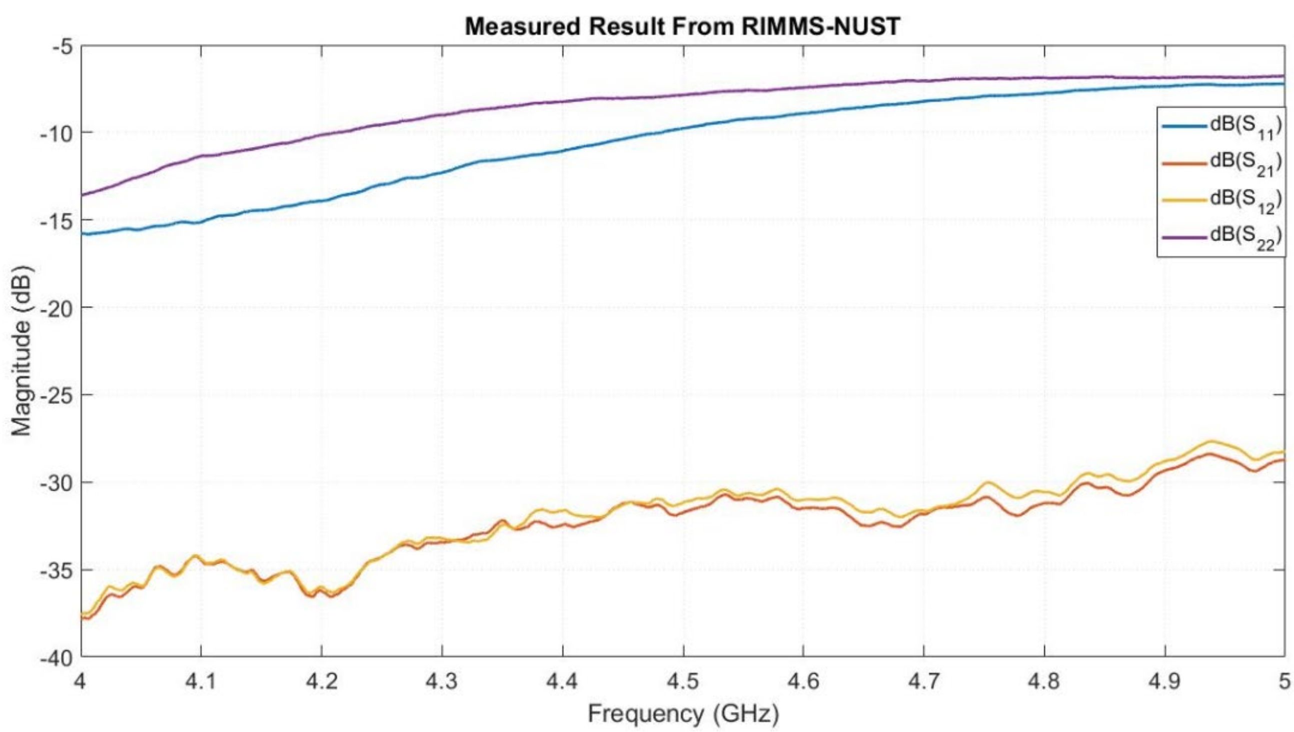

Fig 4.2 (j) Case I – Measured Results at Port 1 and Port 5

Fig 4.2 (k) show tha radiation pattern of MIMO system at 4.45 GHz at different number of angles. Each curve of radiation pattern from phi = 0 degree to phi = 180 degree has been shown in different colors. The curve pattern depicts the change in every 10 degree change of phi direction. Fig 4.2 (l) & (m) representing the curve at phi = 80 degree and phi = 0 degree with fixed theta respectively. Fig (n) represent the 3D polar plot at 4.45GHz frequency. In other words it shows the gain of an antenna in any direction which describes the power radiated as compared to isotropic antenna system. Measured gain obtained from RIMMS – NUST at port 1 is 5.591 dB and at port 5 is 4.239 dB which is nearly equal to simulated gain.

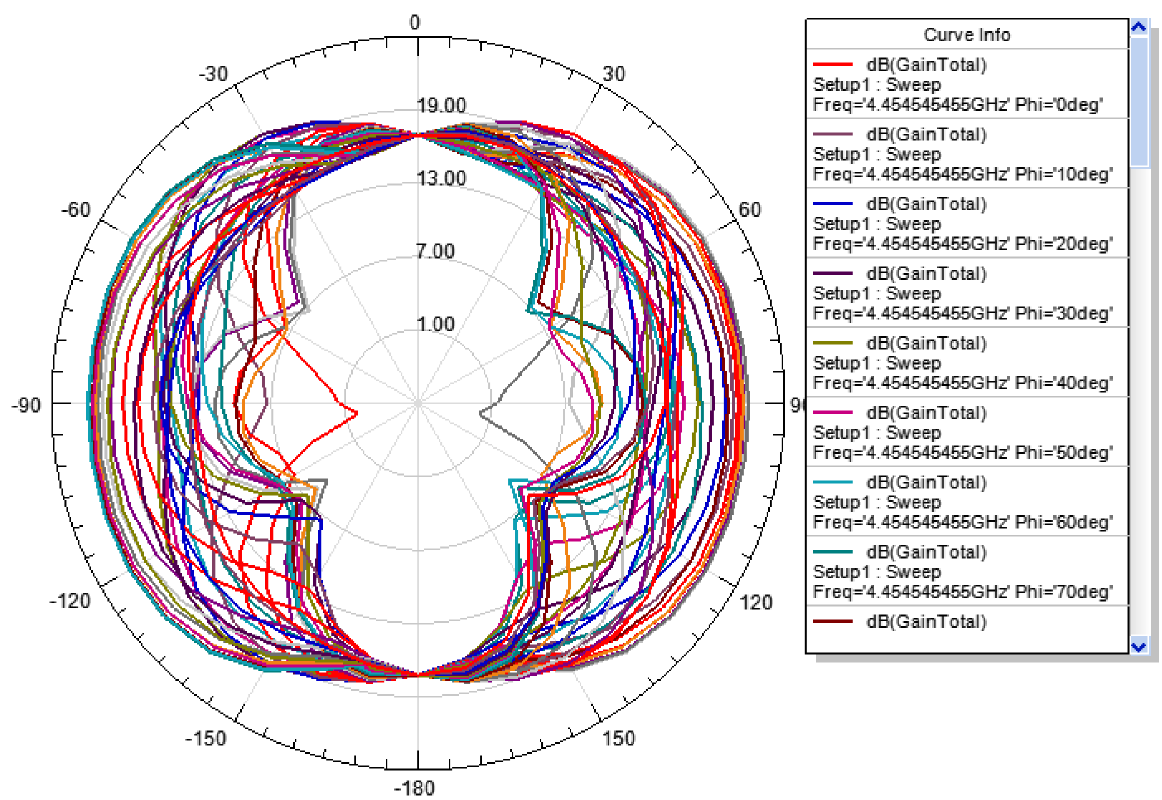

Fig 4.2 (k) Case I - Radiation Pattern at 4.45 GHz

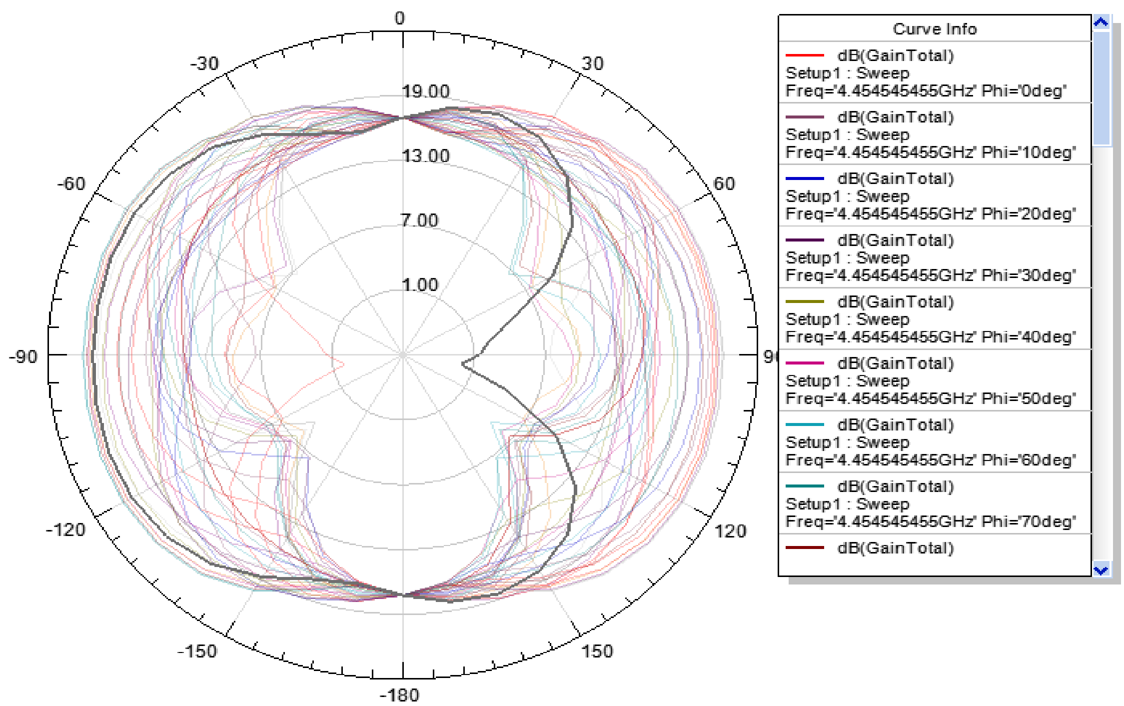

Fig 4.2 (l) Case I – Radiation Pattern at Phi= 80^0 at Fixed Theta

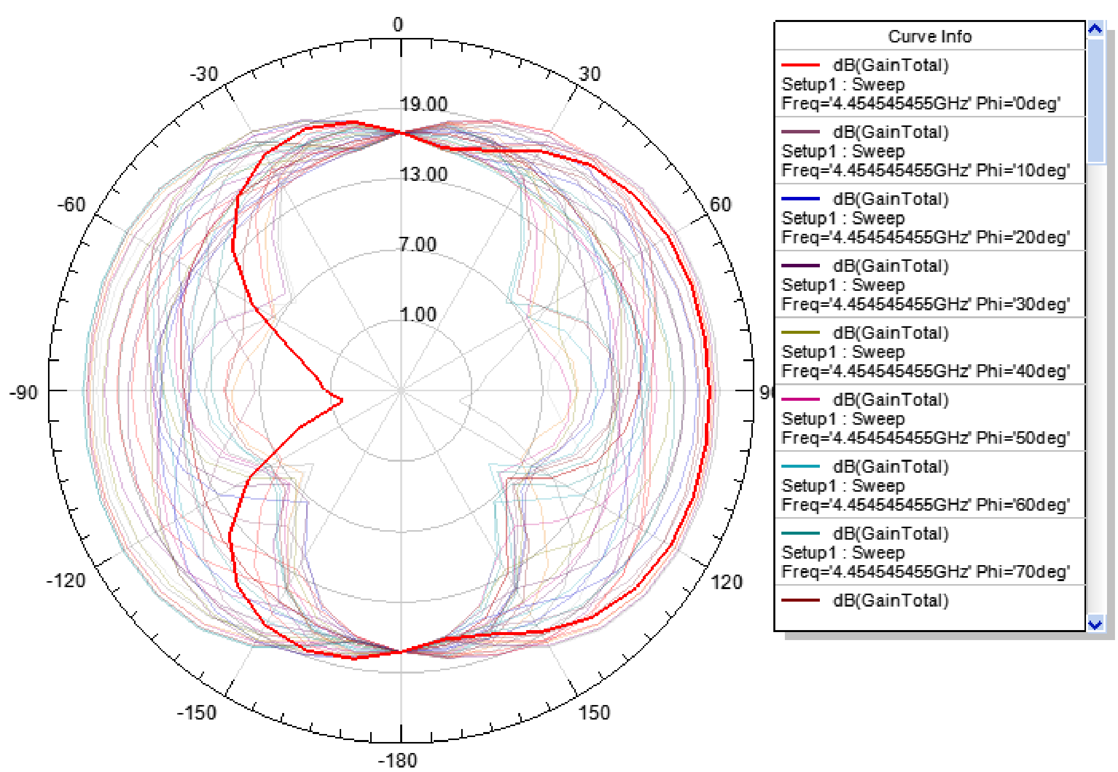

Figure 4.2(m): Case I - Radiation pattern for 4.45 GHz at Phi = 0^0 With Fixed Theta

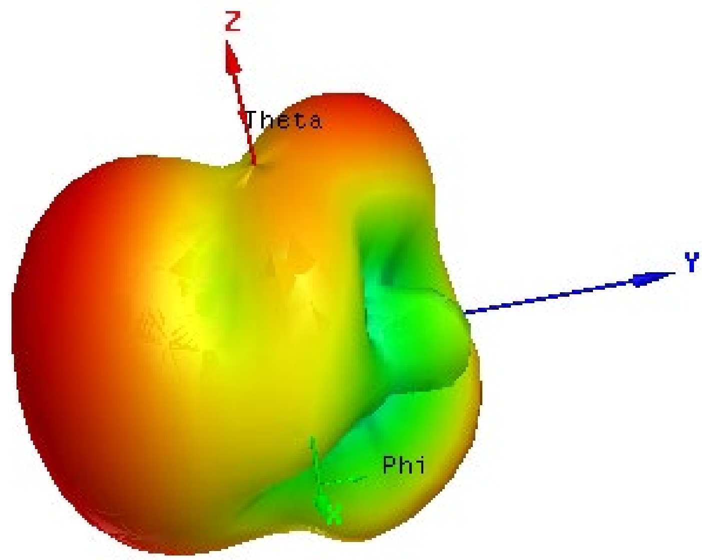

Figure 4.2 (n) Case I - 3D Polar Plot at 4.45 GHz

Case II

In this case we get a return loss of -18.46 dB at center frequency of 4.54 GHz. Reflection Co-efficient plot shows that element's power is reflected more, relatively little power will radiate outward, which is desirable. In the Fig 4.2 (o) S-parameter plot i.e. S11, S22, S33, S44, …….S88 of antenna system has been shown in various colors. It has return loss less than -10dB.

In the MIMO system, it is necessary to validate each element separately in order to measure the accuracy of system. Therefore, in the subsequent figures effect of other elements on one element can be seen. All the figures show us the effect of mutual coupling between the elements. The standard value is -10dB so isolation between the one element to the other should not be greater than the standard value. From the Fig 4.2(p), we can easily see that isolation is -15dB which reflects the good value of impedance matching.

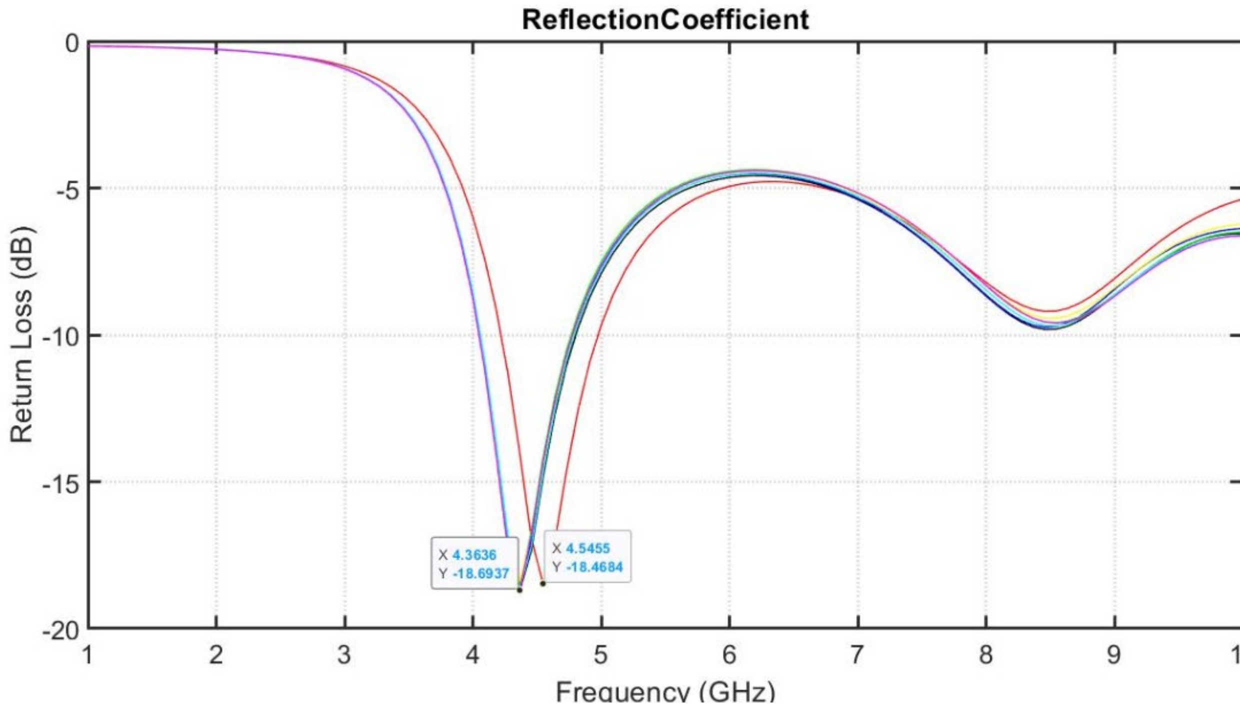

Fig 4.2 (o) Case II - Reflection Coefficient of 8-Elements of MIMO System

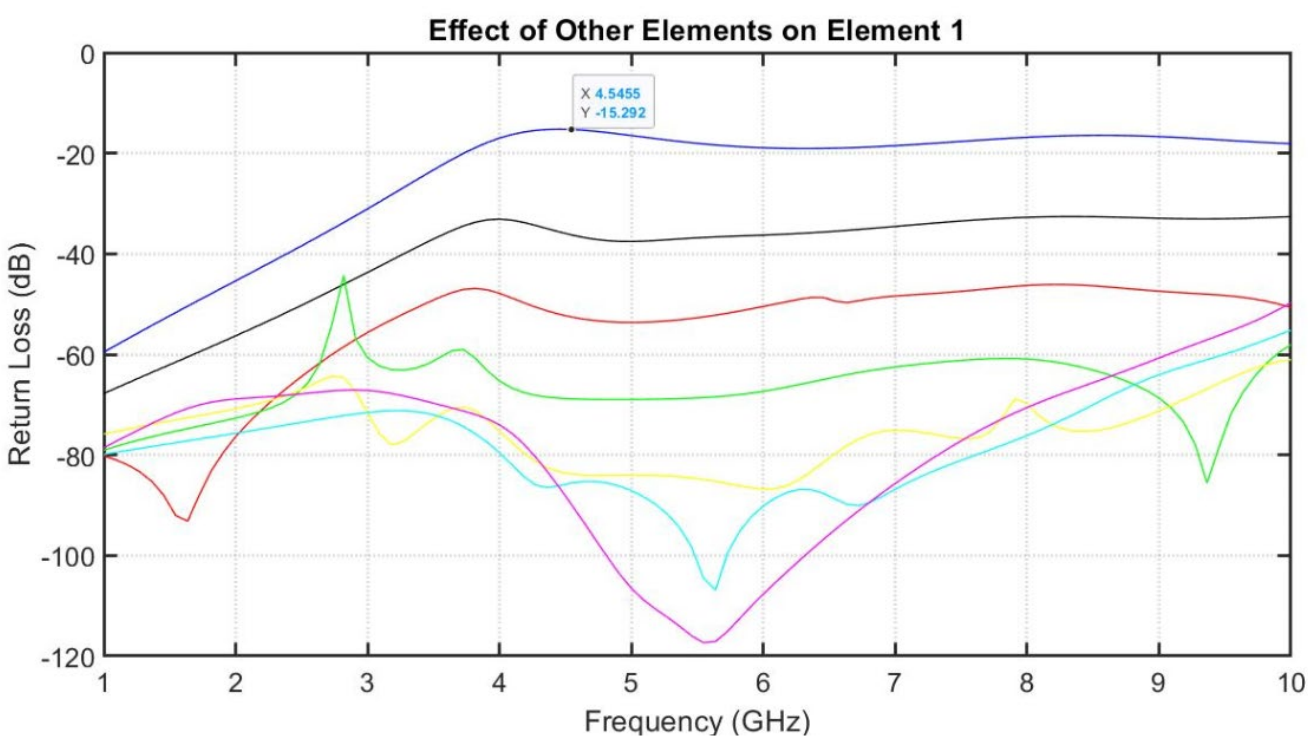

Fig 4.2 (p) Case II – Effect of all other Elements on Element 1

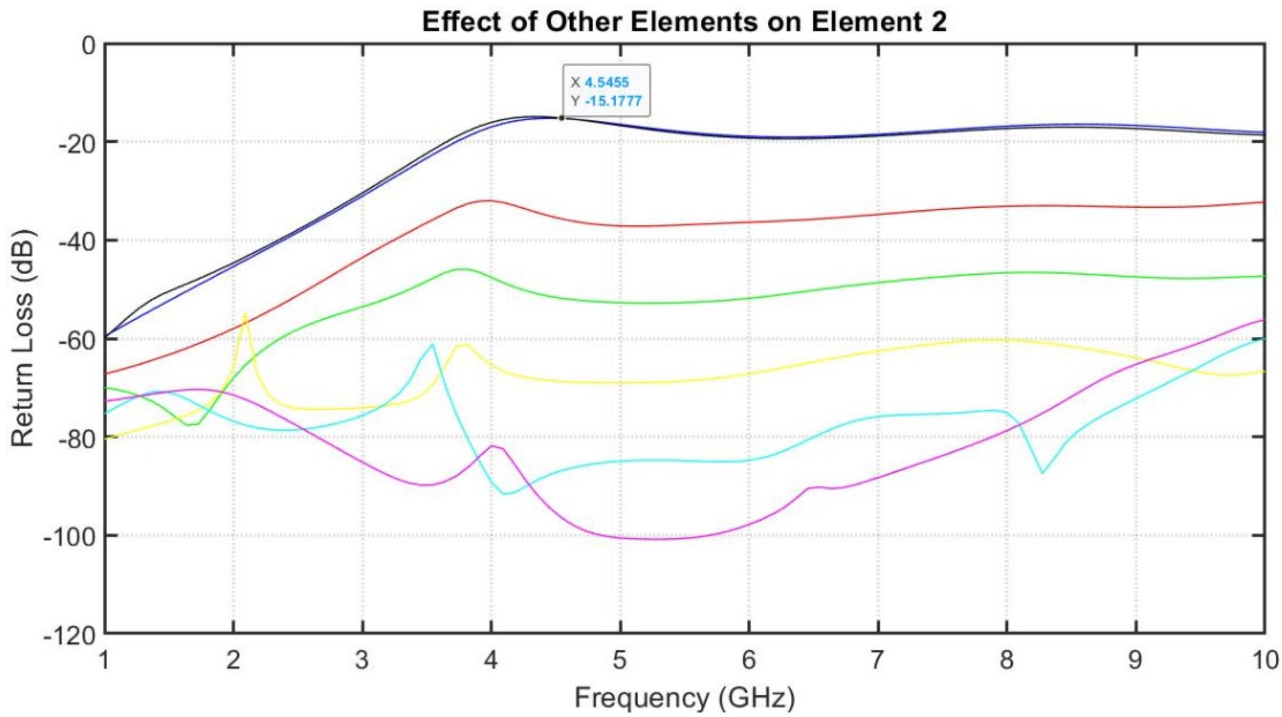

Fig 4.2 (q) Case II – Effect of all Other Elements on Element 2

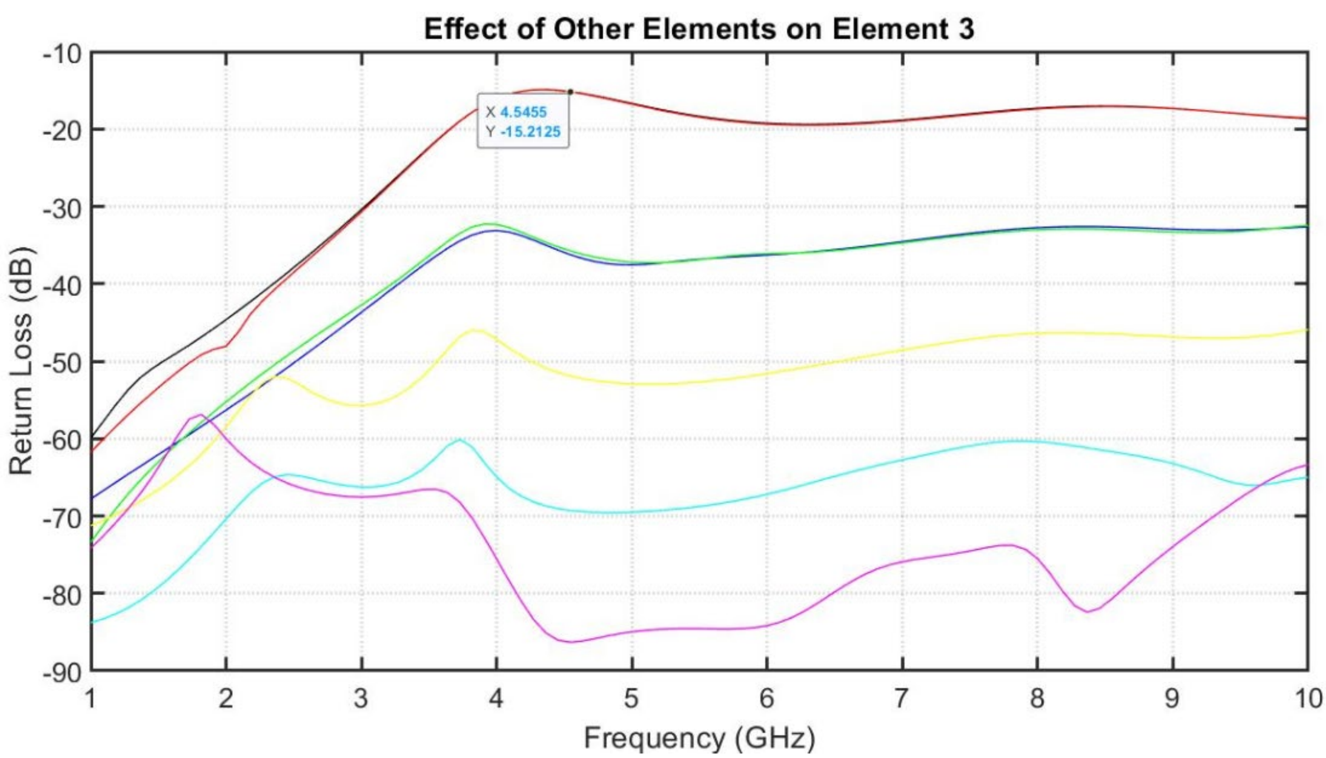

Fig 4.2 (r) Case II – Effect of all Other Elements on Element 3

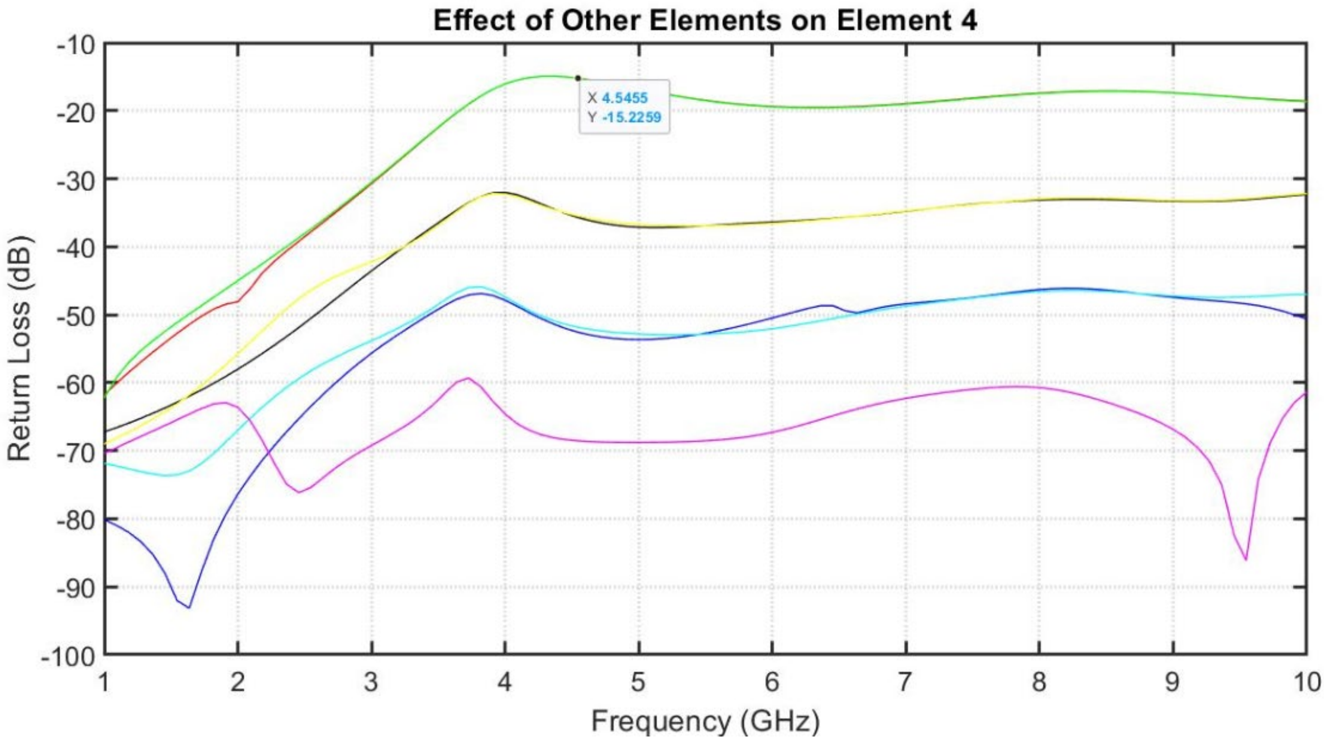

Fig 4.2 (s) Case II – Effect of all Other Elements on Element 4

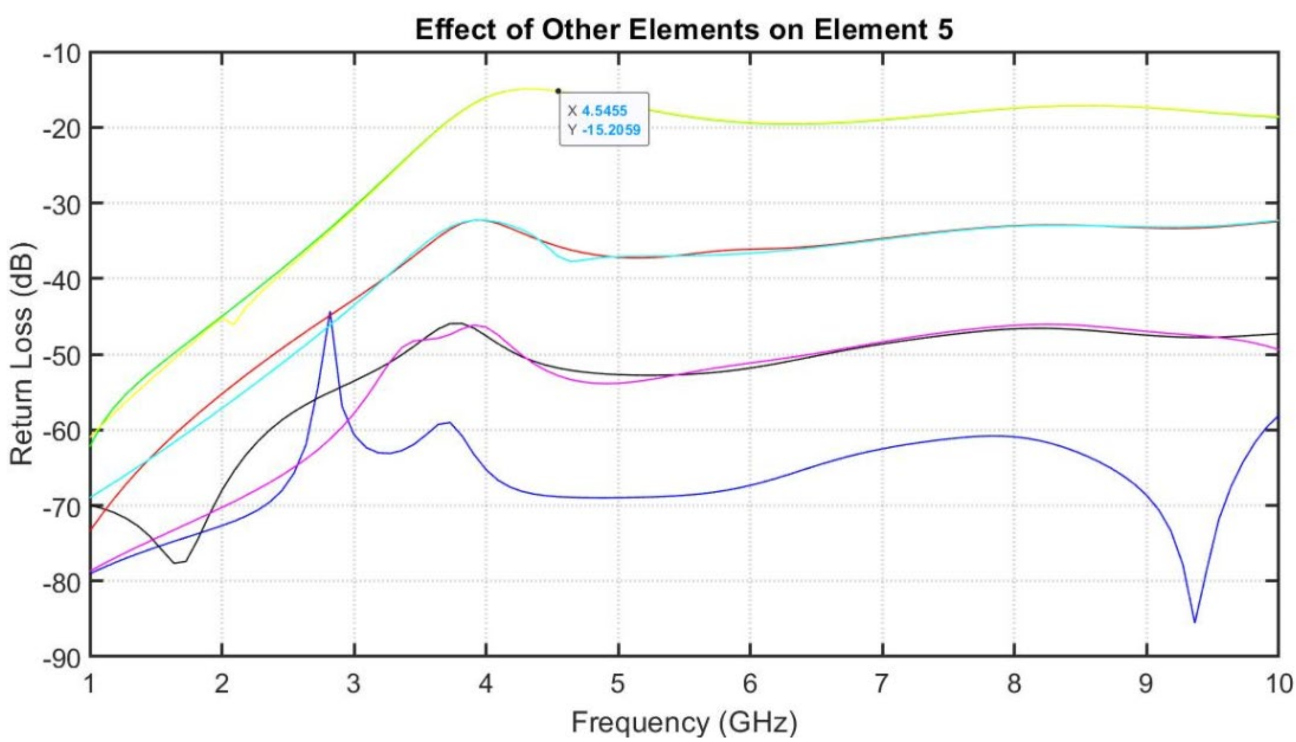

Fig 4.2 (t) Case II – Effect of all Other Elements on Element 5

Different colors have been used to show different curves. In the next fig 4.2 (u) all values of curves are crossing the value of -15.18 dB which also depicts the good mutual coupling between element 2 with rest of the other elements. The results will be the same after carefully analyzing the rest of the plots i.e. effects of other elements on one element which clearly shows that antenna system is acquiring good value of reflection coefficient and isolation between the elements. If we follow the same analysis on fig 4.2 (q – x) at a frequency of 4.54 GHz, then we would be able to know that antenna system is meeting a standard value.

Fabricated antenna system has been measured in RIMMS – NUST. Fig 4.2(x) is showing the measured results of port 1 and port 5 of the said antenna system which are also nearly meeting the standards.

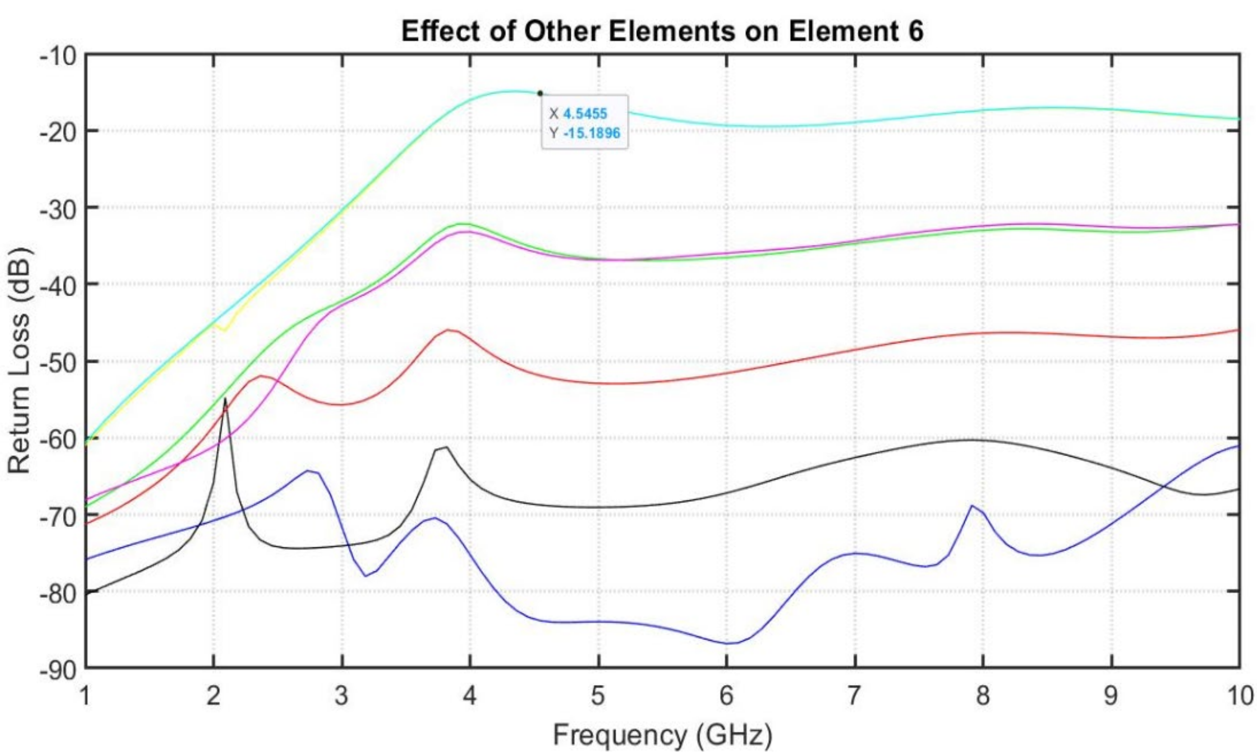

Fig 4.2 (u) Case II – Effect of All Other Elements on Element 6

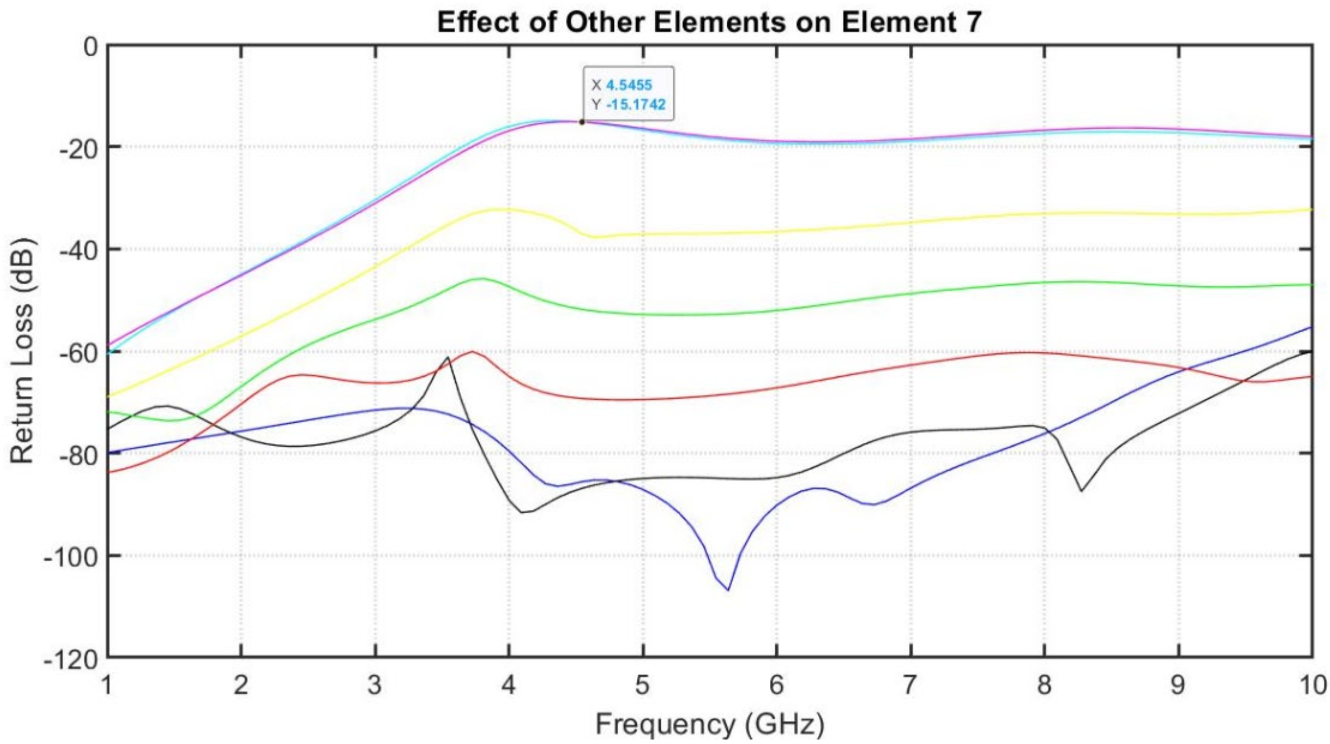

Fig 4.2 (v) Case II – Effect of All Other Elements on Element 7

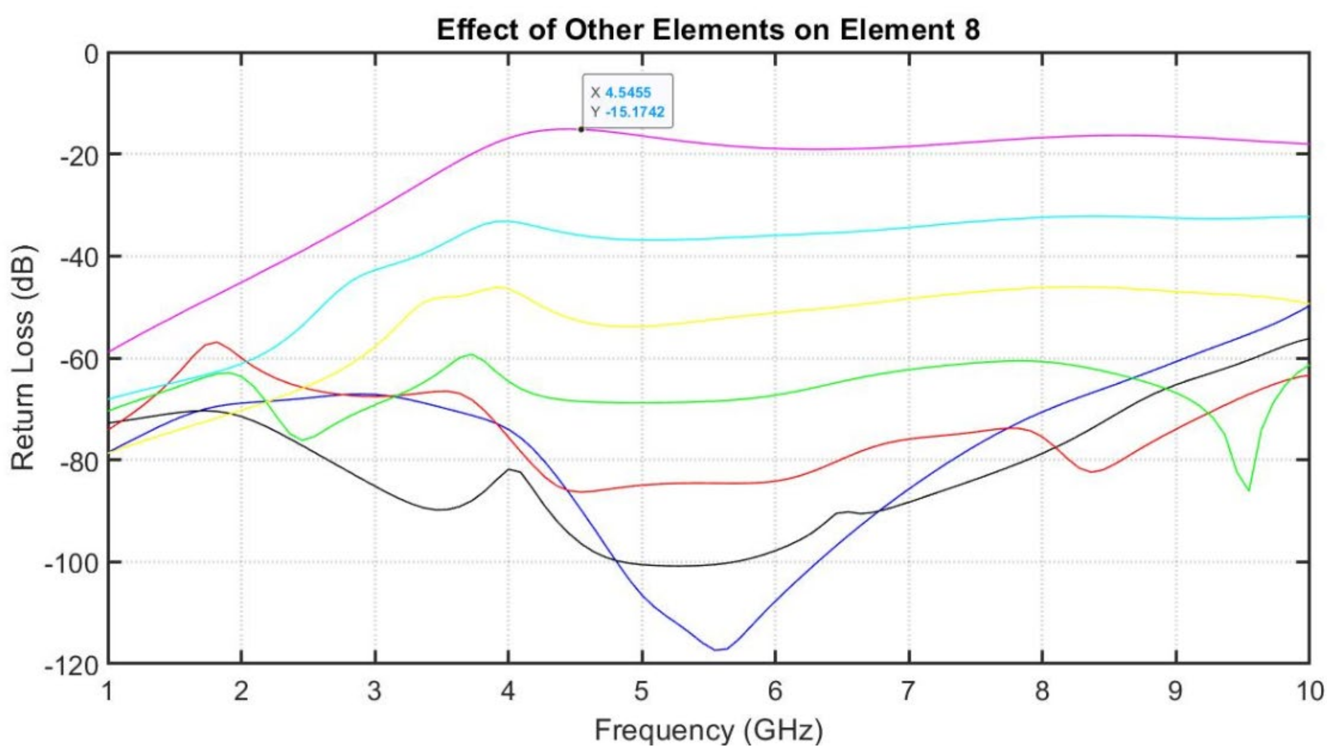

Fig 4.2 (w) Case II – Effect of All Other Elements on Element 8

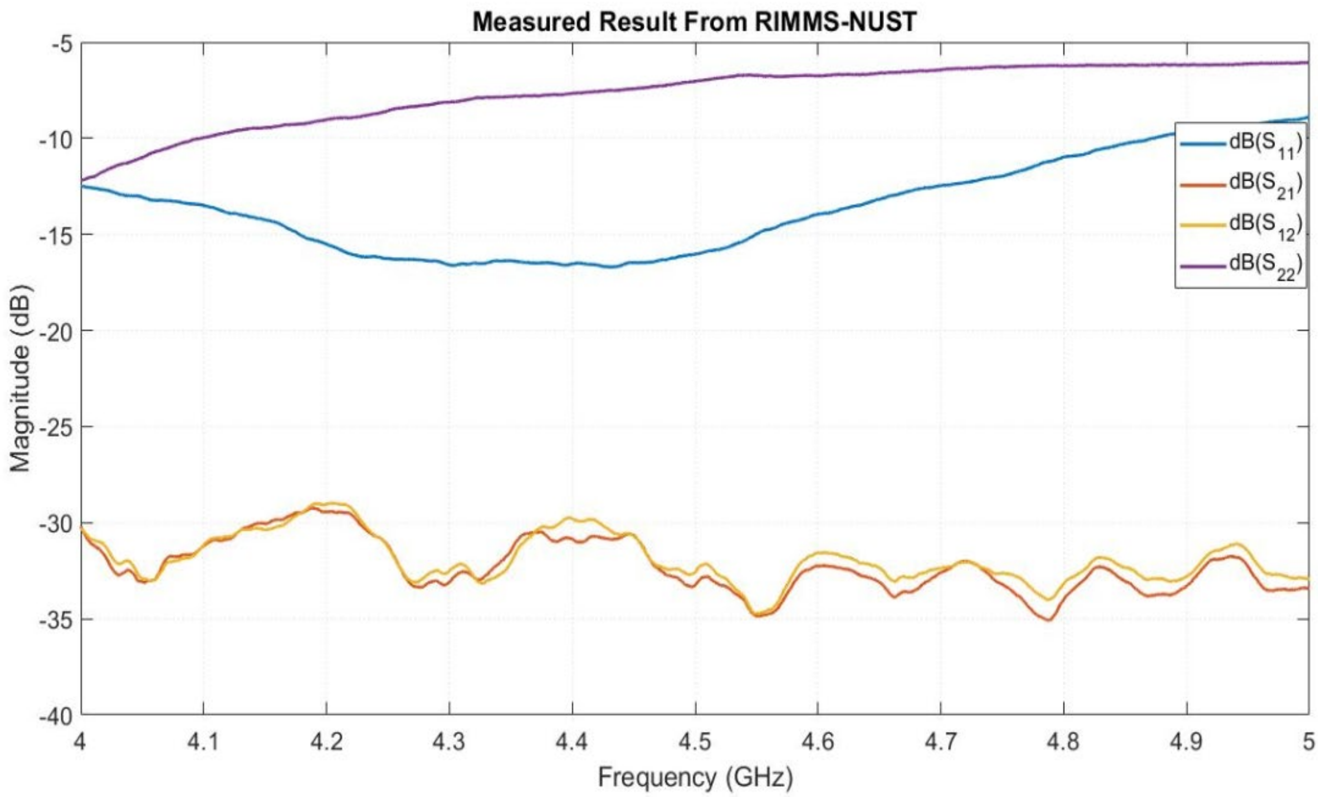

Fig 4.2 (x) Case II – Measured Results at Port 1 and Port 4

Fig 4.2 (y) show tha radiation pattern of MIMO system at 4.54 GHz at different number of angles. Each curve of radiation pattern from phi = 0 degree to phi = 180 degree has been shown in different colors. The curve pattern depicts the change in every 10 degree change of phi direction. Fig 4.2 (z) & (aa) representing the curve at phi = 0 degree and phi = 30 degree with fixed theta respectively. Fig (bb) represent the 3D polar plot at 4.54GHz frequency. In other words it shows the gain of an antenna in any direction which describes the power radiated as compared to isotropic antenna system. Measured gain obtained from RIMMS – NUST at port 1 is 4.271 dB and at port 4 is 4.057 dB which is nearly equal to simulated gain at 5dB approximately.

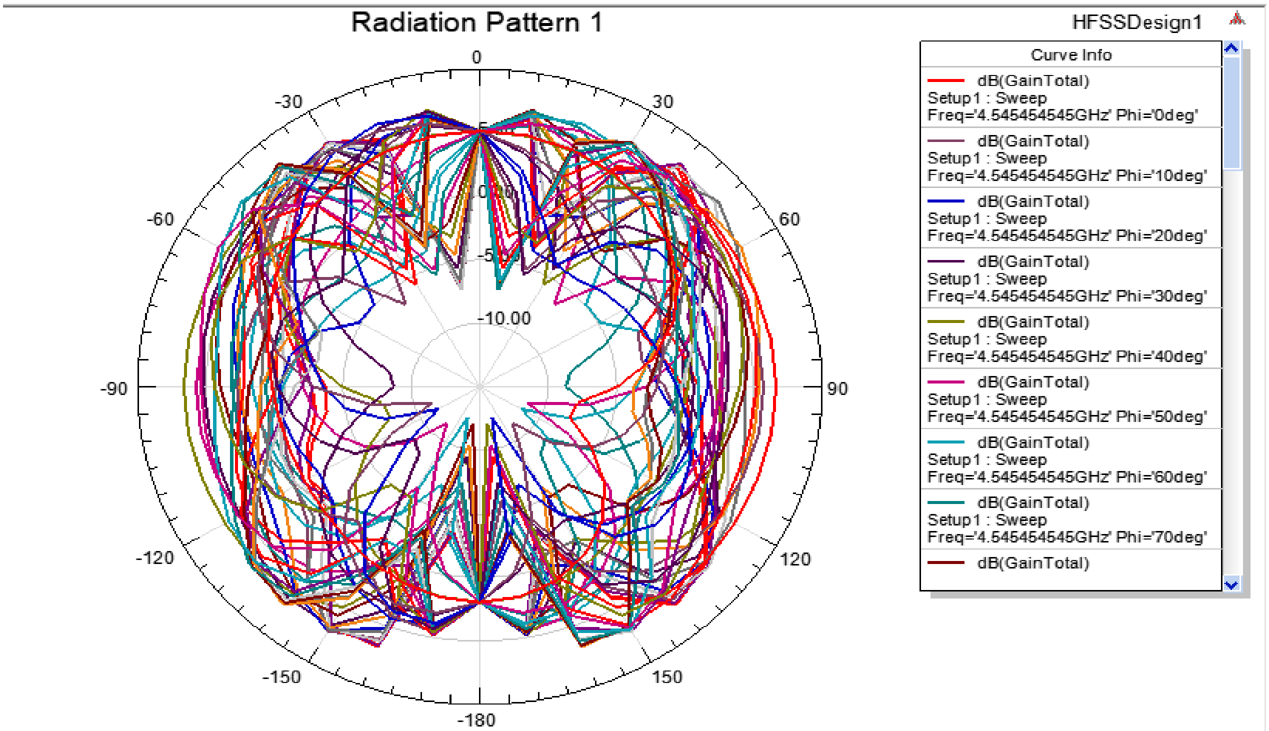

Fig 4.2 (y) Case II - Radiation Pattern at 4.54 GHz

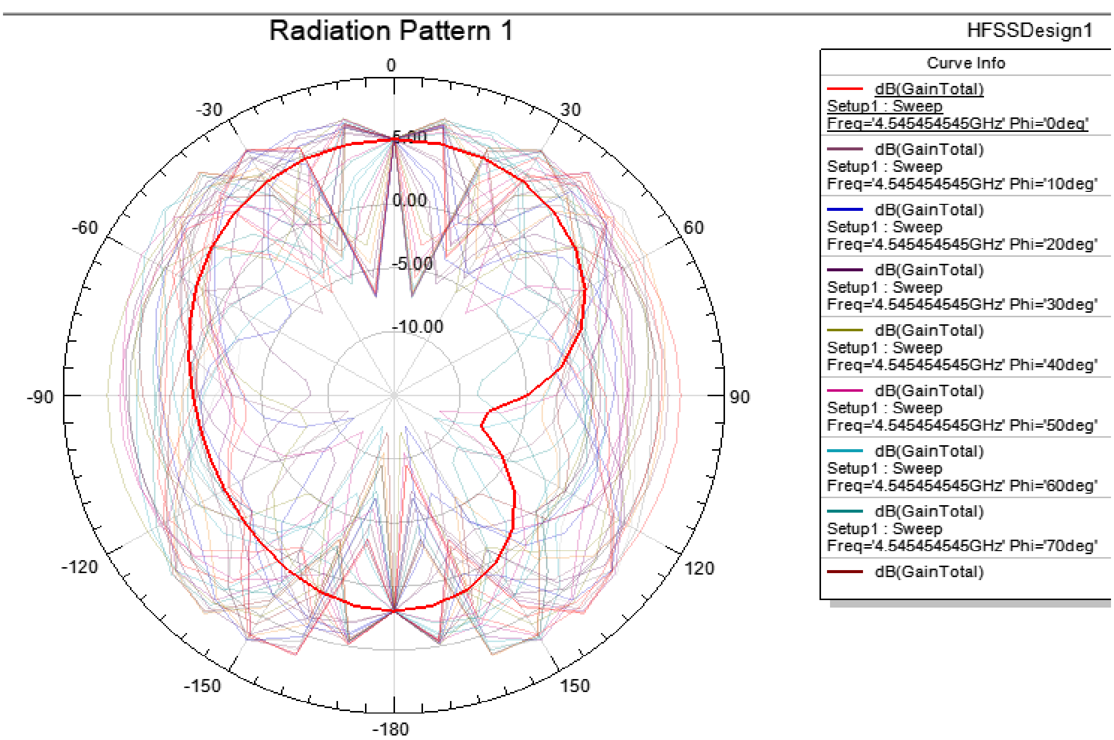

Fig 4.2 (z) Case II – Radiation Pattern at Phi= 0^0 at Fixed Theta

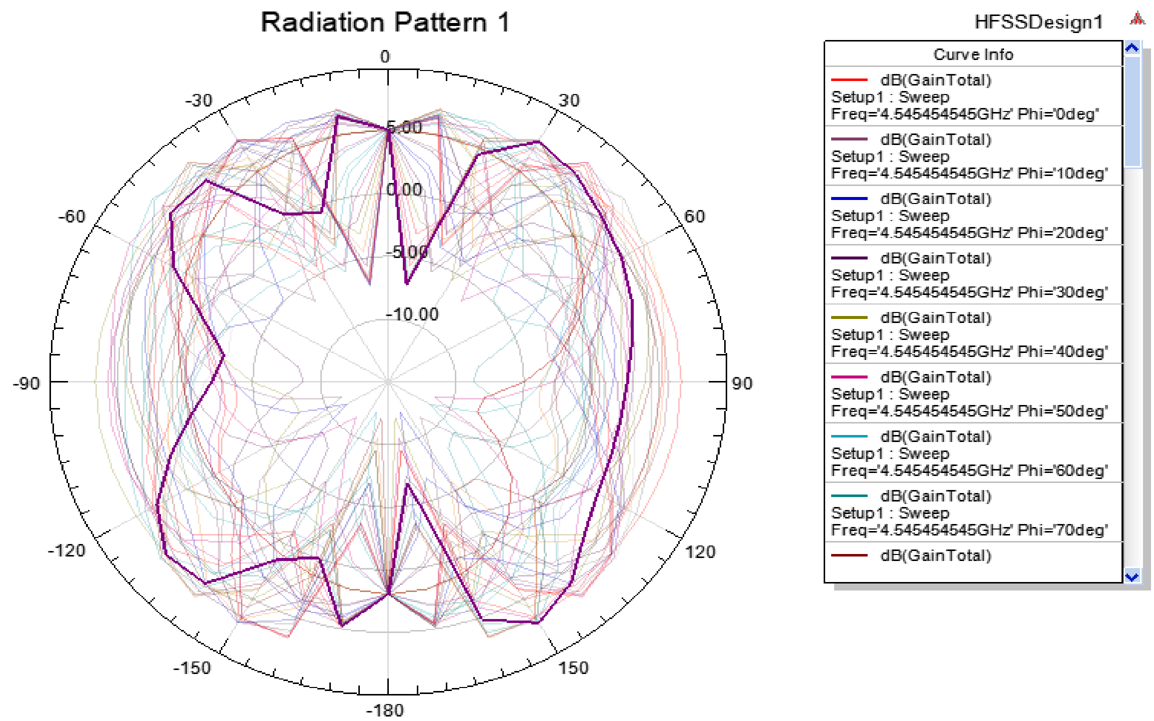

Fig 4.2(aa): Case II - Radiation pattern for 4.54 GHz at Phi = 30^0 with Fixed Theta

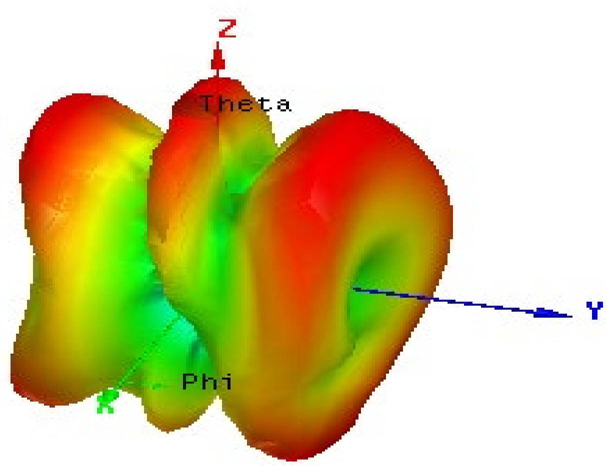

Fig 4.2 (bb) Case II - 3D Polar Plot at 4.54 GHz

CHAPTER 5

FUTURE WORK AND CONCLUSION

5.1 Concluding Notes

MIMO is a significant improvement in technology and design of antenna that enable 5G capable end devices to have a high throughput. Multipath radio propagation, which uses various outputs and various inputs antennas to increase radio transceiver capacity, is the technology. As a result, great thought has gone into designing the most effective and compact antenna for use in the MIMO system.

2. The goal of this project is to design and test a MIMO system. For the compact and narrow 5G mobile terminal, the system consisted of eight elements that were created and experimentally measured. The system was designed to cover single band in two different cases i.e. running at 4.45 GHz and 4.54 GHz centre frequencies.

3. To begin, a single component of the MIMO system, a printed planar structure was constructed and investigated. The MIMO system consists of a single component with single branches that are meant to resonate at 4.81GHz center frequency.

4. The symmetry property was used to expand the design of a single element to create an eight-element system.

5. Furthermore, there is no further decoupling structure in this design, indicating that it is a one-of-a-kind antenna. It was attempted to attain low mutual coupling by imposing pattern diversity, which shown to be an ideal attribute for providing optimal results. The readings were obtained with good isolation and were below -12 dB.

6. High-Frequency Simulation Software is used to simulate the entire structure. The anechoic chamber, which is located in RIMMS, was used to acquire the experimental results. A excellent match was established in both simulated and measured findings, demonstrating a low correlation value with good antenna diversity

performance. The obtained findings suggest that the suggested eight-element MIMO system can be used in the 5G mobile terminal's designated compact environment.

5.2 Future Work

A review of the literature on MIMO reveals that scholars have put in a lot of effort into the theoretical understanding of the system. However, there are a number of concerns that must be addressed before the system's performance can be considered viable.

1. One issue is that in a practical system with a rich scattering environment or the existence of a very wide array, the single element of the system cannot be separated, leading to coupled channels. This conclusion contradicts the theoretical assumption used to support the MIMO system's theoretical analysis.
2. The construction of a network that is commercially viable is the other difficulty. It should be a low-cost solution with sufficient RF components. Practically, a channel has frequency-selective fading, which necessitates the use of expensive RF amplifiers. MIMO is utilized in conjunction with OFDM to resolve this problem, thus more study is needed to reduce the economic burden.

CHAPTER 6

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