GROUND RADIATION MIMO ANTENNA FOR SMARTWATCH APPLICATIONS

By

Syed Abdul Rehman Shah

Supervisor

Asst Prof Dr. Zeeshan Zahid

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

July 2022

ABSTRACT

Large size antennas for smartwatches have lots of disadvantages like mechanical complexity, low flexibility, and less adaptability with small designs coming into the market as antenna design has become more competitive. That is why ground radiation MIMO antennas are promoted to overcome these problems. Several antenna types are used to carry out this technology, the most notable of which are loop-shaped antennas, which are quite lightweight, inexpensive, low profile, and most importantly simple to fabricate.

For smartwatch communication, various ground-based radiation antennas are proposed. To achieve greater efficiency with limited space available to mount the antenna in the smartwatch, the design is developed for Ground Radiation based smartwatch antennas that can be used for Wi-Fi and Bluetooth bands.

Ground radiation MIMO antenna for smartwatch applications antenna with Bezel is proposed with the 2x2 MIMO element. The antenna is embedded on the ground with two loop-shaped antennas placed orthogonal to each other on a P.C.B. Loop type isolator is installed between antenna elements that are attached externally to the ground plane. The operating frequency is 2.45 GHz. This provides a gain greater than 3 dB and a return loss of -19 dB. Furthermore, the antenna is tested for human radiations by keeping in view the international standards of SAR.

DEDICATION

This thesis is dedicated to

MY TEACHERS, FAMILY AND FRIENDS

for their constant support and motivation throughout the journey

ACKNOWLEDGEMENTS

I am extremely thankful to Almighty Allah for bestowing upon me the willpower and dedication to complete this thesis, as well as for His kindness and generosity.

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Multiple Input Multiple Output	MIMO
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Chapter 1

INTRODUCTION

With the rise of modern technologies and wearable gadgets which comes under the umbrella of wireless telecommunications showed great impact in the modern era and have the much influence on today's market. One of the most popular wearable gadgets which is known as smartwatch comes with lots of aspects and features has worth the global market of USD 20 billion dollars that is yet also expected to increase to the USD 30 billion dollars till 2030 [1].

Specifically speaking about the smartwatches which have the capability to connect with the other devices like the Bluetooth and Wi-Fi connectivity has much impact on the daily life specially in the field of communication. In the past the wireless devices for sending the data from one place to another required the high-speed data and reliability [2].

Mobile devices like smartphones, can now be used to control home appliances. Wearable controllers like smartwatches can surely enhance the ease of use and reduce the time required to operate home/office appliances by greatly improving its technology and user experience. Smartwatches wireless devices are looking to find more applications, like heart rate control, electronic mail and interactive media, file sending and receiving, answering cell phone calls, and monitoring user devices.

The wireless transmission power of smartwatches must also be upgraded for them to play an essential part on the Internet of Things (I.O.T). To accomplish this objective, multiantenna concepts can be used; for instance, wireless Wi-Fi Devices uses MIMO technology to obtain higher transmission rate [3].

As compared to this the MIMO antenna system is a way of increasing the throughput of a radio link using the several transmissions and receiving antennas. MIMO systems have greater impact on the today's modern era of communication as they have higher bit rate, they provide better reliability, and they have wider area of coverage.

As the MIMO antennas are providing higher rates and data reliability similarly the smartwatches also have the usage of the MIMO Antennas which occupy less space and provide better performance as compared to the older techniques.

1.1 Thesis Statement and Objectives

To design a Ground Radiation based MIMO Antenna for Smartwatch Applications Operating for WLAN and Bluetooth band.

1.2 Features of the Research

The features of the research are listed below Two element MIMO antenna design at 2.45GHz for circular ground plane with bassel to achieve gain greater than 3dB Isolation better than -15 dB using effective isolation technique that helps to achieve better radiation efficiency and MIMO performance.

In the next we shall see in detail what is MIMO and the smartwatches with MIMO as our main concept is depending on the MIMO with smartwatch concept, as a result, we're going to go over the evolution and history of MIMO in detail. MIMO technology has been evolving for several years. Not only were the fundamental MIMO concepts developed, but new technologies were also required to be developed for MIMO to be fully implemented. New levels of processing were required to enable several features of spatial multiplexing as well as to capitalize on several benefits of spatial diversity [4].

Prior to the 1990s, spatial diversity was frequently restricted to systems that switched between two antennas or combined the signals to provide the simplest signal. Various types of beam switching were also incorporated; however, the systems were normally relatively limited in terms of the amount of processing involved and thus the degrees of computation available. However, with the increased processing power that became available, it was possible to use both spatial diversity as well as full spatial multiplexing.

The early work on MIMO systems concentrated on basic spatial diversity - in this case, the MIMO system was designed to limit the deterioration caused by multipath propagation. However, this was only the first step, as that the system then began to take advantage of multipath propagation, converting the additional signal paths into what could successfully be considered additional channels to retain additional information [5]. There are several types of such antennas available in today's communication market, including MISO, SISO, SIMO, and MU-MIMO.

1.3 IEEE standard for WLAN

IEEE 802.11 was proposed as a standard for WLAN applications. Later, a new WLAN standard with a frequency range of 2.4 GHz (ISM band) was proposed, recognized as 802.11b or 802.11 HR (High Rate), with a data rate of 11 Mbps. In 1999, IEEE 802.11a was used for 5 GHz ISM bands, demonstrating that 802.11a and 802.11b are incompatible. As a result, IEEE proposed an 802.11g standard that is compatible with both 802.11a and 80211b standards. Since these standards are using different bands, dual band antennas or separate antennas are used. The new form of Slot antenna has been designed for mobile applications using WLAN of 2.4 GHz.

1.4 Thesis Outline

This thesis is further divided into five chapters:

- **Chapter 1**: This chapter contains introduction and objectives. It also contains the contributions we have made in this thesis report.
- **Chapter 2**: In this chapter, review of literature and background is given along with brief description of existing technique and quantitative measures used in this report.
- **Chapter 3**: Here we discussed in detail about our proposed technique and gave its mathematical explanation.
- **Chapter 4**: Here we gave the results of the proposed technique and showed that how effectively our system outperforms the others in terms of better performance and gave best results
- **Chapter 5**: The future directions along with the summary of the technique has been given here.

Chapter 2

PRELIMINARIES

In MIMO Systems there are number of communication systems present in the modern world which created a huge impact on human's life. The communication systems like antennas, mobile devices etc. made a great impact on the world and in the field of Tele-com. Similarly, with the Advent of the MIMO systems it revolutionized the world of the Telecom industry, and it gave a huge advantage to Militaries, corporations and Govt sectors. Many other sectors of technology like internet devices and terrestrial networks used these systems to enhance their capacities [6].

The strong MIMO antenna systems in wireless technology can enhance the system capacity by using multiple isolated antenna elements that concurrently receive and transmit signals and can be very useful in 4G communications. Furthermore, because of the small ground size as well as cohesively placed antennas, MIMO antennas frequently suffer from mutual coupling amongst some of the antennas, that can degrade bandwidth and radiation efficiency as well as correlation, leading to lower network capacity. As a result, reducing mutual coupling or improving port isolation is an essential element for highly coupled Multiple input and Multiple output antennas [7].

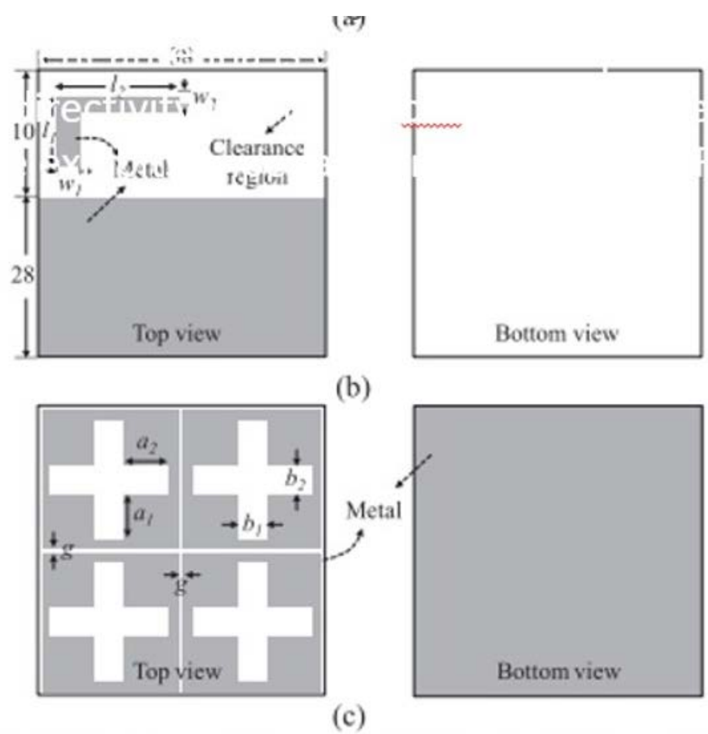
There're many types of MIMO systems which are currently being used by the companies and the govt sectors these are MIMO, MISO and SIMO etc. In this chapter we shall see some baselines and the previously explained techniques by the researchers and scientists. There are some advancements are also occurred with the passage of time in the MIMO systems lie wearable antennas and smartwatches as well our topics of concern here. The literature of the technique is given in the below upcoming paragraphs.

2.1 A low-profile smart watch antenna with a miniature high impedance surface for wearable device applications

A technique is proposed which has the high impedance performance and it is put forward based on the smartwatch applications [8]. The antenna of for the smartwatches must be low profile, highly instruction able, and the absorption rate which is specified is low and most importantly it is vigorously load effective due to human body etc. But as the size of HIS has the larger size in respect to the electricity which is needed to fit in the design space of the smartwatch applications. Moreover, the features of the HIS have been examined by the highly reflection phase of the unit cell. But there is a problem associated with this technique that this technique is not suitable for the finite size and small scale HIS.

The design of this technique is done by the following methods by the help of the two-element design antenna which operates on the frequency of about 2.40-2. 48GHz.Its decree is about the 2.2 db. Both of these elements which are being used are printed the FR4 stratum. The model diagram of this technique is shown below.

Figure 2.1: HIS Framework



2.2 By Implementing the Theory of Characteristic Modes, Design a MIMO Antenna with Superior Isolation for Smart Watch Solutions

The design of the technique in this paper is presented by the help of Multiple input and multiple output systems for the implications of the smartwatch applications [9]. Such frequencies over which the Bluetooth and Wi-Fi normally works this system works similarly on the same frequencies 2.4 2. 49GHz.

Its design is produced on the theory of the features, and which is discussed completely. Over the operating frequency band, a high port to port is resolution achievable and it is obtained by the help of the degenerated modes of the MIMOS which is very good such type of scenarios. It was the good for the smartwatch applications at that time which was operating on the frequencies equal to the Bluetooth and MIMO original systems not its variants.

The designed figure of the proposed technique is given below which shows the thorough working of the technique, but it was not suitable for the larger types of the systems. The second image of this technique is given below as well.

2.3 The Design of Integrated Antenna for smart watch applications with the help of Polarization Diversity

With the help of polarized diversity, the design and technique of the smartwatch integrated antenna has been proposed. By the excitation of the two types of the ports an annular ring of the smartwatch is used by the researchers.

There are two types of the ports which were used here one is fed by the help of the co-planar waveguide (CPW) which is loaded with the T-shaped matching networking devices and the other one is loaded with the co-planer stripe line [10].

The ring can cover the area with the band 2.4GHz in the wireless LAN. In the free space the gain of the antenna is higher than the 3. 2Dbi.There are three layers in the model overall. The top and the bottom of the layers are the Fr4 circuit boards. The middle layer has the value of foam boards is r = 1.1. The model of the proposed technique is shown below which tells us the proper working of the proposed technique.

2.4 Wide band Circularly Polarized MIMO Antenna for High Data Wearable Bio tele-metric Devices

In this technique the miniaturized the circularly polarized multiple input multiple outputs. Antenna is designed for such type of the things which are wearable bio telemetries devices.

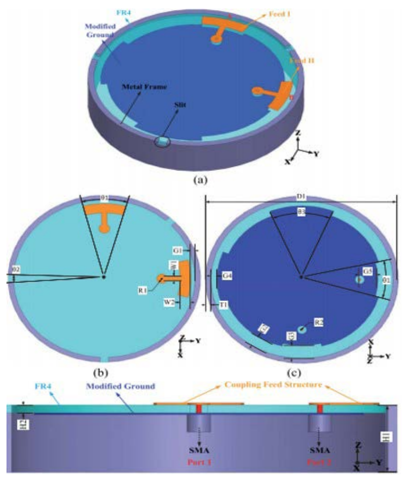


Figure 2.2: Design of the second proposed baseline

The antenna systems which are proposed here are consists of the majorly four parts which are normally placed orthogonality to all the adjacent elements. The systems which are pro- posed has the wide band response 10-db bandwidth of about 2210MGHz which is for the free space and for the industrial, scientific, and medical band it has the value around 2.40to 2.48GHZ.

The antenna is worn on the body and has the value of polarization is 3db having bandwidth equal to the 1300MHZ etc. Its structural diagram and pictorial representation are given below where the complete working of the technique is being shown. The simulated result of the proposed technique provides S11, S22, and S21 of -35dB, -30 dB and -59 dB. On the other hand, the measured results are -35 dB, -30dB and -45dB.

2.5 An equivalent circuit model-based evaluation with a loop-type ground radioactive antenna

An antenna which is based on the loop type shape ground having on the radiations is de- signed in this paper. The designed parameter circuits are installed in such a way that it can be mapped on the circular map shaped antenna [11]. For the demonstration of the model a specific type of the frequency waves has been designed which is having an antenna and its completely a electromagnetic which is model equivalent is optimized in the simulation Process.

The results which are proving the expressions of the return loss and input impedance of the model have been derived. The figure of the proposed system is also given below which shows the complete working of the model and its results are also given here.

The results of simulation are These are the same techniques which are working on the phenomena of the MIMO systems along with the wearable devices.

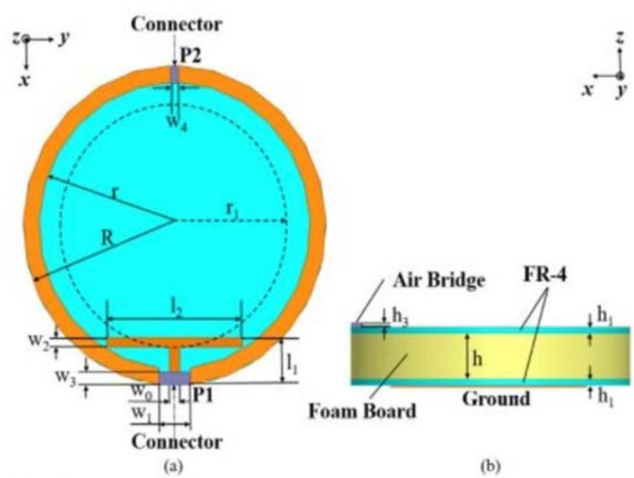


Figure 2.3: Geometry of the proposed antenna techniques

2.6 The smart watch MIMO antenna for Blue-tooth and Wi-Fi applications

This method shows the inverted type F antennas with MIMO applications and developments having the Bluetooth and wearable smartwatch. The whole value and the dimensions of the system are These are the same techniques which are working on the phenomena of the MIMO systems along with the wearable devices 40 × 40 × 5.4mm3 of the given design which has value 40 × 5 × 0.1mm3 and the system has the values for the ground portion is 40 × 40 × 0.4mm3 Based on the FR4 substrate the antenna sides which are designed on the two sides of the ground and extended towards the upwards [12].

Both the antennas are separated by the distance 40mm.With the help of certain readings and results this is demonstrated that the S11 is smaller than the -10dB and the separation is much better than the S12 which is lower than -15dB around the WI-FI and Bluetooth bands.

This proposed system showe4d the much good performance for the small sizes and larger ones but with fully functional areas it lagged in some aspects of smartwatch applications.

2.7 WLAN MIMO Antennas for Smart Watch Applications

This system works in the WLAN bands which is a MIMO based system and designed for the smartwatch applications. It has the values 2.4,5.2,5.8GHz bands. The full dimensions of the MIMO antenna are 41 × 41 × 4.8mm3 Where with the thickness and relative permittivity of 4.4 [13]. Here with the loop shorted arm every antenna is designed.

The overall proposed system is given below with the help of the diagram and this system has same problems as the previous ones.

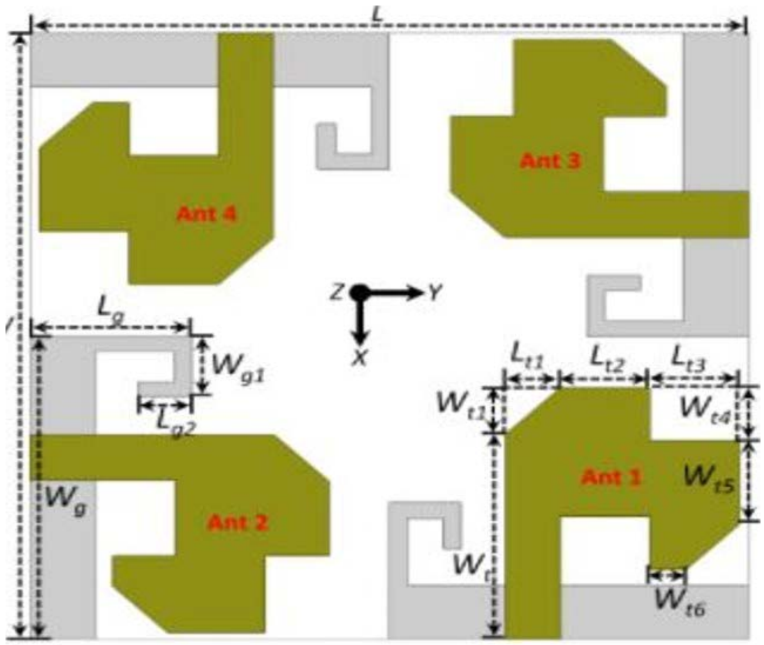


Figure 2.4: The proposed system

2.8 Design of a Watchstrap-Embedded 4 Element MIMO for 5.2–5.8 GHz Wireless Applications

The system which is being represented here is working on the operational frequency of 5.2 to 5.84GHz and WI-FI 802.11 for the applications of the smartwatch. The antenna is first fabricated on polyamide and then inserted into smart watch model [14].

The antenna which is shown here is formed by the four mono pole antennas and which is being connected by the system ground plane of the smartwatch. The most important part of this system is phantom and the frequency which is measured with and without the phantom is 45-55 respectively.

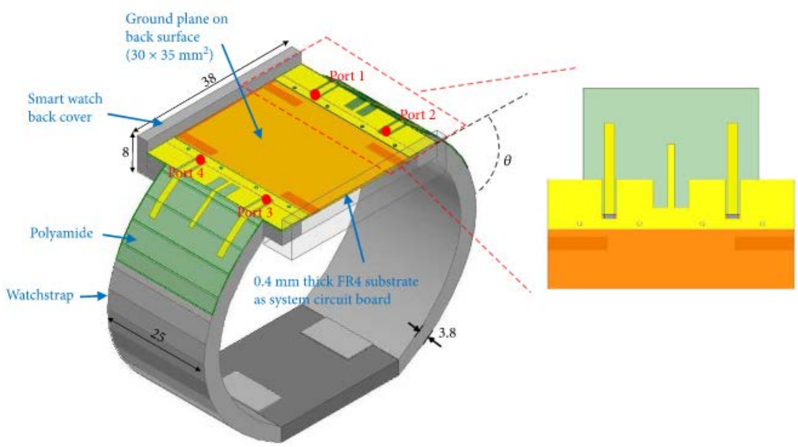
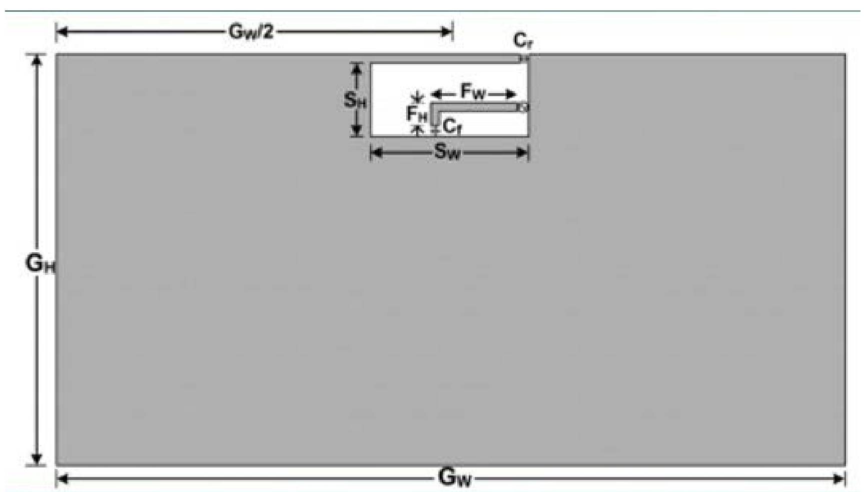


Figure 2.5: Four-element MIMO antenna embedded in the smartwatch model.

2.9 Integrated Surface Metal-Frame Type Antenna for Smartwatch Wearable Device

With the metal-based smartwatch device which was integrated in front of the antenna was introduced in this paper. The antenna device was made up of the 0.3mm rectangular frame having dimensions 5mm× 40mm0mm which was encircling the system circuit board of the watch. This system works well as compared to its state of art but couldn’t be able to sustain in the long run [15].



2.10 A Novel Linear Sparse Array with Re configurable Pixel Antenna Elements

In this paper, based on the repetitive elements of the pixel antenna (RPA) element, a novel linear sparse spar with a compound reconfigurability is introduced. It has the potential advantages of its beam transport with low profit variability, low sidelobe on orthogonal aircraft, and duplicate separation functionality [16].

In addition, both RPA and RPA array proto- types were designed and measured to prove their effectiveness. The rated results are in line with the results, which show the potential of the application in the field of modern wireless communication system of the limited range

2.11 A Decoupling Ground Radioactive with Ground Coupled Isolator Antenna for Bluetooth and WLAN

A compact and simple decoupling method is proposed in this paper to reach high isolation for such multiple-input and multiple-output (MIMO) ground radiation antenna (GradiAnt) systems. The presented MIMO antenna system is made up of two symmetrical, tightly packed loop-type (Gradients') antennas with a ground-coupled loop-type isolator sandwiched in between them [17].

To regulate decoupling, consider the isolator to be a series resonator with lumped components. In the proposed MIMO Gradient system [18], the ground-coupled isolator induces a coupling null, that can be successfully used for isolation advancement between two GradiAnts. Inside the WLAN band, an approximate 14 dB isolation is achieved, with a peak value of 42 dB attained at 2.42 GHz.

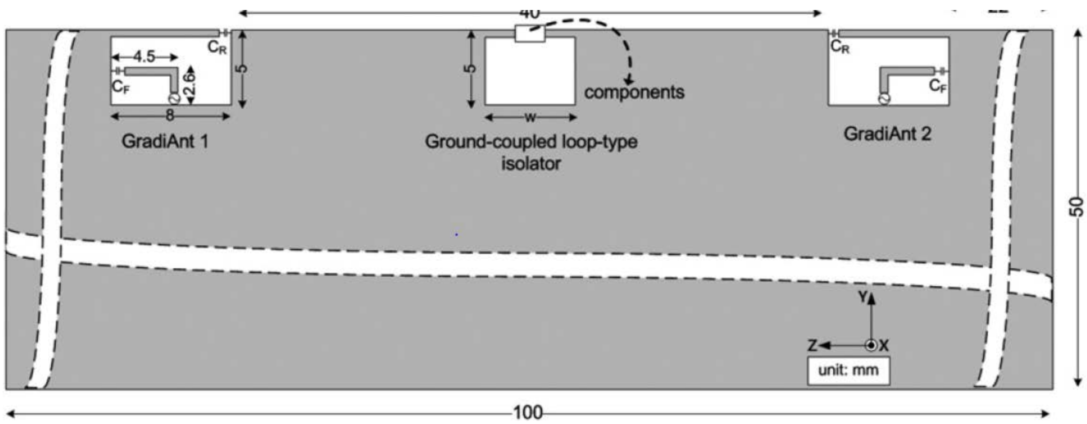


Figure 2.7: Model of the Gradiants with isolator

2.2 Comparison of the proposed design and technique with the literature

The comparison of our proposed work along with the literature review is presented below in the table. Here we can see the name of each antenna and the technique used to achieve required MIMO antenna isolation, return loss and gain values necessary for successful MIMO antenna operations.

Table: 2.1 Comparison of the proposed design with literature review

Ref No	Name of Antenna	Dimensions	Return Loss (S11)	Gain	Technique used
[8]	Low profile miniature antenna	(38 mm × 38 mm × 3 mm)	-18 dB	6.3 dBi	High impedance surfaces (HISs)

[9]	Metal-frame antenna	($\pi \times 182 \times 7$) mm^3	-20.1 dB	3.5 dBi	Theory of characteristic modes (TCM)
[10]	Integrated antenna with polarization diversity	($38 \times 38 \times 7.5$) mm^3	-19 dB	3.2 dBi	Antenna diversity
[11]	loop type ground radiation antenna	(50×25) mm^2	< -27 dB	N. A	Equivalent circuit model
[12]	Inverted-F Antenna	40×40×5.4 mm3	-10 dB	N. A	Inverted-F Antennas (IFAs
[13]	WLAN MIMO antennas	41×41×4.8 mm^3	-15 dB, -17 dB	N. A	Dual band
[14]	polyamide substrate-based 4×4 MIMO	(30×35) mm^2	< -15 dB	4 dBi	polyamide substrate for soft electronics
[15]	Integrated Metal-Frame Antenna	5 mm × 40 mm × 50 mm	-22 dB	4.39 dBi	Loop mode
Proposed	Ground Radiation Based Antenna	41 mm × 41 mm × 1.95 mm	-19 dB	3.6 dBi	Coplanar with external loop isolator

Due to the size of standard devices and the crowded arrangement of the inner components, antenna design is a difficult task in smartwatches, particularly because of strong coupling among the antenna as well as the effect of human body.

Planar Inverted-F antenna (PIFA) had been a popular smartwatch antenna type because it was easy to capture a single band, usually the 2.4 GHz WLAN band, with such a compact size. A few reconfigured multi-band PIFAs or monopole antennas have also been proposed to realize multifunction [12]. However, these structures were difficult to integrate with the framework of a smartwatch and were thus unsuitable for designs with a completely metallic frame.

Antenna diversity techniques can improve the efficiency of wireless communication systems in multi-reflection environments dramatically [10]. Several researchers proposed dual-port antennas with high port isolation and polarization diversity.

These designs, however, could not be applied to real-world smartwatch and body scenarios due to their topologies and sizes. Most of these designs did not take into account antenna-to-smartwatch integration or antenna-to-human tissue coupling.

We also investigated an integrated metal-frame smartwatch antenna with a non-planar HIS [8]. The suggested technique HIS can minimize the impact of human tissue on antenna performance and SAR value, but it's complicated system makes it unsuitable for a meaningful smartwatch application. Even if an HIS is used to reduce the effects of the human body, multipath fading is always caused by the movement of body parts, shadowing, and scattering over the body.

As we have discussed above different types of smart watch antenna design techniques, we come to know that each of them has some disadvantages and cannot meet our desired requirements of smart watch antenna design

Therefore keeping in view, the past work done on smart watch antenna design and the recent demands of the industry we proposed the ground radiation MIMO antenna for smart watch applications which is coplanar and has external loop isolator to reduce the coupling between the two antennas.

The reason of using this type of technique is coplanar antennas utilize very less space and provide enough area for other smart watch circuitry. Hence thinner smart watch can be made possible which is also today's industry demand.

Chapter 3

Novel Design for Smartwatch MIMO Antenna

In this chapter the antenna design and analysis of Ground Radiation MIMO Antenna for Smartwatch Applications is presented. The antenna design process is divided into main three major stages. The first stage is the design of 2 element loop shape antennas as it is MIMO antenna. 2 capacitors are placed at the both the antennas. The Second stage is implementation of loop for the smartwatch application. Third stage is the design of a Notch and Bezel to provide isolation between two the antennas. This is carried out to fulfil the criteria of MIMO Antenna proposed in smartwatch antennas [19].

3.1 Loop Shape Ground Based Antennas

3.1.1 Parameters Selection

The loop shape ground-based antenna design process started by choosing substrate of material FR4 with the dielectric constant of around 4.7. The FR4 Substrate has the height of 1.59 mm which is used here as it low cost and easily available. Copper is selected as ground with the height of 0.35 mm.

The main aim of these antenna design is to attain best possible results for WLAN and Bluetooth Bands smartwatch MIMO Antennas according to the international standards keeping in view the size of smartwatch antenna in normal range.

3.1.2 Basic Structure

The concept of novel design of ground-based loop shaped antenna is the main aim of this thesis and practically not hard to achieve this loop structure. Take a circular shaped ground and cut its top and make another cut orthogonal to it.

Hence, we get two loop shapes antennas orthogonal to each other. Both the antennas have separate ports attached to them with each of them having two capacitors. The antenna is shown below in the figure.

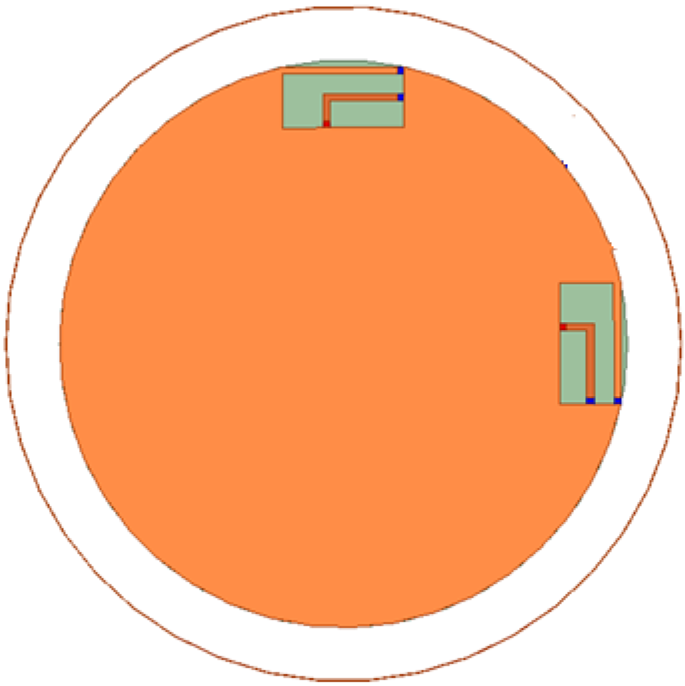


Figure 3.1: Basic model of MIMO Ground radiation Antenna

The ground-based MIMO antenna is two elements MIMO antenna as we discussed above. Other than this it only consists of ground. This is done due the fact that smartwatch antennas are very thin, and we do not have much space. So, antenna is design using ground.

The design of loop shape ground radiation-based antenna starts with the selection of circular shaped ground and loop type antenna's structure.

The ground is selected as radiating element of smartwatch MIMO with its diameter of 47.8 mm including bezel and the inner diameter of 41mm for the antenna operating at 2.45 GHz Wi-Fi and Bluetooth band frequencies. Both the antennas are assigned ports and two lumped elements at each one of the antennas.

3.2 Bezel with Ground Radiation Antenna

As we have discussed earlier that lots of various techniques can be adopted for the improvement of isolation and gain. This is very important to know that the most crucial parameter of 2×2 MIMO antenna is its S11, S12 and S22 parameters. Therefore, the loop shape with notch and bezel structure is applied.

We can enhance the antenna different important parameters with the help of this structure. The placement of external loop and bezel are performed to cater the desired needs. See the figure below to attain the better understanding of the structure.

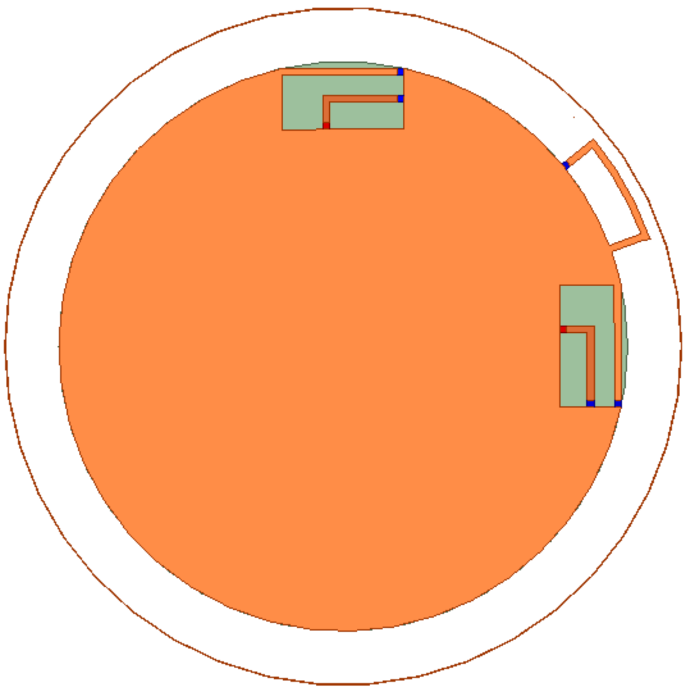


Figure 3.2: Two Element MIMO Structure with Isolator

3.3 Improvement of Different Antennas Parameters

This loop shaped ground antenna structure is very important in the improvement of gain, return loss and efficiency. This loop shaped MIMO antenna design is very helpful in the improvement of gain. I would like to explain and elaborate this with the help of 2×2 MIMO antenna operating at 2.45 GHz. Antenna with bezel provide the much better gain that is necessary required.

So, that is why this technique is for useful in the improvement of gain and achieving the desired results. This technique also fulfils the necessary requirements for the smartwatch antenna both for Wi-fi and Bluetooth applications.

3.4 Reduction in Return Loss with Bessel and Notch Techniques

S11 represents the amount of power reflected from antenna and is thus defined as that of the reflection coefficient (also denoted as gamma: or return loss). If S11 is -50.1 dB, almost all the power is conveyed from the antenna.

The input port voltage reflection coefficient is denoted by S11. The reverse voltage gain is denoted by S12. The forward voltage gain is denoted by S21. S22 is the voltage reflection coefficient of the output port. The S-parameter matrix could be used to calculate the reflection coefficients and transmission gains along both ends of a two-port network.

As we discussed in the above section, keeping in view the excellent results of gain. This technique is also very beneficial for the reduction of return losses. The return loss with Bessel and notch edge technique will be shown in this thesis. With the help of this technique, we can achieve the desired return loss that is required for the smartwatch antennas. Description of Parameters Used in Loop Shape Smartwatch Antennas:

The ground patch of antenna consists of two loop shaped antennas each having two capacitors and with two dedicated ports. These parameters or values are represented by different alphabets in a figure given below. This is very important to elaborate the mentioned following parameters by using alphabets

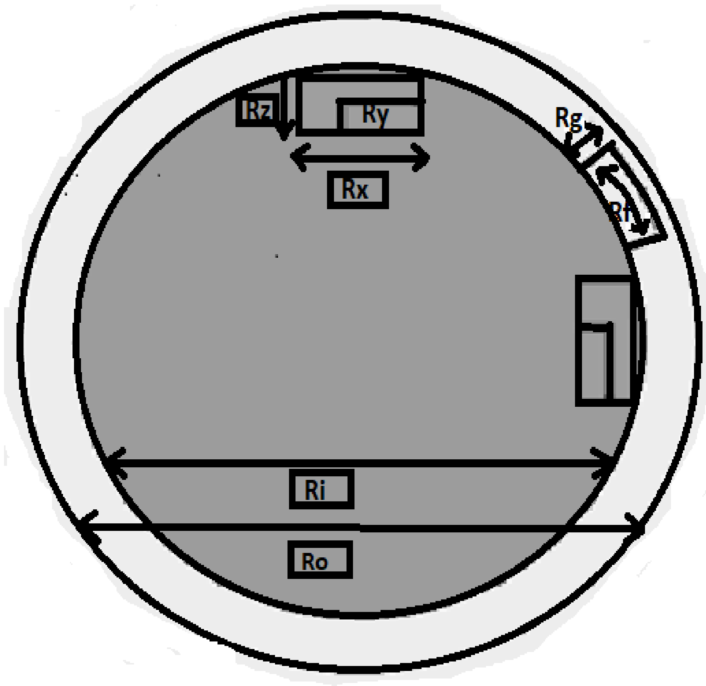


Figure 3.3: Proposed antenna parameters

The above figure of MIMO antenna shows the parameters with explanation given in Table 3.1. The values of parameters are presented in table 3.2.

Table 3.1 Description of parameters used in Ground Radiation antenna

Sr. No.	Parameters	Description
1	Ro	Outer Radius of circular Patch
2	Ri	Inner Radius of circular patch
3	Rx	Length of loop antenna
4	Ry	Length of inner cut
5	Rz	Width of loop antenna
6	Rg	Width of notch
7	Rf	Length of notch

As we have discussed above the parameters of the designed antenna, now in the table 3.2 we are going to discuss the values of these parameters.

Table 3.2: Parameters values used in Ground Radiation antenna

Sr. No.	Parameters	Description	Value (in mm)
1	Ro	Outer Radius of circular Patch	49.5
2	Ri	Inner Radius of circular patch	43
3	Rx	Length of loop antenna	8.88
4	Ry	Length of inner cut	4.5
5	Rz	Width of loop antenna	4.95
6	Rg	Width of notch	3
7	Rf	Length of notch	7.4

3.6 Decoupling Theorem

The proposed antenna MIMO GradiAnt system design is explained by the 3-port microwave network as well as the decoupling theorem; the ground-coupled isolator functions as a third port (port 3) between the two WLAN GradiAnts (port 1 and port 2). The scattering matrix, or [S] matrix, of the 3 Port microwave network is then calculated using equation (3.1), as shown below.

$$[v_1^- \ v_2 \ v_3^-] = [s_{11} \ s_{12} \ s_{13} \ s_{21} \ s_{22} \ s_{23} \ s_{31} \ s_{32} \ s_{33}][v_{1^+} \ v_2^+ \ v_3^+] \quad (3.1)$$

The following expression is implied by the termination condition for port 3 (ground-coupled isolator).

$$\Gamma = \frac{v_3^+}{v_3^-} = \frac{z_L - z_0}{z_L + z_0} \quad (3.2)$$

where the reflection coefficient at port 3, and Z_L and Z_0 are indeed the load and characteristic impedances respectively. We compute from (2) and (1).

$$s'_{12} = s_{12 + \frac{s_{13} s_{23} \Gamma}{1 - \Gamma s_{33}}} \quad (3.3)$$

where S′12 and S12 in equation (3.3) denotes the transmission coefficients from port 1 to port 2 with and without the ground-coupled isolator. This equation is known as the decoupling theorem. As a result, by adjusting the relevant parameters in the latter part of the preceding equation, the coupled ports (port 1 and port 2) can be decoupled, preventing power flow from port 1 to port 2 or even from port 2 to port 1. The decoupling effect is determined by the coupling between the ground-coupled isolator and Gradient (S13 and S23), as well as the ground-coupled isolator's own properties (ZL) [20].

As we have discussed in the literature review various smart watch MINO antenna design techniques and seen that already proposed designed structure are installed external to the ground plane which results in complexity, hence increases the size of smart watch. However, we have designed a coplanar antenna structure which is a critical demand of modern-day smart watch.

Use of only substrate and ground reduces the size of antenna and hence leads to coplanar structures, here we have designed a coplanar antenna with an external loop isolator. Isolator helps us to reduce mutual coupling between two MIMO antennas. The structure is less complex, easy to fabricate and fits in almost every size of smart watch.

Chapter 4

Results and Discussions

4.1 Simulated Results

The proposed MIMO GradiAnt antenna for smartwatch applications is designed for both WLAN and Bluetooth bands operating at 2.45 GHz. Results of this antenna is presented in this chapter. To meet the desired requirements of high gain and minimum low losses for smartwatches, results of loop shaped antenna with bezel is presented. The results of gain, S11, S21, and other different parameters of the antenna are shown one by one.

4.1.1 Return Loss

The frequency of 2.45 GHz is chosen for smartwatch antenna according to the given standard of ITU. The ground radiation antenna operating at 2.45 GHz provides S11 of greater than -50 dB as shown in the figure 4.1

Figure 4.1: S11 of ground radiation MIMO antenna

As we have 2 Element MIMO antenna. So, the return loss of antenna 2 which also is represented by S22 is -30 dB which is considered very good in smartwatch antennas. In the figure 4.2 we can see the results of S22

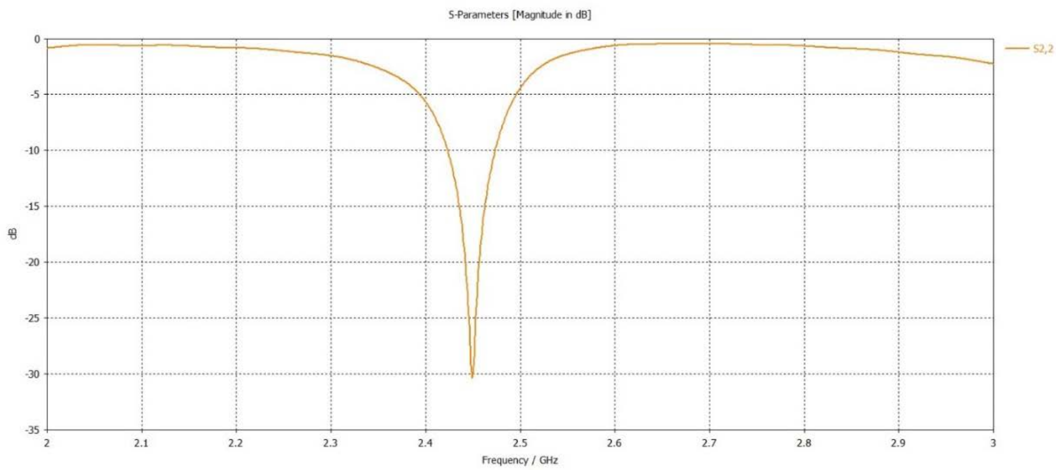


Figure 4.2: Simulated S22

The S12 parameter of the designed antenna that refers to mutual coupling is -22 dB which is suitable for the MIMO operations of smart watch antennas. The mutual coupling between antenna 1 and antenna 2 is well beyond necessary threshold require for successful MIMO antenna operations. Below in the figure 4.3 we can see the results.

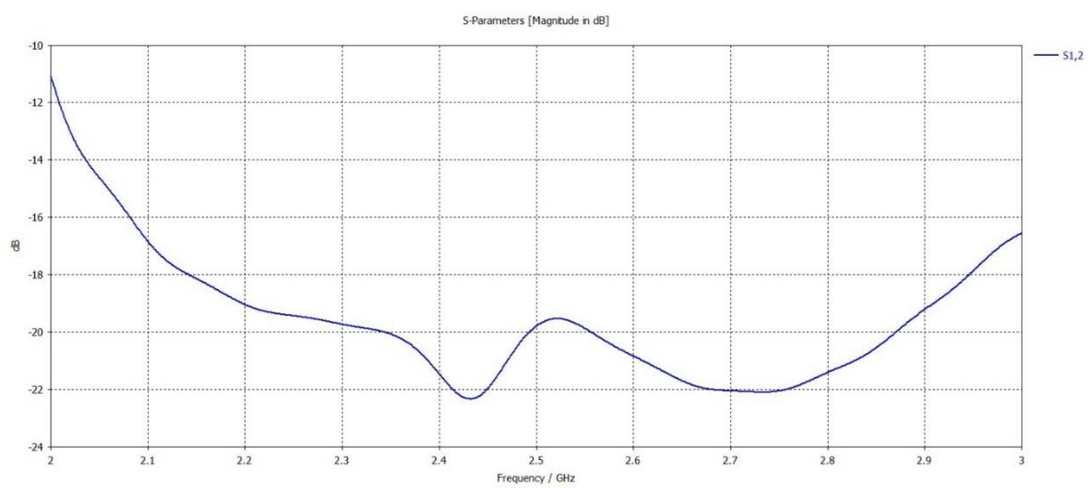


Figure 4.3: S12 of designed antenna

The combined simulated results of return loss of antenna 1 (S11), the coupling of antenna 1 with antenna 2 or in the other words power transferred from port 2 to port 1 (S12). Keeping in mind that the lesser power transmits from port 2 to port 1 the more antenna is set to be isolated and have much greater efficiency. S22 refers to reflected power to antenna 2 as shown in the figure 4.4

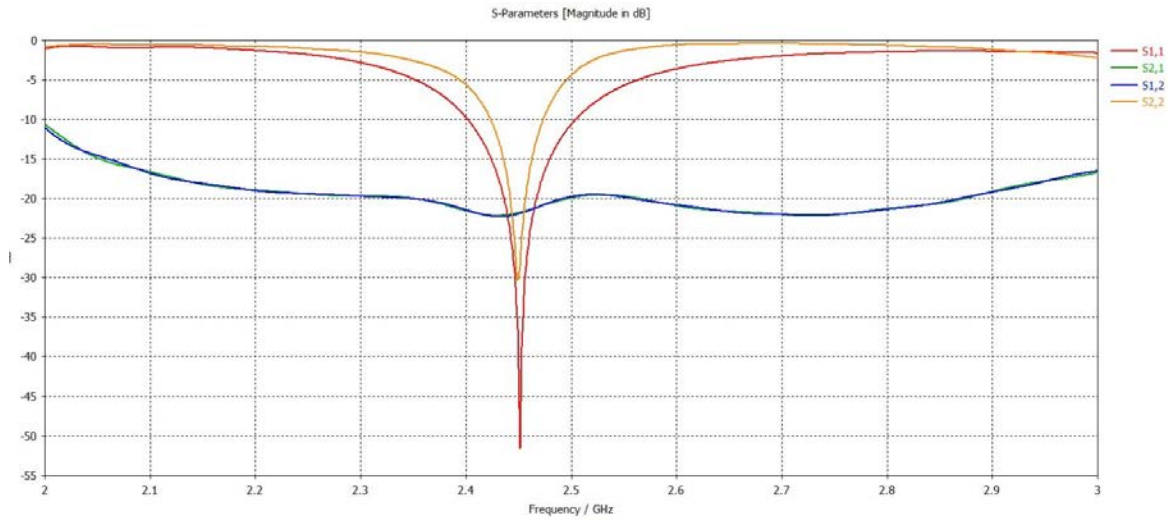


Figure 4.4: The combined results of the proposed antenna

4.1.2 Gain

The 3D simulated gain pattern of the designed antenna is presented in the figure 4.5 with the maximum gain of 3.6.

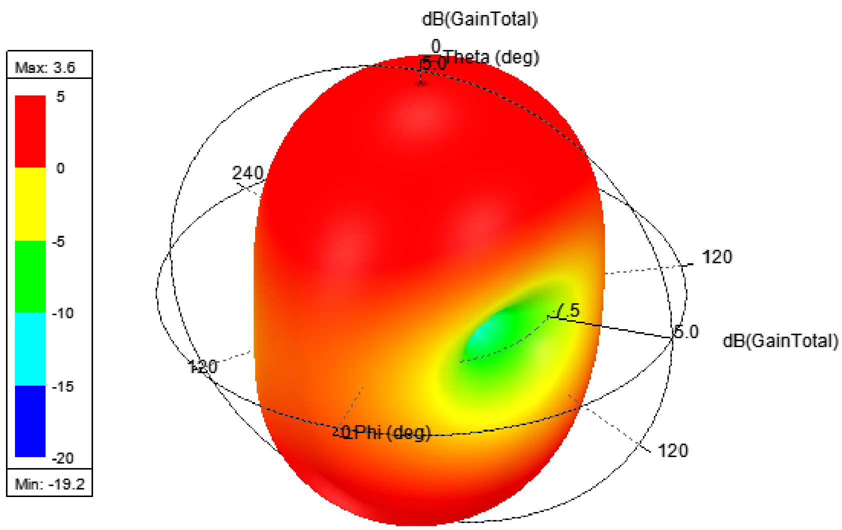


Figure 4.5: Gain of antenna (Simulated)

4.1.3 Diversity Gain

By incorporating antenna elements which then encounter various levels of fading that is why we use diversity techniques to reduce the effect of fading [21]. Diversity order on the other hand is the amount of individually fading antenna elements, could be used to characterize diversity performance. Diversity gain is indeed the avg decrease through necessary receive SNR for just a provided bit error rate (BER).

This is the decrease in fading margin which is achieved by reducing fading with both the smart antenna. The diversity gains of the designed antenna simulated is around 10 which is acceptable for smart watch MIMO antenna.

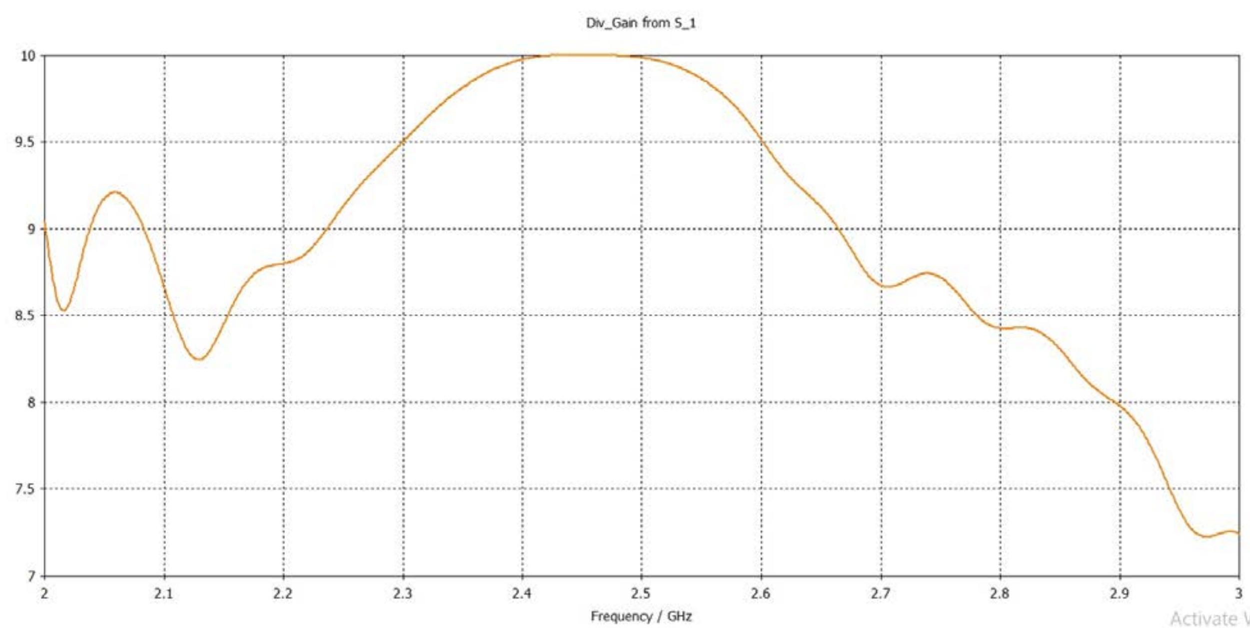


Figure 4.6: Simulated Diversity Gain

4.1.4 Envelope Correlation Coefficient (ECC)

The Envelope Correlation Coefficient indicates how self-sufficient the radiation patterns of two antennas have been to one another [22]. So, if one antenna has been totally horizontally polarized and another was totally vertical position polarized, the correlation between the two antennas would've been zero.

Much of the time, however, ECC is only assessed for just a unified isotropic field, which never occurs in practice! However, a correlation of less than 0.3-0.4 is generally accepted for the MIMO antennas. Here we can see that the ECC achieved is well under the 0.3-point mark.

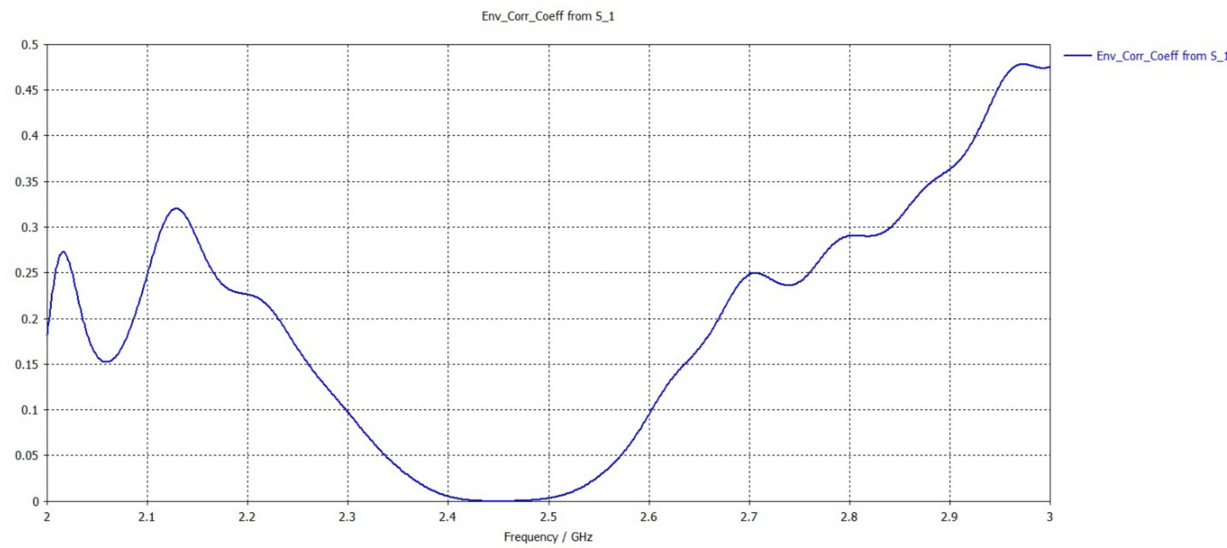


Figure 4.7: ECC (Simulated)

4.1.5 Specific Absorption Rate (SAR)

SAR is said to be the evolution of how transmitted Radio Frequency energy is absorbed by the human tissues [23]. SAR is important in antenna design since if it is too strong, the antenna should be changed. Generally, if the SAR is too significant, the transmission power is reduced, resulting in a lower SAR. Even so, because mobile phones have minimum transmit power specifications, the SAR can indeed be lowered indefinitely.

SAR is determined by the electrical conductivity (evaluated in Siemens/meter), the induced E-field from electromagnetic radiations (evaluated in Volts/meter), as well as the tissue mass density (kg/cubic-meter). SAR is obtained by averaging (or integrating) a fixed volume (generally a 1 gram or 10-gram area)

SAR is measured in W/kg or, more accurately, mW/g. In the United States, the SAR limit for cell devices is 1.6 W/kg, averaging nearly over 1 gram of tissue. The SAR threshold in Europe is 2.0 W/kg estimated over 10 grams of tissue. Because meeting the US requirements is usually more difficult than meeting the European specification, if the device meets the US requirements, it will also fulfil the European standard.

Here in the below image, we can see that according to international standards we got 0.83 W/kg which is perfect for human body and the RF energy don't harm body at that level

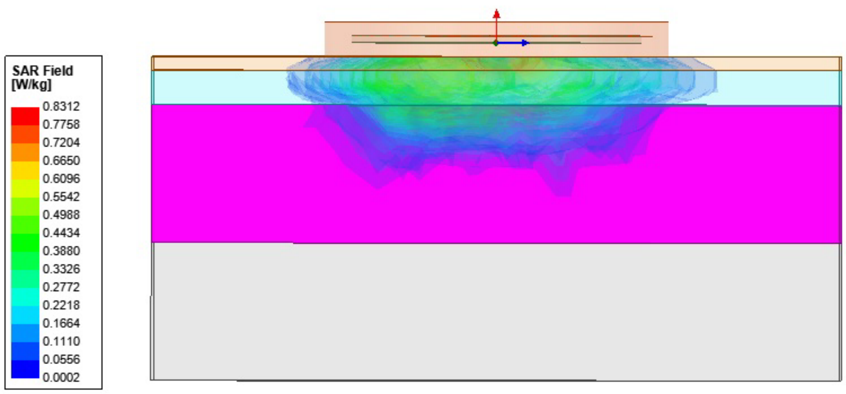


Figure 4.8: SAR measurement of the antenna operating at 2.45 GHz

Now we can see in the fig 4.5 below the SAR field implementation with respect to our antenna. The 0.83 W/kg value is achieved at the muscle which means it does not affect the human body. The radiation of this antenna is controlled at the certain level and hence it

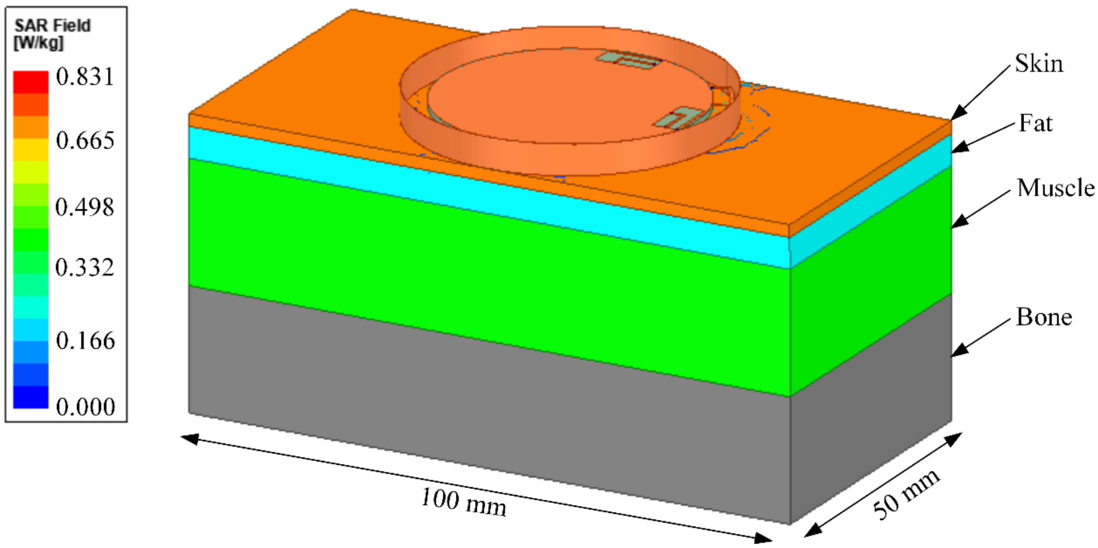


Figure 4.9: SAR Field Pattern

4.2 Measured Results

Measured results of the given antenna is presented. Measure results of the antenna S11 parameter was measured using VNA from National Institute of Electronics N.I.E, Islamabad, Pakistan. Here we can see that in measured results we got S11 the return loss with the value of -19 dB, whereas the measured S22 is -21 dB on the other hand the coupling of antenna S12 is less than -25 dB which is well below the desired MIMO antenna coupling requirement.

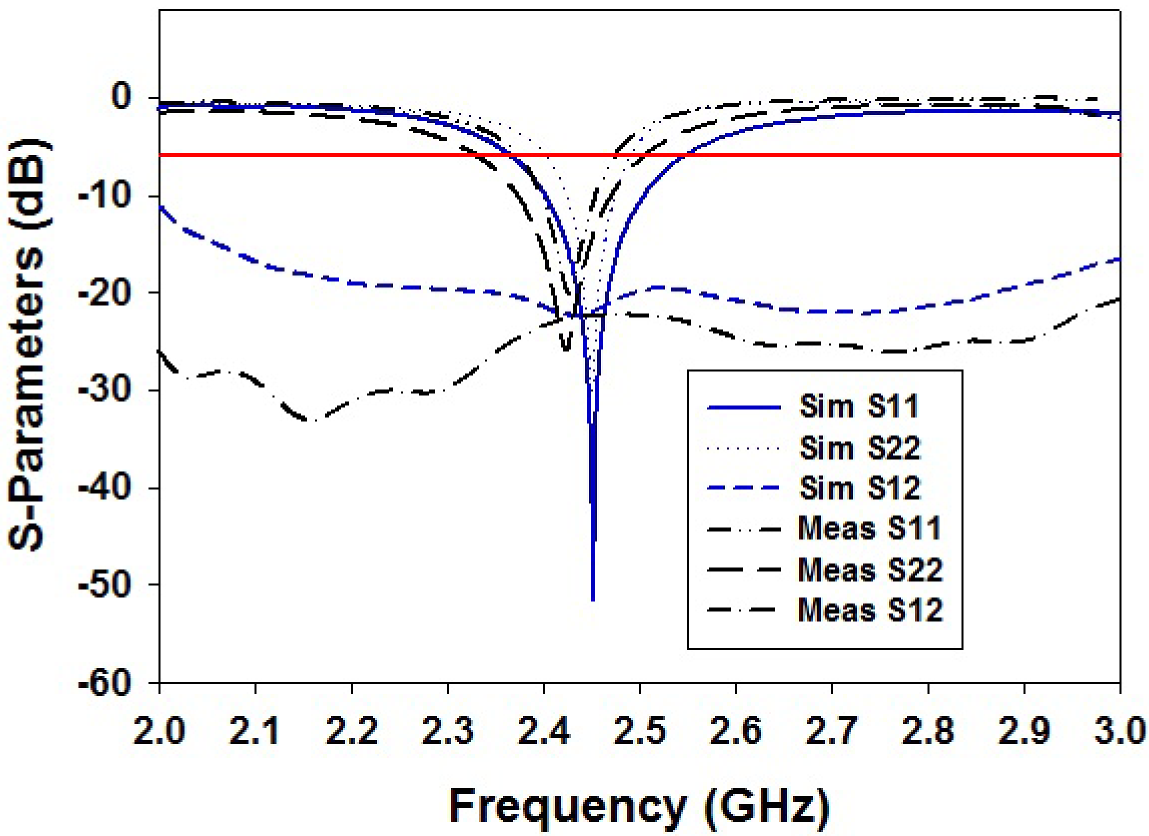
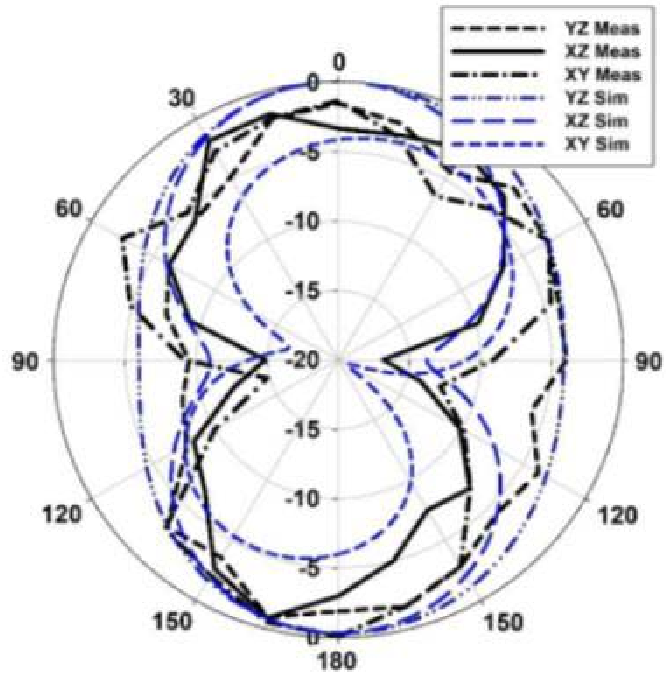


Figure 4.11: Measured results

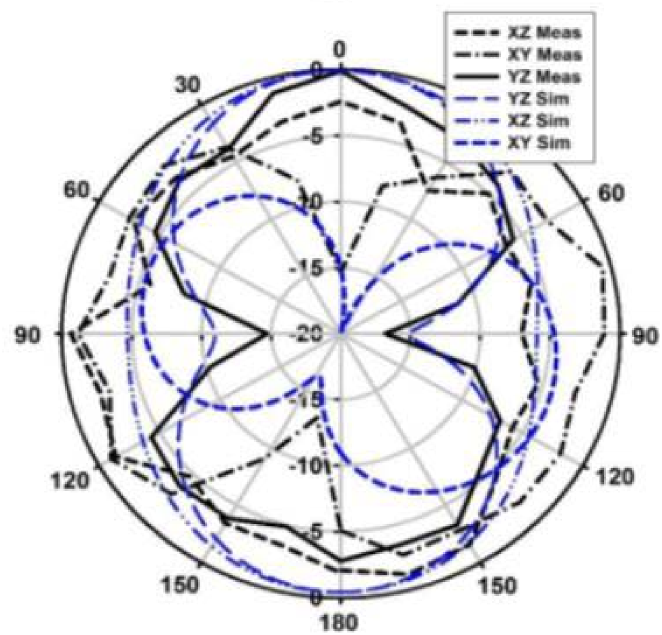
4.3Radiation Pattern

The measure radiation pattern of the designed antenna is reflected in the figure 4.12. Here we can see that we got two dipole like patterns with simulated and measured. The YZ plane is elliptic shaped. Pattern of both the antennas are diverse due to the tilt as both are disjoint to each other. Here we can see that when first antenna was excited the normalized gain was -3 dB.

Furthermore, when the second antenna was excited the measured normalized gain at YZ plane is 0 dB. On the other hand, if we see the simulated normalized gain of the antenna 1 in XZ plane is above 0 dB



(a)



(b)

Figure 4.12: Radiation Pattern (Measured)

Chapter 5

Conclusion and Future Works

5.1 Conclusion

Smartwatches have usually ground radiation MIMO antennas for compact size and high gain. This technology (Ground Radiation Antennas) is used nowadays due to its compactness as the smartwatches have less space for antenna since it is designed on ground and just a single layer of substrate which minimizes its size a lot. This Thesis provides compact size, low return loss MIMO antenna for smartwatch applications.

This Smartwatch antenna is preferable because of its thing compact size, light weight, and is simple and easy to fabricate. Due to the fact of its small size, high gain, and ease of fabrication, the designed antenna is well suited to meet all the requirements of smartwatch antenna and its applications. Furthermore, the novel design which is operating at 2.45 GHz has the diversity gain of 10.1dB.

5.2 Future Works

Ground Radiation MIMO antennas have immense amount of study and advance research. Challenges of small size, isolation and return losses have been achieved. Following advance work can be carried out in this field: To achieve more high gain and high return loss PIFA antennas with T shaped isolator can be designed.

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