DESIGN OF MIMO ANTENNA AND INVESTIGATION OF IT'S PERFORMANCE FOR WIRELESS SYSTEMS

Synopsis of the Thesis to be submitted to the SNDT Women's University for the degree of Doctor of Philosophy in Electronics and Communication

Submitted by

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Declaration

Certified that this synopsis is a bonafide record of work done by Ms. Vandana Jitendra Satam during the Period January 2014 to August 2018 at the Department of Electronics and Communication , Usha Mittal Institute of Technology of SNDT Women's University, Mumbai. It is submitted in partial fulfillment of the requirements for Ph.D. Degree in Electronics and Communication.

Signature

Guide

Date:

I declare that the form and content of the above mentioned thesis are original and have not been submitted, in part or full, for any other degree/ diploma of this or any other University or Institution.

Signature of scholar Guide

Date:

CERTIFICATE

This is to certify that Vandana J. Satam has completed the presynopsis report on the topic "Design of MIMO antenna and investigation of its performance for wireless systems " satisfactorily in partial fulfillment for the presynopsis Seminar for Ph.D in Electronics and Communication under the guidance of Dr.Shikha Nema during the year 2018-2019 as prescribed by SNDT Women's University.

Guide | Head Of Department

Guide name | HOD name

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Chapter 1

Introduction

MULTIPLE INPUT MULTIPLE OUTPUT (MIMO) has proven to be one of the expedient technique in wireless communications from the past few decades. MIMO supports the use of multiple antennas to send multiple signals simultaneously from transmitter to receiver. MIMO allows multiple data to be transmitted over a single channel at the same time. Multiple antennas are used at the transmitter as well as at the receiver to increase the consistency in data transfer link, reliability and the spectral efficiency in wireless systems. A signal broadcasted between a transmitter and a receiver is varied in attenuation over a certain band due to the effect called as fading. Fading is a major factor behind a loss of signal power that results in poor performance in a communication system. One major source of fading is multipath propagation, where various paths can be taken by the signal which results in intersymbol interference. Fading causes attenuation in the transmitted signal. This attenuation reduces the signal quality, which further increases the number of errors in transmitting data. Increment in errors while transmitting the data decreases the effective throughput of the signal, which deteriorates the RF transmitter channel capacity[1]. The solution for reducing fading effect is a use of diversity technique. Use of multiple elelement antennas at the transmitter as well and at receiver builts the MIMO system[2].

1.1 Motivation

The rapid growth in radio communication industries and applications has clustered the electromagnetic spectrum. As most of the current wireless systems operate at high frequency (3 MHz - 30 MHz), very high frequency (30 MHz - 300 MHz) and ultra high frequency (300 MHz - 3 GHz) bands, the electromagnetic spectrum at these bands is crowded. In addition, the relative bandwidth of communication channels at these bands is in the range of few megahertz. According to Shannon-Hartley theorem, a channel capacity (C) is directly dependent on the bandwidth (BW) of a communication channel and the signal to noise ratio.Therefore, applications which require higher data speed cannot operate satisfactorily at these low bandwidth channels. The design prototype developed in this report can be utilized for wireless applications such as internet communications as well as satellite downlink operations. The objective of this work is to design antenna prototype for high gain, compact size, low profile antenna for wireless applications.

Another motivation for designing MIMO antenna is to sort the issues of interference between the wide band and narrow band devices in wireless system networks. Designing MIMO antenna which itself can act as filter to reject unwanted frequency bands is a challenging task. Nowadays different wireless systems require compact size planar antenna with high gain, low correlation coefficient. As antenna size reduces there is degradation in impedance bandwidth. Hence designing antenna with compact size with good performance is a challenging task.

1.2 Problem statement

The aim of this research is to design, simulate, fabricate and validates measurements of MIMO antenna for wireless applications. The designs exihibiting optimum return loss,high gain is to be fabricated and tested in comparision with simulated results.

1.3 Research objectives

1. The main research objective of the thesis is to develop multiple element antenna having high gain, low mutual coupling, compact size applicable to wireless communication systems.

2. To design compact antenna with high gain for ISM, UWB, Ku/K-band as well as wideband characteristics with for planar structures.

3. To study polarization characteristics in MIMO antenna by orienting each antenna element in the different direction so that maximum front to back ratio is desired.

4. To obtain a wide impedance bandwidth to support high data rate channels.

5. To study band-notch characteristic of the MIMO antenna is also one of the objectives of this research work.

Development of the MIMO antenna includes the understanding of the physical configuration of the antenna geometry to have satisfactory antenna performance.The overall objective is to design, fabricate and demonstrate the characteristics of MIMO antennas.

Chapter 2

Multiple Input Multiple Output Antennas

2.1 Challenges in the design of MIMO antenna for wireless systems

Antenna designing for diversity applications in various wireless systems has several challenges. In this section, we will study various key challenges that are faced by the RF designer for wireless systems.

2.1.1 Miniaturization and integration Issues

Antenna miniaturization and integration is a challenging task in the applications such as mobile antennas, satellites antennas where antenna elements are placed in close proximity. Radiation efficiency and bandwith gets affected due to compact size of the antenna.These important factors need to be carefully explored for the adequate performance of wireless system. An appropriate study on such issues was conducted in [4].

2.1.2 Antenna coupling and isolation enhancement

If the distance between two antenna elements is less then high coupling in MIMO antenna is observed. In the devices with compact size such as mobile phones, USB dongles where multiple antenna elements are spaced adjacent to each other and hence high coupling is obvious. Efficiency, data rate and capacity of the MIMO system gets affected due to high coupling between closely spaced antenna elements. Numerous configurations have been proposed in literature to reduce the coupling effects on the basis of the antenna structure, its radiation and feeding mechanisms. Following methods are reported to increase the isolation in the MIMO antenna system:

1) Orientation and placement of antenna elements: Distance between two antenna elements plays important role while studying isolation between two antenna elements. The polarization property of the antenna have been studied by orienting antenna elements in different directions [5] - [8]:

2) Decoupling Networks: Decoupling network is used to increase efficiency of the antenna in terms of radiations to decouple the input ports of adjacent antennas. Lumped elements as well as distributed elements used while designing a matching circuit of decoupling network so that isolation between adjacent antennas can be enhanced.This technique has been used in several designs such as those in [9] - [12].

3) Parasitic elements: . Improvement in efficiency, isolation and envelope correlation coefficient among the nearby antenna elements is observed by canceling most of the coupled fields between them. Coupling current gets reduce because of the creation of opposite coupling fields on the radiating antenna. These fields are opposite in polarity that of original fields. These parasitic elements are studied in [13] -[18].

4) Defected Ground Structures (DGS): The characteristics of printed antenna elements have been affected by modifying ground plane of the antenna system. Ground plane provides the path of the return current and occasionally at lower frequencies becomes part of the radiating structure. The perturbations on the ground plane induces current. This current gets coupled with adjacent antenna elements due to shared ground plane. The perturbations also affects the mutual coupling between adjacent multiple antenna elements. Defected ground structure is process of making perturbations on the ground plane of the antenna for reducing mutual coupling.Previous work includes designs such as a group of slits [19] - [21], the use of dumble-shaped defects [22] - [23]. In literature lot of survey for these kinds of geometries for making defects has been found in in [24].

5) Neutralization lines: This technique is an enhancement in isolation where current phase at particular location is converted by choosing a suitable length of the line.

This inversion in current element is supllied to the adjacent antenna element. Thus neutralization line decreases the amount of coupled current. As the location of a point on neutralization line changes, it varies corresponding impedance which directly affects the effective bandwidth. The point at which impedance is found to be low of radiating structure is chosen as a starting point of neutralization line. This method is effectively used to decrease mutual coupling between adjacent MIMO antenna elements [25] - [28].

6) Use of Metamaterials (MTM): Metamaterials can be one of the solutions for reducing coupling between nearby antenna elements of a MIMO antenna system. In literature lot of work shows the utilization of metamaterial for isolation enhancement such as those in [29] - [32].

2.2 Design challenges to be achieved in MIMO antenna systems

- High isolation
- Wide bandwidth
- Compact size
- Low correlation coefficient

2.3 Proposed solution

To achieve challenges antenna must be designed considering the following factors:

- The antennas must have some degree of directivity that can be controlled
- The antennas must have high gain and efficiency
- The antenna must possess ultra wideband characteristics
- The antenna should have differently-directed spatial radiation patterns
- Coupling between the antennas must be minimized

- The antennas must be compact
- The antennas must have properly matched terminations
- The correlation coefficient between the MIMO antenna must be as low as possible

2.4 Planning to achieve Proposed Solution

- Designing planar antenna
- Modification using different methods such as monopole, slot, fractal, DGS, EBG etc.
- MIMO antenna design for increase channel capacity and to reduce mutual coupling using the above methods
- Orientation of antenna elements to study polarization characteristics
- Increase in number of radiators to study gain characteristics

Chapter 3

Research Methodology

3.1 Current scenario of development of MIMO antenna

In present trends,MIMO antenna focuses on high capacity wireless systems which show applications like WLAN, WiFi, bluetooth, satellite applications etc. The present research will focus on MIMO antenna design for single band applications, multiband applications, band reject characteristics, UWB applications, K band, Ku band applications.

3.2 Use of software tools for MIMO antenna design: Selection of IE3D software for present work

IE3D mentor graphics software is based on method of moments solution is accurate for frequency domain analysis for planar configurations.

3.3 Contribution of the thesis : Result and discussion

In this section discussion about various MIMO antennas using different techniques is done based on applications like WiFi, WiMax, Bluetooth, short range RADAR, Ku band applications etc.

3.3.1 Discussion about results achieved:

In this section design of various antenna configurations is shown and few of characyeristics are discussed.

MIMO antenna with two elements having defected ground structure and vertical slots for low coupling

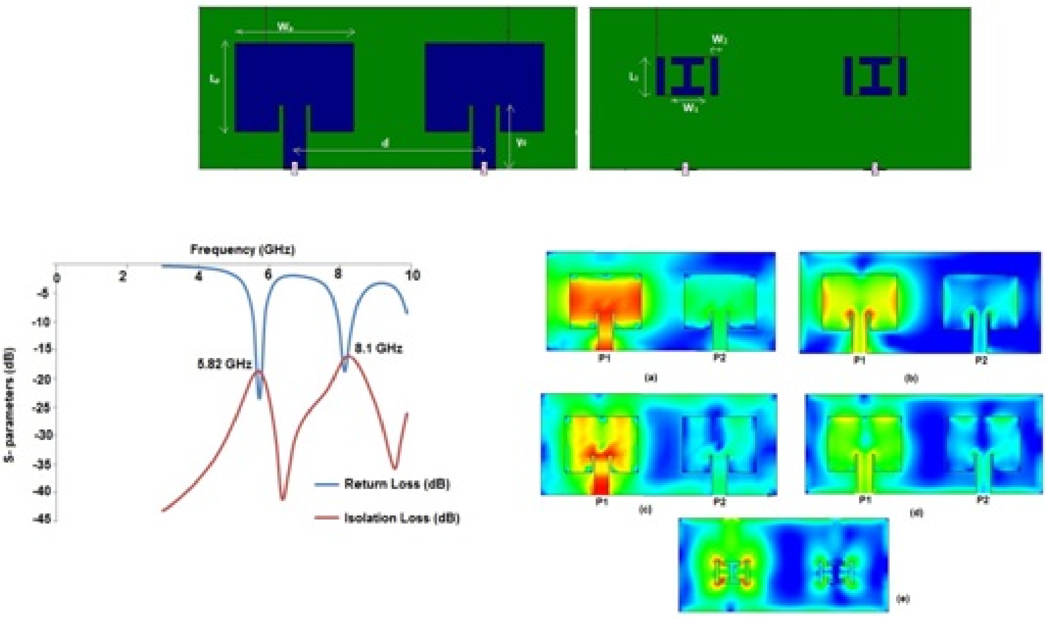

Figure 3.1: Configuration and results of DGS -two elements MIMO antenna

MIMO antenna with two elements with DGS and vertical slots gives less coupling between two elements. Figure 3.1 shows configuration as well as various characteristics for DGS MIMO antenna.It shows multiband response covering bandwidth of 270 MHz (5.55 GHz to 5.86 GHz) and 427 MHz (7.93 GHz to 8.36 GHz).Each resonating band exhibits isolation of -26.94 dB and -24.60 dB respectively. Maximum gain of 6.05 dBi is achieved. Current distribution characteristics shows both elements have less coupling and ideal for MIMO operation.

Three elements MIMO antenna for high gain applications

In proposed work as shown in Figure 3.2, $\lambda/8$ distance between two radiating elements provides good isolation. The measurement results shows impedance bandwidth as 200 MHz (3.2 GHz to 3.4 GHz), 330 MHz (5.51 GHz to 5.84 GHz),770 MHz (7.16 GHz to 7.93 GHz) and 800 MHz (10.8 GHz to 11.6 GHz). Symmetry in structure gives similarity in return loss of respective port by terminating other ports by $50\Omega matchedline.Maximumvalueofgainisobservedas7.3dBiwhichisidealforWLANapplication.Gainu$
$6dBiforshortrangeRADARapplication.$

Three element MIMO antenna for Ku band applications

In the lower frequency band, available bandwidth is also low hence K/Ku band antenna design will be given considerable attention in recent times for wide bandwidth application.It has been observed from simulation result that gain of single element antenna is 4.7 dBi. To increase the gain of antenna elliptical radiators are increased and achieved gain is 5.35 dBi. Then square slot has been introduced in the middle radiator to increase impedance bandwidth of the antenna.Further, to achieve high gain numbers of slotted radiators are increase up to three numbers. All characteristics along with configuration is shown in Figure 3.3. The gain achieved is 10.94 dBi. To maintain high isolation for MIMO antenna the antenna radiators are placed $\lambda/8$ apart.the structure has $|S_{11}| <$ -10 dB for two different frequency bands i.e. 14.8 GHz to 16.76 GHz , 18.44 GHz to 19.28 GHz. Since all the three radiating elements are identical in nature hence $S_{11} = S_{22} = S_{33}$. While measuring S_{11} at the particular port the other two ports are matched with 50Ω matched load. The respective bandwidth of each band i.e. 1.96 GHz, 840 MHz is acceptable for satellite communication application. Current distribution characteristics shows less coupling between radiating elements.

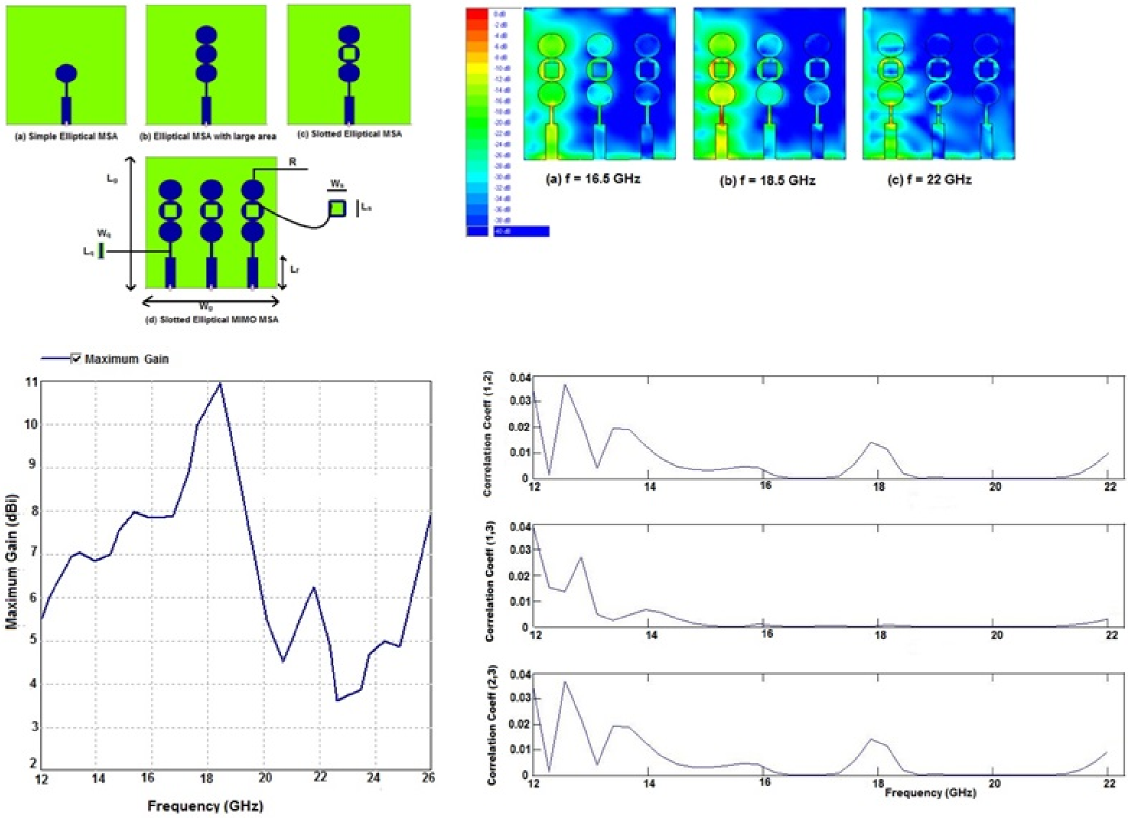

Figure 3.3: Geometry and results of three element slotted MIMO antenna

2- element MIMO antenna using DGS and parasitic structure for UWB applications

Figure 3.4 shows two element MIMO antenna with defected ground structure with parasitics element and simple microstrip line feed. Compact size of diversit antenna was achieved by modifying the radiator with partial ground plane.The separation between 2-antenna elements is maintained as $\lambda/8$.The return loss shows wide bandwidth covering frequency range from 2.43 GHz to 12 GHz. Hardware was tested in semi-anechoic chamber and practically gain was found to be 5.6121 dBi at 5.8 GHz frequency. Overall structure gives low coorelation between nearby elements due to DGS and parasitic elements together.

Two element spanner shape antenna for UWB applications

A compact MIMO antenna with spanner shape and good diversity characteristics is proposed for ultra wide band system application. The slot contributes for spanner shape provides reduction in area of antenna. The coupling between two nearby radiat-

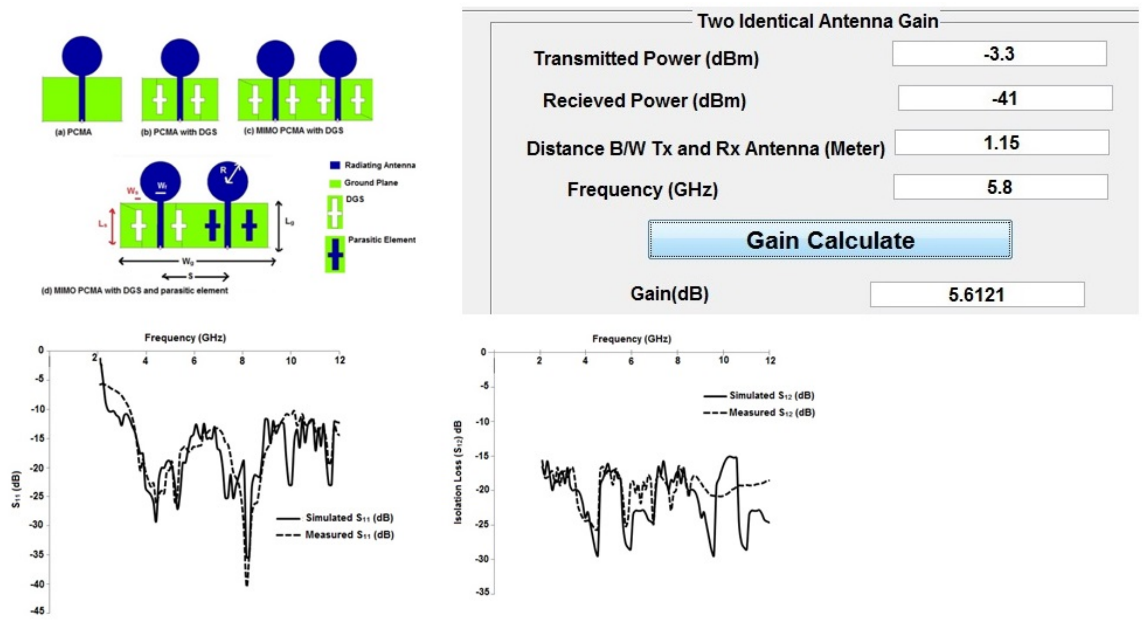

Figure 3.4: Configuration and results of MIMO antenna with 2- elements with DGS and parasitic structure for UWB applications

ing elements is reduced by keeping space of 0.25λ. The ultra-wide band characteristics are achieved by encorporating monopole structure. The proposed antenna (Figure 3.5)has compact dimension of $59.5mm \times 52mm$. The maximum gain of antenna is 5.27 dBi at 7.93 GHz frequency.By excitation of antenna element 1 while terminating others with matched load, the surface current can be seen.

Two element MIMO antenna for band notched characteristics

Many a times the receiver in wireless systems gets loaded due to intbetween narrow band and wide band signals, so filter circuits are used to achieve band rejection characteristics. But addition of external filter circuit increases weight,size and complexity of the system. o overcome this, antenna which shows band rejection properties is desirable.VSWR characteristics in Figure 3.6 shows how different lenghth and width of slot affects the location of notch characteristics. The U shape slot is ethched on radiating elements as well as on feeding line for rejecting WLAN band (4.59 GHz to 6 GHz) and short range RADAR band (8.92 GHz to 9.9 GHz). Distance of $\lambda/8$ between two radiating elemnts helps to achieve desirable isolation.Gain characteristics show maximum gain over entire operating band except notch locations.

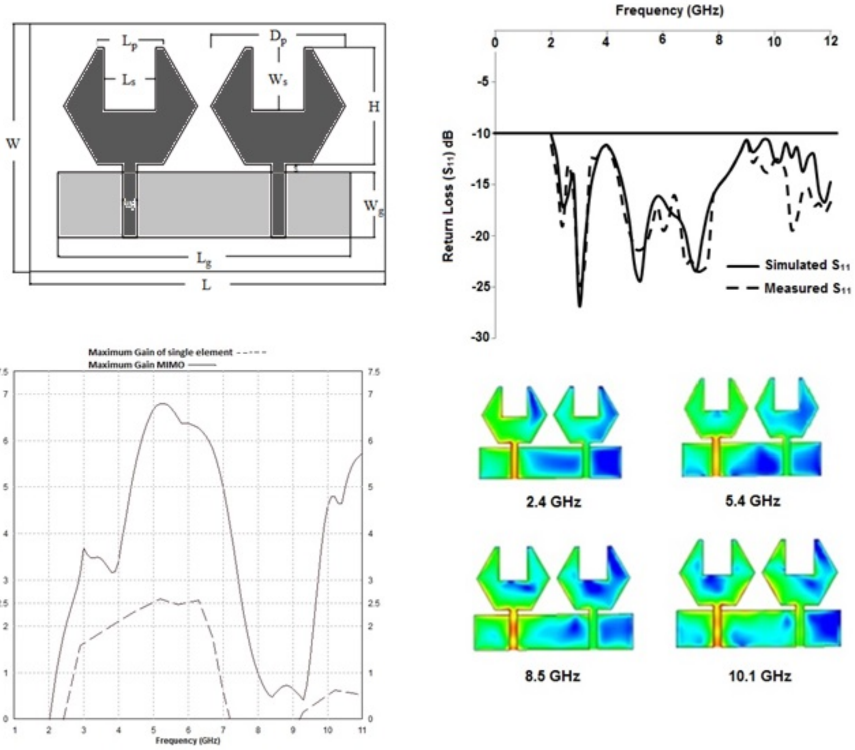

Figure 3.5: Geometry and results of two elements spanner shape MIMO antenna for UWB applications

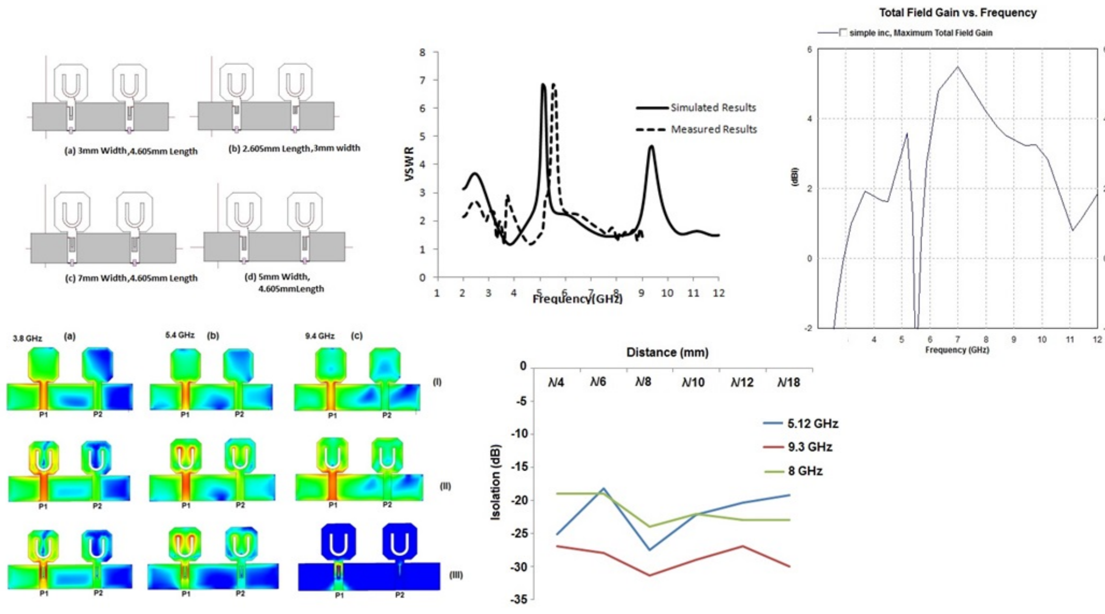

Figure 3.6: Geometry and results of MIMO antenna for band notch characteristics

4- element MIMO antenna for band polarization diversity

Figure 3.7 shows geometry and characteristics of 4- element MIMO antenna for ultra wide band applications.The antenna consists of a simple rectangular radiation patch and reduced ground plane with simple micro-strip line feed. Good isolation is achieved by keeping the distance between two radiating elements as $\lambda/8$. Desired frequency band is achieved by optimizing dimensions of the patch and the ground plane. The return loss characteristics show wide impedance bandwidth varying form 3 GHz to 12 GHz below -10 dB. Low value of mutual coupling is achieved by performing parametric analysis on distance between antenna elements.The minimum isolation between two antenna elements is less than -15 dB. The maximum gain of antenna is 5.27 dBi at 7.93 GHz frequency. Envelope correlation coefficient which decides diversity performance of any antenna in MIMO systems is calculated by S- parameter method and found to be near to zero[10].

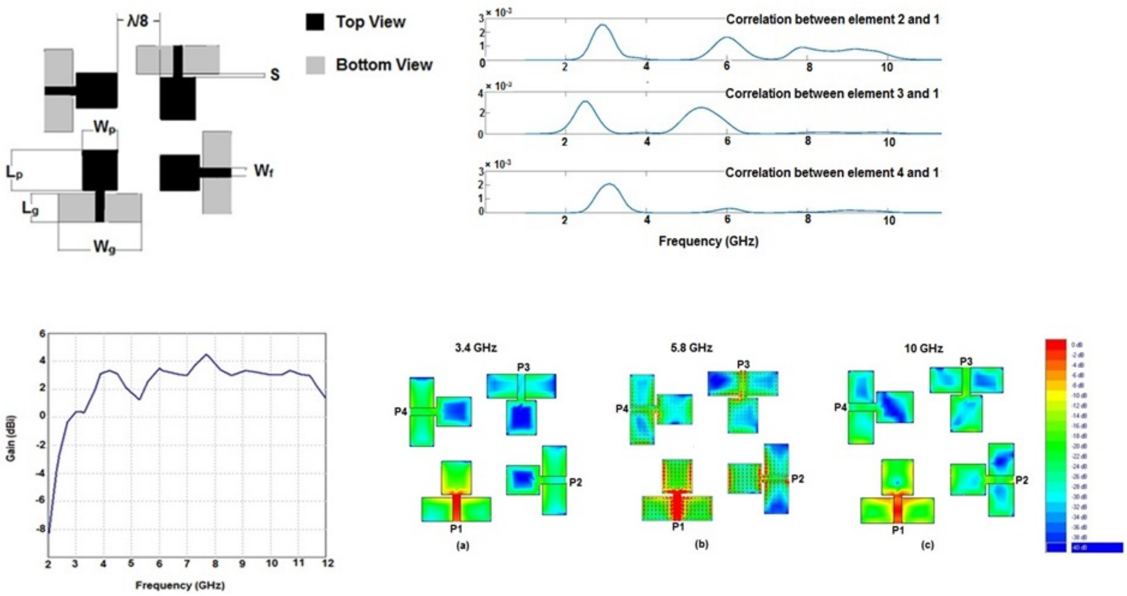

Figure 3.7: Geometry and results of four elements MIMO antenna for polarization characteristics

Six element MIMO antenna for high gain,low coupling for dual polarization characteristics

A recent study shows that use of dual-polarized antenna at the transmitter and/or at receiver extensively increases capacity as well as diversity performance of wireless communication system. Here elements in the system are fed with differently polarized signals.Dual polarized antennas excite generate vertically and horizontally polarized electric fields which has two orthogonal modes. Radiations from excited antenna elements get coupled with nearby antenna elements which affects impedance matching performance of antenna elements as well as diversity performance. Improvement in impedance bandwidth and isolation between antenna radiating elements is achieved by modifying ground structure with L shape decoupling structure as shown in Figure 3.8.The proposed six-element MIMO antenna resonates at different frequencies useful for different applications like WiFi, WLAN, satellite communication etc. The radiation patterns are measured for 2.4 GHz, 5.8 GHz and 12 GHz respectively. At higher frequencies E-plane radiation results in splitting of radiation lobe due to higher order modes. H-plane radiation pattern depicts omnidirectional nature. Overall gain is found to be more than 2dBi throughout operation frequency (2 GHz - 12 GHz).Maximum gain is found to be 6.7 dBi at 15 GHz frequency. It is seen from current distrubution characteristics that antenna with port 1 gives horizontal polarization and antenna with port 5 gives vertical polarization effect.Designed six-element MIMO antenna is practically tested with 802.11N WiFi USB dongle. It has been observed that designed antenna transfer WiFi signals at 2.4GHz as well as 5GHz frequency with a capacity of 130Mbps.

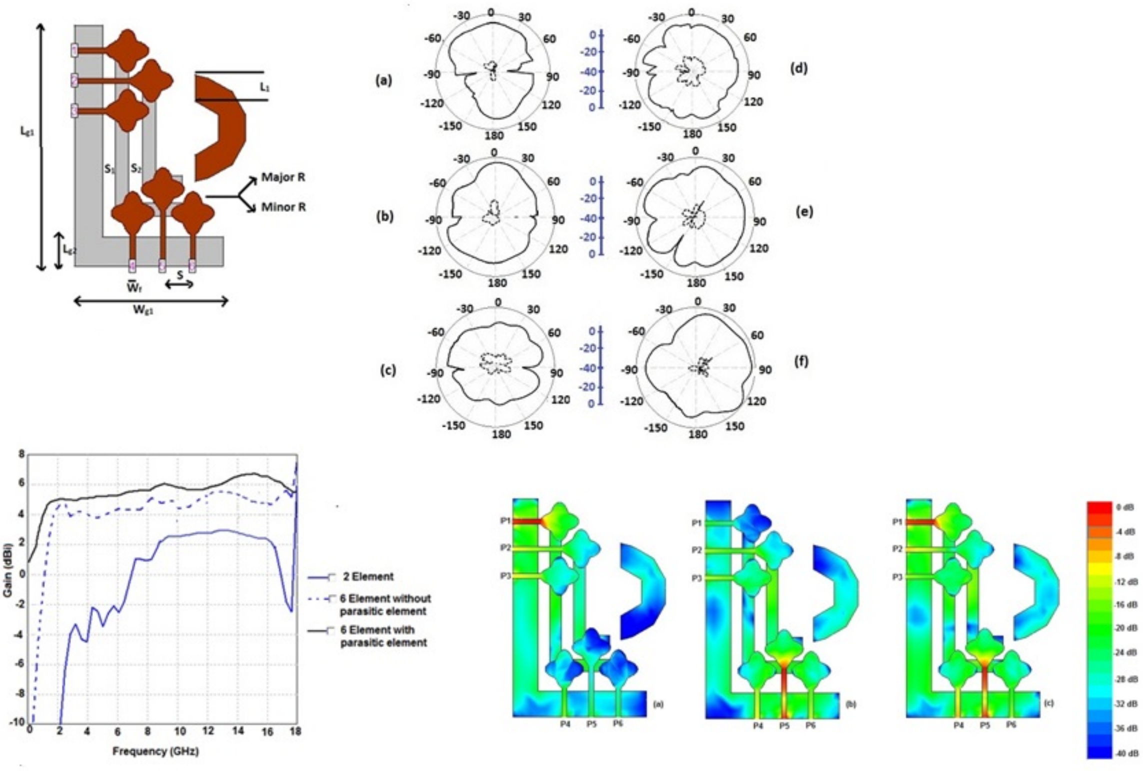

Figure 3.8: Geometry and results of six elements MIMO antenna for polarization characteristics

Chapter 4

Research outcome and Future Scope

4.1 Research outcome

In this research work, various parameters of MIMO antenna for different configurations have been investigated, designed, simulated and measured. Emphasis is given to increase the gain and to reduce envelope correlation coefficient and coupling between two radiating elements with compact size by adopting different configurations and different isolation techniques such as defected ground structure(DGS), the parasitic element, slot technique etc.

Measurements have been carried out on all proposed structures for VSWR, isolation loss, radiation pattern which are in agreement with simulated results. The summary of all results presented in Table 4.1 for proposed MIMO configurations.

Name of Configuration	Size(mm^2)	$S_{21}(dB)$	Bandwidth	Gain (dBi)
DGS MIMO	50.54 ×21.29	-18.70	270 MHz/ 427MHz	6.05
3 Element MIMO antenna	76.76×22.74	less than -15	270 MHz,479MHz,461 MHz	6.7
Spanner shape MIMO	59.5 ×52	less than -15	2.4-10.6GHz	6.79
Four Element dual polarised	61 ×57	less than -15	3.4-12	4.5
UWB notched	23 ×47	less than -10	Notched at 4.59-6/8.92-9.9	5.45
Parasitic and DGS MIMO	66.2 ×40	less than -15	2.4GHz-11GHz	6
K band slotted MIMO	25.4 ×25.4	less than -15	14.52-17.03/18.21-19.37/22.78-23.98	10.94
Six element diversity antenna	45×43	less than -15	1.44-2.88/3.96-4.68/6.84-10.8/15.48-17.28	6.7

Table 4.1: Summary of results for proposed structures

The results and discussion presented in this research work will provide an intuitive perspective on fundamental requirements of the antenna with diversity applications. All MIMO antennas designed to cover different bands of spectrum to support various wireless applications such as ISM band, bluetooth, WLAN. WiFi, short-range radar, satellite applications etc. All structures proposed in thesis tested practically with WiFi dongle for wireless internet connectivity and it has been observed that as number of elements of the antenna increases the data rate of wireless data transfer increases.

4.2 Future work

Design of MIMO antenna with enhanced isolation and high gain have lot of scope in designing MIMO antenna for enhanced data rate.Based on the conclusions and inferences in the thesis, future work could be carried out in the following areas:
The optimized configurations presented in this thesis could be further improved for isolation and miniaturized size. Different geometrical radiating structures can also be used for exciting higher order modes to improve the bandwith performance. Polarization and pattern diversity concept can be used to reduce fading effect and to improve the data rate of wireless systems. In the present research work, all the antenna measurements are carried out inside the laboratory and few of them tested for WiFi systems. However, in future antenna may be embedded inside portable devices like laptops, tablets, smart phones, satellite transmitters/receivers etc. Also, impact of antenna characteristics on human body can also be considered.

List of publications based on present research work

Referred Journals

1. Vandana Satam and Shikha Nema. "Compact, High Gain, Low Profile, Square Slot Diversity Antenna For KU Band Applications", at Microwave and Optical Technology Letters. **(Accepted for Publication)**

2. Vandana Satam and Shikha Nema. "Two Element Compact UWB Diversity Antenna with Combination of DGS and Parasitic Elements." Wireless Personal Communications 98, no. 3 (2018): 2901-2911.

3. Vandana Satam and Shikha Nema. "Dual notched, high gain diversity antenna for wide band applications." Microwave and Optical Technology Letters 59, no. 5 (2017): 1222-1226.

Referred conference proceeding

1. Vandana Satam , Shikha Nema, and Sanjay Singh Thakur. "Spanner Shape Monopole MIMO Antenna with High Gain for UWB Applications." In Proceedings of International Conference on Wireless Communication, pp. 129-138. Springer, Singapore, 2018.

2. Vandana Satam and and Shikha Nema. "Dual polarized four element diversity antenna for UWB applications." In 2017 IEEE International Conference on Antenna Innovations Modern Technologies for Ground, Aircraft and Satellite Applications (iAIM). IEEE, 2017.

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5. Vandana Satam , Shikha Nema and Sanjay Pawar. "Novel MSA using 'I'shape with Vertical Slot DGS.", 2014, ICON RFW 2014.

Under Review

1. Vandana Satam and and Shikha Nema. "Six-Element, Dual Polarized, High Gain MIMO Antenna for Multiband Applications", IEEE transactions on Antenna and propagation.