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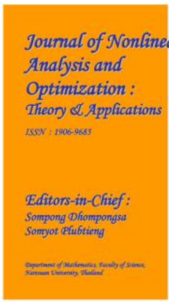

CHARACTERIZATION OF QUAD BAND CP-MIMO ANTENNA UNDERNEATH DGS FOR WIRELESS COMMUNICATION APPLICATIONS

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Abstract

In this study quad band two element MIMO antenna suitable for wireless communication applications is designed and validated experimentally. The footprint of MIMO antenna is 20×40mm^2 over FR-4 substrate of height 1.6mm. Antenna contains two radiating elements with inverted L slots to obtain high degree of isolation. To obtain lower operating bands and circular polarization, the ground of an antenna is iterated with full, half, step size. The antenna performance is evaluated in terms of coefficient of reflection, pattern of radiation, distribution of surface current and axial ratios.

Keywords: *MIMO (Multi-Input Multi-Output) antenna, FR-4 substrate, High isolation, Circular polarization.*

1. Introduction

As the cellular technology is developing at extreme rate every year like 4G (LTE) long term evolution, 5G and Ultra-Wideband technology which has wider frequency range and provides many applications for present upcoming technology where there is a need of high data rate, more channel capacity, so there is a high demand for MIMO antennas. Long evolution MIMO antennas, various forms of MIMO antennas are proposed by many people around the world for applications like ISM, WIMAX, etc. A MIMO antenna must have significant gain and diversity and it should be able to operate at multiple bands [1]. For the 5G networks as new features and services are going to be introduced a MIMO antenna, should have high spectral efficiency to provide high channel capacity with limited available spectrum with low power. In the wireless communication, size matters a lot so, in a MIMO antenna the size of the individual antennas should be compact and spacing between the antenna elements should also be minimum [2-3]. These MIMO antennas as placed at each base station and every mobile so it must provide enhanced data rates and should be reliable in a high fading environment as the mobile users may move from one place to another while communication is taking place and scattering may occur. For MIMO antennas compact and planar antennas have more demand due to their simple integration in wireless devices [4]. As the size of the antennas is decreasing, co-efficient of coupling between MIMO antennas is increased which results in reduction of efficiency of the system. In order to lessen the coupling, the isolation between antennas should be increased and the correlation between them must be minimum [2].

Many Wireless service applications like live HDTV broadcasting, internet, online gaming and real-time video streaming will allow mobile devices to manage high-data applications. To develop data transmission rate without raising the transmitted signal power or the network bandwidth, by incorporating multiple antennas at both the transmitter and receiver sides. It can be used to produce diversity and multiplexing benefits that advance the quality and efficiency of wireless systems [5-6].

The key problem MIMO faces is mutual coupling between radiating elements. This effects the overall antenna performance. By improving the isolation between the antenna elements the gain, direction, and correlation are improved. Two ground stubs may relate to the ground plane to improve the isolation and increase the impedance bandwidth [8-9]. Similar to traditional Single-Input Single-Output (SISO) wireless systems with MIMO technology are different through using multiple antennas both on the receiver and transmitter sides to achieve substantial power gain. Raising the antennas on mobile devices is thus a choice for raising the channel bandwidth [10].

MIMO is the most advanced wireless antenna technology used to transmit and receive information at optimized data rates in multiple antennas. The MIMO antenna system increases the wireless communications data rate without increase in power. The various antennas used by the transmitter are used to simultaneously transfer specific data sources, resulting in large data speeds from Megabits to Gigabits per second. Several studies tested idea of compressed MIMO designs for improved quality of high data rates and transmission. The antenna array consists of technology for increasing gains and directional radiation patterns at the base station for transmitter and receiver. The principle of gain enhancement using a technique called multiplexing was explored and researched the idea by an increase in high data rate signals. The electromagnetic interactions in the MIMO antenna between the radiation components result in mutual coupling. Isolating two antennas determines the association between antenna signals. The isolation of antennas, including the separation between a GPS Smartphone and a Wi-Fi antenna, is usually calculated for antennas. Diversity and separation of antennas sharing the same ground plane as low as 10 dB [11-14].

The defected ground is the ground structure for MIMO antennas by having different shapes of grounds for different antenna elements which are used to decrease the mutual coupling and improve the isolation among the antennas. Defected structured ground are formed by slots etching and adding stubs in ground plane. By adding long stubs in the ground plane, can also shift the lower and higher cut off frequencies and the reflection coefficient can be increased greatly. By etching slots between antenna elements of MIMO systems in the ground plane, can raise the isolation between the antennas which leads to reduction of the mutual coupling among antenna elements. The band is widened by etching slots in the ground plane in ring-shape [15].

MIMO technology has enticed considerable attention from both industry and academia in recent decades, due to its ability to increase spectral efficiency and connection reliability. For the MIMO system to operate well, it is important to have less coefficient of coupling between antenna elements. Generally, an adequate separation can be accomplished simply by putting the $\lambda/2$ elements apart or further, but due to inadequate space, this is often impractical for mobile handsets. MIMOs are recently applied to mobiles, using various networking systems such as WiMAX, WLAN and WCDMA to achieve high-speed transmission of data. Such an application needs a lightweight MIMO wideband because of the limited space available in wireless devices. A MIMO antenna should be of the written form as if it can fit into today's tiny wireless unit, while also offering good insulation characteristics with a low correlation coefficient. Several MIMO multi-band antennas have been suggested for mobile phones [16]. A MIMO antenna was dependent on a modified monopole antenna with a parasitic dimension covering different bands of communication except for the UWB band.

A three-dimensional quad-band MIMO antenna was also proposed for the WiMAX and WLAN bands. Monopole antennas were designed for a wideband MIMO antenna with 2 bent slits. The antenna is a key element of a wireless network since it serves as the wireless equipment input and output controller. Characteristics including bandwidth, channel capacity rate, data transmission speed, network reliability, interference between two signals, cost as well as device size, etc. play a major role in modern wireless systems [17].

When transmitting and receiving electromagnetic waves in wireless applications an antenna is used as a conducting feature. Since the antenna is a resonating device, its application-specific tuning plays a significant role. Multimedia software can be enhanced to deliver higher data levels. The channel capacity theorem used by Shanon's is used to improve channel efficiency by either increasing the signal to noise ratio or a wide range of bandwidth. It is difficult to achieve the above metrics due to specific regulatory laws and costs involved in purchasing bandwidth in the crowded spectrum. Using multiple radiating elements can improve the device data rate at the transmitter as well as at the receiver [18].

Multiple antennas work in different modes in MIMO, based on characteristics of the particular signal. Foschini had pioneered the concept of using multiple antennas for wireless transmission. Issues such as isolation enhancement, low-cost maintenance, and compact size are of vital importance to the designer in only one band as well as too many band applications making the MIMO antenna a challenging area. Information sharing is a vital role in the communications network. Cellular technology uses EM waves to send and receive wireless channel info. Cellular technology is an important part of modern communications networks and is used by most users. Wireless technology relies entirely on the communication medium such as antennas, which transforms electrical waves into EM waves and vice versa. For transmitting and receiving operations antennas used are very diverse. The microstrip patch antenna is a low-profile antenna used by portable devices such as handheld devices, laptops, tablets. Multiple Input and Multiple Output is an essential component of this technology for communication consistency, antenna distortion, less interference, more pectoral efficiency, high range and high data rate. When transmitting and receiving ends it uses multiple antennas [19-20].

This is used to improve system performance without having to increase power at the source. These devices can transmit many signals at a time as normal power levels. It can be done by channel-coding techniques. It increases the performance of data, efficiency of channel and reliability with no extra bandwidth being provided. This goal can be accomplished through the introduction of spatial diversity that spreads equal transmission power through antennas. It is an essential for the standard wireless networking that includes IEEE 802.11n, LTE, Wi-MAX and IEEE 802.11ac [7].

DGS for MIMO antennas by having different shape of grounds for ground structure (different antenna elements which are used to decrease coupling and increase the isolation between the antennas in MIMO system). DGS are formed by design slots and adding stubs in the ground plane. By adding long stubs in the ground plane, we can also shift the lower and higher cut off frequencies and reflection coefficient can be increased greatly. By etching slots between the antenna elements of ground plane in MIMO we can rise the isolation between the antennas which leads reduction of the mutual coupling between antenna elements. The band can be widened by etching slots in the ground plane in ring shape.

2. Design of Antenna

The footprints of MIMO antennas are of LsX Ws is 20X40mm^2 are fabricated on FR4 substrate of height 1.6mm. Two radiating elements are presented in the proposed design, which are present on the patch structure and a ground structure is located on the substrates other side. Microstrip feed lines with dimensions of L_f as length of the feed and the width is W_f is used to feed the radiating elements of the antenna, at the two inputs of the antenna. The radiating elements of the proposed model are of identical and are of polygon-shaped structures formed by using rectangular and triangular patches.

The antenna patch is etched with three slits of inverted L shaped to tune the antenna to operate at certain frequency bands and also to enhance the isolation in between radiating elements of the antenna. Several iterations were made to minimize the mutual coupling by altering the ground structure and increase the reflection factor and also to shift the cut-off frequency of the operating bands to resonate at required frequencies. The proposed antennas performance is vastly depending on the ground structure, it is vital for getting better impedance matching between the components of the antenna but also to improve the isolation among them. The evolution steps in the design of MIMO antenna especially the ground plane are represented in Fig 1. The Fig.2 is depicting (a) top view, (b) bottom view and (c) overall geometry along with parameters and corresponding dimensions in mm are mentioned in the Table.1

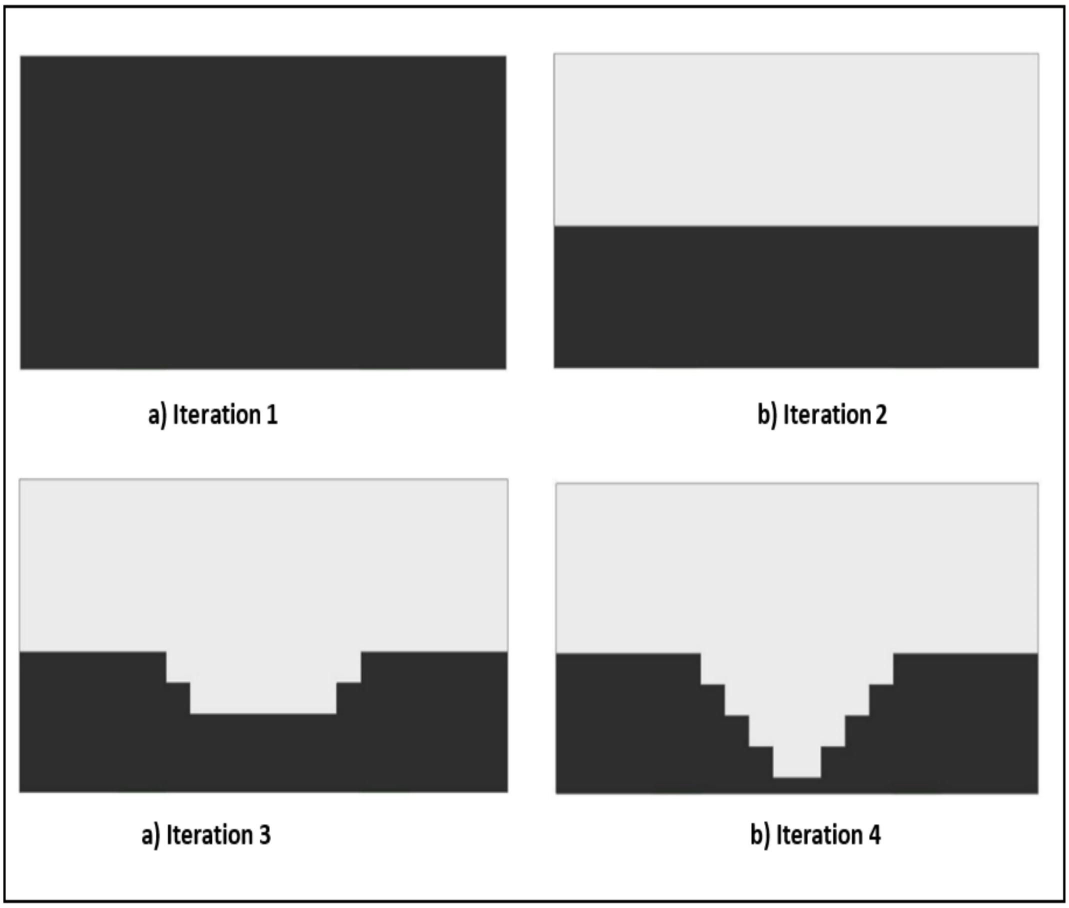

Figure 1. Iterations of the Ground Structure

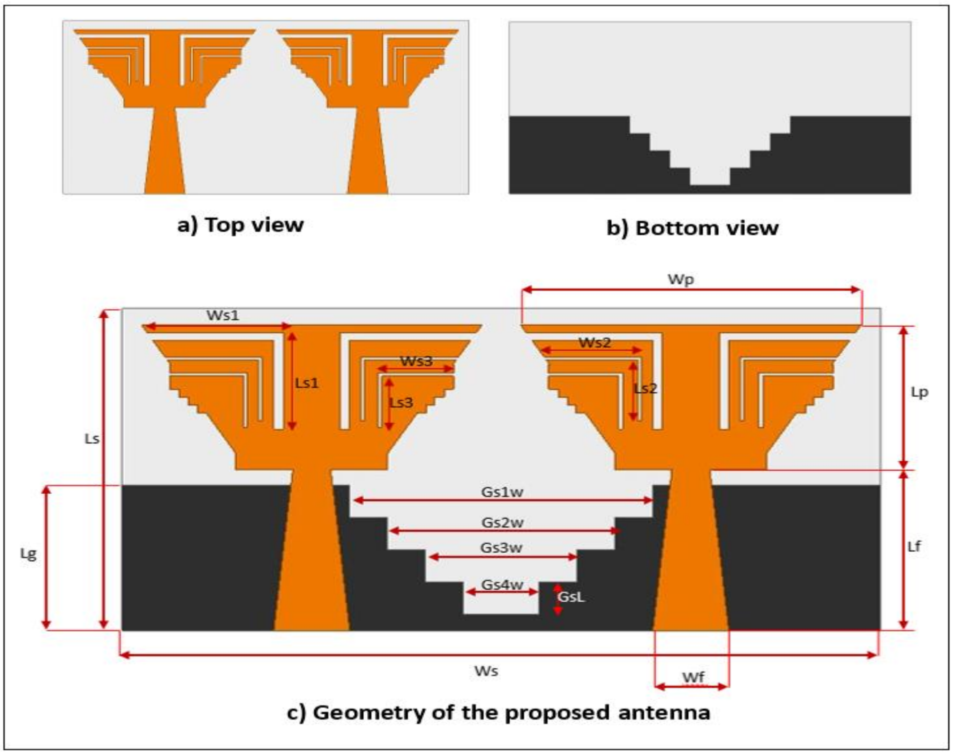

Figure 2. Proposed Antenna Geometry

Table 1: Proposed Antenna Dimensions

Antenna parame	Dimensions (m
Ls	20
Ws	40
Lp	9
Wp	18
Lf	10
Wf	4
Ls1	6
Ws1	7.1
Ls2	4
Ws2	4.8
Ls3	3.4
Ws3	4
Gsl	2
Gs1w	16
Gs2w	12
Gs3w	8
Gs4w	4
Lg	9
Wg	40

Since the two antenna radiating elements are identical and having the common ground structure for both of them so S11 and S12 will be the same as S22 and S21 and as shown in Fig.3. The effects on S11 concerning the change of the ground structure can be clearly represented in Fig.3 in each iteration step.

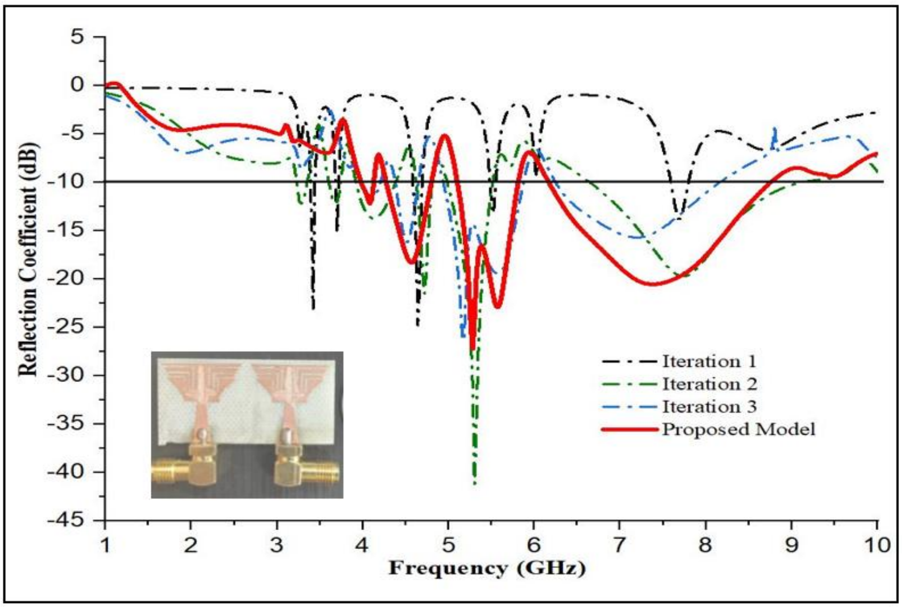

Figure 3. Reflection Coefficient

As shown in Fig.1 in iteration 1 full ground has been used which is having a dimension as Ls ×Ws =20×40 covering the entire bottom layer of the substrate. In this iteration, we have obtained 4 bands at 3.5, 3.8, 4.6, 5.7 GHz with a maximum reflection coefficient of -25dB at 4.6GHz.

In iteration 2 more than half of the ground has been removed and the dimensions of the resulted ground plane are Lg×Ws=9×40. This half ground has produced 5bands at the frequencies 3.3, 3.6, 4.5, 4.7, 5.4 GHz with the highest reflection coefficient of -42dB at 5.4 GHz and -23dB at 4.6GHz. But the remaining three bands are having very fewer reflection coefficients.

In the iteration 3, etching two rectangular slots with the same length but with different widths as Gs1w=16mm, Gs2w=12mm, Gs1=2mm, these slots resulted in shifting of the frequency of the bands that are obtained in the iteration 1 and iteration 2. In this iteration, the bands are obtained at 4.1, 4.5, 5.2, 5.6GHz which are the required frequency bands for the desired applications, but the return loss is very low.

For the proposed antenna to maximize the return loss at respective bands we are etching another two rectangular slots with dimensions Gs3w=8mm, Gs4w=4mm, Gs1=2mm in the ground plane in final iteration which resulted in producing bands at 4.0, 4.5, 5.2, 5.6 GHz frequencies with return losses of -12dB, -18dB, -27dB,-24dB at respective bands. In this final iteration, we have also obtained a wide band of 6.1 to 8.8 GHz with a peak return loss of -21dB which is used for various applications like 5G. And this made as to the final model because it has also attained a circular polarization feature in the 5.2 GHz frequency which is the Industrial, scientific and medical bands.

3. Results and discussions

3.1. Reflection coefficient

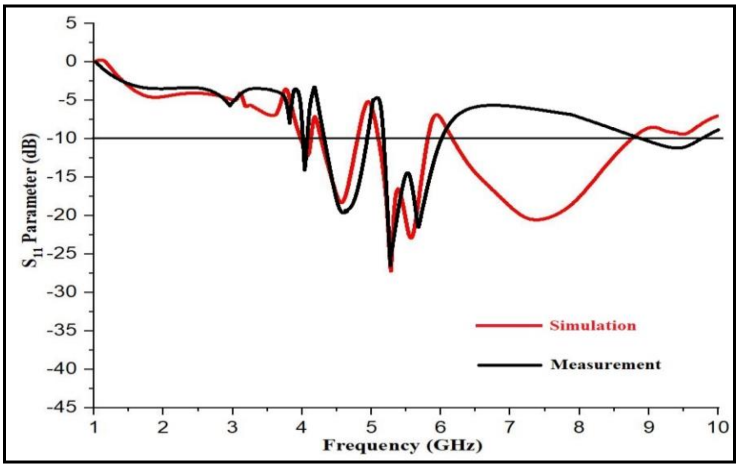

Figure 4. S_{11} Parameter of Proposed Antenna

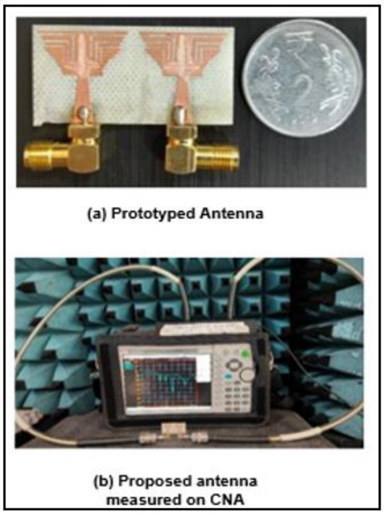

Figure 5. Fabricated Model of the Proposed Antenna

Figure 4. represents the simulation and measured S_{11} parameter values of the proposed MIMO antenna. A good agreement has been observed between the simulation and measured return loss values of the proposed MIMO antenna and it is having a return loss values of -12, -18, -27, -24 dB in simulation and the measured return loss values are -14, -19, -28, -23 at the bands of 4, 4.5, 5.2, 5.6 GHz frequencies respectively. These slight variations between measured and simulated values are due to mistakes that are happened in the fabrication precision and validates that proposed antenna is more suitable for the real time applications at frequencies of 4, 4.5, 5.2, 5.6 GHz for the applications of satellite communication, Fixed mobile, ISM and Radio navigation.

3.2. Radiation Patterns

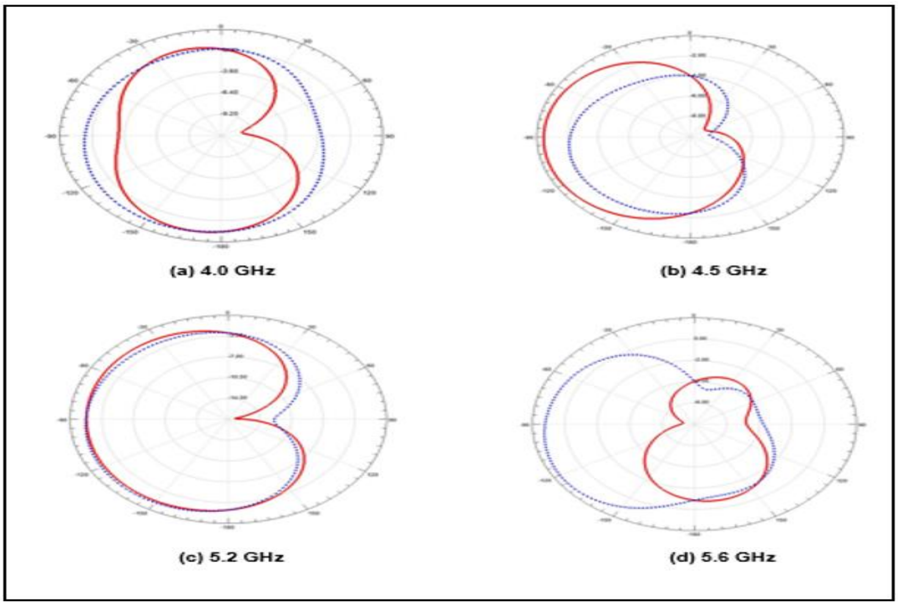

Figure 6. The 2D Radiation Pattern at 4 GHz, 4.5 GHz, 5.2 GHz and 5.6 GHz

The proposed MIMO antennas 2D radiation patterns has been taken at 4.0, 4.5, 5.2 and 5.6Ghz frequencies and are displayed in Fig.6. In radiation patterns the dotted blue line represents the measured value and the thick red line represents the simulated values. During the radiation pattern measurement which were taken in anechoic chamber, and port one is excited and the port 2 is terminated with a load of 50 ohm. Since the two antennas in the proposed antenna system are symmetric and have the same ground the radiation pattern will be same when port 2 is excited and port 1 is terminated. From Fig.6 its been noted that there is a good agreement between the simulated and measured values, which also holds good for the radiating patterns.

3.3. 3D Radiation Patterns

Fig. 7 represents the proposed Multiple-Input and Multiple-Otput antennas 3D radiation patterns at 4.0, 4.5, 5.2, 5.6 GHz frequencies. The 3D radiation pattern represents the gain of the antenna in three dimensional coordinates. The gain of the antenna is high in the direction of the peak radiation. Maximum power can be transmitted and received by antenna in the direction of the availability of peak gains. The gain of the antenna operating in the lower frequencies is little bit less at the higher frequencies. The gain of the antennas at four different frequencies is 4.93, 5.12, 5.95 and 6.73 at 4.0, 4.5, 5.2, 5.6 GHz frequencies.

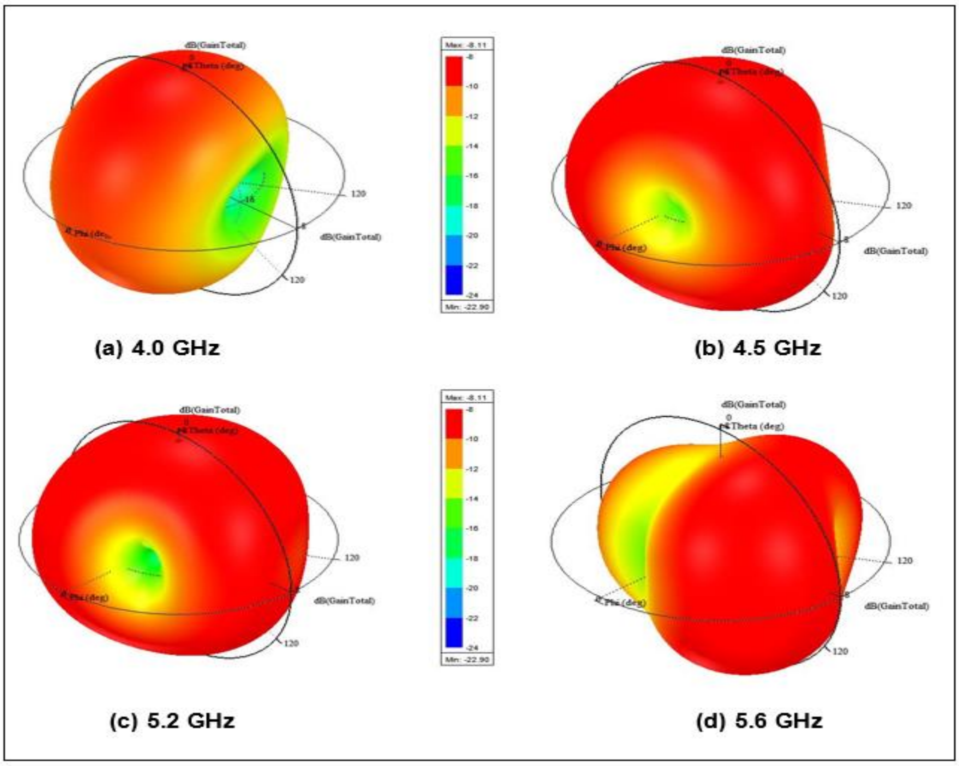

Figure 7. 3D Radiation Pattern at 4 GHz, 4.5 GHz, 5.2 GHz and 5.6 GHz

3.4. Surface Distribution

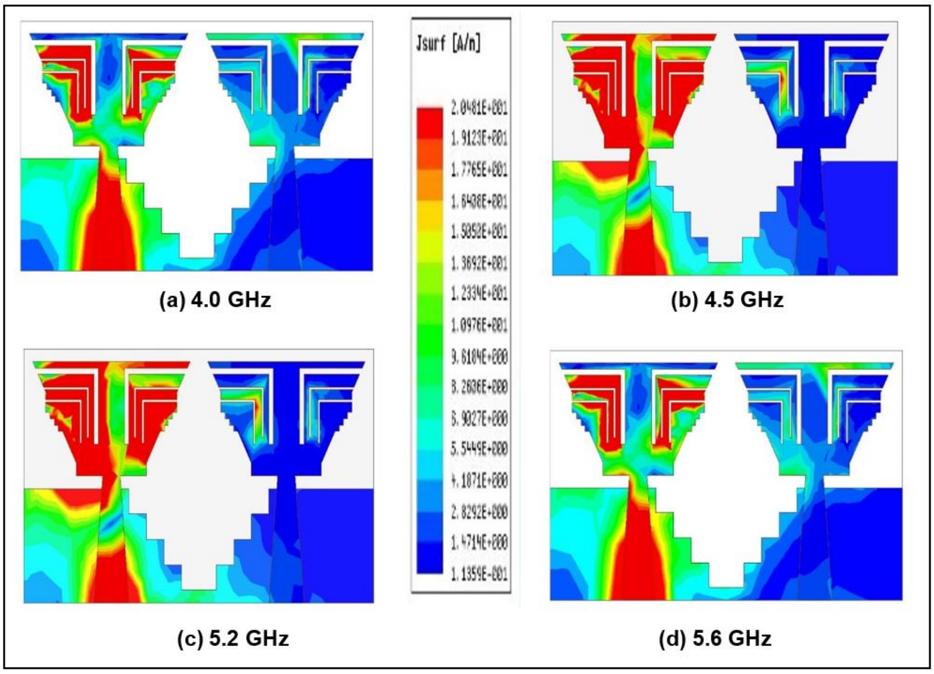

Figure 8. Surface Distribution of the Antenna at 4.0 GHz, 4.5 GHz,

5.2 GHz and 5.6GHz

The proposed antenna surface distributions at 4.0, 4.5, 5.2 GHz and 5.6 GHz has been shown in Fig.8. These surface distributions are taken by exciting the port 1 and terminating the port 2 of the proposed antenna with a load 0f 50ohm. From the figure it can be seen that no current is flowing from excited port antenna to the terminated one at both the frequencies. The surface distribution of the antenna element 2 when port 2 is excited and port 1 is terminated will also show same results since two antenna elements are identical. The mutual coupling of the antenna depends upon the current flow between the radiating elements, as there is no flow the mutual coupling will be very low resulting in the high accuracy of the proposed antenna.

3.5. Circular Polarization

In the recent past the popularity for the circular polarization has been drastically increased which allows the reception of the signal irrespective with the orientation between the transmitter and reciecving antennas and it has also the ability to suppress multipath fading effects. And here in this proposed design we have achieved circular polarization feature at 5.2 GHz frequency, which is ISM band. To furtherly guarenty the circular polarization it can be proved by surface current distribution with respect to change of phase and the axial ratios.

3.6. Surface Current Distributions with respect to Phase Change

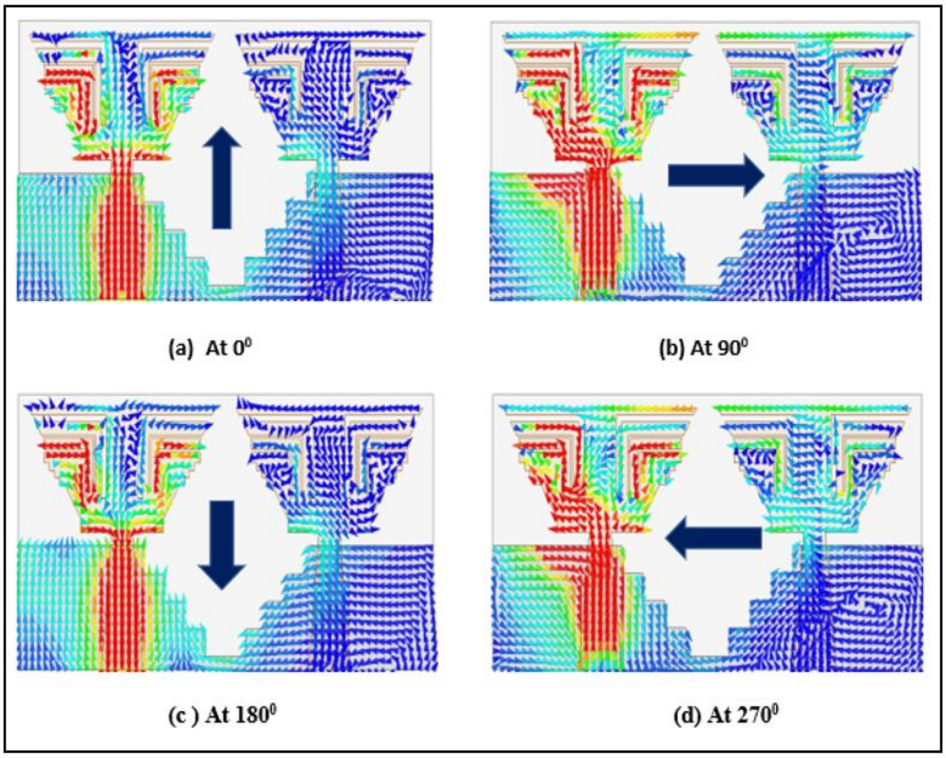

Figure 9. Proposed Antenna Current Distribution of Proposed Antenna at Frequency 5.2 GHz

Fig.9 represents the surface current distribution of the proposed antenna at the 5.2 GHz frequency with respect to the phase change of 0^0, 90^0, 180^0, and 270^0. It is observed from the figure that the directions of the currents are varying with respect to the phase. At the phase angle of 0 the currents are moving in upward direction and at 90-degree phase shift their movement is in right side direction, for 180-degree phase shift they are moving downward, finally for 270-degree phase shift the are moving left hand direction. For entire 360-degree phase shift they are moving in clockwise direction. This will happen in circular polarization and axial ratios furtherly prove the cp feature.

3.7. Axial Ratios

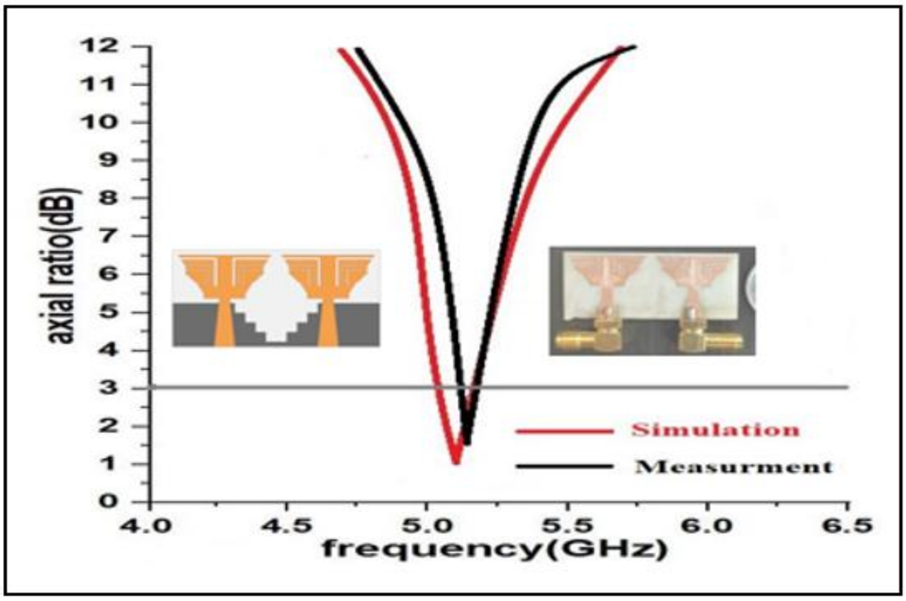

Figure 10. Axial Ratio of the Antenna at 5.2 GHz

Fig.10 shows the axial ratios of the simulated and measured values at 5.2GHz frequency. Generally axial ratios for any structure are the ratio of magnitude of the axis of the structure that is the longer axis is divided by the shorter axis. This value will show how close the structure is to circular pattern and ideally the value is zero and practically it should be less than -3dB. The simulated and the measured values are fall under -3dB. Hence this antenna is operating in circular polarization feature at 5.2 GHz frequency.

4. Conclusion

A compact sized tapped feed multi input multi output antenna with 4 resonating bands of 4.0, 4.5, 5.2, 5.6 GHz has been proposed with defected ground structure of step shape to achieve isolation is reflected less than -21dB and with a improved bandwidth. A decent conformity has been observed in between the simulated and measured values and the entire results indicate this proposed antenna is suitable for the applications of satellite communication, Fixed mobile, ISM and Radio navigation. And circular polarization feature at 5.2 GHz for Industrial Scientific and Medical bands has been a potential advantage for the proposed design.

5. References

[1] Venkateswara Rao M, Madhav BT, Krishna J, Usha Devi Y, Anilkumar T, Prudhvi Nadh B. ., “CSRR-loaded T-shaped MIMO antenna for 5G cellular networks and vehicular communications,” *International Journal of RF and Microwave Computer-Aided Engineering*., **(2019)** Aug; 29(8):e21799.

[2] Madhav BT, Usha Devi Y, Anilkumar T., “Defected ground structured compact MIMO antenna with low mutual coupling for automotive communications,” *Microwave and Optical Technology Letters*., **(2019)** Mar;61(3):794-800.

[3] Nadh BP, Madhav BT, Kumar MS., “Design and analysis of dual band implantable DGS antenna for medical applications,” *Sādhanā*., **(2019)** Jun 1; 44(6):131.

[4] Madhav BT, Krishna TR, Lekha KD, Bhavya D, Teja VD, Reddy TM, Anilkumar T., “Multiband Semicircular Planar Monopole Antenna with Spiral Artificial Magnetic Conductor”. *In Microelectronics, Electromagnetics and Telecommunications*., **(2018)** (pp. 599-607). Springer, Singapore.

[5] Prakash BL, Madhav B, Parimala BS, Sravya T, Anilkumar T., “Dual Band Notch MIMO antenna with meander slot and DGS for ultra-wideband applications,” *ARPN Journal of Engineering and Applied Sciences.*,**(2017)**;12(15):4494-501.

[6] Sai Ram, C., Ramesh, N.V.K., Madhav, B.T.P., Prudhvi Nadh, B., “Split ring loaded slotted patch antenna for wimax and X-band applications,” *International Journal of Innovative Technology and Exploring Engineering*., 8(8), **(2019),** pp. 449-451.

[7] Kishore, M.P., Madhav, B.T.P., Rao & M.V., “Metamaterial loaded elliptical ring structured MIMO antenna,” *International Journal of Engineering and Advanced Technology*., 8(6), **(2019),** pp. 1798-1801.

[8] Tilak, G.B.G., Kotamraju, S.K., Madhav, B.T.P., Sri Kavya, C., Venkateswara Rao, M., “Broken heart shaped monopole antenna for WiMAX applications,” *International Journal of Recent Technology and Engineering.*, 8(2), **(2019),** pp. 2333-2337.

[9] **Dr. Praveen Kumar Kancherla** et.al., “CSRR slotted CPW-Fed Compact Antenna for UWB Applications” International Journal of Psychosocial Rehabilitation, Vol. 24, Issue 06, 2020 ISSN: 1475-7192

[10] **Praveen Kumar Kancherla** et.al.“Multiband slotted Elliptical printed Antenna Design and Analysis” JMCMS, Vol.-14, No.-4, July-August (2019) pp 378-386.

[11] **K. Praveen Kumar** et.al. “Active Quad band Antenna Design for Wireless Medical and Satellite Communication Applications” JMCMS, Vol.-14, No.-4, July-August (2019) pp 239-252**.**

[12] **K. Praveen Kumar** et.al. “Active Coplanar Wave guide Fed Switchable Multimode Antenna Design and Analysis” JMCMS, Vol.-14, No.-4, July-August (2019) pp 188-196.

[13] **K.Praveen Kumar** et.al. “Fractal Array antenna Design for C-Band Applications”, IJITEE, Volume-8 Issue-8 June, 2019.

[14] **K.Praveen Kumar**, et.al. “Active Switchable Band-Notched UWB Patch Antenna”, IJITEE, Volume-8 Issue-8 June, 2019.

[15] **K.Praveen Kumar**, et.al. “Circularly Polarization of Edge-Fed Square Patch Antenna using Truncated Technique for WLAN Applications”, IJITEE, Volume-8 Issue-8 June, 2019.

[16] **K.Praveen Kumar**, et.al. “Triple Band Edge Feed Patch Antenna; Design and Analysis”, IJITEE, Volume-8 Issue-8 June, 2019

[17] **K.Praveen Kumar** et.al. "Optimization of EBG structure for mutual coupling reduction in antenna arrays; a comparitive study" IJET, Vol-7, No-3.6, Special issue-06, 2018. page 13- 20.

[18] **K.Praveen Kumar** et.al. "Active PSEBG structure design for low profile steerable antenna applications" JARDCS, Vol-10, Special issue-03, 2018.

[19] **K.Praveen Kumar** et.al., "Design and characterization of Optimized stacked electromagnetic band gap ground plane for low profile patch antennas" IJPAM, Vol 118, No. 20, 2018, 4765-4776.

[20] **K.Praveen Kumar** et.al." Surface wave suppression band, In phase reflection band and High Impedance region of 3DEBG Characterization" IJAER, Vol 10, No 11, 2015.