GSJ: Volume 13, Issue 5, May 2025, Online: ISSN 2320-9186

www.globalscientificjournal.com

DESIGN AND SIMULATION OF AN EIGHT ELEMENT MIMO ANTENNA FOR 5G WIRELESS COMMUNICATION

[1]Nwiido Friday and [2]Igbudu Augusta. O

[1 & 2] Department of Electrical/Electronic Engineering Technology.

Port-Harcourt Polytechnic, Rumuola, Rivers State, Nigeria.

Email: friday.nwiido@portharcourtpoly.edu.ng[1], austaqueen@gmail.com[2]

ABSTRACT

In this research, the design and simulation of an eight element Multiple Input Multiple Output (MIMO) antenna system for 5G network and millimeter-wave wireless communication was presented. The MIMO antenna was designed to overcome the challenges of signal fading, multipath fading, path loss, interference issues and limited spectrum. A single element Microstrip antenna was first designed, this was followed by the design of the eight element MIMO antenna. Rogers RT Duroid 5880 material was used as the substrate with relative permittivity (ε_r) of 2.2 and loss tangent (tan δ) of 0.019. The MIMO antenna was designed to operate at different frequencies of 26GHz-38GHz which falls within the frequency band for 5G and millimeter-wave communication. Computer Simulation Technology (CST) software was used in the design and simulation of the antenna. The simulation results showed that the MIMO antenna showed a better performance with efficiencies of 85.3%, 81.4% and 79.9% at 30GHz, 38GHz and 37GHz respectively with acceptable values of Voltage Standing Wave Ratios (VSWR), Thus making the MIMO antenna very suitable for 5G and millimeter-wave applications.

Keywords: MIMO, 5G Antenna, Radiation Pattern, Computer Simulation Technology, VSWR.

I. INTRODUCTION

Multiple Input Multiple Output (MIMO) antenna is an antenna technology for wireless communication systems in which multiple antennas are used at both the transmitter and the receiver. The antennas at each end of the communication circuits are combined to minimize errors, optimize data speed and improve the capacity of radio transmissions by enabling data to travel over many signal paths at the same time. Multiple-input and multiple-output (MIMO) technology is therefore identified as the key technology for 5G communication, as it enables systems to achieve peak data rates and higher spectral efficiency [1]. In addition, it also offers a significant capacity gain over conventional single-input–single-output (SISO) systems [2].

Most wireless communication systems use Single Input Single Output (SISO) systems where a single transmit (Tx) antenna is used for transmission to a single receive (Rx) antenna. Additional transmitting antennas and receiving antennas can be used to provide better result at the receiver. In today's communication, this scenario has change with the advent of Multiple Input Multiple Output (MIMO) communication systems. MIMO wireless systems employ multiple transmitter and receiver antennas and increase system capacity by means of spatial multiplexing, making use of the same frequency resources that would be utilized by a SISO system. As opposed to conventional SISO systems, MIMO systems benefit from multipath propagation and multiply transfer rates by taking advantage of random fading and multipath delay spread. In addition, MIMO provides spatial diversity both at the transmitter and the receiver, thus improving the transmission quality in terms of the bit-error rate (BER) [3].

According to Arun etal, (2016), MIMO techniques can be classified into three categories; the first category uses the increased of spatial diversity to enhance the power efficiency. While, the other category aims to increase the capacity by using layered method. Lastly, by knowledge the properties of the transmission channel; the third class analyses the coefficient matrix of the channel and uses these analyzing unitary matrices as filter in transmitter and receiver to improve the capacity.

The predicted increase in mobile network utilization requires a high data rate capacity to transfer information through the network. Currently, the limited capacity of the fourth generation (4G) mobile network cannot satisfy the present high data demand.

To meet this expected requirement, a new fifth generation (5G) mobile network has been proposed. In this paper, an eight element MIMO antenna system is presented. The MIMO antenna is to operate at frequency of 28GHz which covers the 5G wireless communication. This design will drastically improve the data throughput, enhanced the capacity of radio transmission, enabling data to travel through several paths at the same and will thereby improve the overall performance of the system.

II. LITERATURE REVIEW

The fifth generation (5G) of wireless communication networks is expected to drastically improve overall system performance, such as data throughput and energy efficiency [4].

On the other hand, in upcoming 5G wireless technology, improvement of the data throughput is guaranteed mainly by massive multiple-input and multiple-output (MIMO) technology which is capable of serving multiple users simultaneously within the same time and frequency resource, through a multibeam radiation pattern with a consequent increase in the spectral efficiency (SE) of the system [5]. For this reason, the limited available spectrum below 6GHz no longer satisfies the system's needs consequently, the millimeter-wave(mm-wave) band has recently drawn great attention for the next 5G wireless communications systems (Francesco etal, 2021). One of the biggest challenges for 5G at mm-Wave is the high propagation loss incurred. According to the Friis transmission equation, mm-Wave produces high path loss compared with lower frequency band [6].

$$P_r = P_t + G_t + G_r + 20log\left(\frac{c}{4\pi R}\right) \qquad (1)$$

Where; P_r is the power received, P_t is the transmitted power, G_t is the transmitter antenna gain, G_r is receiver antenna gain, c is velocity of light and R is the distance between the transmitter and the receiver.

In MIMO, mutual coupling between multiple antenna elements is a key problem and is a potential area under research. Different techniques have been proposed in related literature by authors across the globe. One such technique is presented in [7], in which a meta-material polarization rotator (MPR) wall is used to improve the decoupling between the two dielectric resonator antennas (DRAs). The isolation achieved at 60 GHz is 22 dB. The proposed design, however, is composed of metamaterials and dielectric resonators, which are quite costly, making it not suitable for future portable terminals.

Several studies and analysis have been proposed for different MIMO designs as potential 5G candidates for mobile terminals [1]. [8] presented a 28 GHz phased array composed of 64 elements (8×8) antenna. Massive MIMO systems with 64 elements operating around 28 GHz and 40 GHz were designed with fully digital beamforming. Dual polarized phased array transceivers able to provide two concurrent independent beams, and hence double the channel capacity, have also been proposed. However, some obstacles prevented the achievement of both seamless and ubiquitous wireless connectivity if only the terrestrial infrastructure is considered. In fact, terrestrial ground stations cannot be deployed in off-grid or inaccessible areas, such as rural zones, oceans, deserts and generally harsh and remote environments. To this end, aerial wireless communication based on the employment of high-altitude platform stations (HAPSs) will play a paramount role in providing everywhere with access to the global network.

An inverted L-shaped monopole eight elements Multiple Input Multiple Output (MIMO) antenna system was presented by [9]. The multi-antenna system was designed on a low cost 0.8 mm thick FR4 substrate having dimensions of 136 × 68 mm^2 resonating at 3.5GHz with a 6dB measured bandwidth of 450MHz and with inter element isolation greater than 15 dB and gain of 4 dBi. The proposed design consists of eight inverted L-shaped elements and parasitic L-shaped stripes extending from the ground plane. These shorted stripes acted as tuning stubs for the four inverted L-shaped monopole elements on the side of chassis. This was done to achieve the desired frequency range by increasing the electrical length of the antennas. A prototype was fabricated and the experimental results show good impedance matching with reasonable measured isolation within the desired frequency range. The MIMO performances, such as envelope correlation coefficient (ECC) and mean effective gain (MEG) were also calculated along with the channel capacity of 38.1bps/Hz approximately 2.6 times that of 4 × 4 MIMO system.

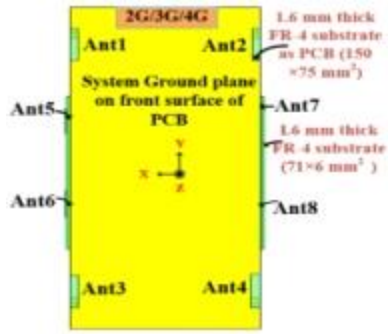


Figure 1: Proposed MIMO Antenna [9].

A MIMO antenna system for modern 5G handheld devices was proposed. The system which consists of health care and high delivery rate was based on an H-shaped monopole antenna system that offers 200MHz bandwidth ranges between 3.4–3.6 GHz and the isolation between any two elements is well below -12 dB without using any decoupling structure. The proposed system is designed on a commercially available 0.8mm-thick FR4substrate. It was found that ECC is 0.2 for any two radiating elements which is consistent with the desirable standards and channel capacity is 38bps/Hz which is 2.9 times higher than 4×4 MIMO configuration [1]. [10] presented a MIMO antenna for future 5G communication with a proposed operating frequency of 37GHz. In this design, a single element patch antenna was used to design a seven element MIMO antenna. The substrate material used for the design was Rogers RT 5880 with dimensions $64\times 32mm^2$ and thickness 0.508mm. The overall dimension of the antenna was $14 \times 16\ mm^2$.

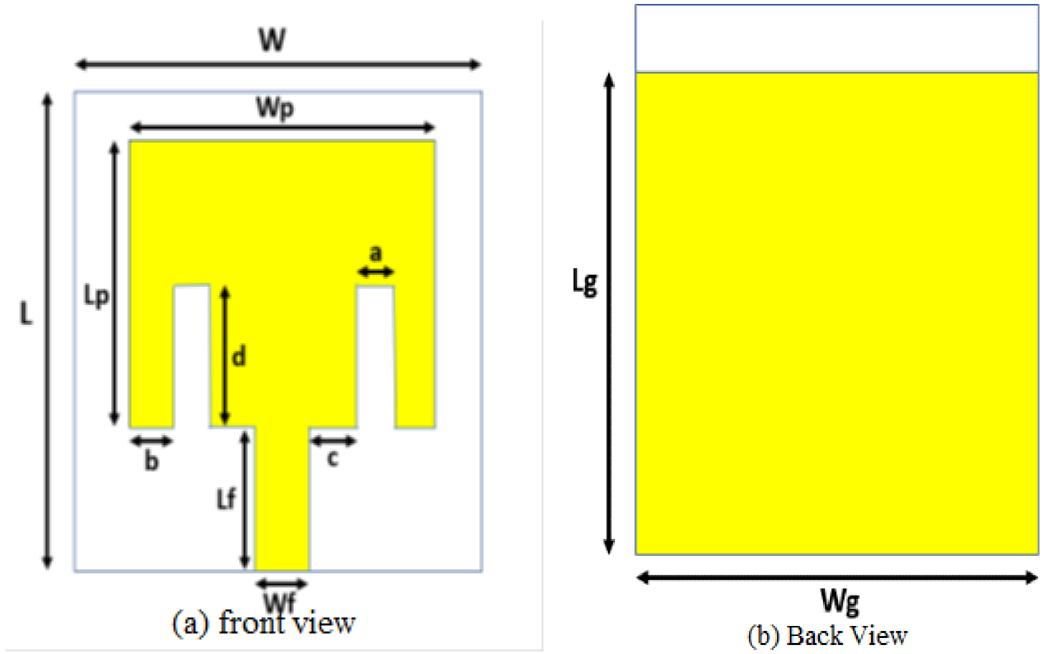


Figure 2.11: The Single element antenna design [10](Muhammad et al, 2020

The MIMO antenna with seven elements was simulated in Microwave wave Studio CST software and the results showed that the antenna resonates at a frequency of 37.02GHz with a single element antenna gain of 7.7dBi and a bandwidth of 1.107GHz. The antenna was bulky in size which does not really match with the compact size requirements for 5G mm-wave communication. Thus, the antennas need to be reconfigured using the right techniques. This will further cause a reduction in the size of the antenna, thereby making it suitable for 5G mm-wave communication.

[11] presented a dual-band 8×8 MIMO antenna that operates in the sub-6 GHz spectrum for future 5G multiple-input multiple-output (MIMO) smartphone applications. The antenna was designed to operate at 3100-3850 MHz and 4800-6000 MHz bands. Isolation between the orthogonal antennas were improved due to the addition of a short neutral line. The fabricated antenna prototype was tested and the result shows that it offers good performance in terms of Envelope Correlation Coefficient (ECC), Mean Effective Gain (MEG), total efficiency and channel capacity. MIMO offers spatial multiplexing gain by enhancing the channel capacity [12].

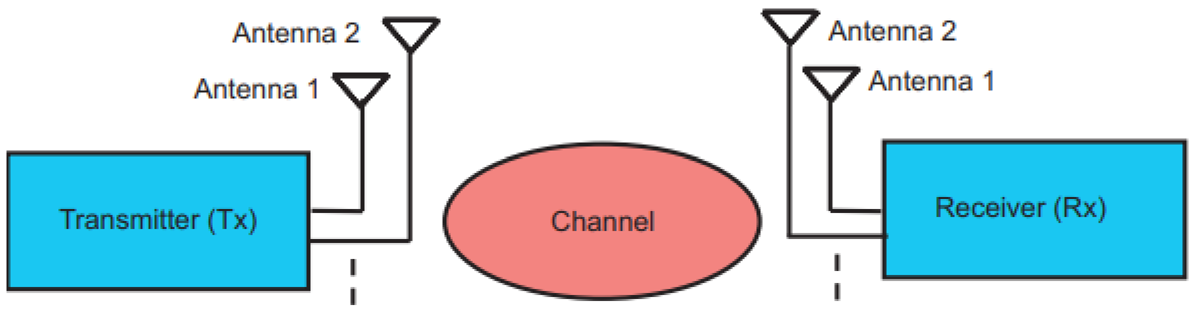


Figure 2.3: Block diagram of MIMO antenna [12]

[13] proposed a four-element MIMO dual band, dual diversity, dipole antenna for 5G-enabled handsets. The proposed antenna design relied on space diversity as well as pattern diversity to provide an acceptable MIMO performance. It simultaneously operates at 3.6 and 4.7 sub-6 GHz bands. Rogers 5880 was used as the substrate material to support the radiating antenna elements. The dimensions of the substrate were given as: 138mm, 67mm and 1.6mm representing the length, width and thickness respectively. The dielectric constant of the substrate material was $\varepsilon_r = 2.2$ with a dissipation factor $\tan \delta = 0.0005$. The measured SAR values averaged over 10 g tissue volume was 1.8 W/kg at 3.6 GHz and 1.7 W/kg at 4.7 GHz, respectively, which satisfy the requirements set by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

The authors [14] proposed a10 element sub-6 GHz Multi-Band double-T Based MIMO Antenna System for 5G Smartphones. The projected T-shaped slot antenna fed with a T-shaped microstrip line (hence named Double-T) was designed for LTE band 42 (3.4-3.6 GHz), LTE band 43 (3.6-3.8 GHz) and LTE band 46 (5.15-5.925 GHz). The dimensions of the PCB was 150×80 mm which is the standard size of 5.7-inch mobile handset [15]. The design was fabricated using flame Retardant 4(FR4) substrate with relative permittivity of 4.4 and loss tangent of 0.002. The individual antenna elements were fed with 50Ω T-shaped microstrip feed-line that is linked to a ground plane through a Sub-Miniature Version A (SMA) connector. The results showed that all three bands have the return loss values (<-6 dB), has a good isolation of more than 20 dB, an Envelope correlation coefficient (ECC) value of less than 0.06 and efficiency of greater than 83%.

The ergodic channel capacity of the proposed antenna was 41 bps/Hz at 20 dB SNR. The antenna was not reconfigurable; it could only operate within the stated frequencies of the sub 6GHz.

III. RESEARCH METHODOLOGY

In this design, an eight-element reconfigurable MIMO antenna was deigned. The design started with the design of a single element antenna. Microstrip patch antenna was used. The design process started with the consideration of the parameters used for the design of a single element antenna, from which the eight element MIMO antenna was designed. The MIMO antenna was designed and simulated using Computer Simulate Technology (CST) Microwave studio software. Thus, it involves the design of the antenna patch, the ground plane, the substrate and the field line dimensions. The computation of the antenna dimensions were achieved using microstrip design equations. The antenna has a basic rectangular patch shape, Rogers RT/Duroid 5880 was used as the substrate with dielectric constant (ε_r) = 2.2, loss tangent (tanδ) = 0.019 and resonant frequency (f_r) = 28 GHz, respectively. According to [16] and [17]. The height (h) of the substrate is determined as given in Equation (1)

$$h \leq 0.3 \times \frac{\lambda_0}{2\pi\sqrt{\varepsilon_r}} \quad (1)$$

The free wavelength(λ_0) is obtained using Equation (2) $\lambda_0 = \frac{c}{f_r}$ (2)

The width of the microstrip patch antenna (W_P) computed from Equation (3) is given by:

$$W_p = \frac{c}{2f_r\sqrt{\frac{\varepsilon_r+1}{2}}} \quad (3)$$

Where; c is the velocity of light ($c = 3 \times 10^8 m/s$), fr is the resonance frequency and ε_r is the dielectric constant.

The actual length of the patch (L_P) is given by $L_P = L_{eff} - 2\Delta L$ (4)

But the effective length is given by $L_{eff} = \frac{c}{2f_r\sqrt{\varepsilon_{reff}}}$ (5)

The extension length ΔL is deducted from the calculated length L_P of the patch as given in Equation (6).

$$\Delta L = 0.412h\frac{[\varepsilon_{reff}+0.3]\left[\frac{w}{h}+0.264\right]}{[\varepsilon_{reff}-0.258]\left[\frac{w}{h}+0.813\right]} \quad (6)$$

The effective dielectric constant (ε_{reff}) is given by Equation (7):

$$\varepsilon_{eff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\frac{1}{\sqrt{1+\frac{12h}{W_p}}} \quad (7)$$

Where; ε_r is the dielectric constant, h is height of the substrate and W_p is width of the patch.

The ground plane dimensions are calculated thus:

$$Lg = L_P + 6h \quad (8)$$

$$Wg = W_P + 6h \quad (9)$$

According to Pozar (2012), the width of the transmission line is calculated thus;

For $\frac{W_f}{h} > 2$;

$$\frac{W_f}{h} = \frac{2}{\pi}\left[B - 1 - \ln(2B-1) + \frac{\varepsilon_r-1}{2\varepsilon_r}\left\{\ln(B-1) + 0.39 - \frac{0.61}{\varepsilon_r}\right\}\right] \quad (10)$$

where $B = \frac{377\pi}{2Z_0\sqrt{\varepsilon_r}}$

The minimum length of the feedline (L_f) is approximated from the expression in equation

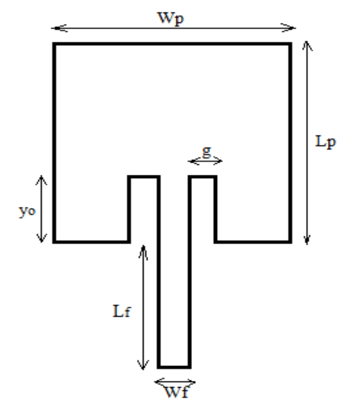
$$L_f = \frac{6h}{4} \quad (11)$$

The resonant input resistance R_{in} is given by Equation (12) as;

$$R_{in}(y = y_o) = \frac{1}{2(G_1 + G_{12})}\cos^2\left(\frac{\pi y_o}{L_p}\right) \quad (12)$$

Where; y_o is the inset fed distance, G_1 is the conductance of the single slot, G_{12} is the mutual conductance and L_p is the length of the patch.

The single element radiating structure with detailed dimensions is shown in Figure 1, while the schematic diagram is shown in Figure 2.



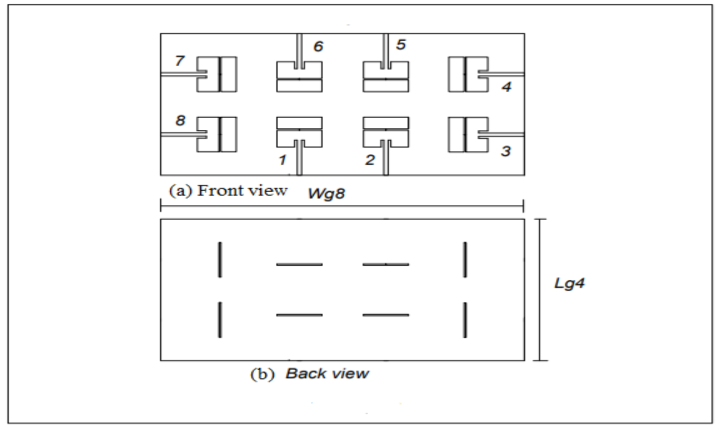
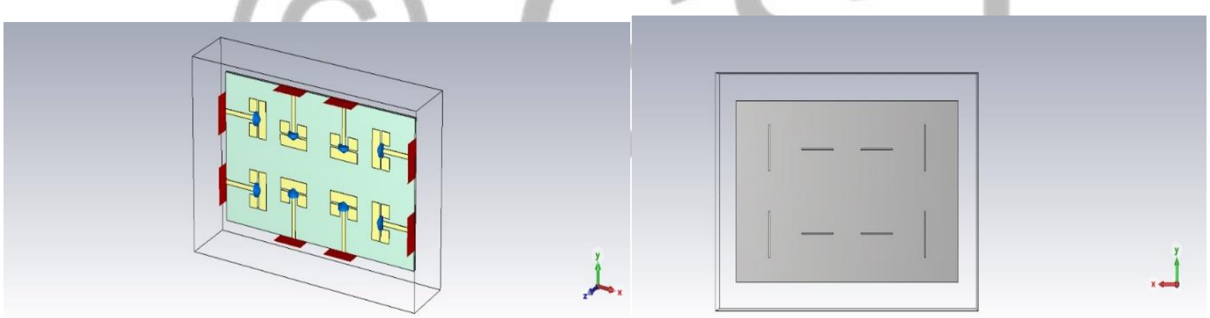


Figure 1: Single antenna element

Figure 2: Schematic diagram of the Eight MIMO Antenna

The simulation process was carried out on Computer Simulation Technology (CST) Microwave studio using the dimensions. Figure 3 shows the 3D view of the reconfigurable MIMO antenna modelled in CST software.



(a) Perspective 3D View

(b) Back View

Figure 3: Eight element reconfigurable MIMO antenna in CST

1V. RESULT AND DISCUSSION

The eight element MIMO antenna was simulated on CST Microwave studio software and the simulated results showing the return loss, VSWR, radiation pattern, gain and efficiency.

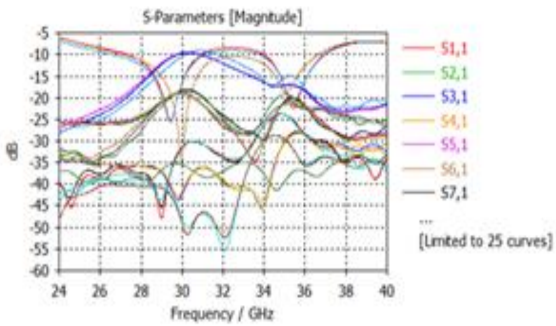


Figure 4: S-Parameter of Eight element MIMO

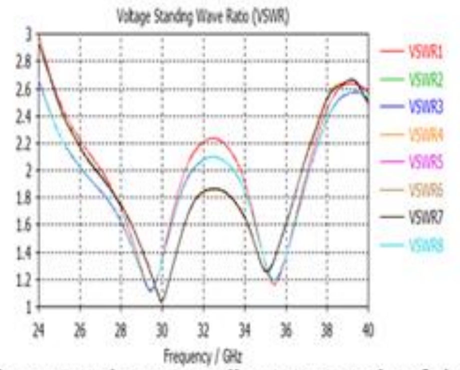


Figure 5:Voltage Standing Wave Ratio of the Eight element MIMO antenna.

Figure 5 shows the Voltage Standing Wave Ratio (VSWR) of the eight element MIMO antenna. From Figure 5, VSWR has values of 1.04 and 1.4 at 30GHz and 1.4 and 1.6 at 36GHz. These values lies within the acceptable values of VSWR.

The results of the realized gain and efficiencies of the eight-element reconfigurable MIMO antenna are summarized in Table 4.1. From the results obtained, at 30GHz, the MIMO antenna exhibit a maximum gain and efficiency of 6.65dBi and 85.3% respectively. Similarly, at a frequency of 36GHz, we have a gain of 6.36dBi and efficiency of 77.4%. This implies that the MIMO antenna will perform optimally at these frequencies.

Table 4.1: Gain and efficiencies of the eight-element reconfigurable MIMO antenna

Frequency (GHz).	**Gain (dBi)**	**Efficiency (%)**
26	5.40	79.2
28	5.93	66.7
30	6.65	85.3
36	6.36	77.4
37	5.64	79.9
38	5.24	81.4

The directivity plots for the eight element MIMO antenna for phi = 0 are shown in Figure 6 and 7 below. From figure 6 and 7, it is observed that the antenna shows an omnidirectional radiation pattern at frequencies 30GHz and 36GHz respectively.

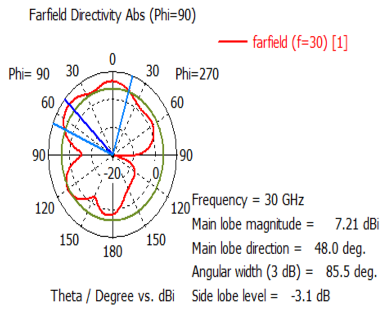


Figure 6: Directivity plot at 30GHz (phi=90)

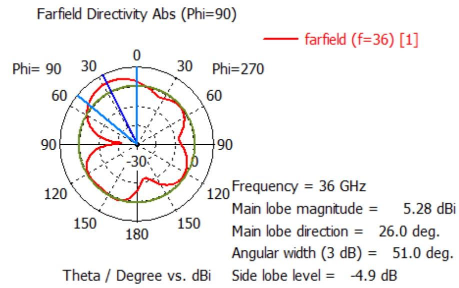


Figure 7: Directivity plot at 36GHz (phi=90)

At phi =0, the directivity plots shows a unidirectional radiation pattern as shown in Figure 8 and 9.

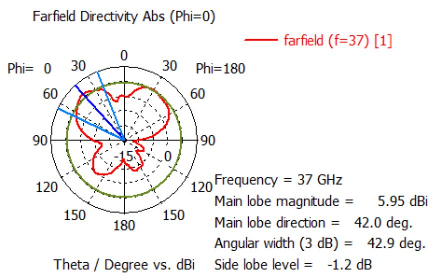


Figure 8: Directivity plot at 37GHz (phi=0)

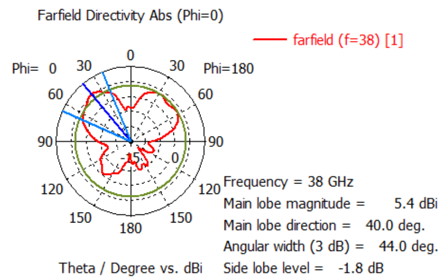


Figure 9: Directivity plot at 36GHz (phi=0)

The results of the directivity plots obtained both for phi=90 and phi=0 shows that the MIMO antenna radiates in different directions. This shows radiation pattern reconfiguration was realized.

V. CONCLUSION

In this research, the design and simulation of an eight element reconfigurable Multiple-input Multiple output (MIMO) antenna for 5G wireless communication was carried out. A single element microstrip patch antenna was first designed using microstrip design equations. Rogers RT 5880 was used as the substrate with relative permittivity of 2.2 and loss tangent of 0.009. The single element antenna was made reconfigurable and modelled using Computer Simulation Technology (CST) software from which an eight element MIMO antenna was designed. The simulated results on CST software showed that frequency and radiation pattern reconfiguration was achieved. Similarly, the performance of the MIMO antenna shows reasonable gain and efficiency at various frequencies with acceptable Voltage Standing Wave Ratios (VSWR) making it very suitable for wireless communication operating at 5G and millimeter wave.

REFERENCES

[1] N.O. Parchin, Y.I. Al-Yasir, H.J. Basherlou, A.M. Abdulkhaleq, M. Sajedin, R.A. Abd-Alhameed & J.M Noras. Modified PIFA array design with improved bandwidth and isolation for 5G mobile handsets. *In Proceedings of the 2019 IEEE 2nd 5GWorld Forum (5GWF), Dresden, Germany*, pp. 199–203, 2019.

[2] M. Johnny & M.R. Aref. Blind Interference Alignment for the K-User SISO Interference Channel Using Reconfigurable Antennas. *IEEE Communication. Letters. Vol*.22, pp.1046–1049, 2018.

[3] A. Arun, . O.A. Siksha & N.M. Saurabh. Design and Performance Analysis of MIMO- OFDM System Using Different Antenna configurations. *International Conference on Electrical, Electronics, and Optimization Techniques (ICEEOT*), 978-1-4673-9939-5/IEEE, India. 2016.

[4] E.G. Larsson, O. Edfors, F. Tufvesson &T.L. Marzetta. Massive MIMO for next Generation Wireless Systems. *IEEE Communication. Mag.* 52, 186-195, 2014.

[5] A.D. Francesco & G. Simone (2021): Spectral Efficiency Improvement of 5G Massive MIMO Systems for High-Altitude Platform Stations by Using Triangular Lattice Arrays *Sensors*, University of Pisa, 56122 Pisa, Italy. https://doi.org/10.3390/s21093202, 2021.

[6] A.A.A. Emad. Reconfigurable and MIMO Antenna Systems for Mobile Communications. *A thesis submitted for the degree of Doctor of Philosophy* University of Queensland, Australia, 2019.

[7] M. Sun, Z. Zhang , Zhang, F & Chen, A (2019). L/S multiband frequency reconfigurable antenna for satellite applications, *IEEE Antennas and Wireless Propagation Letters, Vol*. 18, No. 12, 2617– 2621

[8] K. Kibaroglu, M. Sayginer., T. Phelps & G.M. Rebeiz. A 64-Element 28-GHz

Phased-Array Transceiver With 52-DBm EIRP and 8–12-Gb/s 5G Link at 300 Meters Without Any Calibration. *IEEE Trans. Microwaves. Theory Tech.* 66, 5796–5811, 2018.

[9] U. Abdullah, A. Altaf, M.R. Anjum, Z.A. Arain, A.A. Jamali, M. Alibakhshikenari Falcone & Limiti. Future Smartphone: MIMO Antenna System for 5G Mobile Terminals, *IEEE ACCESS* Vol.9, pp.91593-91603.2021.

[10] J. R, Muhammad, S. Ayesha, Z. Muhammad, J. Anum , A. Yasar & L. Jonathan. MIMO Antennas for Future 5G Communications. *Conference Paper*,pp.2-5 . *DOI*: 10.1109/INMIC50486.2020.9318126, 2020.

[11] D. Serghiou & M. Khally. Sub-6GHz Dual-Band 8×8 MIMO Antenna for 5 G Smartphones, IEEE Antennas and Wireless Propagation, Vol. 19, Issue:9, 2020.

[12] L. Malviya, R.K. Panigrahi & M.V. Kartikeyan. MIMO Antennas for wireless Communication. Theory and Design. Taylor & Francis group, CRC Press 6000 Broken Sound Parkway NW, Suite 300, Boca Raton, FL 33487-2742. http://taylorandfrancis.com, 2021.

[13] M.A. Jamshed, M. Ur-Rehman, J. Frnda, A.A. Althuwayb, A. Nauman & C. Korhan. Dual Band and Dual Diversity Four-Element MIMO Dipole for 5G Handsets. *Sensors*, https://doi.org/10.3390/s21030767, 2021.

[14] N. Jaglan, S.D. Gupta, B.K. Kanaujia & S. S. Mohammad. 10 Element Sub-6-GHz Multi-Band Double-T Based MIMO Antenna System for 5G Smartphones. IEEE Access, DOI: 10.1109/ACCESS.2021.3107625,2021.

[15] H. Zou, Y. Li, C.Y.D. Sim & G. Yang. Design of 8 × 8 dual-band MIMO Antenna array for 5G smartphone applications, *International Journal of RF Microwaves. Computer Aided Eng., Vol.* 28, no. 9, p. e21420, 2018.

16] G. Kumar & K.P. Ray. Broadband Microstrip Antennas, Artech House, USA. pp.18-142, 2003.

[17] J.C. Saturday, K.M. Udofi & A.B. Obot. Compact Rectangular Slot Patch Antenna for Dual Frequency Operation Using Inset Feed Technique. *International Journal of Information and Communication Sciences,* 1(3), 47–53, 2017.