A Broadband MIMO Antenna for UWB Applications

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Abstract- This paper presents 2× 2 multiple-input multiple-output (MIMO) antennas covering UWB wireless applications like portable handset devices, mobile phones, and Bluetooth devices. The overall wide bandwidth of the proposed antenna is 2.4 GHz - 7.3 GHz. The proposed antenna's bandwidth covers different bands of WiMAX and WLAN applications, and it gives better isolation in close space. A U-shaped patch antenna is simulated on the Rogers substrate, to achieve the antenna's broadband features, the size of the proposed antenna is 28.79 × 18.79 mm^2. The achieved isolation, highest gain, and the total efficiency of the 2 x 2 MIMO network is -23dB, 6dBi, and 95% respectively.

Keywords- Portable Devices, MIMO, Mutual Coupling, CPW, Broad Bandwidth

I. Introduction

The dual-band element technology becomes a captivating choice for the antenna designers owing to the growing demands for high data transmission [1]. In the previous techniques, the physical structure of antennas was kept huge, and this required a large amount of power consumption. In need of this constraint, the antenna's size is going to be reduced in the recent few years, which will prove to be favorable in reduced mutual coupling and increased isolation [2]. Isolation can be improved using various methods which have been introduced like ground slots, electromagnetic bandgap (EBG) structures, polarization diversity, etc. [3]. MIMO technology uses different channels for the transmission and reception of data. In this arrangement, the mutual coupling between antenna elements has a significant impact on the overall performance of the antenna.

The MIMO system with compact size and high-gain characteristics is among one of the most promising candidates used for the WiMAX and WLAN systems, and hence, could be used to form multiple antenna systems for Bluetooth applications [4]. The need for a MIMO antenna is to increase the transmission rate in wireless communication. MIMO antenna has wide bandwidth; the structure is compact, undergo orthogonal polarization, high isolation due to which it has applications in 5G communication. The purpose of the MIMO antenna is to give the broader frequency spectrum, high data rate, greater impedance using a cross-polarization mechanism to form bowtie [5]. The requirement of the coverage area of the base station, the antenna should design in such a way that its spectrum covers the ample space with low cost to achieve more excellent isolation. High isolation can be made in compact volume using a polarization diversity technique. Also, the high isolation results in improved efficiency of the antenna [6]. To get multiple applications from the antenna, various bands operate to achieve more than one use from the antenna. Therefore, the MIMO antenna fulfills this requirement to get a higher data rate.

A broadband MIMO system a lot be made up of multiple radiation elements located next to each other. Wideband technology is the most promising solution for wireless communication systems ranges from 3.1 GHz to 10.6 GHz [7]. There are a few approaches for placing antenna elements at different distances and positions. The distance between the various elements of the MIMO antenna also plays a vital role while improving antenna parameters, therefore it is kept small to attain the high radiation efficiency of the whole antenna system [8]. To achieve better mutual coupling, place the elements far away from each other, usually half of the wavelength to get the minimum effect on individual elements. The antenna elements can be positioned at different orientations like 0°, 90°, and 180°. The antenna elements should be placed orthogonal (90°) to each other, to increase the correlation and better mutual coupling of the antenna. The orthogonally mounted antenna elements have the best polarization diversity as well as high isolation [9].

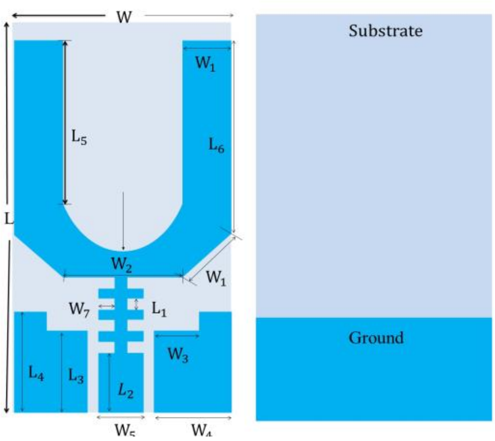
In this paper, the defected ground structure (DGS) [10] has been introduced which is used to study the capacitive and the inductive nature by limiting the surface waves, and as a result of this, the mutual coupling, as well as the correlation coefficient will be reduced between antenna elements. Thus, a practical dual-element antenna must have a less signal correlation, and the antenna elements should be more efficient for good impedance characteristics [11]. The ease of microstrip patch antennas having direct-feed structures should have very compact sizes and also have higher bandwidth [12]. In case coupled feeding structures, the antennas possess higher bandwidths, but their sizes are even more considerable as compared to the direct feed structure antennas [13].

II. ANTENNA DESIGN

As the antenna handling technology grows, the integration of the antenna becomes simpler. But due to the limitation of antenna size and to be used in a mobile phone, the antenna should have high Q value. Furthermore, if antennas are placed in contracted space, then there is strong mutual coupling which results in poor isolation. Consequently, the design of a compact broadband MIMO antenna ought to be realized from two points under a given size and to achieve broadband bandwidth. To get good isolation and bandwidth at low frequencies is challenging to obtain [14]. In general, the patch bandwidth can be enhanced by increasing the thickness of the substrate, but the cross-polarization level and surface wave also become expanded, which is not desirable. Moreover, the isolation will be less between vertical and horizontal polarization. To achieve a broader bandwidth, a U-shaped patch is introduced on the Rogers substrate [15].

A. Geometrical Analysis

The U-shaped patch antenna having multiple slots in feedline is constructed on ROGERS RT/Duroid 5880 substrate of thickness 0.787 *mm* with dielectric constant, ε_r= 2.2 and loss tangent, $tan\delta = 0.0009$. The original dielectric size is 28.79 x 18.79 mm^2.



(a) Front view (b) Back view

Fig. 1. Broadband single element antenna

The length and width of the feedline is L_2=10.54 *mm* and W_3=3 *mm*, respectively. The antenna consists of the co-planner waveguide, and a conducting ground is introduced at the other side of the substrate of size 8 x 18.79 mm to reduce the mutual coupling between the antennas [16]. The patch in the design has size 18 x 18.5 x 0.035 mm^3 and has a circular slot of radius 6 mm. All slots in the feed are of equal length and width. Considering the broadband requirements, a feedline has a symmetrical structure of slots to get a broad bandwidth without increasing the size of the patch. Fig. 1 shows the basic design of a single broadband antenna.

- *Modification in Ground Structure:* The ground is a term used to label the zero point of voltage and the working principle of the antenna. The ground of the antenna plays an essential role in the energy radiation proposed by K. Fuj Imoto in 1968. Feeder cables are used to make a connection with antenna and the ground. The antenna and ground are termed as an asymmetric dipole in which radiofrequency electric current flows through it. So that by changing the structure of the ground will improve impedance matching and enhance the bandwidth [14].
- *Structure of the feedline:* In any antenna design, feedline is very important. Feedline should be simple and easy to implement because it is usually skinny. The feedline helps us to enhance the input impedance of the capacity component, which then produces new resonance points to get wider bandwidth [14].
- In the MIMO antenna structure, each antenna is of 28.79 x 18.79 x 0.787 mm^2 size. The final design of the broadband MIMO antenna is of the size 28.79 x 50.6 x 0.787 mm^3 with different dimensional parameters of slots. The MIMO antenna is built by placing two single antennas at a distance d = 3 *mm* [16]. The second element is placed in three different directions concerning the first element, but it gives maximum isolation at the orthogonal position. The broadband MIMO antenna structure is shown in Fig. 2. The dimensions of the proposed antenna are given below in Table I.

Table I: Optimal Geometrical Parameters

Length (mm)	Width (mm)
$L = 28.79$	W =18.79
L_1=1	W_1=3.25
L_2=10.54	W_2=12
L_3=6.5	W_3=4
L_4=8.5	W_4=7
L_5=12	W_5=3
L_6=15	W_6=3.25
	W_7=1

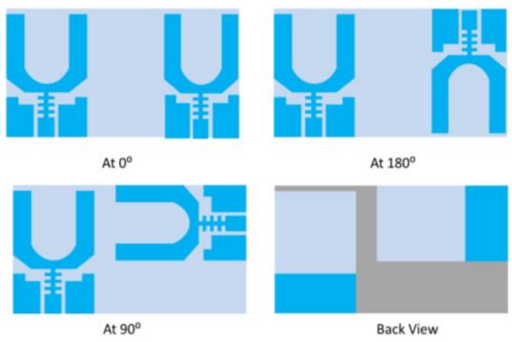


Fig. 2. Broadband MIMO Antenna Structure

B. Parametric Analysis

The need is to have a broad bandwidth. This requirement not only depends upon the design of antenna along with other components such as changing the feedline structure, adding co-planner waveguide, adding parasitic elements, and adding defected ground structures.

- *Parametric analysis of single element:* Before adding the ground at the back of the substrate, the bandwidth was very narrow, it covers from 2 to 3 GHz. A ground of suitable size is introduced at the back, to increase the bandwidth. If we remove the slots from the feedline, we get wideband from 6.2 to 8.2 GHz, and the VSWR also gives a value greater than 2. So, we add the multiple slots in feed to get longer bandwidth and acceptable value of VSWR less than 2.
- *Parametric analysis of double element:* In double element MIMO antenna, if we remove the backgrounds it will affect the bandwidth as in single element. The bandwidth becomes narrow from 1.97 to 2.6 GHz, and gain becomes high, but our focus is on broadband. So that the grounds at the back play an important role in enhancing the frequency range. The feedline is also the central part of antenna design. That's why the effect of slots in feedline must be realized. Before adding slots in feedline, the bandwidth becomes narrow, and the lowest gain will be -8 dB. It resonates around 7.3 GHz, and isolation becomes -25 dB, but we are proposing our antenna for broadband. So, removing slots from the feedline has not a good effect on the proposed antenna. The waves carried by CPW present in two parts of antenna it partially exists in the substrate and partly exists in the air the antenna. When we do not add the co-planner waveguide to the design, it will affect the efficiency.

III. Results and Discussion

A U-shaped MIMO antenna with simulated results are discussed below to calculate the performance of antenna by taking different parameters like return loss, gain, efficiency, radiation patterns, VSWR, TARC, ECC, and isolation in account [15]. HFSS (High-frequency structure simulator) is used as a professional tool for designing different types of antennas. Results of the proposed antenna are simulated on HFSS.

A. Single Element

A U-shaped patch antenna with CPW feed has been shown in Fig. 1 (a) and (b). A 50 Ω CPW feed is introduced on the substrate, and a partial ground is presented at the back [15]. The simulation of a single element is shown in Fig. 3, which show that the single antenna covers bandwidth from 2.4 GHz to 7.3 GHz.

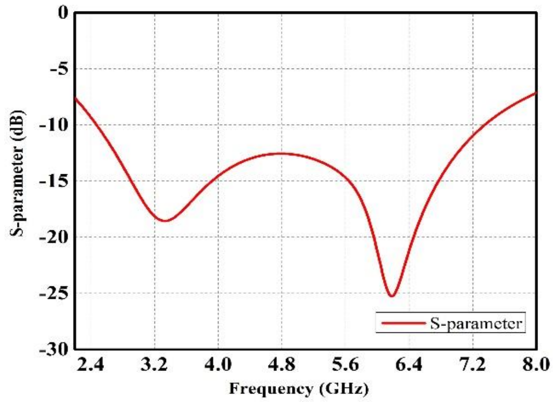


Fig. 3. S-parameter of single element.

The voltage standing wave ratio (VSWR) tells how much energy is accepted by the antenna and how much is reflected. The VSWR plot is shown in Fig. 4. It shows its value less than two because below two, the antenna impedance matching is considered very well.

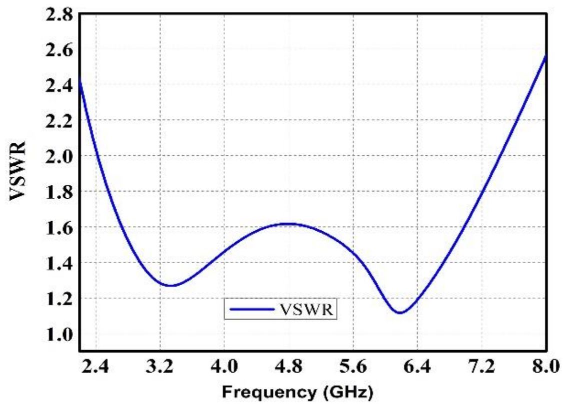


Fig. 4. The VSWR.

B. Antenna Arrays (MIMO)

The performance of the antenna is estimated by different parameters such as return loss, efficiency, gain, ECC, TARC, and the most important is isolation.

- In the antenna array, the second element of the MIMO structure is placed at three different angles to see the effect of direction on the bandwidth it covers. Fig. 5 shows the impact of direction on bandwidth.

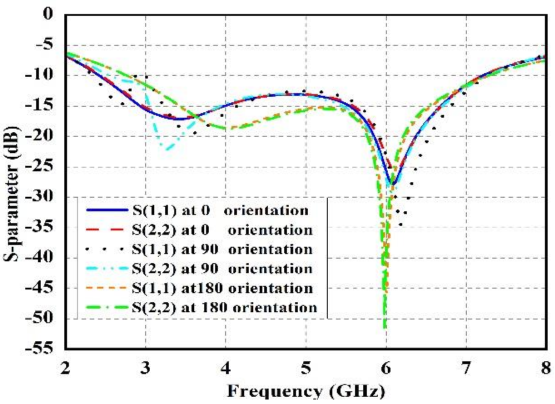


Fig. 5. S-parameter of antenna array at different orientations.

- In the MIMO antenna structure, the second antenna is placed at three different orientations (0 degrees, 90 degrees, 180 degrees) to check the best isolation. The isolation for the three different angles is shown in Fig. 6. When the antennas are placed at a greater distance, the isolation will be higher. But to keep the compact size of the antenna the gap between the antennas should be less. The figure below shows the most senior isolation when the antennas are placed in the orthogonal position.

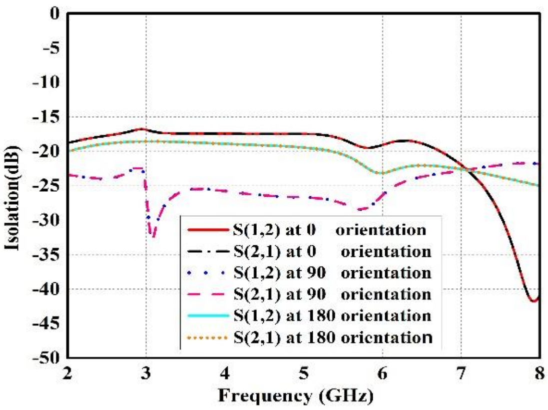


Fig. 6. Isolation (dB) at three orientations.

- The gain of the antenna tells how it focuses the electromagnetic radiations and how far it sends the signals. Gain is linked with beam width, the narrower the beamwidth higher the gain [17]. In the single-element system given, the peak gain achieved is 4 dB as shown in Fig. 7 given below. The gain is improved while designing MIMO. The efficiency of an antenna is the percentage of radiated power compared to the non-reflected power. Its value considered less than 1 because if the efficiency is one then will be ideal case presuming that no losses are there during transmission and reception of the signal. Usually, it is considered efficient at 70% or above this borderline, and in this paper, efficiency is 95% obtained.

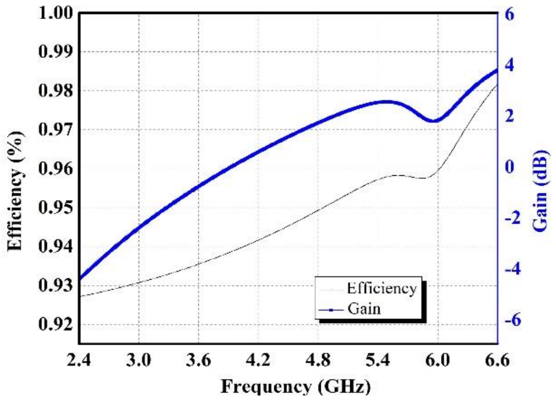


Fig. 7. Efficiency and gain of antenna array

- The diversity gain (DG) is used to measure the performance of the diversity techniques. On the logarithmic scale, the diversity gain is used to check the error probability slope of the received SNR. The diversity gain has a significant impact when used with a correlation coefficient. The lower the correlation coefficient, the higher will be the value of diversity gain. The maximum amount of DG is obtained when the correlation coefficient is zero [17]. The diversity gain is illustrated in Fig. 8. The formula for calculating the diversity gain is given below:

$$DG = 10\sqrt{1-|p|^2}$$

Where DG is diversity gain and p is the correlation coefficient.

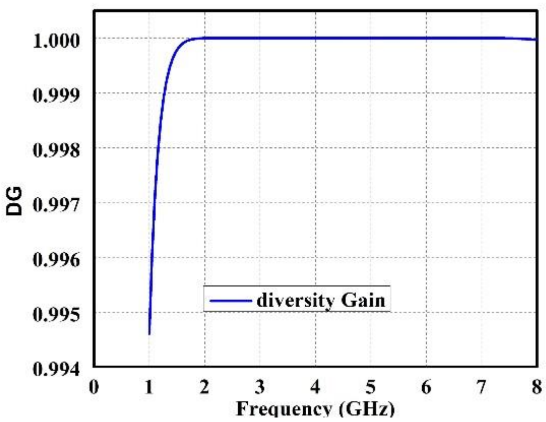


Fig. 8. The diversity gain.

- *Envelope Correlation Coefficient:* The ECC of the MIMO systems checks how the received signal is similar to the transmitted ones, and in other words, it checks the diversity of the systems. It also has a value between zero and one [18]. The amount of ECC in dB should be less than -3dB. Fig. 9, given below, shows the value of ECC is in an acceptable range.

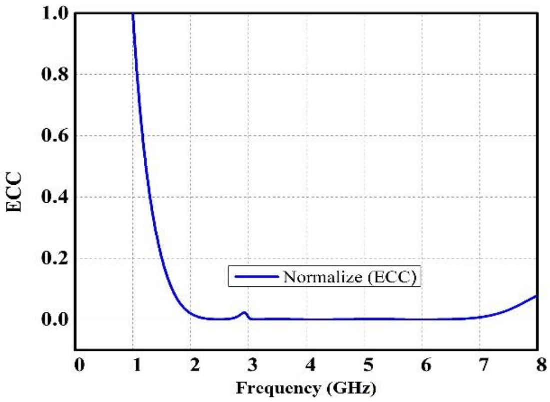


Fig. 9. ECC.

The formula of ECC is given below:

$$p_e = \left| \frac{S_{11}^* S_{12} + S_{21}^* S_{22}}{\sqrt{1-|S_{11}|^2-|S_{21}|^2} \cdot \sqrt{1-|S_{22}|^2-|S_{12}|^2}} \right|^2$$

Where p_e is the envelope correlation coefficient and $S_{11}, S_{12}, S_{21}, S_{22}$ are the s parameter values of two ports 1 and 2.

- The direction of the radiation produced by the antenna is described by the radiation pattern [14]. It defines the changes in the radiation. The radiation pattern of the proposed broadband MIMO antenna at three different frequencies (4.5 GHz, 5.5 GHz, 6.5 GHz) are shown in Fig. 10 at theta=90 and Phi=90. Radiation patterns of the figure below show that the antenna has a directional pattern.
- *Current density plot:* Current density plot defines the path for the flow of current. Current density plot of the proposed antenna at 3.5 GHz is shown in Fig. 11, which shows the highest current flow at the feedline [14].

TABLE II: COMPARISON WITH PUBLISHED WORK

Ref.	Size (mm)	Thickness (mm)	Gain (dBi)	Isolation (dB)	Bandwidth (GHz)
[15]	20 × 36 × 0.8	4.4	2.4 - 4.4	15	5.15 – 5.85
[19]	32 × 32	0.8	1.7 - 4.2	15	3.1 – 10.6
[20]	10.6 × 7.6	0.8	6	40	1.8 – 4.2
[21]	36 × 36	1.6	4.5	20	5.15 – 5.85
[22]	6 × 6	0.16	1 - 3	20	3.4 – 12
This Work	28.79 × 18.79	0.787	-4 - 5	23	2.4 – 7.3

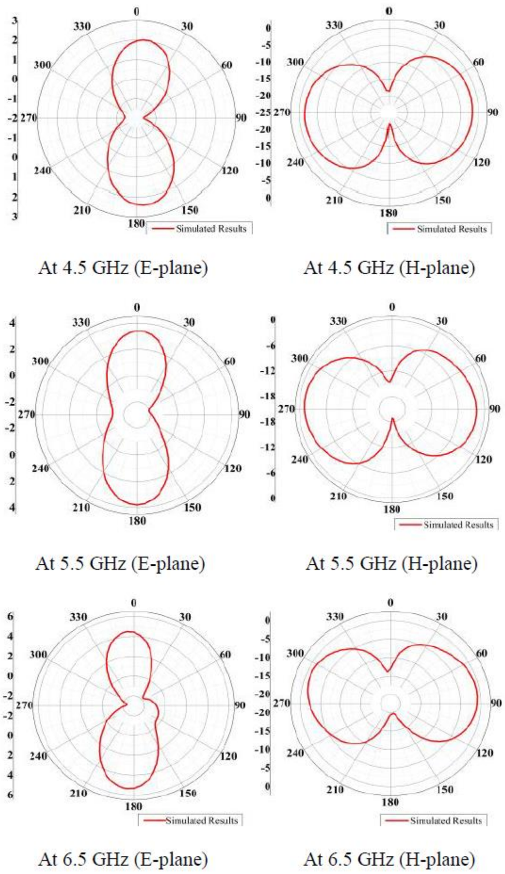


Fig. 10. Simulated results of radiation patterns at three different frequencies

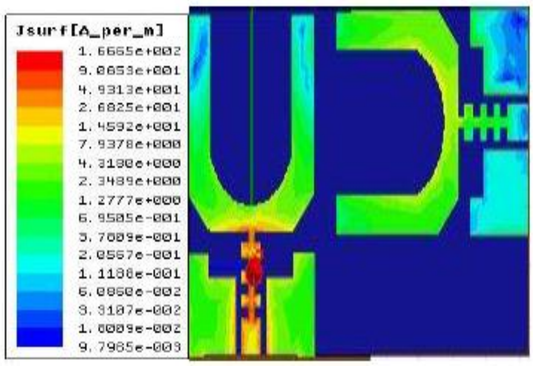


Fig. 11. Current density plot

IV. COMPARISON

This proposed antenna is compared with some published work in the above Table II.

V. CONCLUSION

This paper presented a two-element MIMO antenna. A CPW feed and conducting ground is introduced in the substrate to enhance the gain and reduce the mutual coupling between the antennas. The antenna is covering applications like WiMAX, Bluetooth, and WLAN. The ease of microstrip patch antennas having direct-feed structures should have very compact sizes and also have greater bandwidth. The isolation of the antenna achieved is -23 dB and a positive gain of 5 dBi, and the antenna is 95% efficient. MIMO technology uses different channels for the transmission and reception of data. In this configuration, the mutual coupling between the elements has a significant impact on the overall performance of the antenna.

REFERENCE

[1]. H. T. Chattha, Y. Huang, M. K. Ishfaq, and S. J. Boyes, “A Comprehensive Parametric Study of Planar Inverted-F Antenna,” *Wireless Engineering & Technology*, vol. 3, no. 1, pp. 1-11, Jan, 2012.

[2]. J. Yan, and J. T. Bernhard, “Design of a MIMO Dielectric Resonator Antenna for LTE Femtocell Base Stations,” in *IEEE Transactions on Antennas Propagation*, vol. 60, no. 2, pp. 438-444, Feb. 2012.

[3]. L. Zhang, W. Liu, and T. Jiang, "A Compact UWB MIMO Antenna with High Isolation," *2016 IEEE International Symposium on Antennas and Propagation (APSURSI)*, Fajardo, 2016, pp. 913-914.

[4]. W. Hong, K. Baek, Y. Lee, and Y. G. Kim, “Design and Analysis of a Low-Profile 28 GHz Beam Steering Antenna Solution for Future 5G Cellular Applications,” 2014 *IEEE MTT-S International Microwave Symposium (IMS2014)*, Tampa, FL, 2014, pp.1-4.

[5]. W. Zhang, Z. Weng and L. Wang, "Design of a Dual-Band MIMO Antenna for 5G Smartphone Application," *2018 International Workshop on Antenna Technology (iWAT)*, Nanjing, 2018, pp. 1-3.

[6]. Kyeong-Sik Min, Dong-Jin Kim, and Young-Min Moon, "Improved MIMO Antenna by Mutual Coupling Suppression between Elements," *The European Conference on Wireless Technology, 2005*. Paris, 2005, pp. 125-128.

[7]. US Federal Communications Commission, et al., “Revision of Part 15 of the Commission’s Rules Regarding Ultra-Wideband Transmission Systems: First report and order,” *Technical Report*, Feb. 2002.

[8]. B. P. Chacko, G. Augustin, and T. A. Denidni, “Uniplanar Polarization Diversity Antenna for Ultrawideband Systems,” in IET Microwaves, Antennas & Propagation, vol. 7, no. 10, pp. 854–857, July 2013.

[9]. A. Al-Rawi, A. Hussain, J. Yang, M. Franzén, C. Orlenius, and A. A. Kishk, "A New Compact Wideband MIMO Antenna—The Double-Sided Tapered Self-Grounded Monopole Array," in *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 6, pp. 3365-3369, June 2014.

[10]. A. Habashi, J. Nourinia, and C. Ghobadi, “A Rectangular Defected Ground Structure (DGS) for Reduction of Mutual Coupling between closely Spaced Microstrip Antennas,” *20th Iranian Conference on Electrical Engineering (ICEE2012)*, Tehran, 2012, p. 1347–1350.

[11]. J. R. Costa, E. B. Lima, C. R. Medeiros, and C. A. Fernandes, “Evaluation of a New Wideband Slot Array for MIMO Performance Enhancement in Indoor WLANs,” in *IEEE Transactions on Antennas and Propagation*, vol. 59, no. 4, pp. 1200–1206, Apr. 2011.

[12]. V. K. Kothapudi, and V. Kumar, “A 6-port Two-Dimensional 3 × 3 Series-Fed Planar Array Antenna for Dual-Polarized X-Band Airborne Synthetic Aperture Radar Applications,” in *IEEE Access*, vol. 6, pp. 12001–12007, 2018.

[13]. D. Sun, W. Dou, and L. You, “Application of Novel Cavity-Backed Proximity-Coupled Microstrip Patch Antenna to Design Broadband Conformal Phased Array,” in *IEEE Antennas Wireless Propagation Letters*, vol. 9, pp. 1010– 1013, 2010.

[14]. S. F. Jilani, and A. Alomainy, “Millimetre-wave T-shaped MIMO antenna with defected ground structures for 5G cellular networks,” in *IET Microwaves, Antennas & Propagation*, vol. 12, no. 5, pp. 672-677, April, 2018.

[15]. L. Y. Chen, J. S. Hong, and M. Amin, “A Compact CPW-Fed MIMO Antenna with Band-Notched Characteristic for UWB System,” in *Applied Computational Electromagnetics Society Journal*, vol. 33, pp. 818-821, 2018.

[16]. H. Xia, T. Zhang, L. Li, and F. Zheng, “A low-cost dual-polarized 28 GHz phased array antenna for 5G communications,” *2018 International Workshop on Antenna Technology (iWAT)*, Nanjing, 2018, pp. 1-4.

[17]. A. A. A. Asaker, R. Ghoname, and A. Zekry, “Design of a planar MIMO antenna for LTE-advanced,” *International Journal of Computer Applications*, vol. 115, no. 12, April, 2015.

[18]. A. I. Najam, Y. Duroc, and S. Tedjini, “Multiple-input multiple-output antennas for ultra-wideband communications,” *Ultra-Wideband-Current Status and Future Trends*, Intech Open, Chap. 10, Oct. 2012.

[19]. J. Ren, W. Hu, Y. Yin, and R. Fan, “Compact Printed MIMO Antenna for UWB Applications,” in *IEEE Antennas and Wireless Propagation Letters*, vol. 13, pp. 1517-1520, 2014.

[20]. N. Ojaroudiparchin, M. Shen, and G. F. Pedersen, "Multi-layer 5G mobile phone

antenna for multi-user MIMO communications," *2015 23rd Telecommunications Forum Telfor (TELFOR)*, Belgrade, 2015, pp. 559-562.

[21]. M. D. Ardakani, and R. Amiri, "Mutual coupling reduction of closely spaced MIMO antenna using frequency selective surface based on metamaterials," *Applied Computational Electromagnetics Society Journal*, vol. 32, pp. 1064-1068, Dec. 2017.

[22]. J. Aquil, D. Sarkar, and K. V. Srivastava, "A quasi self-complementary UWB MIMO antenna having WLAN-band notched characteristics," *2017 IEEE Applied Electromagnetics Conference (AEMC)*, Aurangabad, 2017, pp. 1-2.