Turkish Journal of Computer and Mathematics Education Vol.12 No.12 (2021), 1934-1943

Research Article

A Novel UWB MIMO Antenna with High Isolation for Sub-6 GHz Band Application

Karthi J[a], Vagheaswari S[b], Varsha L[c], Vishnu Girish N I[d], Viswanath M[e]

[a] karthi.j@rajalakshmi.edu.in, [b] vagheaswarisethu@gmail.com, [c] varsha.vani1511@gmail.com, [d] vishnugirish.i.2017.ece@rajalakshmi.edu.in, [e] viswanath.m.2017.ece@rajalakshmi.edu.in

Article History: Received: 11 January 2021; Revised: 12 February 2021; Accepted: 27 March 2021; Published online: 23 May 2021

Abstract: A compact Multiple input Multiple output (MIMO) patch antenna with Electromagnetic Band Gap (EBG) structure to provide high isolation and defected ground for sub-6 GHz UWB 5G application is presented. The proposed design comprises of two symmetrical radiating semi-circular patch antenna with stubs and slots separated by a slotted EBG structure with the size of 30 x 30 mm2. The performance of the antenna is also been studied under the topics of impedance bandwidth, radiation patterns, envelope correlation coefficient and gain. The proposed design resonates at 3.7GHz and 5.05GHz with a return loss of -40dB and -35dB respectively and has a bandwidth of 3GHz to 5.05GHz and ECC less than 0.007 throughout the band. The proposed antenna is designed and simulated using Computer Simulation Technology (CST)..

Keywords:

1. Introduction

The rapid development of Wireless Technologies resulted in the escalating demand for next generation i.e., 5G.For many wireless devices, antenna plays an important role at its end terminal The Fifth generation network is classified into sub-6GHz band and mm Wave band. The sub-6GHz band refers to the spectrum that is under 6 GHz. This low frequency spectrum can travel faster with low penetration loss, which makes it ideal for 5G application [8].

The proposed design has been composed of Flame Retardant 4 (FR4) substrate that is sandwiched between copper patch and copper defected ground plane. The FR4 material has an excellent mechanical strength and high insulating qualities at low cost. With the properties such as relative permittivity of 4.3, permeability of 1 and loss tangent of 0.025, it becomes an ideal material for substrate [1]. At low cost, Copper patch with copper ground furnish maximum gain with minimum return loss as copper has high electrical conductivity of 59.7×10^6 S/m[2].

The Ultra wide Band (UWB) spectrum covers the frequency range between 3.1 GHz – 10 GHz [3,4]. This unlicensed spectrum is approved for commercial wireless communication which leads researchers to design compact antennas for UWB applications[5,6,7,15]. The UWB antennas have a large channel capacity that helps in transmitting signals with low power and high noise immunity [3,10].

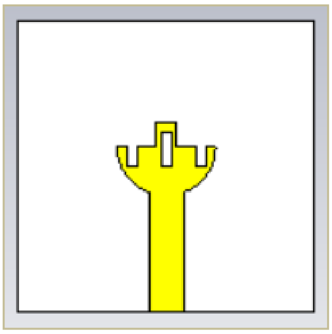
The high transmission rate with stable communication quality without the need of extra power and bandwidth is incurred by implementing Multiple Input and Multiple Output (MIMO) technologies. In MIMO antennas, Mutual coupling is an undesirable parameter [1,3,4,5]. The Electromagnetic Band Gap structure is used to provide high isolation between the symmetric structures to reduce mutual coupling [10]. Implementing 5G Antenna with UWB and MIMO technologies promise high data speed, large channel capacity, good quality and low latency [9,10].

The described antenna's design and its geometry with simulation and results have been examined within the assist segments of this paper.

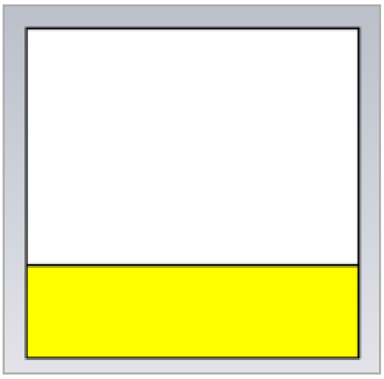
2. Antenna Design Evolution

Individual monopole antenna

A semi-circular patch antenna with a stub and slots along with a defected ground structure with the size of 30 x 30 x 1.6 mm^3 was initially designed as shown in Fig.1. The antenna is designed with FR-4 substrate with dielectric constant of 4.4sandwiched between copper patch and substrate of thickness 0.035 mm^2. The monopole antenna is fed through 3.5 mm^2 feed line. The single patch antenna resonates at 4.37GHz with a return loss of -66dB and has a Bandwidth of 3.7 GHz to 5.05 GHz is observed from the S11 plot shown in Fig.2. To advance the progress of the execution of the antenna for the specified application we are further moving with MIMO technology. The proposed design and simulations are performed using Computer Simulation Technology (CST).



(a)



(b)

Fig.1. (a) single patch antenna with stub and slots (b)Defected ground structure

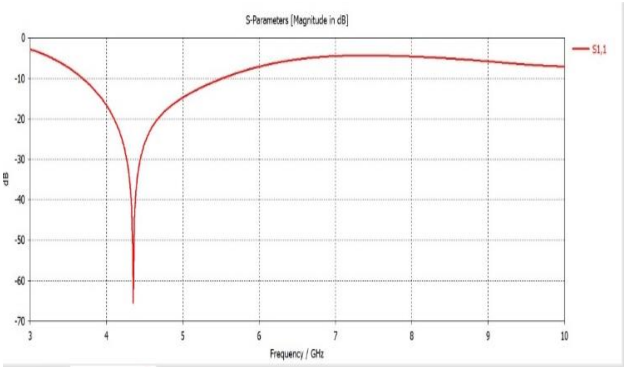
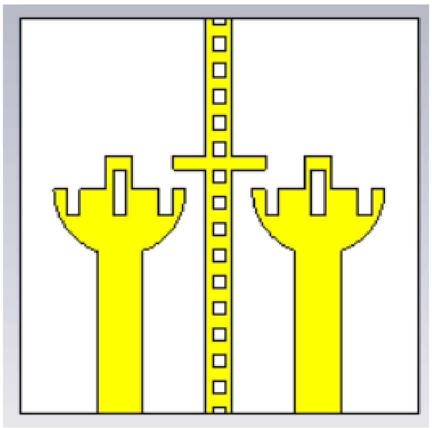


Fig.2. The Return loss of the individual patch antenna

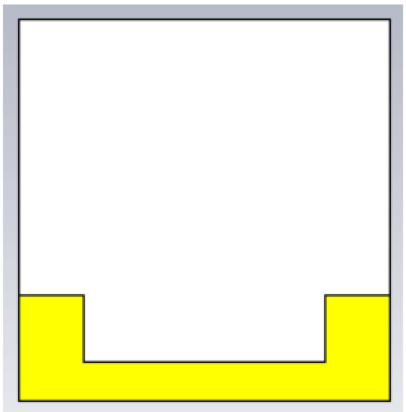
3. MIMO Arrangement

The antenna is further implemented with 2x2 MIMO design to improve the performance. Mutual coupling is an important parameter when it comes to MIMO and it is undesirable between the radiating elements[24,25]. To eliminate the mutual coupling, the radiating elements must be isolated. It can be achieved by incorporating the Electromagnetic Band Gap (EBG) structure between these elements of this compact antenna[24-26].Thus, the antenna design have been evolved to MIMO structure with EBG structure as shown in the Fig 3(a) with the size of 30 x 30 x1.6 mm^3. The Dimensions of the antenna parameters are furnished in Table 1.

The execution and the achieved results of this MIMO antenna will discussed in the further sections of this paper.



(a)



(b)

Fig.3. (a) MIMO Arrangement with EBG (b) Defected ground Structure

Table 1.Optimised Dimentions of the proposed antenna

Parameters	**Dimension (mm)**
Substrate length	30
Substrate width	30
Substrate thickness	1.6
Radius of semi-circle patch	5
Feed length	15
Feed width	3.5
Ground length	3.34
Ground width	30
Ground stub length	5
Ground stub width	6.875
Patch stub at centre length	3

Patch stub at centre width	2
Patch slot length	2
Patch slot width	1
Patch centre slot length	3.5
Patch centre slot width	1
Isolation length	30
Isolation width	2
Isolation stub length	1
Isolation stub width	3
Isolation slot length	0.5
Isolation slot width	0.5
Distance between slots in isolation	1

4. Results and Discussion

Return Loss:

Return loss is characterized by the proportion of the input power of the antenna to the power reflected back from the source.When the feed applied to the radiating element, portion of the signal gets reflected by a discontinuity in a micro strip line feeder. It is measured in decibels (dB).It indicates how perfectly the impedance of the patch elements are matched. In general for an antenna the return loss must be less than -10dB[9-25].From Fig.4, The return loss of the proposed design with and without isolation is perceived. The antenna with EBG resonates better than the antenna without EBG at 3.7GHz and 5.05GHz with a return loss of -40dB and -35dB respectively and has a Bandwidth of - 3GHz to 5.05GHz.

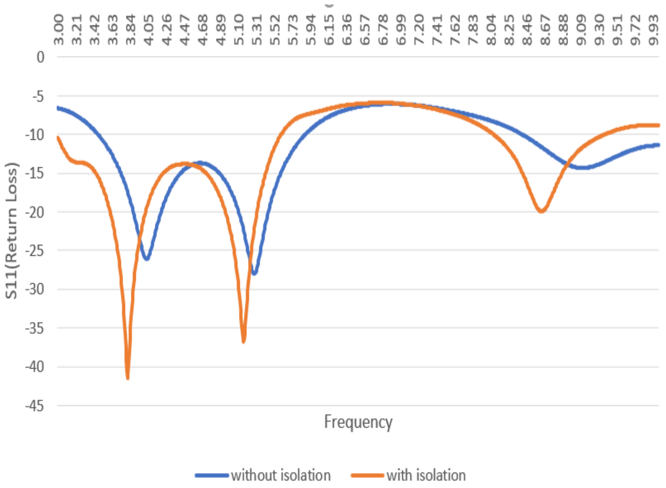


Fig.4.(a) S11 of the MIMO structure with defected ground with and without EBG

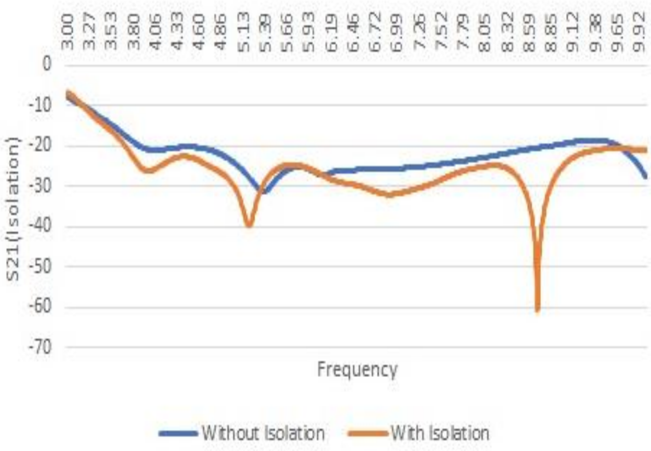


Fig.4.(b)S21 of the MIMO structure with defected ground with and without EBG

VSWR:

The Voltage Standing Wave Ratio is a numerical measure that defines how good the micro-strip patch antenna and feed line are matched to their impedances. The VSWR is calculated by,

VSWR $=\frac{1+\rho}{1-\rho}$

Where, ρ is the reflection coefficient.

For an ideal antenna the minimum VSWR is 1, where no power is reflected from the antenna. But themaximum acceptable VSWR of an antenna is that it must be less than 2[9-25]. The VSWR for the proposed MIMO antenna is less than 2for the range of 3 GHz-5.5GHz as shown in Fig.5.

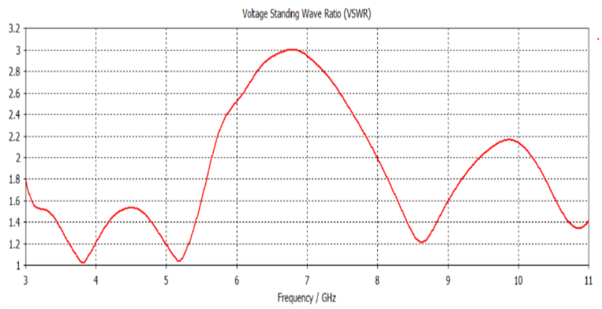


Fig.5. VSWR plot of the MIMO antenna

Gain:

Gain of the antenna is an important parameter which merges the directivity and efficiency.It is described as how much incident power is transformed as radio signals [10-20].Fig.6, illustrates the gain that is obtained from the MIMO antenna with EBS.

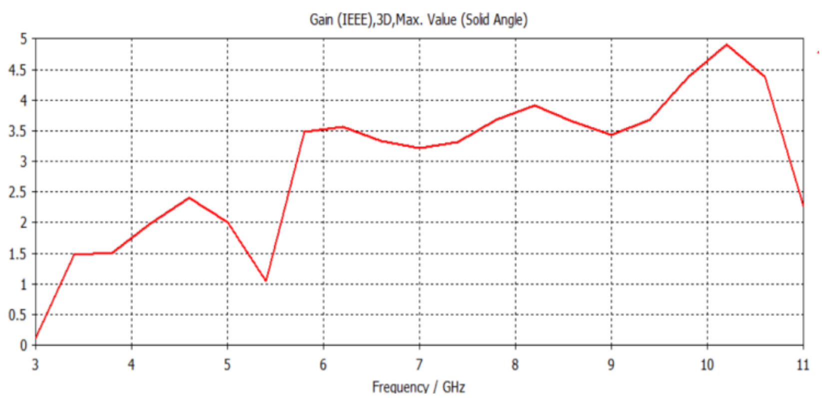
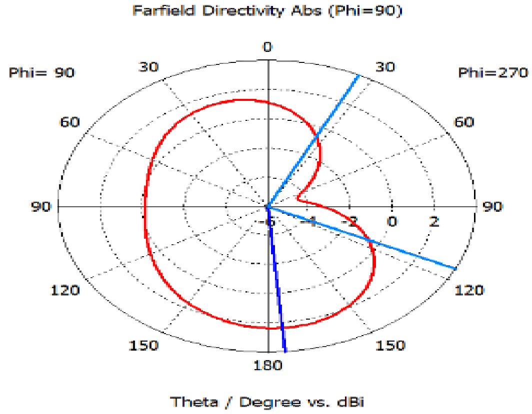


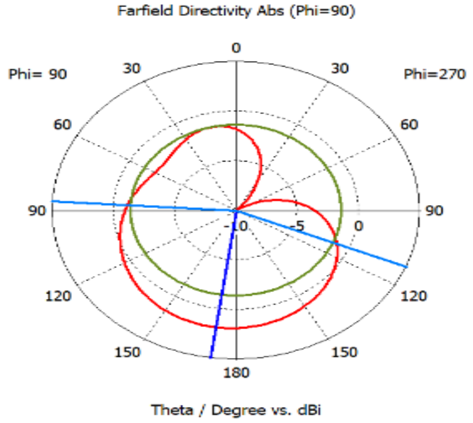
Fig.6. Gain of the MIMO antenna

Radiation pattern:

In reality no antenna is isotropic, so the directive radiation pattern of our antenna is shown below; we have shown the plots for the resonant frequency i.e. 3.9 and 5.05GHz.In Fig.7 (a) the radiation patterns are optimum at 30°, 120°, and 180°.In Fig.7 (b) the radiation patterns are optimum at 110,180 and 90 degrees.



(a)



(b)

Fig.7. Far field directivity where (a) frequency=3.9GHz (b) frequency=5.05GHz

ECC:

Envelope Relationship Coefficient describes about how autonomous two antenna's radiation designs are from each other. Distinct polarization, i.e. one vertical and other horizontal will imply ECC to be 0. The allowable restrain of ECC is not more than 0.5 and anything less than 0.3 is much better [9-25].

The ECC can be calculated from the S parameters using the formula,

$$\rho_e = \frac{|S_{11}^{\star} S_{12} + S_{21}^{\star} S_{22}|^2}{(1 - |S_{11}|^2 - |S_{21}|^2)(1 - |S_{22}|^2 - |S_{12}|^2)}$$

Fig.8. gives the ECC of the proposed structure with EBG and without EBG. The Isolation of the elements using Electromagnetic Band Gap structure improves the ECC which is less than 0.007 throughout the band.

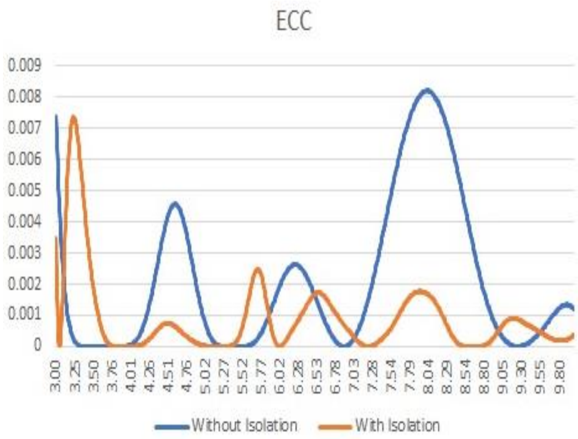


Fig.8. ECC with and without isolation

Ref.	Antenna Size (mm)	Orientation of Antenna	No. of elements	Bandwidth (GHz)	Isolation (dB)	ECC	Peak Gain(dB)
#7	36 x 22	parallel	2	2 - 18GHz	>15	<0.005	5
#8	20 x 35	parallel	2	3.34-3.87GHz	>20	<0.012	2.34
#3	19 x 30	parallel	2	3.1 - 10.6 GHz	>18	<0.13	1.2-2.9
#15	39 x17.5	parallel	2	3.13 - 3.20GHz	>20	<0.001	2.9
#4	150 x 75	parallel and orthogonal	8	3-6GHz	>11	<0.1	-
#24	50 x 30	parallel	2	2.5-14.5GHz	>20	<0.04	4.3
Proposed	30 x 30	parallel	2	3.9-5.0GHz	>20	<0.007	5

Diversity Gain:

It is characterized as how much the transmitted power can be diminished to other interferences due to various sources of noise. [9-23]

From the below Fig.9 it can be observed that the diversity gain over the entire operating band is more than 9.965.

Diversity Gain = $10\sqrt{1-ECC2}$

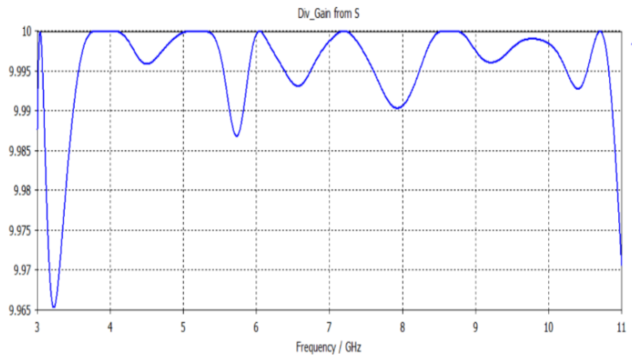
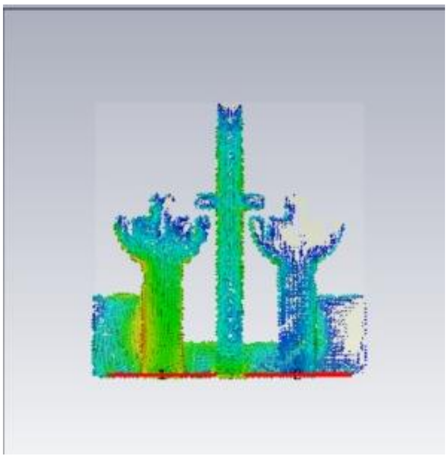


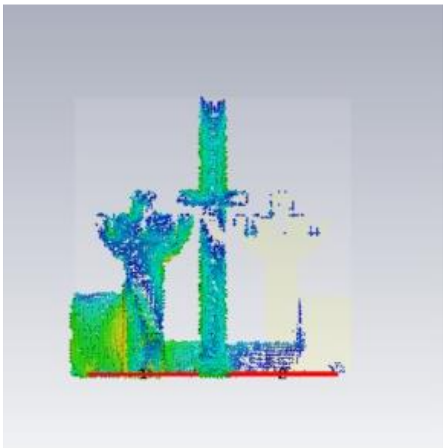
Fig.9. Diversity gain of the proposed MIMO antenna

Surface Current:

To get more in-depth analysis into surface current patterns of the proposed antenna, the stimulated results are shown in Fig. 10 a) at 3.9Ghz and in Fig. 10 b) at 5.05GHz. At lower frequency the current is majorly distributed in both the patches but as the frequency increases the current is majorly distributed at one side of the patch which is evident from the given below figures.



(a)



(b)

Fig.10. Surface current of the proposed MIMO antenna at (a) frequency=3.9Ghz (b) frequency=5.05Ghz

Impedance

The SMA 50 connector impedance is 50 ohm, so our antenna's impedance should be nearer in the range of 50 ohm in order to reduce the reflection at the load and thereby achieving the maximum power transfer between connector and antenna[20].

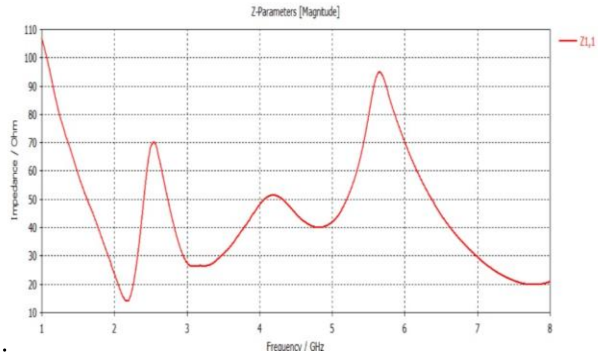
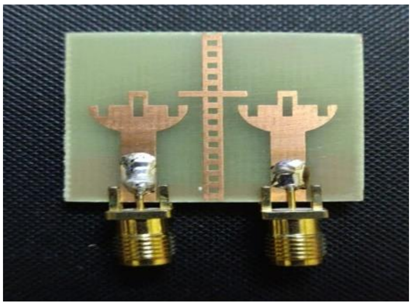


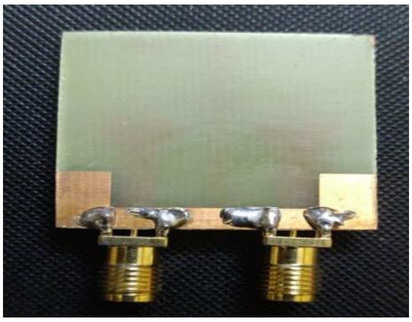
Fig.11. Impedance of the antenna

The above results show's us the impedance is nearer to 50 ohms in the band of our interest i.e. 3.9 to 5.05Ghz.

Fabricated Antenna:



(a)



(b)

Fig.12. (a) Fabricated patch antenna with stub and slots (b)Defected ground structure

5. Comparision With Existing Antennas

To evaluate the adequacy of the proposed MIMO structure, Table 2 appears as comparison of parameters between existing antenna and the proposed antenna. From the comparison, it is taken note that the proposed MIMO antenna is compelling than existing UWB MIMO antennas. The proposed MIMO antenna has an optimum return loss and good ECC over the operating frequency band with compact size and has low mutual coupling.

6. Conclusion

This work presents the importance of isolation in the MIMO antenna with the help of Electromagnetic Band Gap Structure. The novel semi-circular patch antenna with slots and stub along with Defected Ground Structure is proposed. The compact 30x30 mm^2MIMO structure with EBG provides optimum results that satisfy the specified application.The proposed MIMO antenna system has mutual coupling <20 dB over 3.9–5GHz frequencyband. It also has ECC<0.007 and diversity gain >9.9 which is very ideal for a MIMO antenna.Hence, the proposed antenna with Defected Ground and the Electromagnetic Band Gap structure for isolation is ideal for UWB sub 6GHZ application.

References

1. G. Kaur, A. Singh, D. Mittal, A. Prince, Kaur, P. Panday and E. Sidhu, "Performance analysis of conductive patch materials for the design and fabrication of microstrip patch antennas," Progress in Electromagnetics Research Symposium - Spring (PIERS), pp. 502-508, 2017.
2. J. R. Aguilar, M. Beadle, P. T. Thompson and M. W. Shelley, "The microwave and RF characteristics of FR4 substrates," IEE Colloquium on Low Cost Antenna Technology London, UK, pp. 2/1-2/6,1998.
3. Kim, J. Ghimire, J. Maharjan, I. Nadeem, S. Kim and D. Choi, "Ultra Wideband (UWB) Microstrip Patch Antenna with Adjustable Notch Frequencies," IEEE International Conference on Industry 4.0, Artificial Intelligence, and Communications Technology (IAICT), pp. 70-73, 2019.
4. N.M. Awad, M.K. Abdelazeez,"Multislotmicrostrip antenna for ultra-wide band applications," Journal of King Saud University - Engineering Sciences, vol.30, no.1, pp. 38–45, 2018.
5. S. u. Rehman and M. A. S. Alkanhal, "Design and System Characterization of Ultra-Wideband Antennas with Multiple Band-Rejection," in IEEE Access, vol. 5, pp. 17988-17996, 2017.
6. Z. Li, X. Zhu, and C. Yin, ‘‘CPW-fed ultra-wideband slot antenna with broadband dual circular polarization,’’ AEU-Int. J. Electron. Commun.,vol. 98, pp. 191–198, Jan. 2019.

7. P. Khanna, A. Sharma, A. K. Singh, and A. Kumar, “A CPW - Fed Octagonal Ring Shaped Ultra Wide Band Antenna for Wireless Applications,” Advanced Electromagnetics, vol. 7, no. 3, pp. 87-92, August 2018.
8. A.K. Saurabh and M.K.Meshram, ”Compact sub-6 GHz 5G-multiple-input-multiple-output antenna system with enhanced isolation,”Int J RW MicrowComput Aided Eng. vol.30, no. 8, e22246, Aug.2020.
9. Y. Chang, Q. Liu, X. Tang, G. Du, G. Li and D. Cheng,” Compact MIMO antenna with high isolation characteristic for UWB portable applications, “Microw Opt TechnolLett. vol.62, no.3, pp. 1391-1397, 2019.
10. T. Addepalli, V.R. Anitha, “A Very Compact and Closely Spaced Circular Shaped UWB MIMO Antenna with Improved Isolation,” International Journal of Electronics and Communications, vol.114, Feb.2020.
11. W. A. E. Ali and A. A. Ibrahim, ‘‘A compact double-sided MIMO antenna with an improved isolation for UWB applications,’’ AEU-Int. J. Electron. Commun., vol. 82, pp. 7–13, Dec. 2017.
12. X. Zhao, S. P. Yeo, and L. C. Ong, ‘‘Planar UWB MIMO antenna with pattern diversity and isolation improvement for mobile platform based on the theory of characteristic modes,’’ IEEE Trans. Antennas Propag., vol. 66, no. 1, pp. 420–425, Jan. 2018.
13. M. Irshad Khan, M. I. Khattak, S. U. Rahman, A. B. Qazi, A. A. Telba, and A. Sebak, “Design and Investigation of Modern UWB-MIMO Antenna with Optimized Isolation,” Micromachines, vol. 11, no. 4, p. 432, Apr. 2020.
14. Gnanaharan and R. Anbazhagan, “Review on the design of the isolation techniques for UWB-MIMO antennas,” Adv. Electromagn., vol. 7, no. 4, pp. 46–70, 2018.
15. M.N. Hasan, S. Chu and S. Bashir,” A DGS monopole antenna loaded with U-shape stub for UWB MIMO applications,”Microw Opt TechnolLett. vol.61, no.9, pp.2141–2149, Sep.2019.
16. R. Gurjar, D.K. Upadhyay, B.K. Kanaujia, A. Kumar, “A Compact Modified Sierpinski Carpet Fractal UWB MIMO Antenna with Square-shaped Funnel-like Ground Stub, “International Journal of Electronics and Communications ,2020.
17. D. Sipal, M. P. Abegaonkar, and S. K. Koul, ‘‘Easily extendable compact planar UWB MIMO antenna array,’’ IEEE Antennas Wireless Propag. Lett., vol. 16, pp. 2328–2331, 2017.
18. Z. Li, C. Yin and X. Zhu, "Compact UWB MIMO Vivaldi Antenna with Dual Band-Notched Characteristics," in IEEE Access, vol. 7, pp. 38696-38701, 2019.
19. D. Sipal, M. P. Abegaonkar, and S. K. Koul, ‘‘Easily extendable compact planar UWB MIMO antenna array,’’ IEEE Antennas Wireless Propag. Lett.,vol. 16, pp. 2328–2331, 2017.
20. R. Chandel and A. K. Gautam, ‘‘Compact MIMO/diversity slot antenna for UWB applications with band-notched characteristic,’’ Electron. Lett.,vol. 52, no. 5, pp. 336–338, Mar. 2016.
21. Z. Tang, X. Wu, J. Zhan, Z. Xi, and S. Hu, ‘‘A novel miniaturized antenna with multiple band-notched characteristics for UWB communication applications,’’ J. Electromagn. Waves Appl., vol. 32, no. 15, pp. 1961–1972, Jun. 2018.
22. J. Zhu, S. Li, B. Feng, L. Deng, and S. Yin, ‘‘Compact dual-polarized UWB quasi-self-complementary MIMO/diversity antenna with band-rejection capability,’’ IEEE Antennas Wireless Propag. Lett.,vol. 15, pp. 905–908, 2016.
23. Iqbal, O. A. Saraereh, A. W. Ahmad, and S. Bashir, “Mutual coupling reduction using F-shaped stubs in UWB-MIMO antenna,’’ IEEE Access, vol. 6, pp. 2755–2759, 2018.
24. Nadeem and D.-U. Choi, ‘‘Study on mutual coupling reduction technique for MIMO antennas,’’ IEEE Access, vol. 7, pp. 563–586, 2019.
25. H.F. Huang and Z.-P. Zhang, ‘‘Mutual coupling reduction of a very compact UWB-MIMO linearly tapered slot antenna using a simple stepped slot,’’ in Proc. IEEE Int. Appl. Comput. Electromagn. Soc. Symp. (ACES), pp. 1–2, August 2017.
26. B.T.P. Madhav, “Defected ground structured compact MIMO antenna with low mutual coupling for automotive communications, “Microw. Opt. Technol. Lett. pp.1-7,2018.