

High Isolation with T shaped Decoupling Structure MIMO Antenna for 5 G Applications

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Abstract

In this paper, MIMO antenna for 5G (3.5 and 5.5GHz) applications is presented with less than -22dB isolation. Return loss of antenna, designed on FR-4 substrate is less than -10dB by the size of 26×22×0.8mm³. Diversity performance of antenna is also permissible through ECC and diversity gain is 0.0015 and 9.99dB respectively. Simultaneously, radiation characteristics of proposed antenna like radiation efficiency (>0.65), TARC (<-35dB) has better agreement. Proposed MIMO antenna is appropriate for 5G communication and weapon investing RADAR system.

Keywords: Multiple Input Multiple Output (MIMO), Envelope Correlation Co-efficient (ECC), Total Active Reflection Co-efficient (TARC), Channel Capacity Loss (CCL).

1. Introduction

Wireless communication systems has paradigm of different invention from single input single output (SISO), multiple input single output (MISO) systems to multiple input multiple output (MIMO) systems and bandwidth is an important factor in this system. In wireless communication, high data transmission rates are crucial for the services like i.e. data, voice and video. At receiver end, the channel capacity is directly influence the superiority of the communication systems and MIMO system fostering these features to the challenging world to acquire a high data bit rate, low channel capacity loss (CCL) and lofty signal to noise ratio (SNR). For above scenario MIMO antenna is widely used in modern wireless RF-communication system with excellent diversity performance then SISO antenna. MIMO antenna consist spatial diversity and spatial multiplexing capability for outstanding change in reliability and data rate. To introduce feeding network in antenna array to improve antenna parameters like antenna gain, bandwidth, radiation pattern and desired circularly polarised (CP) diversity property [1]. Two-input four-output feed network structure provide polarization diversity. By introducing a feed network and suitable antenna array wide Impedance bandwidth, good axial ratio bandwidth and the high peak gain in C-band is achieved [2]. MIMO antenna with decoupling structures, artificial magnetic conductor on the surface and upturned T-slot on the ground provide good isolation and good diversity performance of MIMO antenna [3-4]. MIMO with EBG is popular to enhance the isolation level between two antennas and militarization of antenna dimension because of by suppressing surface wave

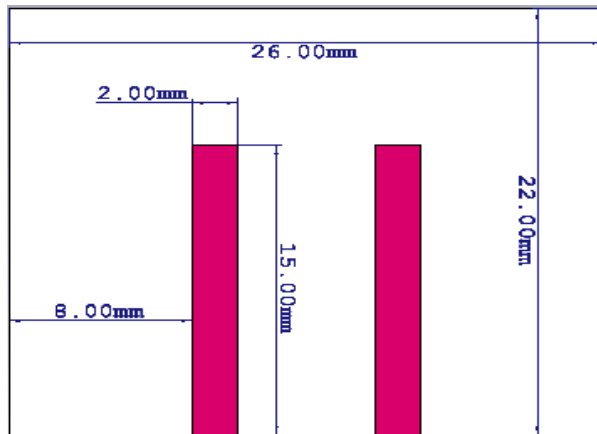
propagation [5-9]. To introducing slow wave structure with EBG to improve the size reduction, isolation level and diversity performance of the antenna [10]. MIMO antenna with four orthogonally-deployed Bow-Tie arrangements is Improved the isolation and impedance bandwidth [11].

In this article, T shaped decoupling structure is introduced for improving the isolation in 5G-band range is deliberate on low

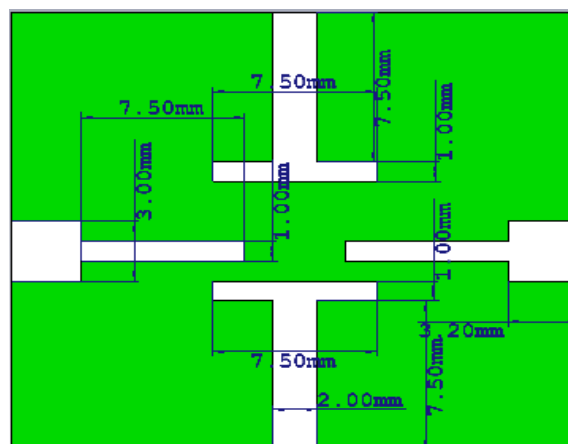
cost material FR-4 ($\epsilon_r = 4.4$) substrate with 1.6mm thickness. Section-II shows the proposed Antenna results analysis. Section-III shows the diversity performance of MIMO antenna in terms of different diversity performance parameters like ECC, DG, MEG, TARC and CCL. Section- IV depicted the conclusion about overall antenna performance which is suitable in 5G applications.

2. Antenna Analysis and Results

EBG MIMO antenna is depicted in figure-1 (a)-(b). This designed antenna works for sea based C-band RADAR applications. The fundamental resonant frequency of MIMO antenna is given by Equation (1) [10]. Where A_1 and A_2 area accumulated by ground plane and radiating MIMO antenna and l_1 and p_2 is the total length which is accumulated by ground plane and length of radiating proposed MIMO antenna in that order. h is the substrate thickness and all the dimensions are considered in mm.



(a)

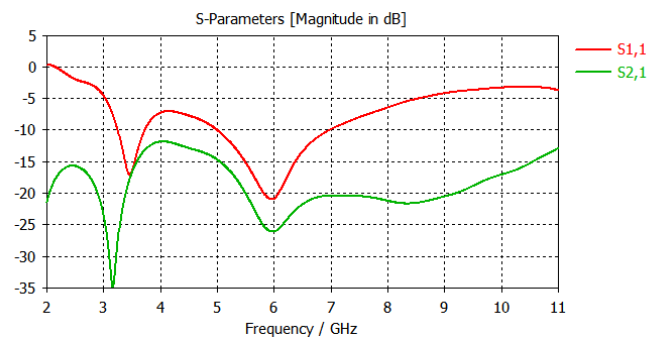




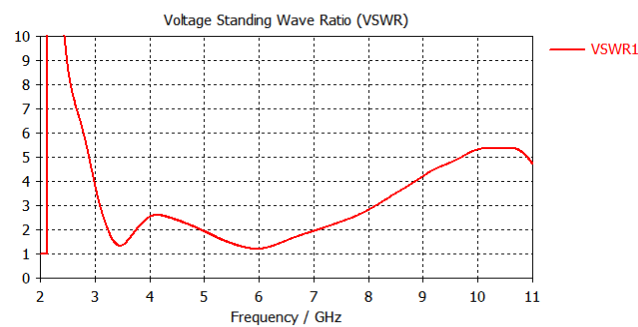
(b)

Fig. 1 Proposed 5G-band MIMO antenna structures view (a) Front (b) Bottom.

$$f_r \text{ (GHz)} = \frac{144}{l_1 + p_2 + h + \frac{A_1}{2\pi\sqrt{\epsilon_r + 1}} + \frac{A_2}{2\pi\sqrt{\epsilon_r + 1}}} \quad (1)$$



(a)



(b)

Fig.2. (a) Simulated S-Parameters (S_{11} & S_{21}) (b) vswr vs frequency

Proposed antenna has circular radiating patch with diameter 20mm including four EBG slots on each antenna in MIMO, which provide better isolation in the intended band. T-shaped stub introduce on the ground plane that is improved isolation as well as diversity performance of antenna

Figure-2(a) shows the simulated scattering parameters in terms of return loss and isolation loss of projected MIMO antenna and it is observed that the return loss is less than -10dB in entire C-band and isolation between two antennas is below -22dB, which gives the best suitability in imminent RF communication system. Figure-2(b) shows the VSWR characteristics in anticipated frequency range (3.5,5.5GHz).

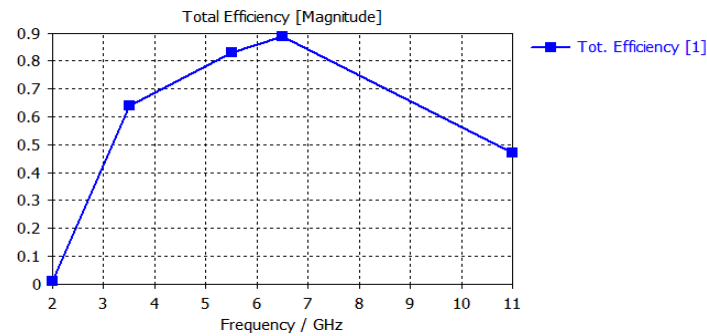


Fig.3. Simulated Radiation Efficiency of proposed MIMO Antenna.

Radiation efficiency is the ratio of radiated power by radiation resistance of radiated patch to the total effective incident power given to the MIMO patch antenna at port-1 and port-2. Radiated and Total efficiency of proposed MIMO antenna is greater than 0.65, which is acceptable value in proposed band for 5G Communication and RADAR system applications as depicted in Figure-3. The IEEE gain of proposed MIMO antenna is more than 1.2dB in the range of 3-7GHz. Gain bandwidth product of antenna is also almost constant, therefore bandwidth of antenna is increased as well as gain is reduced, so Impedance bandwidth of this proposed MIMO antenna is 53.33%. Axial ratio is depicted in Figure- 4.

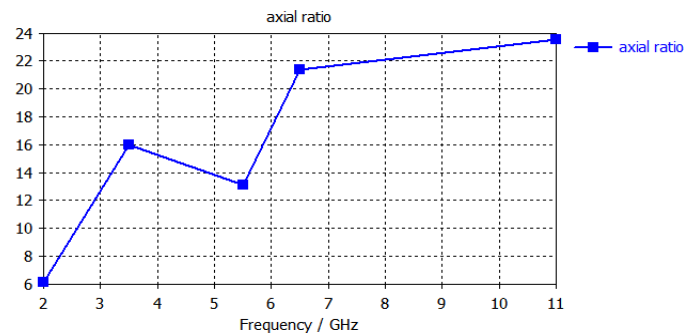
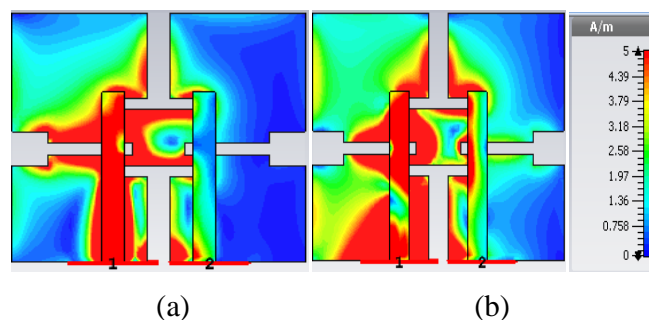


Fig.4 Simulated axial ratio of proposed MIMO antenna.



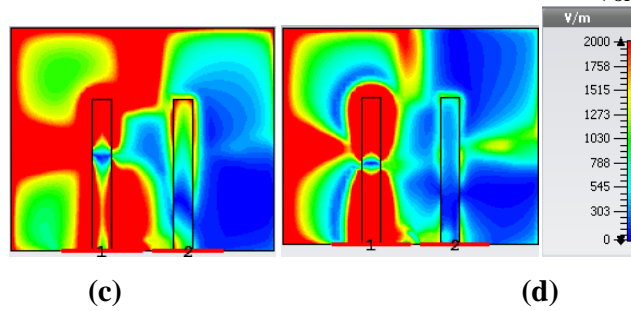


Fig.5 Current Density and electric field of proposed MIMO antenna at (a) 3.5 (b) 5.5GHz Frequency when port-1 excited and port-2 terminated by 50Ω impedance.

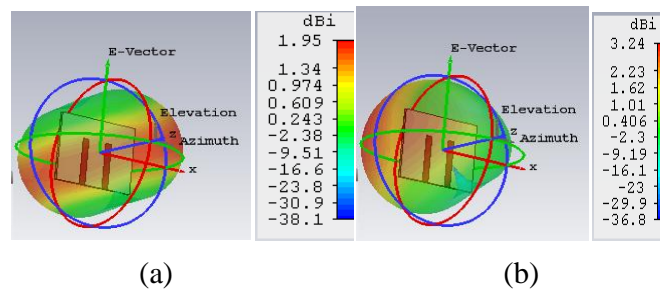


Fig.6. 3D radiation pattern of proposed MIMO antenna at (a) 3.5GHz (b) 5.5GHz with port-1 excited by external source and port-2 attached by 50Ω .

Current density of proposed antenna at 3.5, 5.5 GHz frequency is depicted in Figure- 5, which shows that charge will not accumulate at particular frequency, provide low current density on the radiated patch, so the final conclusion that most of the power is radiated in proposed frequency.

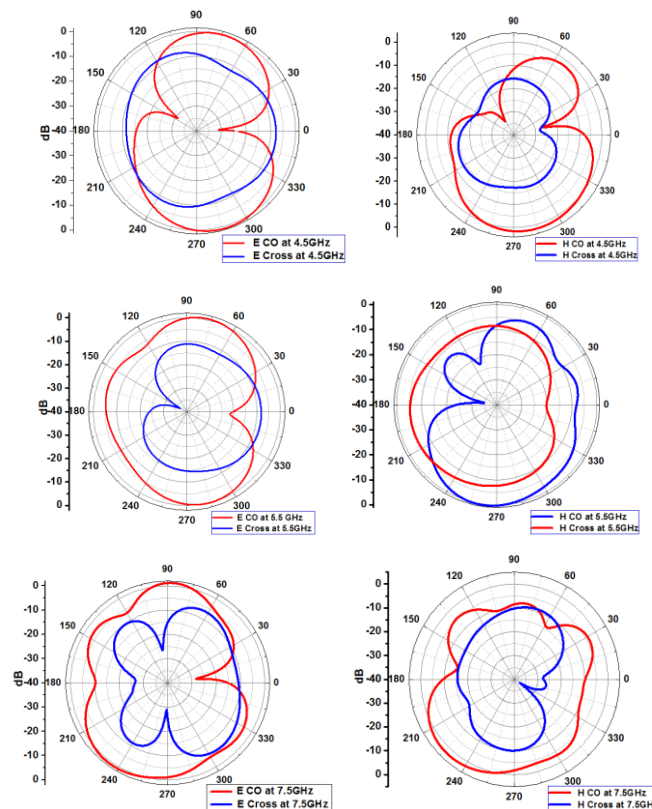




Fig.7. Polar 2D radiation plot of proposed antenna at 3.5, 5.5 and 7.5GHz frequency in operating band, when port-1 excited and port-2 terminated by 50Ω impedance.

Figure-6 shows the 3D radiation pattern of proposed MIMO antenna at 3.5, 5.5 and 7.5GHz to achieve maximum gain of 3.23dB at 5.5GHz. According to Poynting vector theorem power radiated in \mathbf{a}_z (x-y) plane while \mathbf{E} field is confined in \mathbf{a}_x (y-z) plane and \mathbf{H} field is confined in \mathbf{a}_y (x-z) plane $\mathbf{P}_{\text{rad}}(\mathbf{a}_z) = \mathbf{E}(\mathbf{a}_x) \times \mathbf{H}(\mathbf{a}_y)$.

Fig. 7 shows the radiation pattern of E and H-plane at 3.5, 5.5 and 7.5GHz frequency. In co-polarization the radiation pattern is almost Omni-directional, which radiates the power in all the direction but in the cross-polarization which is orthogonal to co-polarization becomes least radiated power as depicted in fig. 6 and the entire graph is stable for best fit in MIMO antenna applications. Table-I shows the comparison of proposed MIMO antenna with referred articles on various physical and radiation parameters as size, isolation, ECC, operating frequency range etc.

Table-I: Comparison table of proposed antenna performance with existing references on various parameters

Size (mm ²)	Isolation (dB)	ECC	Frequency Range (GHz)	Reference
$0.94\lambda_0 \times 3.06\lambda_0$	28>	<0.002	(2.4- 2.65GHz)	4
$0.14\lambda_0 \times 0.14\lambda_0$	15>	<0.005	(2.14- 2.58GHz)	8
$0.90\lambda_0 \times 0.25\lambda_0$	15>	<0.005	(2.0- 7.0GHz)	9
$0.44\lambda_0 \times 0.44\lambda_0$	30>	<0.002	(2.43- 2.54GHz)	11
$0.28\lambda_0 \times 0.38\lambda_0$	22>,25>	<0.0018	3.5,5.5GHz	Proposed

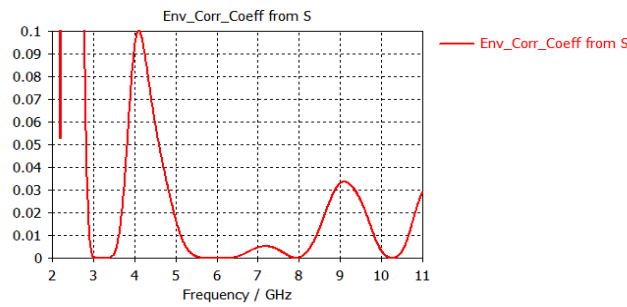
3. Diversity Performance of MIMO Antenna

Primarily, diversity performance of proposed MIMO antenna is judged by ECC, which shows the mutual coupling between two antenna radiators and the correlation factor of antenna one to antenna two is calculated by ECC by using equation 2(a, b). For satisfactory performance its value should be less than 0.1. Proposed antenna ECC and diversity gain-DG are depicted in fig. 8 and the values of ECC & DG are 0.002 and 9.99dB respectively in requisite bandwidth.

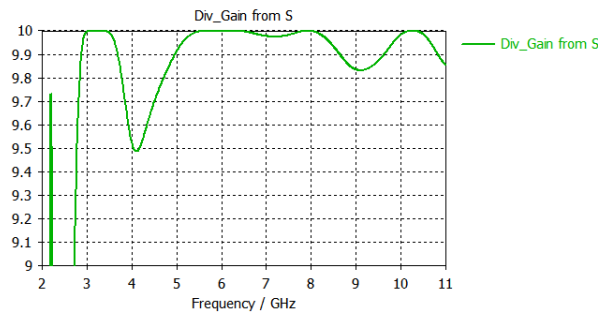
$$ECC = \frac{|s_{11}^* s_{12} + s_{21}^* s_{22}|^2}{(1 - |s_{11}|^2 - |s_{21}|^2)(1 - |s_{22}|^2 - |s_{12}|^2)} \quad 2(a)$$

ECC calculated by equation 2(a) [10], taking an assumption that the entire radiated field is uniformly distributed and antenna is lossless but it is a hypothetical term and ECC should be calculated by equation 2(b) [10] in terms of radiated electric field.

$$ECC = \frac{\left| \iint_{4\pi} [E_i(\theta, \phi) \times E_j(\theta, \phi)] d\Omega \right|^2}{\iint_{4\pi} |E_i(\theta, \phi)|^2 d\Omega \times \iint_{4\pi} |E_j(\theta, \phi)|^2 d\Omega} \quad 2(b)$$



(a)



(b)

Fig.8 Simulated (a) ECC and (b) Diversity Gain (DG) of proposed MIMO antenna.

$DG (dB) = 10\sqrt{1 - (ECC)^2}$, for ideally $ECC = 0$ and DG value should be 10dB. MEG ratio for projected antenna lies between $\pm 3dB$. Mean effective gain is the ratio of mean effective received power to the mean effective transmitting power to the antenna along the similar random route.

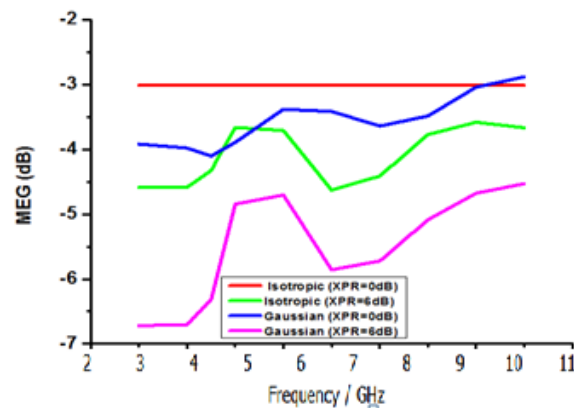


Fig.9 Simulated MEG Vs Frequency plot at different XPR and medium.

The mean effective gain (MEG) of the antenna is defined by the ratio of the mean effective received power in particular medium to the mean incident effective power in similar medium of the antenna with the same route, $MEG_i = \epsilon_{Total}/2$. Where ϵ_{Total} is the total efficiency associated with i^{th} antenna, *i.e.* $\epsilon_{Total}^i = \epsilon_{mis}^i \times \epsilon_{rad}^i$ where, $\epsilon_{mis}^i = 1 - \sum_{j=1}^N |S_{ij}|^2$, $\epsilon_{rad}^i = \sum_{j=1}^N |S_{ij}|^2$ where ϵ_{mis}^i and ϵ_{rad}^i are mismatch efficiency and radiation efficiency of i^{th} antenna. MEG for different XPR can be calculated by equation (3) [10].

$$MEG_i = \frac{P_{rec.}}{P_{inc.}} = \iint \left[\frac{XPR \times G_{\theta i}(\Omega) + G_{\phi i}(\Omega) \times P_{\phi}(\Omega)}{1 + XPR} \right] d\Omega \quad (3)$$

Where, XPR is the cross-polarization ratio, $G_{\theta i}(\Omega)$, $G_{\phi i}(\Omega)$ and $P_{\phi}(\Omega)$ is gain and power density function of incident wave, Ω = beam area.

The MEG for isotropic medium with XPR = 0dB is constant at -3dB in the C-band range and at XPR = 6dB lies in the span of -3.5 to -4.9 dB. Similarly, the MEG for Gaussian medium with XPR = 0 dB and XPR = 6dB lie in the span of -3dB to -4.5dB and -4.9 to -6.8dB, respectively. Fig.9 shows the simulated MEG in isotropic and Gaussian medium with different XPR value for indoor XPR = 6dB and outdoor XPR = 0dB.

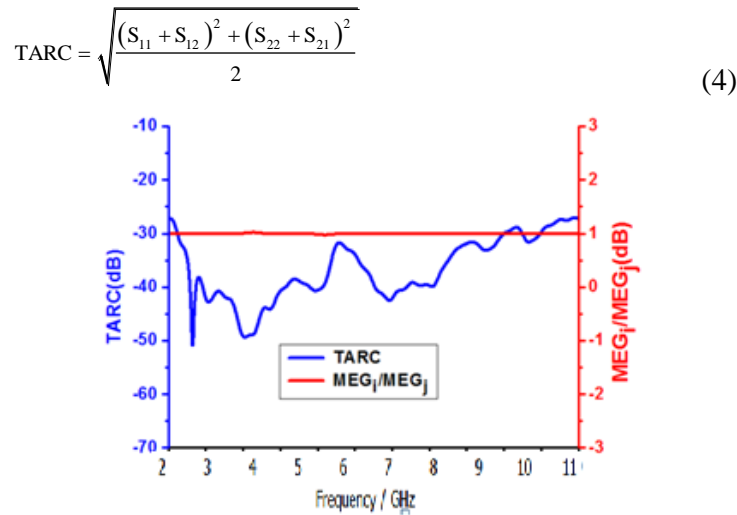


Fig.10 Simulated TARC and MEG of proposed MIMO antenna.

Diversity performance is also judged by TARC which is calculated by in terms of S-parameters. TARC is the ratio of square root of total active reflected power to the total active incident power. TARC gives the information about apparent return loss of the MIMO antenna. TARC value is less than 0dB for MIMO antenna. TARC can be calculated by equation (4) and its value less than -35dB which are depicted in fig.10.

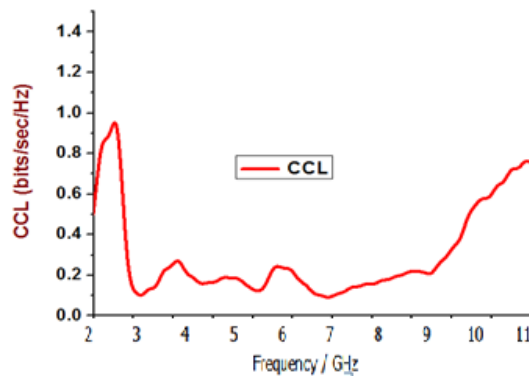


Fig.11 Simulated result of CCL of proposed MIMO antenna in 5G-band.

$$\text{CCL (dB)} = -\log_2 \text{Det}(\varphi^s)$$

Where, φ^s show a 2×2 correlation matrix to be evaluated by S-parameters, $\varphi_{ii} = 1 - |S_{ii}|^2 - |S_{ij}|^2$, $\varphi_{ij} = -(S_{ii} \times S_{ij} + S_{ji} \times S_{jj})$. Channel capacity loss should be determined by equation (5). For MIMO-antenna channel bandwidth should be improve but as well as channel capacity loss also increase for 2×2 MIMO-antenna it should be less than 0.30bits/sec/Hz, Proposed MIMO-antenna have CCL is < 0.30 bits/sec/Hz which is shown in fig. 11.

4. Conclusion

EBG based MIMO antenna has been designed and the working performance of antenna has also been simulated for C-band applications with improved isolation < -22 dB and good diversity performance in terms of ECC, DG, TARC, CCL and MEG, which are in satisfactory limit for wireless communication and provide better data rate and high SNR with respect to SISO antenna. So, as per table-I and above discussed results related to diversity concern of proposed MIMO antenna, it is a good entrant for 5G applications.

References

- [1] M. J. Al-Hasan, T. A. Denidni, and A. R. Sebak, "Millimeter-wave compact EBG structure for mutual coupling reduction applications," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 2, pp. 823–828, 2015.
- [2] J. Deng, J. Li, L. Zhao, and L. Guo, "A Dual-Band Inverted-F MIMO Antenna with Enhanced Isolation for WLAN Applications," *IEEE Antennas and Wireless Propagation Letters*, vol. 16, no. c, pp. 2270–2273, 2017.
- [3] Y. Fan, J. Huang, T. Chang, and X. Liu, "A Miniaturized Four-Element MIMO Antenna With EBG for Implantable Medical Devices," *IEEE Journal of Electromagnetics, RF and Microwaves in Medicine and Biology*, vol. 2, no. 4, pp. 226–233, 2018.
- [4] S. Ghosh, T. N. Tran, and T. Le-Ngoc, "Dual-layer EBG-based miniaturized multi-element antenna for MIMO systems," *IEEE Transactions on Antennas and Propagation*, vol. 62, no. 8, pp. 3985–3997, 2014.
- [5] S. Karamzadeh, M. Kartal, H. Saygin, and V. Rafii, "Polarisation diversity cavity back reconfigurable array antenna for C-band application," *IET Microwaves, Antennas & Propagation*, vol. 10, no. 9, pp. 955–960, 2016.
- [6] M. Kartal and S. Karamzadeh, "Circularly polarised MIMO tapered slot antenna array for C-band application," *Electronics Letters*, vol. 51, no. 18, pp. 1394–1396, 2015.
- [7] J. Y. Lee, S. H. Kim, and J. H. Jang, "Reduction of Mutual Coupling in Planar Multiple Antenna by Using 1-D EBG and SRR Structures," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 9, pp. 4194–4198, 2015.
- [8] Q. Li, A. P. Feresidis, M. Mavridou, and P. S. Hall, "Miniaturized double-layer EBG structures for broadband mutual coupling reduction between UWB monopoles," *IEEE Transactions on Antennas and Propagation*, vol. 63, no. 3, pp. 1168–1171, 2015.
- [9] K. Payandehjoo, S. Member, R. Abhari, and S. Member, "Employing EBG Structures in Multiantenna Systems for Improving Isolation and Diversity Gain," vol. 8, pp. 1162–1165, 2009.
- [10] Qingchong Liu, Qi Liu, and Fangchao Zhou, "A novel EBG-based MIMO antenna with enhanced isolation for WLAN applications," vol. 1, pp. 2782–2785, 2016.
- [11] H. Zhai, L. Xi, Y. Zang, and L. Li, "A Low-Profile Dual-Polarized High-Isolation MIMO Antenna Arrays for Wideband Base-Station Applications," *IEEE Transactions on Antennas and Propagation*, vol. 66, no. 1, pp. 191–202, 2018.