Mutual Coupling Reduction Between MM-Wave Microstrip Antennas Using Split Rectangular Structure

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Abstract

A novel design of metamaterial structure has been developed to reduce the mutual coupling between two microstrip patch antennas. A split rectangular structure loaded between the two microstrip patches is the method used to decrease coupling. The proposed antenna is designed to operate at a frequency of 28 GHz. This construction is suited for use with mm-wave, 5G antenna systems, and mobile applications. The connection between antennas is significantly improved. The maximum isolation achieved is 29.5 dB by etching the split rectangular structure on the ground of the proposed antenna and on a floated ground between the two patches. The distance between the two elements of the antenna, from edge to edge, is 0.4λ. The design is achieved with CST Studio software.

Keywords: 5G; mm-wave; mutual coupling; CSRR; CST

1. Introduction

A high-data-rate communication service has been required in mobile applications and 5G networks. In mobile systems, a greater frequency spectrum and a wider bandwidth are important [1,2]. To achieve these requirements of this system, array antennas have been developed. Due to the use of several antennas in the same structure that operate at the same frequency, strong coupling and excessive interference appear. The performance of an antenna communication system can be degraded by mutual coupling. The effectiveness of multiple-input, multiple-output (MIMO) systems is also impacted by reciprocal coupling effects. There are several methods and techniques used to reduce the mutual coupling, such as electromagnetic band-gap structures [EBG] [3], and complementary split-ring resonators [4-6]. Other approaches to reducing mutual coupling between microstrip antenna elements include DGS structures such as H-shaped [7]. Metamaterial (MTM) structures [8, 9] are another strategy for increasing isolation between two patch antennas and decoupling waves. In this paper, a split rectangular structure shape has been used between two microstrip patch antennas in order to reduce their mutual coupling. The printed antennas make it simple and inexpensive to construct. This structure is highly isolated and can be employed in a variety of applications, including MIMO technologies, medicinal applications, radar applications, 5 G applications. The distance from edge to edge is 0.4λ mm, and 7.5 mm separates two elements. The proposed antenna can be used to enhance the performance of the antenna and reduce mutual coupling between the two patch antennas. The proposed design is simulated by CST program.

2. Related Work

In the past, a variety of methods were used to increase isolation between the microstrip patch antennas. As a consequence, the mutual coupling in the target region of 57–63 GHz was reduced to –30 dB. Utilizing a dielectric superstrate atop the MIMO DRA is another decoupling approach described in [10]. The creation of orthogonal modes by a sophisticated hybrid feeding mechanism is the subject of several investigations [11–12]. Similar to [11], a hybrid isolator is used to create isolation ranging from 29 to 49 dB. It consists of an EBG structure and a millimeter wave choke absorber. To enhance

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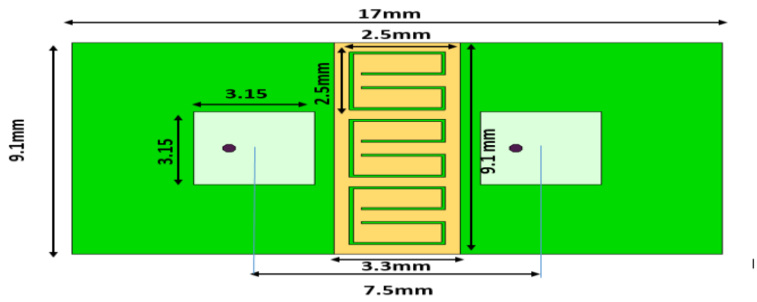
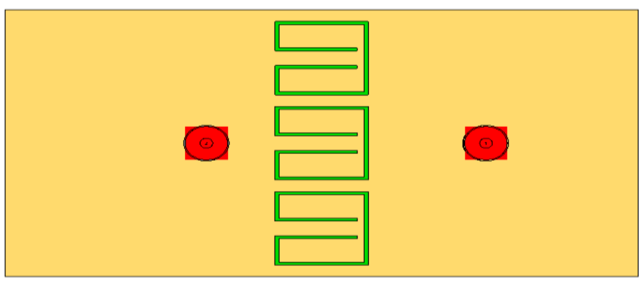
isolation, metal strips were printed on the top surface of the DRAs in [12]. In the whole bandwidth of 27.5-28.35 GHz, the isolation is 25–28 dB. Without employing the decoupling structure, a different technique in [13] isolates the MIMO DRA components by 45 dB at the design frequency. The activation of high order modes in the DRA that are obstructing the feeding port is the foundation of this technique. Utilizing the metallic strips on the lateral walls of the DRA components, [14] reports a MIMO DRA with an isolation level of 25 dB at 15 GHz. The isolation technique is really straightforward and small. Magnetic coupling exists between the MIMO components. The strips printed on the lateral walls deflect the coupling fields in the DRA. The DRA's bordering walls' central part, where the field is isolated, is not well emphasized. Similar to this, printing several metallic strips on the DRA components has decreased coupling in [15] in the E-plane. In paper [16], the manufacturing tolerance of the metallic strips on two MIMO DRA prototypes is checked, and the measured findings are validated by comparing them to simulations. The proposed MIMO DRA has an impedance bandwidth of 4.73 GHz to 5.1 GHz with measured isolation of 28 dB at the design frequency. With a steady radiation pattern for each port and a low ECC of 0.05 in the Sub-6GHz 5G band, a measured isolation level of 28 dB was achieved. The suggested design's performance was compared to that of the conventional design, top strip-based design, and grounded strip-based design to see which performed the best.

3. Antenna Design

In this section, two square microstrip patch antennas are implemented at a resonance frequency of 28 GHz. To reduce the coupling effect, the G shape structures are suited for modifying and redistributing the electric and magnetic quantities. A triple G-shape structure is etched in the ground and printed on the floating ground to achieve isolation. This technique reduces the mutual coupling between the two patches and redistributes the surface current between them. The proposed antenna dimension is 3.15 mm in width and 3.15 mm in length. The distance between the two square patch antennas is 7.5 mm (center to center). The antenna structure contains split rectangular arrays; one array is cut from a floated ground between the two patches, while the other is cut into the antenna ground. The unit-cell spacing has been changed to 0.2 mm. The antenna's overall dimensions are 9.1x17 mm2. The antenna was designed and printed on a Roger/RT Duroid substrate of type 5880 with a dielectric constant of 2.2 and a thickness of 0.508mm. Figure 1 shows the top and bottom views of the proposed antenna structure with the split rectangular metamaterial structure system. The dimensions of the split rectangular shape are 2.5 mm and 0. 5 mm as shown in the complete antenna design in figure. The distance between the unit cells is equal to 0.4 mm.



(a)



(b)

Figure 1: The complete antenna structure (a) Upper view of the structure
(b) Lower view of the structure

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4. Results and discussion

As a result, parametric research was carried out for all parameters of the G-shaped and the distance between the structure elements. Figure 2 shows the simulated S-parameters for the proposed antenna with and without a split rectangular structure.

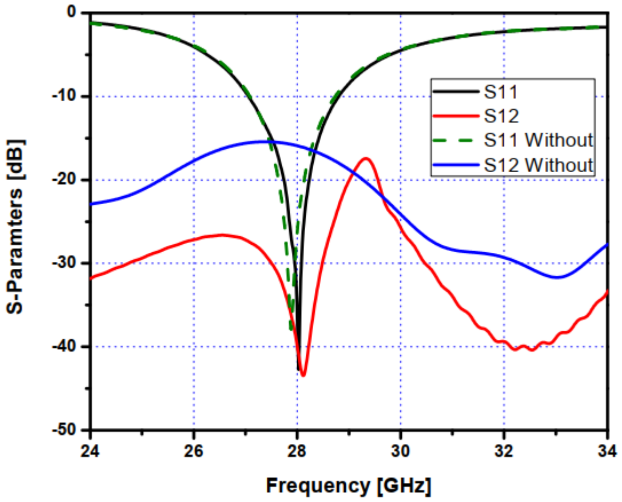

Figure 2: The S-parameters results of the proposed antenna with and without using

The suggested antenna has wide S11 and S22 coverage from 27 GHz to 29 GHz (2 GHz BW). As shown in Figure 2, S12, the near distance between two patches is equal to 15 dB. By placing the MTM structure, mutual coupling has been reduced, and the radiation coupling or surface current due to ground has been overcome. With split rectangular metamaterial, mutual coupling is reduced to -43 dB, compared to dB without the metamaterial structure. Thus, a mutual coupling reduction of -29.5 dB is achieved. Figure 3 depicts the S-parameters of the final designed antenna with a split rectangular structure.

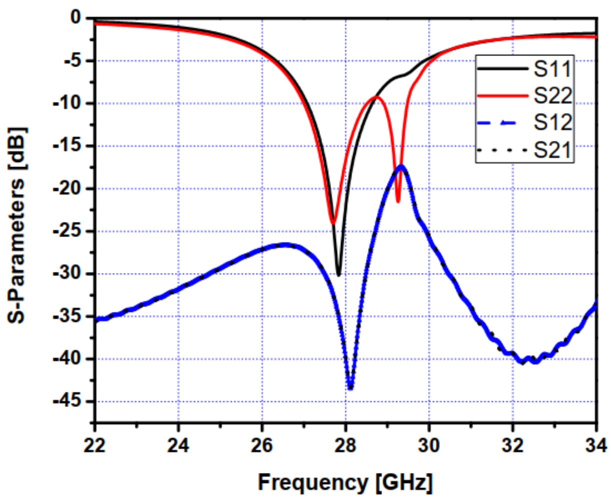

Figure 3: The S-parameters results of the proposed antenna

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All parameters in the antenna structure are studied parametrically and explained. Also, parametric studies are made for the number of GSRR and the direction of the slot in the rings with respect to the antenna patch. The best results are achieved by using a 3-GSRR array that is arranged as presented. Figure 4 presents the gain of these antennas, which achieve 7 dB at the resonance frequency.

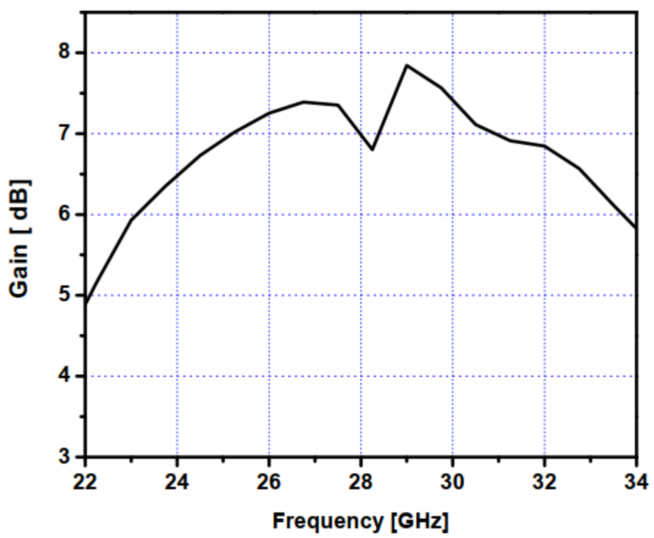

Figure 4: Gain verses frequency of the designed antenna

In figure 5, the surface current distribution of the proposed antenna has been shown.

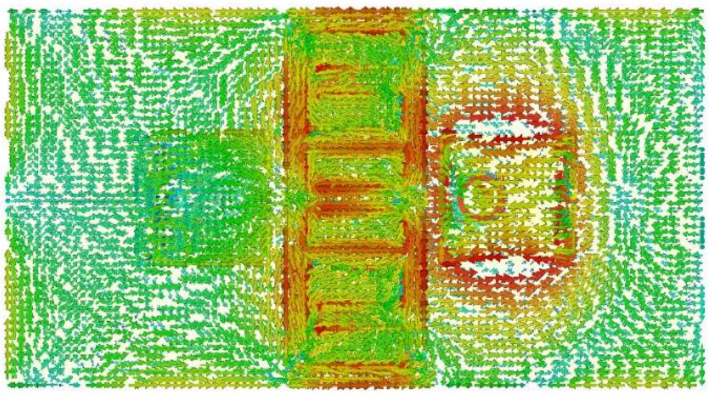

Figure 5: The surface current distribution of the proposed antenna

The G-shaped split ring resonators block the surface current from moving toward the second patch and dispersing it in other directions. Figure 6 shows the radiation patterns of the designed patch antenna in the array with decoupling structures, whereas another patch antenna is terminated with a 50-ohm load on the radiation characteristics. A comparison between this work and the related research in mutual coupling reductions is listed in Table 1.

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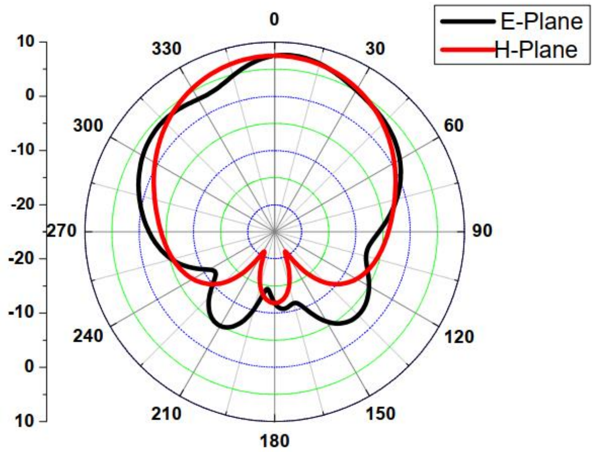

Figure 6. Simulation results for the far field gain(E and H plane)

patterns for the two patches with CSSRs resonators at 28 GHz

Table 1: A comparison between the proposed structure and previous reported design

Ref.	Technique	Response Frequency (GHz)	Center to Center Distance	Bandwidth	Coupling Reduction (dB)
[4]	CSRR MTM Structure	28	$0.7\lambda_o$	Wide	31.7
[5]	Spiral MTM Structure	6.58	$0.5\lambda_o$	Narrow	2-3
[8]	MTM waveguide	3.525	0.737	Narrow	6-20
This work	G-EBG MTM Structure	28	$0.7\lambda_o$	Wide	29.5

6. Conclusion

By utilizing the split rectangular structure etched on the ground plane and the floated ground plane which placed between the patch antennas, this study provides a unique achievement of mutual coupling reduction between two microstrip patch antennas that can be applied for many applications specially for MIMO systems in 5G applications. The highest decrease achieved is 29.5 dB, with a gap of 0.4 (edge-to-edge) between the two patches. This achievement with a small gap is important to make the antenna system compact and suitable for MIMO systems. The developed antenna has a 10dB wide band that extends to 1.62 GHz. The suggested antenna can be used for 5G applications, MIMO antenna systems, and mm-wave antenna arrays.

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References

[1] C.-Y. Chiu, C.-H. Cheng, R. D. Murch, and C. R. Rowell, Reduction of mutual coupling between closely-packed antenna elements. IEEE Trans. Antennas Propag., 55(6), 1732–1738, 2007.

Doi: https://doi.org/10.54216/IJWAC.050106
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[2] K. S. Vishvaksenan, K. Mithra, R. Kalaiarasan, and K. S. Raj, Mutual coupling reduction in microstrip patch antenna arrays using parallel coupled-line resonators. IEEE Antennas Wireless Propagation Letter, 16, 2146–2149, 2017.

[3] A. Suntives and R. Abhari, Miniaturization and isolation improvement of a multiple-patch antenna system using electromagnetic band gap structures. Microwave and Optical Technology Letter, 55(7), 1609–1612, 2013.

[4] Ameen, A. M., Yousef, B. M., & Attiya, A. M., Mutual coupling reduction between mm-wave microstrip antennas using CSRR metamaterial structure. In 2020 37th National Radio Science Conference (NRSC), 48-56, Sept. 2020.

[5] Allam M. Ameen, Basma M. Yousef, Mohamed I. Ahmed, Improved Isolation and Reduction of Mutual Coupling Between Two Microstrip Antennas for 5G Applications. International Journal of Microwave and Optical Technology, 15(5), September 2020.

[6] Basma M. Yousef, A. A. Shaalan, Hussein Attia, Kamal H. Awadalla, Mutual Coupling Reduction between Microstrip Antennas Using Complementary Split Spiral Resonators (CSSRs). IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), 10(5), 38-44, 2015.

[7] Raghuraman Selvaraju, Mohd H. Jamaluddin1, Muhamad R. Kamarudin, Jamal Nasir3, and Muhammad H. Dahr, Complementary Split Ring Resonator for Isolation Enhancement in 5G Communication Antenna Array. Progress In Electromagnetics Research C, 83, 217–228, 2018.

[8] Masullo, M. R., Vaccaro, V. G., Losito, R., Masi, A., Passarelli, A., Chikhi, N., ... & Andreone, A., Metamaterial-based absorbers for the reduction of accelerator beam-coupling impedance. IEEE Transactions on Microwave Theory and Techniques, 68(4), 1340-1346, 2019.

[9] O. F. Siddiqui, M. Mojahedi, and G. V. Eleftheriades, Periodically loaded transmission line with effective negative refractive index and negative group velocity. IEEE Transaction on Antennas and Propagation, 51(10), 2619 – 2625, 2003.

[10] M. Li and S. Cheung, Isolation enhancement for MIMO dielectric resonator antennas using dielectric superstrate. IEEE Trans. Antennas Propag., 69(7), 4154–4159, 2021.

[11] M. Al-Hasan, I. B. Mabrouk, E. R. F. Almajali, M. Nedil, and T. A. Denidni, Hybrid isolator for mutual-coupling reduction in millimeter-wave MIMO antenna systems. IEEE Access, 7, 58466–58474, 2019.

[12] Y. Zhang, J.-Y. Deng, M.-J. Li, D. Sun, and L.-X. Guo, A MIMO dielectric resonator antenna with improved isolation for 5G mm-Wave application. IEEE Antennas Wireless Propag. Lett., 18(4),747–751,2019.

[13] Y. M. Pan, Y. Hu, and S. Y. Zheng, Design of low mutual coupling dielectric resonator antennas without using extra decoupling element. IEEE Trans. Antennas Propag., 69(11), 7377–7385, 2021.

[14] M. Elahi, A. Altaf, J. Yousaf, and E. R. A. Majali, Isolation improvement in MIMO dielectric resonator antenna. in Proc. IEEE Int. Symp. Antennas Propag. USNC-URSI Radio Sci. Meeting (APS/URSI), 111-1152, 2021.

[15] X.-J. Wu, Z. Chen, T. Yuan, and S.-Z. Liu, A decoupling method for E-plane coupled millimeter-wave MIMO dielectric resonator antennas. in Proc. Cross Strait Radio Sci. Wireless Technol. Conf. (CSRSWTC), 109-111, 2021.

[16] ELAHI, Manzoor, et al., Mutual Coupling Reduction in Closely Spaced MIMO Dielectric Resonator Antenna in H-Plane Using Closed Metallic Loop. IEEE Access,10, 71576-71583, 2022.

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