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Design of modified staircase-enriched rectangular microstrip antenna for mm-wave applications

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Abstract. A two-element rectangular staircase-shaped multiple-input multiple-output (MIMO) antenna has been suggested in this communication for 5G mm-Wave applications. The intended antenna occupies a volume of 15 × 10 × 1 mm^3 is constructed on Rogers RT5880(lossy) dielectric material with relative permittivity of 2.2. The antenna comprises of two staircase shaped radiators and a feed is inserted on bottom side of substrate and circle shaped ground on bottom side. The rectangular slots are fused on each radiator to improve the impedance matching at 29 and 39GHz. And, the MIMO antenna radiators are positioned orthogonally each other to enhance the isolation between the ports. The planned antenna operates at 29 GHz between 28.98 and 30.79 GHz and 39GHz between 37.78 and 40.42Ghz, with isolation (S12) of -21.41 dB and S11 of -10.12 dB. Furthermore, the design provides high peak gain (6.48 and 6.17 dBi), acceptable radiation efficiency (77 and 78%), omni-direction patterns, a considerable mean effective gain (-3dB) and MEG ratio, a low envelope correlation coefficient (<0.01), an adequate diversity gain (10dB).
Keywords: Staircase shaped MIMO antenna, rectangular slotted radiators, insert feed, isolation, 5G 29 and 39GHz mm-Wave, wireless communication.

Introduction

Recent developments in wireless technologies have led to an increase in the diversity of wireless networks. Since the existing fourth generation (4G) network has reached a bottleneck and might not be able to handle the massive demand for data, the focus is now on 5G. Significant advancements over 4G are also anticipated with 5G technology, including faster transfer rates, more efficient use of spectrum, and lower latency. The mm-Wave frequency band, which goes beyond 24 GHz, offers a lot of available spectrum, allowing for remarkable low latency, high throughput, and capacity. Different versions of 5G mm-Wave antennas have therefore been proposed [1-4].

Techniques such as multiple input multiple output (MIMO) are being developed to boost wireless connection capacity. Therefore, MIMO technology is one of the most viable options for 5G applications. Multiple antennas are used at both ends of the communication channel in a MIMO system. Without requiring more power or bandwidth for transmission, MIMO systems can significantly increase channel capacity and communication reliability. When many antenna elements in an array receive energy simultaneously, a phenomenon known as mutual coupling takes place. The performance of the antennas will be reduced as a result of this mutual coupling, which will affect the current flowing through them [5]. Therefore, in space-constrained MIMO systems, enhancing isolation or decreasing reciprocal coupling among neighbouring antennas is always a challenging problem. To properly separate the radiating element ports in two- port MIMO systems, a number of techniques have been proposed [6-14]. Rectangularly protruding strips and slotted T-shaped stubs [6], mirrored radiator arrangements [7], the use of double-side EBG (DS-EBG) structures [8], vertically stacked dipole antennas on flexible liquid crystal polymer substrates [9], oppositely positioned antenna elements [10, 11], keeping an edge-to-edge distance between elements and using orthogonal arrangements [12, 13], and orthogonal positioning of radiating elements and slots on the ground [14] are some strategies for reducing mutual coupling.

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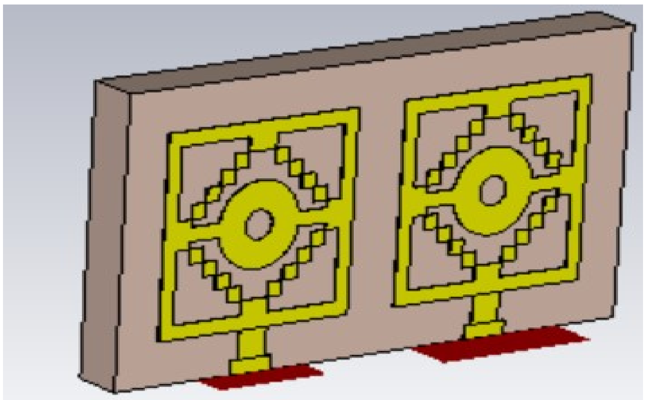
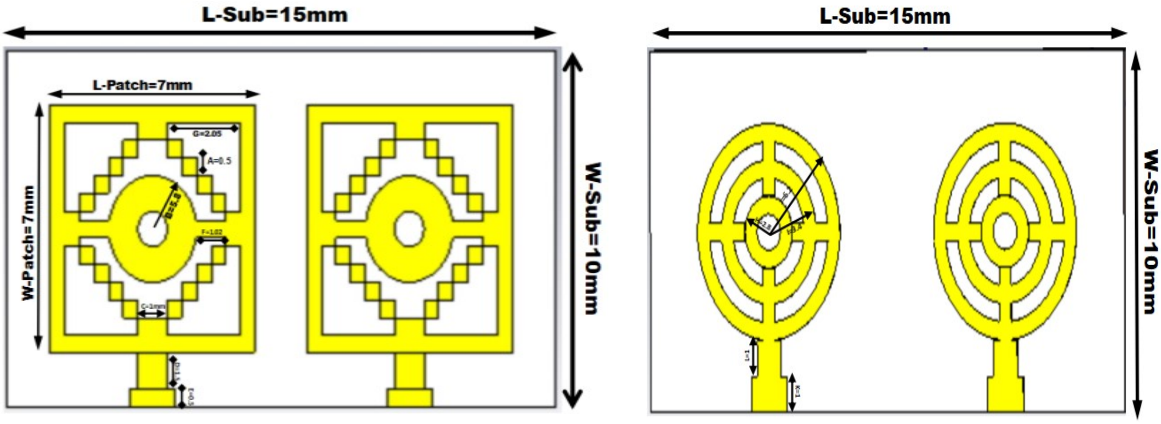
A two-element MIMO antenna with a rectangular slotted staircase shape is advised for 5G 29 and 39GHz mm-Wave applications. The antenna comprises of two staircase shaped radiators and a feed is inserted on bottom side of substrate and circle shaped ground on bottom side. It is constructed of Rogers RT5880 (lossy) dielectric material. At 29 and 39GHz, the rectangular shaped of each radiator are fused to improve impedance matching. Additionally, the MIMO antenna radiators are aligned orthogonally to provide port isolation. The antenna operates at 29 GHz between 28.98 and 30.79 GHz and 39GHz between 37.78 and 40.42 GHz has good matching and isolation characteristics. Additional design criteria include a high peak gain, suitable radiation efficiency, omnidirectional patterns, a small envelope correlation coefficient, sufficient diversity gain, omnidirectional patterns, a considerable mean effective gain.

Design of Two-element MIMO Antenna

This communication proposes a two-element, rectangular slotted staircase multiple-input multiple-output (MIMO) antenna for 5G 29 and 39GHz mm-Wave wireless communications as depicted in Fig. 1. Rogers RT5880(lossy) dielectric material with a relative permittivity of 2.2, a breadth of 1 mm is used to construct the required antenna, which has a total area of 15 × 10 mm^2. The antenna's two staircase shaped radiators and insert feed of size 2 x1 mm^2 on the substrate's bottom side and ground on its bottom as shown in Fig. 1 (a) and (b), respectively. Every rectangular staircase-shaped radiator having dimensions of 7 x 7 mm^2 and the circle shaped ground having dimensions of 6.2mm*3.4mm*2.8mm.



(a) trimetric view



(b) top side (c) bottom side

Fig. 1. Two-element MIMO design; (a) trimetric view, (b) top side, and (c) bottom side.

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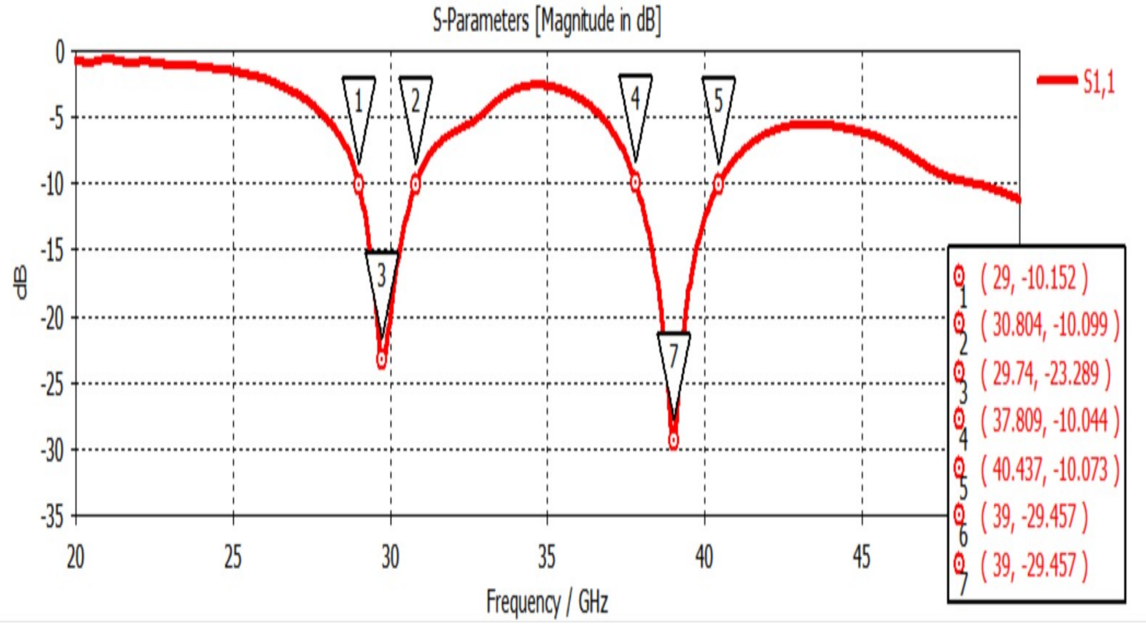
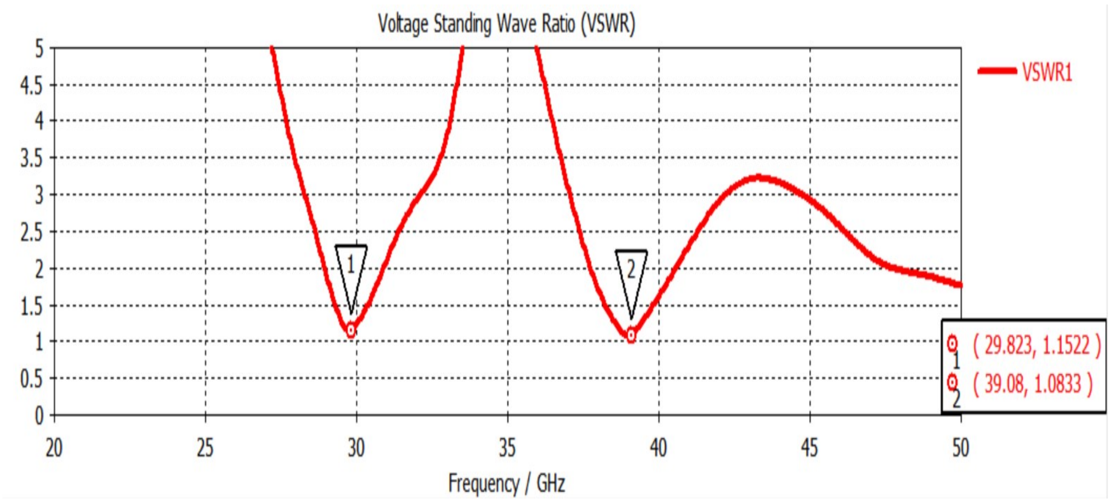
Results and Discussion

In a two-element MIMO antenna, the impedance characteristics are represented by Sii, where i is an integer between 1 and 4, and Sij (i≠j), which denotes the MIMO antenna's isolation or mutual coupling characteristics, where i and j are numbers between 1 and 2. Fig. 2 (a), 2 (b) and 2 (c), respectively display the impedance, VSWR and isolation properties of the suggested design. The antenna has a Sii, or S11/S21/S12/S22, of -21 dB and a VSWR of 1:2. It works at 29 GHz with a return loss bandwidth between 28.98 and 30.79 GHz and at 39 GHz with a return loss bandwidth between 37.78 and 40.42Ghz. Furthermore, across the whole functional range, the antenna shows a high isolation Sij, or S12/S21/S12/S22, of more than 29.5 dB among two antenna ports because of the orthogonal placement of the radiators. Furthermore, in order to analyse the isolation characteristics of an antenna, the surface current distributions at 29 GHz were also investigated, as shown in Figs. 3(a) and 3(b), respectively when port 1 (p1) is activated and other ports are loaded with 58ohms and vice-versa. It is evident that surface waves and radiative near-field coupling effects between any two neighboring antenna elements are redirected in a different direction and prevented from accessing adjacent ports.



(a) Reflection coefficient plot



(b) VSWR plot

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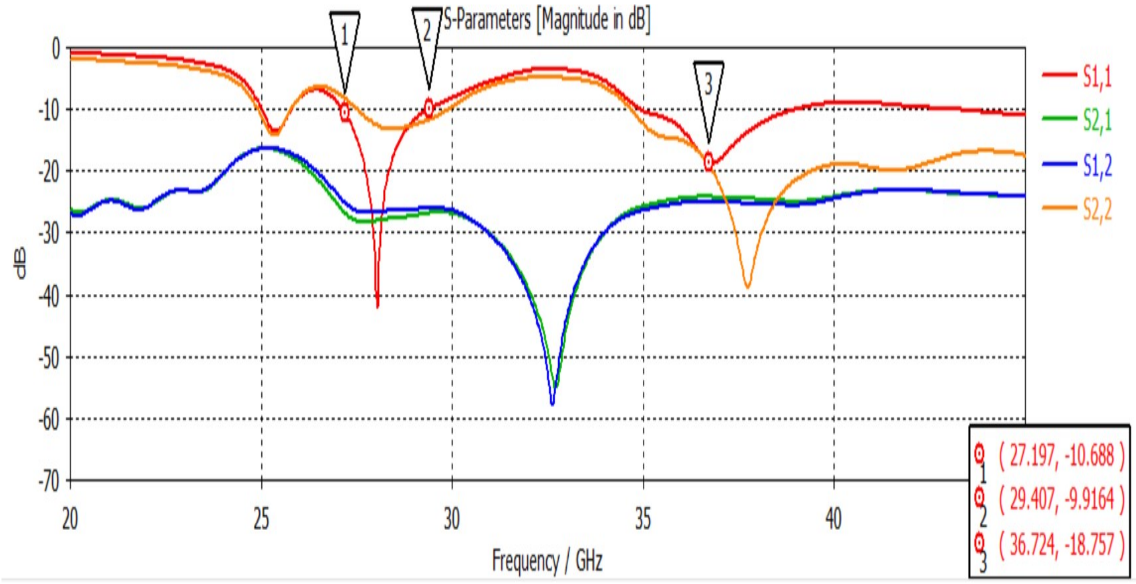
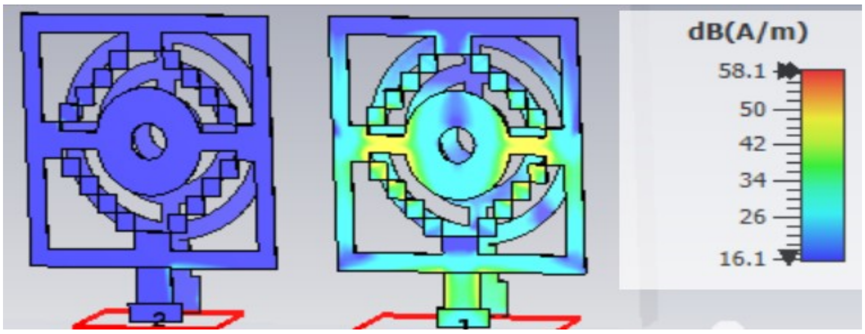


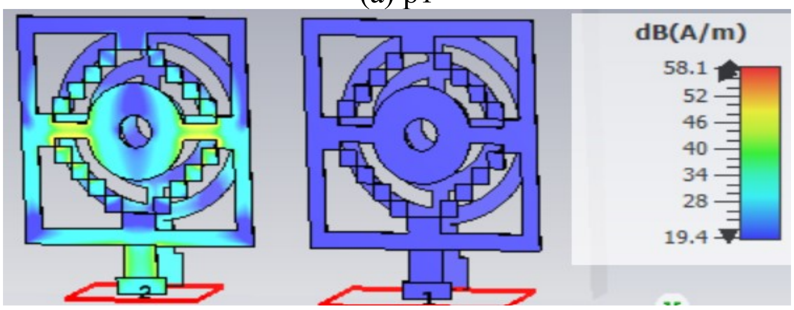
(c) Isolation plot

Fig. 2. Two-element MIMO design's s-parameter and VSWR plots.

Figure 4 (a) to Figure 4 (b) show the 2-D radiation patterns at 29 GHz for the proposed 2-element MIMO antenna. One port is activated and the other port is terminated with matching impedance in order to perform the far-field radiation patterns at 29 GHz on the E-plane and H-plane. Within the operational bands, the antenna appears to support both bidirectional E-plane and omnidirectional H-plane patterns. The MIMO antenna's diversity performance is evaluated using characteristics such as peak gain, radiation efficiency, envelope correlation coefficient (ECC), Diversity Gain (DG), and mean effective gain (MEG) as presented in Fig. 5. As illustrated in Figure 5(a) and Figure 5(b), the chosen MIMO antenna offers a peak gain of 6.48 and 6.17 dBi and radiation efficiencies of 77 and 78%, respectively, at the bands of operation of 29GHz and 39GHz.



(a) p1



(c) p2

(d) **Fig. 3.** Surface current distribution at 29 GHz at all ports.

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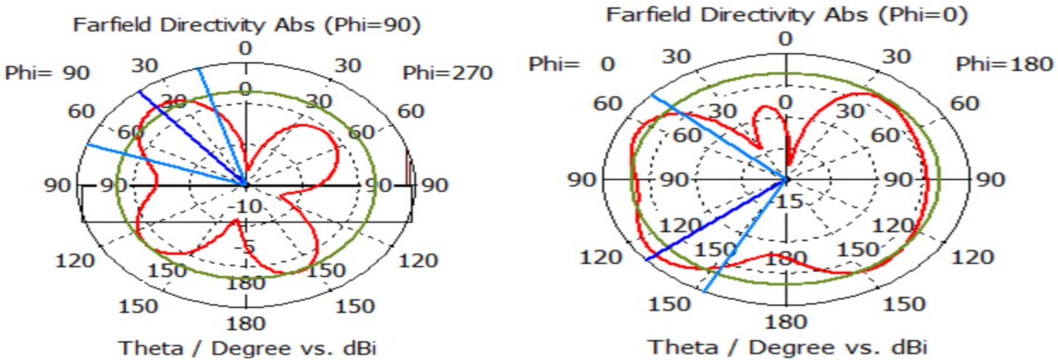
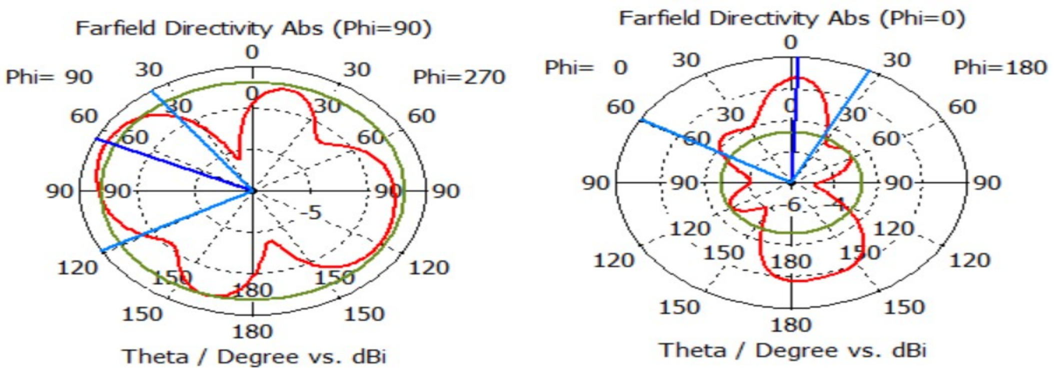


(a) E- & H fields at 29 GHz



(b) E- & H fields at 39Ghz

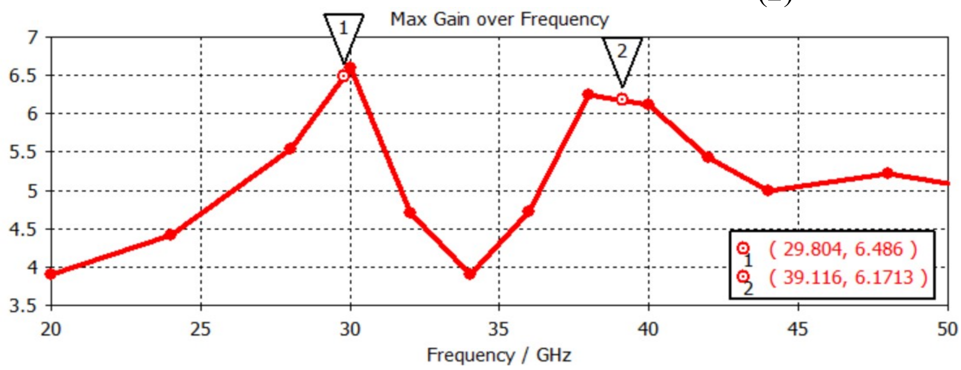
Fig. 4. Two-element MIMO design 2-D radiation patterns at 29 GHz and 39 GHz

In MIMO systems, ECC is a key parameter that shows how each antenna element is independent based on its own properties [16]. The following expression in equation (1) will be used in order to do a numerical calculation of ECC [17, 18]. The measured and simulated ECC values are calculated from s-parameters. The results in Fig. 5(c) show that the ECC values over the dual-bands are <0.003

$$\rho_e (or) ECC_{s-parameters} = \frac{|S_{11}^* S_{12} + S_{21}^* S_{22}|^2}{(1-|S_{11}|^2-|S_{21}|^2)(1-|S_{22}|^2-|S_{12}|^2)} \quad - (1)$$

The diversity gain is a figure of merit used to measure the performance level of antenna diversity techniques [16]. The designed MIMO antenna diversity performance can be evaluated by using the Equation (2) [17, 18]. The results in fig 5(d) show the DG is approx. 10dB is achieved over the dual-bands.

$$Diversity\ Gain\ (DG) = 10\sqrt{1-\rho_e^2} \quad - (2)$$



(a) Peak gain in dBi.

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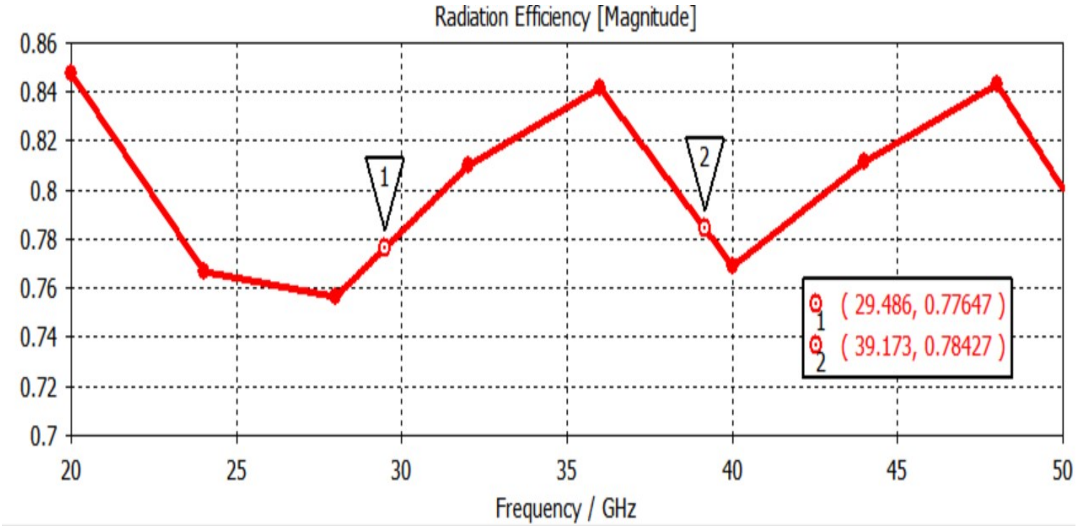
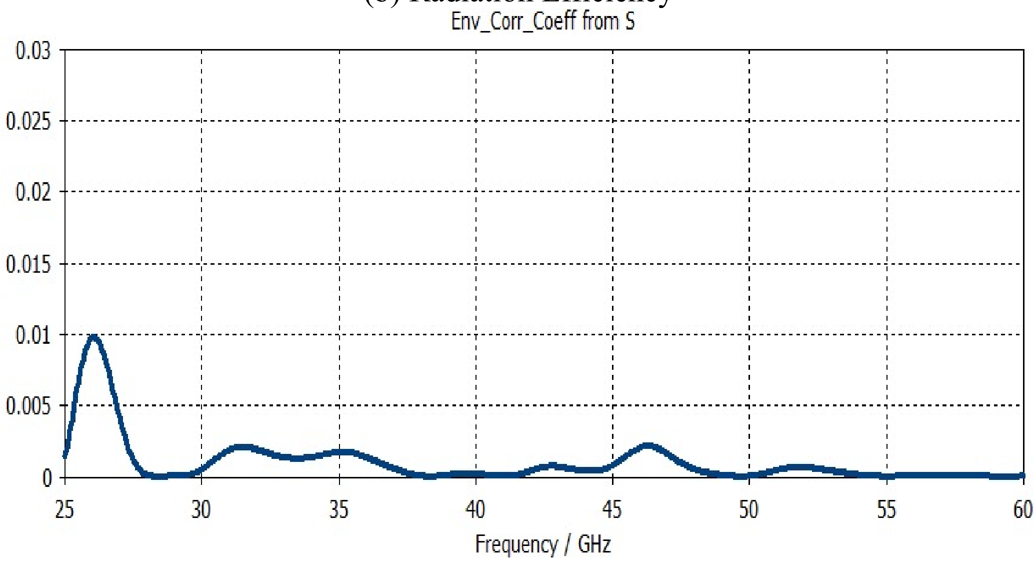
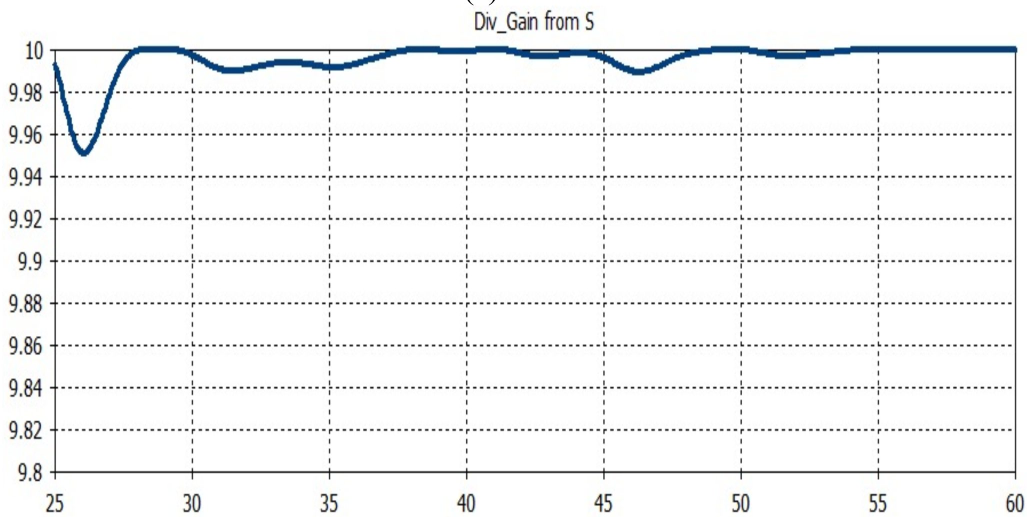


(b) Radiation Efficiency



(c) ECC



(d) Diversity Gain

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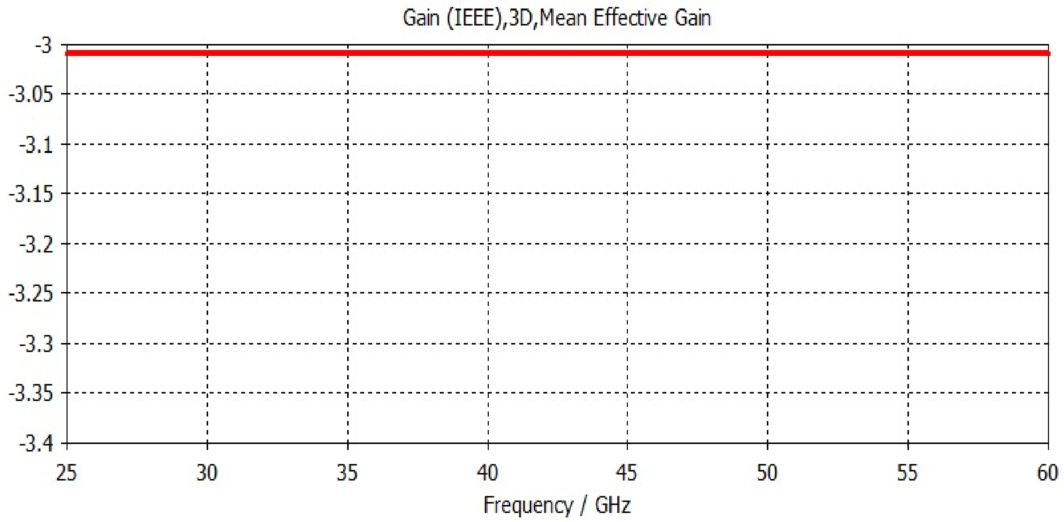

(d) MEG

Fig. 5. Two-element MIMO design diversity parameters.

The potential of an antenna to detect electromagnetic radiation in a multipath scenario is measured by diversity metric known as mean effective gain (MEG). The intended MIMO antenna achieves a MEG of -3dB at the operating bands, as shown in Fig. 5(e). To calculate the ECC,DG, and MEG parameters, the formulas in [14, 18] are utilized.

Table 1 shows how the performance of the proposed two-element MIMO antenna relates to other current antennas in terms of isolation, size, gain, MIMO diversity factors, and antenna elements. When it comes to impedance bandwidth, isolation, RE, and ECC, the suggested design outperforms traditional antennas.

Table 1. Antenna design comparison with previous antennas

Ref.	**No., of Elements**	**Size (mm^2)**	**Bands**	**Isolation**	**R.E (%)**	**ECC**	**Gain**
[6]	2	22x26	3.1-11.8	>20	>85	<0.03	3-6.6
[7]	2	30x15	28/38	>21	>80	<0.0001	5.7
[8]	2	15x8.5	28/38	>19	>83	<0.02	3
[10]	2	10x16	28/39	>20	>80	<0.04	4
[19]	2	26x11	27/39	<-18	>98	<0.001	5/5.7
[20]	2	14x12	28/38	<-20	>76	<0.004	1.27/1.83
Prop*	2	15x10	29/39	<-21	>77	<0.01	6.48

Conclusion

For 5G 29 and 39GHz mm-Wave applications, a two-element MIMO antenna with a rectangular slotted staircase configuration is recommended. The antenna is made of Rogers RT5880(lossy) dielectric material and has two staircase-shaped radiators that are powered by a circle shaped ground on the bottom and a feed is inserted. Each radiator's rectangular shapes are fused to enhance impedance matching at 29 and 39GHz. Additionally, to improve port isolation, the MIMO antenna radiators are oriented orthogonally. The antenna has good matching and isolation capabilities and works at 29 GHz between 28.98 and 30.79 GHz and at 39 GHz between 37.78 and 40.42Ghz. High peak gain, appropriate radiation efficiency, omnidirectional patterns, a minimal envelope correlation coefficient, enough diversity gain, omnidirectional patterns, a significant mean effective gain, and channel capacity loss are further features of the design.

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