Design and analysis of wideband four-port multiple input multiple output antenna using defective ground structure for 5G communication

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ABSTRACT

This research work describes a compact four-port multiple input multiple output (MIMO) antenna using defective ground structure (DGS), and it perfectly supports the n77, n78, and n79 frequencies in 5G new radios (NR) bands. It can cover a wideband from 3.4 to 5.4 GHz with good impedance matching. The pair of antenna elements are orientated opposite to another pair with DGS. Due to this technique, it has minimal complexity, is less expensive, and improves isolation. It has also improved the frequency band's reflection coefficient and range using MIMO antenna with different stub lengths. Because it is less expensive, FR-4 substrate is used in the implementation of all antennas. Each antenna element has two identical stubs linked to the primary radiator. On the primary radiating element, a "HI" slot is created. The partial ground enhances impedance matching and radiation properties throughout the targeted band. The total dimensions of the four-port MIMO antenna are 46×30×1.6 mm^3. The array elements' mutual coupling in the simulation is -14 dB. The ECC value is below 0.01, and the diversity gain (DG) is less than 10 dB. The suggested designs' measured gain ranges from 10 to 11.0 dB, and the radiation efficiency is nearly 91%.

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1. INTRODUCTION

Today, there is an increasing demand for compact, wideband multiple input multiple output (MIMO) microstrip patch antennas. Therefore, the MIMO antennas are crucial in developing the 5G wireless communication system. Using defective ground to achieve the compact wideband MIMO patch antenna is challenging to build. This strategy results in cost, energy, and spectrum efficiency. The MIMO system can enhance the channel capacity, which is frequently applied in numerous scenarios. The bow-tie aperture four port MIMO antenna was designed for Hexa bands using optimization techniques. The maximum efficiency is 90% at the 2.4 GHz band [1].The brand-new MIMO antenna structure is resonant from 2.25 to 2.87 GHz and implemented with four printed dipoles and a decoupling element. The self-isolated MIMO antenna provides better radiation characteristics and more than 19 dB isolation. It has a gain of 8.6 dB, an ECC of less than 0.0009, and impressive efficiency figures of more than 85% [2]. According to this design, the MIMO antenna has more than 10 dB element isolations, overall efficiencies better than 50%, and ECCs less than 0.23 in the frequency bands 3.40 to 3.93 GHz and 4.50 to 5.30 GHz. A promising parasitic sub-technique used for 5G applications [3].

The recommended antenna resonant from 3.2 to 6.0 GHz, and its S11 ranges below 6 dB. The authors' suggested 8×8 MIMO antenna perfectly covers 5G NR bands. The overall efficiency of the antenna varies from 38% to 83%. The ECC simulation results are less than 0.31. The 8×8 MIMO antenna is suitable for applications of 5G smartphones [4]. In this study, six-port UWB MIMO antennas (2.9 to 11 GHz) with a decoupling structure are designed. The 6×6 MIMO antenna offers better gain (8dBi) and a 69% efficiency. Its isolation is more than 20 dB, whereas the DG is close to 10 dB [5]. In this paper, the authors designed an n77 band quad-port MIMO antenna with a dielectric decoupler to achieve high isolation. The quad port MIMO antenna has an isolation of more than 21.5 dB. The efficiency is 78%, and the gain is 5 dB [6]. This article describes the construction of an eight-port MIMO antenna for high isolation (20 dB) using a coupler structure. It meets the practical requirements of 5G terminal antennas [7].

For 5G mobile communication applications, this article suggests a four-port MIMO antenna setup that is operational between 3.3 and 3.82 GHz over sub-6 GHz. The flawed ground construction also accomplishes good isolation (20 dB). The suggested antenna system's MIMO characteristics are DG approaches 10 dB, and ECC is 0.03 over the n77 band. It demonstrates that the suggested system's MIMO characteristics fall within allowable bounds, making it appropriate for 5G mobile communication [8]. This study created a high-isolation MIMO antenna using a linear patch array (LPA). Results show that it operates in the 3.3-5 GHz interval is achieved and that an antenna with a gain of 9.7 dB, more than 20 dB isolation, 80% radiation efficiency, and an ECC of less than 0.03 can do so [9]. A shared-aperture antenna with three bands and two polarizations is produced at the following frequencies: 0.69-0.96 GHz, 1.80-2.70 GHz, and 3.30 to 3.80 GHz. It has a 67% radiation efficiency and an achieved antenna gain of 8. 2 dB. It is intended for 5G base station applications using several bands [10]. The authors studied the performance of n79 (4.4 to 5.04 GHz) band eight-element MIMO antenna in that all the MIMO parameters are in an accepted level like ECC (0.24), mean effective gain (MEG) is (1.96 dB) and efficiency (42%) [11].

A two-element multi-band MIMO-CP antenna in the shape of a robot is proposed. This article demonstrates that isolation is more than -25 dB, radiation efficiency is greater than 80%, antenna gain is greater than 5 dB, and ECC is accomplished [12]. This article introduces a dual-band 8×8 MIMO setup. In the 3.3 to 3.6 GHz and 4.4 to 5.0 GHz frequency ranges, the 8×8 MIMO system has excellent isolation (-24.5 dB), and ECC below 0.18 is measured. The 8×8 MIMO method is also more efficient than 68% [13]. Self-isolating mm-wave 1×2 MIMO antenna with a gain of 9.6 dB, extreme isolation of 51 dB, efficiency above 90%, and ECC smaller than 0.005 for a given frequency of 28–37.5 GHz [14]. The 5G NR LTE and WLAN 5 GHz bands can all be covered by the authors' proposed 8×8 wideband MIMO antenna with isolation more significant than 12 dB. It demonstrates that the ECC is below 0.069. The 42.7 bps/Hz channel capacity has also been attained. At 0.41 w/kg, the average specific absorption rate (SAR) values are under the FCC's allowable limit. As a result, a 5G mobile terminal can use the suggested MIMO antenna [15]. This paper proposes a conformal feed method to achieve circular polarization using an RDR antenna for 5G communication [16].

2. METHOD AND ANALYSIS OF PROPOSED MIMO ANTENNA

2.1. Design of single-element antenna

Initially, the design parameters of rectangular microstrip patch antenna are calculated using (1)-(4) [17], after that parameters are optimized for better results. The length L and width W of the patch. h and ε_r are the height and relative permittivity of the substrate. ε_{reff} is effective permittivity, f_r is the resonant frequency, ΔL is the length extension on each end, and v_0 is the velocity of light.

$$W = \frac{v_o}{2f_r}\sqrt{\frac{2}{\varepsilon_r+1}} \tag{1}$$

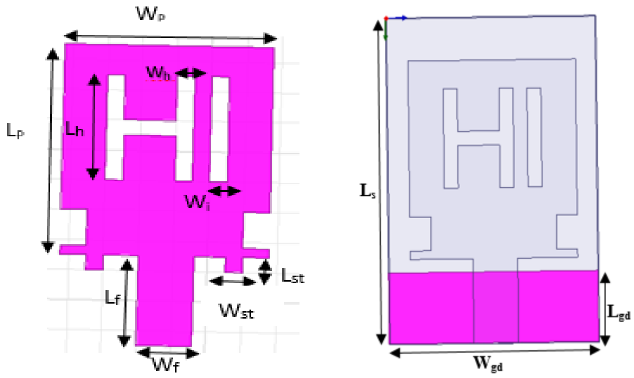
$$\varepsilon_{reff} = \frac{\varepsilon_r+1}{2} + \frac{\varepsilon_r-1}{2}\left[1+12\frac{h}{W}\right]^{-1/2} \tag{2}$$

$$\frac{\Delta L}{h} = 0.412\ \frac{(\varepsilon_{reff}+0.3)(\frac{W}{h}+0.264)}{(\varepsilon_{reff}-0.258)(\frac{W}{h}+0.8)} \tag{3}$$

$$L = \frac{v_0}{2f\sqrt{\varepsilon_{reff}}} - 2\Delta L \tag{4}$$

Initially, H and I shaped slots are created on a rectangular patch wideband microstrip antenna, and two identical stubs 1×1 mm^2 are attached. The overall size is 23×15×1.6 mm^3 with partial ground 15×5 mm^2 for a basic single-element design. It is built on FR-4 epoxy. It measures 1.6 mm in height with a relative permittivity of ε_r = 4.4 and a tanδ of 0.02. Figure 1 illustrates the front view in Figure 1(a) and the back view in Figure 1(b) shows length L_{gd} and width W_{gd} of a ground structure for a single element H and I-shaped slot antenna. The size of the microstrip feed line is L_f=6mm and W_f=3mm, used as excitation for this design. The proposed structure is developed using a high-frequency structure simulator (HFSS).

The parametric analysis is applied to the stub length (L_{st}), which is varied from 1 to 5 mm. Then the simulated reflection coefficient (S_{11}) of a single-element antenna for five different stub lengths is seen in Figure 2. The length of the 1 mm is chosen because it shows that a -10 dB reference is used for the broadband from 3.4 to 5.4 GHz. The geometric parameters are shown in Table 1 of a single H and I slot patch antenna.



(a) (b)

Figure 1. Geometry of a reference antenna with ‘HI’ slot (a) front side and (b) back side

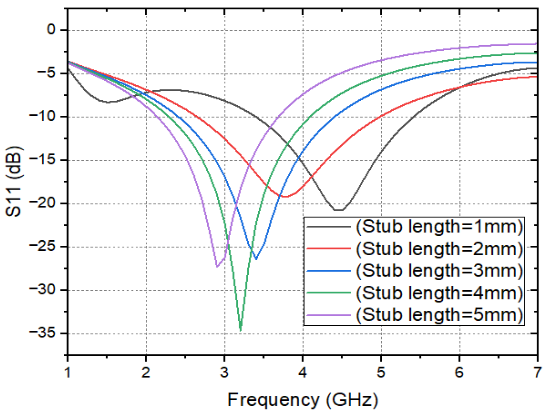


Figure 2. Simulated reflection coefficient of a single patch antenna with various stub lengths

Table 1. Geometric parameters (mm) of the proposed single patch antenna

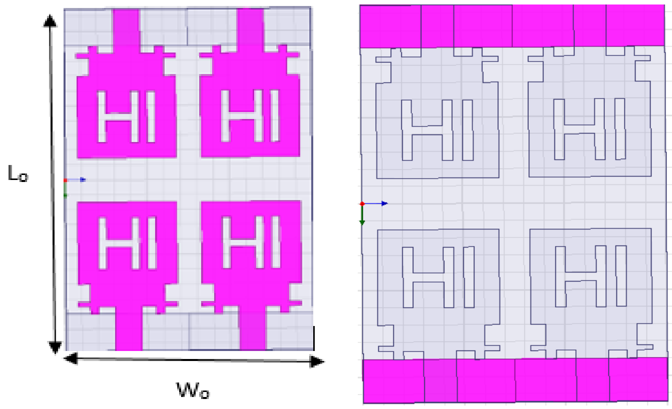
Parameter	Value(mm)	Parameter	Value(mm)	Parameter	Value(mm)
L_p	14	L_h	7	W_i	1
W_p	12	W_h	1	L_f	6
L_{st}	1	W_{st}	1	W_f	3
L_s	23	W_{gd}	15	L_{gd}	5

2.2. Design of four-port MIMO antenna

The four-port H and I slot MIMO antenna was designed using four single patch antennas on an FR-4 substrate, as shown in Figure 3, and Figure 3(a) depicts the front view of it. The antennas are positioned in the opposite direction of another pair of antennas. The four-port MIMO antenna's overall dimension is L_o=46 mm, W_o=30 mm, and height is 1.6 mm. The space between two adjacent antennas is 3 mm, and the opposite side is 6mm. The defective ground structure is used for the proposed antenna, shown in Figure 3(b).

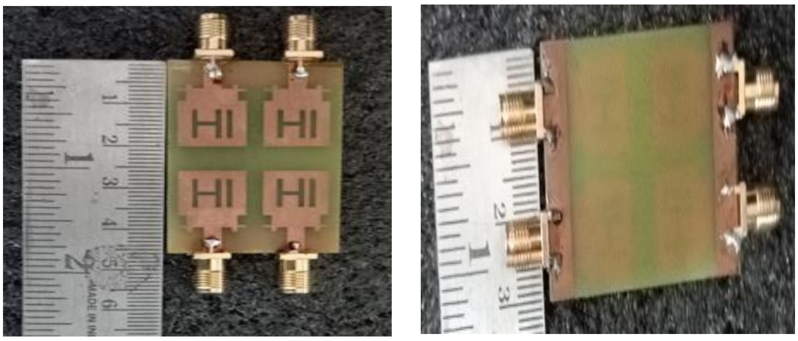
Figure 4 shows the forefront and rear view of the prototype fabricated four port H and I slots MIMO antenna. Here, Figure 4(a) shows the front view, and Figure 4(b) depicts the back view of a MIMO antenna.

Each feedline is connected to the SMA connector. Figure 5 depicts the proposed HI slot four-port MIMO antenna in a simulated view in Figure 5(a), and Figure 5(b) illustrates the measurement setup for S12 in an anechoic chamber.



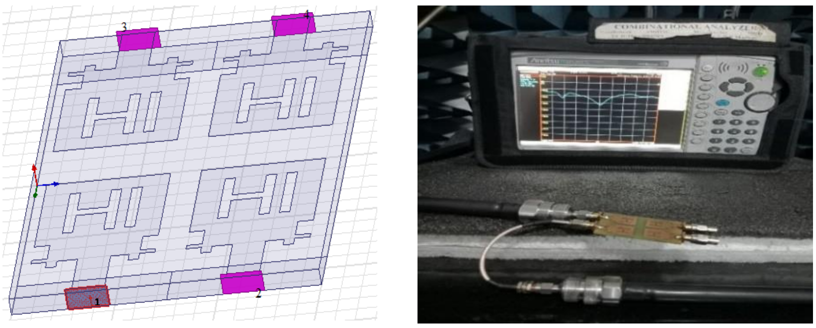
(a) (b)

Figure 3. Four-port MIMO antenna geometry (a) front view (b) back view



(a) (b)

Figure 4. Fabrication of H and I slot MIMO antenna (a) front and (b) back view



(a) (b)

Figure 5. MIMO antenna(a) simulated port 1 front view (b) measurement setup in an anechoic chamber

3. RESULTS AND DISCUSSION

Figure 6 shows the S parameters S11, S22, S33, and S44 of four port MIMO antennae at ports like 1, 2, 3, 4. All the S parameters resonate between 3.4 and 5.4 GHz with a -10 dB reference line. The reflection coefficient is more than -20 dB at all ports. Figure 7 depicts the simulated reflection coefficient of a four-port MIMO antenna with the HI slots. The proposed antenna resonates between 3.4 and 5.4 GHz, with a -10 dB as a reference line for an impedance bandwidth is 2 GHz. It can wrap the NR n77, n78, and n79 frequency bands. The measured maximum reflection coefficient is -27 dB. The measured and simulated isolation between the proposed antenna at various ports, S12 and S14, is shown in Figure 8. The two antennas are positioned in opposition to one another. As a result, minimal isolation, -14 dB, is found at a specific port (S12), and it is noticed between the intended frequency interval of 3.4 to 5.4 GHz. All the isolations among various ports are more than -10 dB without any isolation strategies. Figure 9 shows measured and simulated gain of the proposed MIMO antenna and its maximum value is 11 dB.

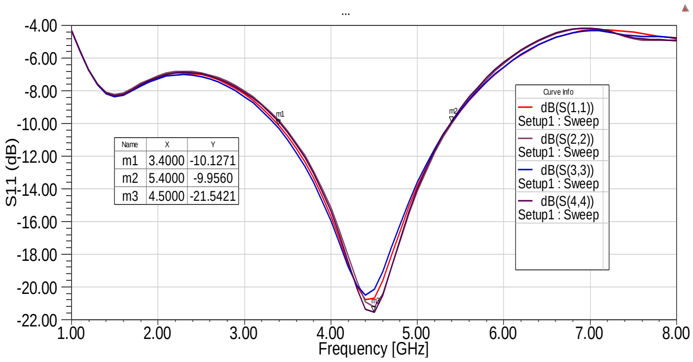


Figure 6. Reflection coefficients of four port MIMO antenna at port 1, 2, 3, and 4

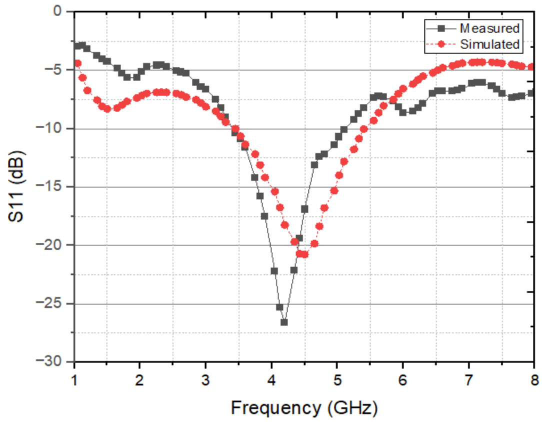


Figure 7. S_{11} of the four-port MIMO antenna

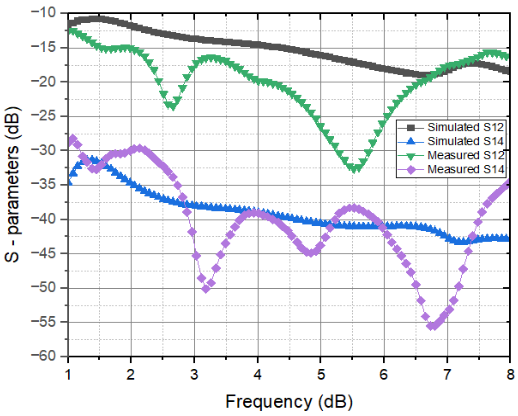


Figure 8. Measured and simulated isolation at S12 and S14 ports

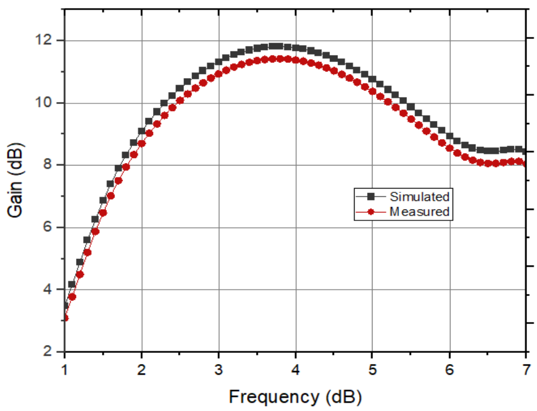


Figure 9. Gain of a four-port H and I slot MIMO antenna

The accomplishment of any MIMO antenna can be assessed by different variables. In ECC is one of the essential parameters. It can be determined using (5) from S-parameters [18].

$$ECC = \frac{|S_{ii}*S_{ij}+S_{ji}*S_{jj}|^2}{\left(1-|S_{ii}|^2-|S_{ji}|^2\right)*\left(1-|S_{jj}|^2-|S_{ij}|^2\right)} \quad (5)$$

Figure 10 illustrates the measured and simulated envelope correlation coefficient (ECC). For a desirable resonant frequency band, the ECC value is below 0.01. Diversity gain (DG) is the transmission power loss caused by the diversity mechanism on the MIMO antenna. Equation (6) is used to determine the DG.

$$\text{DG} = 10\sqrt{1-(ECC)^2} \quad (6)$$

Figure 11 depicts the measured and simulated diversity gain (DG). For a specific frequency band, it is close to 10 dB, and the proposed four-port MIMO antenna's simulated and measured radiation pattern is illustrated in Figure 12. Here, two antennas are arranged adjacent, and the other two are opposite. So, the gain of the MIMO antenna is enhanced. The measured and simulated efficiency of a four-port H and I slot MIMO antenna is presented in Figure 13. Its efficiency for a desired resonant frequency band (3.4-5.4 GHz) is greater than 89%. Figure 14 shows the simulated surface current of a four-port MIMO antenna at 4.5 GHz in Figure 14(a) and 5 GHz in Figure 14(b). The features of the suggested MIMO and earlier designed four-port MIMO antennas are summarized in Table 2. The recommended four MIMO antenna is compact compared to the other MIMO antennas. The proposed four port MIMO antennas are arranged opposite each other, improving the gain.

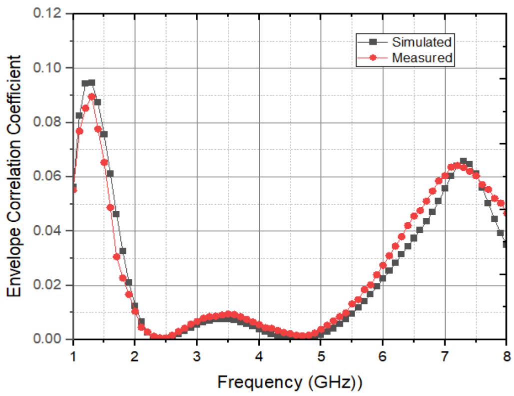


Figure 10. Measured and simulated ECC for a four-port MIMO antenna

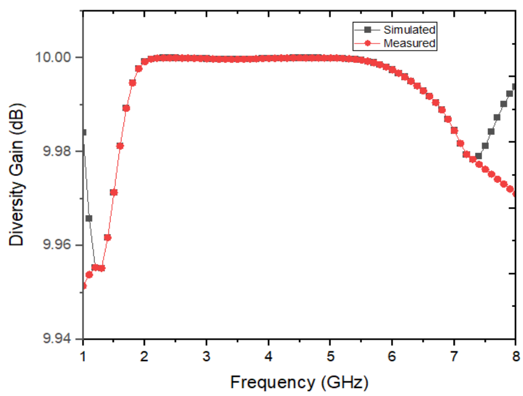


Figure 11. measured and simulated diversity gain for a four-port MIMO antenna

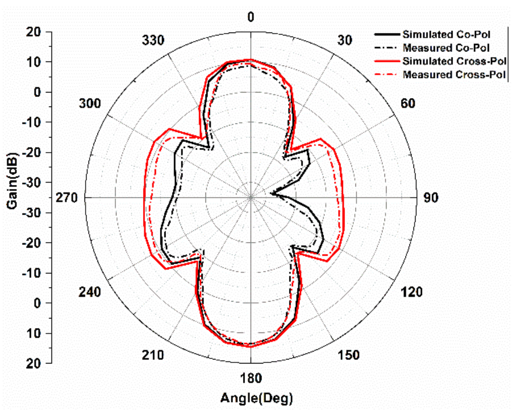


Figure 12. measured and simulated the radiation pattern of the Four-port MIMO antenna

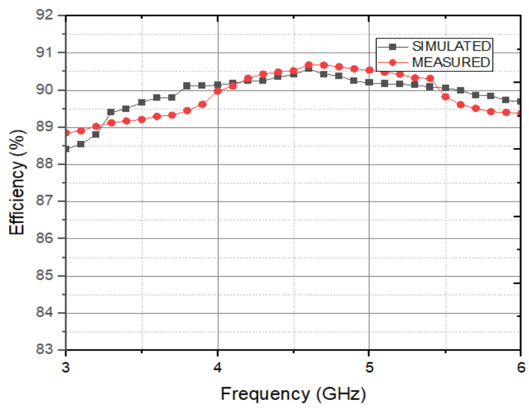


Figure 13. measured and simulated the efficiency of the four-port MIMO antenna

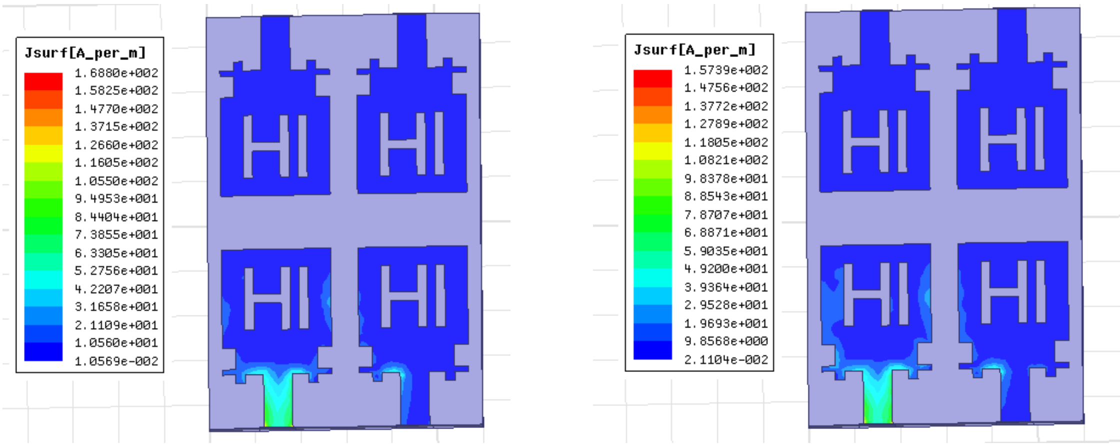


Figure 14. A simulated surface current of MIMO antenna (a) 4.5 GHz and (b) 5 GHz

Table 2. Performance comparison of proposed antenna and previous studies

Ref.	Bandwidth (GHz)	Size (mm^3)	Efficiency (%)	MIMO order	Isolation (dB)	ECC	Gain (dB)
[18]	3.2-5.7	40×40×1.6	91	4	> -22	<0.05	9
[19]	3.3 -5.8	150×75×0.8	55-87	4	>-15	<0.03	6
[20]	3.3-7.5	60×14×0.8	40-78	4	>-10	<0.06	5
[21]	4.0 – 5.2	60×60×1.6	90	4	>-17.5	<0.2	8
[22]	3.2 -5.7	40×30×1.6	82	4	>-10	<0.05	3.5
[23]	4.5-6.1	30×30×0.8	67-82	4	>-15	<0.15	4.02
[24]	5.8	110v110×1.52	77	4	>-25	<0.12	5
[25]	10.2-14.0	46.2×38.2×1.6	85	4	>-28.5	<0.04	NA
[26]	3-5	134×75×0.8	86	6	>-20	<0.0045	2.71
Pro.	**3.4 -5.4**	**46×30×1.6**	**90.6**	**4**	**>-14**	**<0.01**	**11**

4. CONCLUSION

The compact four-port wide band H and I slot MIMO antenna is intended for 5G communication. The suggested MIMO antenna resonates from 3.4 to 5.4 GHz, has a -10dB impedance bandwidth of 2.0 GHz, and covers 5G NR bands such as n77, n78, and n79. The isolation exceeds -14 dB. For a specific band, the efficiency ranges from 89 to 90.6%. ECC has a maximum value of 0.01. The gain of the MIMO antenna is 11 dB, and the DG is close to 10 dB. The recommended four-port MIMO antenna is constructed, and the various antenna characteristics are tested to confirm the design.

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