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Wideband Two-Port Multiple-Input Multiple-Output Antenna in the C Band

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Abstract

A compact, two-element, wideband, multiple-input multiple-output (MIMO) antenna for applications in the 4.68 GHz to 6.62 GHz frequency range is presented here. The design consists of two identical, circular ring patch antennas. A hollow cylindrical substrate made of FR4 dielectric material is used for each antenna. The proposed two-port MIMO antenna is unique in its broad (1.94 GHz) frequency range of operation within the C band, along with its compact size of only 0.435 λ_0^2 (λ_0 corresponds to the free-space wavelength at 5 GHz). This wideband antenna is investigated and analysed using 3D electromagnetic software. Maximum directivity values ranging from 5.6 dBi to 7.4 dBi across the operating bandwidth range of 4.68 GHz to 6.62 GHz are obtained for this MIMO antenna. An envelope correlation coefficient less than 0.005 and a diversity gain of 10 dB are obtained within the operating frequency range. The ratio of the mean effective gain of the two antennas is found to be less than 0.8 dB for the entire range of operation. A channel capacity loss of less than 0.028 bits/s/Hz at 5 GHz and 0.041 bits/s/Hz at 6 GHz are obtained, respectively. The performance parameter values of the MIMO antenna system described here are compared with those of similar types of antennas presented in recently published papers.

Categories: Microwave and RF Engineering, Wireless Communication Systems
Keywords: antenna, mimo antenna, two-port mimo antenna, wideband mimo antenna, circular ring patch antenna, 5 ghz/6 ghz wlan, patch antenna

Introduction

Multiple-input multiple-output (MIMO) antennas are a key part of modern wireless technology and play a vital role in high-speed communication systems. The idea of a wideband MIMO antenna system has recently emerged so that the same system can support different standard operating frequency bands for multipurpose use. Obviously, designing wideband MIMO antennas is more difficult than designing narrowband MIMO antennas. Considerable related research has been published in this area [1-7] in the last few years. Since the same signal is to be transmitted via several mutually separated paths, high isolation among the antennas of a MIMO antenna system must be maintained. When multiple antenna elements are positioned in a small space, the antenna radiation characteristics deteriorate due to high mutual coupling effects. The design becomes more complex due to the requirement to achieve desired performance characteristics over a wide frequency range while maintaining the compactness of the MIMO antenna system.

A simple technique for designing two-port wideband MIMO antennas using two circular ring patch antennas is proposed in this paper. The operating frequency range of the proposed two-port MIMO antenna is 4.68 GHz to 6.62 GHz, thus covering almost the entire C band. This MIMO antenna system is suitable for Wi-Fi and WLAN applications within the above frequency range, which includes 5 GHz (802.11a/h/j/n/ac) and 5.9 GHz (802.11p) standards. These bands are comparatively less crowded than the 2.4 GHz Wi-Fi band and provide more data than the widely used 2.4 GHz band. The performance characteristics of the two-port MIMO antenna are investigated and compared with those of similar antennas found in recently published papers [3-7].

Materials And Methods

The proposed two-port MIMO antenna system has two identical antennas. The first antenna is designed to meet the requirements of wideband antennas operating in the C band. In the next step, a two-port MIMO is designed on the same ground plane, maintaining the compactness of the two-port MIMO as well as proper isolation between the antennas.

Single-antenna design

The resonant frequency of the dominant mode of a circular patch antenna is given by [8]:

$$f_r = \frac{1.8412 v_0}{2\pi a \varepsilon_r^{\frac{1}{2}}} \qquad (1)$$

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where 'v_0' is the velocity of light in free space, 'a' is the radius of the patch and 'ε_r' is the dielectric constant of the substrate. From Equation (1), the approximate radius of the antenna for operating frequency f_r can be determined for a given substrate material. However, the bandwidth of such an antenna is narrow. The annular-ring patch antenna represents a good alternative to simple circular geometry for more sophisticated applications where wide bandwidth is needed. Another advantage of annular-ring antennas is that they require a smaller radius than circular-disk patch antennas when both are operated in the lowest mode. Based on ring resonator theory, the resonant frequency of an annular ring patch antenna is given by [9]:

$$f_0 = \frac{nv_0}{4\pi r\varepsilon_{eff}^{\frac{1}{2}}} \qquad (2)$$

where 'r' is the radius of the ring, 'ε_{eff}' is the effective dielectric constant and 'n' is an integer indicating the mode of resonance. Although annular-ring patch antennas provide better bandwidth than circular-patch antennas, wideband operation is insufficient. The bandwidth of the patch antenna is inversely proportional to $\sqrt{\varepsilon_r}$ [8], which means that the bandwidth can be increased by inserting an air gap into the substrate material and thereby reducing the effective ε_r of the substrate. The effective dielectric constant in the presence of an air gap is approximately given by:

$$\varepsilon_{reff} = \frac{(\epsilon_r\,(V - V_{air})) + V_{air}}{V} \qquad (3)$$

where V is the total volume of the substrate under the patch and V_{air} is the volume of the air gap. In the present case,

$$\varepsilon_{reff} = \varepsilon_r - (\varepsilon_r - 1)\frac{{r_{air}}^2}{{r_0}^2} \qquad (4)$$

where r_{air} is the radius of the air gap and r_o is the outer radius of the patch considering that the height of the air gap and that of the substrate are equal. However, this increase in bandwidth achieved by reducing ε_{reff} is also associated with a shift in the resonance frequency to the higher frequency end, so judicious selection of the volume and position of the air gap inside the substrate material is necessary according to the requirement.

Impedance matching is another important factor that must be achieved over the whole operating frequency range of an antenna. In the present design, an annular-ring patch antenna is used, as shown in Figure *1*. The circular-disk-like substrate is made of FR4 material. A parallel resonant circuit is used for impedance matching along with probe feeding. Table *1* shows the design parameters of the single antenna.

A 3D electromagnetic simulation tool is used for designing and analysing the performance of the antenna. Appropriate boundary conditions are applied to realize free space behind the boundary planes.

Figure *2* shows the s_{11} versus frequency characteristics of an antenna with solid substrate material and without any air gap. All the other design parameters are the same as those given in Table *1*. Figure *2* shows that the antenna has a very narrow bandwidth (~320 MHz) and that the resonant frequency is more than 7 GHz. When a disk-shaped air gap is introduced inside the substrate, a wide bandwidth is obtained. Figure *3* shows that the s_{11} value is less than −10 dB from 4.668 GHz to 6.69 GHz; thus, an antenna with an air gap in the substrate is suitable for operation in this wide frequency range.

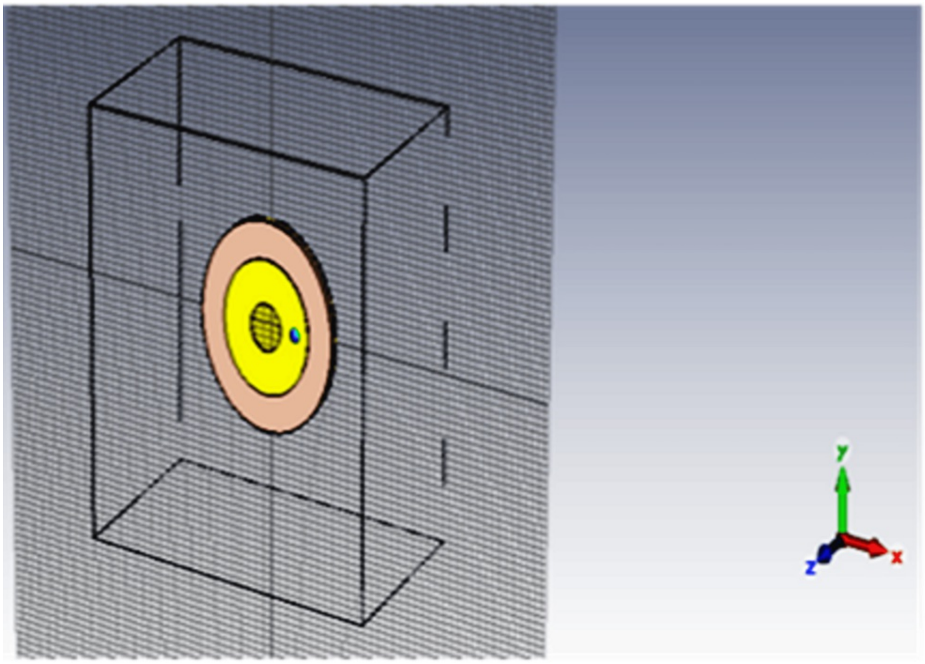

FIGURE 1: Single-antenna element of the proposed MIMO system

MIMO, multiple-input multiple-output

Outer radius of the annular patch (mm)	Inner radius of the annular patch (mm)	Radius of the air gap (mm)	Height of the substrate (mm)	Radius of the substrate (mm)	Substrate material/dielectric constant	Parameters of LCR matching circuit
9	3.2	6.1	1.6	14	FR4/4.3	L = 1.1 nH, C = 0.9 pF, R = 50 Ohm

TABLE 1: Design parameters of the single circular annular patch antenna with air gap

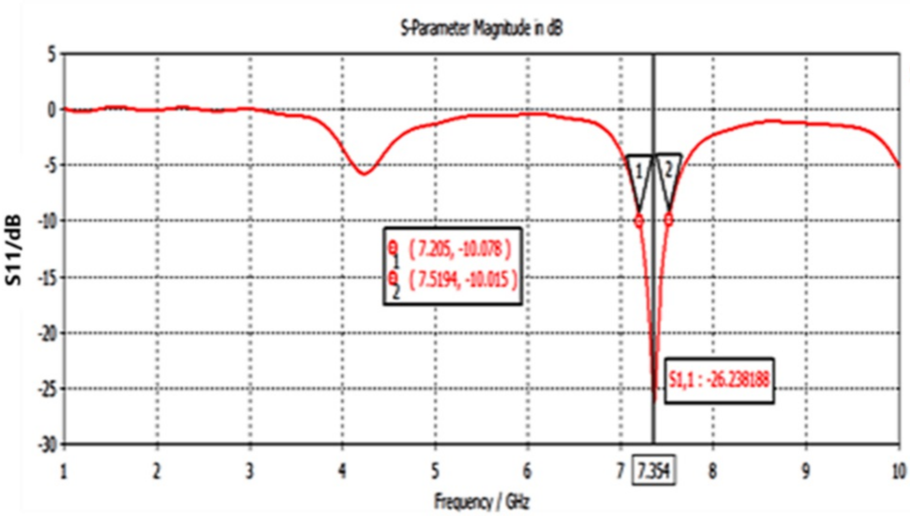

FIGURE 2: Reflection coefficient versus frequency plot for the antenna without an air gap

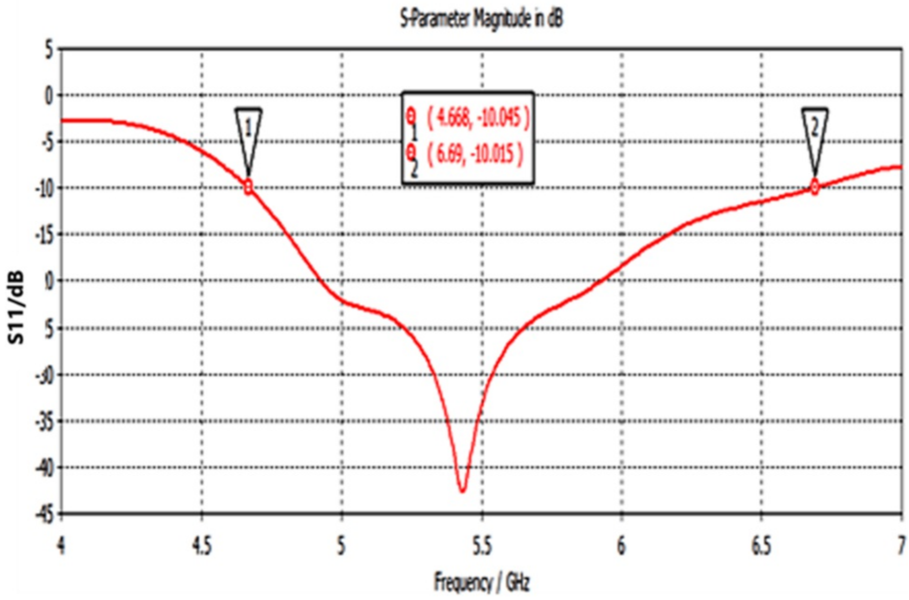

FIGURE 3: Reflection coefficient versus frequency plot for the antenna with an air gap

Two-port MIMO antenna design

Here, two patch antennas, as shown in Figure 4, are used for the two-port MIMO antenna system. A 1.6 mm thick FR4 material is used as the substrate for each antenna. These two antennas share a common conducting ground plane with a rectangular shape that covers the bottom of the substrate of each antenna. The two-port MIMO antenna is shown in Figure 4. The length and width of the ground plane are 56 mm × 28 mm. There is no gap between the circular substrates of the antenna elements. The distance between the two patches is only 10 mm. Thus, the MIMO antenna is compact in size. The antennas are fed at an angle of 90° to provide better isolation between antennas. No additional component is introduced for isolation purposes. Each antenna is fed by probe feeding via a parallel resonant LCR circuit for impedance matching.

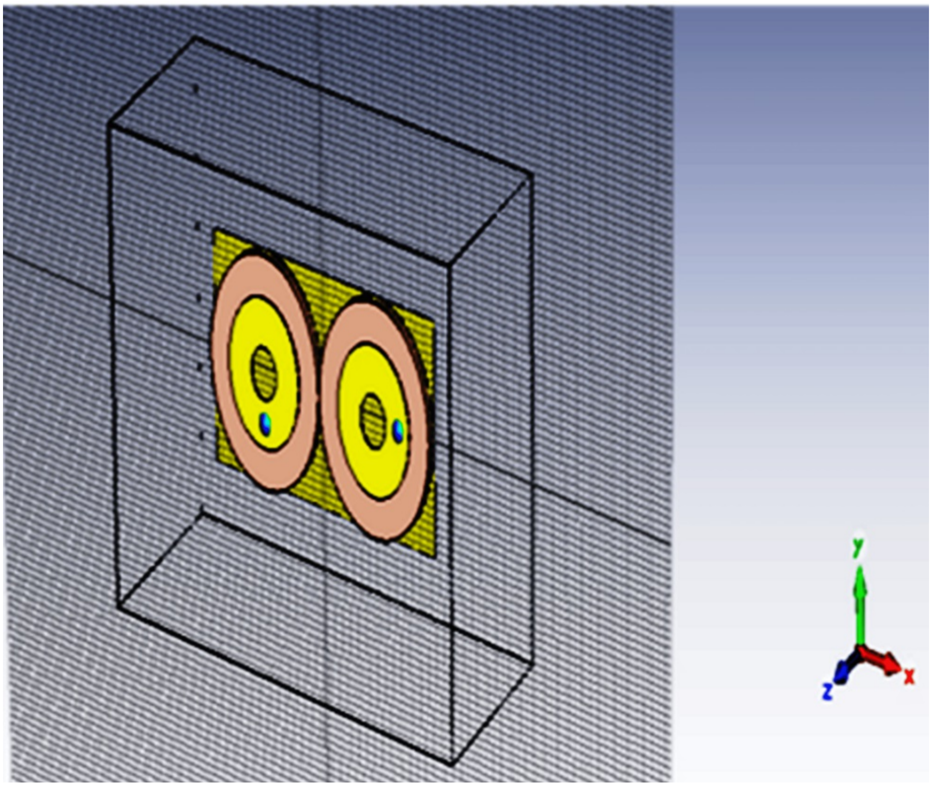

FIGURE 4: Two-port MIMO antenna

MIMO, multiple-input multiple-output

Results

The scattering or S parameter (s_{ij}), envelope correlation coefficient (ECC), diversity gain (DG), mean effective gain (MEG) and channel capacity loss (CCL) are considered for evaluating the performance of the proposed MIMO antenna. Figure *5* shows that the s_{11} and s_{22} parameters of the MIMO antennas are less than −10 dB in the frequency range from 4.683 GHz to 6.62 GHz, and a 10 dB impedance bandwidth of 1.937 GHz is obtained. As shown in the s_{ij} plot of Figure *5*, the isolation between two antennas is better than 40 dB for this antenna system. This plot indicates high isolation or low coupling between the two antennas of this system. These values are quite satisfactory considering the compactness of the system. A small ECC ensures good pattern diversity for MIMO antennas [10]. Figure *6* shows that the ECC between two antennas is less than 0.005 over the entire frequency range. An excellent diversity gain (10 dB) is also achieved in the operating frequency range of this antenna system, as shown in Figure *7*.

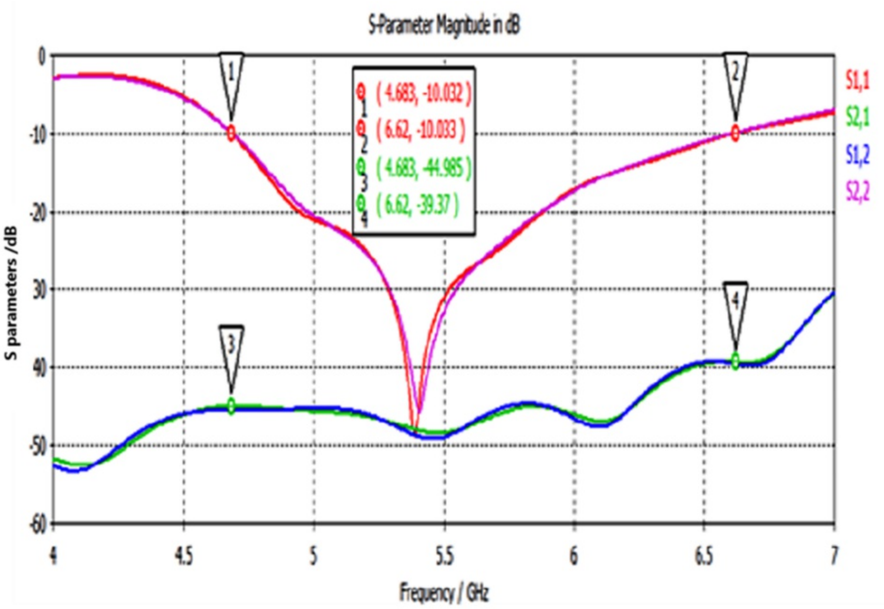

FIGURE 5: Reflection and transmission coefficients versus frequency of the two-port MIMO antenna

MIMO, multiple-input multiple-output

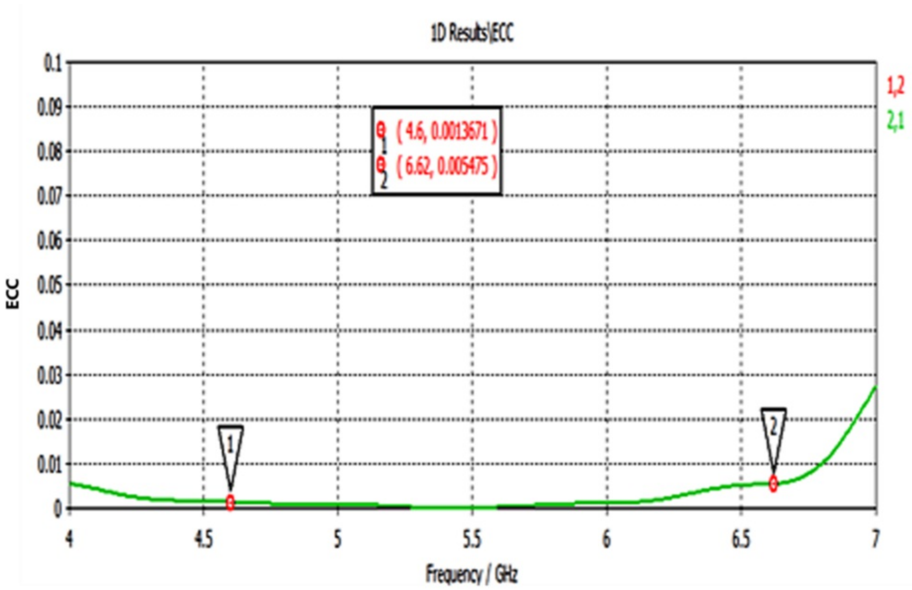

FIGURE 6: ECC of the two-port MIMO antenna

ECC, envelope correlation coefficient; MIMO, multiple-input multiple-output

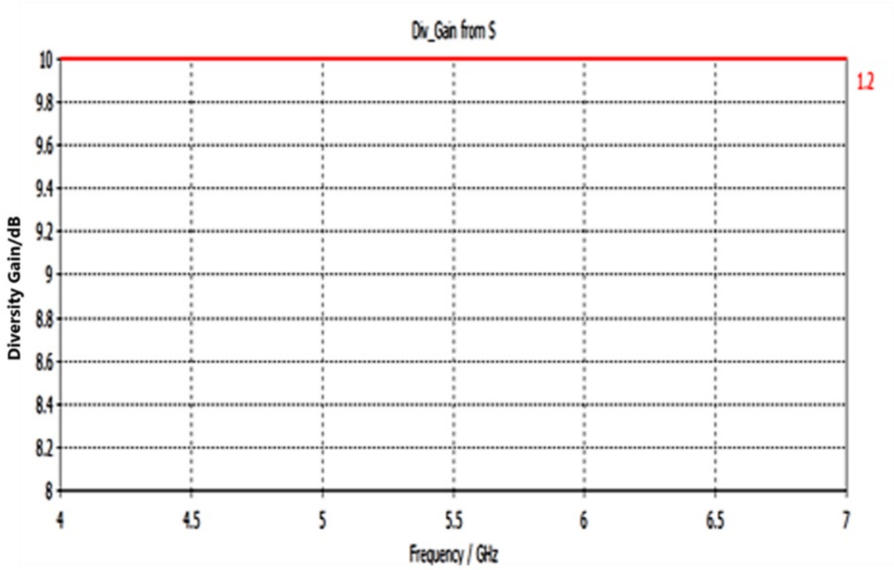

FIGURE 7: Diversity gain of the two-port MIMO antenna

MIMO, multiple-input multiple-output

Radiation patterns are shown in Figure *8* and Figure *9*. The maximum directivity is more than 7 dBi for these antennas at 5 GHz and more than 5.8 dBi at 5.9 GHz. Wide beamwidths of the antennas ensure large area coverage by the antennas. The surface current distribution on the antennas is also investigated. Figure *10* and Figure *11* show the surface current distributions in antennas 1 and 2 when only antenna 1 is excited at 5 GHz and 5.9 GHz. It is clear from Figure *10* and Figure *11* that there is a negligible induced surface current on antenna 2 due to the excitation of the other antenna, and thus, it is almost decoupled from antenna 1. Figure *12* shows the directivity plots of each antenna within the operating frequency range. The directivity is more than 5.8 dB over almost the entire frequency range of interest. Figure *13* shows that the |MEG1-MEG2| of the MIMO antennas is less than 1 dB in the operating frequency range. CCL values are calculated using the formula given in [11], and the values are much less than the maximum permissible value of 0.4 bits/s/Hz [12].

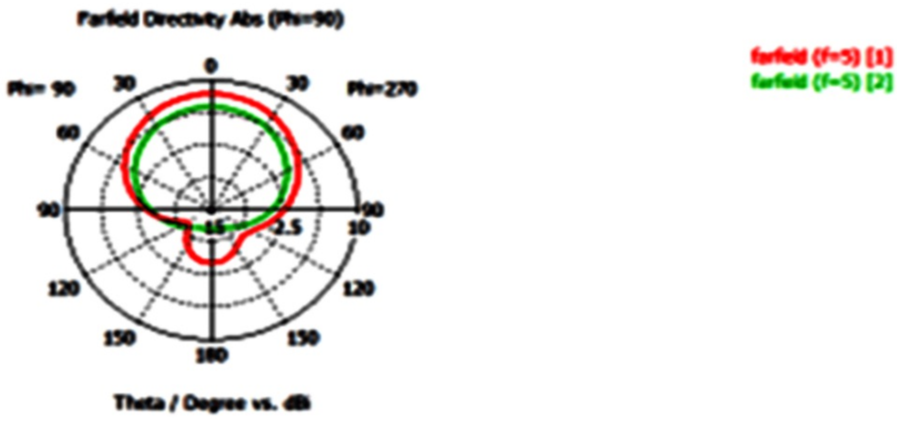

FIGURE 8: Far-field directivity of MIMO antennas at 5 GHz

MIMO, multiple-input multiple-output

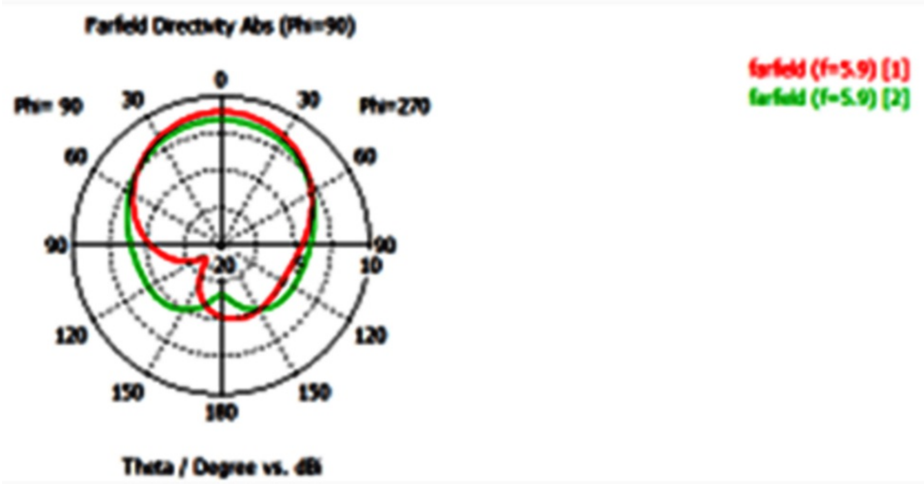

FIGURE 9: Far-field directivity of MIMO antennas at 5.9 GHz

MIMO, multiple-input multiple-output

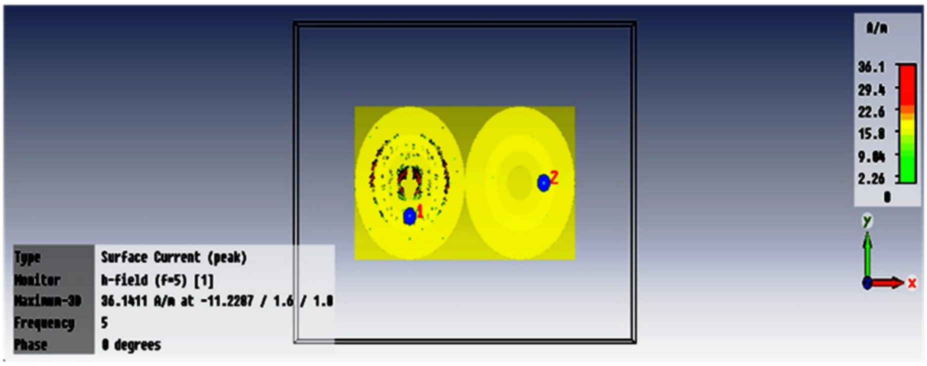

FIGURE 10: Surface current distribution at 5 GHz

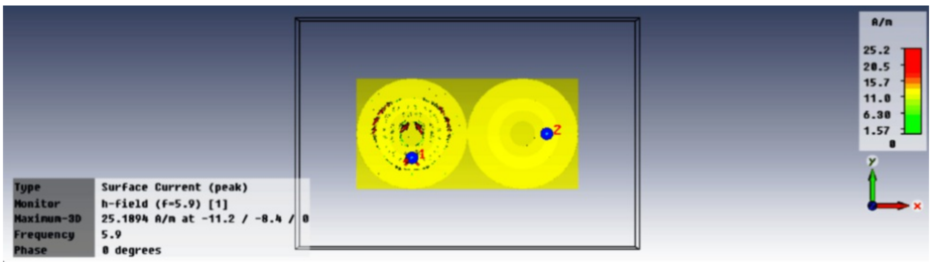

FIGURE 11: Surface current distribution at 5.9 GHz

Table 2 shows the different performance parameter values of the proposed MIMO antenna. All of the performance parameter values given in Table 2 conform well to the standard specified limits found in the literature.

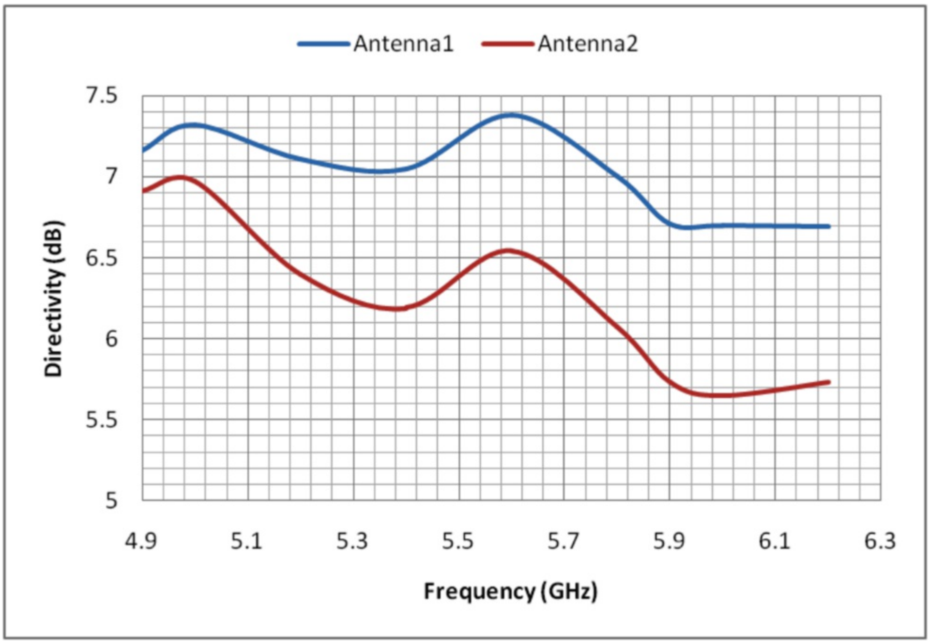

FIGURE 12: Directivity plot of two antennas of the MIMO system

MIMO, multiple-input multiple-output

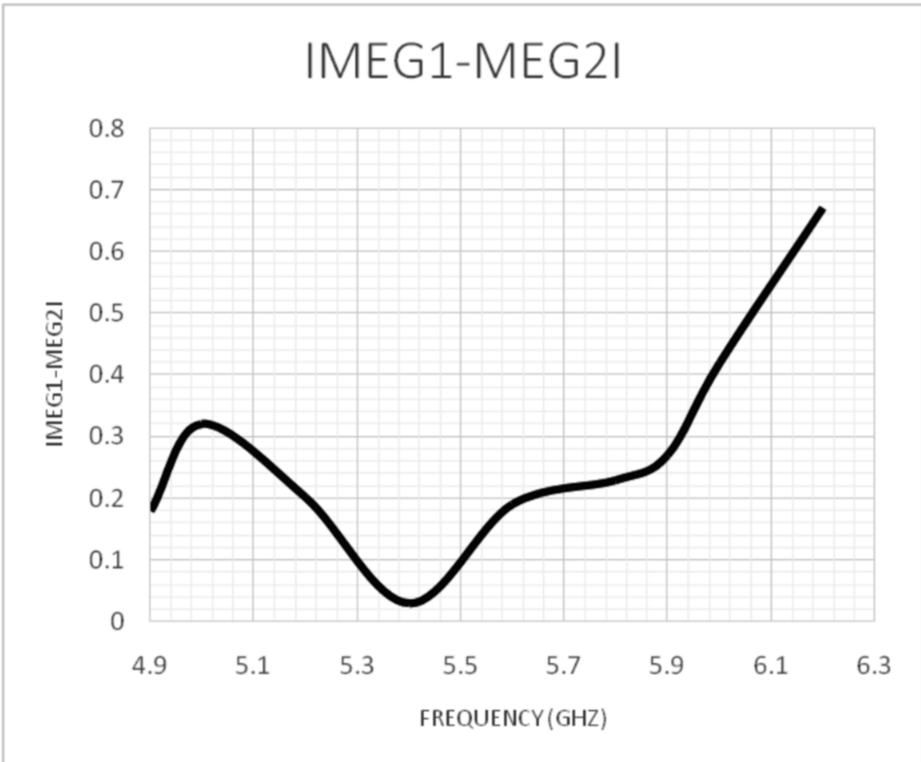

FIGURE 13: IMEG1-MEG2I plot of antennas of the MIMO system

MIMO, multiple-input multiple-output

Operating frequency (GHz)	Bandwidth (GHz)	Occupied area (mm^2)	Isolation (dB)	Gain (dBi)	ECC	DG (dB)	$\lvert MEG_1-MEG_2 \rvert$ (dB)	CCL bits/s/Hz
4.683-6.62	1.937	56 × 28	≤−40	>5.6	<0.005	10	<1	<0.049

TABLE 2: Performance parameters of the proposed wideband MIMO antenna

MIMO, multiple-input multiple-output

Discussion

The performance parameters are compared in Table *3* with those of recently published works. The isolation, directivity and diversity gain of the proposed antenna are better than those of all the antennas presented in Table *3* over the entire operating band. The ECC of the proposed MIMO antenna is also approximately equal to or better than the reported values in Table *3*. Moreover, the proposed MIMO antenna has a simple feeding mechanism and ground plane structure. No other published works in Table *3*, except for the present one, have investigated all the performance parameters of their MIMO antennas.

References	Operating frequency (GHz)	Bandwidth (GHz)	Area occupied (mm^2)	Volume (mm^3)	Isolation (dB)	Gain (dBi)	ECC	DG (dB)	[(MEG1-MEG2)] (dB)	CCL bits/s/ Hz
[3]	2.5-14.5	12	30 × 50	-	−20	1 at 2.5 GHz	<0.04	>7.4	-	-
[4]	2.26-6.78	4.52	55 × 50	55 × 50 × 0.8	>22.5	≤3.51	-	-	0.01	-
[5]	2-3	1	108 × 108	108 × 108 × 1.6	>12	-	<0.2	~10	-	-
[6]	2.8-13	10.2	18 × 22	18 × 22 × 1.6	>20	<5	<0.007	>9.97	-	-
[7]	2.3-7.4	5.2	82 × 44	82 × 44 × 1.6	>20	-	<0.004	>9.96	-	<0.4
Proposed MIMO	4.683-6.62	1.937	56 × 28	56 × 28 × 1.6	>40	>5.6	<0.005	10	<1	<0.049

TABLE 3: Performance comparison with recently published works

ECC, envelope correlation coefficient; MIMO, multiple-input multiple-output

Conclusions

A two-port, planar, wideband, compact MIMO antenna is proposed, and its performance parameters are evaluated and compared with those of a number of wideband MIMO antennas reported in recently published works. This antenna covers an area of only 0.435 λ_0^2 and operates over a wide bandwidth of 1.94 GHz in the C band. Isolation between antennas of this MIMO system is greater than 40 dB and the ECC value is smaller than 0.005. High isolation and low ECC ensure independent radiation patterns of the antennas of the MIMO system, which results in enhanced capacity of the communication channel without the need for enhancing the transmitted power or bandwidth of the channel. A diversity gain of 10 dB of the proposed MIMO antenna ensures reliable transmission even in the adverse conditions of communication channel. As discussed in the previous section, most of the performance parameters of the proposed antenna are better than those reported in Table *3*. Hence, the present two-port wide band MIMO antenna has the potential for use in many types of C band wireless indoor or outdoor applications, including Wi-Fi and WLAN applications at 5 GHz (802.11a/h/j/n/ac) and 5.9 GHz (802.11p), vehicle-to-vehicle (V2V) communication, and vehicle-to-everything (V2X) communication over the frequency range of 4.683 GHz to 6.62 GHz.

Additional Information

Author Contributions

All authors have reviewed the final version to be published and agreed to be accountable for all aspects of the work.

Concept and design: Sukla Basu

Acquisition, analysis, or interpretation of data: Sukla Basu

Drafting of the manuscript: Sukla Basu

Disclosures

Human subjects: All authors have confirmed that this study did not involve human participants or tissue. **Animal subjects:** All authors have confirmed that this study did not involve animal subjects or tissue. **Conflicts of interest:** In compliance with the ICMJE uniform disclosure form, all authors declare the following: **Payment/services info:** All authors have declared that no financial support was received from any organization for the submitted work. **Financial relationships:** All authors have declared that they have no financial relationships at present or within the previous three years with any organizations that might have an interest in the submitted work. **Other relationships:** All authors have declared that there are no other relationships or activities that could appear to have influenced the submitted work.

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