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Circularly Polarized Wideband MIMO Rectangular Antenna in Cube form for X-Band with Pattern and Polarization Diversity

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Abstract—The present work describes a new wideband circularly polarized MIMO rectangular antenna in cube form for X-band application (8 to 11.8 GHz). The proposed antenna structure shows pattern diversity in whole 360° angle with polarization diversity. The isolation between the antennas is more than −14.5 dB. The impedance matching bandwidth (IMBW) is 3.8 GHz, and 3 dB axial ratio bandwidth is 2.91 GHz. The envelope correlation coefficient is less than 0.035, and its diversity gain is 10 dB. A copper metallic cylinder is placed inside the cube antenna to reduce the mutual coupling between the antennas.

1. INTRODUCTION

Nowadays, wireless communication systems have been demanding high data rate for improving the channel capacity and signal to noise ratio (SNR). The indoor and urban environment has several effects of multipath fading on the channel capacity. Multipath fading decreases the channel capacity and SNR. To overcome this problem, different diversity schemes such as switched diversity, selection diversity, equal gain, or maximal ratio are preferred [1–8]. In this method, several antennas are used to receive uncorrelated signals. Recently, another effective way is suggested by employing a multiple-input multiple-output (MIMO) system for enhancing the channel capacity. MIMO system uses multiple antennas at the transmitter and receiver. In MIMO systems, the received signals from each antenna should have low correlation. To decorrelate received signals, antennas are separated with considerable distance known as spatial diversity. It is beneficial to use both pattern and polarization diversities rather than spatial diversity in order to reduce terminal sizes. MIMO system gives promising results to achieve high throughput as well as the quality of transmission. Many designs are reported in the literature to exploit the diversity of fast and immune data transmission [1–8]. In [1], a cube-type antenna based on electromagnetic cavities and slots having both pattern and polarization diversity for narrowband has been suggested. A slotted cube antenna with PIN diode for reconfigurable pattern has been designed for switching the radiation pattern in a different direction [2]. Different antennas are arranged in ring configuration for different radiation patterns with different polarizations in [3]. Electrical dipole antennas are placed in cube form exhibiting both pattern and polarization diversity [4]. Slots can also be used to realize a multiple-element MIMO antenna [5]. PIN diodes are used to switch the radiation pattern [6]. A dielectric resonator antenna (DRA) with multidirectional pattern diversity is presented in [7]. A MIMO antenna with an orthohexagon-shaped antenna with a magnetoelectric dipole is presented in [8] for 5G/WiMAX/WLAN/X-band. In [9], a cubic antenna for wireless sensor networks (WSNs) and RFID applications using a liquid crystal polymer (LCP) substrate is suggested while in [10] cascaded Rotman lenses feeding a circular array are used for beam steering. In [11], four rectangular loop elements are printed on a flexible substrate and then rolled into a hollow cylinder for

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omnidirectional CP performance. At the same time, in [12] an electronically steerable parasitic array radiator (ESPAR) antenna is presented. The above suggested MIMO antennas [1–8] have a narrow bandwidth, and some of them do not have pattern and polarization diversity instantaneously.

In this work, we design *a new wideband circularly polarized MIMO rectangular antenna in cube form* with eight elements having polarization and pattern diversity in whole 360° angle. All the antenna elements are arranged in such a way that their radiation patterns are directed in a specific direction. A copper cylinder inside the cube is used to avoid the mutual coupling between antennas. The isolation between the antennas is more than -23 dB while for adjacent antennas it is better than -14.5 dB.

2. ANTENNA DESIGN

The geometry of the proposed MIMO *rectangular antenna in cube form* and the fabricated prototype are shown in Fig. 1. The antenna is designed on a 0.8 mm thick FR-4 substrate with permittivity of 4.4 and loss tangent of 0.02. The overall dimension is $34 \times 34 \times 23\,\text{mm}^3$. The proposed MIMO antenna structure consists of eight antennas which are arranged on the face of the cube with a copper cylinder having height same as the cube, and it is placed inside the cube to avoid unnecessary mutual coupling. All antennas are excited by SMA connectors of the impedance of $50\,\Omega$. The proposed antenna structure is designed in systematic steps. First, we have designed two-element quadrilateral shaped antennas facing each other as shown in Fig. 1(c), and then by placing these antennas on each face of the cube, we have made a MIMO antenna in the form of a cube. These antennas have a common ground plane and are placed closely at a distance of $0.16\lambda_o$ (5 mm) at $fc = 9.86$ GHz. The layout and dimensions of the antenna are shown in Fig. 1(c), which are as follows: $Ws = 29$ mm, $Ls = 23$ mm, $W = 12$ mm, $L = 12.5$ mm, $W2 = 3.5$ mm, $L2 = 11$ mm, $L1 = 9$ mm, $Wf = 1.4$ mm, $Lf = 9.5$ mm, and $L3 = 10.5$ mm. A strip in ground plane and lower and upper truncation in patch provides wide axial ratio bandwidth, pattern, and polarization diversity simultaneously. The numbering of the eight antennas on the face of the cube is assigned in clockwise and shown in Fig. 1(b).

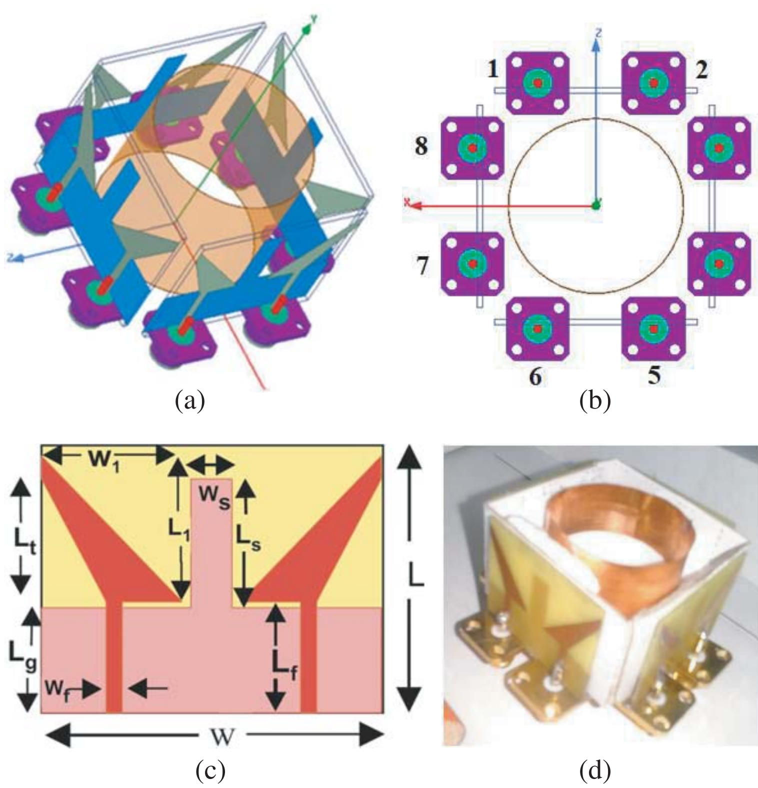
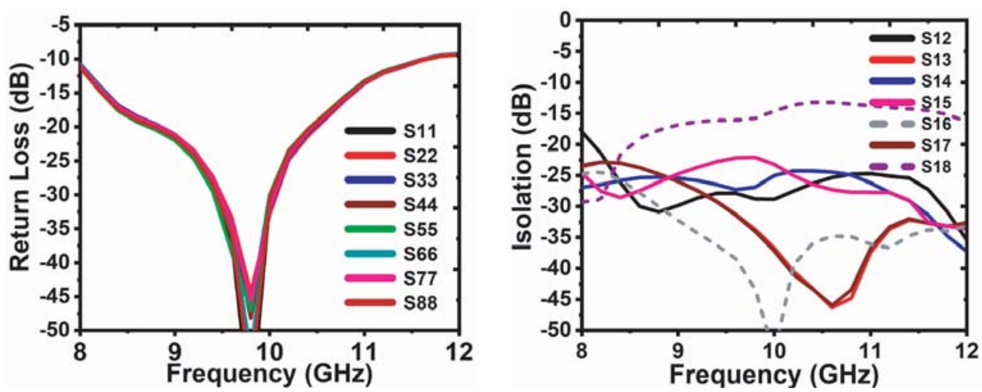


Figure 1. Proposed antenna geometry. (a) Isometric view. (b) Top face. (c) Side face view. (d) Fabricated prototype.

3. *S*-PARAMETER, AXIAL RATIO AND GAIN

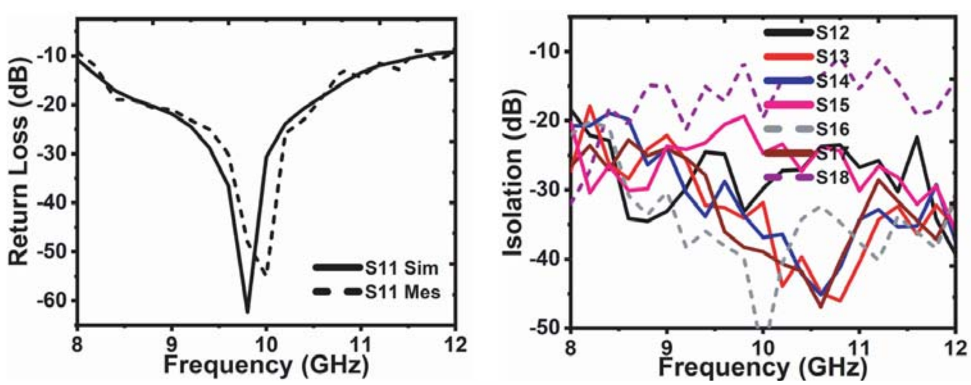
The simulated return losses and isolations of all the eight antennas are shown in Figs. 2(a) and 2(b). The impedance matching bandwidths (IMBW) of all antennas are from 8 to 11.8 GHz. In contrast, simulated isolation between antennas is better than −24 dB, and it is slightly worse for adjacent antennas, but it is still better than −14.5 dB. Fig. 3 shows the measured IMBW, which is 3.8 GHz (8 to 11.8 GHz), and the measured isolation is more excellent than −13.5 dB between antennas 1 and 2 whereas for other antennas it is better than −20 dB. Fig. 4(a) shows the simulated and measured axial ratios and gains. The simulated axial ratio bandwidth (ARBW) is 2.91 GHz (8.17–11.08 GHz) while in measurement, it is 1.95 GHz (8.8 to 10.75 GHz). The results are slightly deteriorated in measurement; this deviation is due to the slight misalignment of the copper cylinder from the axis of cube. Consequently, some antennas are nearer to the cylinder than others. So, the reduction in coupling energy is not the same for all antennas. The simulated gain varies from 2.8 to 4 dB within the IMBW, and measured gain is in good agreement with a simulated one.

Table 1 compares the performances of our proposed MIMO antenna with the recently published works. The performance of our antenna is comparable with other antennas. One face of the cube has two same antennas which are facing each other. Left-hand side antenna generates right-hand circular polarization (RHCP) while the right-hand side antenna generates left-hand circular polarization (LHCP). Hence the proposed MIMO antenna has polarization diversity.



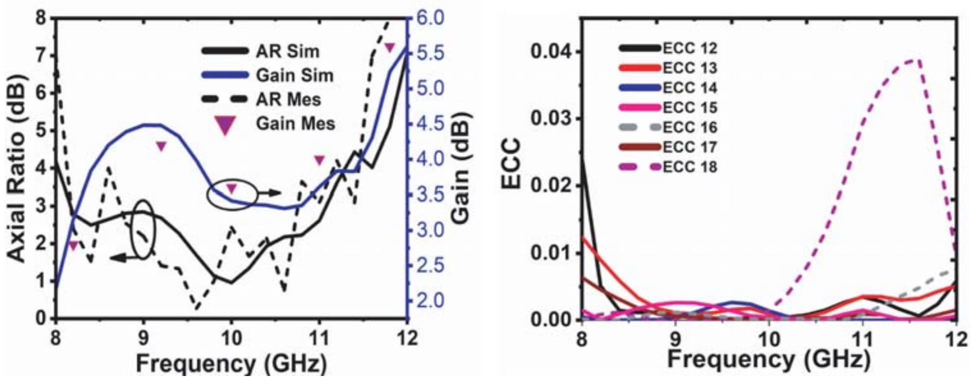
(a) (b)

Figure 2. Simulated (a) return loss, (b) isolation.



(a) (b)

Figure 3. Measured (a) simulated and measured return loss, (b) isolation.



(a) (b)

Figure 4. (a) Simulated and measured Axial Ratio and Gain. (b) ECC.

Table 1. Performance comparison with earlier published work.

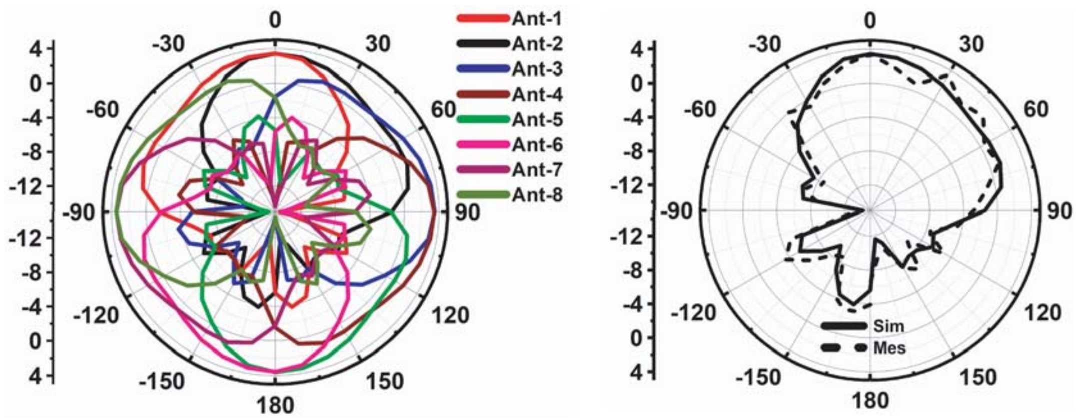
Ref.	Type	Bandwidth, GHz		Diversity	
		IMBW	ARBW	Pattern	Polarization
1	Slotted cube	5–5.45	-	Yes	Linear
2	Slotted cube	5.05–5.4	-	Yes	Linear
3	Cube with ME dipole	1.73–2.57	-	Yes	Linear
5	Slotted cube	1–2.5	-	Yes	-
6	Planar	2.78–20.85	-	Yes	-
7	Orthogonally placed	5.6–5.9	-	Yes	Linear
8	Ortho hexagon shape	3.1–6.2 and 7.1–8.7	-	No	No
Our	**Cube shape**	**8–11.87**	**8.8–10.75**	**Yes**	**Circular**

4. MIMO PERFORMANCE

Envelop correlation coefficient (ECC) is essential parameters in MIMO antenna. In MIMO each antenna is in close proximity to another antenna, hence the chance of coupling is very high. The correlation factor gives how much their radiation patterns are spatially apart in space. The ECC of all the antennas is near 0 as shown in Fig. 4(b), because the given antenna has pattern diversity and radiates all the energy in a particular different direction. A copper cylinder inside the cube reduces the coupling. ECC between antenna-1 and antenna-2 is slightly high at a higher frequency, but within 0.04, and the acceptable limit is less than 0.5 which can be seen in Fig. 4(b).

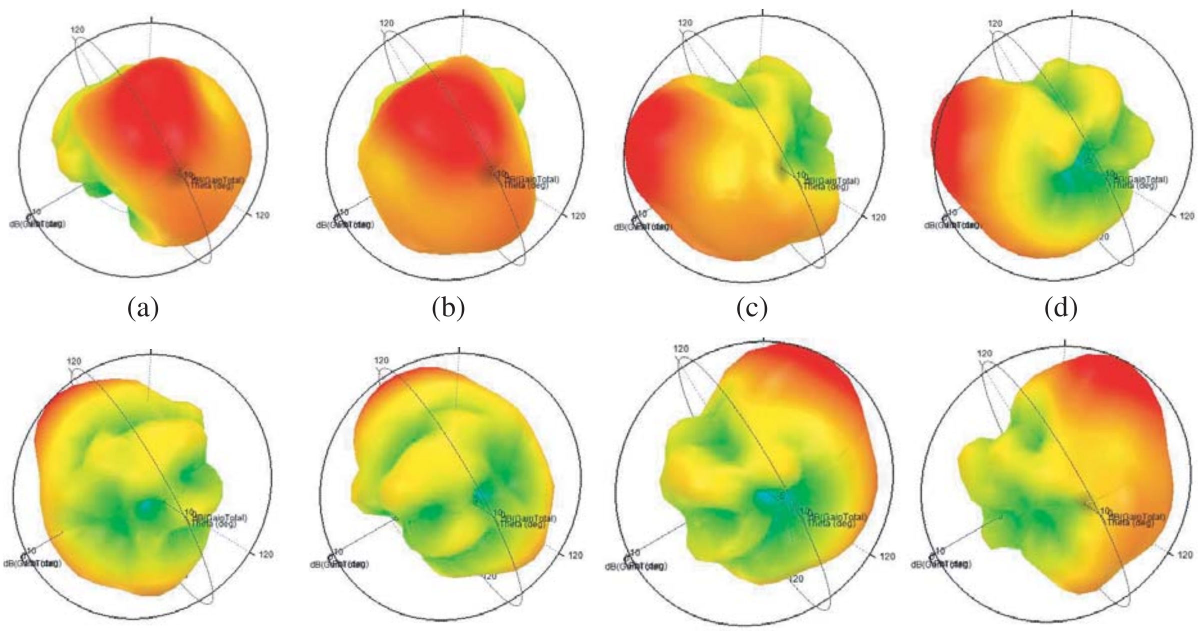
5. RADIATION PATTERN

The radiation pattern in ZX plane for MIMO rectangular antenna in cube form is shown in Fig. 5. The numbering of the eight antennas on the face of the cube is assigned in clockwise and shown in Fig. 1(b). Radiation patterns of all the antennas are in different directions, and each one of the antennas radiates in a different direction. All the antennas are arranged on the face of a cube, and their radiation patterns cover the whole 360° as can be seen in Fig. 5(a). Fig. 6 shows the radiation pattern of the antenna in 3-D, which shows pattern diversity. Antenna-1 radiates in $-30°$; antenna-2 radiates in 30°; antenna-3 radiates in 60°; antenna-4 radiates in 120°, antenna-5 radiates in 150°; antenna-6 radiates in $-150°$; antenna-7 radiates in $-120°$; and antenna-8 radiates in $-60°$.



(a) (b)

Figure 5. Radiation pattern in ZX plane at 10 GHz. (a) Simulated pattern for antenna-1 to 8. (b) Simulated and measured pattern for antenna-2.



(a) (b) (c) (d)

(e) (f) (g) (h)

Figure 6. 3-D radiation pattern of antenna 1–8 showing pattern diversity at 10 GHz.

6. CONCLUSION

A wideband circularly polarized MIMO antenna in cubic form is designed for X-band (8.0 to 11.8 GHz) application with both pattern and polarization diversity. The proposed MIMO antenna has pattern diversity with angular coverage within the whole 360°. The isolation between the antennas is more than 23 dB. The impedance matching bandwidth (IMBW) is 3.8 GHz (8 to 11.8 GHz), and 3 dB axial ratio bandwidth is 2.91 GHz (8.0 to 11.8 GHz). The envelope correlation coefficient is less than 0.035, and its diversity gain is 10 dB. High isolation and uncorrelated radiation patterns between the adjacent elements make the proposed eight-element antenna a good candidate for the use in massive MIMO antenna systems. The size of the antenna is $34 \times 34 \times 23\,\text{mm}^3$ ($1.11\lambda_o \times 1.11\lambda_o \times 0.754\lambda_o$). The proposed MIMO antenna could be robust in challenging weather condition, and it can provide exceptionally high link availability for voice, data, or HD video streaming.

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