



# A Dual-Band Dual-Polarized Omnidirectional Antenna

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A dual-band dual-polarized omnidirectional antenna is investigated. The two bands are generated by a lower circular patch and an upper circular patch, respectively. A set of conductive vias and a coupled ring are utilized to widen the antenna bandwidth. Curved branches are introduced to contribute to circularly polarized radiation. A prototype was designed, fabricated and measured to demonstrate the performance of the antenna. Measured results show that an overlapped bandwidth of 15% from 2.22 to 2.58 GHz for both  $S_{11} \leq -10$  dB and axial ratio  $\leq 3$  dB is obtained in the low band, and an impedance bandwidth of 11.1% from 5.63 to 6.29 GHz is achieved in the high band. Measured peak gains are approximately 4.3 dBic and 5.4 dBi at two bands. Moreover, omnidirectional radiation patterns are also obtained within the operating band.

**Keywords:** antenna, dual-band antenna, circularly polarized and linearly polarized, omnidirectional radiation, patch antenna

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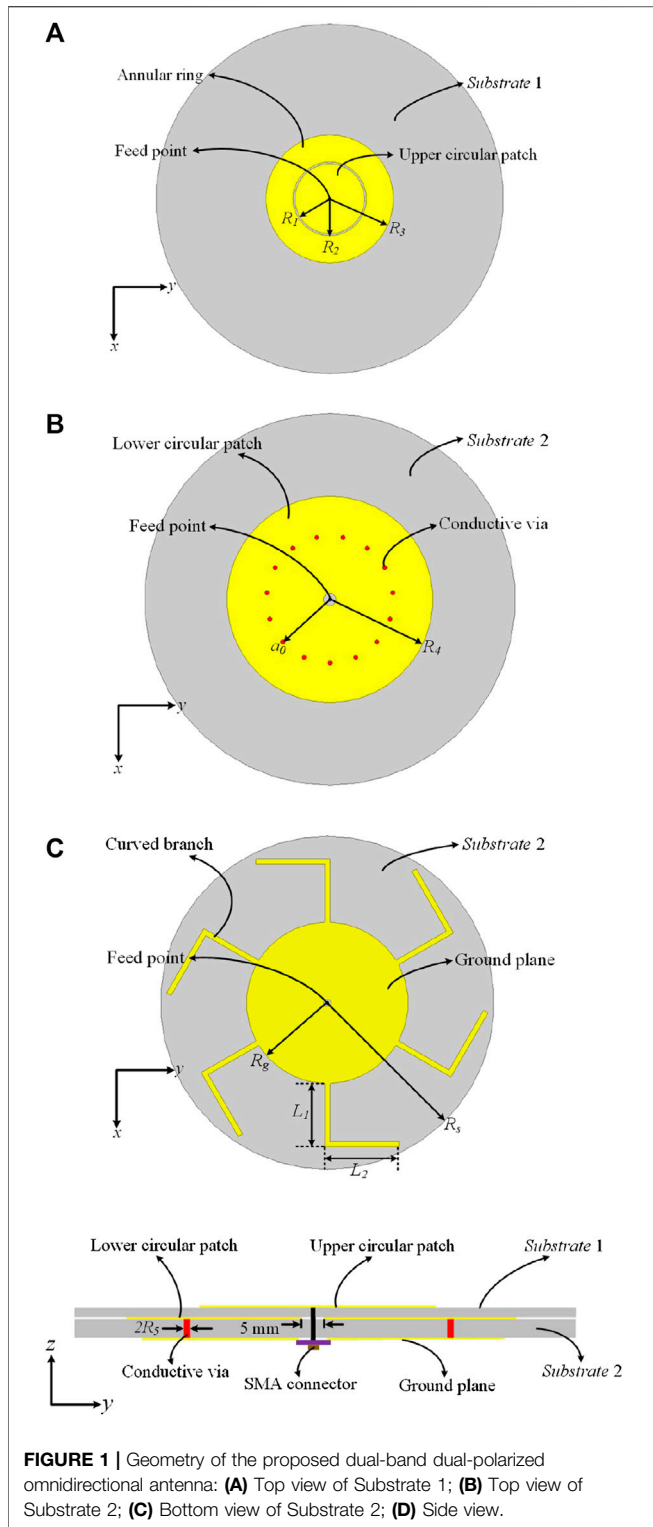
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## INTRODUCTION

Recently, circularly polarized (CP) omnidirectional antennas are of great interest since they can effectively reduce multipath effects, enhance the stability of wireless communication systems and provide a wide signal coverage. Therefore, a large number of efforts have been put into developing CP omnidirectional antennas [1–8]. In Ref. 1, by introducing shorting vias and vortex slots into a monopolar patch antenna, omnidirectional radiation patterns and wide axial ratio (AR) bandwidth were achieved. Based on dielectric resonator antennas, the designs presented in Refs. 2 and 3 could achieve AR bandwidths of 25.4 and 54.9%, respectively. However, the aforementioned designs all had profiles of more than  $0.1\lambda_0$ , which are not appropriate for space-limited applications. Patch antennas have advantages of low profile and simple structures, and are therefore suitable for designing CP omnidirectional antennas [4–8]. For instance, in Refs. 4–6, the antennas loaded with curved branches owned profiles of lower than  $0.07\lambda_0$  and AR bandwidths of more than 14%. In Refs. 7 and 8, by cutting slits on radiating patches and ground planes, CP omnidirectional radiation performances were obtained and the antenna heights were only  $0.028$  and  $0.026\lambda_0$ , respectively.

With the blooming of wireless technologies, antennas with more than one operating band are becoming more and more necessary to satisfy various wireless standards. In Ref. 9, a dual-band CP omnidirectional antenna was proposed. By combining a dielectric resonator antenna and a patch antenna together, the design was able to realize AR bandwidths of 3.16 and 5.06% at two bands, separately. In Ref. 10, by utilizing a stacked-patch configuration, a dual-band frequency reconfigurable antenna was presented. In addition, based on artificial  $\mu$ -negative transmission lines, a dual-band CP antenna was investigated in Ref. 11. As it is known, CP antennas are required for global positioning systems, satellite communications and linearly polarized antennas are needed for lots of other commercial applications. But few published designs are able to offer dual-band omnidirectional antennas with different polarization states in the two frequency bands. In Ref. 12, a dual-band dual-polarized antenna was proposed. Omnidirectional circular polarization is achieved in the low band and omnidirectional linear



**FIGURE 1 |** Geometry of the proposed dual-band dual-polarized omnidirectional antenna: **(A)** Top view of Substrate 1; **(B)** Top view of Substrate 2; **(C)** Bottom view of Substrate 2; **(D)** Side view.

polarization is obtained in the high band. In Ref. 13, a dual-band antenna with different polarization and radiation properties over two bands for vehicular communications is presented. However, the AR bandwidth of the designs [12, 13] is too narrow to satisfy the modern wireless systems.

**TABLE 1 |** Dimensions of the proposed antenna.

Parameters	$R_1$	$R_2$	$R_3$	$R_4$	$R_5$
Values/mm	17	17.3	29.3	48.3	0.7
Parameters	$R_g$	$R_s$	$L_1$	$L_2$	$a_0$
Values/mm	43.6	90	35.2	40.1	30.7

In this paper, a dual-band dual-polarized omnidirectional antenna is presented. The two bands are generated by two circular patches, separately. By adding a set of conductive vias and a coupled ring, the antenna bandwidths are enhanced significantly [14, 15]. Owing to the introduction of curved branches, a current loop can be formed to provide horizontally polarized field. Together with the vertically polarized field created by the lower circular patch, a CP omnidirectional radiation can be generated in the low band. To verify the design idea, a prototype was designed, fabricated and measured. Both simulated and measured results reveal that wide bandwidths, omnidirectional circular polarization and omnidirectional linear polarization can be achieved.

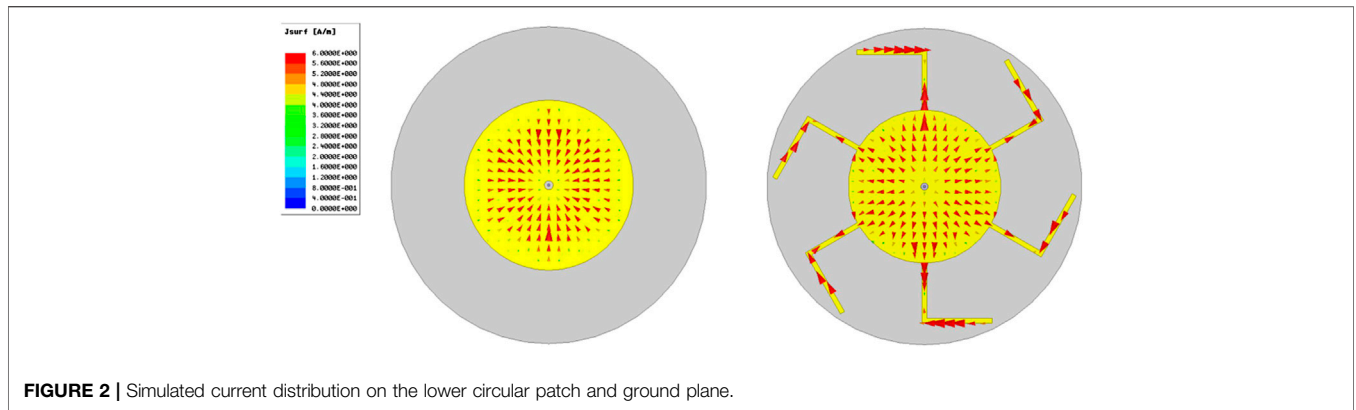
## ANTENNA GEOMETRY AND OPERATING PRINCIPLE

### Antenna Geometry

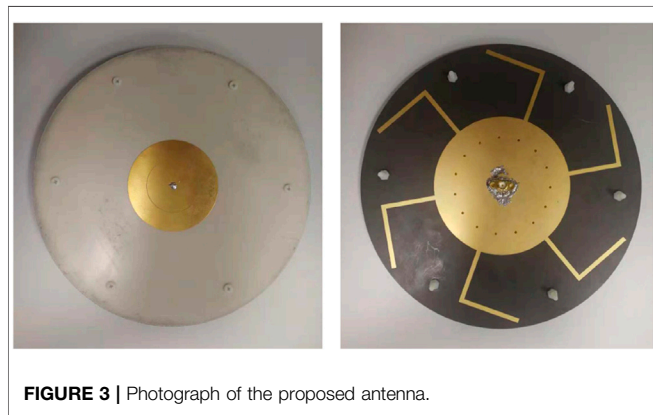
**Figure 1** shows the geometry of the proposed dual-band dual-polarized omnidirectional antenna and the detailed dimensions are listed in **Table 1**. As shown in **Figure 1**, the proposed antenna is mainly composed of an upper circular patch, an annular ring, a lower circular patch, a set of conductive vias, a ground plane, six curved branches and a coaxial probe. The upper circular patch is printed on the top of *Substrate 1* (Taconic RF-30, thickness = 1 mm,  $\epsilon_r = 3.0$ ) and the annular ring is concentrically placed around the upper circular patch. The lower circular patch and the ground plane are printed on the top and bottom surfaces of *Substrate 2* (Rogers 5,870, thickness = 3.175 mm,  $\epsilon_r = 2.33$ ). In order to excite two circular patches simultaneously to achieve a dual-band property, a clearance hole with a radius of 2.5 mm is etched in the center of the lower circular patch. In this way, the upper circular patch is directly fed by the inner conductor of the coaxial probe and the lower circular patch is fed by the coupling with the clearance hole. As a result, the design is able to operate at two bands. In addition, a set of  $N$  conductive vias ( $N = 15$ ) are used to short the lower circular patch to the ground plane and six curved branches are loaded around the ground plane to contribute CP radiation in the low band.

### Operating Principle

As previously stated, by adding the annular ring and a set of conductive vias into the antenna structure, antenna bandwidths can be enhanced dramatically. The curved branches are used to contribute CP radiation. Therefore, in this part, principles of the annular ring, the conductive vias and the curved branches will be further discussed.



**FIGURE 2** | Simulated current distribution on the lower circular patch and ground plane.

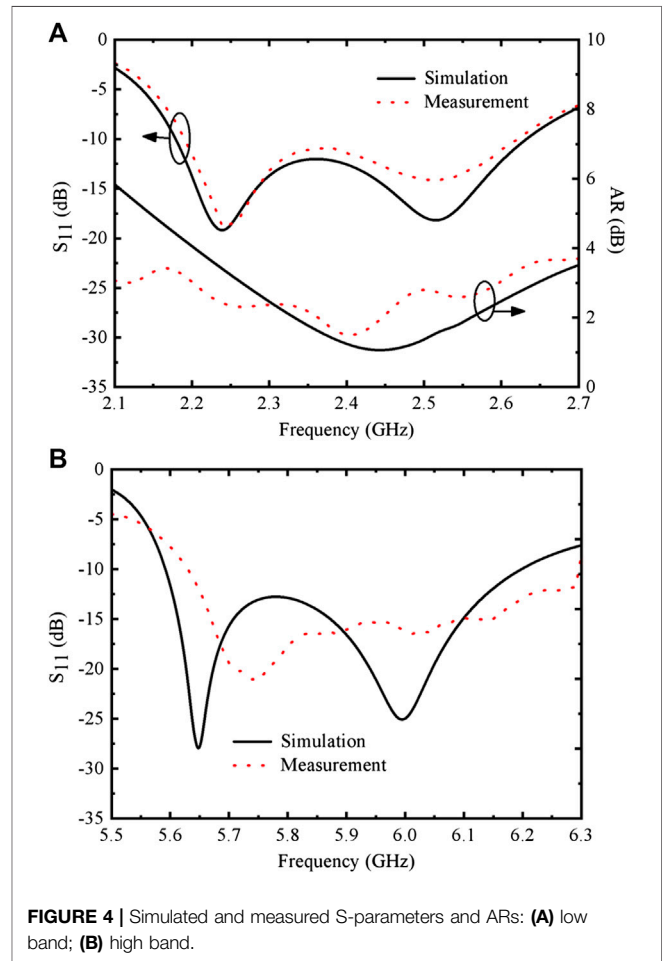


**FIGURE 3** | Photograph of the proposed antenna.

In this design, the annular ring is concentrically placed around the upper circular patch. In consequence, when the upper circular patch is fed, the annular ring can be excited simultaneously by energy coupling. By tuning the radius of the upper circular patch, the size of the annular ring and the distance between them, their resonant frequencies can be moved in proximity to each other. Hence, a wide impedance bandwidth can be obtained in the high band.

As illustrated in Ref. 15, a non-zero resonant frequency of  $TM_{01}$  mode can be created due to the loading of conductive vias. Together with the well-known  $TM_{02}$  mode generated by the lower circular patch, a wide impedance bandwidth can be realized then. The number, radius, and location of the conductive vias have effect on impedance matching of the antenna, and these parameters can be determined based on the design guideline given in Ref. 15.

As it is known, CP radiation requires two orthogonal electric fields with an equal amplitude and  $90^\circ$  phase difference. In this design,  $TM_{mn}$  mode ( $m = 0, n = 1, 2$ ) is generated by the via-loaded lower circular patch, leading to vertically polarized electric field  $E_\theta$ . And the introduction of curved branches can form a current loop around the ground plane, leading to horizontally polarized electric field  $E_\phi$ . When these two orthogonal fields have an equal amplitude and a quadrature phase difference, CP radiation is achieved in the far field. **Figure 2** gives the simulated current distribution on the lower circular patch and the ground plane at 2.4 GHz. It is seen that an equivalent vertical current formed by the circular

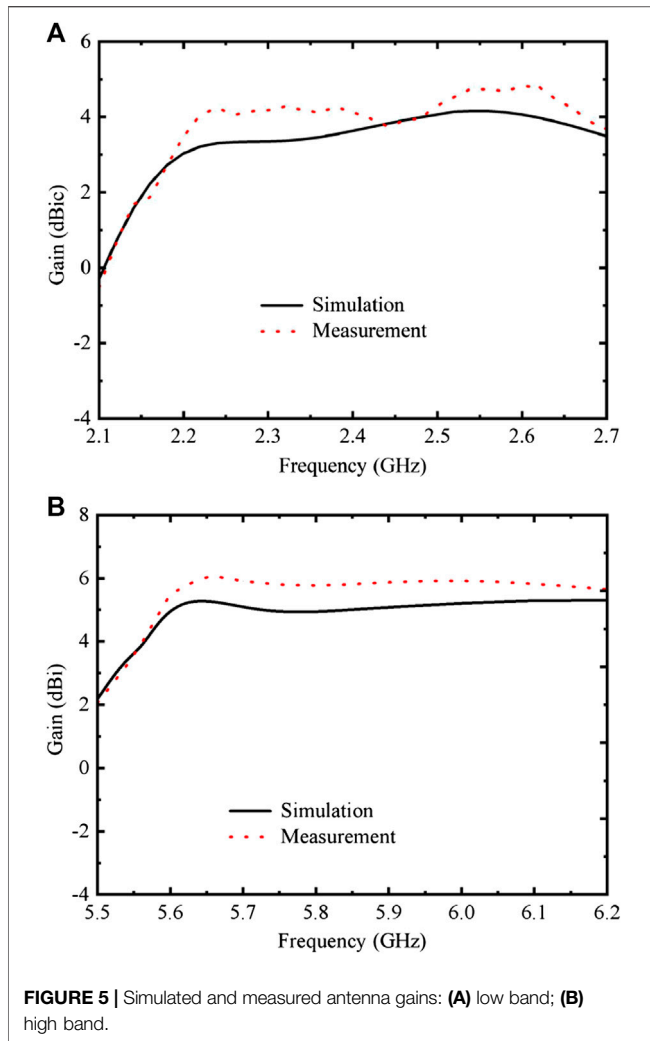


**FIGURE 4** | Simulated and measured S-parameters and ARs: **(A)** low band; **(B)** high band.

patch and a current loop formed by the curved branch on the ground plane are excited simultaneously. Hence, circular polarization is achieved.

## RESULTS

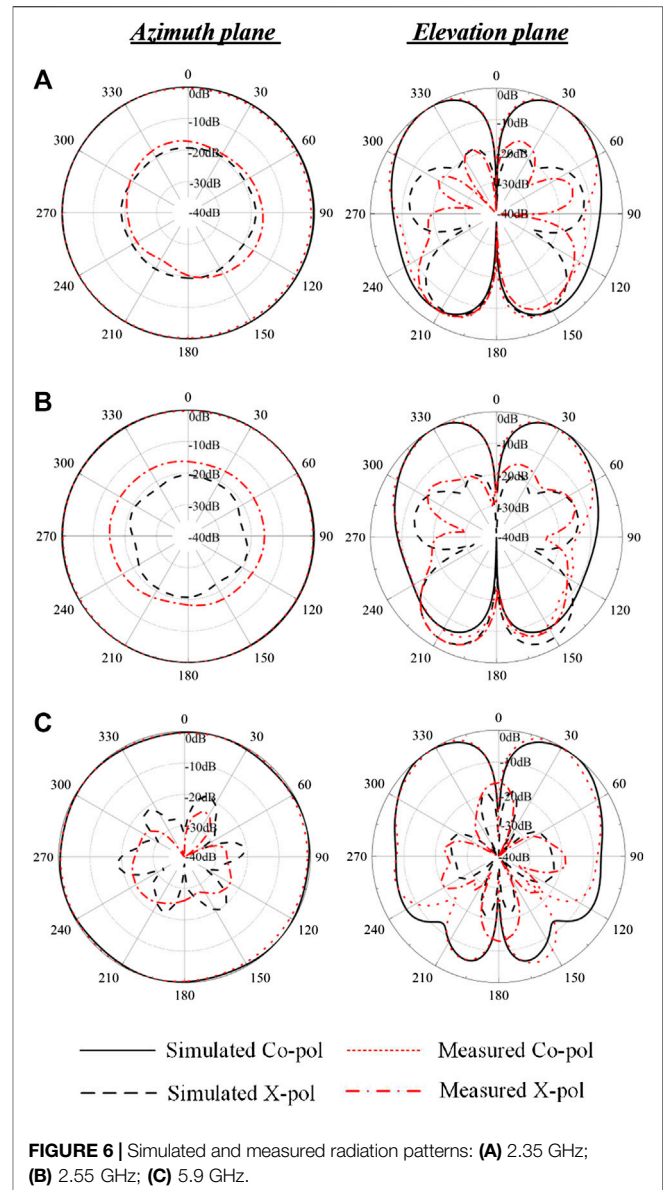
To verify the proposed design, a fully functional prototype shown in **Figure 3** was fabricated and measured. Ansys HFSS, a vector



network analyzer and a near-field measurement system were used to obtain the simulated and measured results.

Simulated and measured S-parameters and axial ratios (ARs) of the proposed antenna are given in **Figure 4**. From the figure, it can be seen that the measured impedance bandwidths for  $S_{11} \leq -10$  dB are from 2.2 to 2.62 GHz in the low band and from 5.63 to 6.29 GHz in the high band, which agree well with the simulated results. The measured AR bandwidth for  $AR \leq 3$  dB is from 2.22 to 2.58 GHz. Therefore, the effective bandwidths of the proposed design are from 2.22 to 2.58 GHz and 5.63–6.29 GHz at two bands, respectively. **Figure 5** shows the simulated and measured peak gains of the proposed antenna. The measured peak gains are approximately 4.3 dBic in the low band and 5.4 dBi in the high band. The discrepancies between the simulated and measured gains are mainly due to the fabrication tolerances and imperfect measurement system.

The simulated and measured radiation patterns in the azimuth plane ( $\theta = 30^\circ$ ) and elevation plane ( $\varphi = 0^\circ$ ) at 2.35, 2.55 and 5.9 GHz are depicted in **Figure 6**. The measured radiation patterns are in well agreement with simulations. In the low band, omnidirectional radiation patterns can be observed and



the left-hand (LH) CP fields are almost 15 dB stronger than the right-hand (RH) CP fields at  $\theta = 30^\circ$  and the whole azimuth plane, demonstrating LHCP radiation is achieved in the far field of the proposed design. In the high band, omnidirectional radiation patterns are also obtained and the cross-polarization levels are lower than  $-15$  dB compared with the co-polarization counterpart in both planes. In consequence, a dual-band and dual-polarized antenna with well-controlled omnidirectional radiation patterns is realized in this design.

## CONCLUSION

In this paper, a low-profile dual-band dual-polarized omnidirectional antenna has been proposed. A prototype was constructed and measured to demonstrate the antenna

performance. The proposed antenna can achieve bandwidths of 15 and 11.1%, gains of approximately 4.3 dBi and 5.4 dBi at two bands, respectively. Besides, omnidirectional radiations with low cross-polarization levels can also be obtained. With these properties, the proposed antenna shows superiorities over the reported designs and is attractive for indoor communication systems.

## DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/Supplementary Material, further inquiries can be directed to the corresponding author.

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## AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct, and intellectual contribution to the work and approved it for publication.

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**Conflict of Interest:** The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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