

Low-profile broadband circularly polarized heterogeneous dipole antenna with backed cavity

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A broadband heterogeneous circularly polarized (CP) dipole antenna with a backed cavity is presented in this letter. The proposed antenna consists of a pair of rotational symmetric short-circuited heterogeneous branches and a Γ -shaped feed structure. Each branch is designed to be axe-shaped so that the antenna can achieve a broad 3dB axial ratio (AR) bandwidth. The coupled feeding method assures the antenna is wideband, and the shorting-to-the-ground technique miniaturizes the lateral dimensions of the antenna. The profile of the proposed antenna is around $0.16\lambda_L$ (λ_L denotes the wavelength of the lower bound frequency). The introduction of a back cavity effectively enhances the boresight gain and improves the isolation level if the antenna is used to form an array. Finally, the design is prototyped, and the measurement results agree well with the simulation. The fractal -10 dB S11 bandwidth and 3dB AR bandwidths are 54.3% (2.74-4.78 GHz) and 45.9% (3.15-5.03 GHz), respectively. The antenna's efficiency exceeds 91.5% over the target frequency band.

Introduction: Circularly polarized (CP) antennas are essential for line-of-sight (LoS) communication systems, such as satellite communications, due to their ability to effectively suppress multi-path effects [1]. Broadband antennas enhance these systems by providing larger information capacity and supporting various services. Numerous broadband CP antennas have been proposed, including cross dipole CP antennas [2]-[7] and magneto-electric (ME) dipole antennas [8]-[11].

Despite their advantages, most crossed dipole antennas rely on printed circuit boards (PCBs), which limits their power-carrying capacity. Consequently, PCB-based crossed dipole antennas are primarily suited for receiving-only or low-power applications. Dr. Luk first introduced the ME dipole antenna for wideband axial ratio (AR) in 2009, leading to numerous subsequent broadband CP antenna designs. However, these antennas often require either two feeding ports or a complex feeding network, limiting their applications or introducing additional losses. Other CP antennas also have their own shortcomings, such as CP patch antennas struggle to achieve broad bandwidth [12], while helical antennas have high profiles [13].

This letter presents a novel single-feed, broadband, heterogeneous CP dipole antenna with a backed cavity. A single Γ -shaped feed structure is employed to couple-feed the asymmetrically placed branches of the dipole, achieving a wide S11 bandwidth without the need for additional power dividers or phase shifters. By short-circuiting the end of each branch to the ground, lateral size miniaturization is achieved. The entirely metal structure enables high power handling and high efficiency. Additionally, the surrounding wall efficiently isolates mutual coupling, making the antenna suitable for array applications.

Antenna Configuration: Fig. 1 presents the top view, perspective view, and side view of the antenna. The antenna consists of two rotationally symmetric short-circuited dipole arms, a Γ -shaped feed structure, and a backed cavity. The entire structure is made of metal, eliminating dielectric loss. Although the cavity effect may reduce the antenna's S11 bandwidth performance, it enhances the antenna's AR performance due to the induced currents on the wall. Furthermore, the surrounding wall effectively prevents laterally propagating waves, which are generated by the short-to-the-ground parts, and thus improving the antenna's gain.

Crucially, the dipole branch is designed with an axe-like shape, which offers superior 3 dB AR bandwidth performance. The choice of feeding point and the relative positioning of the two branches determine the antenna's radiation to be left-handed (LH) CP. Mirroring the entire structure along the x -plane would result in right-handed (RH) CP radiation. The antenna's height is approximately a quarter-wavelength of the center frequency, ensuring that the waves generated by the ground and the dipole are in phase. Detailed specifications of the design parameters are provided in Fig. 1's caption.

Design Evolutions and Mechanism Analysis: Fig. 2 depicts the evolutionary process of the antenna design, while Fig. 3 presents the simulated AR results for each design iteration. The initial simple

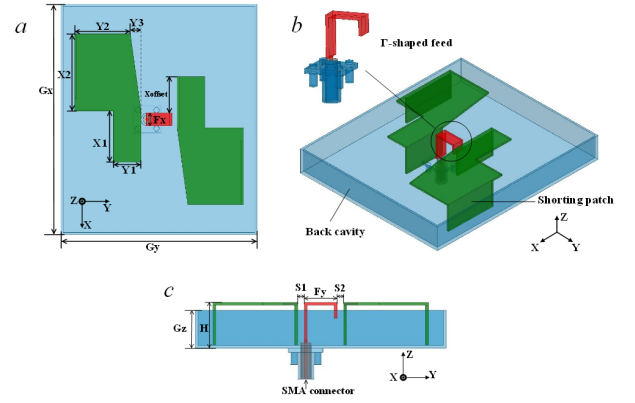


Fig. 1. Geometry of the proposed antenna. a. Top view. b. Perspective view. c. Side view.

* $Gx=106$ mm, $Gy=90$ mm, $Gz=13$ mm, $X1=24$ mm, $X2=36$ mm, $H=15$ mm, $Y1=13$ mm, $Y2=26$ mm, $Y3=5$ mm, $Fx=6$ mm, $Fy=12$ mm, $Fz=5$ mm, $S1=2.5$ mm, and $S2=2.5$ mm.

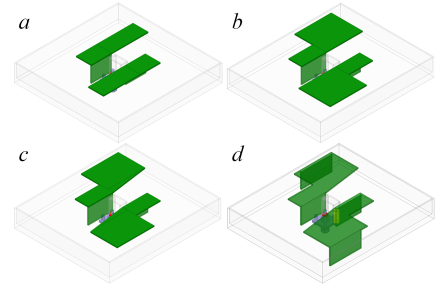


Fig. 2. Configurations of the evolutionary designs a. The initial design. b. The axe-shaped design. c. The triangles cut design. d. The short-circuiting antenna.

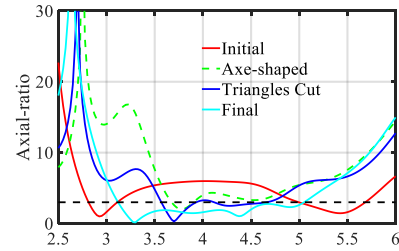


Fig. 3. The AR simulations results of each iterative design.

rotational dipole antenna exhibits two widely separated 3-dB AR bands, suggesting a significant imbalance between the two orthogonal modes within the central band. A thorough investigation of the antenna's surface current distributions at 4 GHz led to a modification of the dipole branch shape to an axe-like form. Consequently, the y -polarized waves are enhanced, resulting in a second design with an AR below 3 dB within the central band.

As depicted in Fig. 2(c), the dipole branch's shape is further modified by removing a narrow triangle from each arm, which broadens the 3-dB AR bandwidth. Compared to the initial design, the second and third iterations achieve AR values below 3 dB near 4 GHz. However, the AR performance declines at both the low and high bands, especially in the low-band region. To enhance the antenna's AR bandwidth, the end of the dipole branch is short-circuited to the ground, introducing a new resonance—the quarter-wavelength short-circuited resonance. This newly excited resonance improves the antenna's AR at the low-band, ultimately resulting in a final design with a broad 3-dB AR bandwidth.

Fig. 4 illustrates the antenna's two orthogonal eigenstates at different frequencies. Since the dipole and the ground are connected, the current distributions on both should be simultaneously examined to investigate the antenna's operating mechanism. As it may be challenging for readers to discern the currents, we represent the energy flows on the dipole using black arrows and those on the ground using red arrows. Observing the three sets of current diagrams, we can conclude that at low frequencies, the currents on the ground follow a longer path, whereas at high

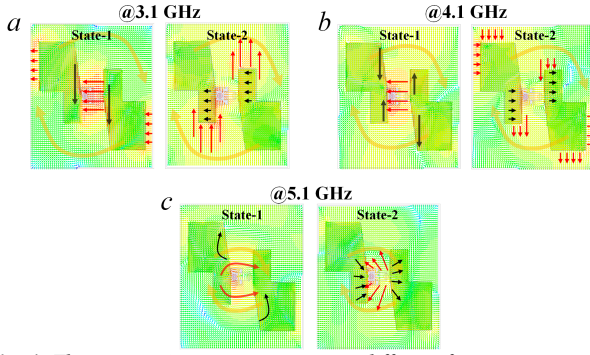


Fig. 4. The antenna's two eigen-states at different frequencies.



Fig. 5. The picture of the fabricated antenna.

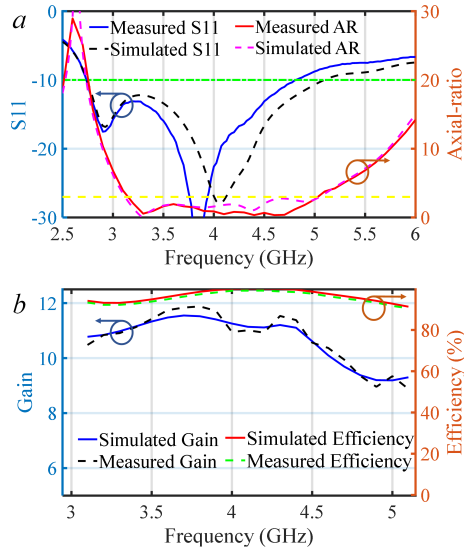


Fig. 6. a. The simulated and measured S11 and AR results. b. The simulated and measured peak gain and efficiency.

frequencies, most energy is concentrated near the central region. The short-circuited metallic plates enforce boundary conditions, thereby exciting the corresponding resonance and ultimately achieving a wide 3-dB AR bandwidth. Owing to the inherent broadband properties of both the feeding method and the dipole structure, we have determined not to focus extensively on discussing the optimization process for the antenna's S11 bandwidth in this paper.

Measurement and Analysis: The proposed antenna has been prototyped, as illustrated in Fig. 5. Fig. 6(a) displays the simulated and measured S11 and the AR at boresight results of the antenna, while Fig. 6(b) presents the simulated and measured peak gain and efficiency. It can be observed that the simulated and measured AR results align exceptionally well, with the 3-dB fractal bandwidth being approximately 46%, ranging from 3.15 GHz to 5.03 GHz. The measured -10 dB S11 bandwidth is slightly worse than the simulation, resulting in a 54% bandwidth from 2.74 GHz to 4.78 GHz. As seen in Fig. 6(b), the antenna's efficiency exceeds 91.5% in the entire band, and the gain varies from 8.3 dBic to 12 dBic across the entire band of interest. Additionally, the measured and simulated results correspond closely with one another.

The co- and cross-polarization radiation patterns in the XoZ- and YoZ-planes at 3.1 GHz, 4.1 GHz, and 5.1 GHz are depicted in Fig. 7, with the measured and simulated results showing excellent agreement. It can be

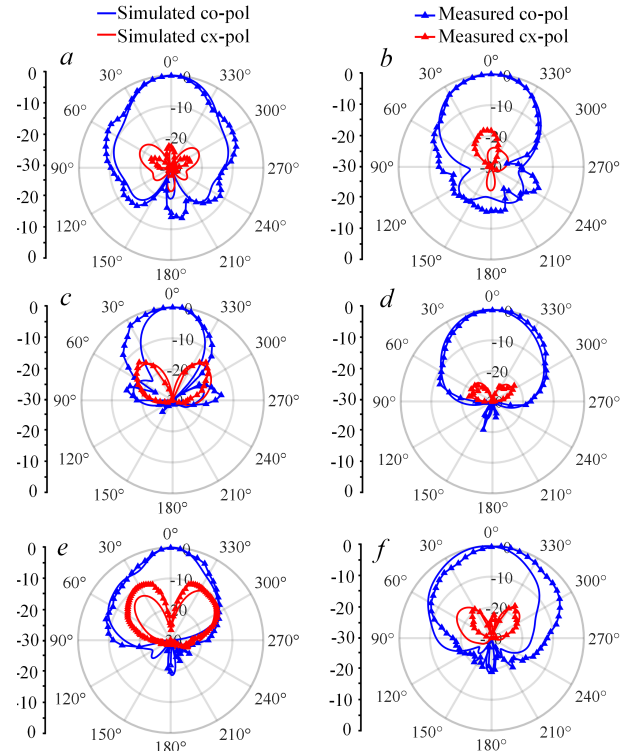


Fig. 7. The antenna's co- and cross-polarization radiation pattern in a. XoZ plane and b. YoZ plane at 3.1 GHz. The co- and cross-polarization radiation patterns in c. XoZ plane and d. YoZ plane at 4.1 GHz. The co- and cross-polarization radiation patterns in e. XoZ plane and f. YoZ plane at 5.1 GHz.

noted that the co-cross polarization ratio deteriorates as the operating frequency increases. This is because, as the antenna's electrical size expands, side-lobes and higher-order modes are more easily excited, leading to pattern degradation. Overall, the radiation pattern of the antenna remains stably unidirectional, with a reasonable co-cross ratio within the operating band.

Conclusion: A novel back-cavity CP heterogeneous dipole antenna has been proposed. This antenna achieves a 46% (3.15-5.03 GHz) 3-dB AR bandwidth with a low profile of only $0.16\lambda_L$. Stable radiation patterns and exceptional radiation efficiency are maintained throughout the entire 3-dB AR band. Additionally, the antenna features a compact structure and is easy to produce consistently in high power-carrying applications. The proposed antenna also serves as an excellent candidate for use as an element in massive antenna arrays, as its surrounding wall effectively prevents the propagation of lateral waves and improves isolation.

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