Pin-loaded planar wideband end-fire circularly polarised antenna

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A single-layer planar end-fire circularly polarised microstrip antenna with enhanced bandwidth is proposed by loading with a metal pin. The original antenna is designed with a shorted parallel-plate cavity that serves as a magnetic dipole, and a double-sided printed bowtie dipole acts as an electric dipole. Then a metal pin is loaded connecting two metal surfaces and impedance bandwidth is improved obviously. One prototype is fabricated for verification and measured 19% –10 dB impedance bandwidth and 36% 3 dB axial ratio bandwidth are achieved.

Introduction: Planar circularly polarised (CP) antennas are widely required in modern wireless systems because of their features of easy integration on carriers and stable signal quality when transmitting and receiving electromagnetic waves. Most planar CP antennas have broadband radiation patterns with the main beam perpendicular to their planes. For better conformal with other systems, end-fire radiation patterns with the main beam parallel with the planes are demanded. Methods such as planar helical/spiral geometry [1, 2], substrate integrated waveguide [3, 4], composite structure [5], side-fed with microstrip line [6], and others have been adopted to realise end-fire CP radiation. However, most of them are limited by the impedance bandwidth or axial ratio (AR) bandwidth. Among them, one kind of compact design is the superposition of electric/magnetic dipoles (EMDs) [7–12]. Such method owns the advantages of compactness and array realisation. Other methods have also been reported [13–15]. Nevertheless, inherent narrow bandwidth or complex structure limited their applications. More methods are needed to realise broadband properties as well as compact structure.

In this letter, a planar end-fire CP antenna with enhanced bandwidth is presented. Unlike conventional EMD-based end-fire CP type that usually owns wide AR bandwidth but limited impedance bandwidth, a metal pin is loaded to improve the impedance bandwidth while maintaining the AR bandwidth. By optimising the pin geometry, the capacitance-inductance condition is tuned and the impedance bandwidth is effectively enhanced. Measured results indicate that such design owns 19% –10 dB impedance bandwidth compared with the unloaded one of only 6%, totally covered in the 36% 3 dB AR bandwidth.

Antenna design and analysis: Figure 1 shows the antenna geometry with top and explored views. Only one substrate is used with metal patches printed on both top and bottom surfaces. The magnetic dipole is made by the parallel patches, while the electric dipole is made by the double-sided printed bowtie dipole, both excited by the coaxial probe. By adjusting the distance between two parts (L1, a 90 degrees phase difference can be obtained and CP can be realised. Three via walls serve as a reflector and the main radiating direction is along the end-fire +y axis. Right-handed CP (RHCP) is investigated in this design.

In order to improve the impedance bandwidth, the metal pin is loaded between the probe-fed via and the printed bowtie dipole. The distance d plays a vital role on the matching as well as the pin size. As is shown in Figure 2(a), S11 is studied without or with the pin of different distance d. When no pin is introduced, the – 10 dB impedance bandwidth is only 6%. The distance is optimised for better reflection coefficients. New resonant point is introduced by the pin. Actually, the input capacitance and inductance could be tuned as needed by the distance as well as the size (diameter and length) of the pin. Finally, a wider bandwidth is achieved by merging different resonant points. Figure 2(b) describes that AR condition could be maintained with broad bandwidth when varying the pin geometry.

Figure 3 illustrates the current distributions. At the higher frequency point of 8.8 GHz, both the parallel patches and double-sided printed bowtie dipole are excited by the coaxial probe. At the lower frequency point of 7.8 GHz, the loading metal pin contributes a lot as a main radiating part as well as maintaining the original magnetic dipole and the electric dipole. Thus, the impedance bandwidth could be enhanced without deteriorating the CP property.

Measurement and simulation results: Photograph of the fabricated prototype is shown in Figure 4. The prototypes are fabricated using Rogers RT 5880 material with relative permittivity \( \varepsilon_r = 2.2 \). Optimised parameters are given in Table 1. The S-parameter (S11) and far-field

| Parameter | Value |
|-----------|-------|
| L         | 38 mm |
| B         | 28 mm |
| h         | 3 mm  |
| d         | 6 mm  |
| θ         | 57°   |
| R         | 10.5  |
| L1        | 16    |
| W1        | 1.8   |

Fig 1  Geometry of proposed antenna (a) top view, (b) exploded view

Fig 2 Parameter analysis of the proposed antenna (a) S11, (b) axial ratio (AR) of the proposed antenna with different distance d between the probe-fed via and the loading pin

Fig 3 Current distributions of the proposed antenna (a) at 7.8 GHz, (b) at 8.8 GHz

Fig 4 The fabricated prototype of the antenna (a) top view, (b) bottom view

Table 1. Parameters of the proposed antenna (unit: mm)
maximum gain of about 3 dB. Measured radiation patterns. The end-fire radiation patterns with a max-
imum of 19% centred at 8.4 GHz. The impedance bandwidth is totally covered in the 3 dB
AR bandwidth. The measured results shift to the higher band a little.

Table 2. Comparisons of the performances of the several probe-fed end-fire circularly polarised antennas ( \( \lambda_o \) is the free-space wavelength)

| Ref. | Size (\( \lambda_o^3 \)) | Substrate parameters | Impedance BW (%) | Axial ratio BW (%) | Overlap BW (%) |
|------|-----------------|---------------------|------------------|-------------------|---------------|
| [2]  | 1.27 \times 1.23 \times 0.11 | \( \varepsilon_r = 2.20; h = 3.175 \text{ mm} \) | 54 | 34 | 34 |
| [5]  | 1.00 \times 0.83 \times 0.03 | \( \varepsilon_r = 1.08; h = 4 \text{ mm} \) | 24.8 | 18.8 | 17.8 |
| [7]  | 0.74 \times 0.60 \times 0.04 | \( \varepsilon_r = 2.65; h = 2 \text{ mm} \) | 2.4 | 9.24 | 2.4 |
| [8]  | 0.74 \times 0.65 \times 0.04 | \( \varepsilon_r = 2.65; h = 2 \text{ mm} \) | 3.62 | 14.34 | 3.62 |
| [9]  | 0.74 \times 0.62 \times 0.04 | \( \varepsilon_r = 2.65; h = 2 \text{ mm} \) | 3.3 | 13.7 | 3.3 |
| [10] | 1.00 \times 0.67 \times 0.04 | \( \varepsilon_r = 1.10; h = 5 \text{ mm} \) | 22.23 | 8 | 8 |
| [11] | 1.00 \times 0.95 \times 0.05 | \( \varepsilon_r = 2.20; h = 3 \text{ mm} \) | 10.8 | 13.7 | 5.6 |
| [12] | 0.60 \times 0.32 \times 0.029 | \( \varepsilon_r = 2.65; h = 1.5 \text{ mm} \) | 3.5 | 4.3 | 3.5 |
| Proposed | 1.00 \times 0.75 \times 0.08 | \( \varepsilon_r = 2.20; h = 3 \text{ mm} \) | 19 | 36 | 19 |

Fig 5 Simulated and measured (a) reflection coefficients, (b) AR of the proposed antenna

Fig 6 Simulated and measured radiation patterns at 8 GHz (a) yoz plane (\( \theta \)-plane), (b) xoy plane (\( \phi \)-plane)

characteristic (AR and radiation patterns) was measured using an Agilent N5230A network analyser and an anechoic chamber, respectively.

Figure 5 illustrates that the measured –10 dB SI11 bandwidth is about 19% centred at 8.4 GHz (from 7.64 to 9.2 GHz), while simulated one is 20% (from 7.43 to 9.14 GHz). Meanwhile, both measured and simulated AR bandwidths are about 36% centred at 7.7 GHz (from 6.3 to 9.15 GHz). The impedance bandwidth is totally covered in the 3 dB AR bandwidth. The measured results shift to the higher band a little. However, the agreement is acceptable. Figure 6 shows the simulated and measured radiation patterns. The end-fire radiation patterns with a maximum gain of about 3dBic along \( + \phi \)-axis are in the 90 degrees direction of \( + \phi \)-plane (parallel to y-axis) and 180 degrees direction of \( \theta \)-plane. The antenna gain and efficiency in the band range are higher than 1.2dBic, a little lower than conventional designs because of the loading pin. However, it is acceptable. The cross-polarisation level is better than 22 dB. Pattern deviation exists in the backward and lateral directions because of the measurement tolerances such as the platform of larger metal plane. However, the results confirm the theoretical analysis.

Different from side-fed type with microstrip feeding line [6], probe-fed type is easy to realise array as well as weak affected by welding. Comparisons between the proposed antenna and former probe-fed planar CP end-fire ones are presented in Table 2. The former designs own relatively narrow bandwidth (less than 10%) in [7–12], which are limited by the impedance bandwidth or the 3-dB AR bandwidth. The proposed one has an improved overlap bandwidth of 19% compared with the previous research with a relatively compact structure. Although design in [2] expanded the effective bandwidth at a considerable level, the size is much larger than our design, especially the transverse dimension. Although a little larger transverse size, design in [5] owns favourable size and bandwidth performance.

Conclusion: In this letter, a planar wideband end-fire CP antenna is proposed. Thanks to the loading pin, impedance bandwidth is much improved and thus the overlap bandwidth. Measured results show that 19% bandwidth is achieved and is among the best for the probe-fed type. With the advantages of simple geometry and considerable bandwidth, the proposed antenna could be a good option in the future wireless communication system.

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