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Research Article

Circularly Polarized Leaky-Wave Antenna Based on Low-Loss Transmission Line

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A leaky-wave antenna with circular polarization property is proposed in millimeter-wave band, which can be applied in the wireless communication systems and remote sensing. The radiation is produced by the periodic patches on both sides of the dielectric slab of the antenna based on a low-loss planar Goubau line structure. The circular polarization unit cell of this antenna is made of two pairs of H-shaped patches, orthogonally set on each side of the dielectric substrate, which can efficiently reduce the cross polarization. This antenna is excited by a central strip line on the upper surface of the slab, removing the ground of the traditional microstrip structure, to reduce the loss of the antenna. The circular polarization property is achieved by optimizing the size and the distribution of the radiation unit cell and the structural periodicity. The radiation performance of this antenna is analyzed by CST simulation, which shows that the overlapping bandwidth of this antenna for 3 dB axial ratio with $S_{11} < -10$ dB is about 5.3%, with cross polarization 23 dB lower than copolarization. The simulated maximum directivity is l5.5 dBi with efficiency over 90% during the whole band.

1. Introduction

Circularly polarized (CP) antenna has become increasingly important in so many wireless communication systems. Compared to linearly polarized antenna, the CP antenna shows more advantages in so many applications. It allows for better flexibility in orientation angle between transmitting antenna and receiving antenna and brings about stronger mobility and weather penetration. In radar detection and satellite communication applications, CP antenna is still indispensable to eliminate the polarization mismatch and reduce the multipath interference.

Recently, many types of CP antenna are proposed. Xu et al. [1] presented a low-profile conical-beam antenna with CP property, with ring-shaped parasitic elements centered by a monopolar patch. Karki et al. [2] designed a novel CP antenna with a monopole surrounded by two orthogonal parasitic radiator units which can directly determine the beam angle by adjusting its height. In [3], a planar substrate integrated waveguide (SIW) antenna is proposed, utilizing a radial current source and a loop current source for a CP radiation. In [4], a square patch array with broadside radiation is proposed, and the feeding structure is a circularly meandered microstrip transmission line under the radiating layer, which can produce a CP radiation. In [5], a planar monopole antenna is designed for compound reconfigurable circular polarization with pattern tilting ability in two switchable frequency bands. Trinh-Van et al. [6] also presented a low-profile CP magneto-electric dipole antenna, simply fed by a microstrip line aperture-coupled structure, to enhance the CP bandwidth. In [7], a high-gain array antenna with very good CP property is designed and analyzed.

It is found that most of the aforementioned CP antennas are based on the microstrip line transmission structures because of the low profile, light weight, and easy fabrication. However, either the dielectric or the ohmic losses rises with the increasing frequency band, leading to the low efficiency

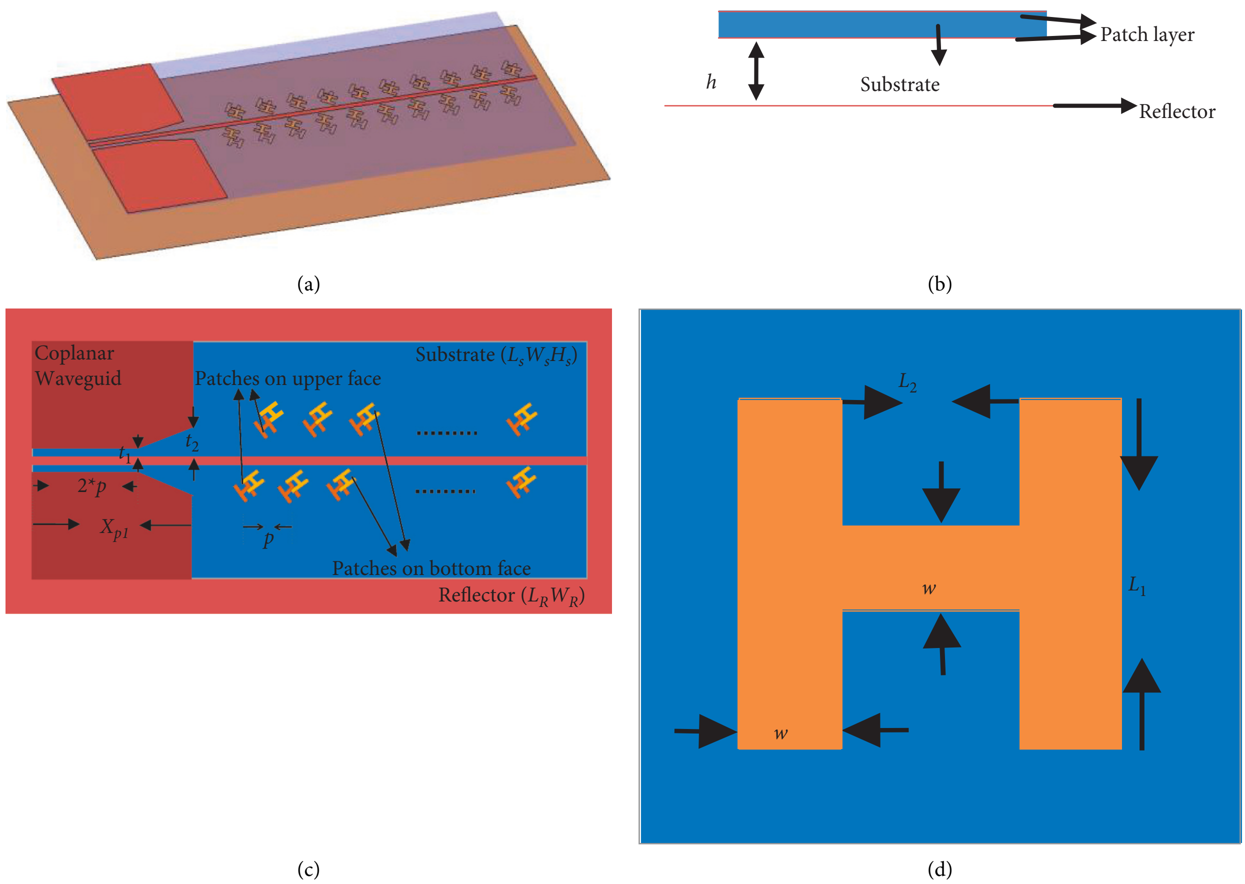


Figure 1: Parameters and configuration of the CP antenna. (a) 3D view. (b) Side view. (c) Top view. (d) *H*-shaped patch.

of the antenna [8, 9]. Thus, in this paper, the planar Goubau line (PGL) is adopted instead of the microstrip line to excite the periodic patches instead, with a strip line removing the ground to improve the efficiency [10].

In this paper, a new CP LWA based on the PGL is designed for a high efficiency. The CP unit cell is made of two pairs of H-shaped patches, orthogonally set on each side of the dielectric substrate, which can reduce the cross polarization, as shown in Figure 1. In the feeding structure of this antenna, one segment of coplanar waveguide is set in between the input coaxial cable and the PGL, for a smooth transfer of impedance [11]. Since the patches are on both sides, a reflector is utilized to suppress the backward radiation, located under the substrate by a distance of h, which is shown in Figure 1(b). There are totally 10 periods of *H*-patch units, located on both sides of the PGL's central metallic strip. The simulated results of the radiation performance of this antenna are analyzed by CST and quantitatively compared with those from several CP antennas reported in the literature.

2. Antenna Structure and Radiation Mechanism

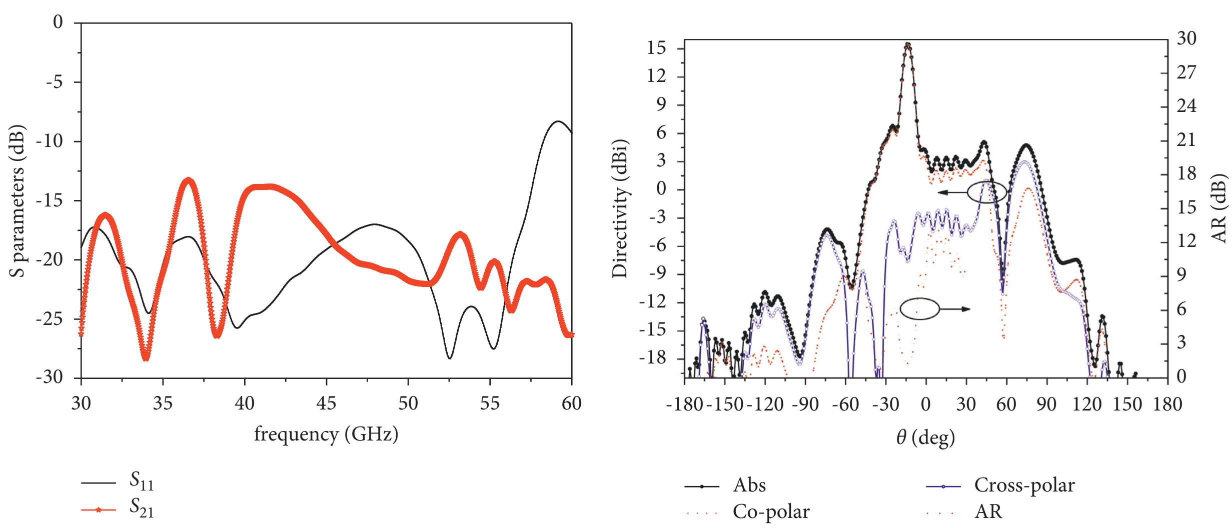
Figure 1(c) shows the top view of the proposed CP antenna. The basic feeding structure of the antenna is the classical PGL, which is a metallic strip along the longitudinally symmetrical line on upper surface of the dielectric substrate

Table 1: Parameter list of the proposed CP antenna

Parameter	Value (mm)
L_1	2
w	0.5
S_d	2
A	53°
X_d	0.1
Y_d	1.5
t_1	0.625
t_2	1.625
H_s	0.4
L_R	78
W_R	35
L_s	68
W_s	30

[12], which is a slow-wave structure with fundamental mode radiation suppressed [13]. Thus, periodic perturbations are added to generate radiation from the spatial harmonics.

The proposed design uses *H*-shaped patches as periodic perturbations in the PGL. The unit cell is formed by four H-shaped patches, divided into two sets for reducing the cross polarization. One set of patches is on the upper side of the substrate with a rotation angle of α (in terms of patch center) and another is on the lower side with a rotation angle of $\alpha + 90^\circ$. Each set of the unit cell is formed by two patches



(a) (b)

FIGURE 2: Simulated results of (a) S parameters and (b) the radiation pattern and axial ratios in the xz-plane at 48 GHz.

separated by $P/2$, placed on each side of the metallic strip to compensate the phase difference. The two orthogonal patches are set with longitudinal and transverse distances: X_d and Y_d. The distance from the patch center to the central strip mainly determines the coupled energy and finally decides the efficiency, which is denoted by S_d. According to the EM field theory, for realizing a CP radiation, there are two fundamental conditions: one is that the two orthogonal field components should have the same amplitudes and the other is that they have a 90° phase difference. In this antenna, the parameter rotation angle α decides the amplitudes of the two orthometric aperture fields, which satisfies the first condition. Then, the second 90° phase-shift condition can be achieved by changing the thickness of the substrate H_s and adjusting the deviations between the two orthogonal patches (longitudinal and transverse: X_d and Y_d). Figure 1(d) gives the structural parameters of the H-shaped patch.

There are totally 10 periods of H-patch sets in the CP antenna. According to the harmonic radiation mechanism, the period of the set p is set to 4.7 mm (0.752 λ_0) to produce a single radiation beam from the -1^{th} spatial harmonic. In this antenna, the radiation from the upper patches is left-hand CP, and the radiation from the lower patches is in opposite direction with right-hand CP. Thereby, the reflector is also designed for generating a single upward CP beam, which is set under the bottom face of the substrate by 5 mm, optimized by simulations.

3. Results and Analysis

This CP antenna is analyzed at $f = 48$ GHz. The loss tangent and permittivity of the substrate are $\tan\delta = 0.02$ and $\varepsilon_r = 1.8$, respectively, and the parameters of the whole antenna are listed in Table 1, which are optimized in the CST simulations.

The simulated results of S parameters of the CP antenna are given in Figure 2(a). It shows that the impedance bandwidth with $S_{11} < -10$ dB is over 60% with the radiation efficiency as high as 90% during the whole frequency band. Besides, the simulated results of the copolar and cross-polar components of the radiation pattern in the xz-plane at 48 GHz are depicted in Figure 2(b), indicating that this antenna can generate a pure CP radiation with the cross-polar component 23 dB lower. It also shows that the axial ratio can keep below 3 dB in the main beam direction in simulation.

Figure 3 depicts the propagation of the EM energy along the longitudinal direction of this antenna. It indicates that most of the energy propagates longitudinally like a traveling wave, and the radiation is mainly generated from the CP units.

When the feeding phase is changing from 0° to 270°, the direction of the electric field rotates clockwise as shown in Figure 4, illustrating the achievement of circularly polarized property.

The results of the directivity and axial ratio of this antenna from simulation are shown in Figure 5. It is found that the beam width and the directivity remain stable (about 10° and 15.5 dBi, respectively) with frequency increasing from 46.5 GHz to 49 GHz. Simultaneously, the axial ratio within the main beam shows a good property within the frequency band. It can be seen that the simulated 3 dB AR bandwidth is about 2.5 GHz bandwidth (from 46.5 GHz to 49 GHz), corresponding to 5.3% with respect to the center frequency of 47.75 GHz.

The simulated results of the radiation performance of this antenna are quantitatively compared with those from several CP antennas reported in the literature, as shown in Table 2. It indicates that the proposed antenna has a high

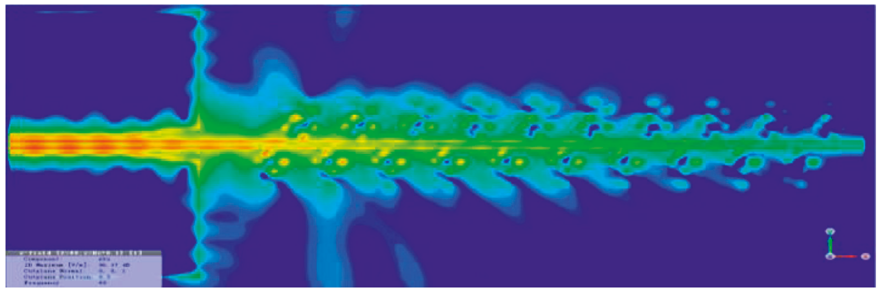


Figure 3: Propagation of the EM energy on the surface of this CP antenna.

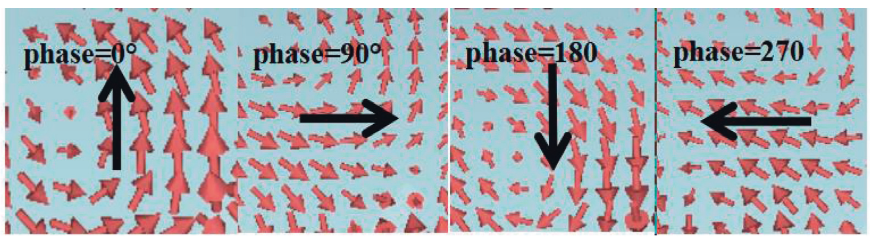


Figure 4: E-field around the aperture of one patch with 0°–270° feeding phases.

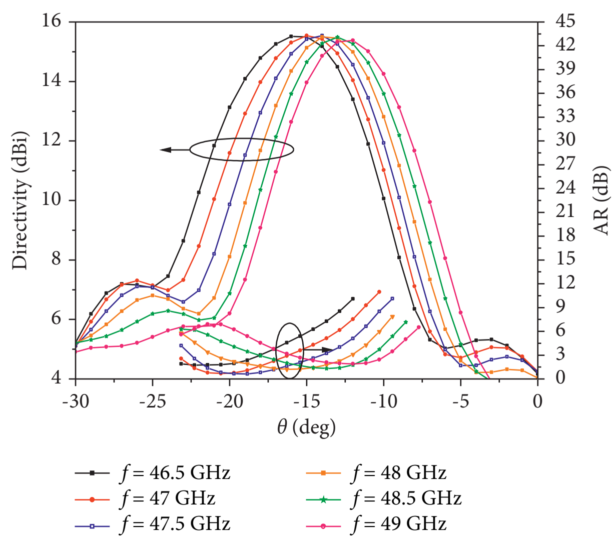


Figure 5: Simulated results of the directivity and axial ratios in the *xz*-plane for different frequencies.

Table 2: Comparison of simulated CP antenna.

Antenna Ref.	Impedance bandwidth (%)	3 dB AR band (%)	Cross polarization (dB)	Peak gain (dBi)
[3]	20.4	17	−18	8.25
[6]	51.35	51.35	−22.5	9.75
[11]	15	7.6	−15	15.6
Our work	60	5.3	−23	14.8

gain with low cross polarization, but the 3 dB AR band is limited compared to its wide impedance bandwidth.

4. Conclusion

In this paper, a periodic leaky-wave antenna with CP property is proposed and analyzed in the millimeter-wave frequency band. The structure is based on the planar low-loss Goubau line without ground, and a reflector for a single upward beam is designed, which acts as an effective polarizer simultaneously. The circular polarization radiating unit consists of two orthogonal and slide H-shaped patches, which ensures the good circular polarization and low cross-polarization properties of the proposed antenna. The axial-ratio bandwidth within 3 dB of this antenna is about 5.3%, and the efficiency of the antenna is over 90%, with a peak gain of 14.8 dBi over the CP operating band.

Data Availability

The data used to support the findings of this study are included within the article.

Conflicts of Interest

The authors declare that they have no conflicts of interest.

Acknowledgments

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