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A Singular-Feed Circularly Polarized Metasurface Antennas Using Characteristic Mode Analysis

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Abstract – In this paper, a singular-feed circularly polarized (CP) metasurface antenna with broad impedance bandwidth is presented. The antenna consists of modified slots with a lattice of 3 × 3 square conductive patches. Modes are selected and excited by modified slot by using characteristic mode analysis. Wideband characteristics are achieved thanks to the modified slots, leading to a new resonance. The circular polarization characteristics are generated by exciting via single feeding simultaneously. The positions of feeding are determined via characteristic mode analysis. Compared with conventional methods, the presented analysis can simplify the feeding structure and provided a compact antenna. The simulated results show an impedance bandwidth of 82% and 3 dB AR at 2.4 GHz Wireless Local Area Network (WLAN) bands.

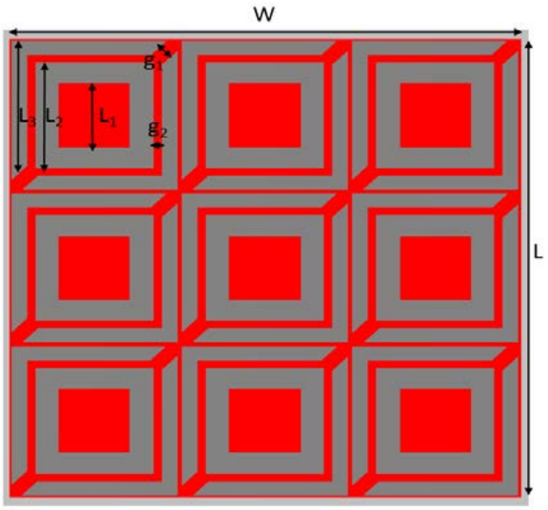
Keywords –circularly polarized, singular-feed, wideband, metasurface antenna, characteristic mode analysis,

I. INTRODUCTION

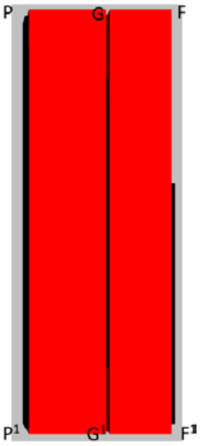
The circularly polarized (CP) antennas have been preferred in wireless systems due to their superior advantages in overcoming multipath distortion and polarization mismatch, as they operate independently of the orientation of the transmit and receive antennas. Moreover, it is expected that CP antennas have broadband and compact structures. Loop antennas, microstrip patch antennas and metasurface antennas are frequently used in the literature[1]–[7]. Performance limitations such as narrow bandwidth are quite common with conventional CP microstrip and loop antennas. Metasurfaces structures have recently become a frequently used new technique to improve the performance of conventional CP microstrip antennas[4], [7]–[10]. In addition, it is used to increase bandwidth, reduce antenna dimensions, increase efficiency, and improve axial ratio (AR) characteristics . When the literature is considered, various designs of metasurface CP antennas have been proposed. The metasurface structure was first used to obtain CP radiation [9], [11]–[14].In [11], a metasurface-based antenna is designed to achieve circular polarization. However, these methods have problems with complex feed structure. Characteristic Mode Analysis (CMA) is a precise and unique technique that provides a clear and insightful mechanism of electromagnetic radiation for designing and optimizing antennas. For example, the harmonic suppressed stepped impedance strip dipole antenna is studied with CMA in [15], a wideband dual CP shared aperture antenna array is designed using CMA for 5G applications in [16], [17]. This work proposes a singular feed wideband CP antenna consisting of modified slots and a 3x3 square metasurface structure. With CMA, desired modes and suitable feeding positions are found. The modified slots enable the desired modes, allowing the appropriate location to be placed for the feed. A modified slot provides extra resonance. It is observed that the resonances of the modified slot excite the metasurface antenna and the modified slot is combined to achieve a wideband CP operation. The simulated results show that the proposed antenna achieves wide bandwidths. All results show that the proposed antenna succeeds a wideband singular feed CP potential.

II. ANTENNA DESIGN

Figure 1 shows the proposed antenna geometry for the 2.4 GHz WLAN band. The antenna is comprised of the metasurface structure (P-P' plane), the ground plane (G-G' plane), and the feed line (F-F' plane). The FR4 was used as a dielectric substrate. The distance between the patch and the ground is 1.6 mm, and the distance between the ground and the feed is 0.4 mm. The metasurface consists of a 3x3 array of square slot patches. In the center of the ground plane is a feed slot of length L_f and width W_f. The geometric dimensions are presented in Table 1.



a)



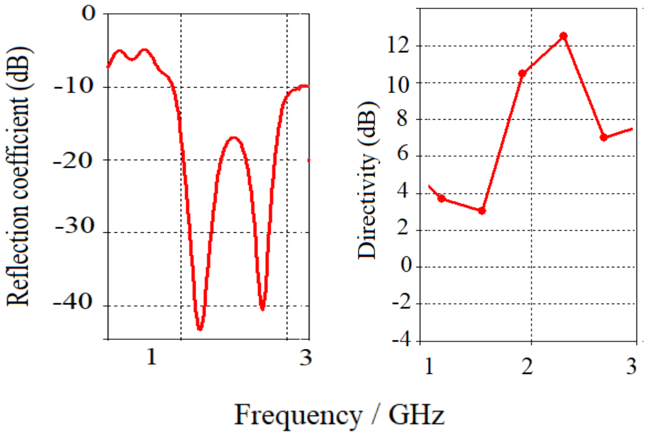
b)

Fig. 1 Schematic of the proposed antenna a) Front view b) side view

Table 1. Parameters of the proposed antenna

Par.	L	L_1	L_2	L_3	W	g_1	g_2	L_f	W_f
mm	35	3.89	6.89	9.99	35	1	0.45	L/4	0.74

In Figure 2, the reflection coefficients and directivity obtained using Computer Simulation Technology (CST) are shown. According to the results, the impedance bandwidth for $|S_{11}|=-10$ dB 82.9% (1.2–2.9 GHz) and the directivity between 3.8 and 12.72 dB.



a) b)

Fig. 2 The simulated results of a) reflection coefficients b) directivity.

III. CHARACTERISTIC MODE ANALYSIS

When operating in fundamental and higher-order modes, microstrip antennas have different radiation and impedance characteristics. In high-order mode, the impedance bandwidth can be improved while narrowing the radiation characteristic bandwidth[11]. Related theories have demonstrated that grid structure metasurfaces can offer high-order modes to excite multi- resonances in the antenna. CMA has become a popular tool for analyzing and designing antennas with the physical knowledge gained about antenna operating principles regardless of feed[7]. It provides a clear understanding of the resonant frequency of certain modes, the radiation patterns, and the mode current of interest. In addition, it is a modal analysis technique for antennas of random structure. The details of characteristic mode theory and its applications in antenna design can be found in [18]. In CMA applications, the results are interpreted with the eigenvalue, characteristic angle, and modal importance parameters on the desired frequency band. The behavior of the relevant structure can be examined from these three parameters.

Using a characteristic mode analysis, we first simulate modal significance to know the resonant frequency. The modal significance of the first four modes is illustrated in Figure 3. As shown in Figure 3, the first four modes have similar resonant frequencies. In order to obtain the desired radiation characteristic, we need to select and excite the desired modes, while the undesired modes must be weakly excited. We simulate the mode current to investigate the radiation properties. The mode current of the first four modes is shown in Figure 4. Figures 4(b) and 4(c) show that J2 and J3 are the superpositions of dipole mode, respectively. J1 is a loop and J4 is two half-wavelength loop modes in the metasurface plane.

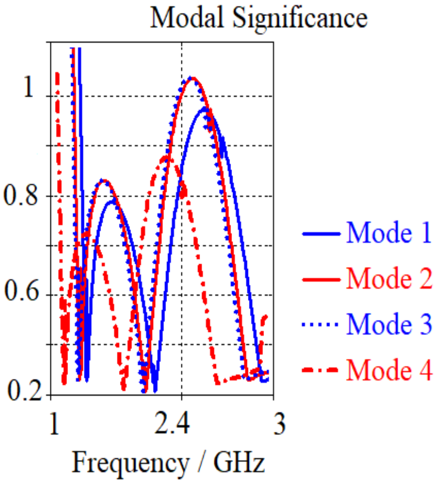
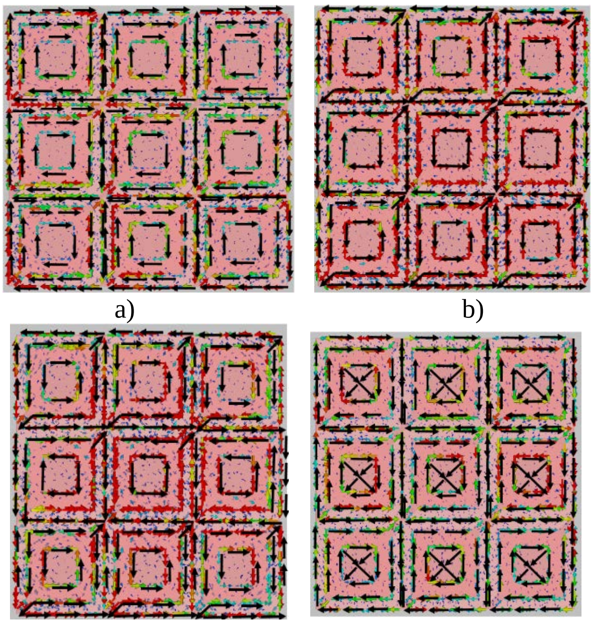


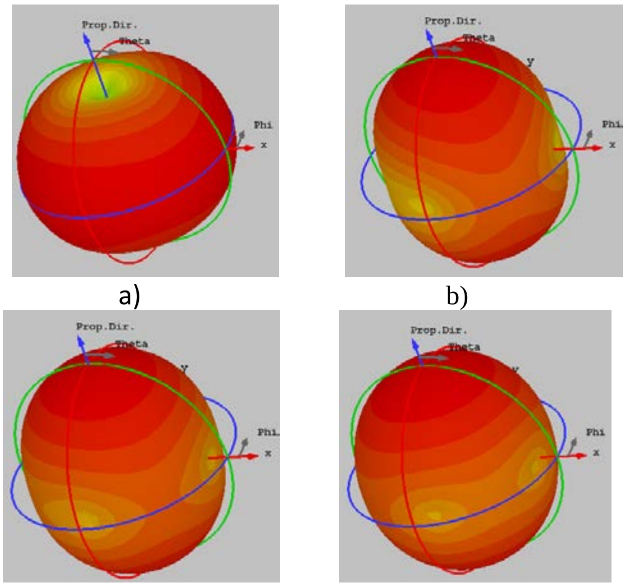
Fig. 3 The modal significance of the first four modes.



a) b)

c) d)

Fig. 4 The mode current of the first four modes a) J1, b) J2, c) J3, d) J4



a) b)

c) d)

Fig. 5 The modal radiation patterns of the first four modes

According to the current distributions, J1-J4 are the degenerate modes. J1 and J4 are shown in Fig. 4(a) and 4(d), respectively. The results of the modal radiation patterns are consistent with the current analysis results (Fig.5).

In this paper, we want to achieve a CP radiation model with a metasurface antenna with a CMA routing. The feed position and structure are crucial to excite the desired mode. As seen in Figure 4, the maximum modal current distribution of J2 and J3 is at the center of the metasurface. That is, these modes can be efficiently joined. To join the J2 and J3 modes, the feed structure should be placed in the middle of the metasurface with a high current density. In addition, the maximum current distribution of J1 and J4 is at the corners of the metasurface. If a common feed is designed from these points, it is possible to join these two modes. In this way, modes can be stimulated efficiently or modes can be stimulated weakly. In the study, it was preferred to join J2 and J3 modes. According to the current density graph, the feed line with microstrip width (W_f) and microstrip length (L_f) values is placed at the center point and polarization transformation is performed and CP radiation is obtained. The resulting axial ratio graph is given in Figure 6. According to the axial ratio graph, while mode 2 and mode 3 are in linear polarization alone, circular polarization is obtained by combining the modes.

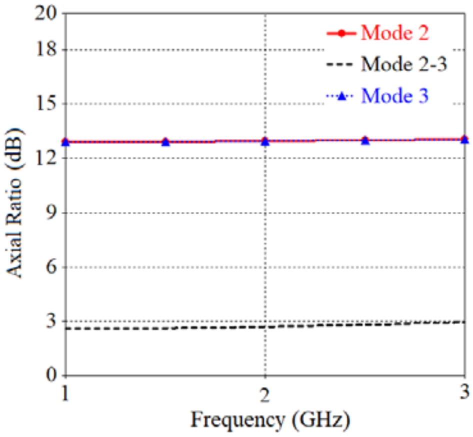


Fig. 6 The simulated results of axial ratio

IV. CONCLUSION

In this study, a singular feed CP antenna is proposed using a metasurface structure with CMA. The proposed antenna is analyzed using a CMA. A modified slot is stimulate the desired modes. With the appropriate feeding structure, CP radiation is obtained. In the modeling and design of the proposed antenna, the CMA has been seen to be an effective approach to uncovering optimization. The proposed antenna has application prospects in 2.4 GHz WLAN bands with the advantages of as wide bandwidth and CP radiation.

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