Low profile wideband circular patch antenna surrounded by mushroom-type structure

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Abstract
A novel low profile wideband circular patch antenna is proposed for millimetre-wave applications. Seven mushroom units are uniformly placed along with the edge of the circular driven patch. Two resonant modes, TM$_{10}$ mode and quasi-TM$_{30}$ mode, are generated by the driven patch and mushroom-type structure, respectively. These two modes will move in proximity to each other by optimising the size and location of mushroom-type structure, resulting in wideband performance. Compared with our previous work, the proposed antenna owns the advantage of low profile and rotational symmetric structure. Therefore, the radiation performance is improved. Measured results show that the impedance bandwidth of 26.4% from 12.2 to 15.9 GHz is obtained with a low profile less than 0.047 $\lambda_0$.

1 | INTRODUCTION

Microstrip patch antennas have always been one of the hot topics due to its attractive advantages. However, the intrinsic narrow bandwidth limits its extensive applications. A series of methods have been presented to broaden the bandwidth of microstrip antennas, such as parasitic patches, U-shaped slots, thick substrate with low permittivity, aperture-coupled feeding network, stacked patches, and so on [1].

Recently, metasurface antenna has been studied based on characteristic mode analysis (CMA), and wideband performance was realised [2]. By loading shorting pins and etching slots in proper position of a conventional patch antenna, two resonant modes could be excited simultaneously, leading to wide bandwidth [3]. Mushroom antennas and mushroom-loaded antennas were employed to broaden impedance bandwidth [4, 5].

In this letter, different from our previous work [6], a conventional circular patch antenna is surrounded by mushroom-type structure. The mushroom structure is rotational symmetric in this letter while that is axisymmetric in ref. [6]. Besides, the profile is lower than that in ref. [6]. Therefore, the radiation performance is improved, such as high gains and relatively low side lobe level.

2 | ANTENNA GEOMETRY

The proposed antenna is constructed on a single layer 1-mm-thickness RT/Rogers 5880 substrate with permittivity of 2.2 and loss tangent of 0.0009 and the top view is shown in Figure 1. The whole antenna includes four parts: a ground plane with radius $r_1$, a driven circular patch with radius $r_2$, seven identical circular mushroom units with patch radius $r_3$ and via diameter $d$, and a feeding probe with an offset distance of $l$ in $y$-direction. The rotational symmetric mushroom structure surrounds the driven patch with periodicity angle $2\pi/7$. Besides, the coupling gap between driven patch and mushroom structure is $s$.

Thanks to the mushroom structure, a new resonant mode is generated, which is close to the original mode, resulting in wideband performance. Therefore, the two resonant modes are studied. In order to directly distinguish these two modes, the current distributions on metal patches and electric field distributions underneath the metal patches for two resonant frequencies are described in Figures 2 and 3.

At resonant frequency 12.8 GHz, the current on those metal patches shown in Figure 2(a) maintains the same direction, which indicates the TM$_{10}$ mode. Besides, the current distributions on metal patches and electric field distributions underneath the metal patches for two resonant frequencies are described in Figures 2 and 3.
in Figure 2(b) also proves TM\textsubscript{10} mode. As a result, the proposed antenna is equivalent to a conventional circular patch antenna without mushroom structure at the first resonance.

At resonant frequency 15.4 GHz, the field distributions described in Figure 3 are totally different from those in Figure 2. As shown in Figure 3(a), the current reverses twice in y-direction if the top and bottom mushroom units in x-direction are neglected, which is similar to the TM\textsubscript{30} mode, characterised as quasi-TM\textsubscript{30} mode. What is more, the electric field distribution depicted in Figure 3(b) has three nulls along with x-direction, which also proves the quasi-TM\textsubscript{30} mode. Above all, wide impedance bandwidth is obtained based on the TM\textsubscript{10} mode and quasi-TM\textsubscript{30} mode.
EXPERIMENTAL RESULTS

The proposed antenna is optimised by using the CST software and the optimised dimensions are tabulated in Table 1. The fabricated prototype of the proposed antenna is shown in Figure 4. Three outer vias are used to determine location in the process of fabrication, which has no effect on antenna performance.

The simulated and measured reflection coefficients and broadside gains are plotted in Figures 5 and 6. Simulated and measured results are in good agreement. Measured bandwidth of 26.4% from 12.2 to 15.9 GHz is obtained, and 3-dB gain from 9.1 to 11.7 dBi is achieved across the operating bandwidth. Far field radiation patterns at three representative frequencies are depicted in Figure 7. Measured patterns are in accordance with simulated results. Moreover, side lobe level is much lower than that in [6]. Therefore, the maximum gain is higher than that in ref. [6].

CONCLUSION

In this letter, a novel wideband circular patch antenna is designed, investigated and fabricated. A new resonant mode, quasi-TM30 mode, is generated by mushroom-type structure. Therefore, wide bandwidth is realised based on two adjacent resonant modes. Good radiation performance is achieved due to the low profile and rotational symmetric mushroom structure.

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REFERENCES

1. Lee, K.F., Tong, T.F.: Microstrip patch antennas: basic characteristics and some recent advances. Proc. IEEE 100(7), 2169–2180 (2012)
2. Lin, F.H., Chen, Z.N.: Low-profile wideband metasurface antennas using characteristic mode analysis. IEEE Trans. Antennas Propag. 65(4), 1706–1713 (2017)
3. Liu, N.W., et al.: A low-profile aperture-coupled microstrip antenna with enhanced bandwidth under dual-resonance. IEEE Trans. Antennas Propag. 65(3), 1055–1062 (2017)
4. Liu, W., Chen, Z.N., Qing, X.: Metamaterial-based low-profile broadband mushroom antenna. IEEE Trans. Antennas Propag. 62(3), 1165–1172 (2014)
5. Cai, Y., et al.: Design of low-profile metamaterials-loaded substrate integrated waveguide horn antenna and its array applications. IEEE Trans. Antennas Propag. 65(7), 3732–3737 (2017)
6. Cao, Y., et al.: Broadband and high gain microstrip patch antenna loaded with parasitic mushroom-type structure. IEEE Antennas Wireless Propag. Lett. 18(7), 1405–1409 (2019)

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