NOVEL DUAL-FREQUENCY DESIGN OF CIRCULAR MICROSTRIP ANTENNA WITH COMPACT OPERATION

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1. Introduction

Dual-frequency operation is an important subject in microstrip antenna designs [1], and dual-frequency microstrip antennas are also attractive in mobile communications applications. Some related single-feed dual-frequency microstrip antennas with orthogonal polarization planes have also been reported [1-6]. Among these designs, the cases of using slotted rectangular microstrip antennas [4,5] or circular microstrip antennas with a pair of inserted slits of unequal length [6] can also achieve compact dual-frequency operations. In this article another promising compact dual-frequency design of circular microstrip antenna with an offset circular slot (see Fig. 1) is proposed and experimentally studied. By selecting various sizes of the circular slot, the fundamental resonant mode of TM_{11} for an unslotted circular microstrip antenna can be split into two separate resonant modes with orthogonal polarization planes. Good impedance matching of the two resonant modes can also be achieved using a single probe feed. Also, due to the circular slot embedded inside the patch, the resonant lengths of the two resonant modes are greatly increased. That is, the two resonant frequencies are much lowered as compared to the fundamental resonant frequency f_{11} of the unslotted circular patch antenna. A compact dual-frequency operation can thus be obtained.

2. Antenna design

Figure 1 shows the geometry of the proposed compact dual-frequency circular microstrip antenna with an offset circular slot. The circular patch has a radius of D and is printed on a substrate of thickness h and relative permittivity ε_r. The circular slot is of a radius d, with the slot center in the x-axis. The circular slot is also offset close to the patch boundary, with a small distance of 1 mm between the slot edge and the patch boundary in this study. Owing to the offset circular-slot perturbation, the equivalent patch surface current paths in the x and y directions are unequal. This behavior makes it possible for dual-frequency operations. And by increasing the slot size, it is expected that the two equivalent patch surface current paths in orthogonal directions are both lengthened, resulting in two lowered resonant frequencies for a compact dual-frequency operation. It is also found that a single probe feed (point A in Fig. 1 with a distance dp away from the patch center) placed 45^{o} away from the center lines (x-axis or y-axis) of the circular patch can excite the two resonant modes with good impedance matching.

3. Experimental results

Based on the above-described antenna design, typical proposed antennas with various slot radii were constructed and investigated. The results of the measured return loss are also shown in Fig. 2. The corresponding dual-frequency characteristics are listed in Table 1. First note that when the slot radius is less than 8 mm (about 0.38D), no good excitation of two separate resonant modes in the vicinity of the fundamental resonant modes (TM_{11}) of the corresponding unslotted circular patch antenna can be observed; that is, no dual-frequency operation can be achieved. And with the slot radius within the range of 8 mm to 13 mm (about 0.62D), good excitation of two separate resonant modes can easily be achieved by using a single probe feed. The associated optimal feed positions for the cases of different slot radii are shown in Table 1, and the obtained frequency ratios are within a range of about 1.15 to 1.18, depending the slot radius. It should also be noted that the optimal feed position is shifted toward the patch center as the slot radius increases. This behavior leads to the fact that when the slot radius is greater than 13 mm in this study, there exist no proper feed positions in the circular patch for good impedance matching of the two operating frequencies. This suggests that single-feed dual-frequency operation of the proposed antenna can only be obtained when the slot radius is within a specific range of about 0.38 to 0.62 times the disk radius.

The results of the measured return loss for the designs with various slot radii are also shown in Fig. 3. It can be seen that for the case with d = 13 mm, both the two resonant frequencies (1490 and 1733 MHz) are lowered about 25% and 13%, as compared to the fundamental resonant frequency f_{11} (about 2.0 GHz) of a corresponding simple circular patch antenna without a circular slot. This suggests that the proposed antenna can have an antenna size of about 44% or 25% lower than that of a simple circular patch antenna operated at the lower or higher frequency of the dual-frequency operation. Fig. 4 also plots the measured radiation patterns for the cases with d = 10 and 13 mm. It is seen that the two operating frequencies are with orthogonal polarization planes, and good cross-polarization radiation for both frequencies is also observed.

4. Conclusions

A single-feed compact dual-frequency circular microstrip antenna with an offset circular slot has been proposed and successfully implemented. The proposed antenna provides a dual-frequency operation with a low frequency ratio of about 1.15 to 1.18, depending on the radius (about 0.38 to 0.62 times the disk radius) of the offset slot in the patch. The proposed antenna is especially suited for applications where dual-frequency operation with a low frequency ratio is required. Also, with a large slot radius of about 0.62 times the disk radius, the proposed dual-frequency antenna can also have an antenna size reduction as large as about 44% or 25%, as compared to a simple circular patch antenna operated at the lower or higher frequency of the dual-frequency operation.

5. References

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Table 1 results of the proposed compact dual-frequency circular microstrip antennas with different slot radii studied in fig. 2; ε_r = 4.4, h = 1.6 mm, d = 21 mm. the antenna bandwidth is determined from 3-db return loss.

d (mm)	d_p (mm)	f_1 (MHz), BW (%)	f_2 (MHz), BW (%)	f_2 / f_1
8	12.9	1742, 1.78	2009, 1.94	1.153
8.5	12.6	1731, 1.85	2006, 2.09	1.158
9	12.5	1733, 1.85	2003, 2.15	1.156
9.5	12.2	1653, 1.69	1952, 1.90	1.181
10	11.9	1619, 1.73	1919, 1.98	1.185

11	11.8	1574, 1.65	1860, 1.83	1.182
12	11.4	1533, 1.57	1802, 1.78	1.175
12.5	10.8	1490, 1.68	1728, 1.79	1.160
13	10.5	1490, 1.61	1733, 1.79	1.163

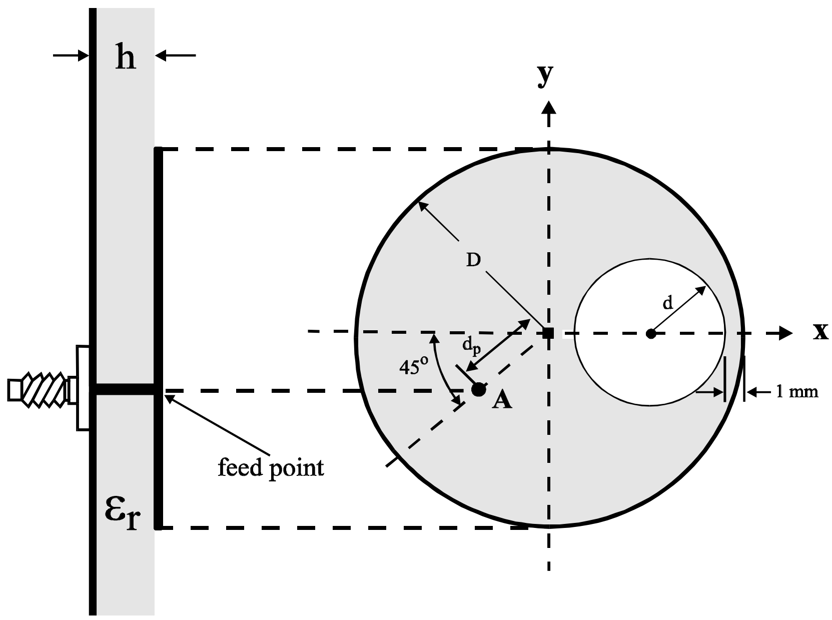

Fig. 1 Geometry of a single-feed compact dual-frequency circular microstrip antenna with an offset circular slot.

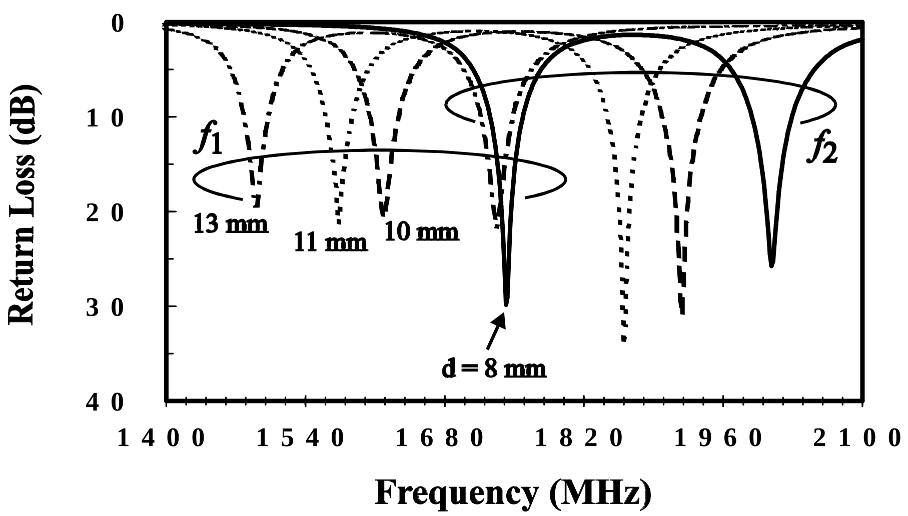

Fig. 2 Measured return loss for dual-frequency operation with various slot radii; ε_r = 4.4, h = 1.6 mm, D = 21 mm, ground-plane size = 75 mm × 75 mm.

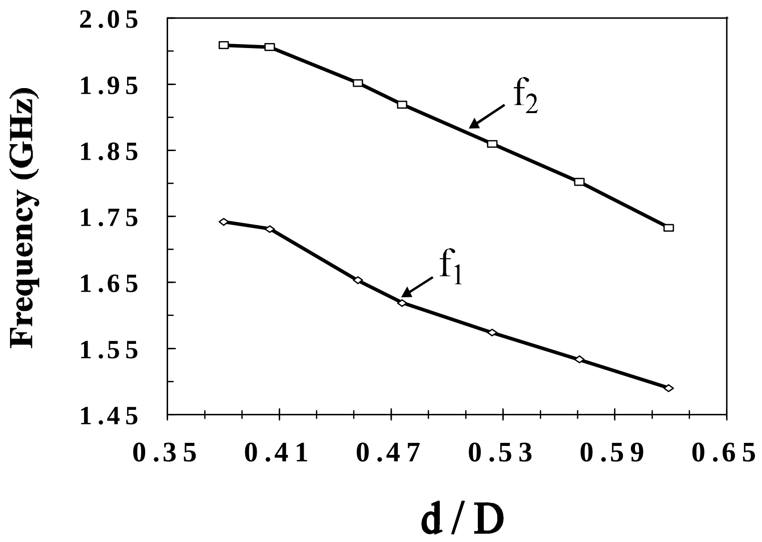

Fig. 3 The first two resonant frequencies, f_1 and f_2, against the radius of the circular slot; antenna parameters are given in Fig. 2.

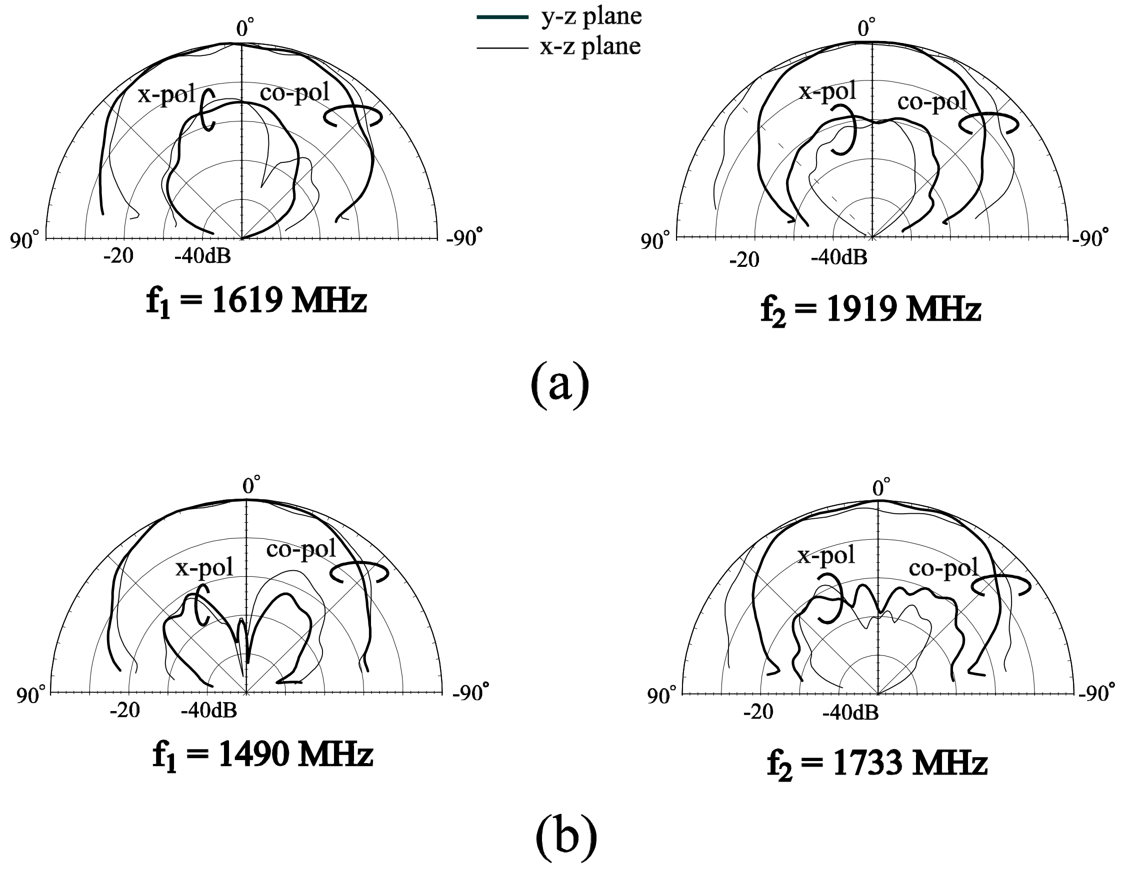

Fig. 4 Measured radiation patterns in two orthogonal planes for the proposed antenna with various slot radii; antenna parameters are given in Fig. 2. (a) d = 10 mm. (b) d = 13 mm.