DESIGN CONSIDERATIONS OF DUAL-FREQUENCY AND BROADBAND CIRCULAR MICROSTRIP ANTENNAS WITH OPEN-RING SLOTS

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1. Introduction

Dual-frequency operation of single-layer, single-patch microstrip antennas can be achieved by using slot-loading technique, and related designs include the use of a pair of narrow slots embedded close to the radiating edges of a rectangular patch [1] or a bow-tie patch [2], a pair of arc-shaped slots close to the boundary of a circular patch [3], a pair of bent slots close to non-radiating edges of a rectangular patch [4] and so on. In this article, we demonstrate a dual-frequency design with its two operating frequencies with very similar radiation characteristics and antenna gain levels. The design is achieved by loading an open-ring slot close to the boundary of the circular patch (see Fig. 1). From the simulation results of the excited patch surface current densities, it is found that due to the open-ring slot loading, two resonant modes with very similar radiation characteristics as the fundamental mode of TM_{11} can be excited. By varying the width of the open-ring slot, it can lead to various frequency ratios between the higher and lower operating frequencies of the proposed antenna.

As for broadband operation, bandwidth enhancement of single-layer, single-patch microstrip antennas can also be achieved by loading some specific slots on patches. The related designs include the use of two sectorial slots on a circular patch [5], a pair of bent slots on a triangular patch [6], a pair of toothbrush-shaped slots on a rectangular patch [7], a pair of dual-bent slots on a rectangular patch [8] and so on. We propose in this article another promising slot-loaded circular microstrip antenna with two open-ring slots for broadband operation [see Fig. 1(b)]. This design is achieved by embedding another open-ring slot along the boundary of the dual-frequency circular microstrip antenna shown in Fig. 1(a). For such a design, two adjacent resonant modes with very similar radiation characteristics are usually excited at frequencies near that of the fundamental resonant mode of the simple unslotted microstrip antenna. These two resonant modes can then cause enhancement in impedance bandwidth of the microstrip antenna. Details of the antenna designs based on the proposed slot-loading technique are presented, and experimental results are discussed.

2. Antenna designs

The proposed dual-frequency design with an open-ring slot is shown in Fig. 1(a). An open-ring slot of width W is embedded close to the boundary with a small distance 1 mm away. For the present design, the portion of the patch enclosed by the open-ring slot can be viewed as another circular patch such that it provides the higher operating frequency of the proposed dual-frequency antenna. From the simulation results obtained from IE3D^{TM} simulation, it is found that the corresponding resonant mode of the higher operating frequency is with similar radiation characteristics to that of the lower frequency. It is also found that with a suitably chosen feed position, two resonant frequencies all associated with the TM_{11} mode of the circular microstrip antenna can be excited simultaneously with good impedance matching. Thus, based on the design with an open-ring slot, dual-frequency operation can be obtained. Another proposed slot-loaded broadband circular microstrip antenna is shown in Fig. 1(b). The design is with two open-ring slots of same narrow width 0.5 mm, and the distance between the two slots is set to be 1 mm. The inner open-ring slot has a small opening 2 mm in this design. The outer one has a relatively large opening with an angle of 32°. Owing to the two patch portions that are enclosed by different open-ring slots, two adjacent resonant modes can be excited to form a wide operating band.

3. Results and discussion

Many design examples of the proposed circular microstrip antenna with open-ring slots have been constructed and studied. The design examples are constructed by using an inexpensive FR4 microwave substrate with thickness 1.6 mm and relative permittivity 4.4. Typical measured return loss against frequency for the design with an open-ring slot is shown in Fig. 2. Dual-frequency operation with a tunable frequency ratio in a range of about 1.23 to 1.32 is obtained. As for the design with two open-ring slots for broadband operation, measured input impedance is shown in Fig. 3. An impedance bandwidth of 90 MHz or about 4.1%, which is 2.1 times that of the corresponding simple circular microstrip antenna, is obtained. Measured radiation patterns of the dual-frequency design example shown in Fig. 2 with W = 0.5 mm are shown in Fig. 4. Results indicate that very similar broadside patterns for the two operating frequencies are obtained. Measured patterns for operating frequencies within the impedance bandwidth of the design example studied in Fig. 3 also show similar results. Figs. 5 and 6 show the measured antenna gain in the broadside direction for the operating frequencies within the impedance bandwidth. From the obtained results, it indicates that the two operating frequencies of the proposed dual-frequency design [Fig. 1(a)] are with about the same antenna gain levels. And the gain variation within the impedance bandwidth of the broadband design [Fig. 1(b)] is within a variation less than 2.6 dB.

4. Conclusions

Circular microstrip antennas with an open-ring slot and two open-ring slots, respectively, for achieving dual-frequency and broadband operations have been demonstrated. The obtained two frequencies of the dual-frequency design show a frequency ratio tunable in a range of about 1.23 to 1.32, depending on the widths of the open-ring slot. Moreover, very similar radiation characteristics between the two frequencies have been observed. Also, the obtained impedance bandwidth of the broadband circular microstrip antenna can be about 2.1 times that of the corresponding simple circular microstrip antenna without slots. More design considerations and experimental results will be discussed in the presentation.

5. References

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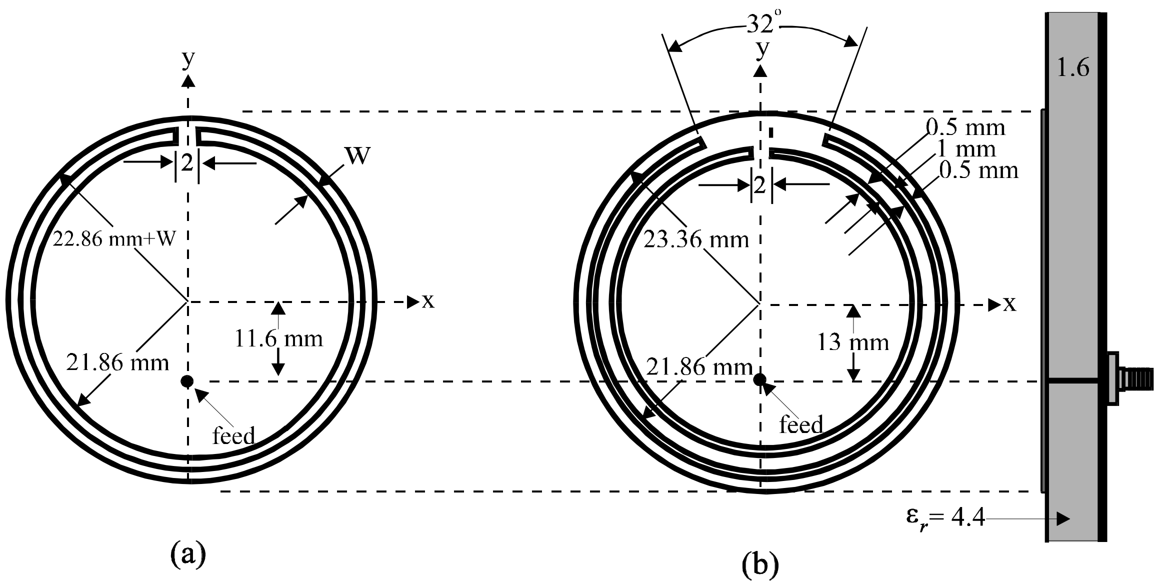

Fig. 1. Geometry of slot-loaded circular microstrip antennas. (a) Design with an open-ring slot for dual-frequency operation. (b) Design with two open-ring slots for broadband operation.

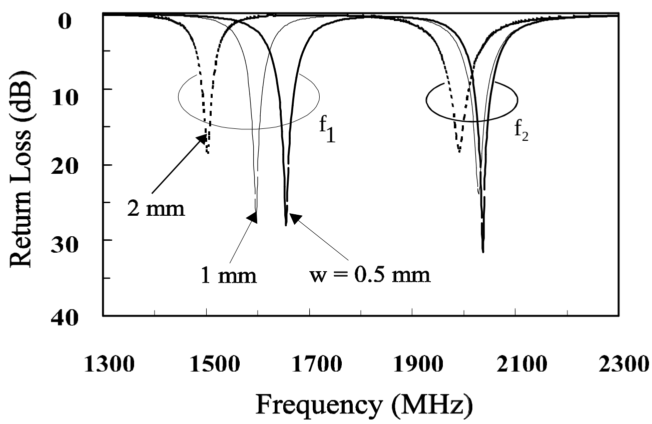

Fig. 2. Measured return loss against frequency for the design with an open-ring slot; parameters are given in Fig. 1(a).

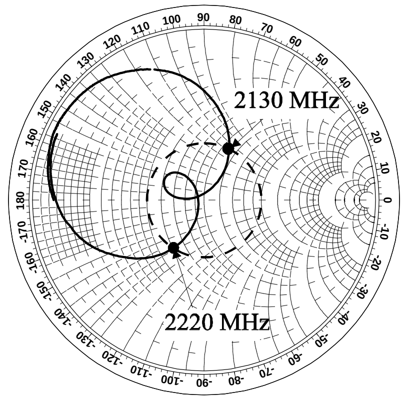

Fig. 3. Measured input impedance for the design with two open-ring slots; parameters are given in Fig. 1(b).

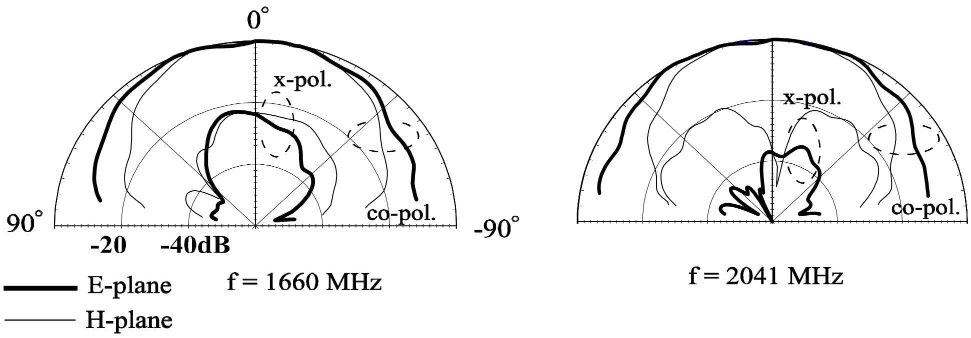

Fig. 4. Measured E-plane and H-plane radiation patterns for the design with an open-ring slot; W = 0.5 mm.

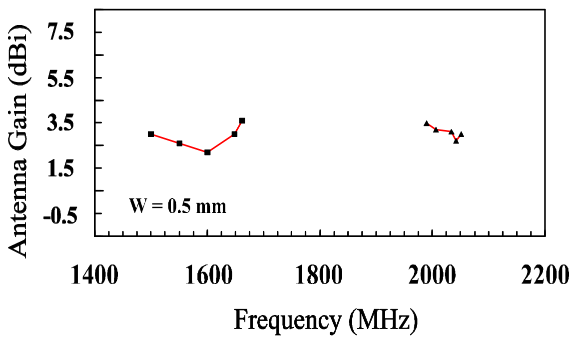

Fig. 5. Measured antenna gain in broadside direction against frequency for the design with an open-ring slot [Fig. 1(a)].

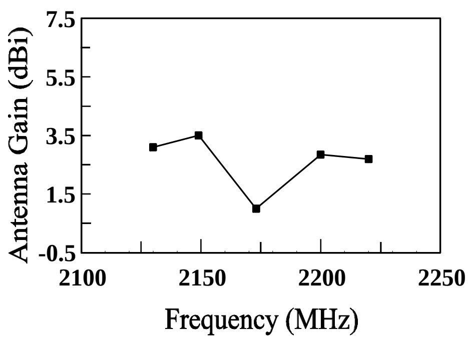

Fig. 6. Measured antenna gain in broadside direction against frequency for the design with two open-ring slots [Fig. 1(b)].