Multiband Circular MSA with Half-ring Slots Fed by an L-Probe

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Abstract

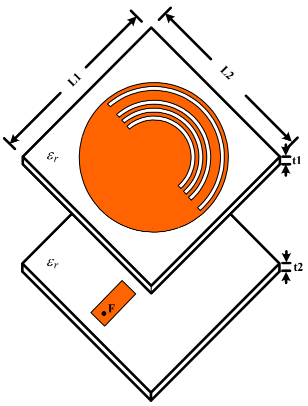
A novel circular MSA with half-ring slots for multiband operation is presented in this paper. The patch is fed by an L-probe due to its remarkable performance as a wideband impedance matching feeder. Four half-ring slots are assumed on the patch and hence five resonant frequencies are accomplished. The antenna performances are predicted by IE3D simulator based on the method of moments, and are confirmed by experiments. The antenna is manufactured on a double-layered PTFE substrate of which the patch is printed on the top layer and the L-probe is printed on the bottom one. Broadside radiation patterns and gain of 5.0-6.0 dBi are achieved for the entire observed modes. Good agreements are accomplished between measured and simulation results. Thus, the proposed antenna is well suited as an alternative model for a multiband planar antenna.

1. INTRODUCTION

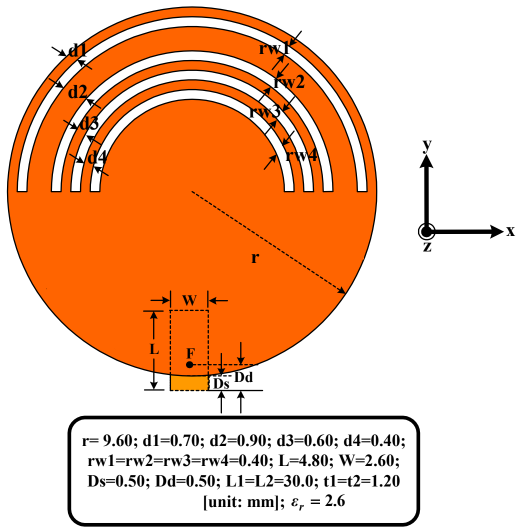
Due to the rapid growth of wireless communications technology, the necessities to cover multiple applications with a single antenna have been developing extensive researches on multiband microstrip antennas. Sierpinski gasket geometry with a fractal structure has been intensively studied to have multiband operation due to its self-similarity and space-filling property. Puente et al. [1] reported experimental and numerical results of the planar antenna with Sierpinski gasket geometry. It was demonstrated that the self-similarity properties of the fractal structures can be utilized to perform as a multiband antenna.

Best [2] investigated the comparison of multiband behavior between Sierpinski gasket and the several modified geometries. It was revealed that significant portions of the self-similar gap structure could be removed from the Sierpinski gasket without affecting its multi-band behavior. Tada et al. [3], [4] investigated a modified Sierpinski gasket microstrip antenna (SG-MSA) fed by an L-shaped probe. A multiband behavior with excellent performances was achieved for the three operating frequencies.

However, it faces critical difficulty in performing miniaturization because of complexity of the structure. Furthermore, it is also difficult to have more than three operating frequencies with excellent radiation properties. Alternative methods were proposed to solve this problem i.e. introducing the V-shaped slots for creating multiple current paths on the patch [5], [6]. An appropriate slot shape of the patch should be considered to realize the miniaturized antenna. However, gain of these antennas seems to be degraded as increment of the number of operating frequencies.



(a) Perspective view



(b) Structure and dimensions

Fig. 1: Perspective view, structure, and dimensions of circular MSA with four half-ring slots

In this paper, a circular microstrip antenna with half-ring slots is proposed for the objective of miniaturizing the antenna and improving the antenna gain compared to the reported paper [7]. The structure of the proposed antenna is shown in Fig.1. The antenna is fed by the L-probe which is known as a wideband impedance matching feeder. The advantages of the L-probe are used for the bandwidth of the proposed antenna in spite of the insufficient total thickness of the antenna i.e. 2.4 mm (about 2.9 % of guided wavelength of the 1st mode). However, the utilization of the L-probe in this paper still exhibits good performance i.e. each of the excited mode has a good impedance matching with a reference of VSWR<2. In this paper, four slots with half-ring structure are assumed on the circular patch. The half-ring slot is adopted rather than full-ring one in terms of miniaturization of the antenna. The numerical simulator used throughout this paper is IE3D^{TM}, based on MoM [8]. Experiments were carried out to verify the simulation results. Good agreements between the measured and simulated results are obtained.

2. Basic Operation and Characteristics of Circular MSA with Half-ring Slots

In this section, basic operation of the proposed antenna is explained in detail by using current distributions of the excited modes in order of increment of the number of frequencies. The displayed current distributions are obtained by IE3D simulator. Furthermore, influences of distance between the half-ring slots (*d*) and width of the half-ring slots (*rw*) on the operating frequency and gain of the antenna are also investigated.

A. Basic Operation

Figure 2 shows current distributions of the circular MSA as a function of the number of half-ring slots. In case of one half-ring slot, a new mode (2nd mode) is excited in addition to the 1st mode (dominant mode). Correspondingly, in case of two, three, and four half-ring slots, the number of new modes are increased to two, three, and four, respectively. In conclusion, the number of operating frequencies is equivalent to the number of slots + 1. It is also interesting to note that the length of current path is corresponding to the resonant frequency. It plays a major role in miniaturization purposes. As shown in Fig. 2, the current of the 1st mode initiates from the bottom portion of the circular patch, due to the existence of the L-probe, and it terminates at the centre of upper portion of the circular patch. Moreover, the currents of the other modes terminate at the centre of each half-ring slot.

The half-ring slot is adopted rather than full-ring one because of its miniaturization feature. Figure 3 shows a comparison of resonant frequencies between the half- and full-ring slots as a function of distance between the circumference of the circular patch and the 1st slot (*d1*). Only one slot is assumed on the patch and the dimensions presented in the figure caption are utilized in the simulation. It is revealed that the half-ring slot has the advantage of miniaturizing the antenna electrically mainly at the 2nd mode while the 1st mode tends to constant for the change of *d1*, as shown in Fig. 3. This is due to the length of current paths which is longer than those of excited in the full-ring slot. Another advantage of adoption of the half-ring slot is easiness to obtain matching at the higher frequency without significantly modifying the L-probe.

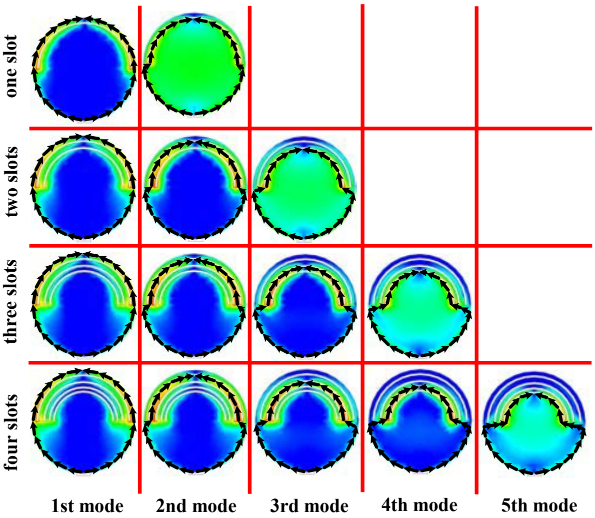


Fig. 2: Current distributions of the proposed antenna obtained by IE3D

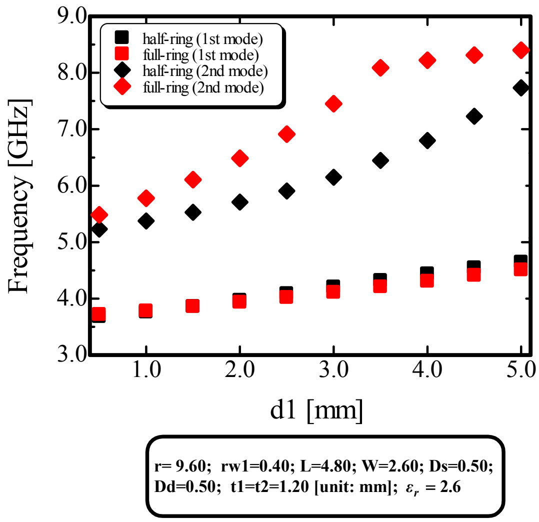


Fig. 3: Comparison of resonant frequencies between a half- and full-ring slot as a function of *d1* (sim.)

B. Characteristics

This sub-section will focus on the effect of distance between the half-ring slots (*d*) and width of the half-ring slot (*rw*) on the operating frequency and gain of the antenna. In multiband antennas, one of the most important properties that should be considered is easiness in tuning the resonant frequency. Following description will be concerned upon the dependency of operating frequency on both parameters of *d1* and *rw1*. Figure 3 describes the operating frequency as a function of *d1*, where width of one half-ring slot (*rw1*) is remained at 0.4 mm. As shown in Fig. 3, tweaking the slot position, i.e. changing the value of *d1*, is one of the considerations to control the resonant frequency. In other words, modifying the distance of *d1* also changes the length of current path. The frequency of the 1st mode has a constant tendency while that of the 2nd mode is increased as the distance *d1* becomes wider, as shown in Fig. 3.

In addition, the resonant frequency also depends on width of the half-ring slot (*rw*). Figure 4 presents the change of resonant frequency as a function of *rw1*, where only one slot is assumed and the distance *d1* is set at 0.5 mm. The dimensions in the figure caption are utilized in the simulation. It is observed by the simulation that the 2nd mode is much depending on the parameter *rw1* rather than the 1st mode, as obviously shown in Fig. 4. This is because the current of the 1st mode flows along the edge of the circular patch while the current path length of the 2nd mode becomes shorter as the *rw1* is increased, as can be inspected in Fig. 2.

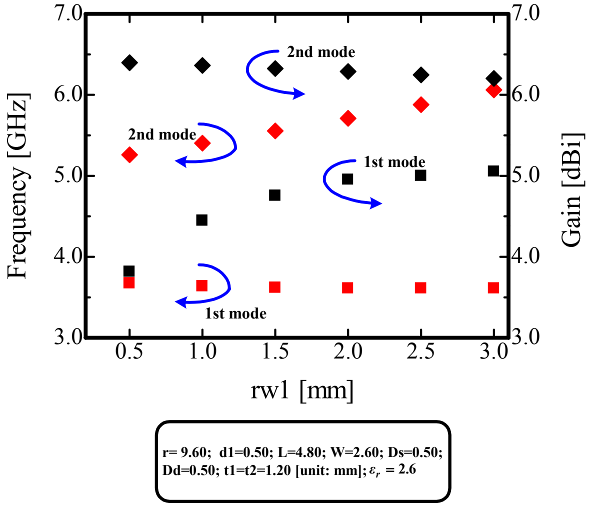


Fig. 4: Simulated resonant frequency and gain as a function of width of one half-ring slot (*rw1*)

Another property that also needs to be focused on is the antenna gain. Following explanation will be discussed upon the dependency of the antenna gain on width of one half-ring slot (*rw1*) and distance between the 2nd and 3rd half-ring slots (*d3*). Figure 4 also presents gains of the antenna as a function of *rw1*. Gain of the 1st mode has an increasing trend while that of the 2nd mode has a constant tendency as the increment of *rw1*. The increasing tendency of the 1st mode is due to the Q-factor of the antenna. Additionally, Fig. 5 illustrates gain of the proposed antenna as a function of distance between the 2nd and 3rd half-ring slots (*d3*), where three half-ring slots are assumed in the simulation and the dimensions shown in the figure caption are utilized. It is obviously shown in Fig. 5 that gains of the 1st and the 2nd mode behave with a stable value as *d3* increases. On the other hand, gains of the 3rd mode appear to be increased while those of the 4th mode degrade in order of increment of *d3*. The reason of why the 3rd mode has such tendency is because of the Q-factor of the antenna, which is the same situation as the previous explanation in case of *rw1*. The effect of higher mode is the key reason of the decreasing tendency of the 4th mode.

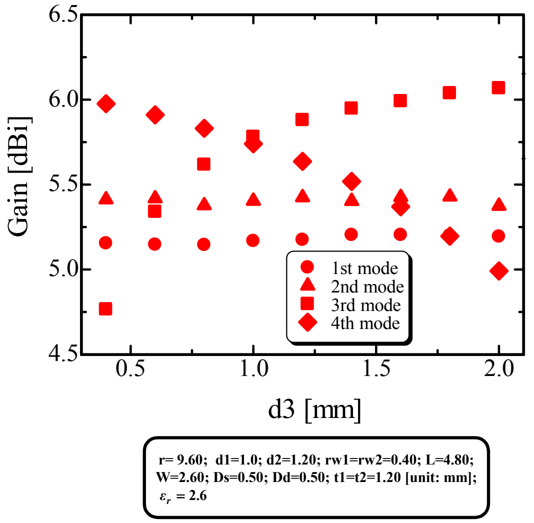


Fig. 5: Gains of the proposed antenna as a function of *d3* (sim.)

3. Experimental Results

The antenna with optimum parameters is manufactured and measured in our laboratory. The structure of the proposed antenna is clearly shown in Fig. 1, where the dimensions presented in the figure caption are utilized in both simulation and experiment. The antenna is composed of a double-layered PTFE substrate having relative permittivity ε_r = 2.6, tanδ = 0.0018, and 1.2 mm thickness. The circular patch with four half-ring slots is printed on the top layer while the L-probe is printed on the bottom one. The ground plane with size of 30x30 mm is used in both simulation and experiment, which makes the antenna compact and is easy to be installed in the small required area. Five resonant frequencies, in which four of them are referred as new modes, are examined at 3.64, 4.25, 4.95, 5.68, and 6.63 GHz, respectively, as shown in Fig. 6. The measured results agree well with the results obtained by IE3D.

As obviously shown in Fig. 6, satisfactory matching is accomplished at the five observed frequencies. This is due to the utilization of the L-probe. Furthermore, the existence of the half-ring slot succeeds in shifting the frequency of the 1st mode to lower region, while the size of the circular patch without half-ring slot is designed to be operated at 5.0 GHz. Hence, the miniaturization objective is achieved by the half-ring slots. Figure 7 presents the measured and simulation results of radiation patterns of the proposed antenna for the five observed modes. It is revealed by the experiment that good agreements between the both results are achieved for the co-polarization in both E- and H-planes. Cross-polarization levels are about -20 dB for the 1st, 2nd, 3rd, and 4th mode, respectively, while slightly increased for the 5th mode due to the effect of higher mode. In addition, gain of 5.0-6.0 dBi with 0.5 dBi deviations between the measured and simulated data is observed at the frequencies, as shown in Fig. 8. These gains are relatively higher than those of reported in [7].

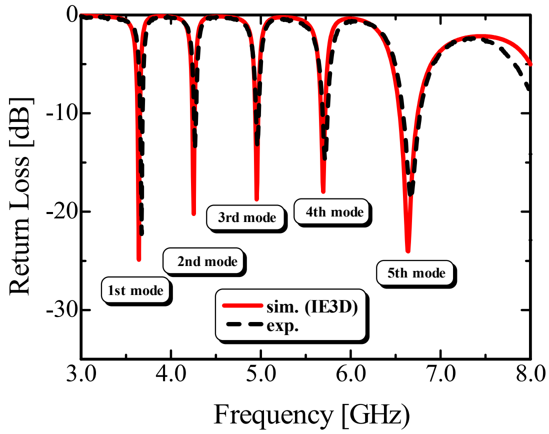
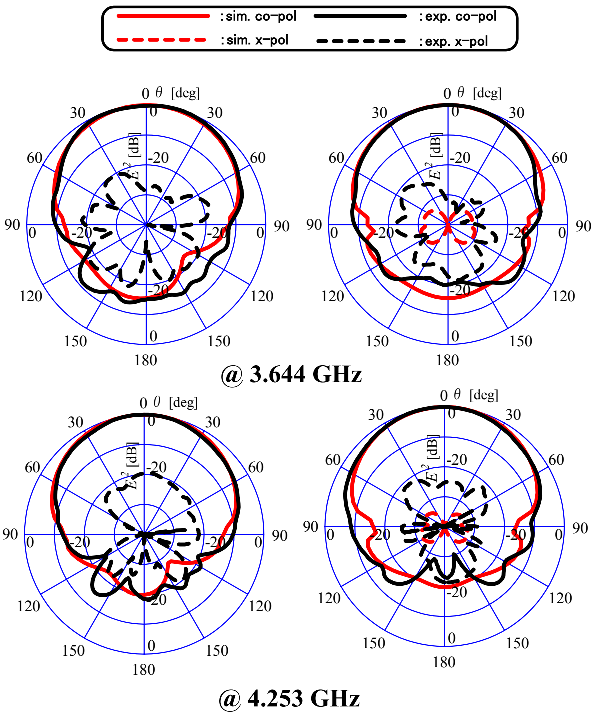


Fig. 6: Return loss characteristics of circular MSA with four half-ring slots



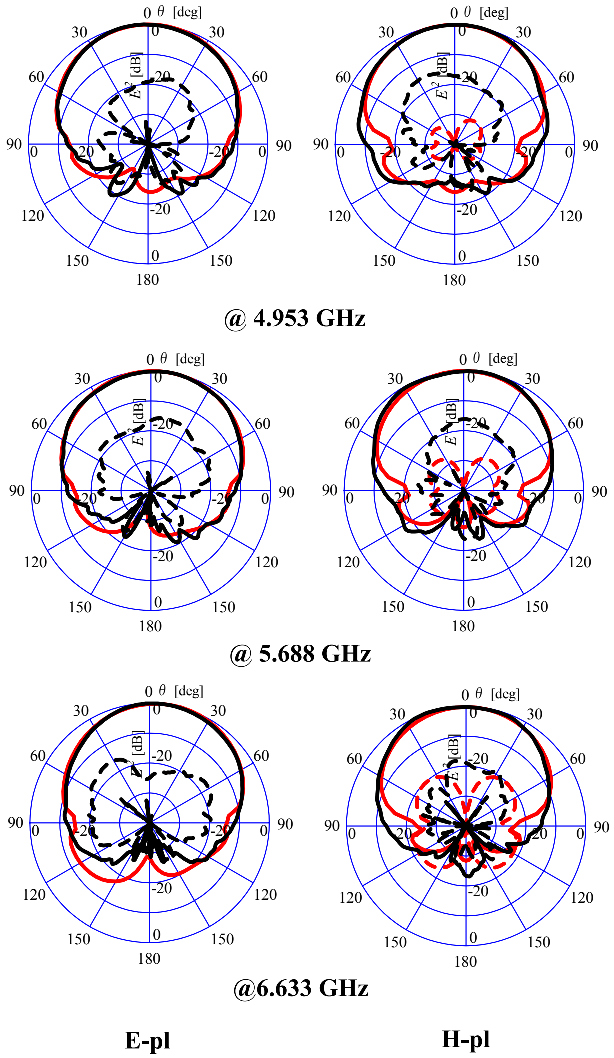


Fig. 7: Radiation patterns of the proposed antenna

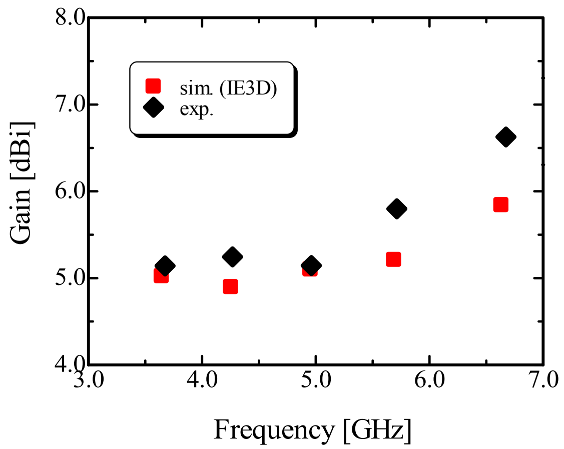


Fig. 8: Simulated and measured gains of the proposed antenna

4. CONCLUSION

A Circular MSA with half-ring slots has been demonstrated in this paper. The half-ring slot is found as an effective method to miniaturize the circular patch antenna electrically. The distance between half-ring slots (*d*) has the advantage as a frequency controller of the proposed antenna. Furthermore, selecting an appropriate value of *d* is also observed to control the antenna gain. Experiments are carried out to verify the results of simulation. Five resonant frequencies and broadside radiation patterns are confirmed by the experiment. Gain of 5.0-6.0 dBi is also achieved at the frequencies as predicted in the simulation within 0.5 dBi deviation. Good agreements are accomplished between the experiments and the simulation. Thus, the proposed antenna is well performing as an alternative design for multiband operation.

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