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Design of Multiband Single-Layer Circular MSA Fed by CPW

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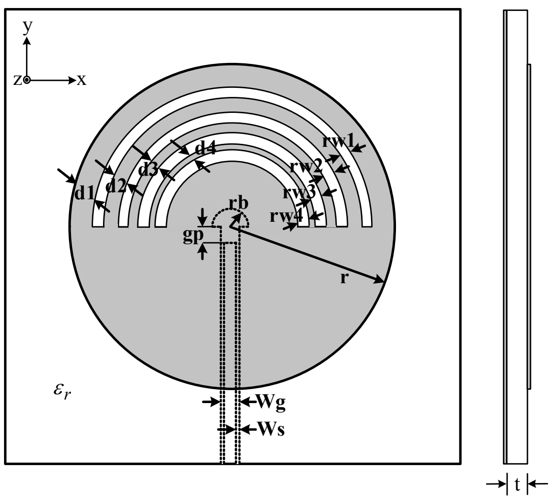
1. Introduction

Multiband antennas have been rapidly developed since they can simplify the complex antenna systems for multi-frequency applications. Radiation properties those are often required for multiband antennas are stable frequency dependence of radiation pattern and gain over the operating frequencies. To deal with these requirements, a modification of a fractal Sierpinski gasket microstrip antenna (SG-MSA) was proposed with satisfactory performances of three operating frequencies [1]. The antenna was fed by the L-probe, which is already known as a wideband impedance matching feeder for an MSA. However, the need for antenna systems to cover more than three operating frequencies could not be satisfied by the SG-MSA due to the structural complexity. As alternative designs to overcome such problem, the rhombic MSA with slots [2] and the equilateral triangular MSA (ET-MSA) with folded slots [3], which are completely a non-fractal structure, were proposed. However, a double-layer dielectric substrate was used because these antennas were also fed by the L-probe.

The use of a single-layer substrate is a promising design to be easily integrated with MMICs. In most of publications, the utilization of a single-layer substrate for dual frequency applications was reported. A circular microstrip antenna fed by a coaxial probe with one or two open-ring slots [4], a slot-loaded rectangular patch [5], a slot-loaded bow-tie MSA [6], and a rectangular MSA with a pair of bent slots [7] were proposed as a dual or broadband frequency antenna, while Suzuki et al. reported the utilization of coplanar waveguide (CPW) for multiband operation [8]. The rectangular MSA with two folded slots was confirmed to have three operating frequencies.



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rw1=rw2=rw3=rw4=0.4; r=9.6; rb=2.5; gp=3.5;
Wg=2.8; Ws=0.5; t=1.2; unit: [mm]; ε_r=2.6

Figure 1: Structure of the proposed antenna

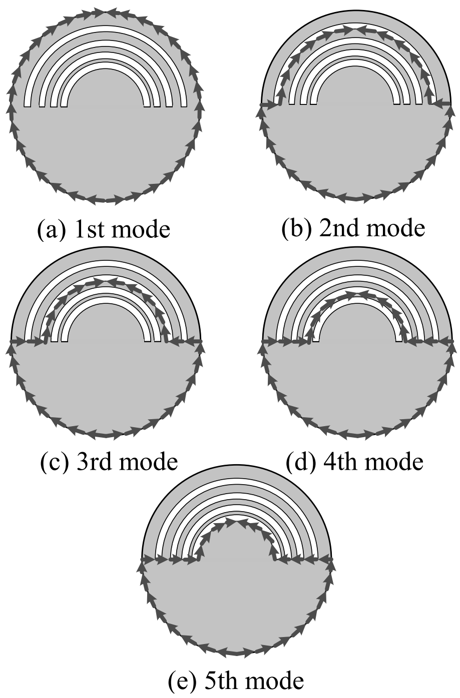

Figure 2: Generalized current distributions

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This paper presents a novel multiband circular microstrip antenna (C-MSA) with four half-ring slots fed by CPW for five operating frequencies, as shown in Figure 1. Broadside radiation patterns with high gain of more than 4.0 dBi are confirmed over the observed frequencies. The half-ring slot position can be used to tune frequency and gain of the existing communication system requirements. Fine-tuning of the inner conductor of CPW line is an effective method to lower the minimum return loss value. The main contribution of this paper is realizing a multiband microstrip antenna having over three operating frequencies and stable high gain performance with a single-layer substrate. To evaluate the performance, experiments were conducted and the results obtained by IE3D simulator are compared. Good agreements between the simulation and the experimental results are confirmed. Thus, this antenna design is applicable as an alternative model for a single layer multiband planar antenna.

2. Basic Operation and Design Considerations

2.1 Basic Operation

IE3D simulator is utilized to analyze the current distribution on the C-MSA with four half-ring slots fed by CPW. The current behaves similar to that of the C-MSA fed by an L-probe [9] i.e. it initiates from the bottom portion of the C-MSA patch for all the five observed modes. It terminates at centre of the upper portion of the C-MSA patch for the 1st mode (dominant mode) and upper centre of each slot for the new excited modes (2nd, 3rd, 4th, and 5th mode), respectively, as shown in Figure 2. IE3D simulator also examines that increasing number of the slot increases number of resonant frequency.

2.2 Design Parameters

Figure 3 shows variations of resonant frequency and gain of the C-MSA as a function of the distance between two half-ring slots, where only two slots are assumed and the dimensions shown in the figure caption are utilized in the simulation. The parameters of t and ε_r are the thickness and dielectric constant of the substrate, respectively. Resonant frequencies of the 1st and 2nd mode tend to remain constant while that of the 3rd mode has an increasing tendency as the slot distance becomes larger. This is due to the fact that current paths of the 1st and 2nd mode are almost unchanged; on the other hand, the current path length of the 3rd mode becomes shorter as increment of the slot distance. Concerning the antenna gain, gains of the 1st and 3rd mode have a tendency to remain stable while that of the 2nd mode tends to increase as increment of the slot distance, as shown in Figure 3. The tendency of the 2nd mode gain is found to be the same as in the previous study [9]. Figure 3 also concludes that the C-MSA with half-ring slots could be the promising candidate as a multiband planar antenna with stable gain.

Figure 4 shows the return loss characteristics as parameters of the offset length of inner conductor of CPW, where three half-ring slots are assumed in the simulation and only those of the 4th mode are presented. The other three frequencies are observed to have minimum return loss value of less than -10 dB. The dimensions listed in the figure caption are utilized in the simulation. It is difficult to obtain more than three resonant frequencies (reference of -10 dB) without adjusting the length of inner conductor of CPW, as shown in Figure 4. The offset length *gp* is appropriately selected to have the return loss value of less than -10 dB. The offset length *gp* of 3.0 mm is suitable for the C-MSA with three half-ring slots, as obviously shown in Figure 4. As a comparison, the offset distance *gp* of 0.0 mm for the C-MSA with two half-ring slots will be presented in section 3.

3. Experimental Results

Experiments were conducted to evaluate the results predicted by IE3D simulator. The antenna is comprised of a single layer PTFE substrate having relative permittivity $\varepsilon_r = 2.6$, $\tan\delta = 0.0018$, and $t = 1.2$ mm. The C-MSA with half-ring slots is printed on the top surface of the substrate while CPW feed is printed on the bottom one. The ground plane with size of 60 mm x 60 mm is utilized in both the simulation and the experiment. The C-MSAs with two half-ring slots with dimensions listed in the caption of Figure 5 and with four half-ring slots with dimensions shown in the caption of Figure 6 were manufactured to have three and five operating frequencies with different offset length *gp*, respectively. Satisfactory matching is accomplished at the entire observed frequencies of both two and four half-ring slot cases, as shown in Figure 5 and Figure 6, respectively. Good agreements between the simulated and the measured results are confirmed. Figure 7 shows the simulated and the measured radiation patterns of the C-MSA with four half-ring slots. It is revealed that good agreements between the simulation and the measurement are achieved in the co-polarization for both the E- and H-planes. The cross-polarization for the 1st, 2nd, and 3rd modes are evaluated of about -20 dB while it is increased for the 4th and 5th modes, respectively. Furthermore, the measured gains of the C-MSA with four half-ring slots are in the range between 4.2 and 6.0 dBi, which are confirmed to have good agreement to that of the simulation with deviation of about 0.5 dBi.

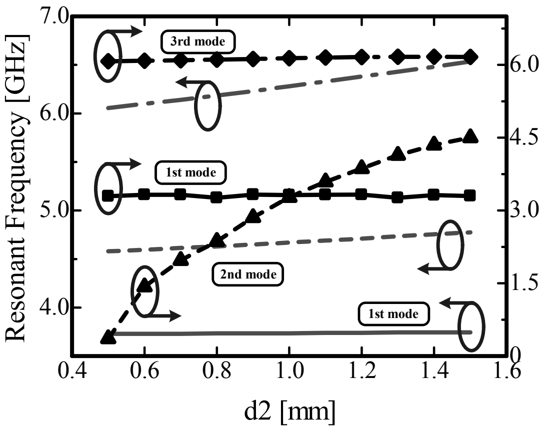

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Figure 3: Simulated resonant frequency and gain of C-MSA with two half-ring slots against *d2*

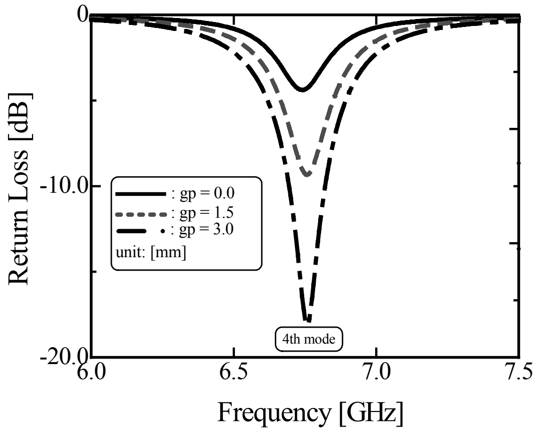

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Figure 4: Return loss characteristics of C-MSA with three half-ring slots as a function of *gp* (sim.)

4. Conclusion

A novel circular microstrip antenna (C-MSA) with four half-ring slots fed by CPW has been presented to perform as a multiband antenna. The proposed antenna has capability to control resonant frequency and gain by tuning the distance between slots. This feature allows one to have stable gain over the observed frequencies. Moreover, the offset length of inner conductor of CPW feed has feasibility to lower the minimum return loss value. Experiments were conducted to verify the antenna performances as predicted in the simulation. Five operating frequencies with broadside radiation patterns and stable gain of more than 4.0 dBi are confirmed. Good agreements are achieved between the simulated and the measured results. The performance of this antenna is almost similar to that of the C-MSA fed by an L-probe, which was reported in utilizing a double-layer substrate. Thus, due to its simple configuration and the performance, this antenna model is suitable as a multiband planar antenna for easy integration with MMIC design.

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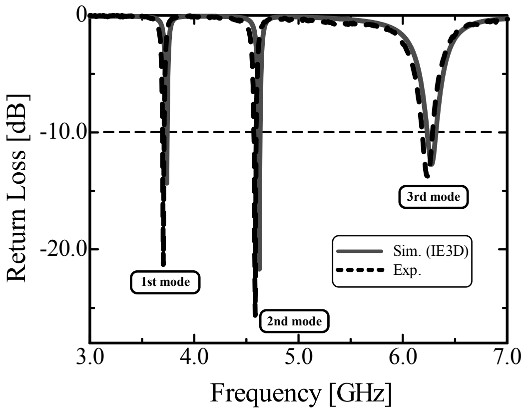

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Figure 5: Return loss characteristics of C-MSA with two half-ring slots

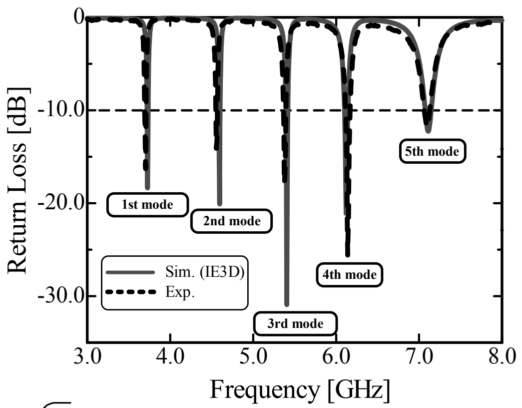

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Figure 6: Return loss characteristics of C-MSA with four half-ring slots

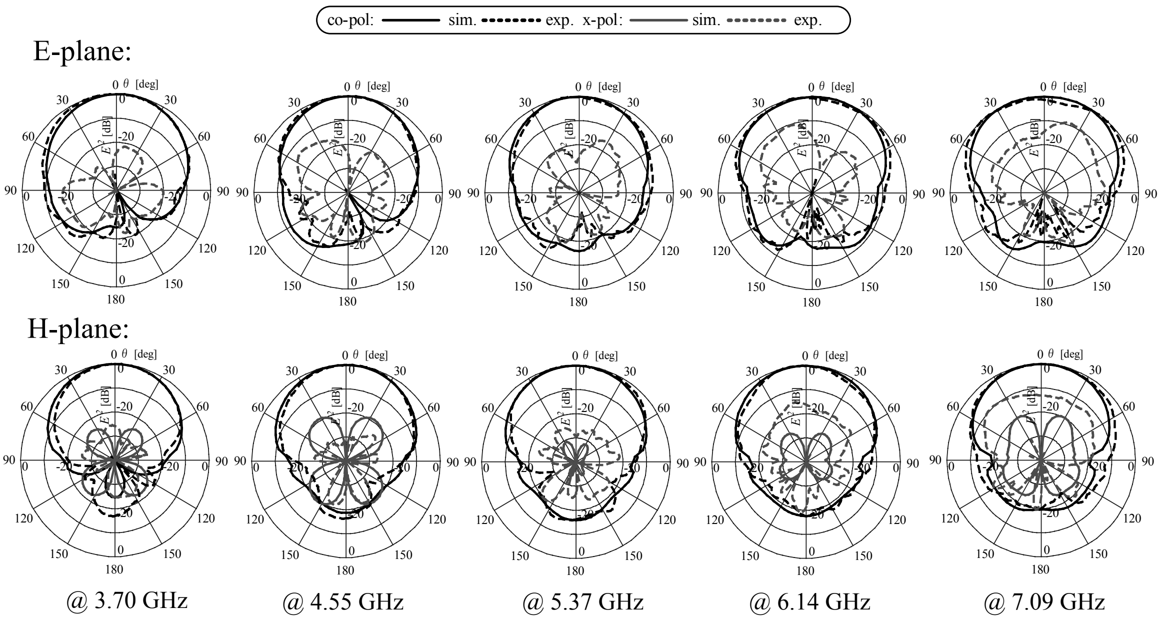

Figure 7: Radiation patterns of C-MSA with four half-ring slots