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Design Considerations of Feeding Dual-Port Microstrip Square-Ring Antenna

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Abstract—In this paper, the design considerations for feeding dual-port microstrip square-ring antenna are discussed. In particular, the antenna is evenly divided into eight sectors for analysis with the aid of characteristic modes and electric near-fields. The results can be used to guide the design of the excitation configuration for two ports with low mutual coupling for the square-ring antenna. The rotational and mirror symmetry of eight sectors helps simplify the investigation. The results from characteristic mode analysis (CMA) have also been validated in full-wave simulation with different two-port combinations.

Keywords—Antenna feed design, CMA, dual-feed, dual-port, microstrip ring antenna, MIMO antenna, mutual coupling

I. INTRODUCTION

The square-ring is a common geometry for designing microstrip patch antennas [1]–[4]. It provides additional parameters for achieving better antenna performance, such as bandwidth widening, size reduction, operating frequency and radiation pattern optimization compared to a square geometry. Furthermore, multiple frequency band operation can also be realized by introducing an additional square-ring laterally [1] or in different layers [2], or inserting additional stub to the inner edge of the ring [3], or slot to the ring [4]. To enhance impedance matching, the microstrip ring antenna can also be capacitively excited by a feed line located outside or under the ring at a small distance [2], [3].

Recently, we have proposed to use the theory of characteristic modes to design a trimodal broadside antenna element in which it is suitable for compact massive multiple-input multiple-output (MIMO) arrays [5]–[7]. It was found that the phase distribution of the z -directed characteristic E -fields under a snowflake-shaped plate was able to provide insight into how to generate orthogonal radiation patterns when all three modes were simultaneously excited. We then continue to reveal candidate regions to locate two direct probe feeding ports to jointly excite two significant modes of a Y-shaped patch with low mutual coupling [8]. In this paper, the same strategy will be applied for analyzing possible regions to locate excitation by two-ports for a microstrip square-ring antenna, but not necessarily limited to direct probe feeding.

II. POSSIBLE REGIONS FOR ANTENNA PORTS

A. Antenna Geometry

Figure 1 shows a microstrip square-ring antenna in the xy -plane and situated on top of an infinite ground plane. The radiating plate is made from a square perfect electric conductor (PEC) with a small square cut at the center. No substrate has been used for this investigation, and all corresponding dimensions are listed in the figure.

Fig. 1. Microstrip square-ring antenna. (units: mm)

B. Analysis from Characteristic Modes

Following the approach used in [8], the method of moments solver by Altair FEKO [9] has been utilized to perform characteristic mode analysis (CMA) of the microstrip square-ring plate in this study. It should be noted that an infinite ground plane is used because this can avoid dealing with many finite-ground based CMs. The calculated eigenvalues of the first six characteristic modes are given in Fig. 2. It is found that the first two modes are overlapped and dominated between 2.0 to 2.5 GHz. This implies there is a potential to excite two ports to the plate with low mutual coupling within this frequency range.

Fig. 2. Eigenvalues of first six characteristic modes of microstrip square-ring plate.

To analyze possible regions for antenna ports, the microstrip square-ring plate is evenly divided into eight sectors as shown in Figs. 3 and 4, and we try to fix Port 1 in Region I. In addition, three criteria need to be satisfied for generating two orthogonal far-field radiation patterns [8]. They are:

- 1) Mode 1's amplitudes and phases of z -directed characteristic E -fields at Ports 1 and 2 are the same;
- 2) Mode 2's amplitudes of z -directed characteristic E -fields at Ports 1 and 2 are the same, but their phases are 180° different;
- 3) Amplitudes of z -directed characteristic E -fields of Modes 1 and 2 at Port 1 are the same.

Fig. 3. Amplitude distribution of z -directed characteristic electric fields at 1 mm under the microstrip square-ring plate at 2.15 GHz (left: Mode 1; right: Mode 2).

Fig. 4. Phase distribution of z -directed characteristic electric fields at 1 mm under the microstrip square-ring plate at 2.15 GHz (left: Mode 1; right: Mode 2).

It should be noted that since the eigenvalues of Modes 1 and 2 overlap as depicted in Fig. 2, the two modes can be interchanged. Thus, Regions III and VII are good candidates for Port 2 to be located. Furthermore, in order to guarantee balanced antenna performance, rotational or mirror symmetry for two ports should be applied. Region V is not recommended as it violates the second criterion. It is also observed that the remaining four regions are partially satisfied especially they are close to the boundaries of Regions III and VII.

III. VALIDATION

In this section, we try to simulate S -parameters of dual-port microstrip square-ring antenna with Port 1 fixed in Region I, while Port 2 falls into different regions. The corresponding coordinates of port locations are listed in Table I. All selected location pairs are in geometric symmetry. This time, the size of the ground plane used is $200 \times 200 \text{ mm}^2$ which is large enough, and all metals are selected as copper. The calculation is performed in the time-domain solver of CST Microwave Studio [10].

TABLE I. EXAMPLES OF MICROSTRIP SQUARE-RING ANTENNA PORT LOCATIONS

Sector	Port 1 (x, y coordinates)	Sector	Port 2 (x, y coordinates)
I	(2, 20)	II	(20, 2)
I	(9, 18)	III	(18, -9)
I	(15, 18)	IV	(15, -18)
I	(2, 20)	VI	(-20, -2)
I	(9, 18)	VII	(-18, 9)
I	(15, 18)	VIII	(-15, 18)

Figure 5 shows simulated S -parameters of dual-port microstrip square-ring antennas with different feed locations. In order to better excite CMs, parasitic elements (capacitive) or longer probe lengths (inductive) have been applied in this study. The capacitive excitation (for Sectors II, III, VII and VIII) refers to a 4 mm-length probe connected to a $6 \times 6 \text{ mm}^2$ copper which is 1 mm under the square-ring plate, while the inductive excitation (for Sectors IV and VI) refers to a 6 mm-length probe connected to the square-ring plate which also makes the antenna thicker and so widening the bandwidth. All

Fig. 5. S -parameters of dual-port microstrip square-ring antennas with different feed locations corresponding to Table I.

port combinations exhibit low mutual coupling with gains and efficiencies greater than 9 dBi and 90%, respectively. In addition, the results from Sector III are identical to those from Sector VII which can be explained by rotational symmetry.

IV. CONCLUSION

We have reviewed a typical microstrip square-ring antenna from the CMA point of view in this paper. Two dominant CMs are identified and possible two port locations for exciting these two modes are provided and discussed. The reported analysis can be applied to other microstrip antennas.

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