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Two-port Design of Y-shaped Patch using Characteristic Mode Analysis

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***Abstract*—The design of two antenna ports for a compact Y-shaped patch on top of a square ground plane is considered. Specifically, characteristic mode analysis reveals candidate regions to locate two direct probe feeding ports to jointly excite two significant modes of the Y-shaped patch with low mutual coupling and correlation. The feed design procedure, based on both the amplitude and phase distributions of the characteristic electric near-fields, is validated by full-wave simulation with two example realizations of two-port designs.**

Keywords—Antenna feed design, characteristic modes, MIMO antenna, multimode antenna, patch antenna

I. INTRODUCTION

Multimode antennas are well suited for multiple-input multiple-output (MIMO) applications, as multiple modes can be leveraged to design multiple ports with orthogonal radiation patterns. The simplest example of a multimode MIMO antenna is a dual-polarized square patch on a ground plane. Two modes of the structure are excited by two feeds aligned on the two perpendicular central lines of the patch, resulting in two orthogonally polarized radiation patterns. Another classical example is the two-port Y-shaped patch antenna proposed in [1]. In this design, the feeds are placed on the two sides of the patch, near the "waist" of the Y shape. The feed positions were chosen such that one feed is placed at the position along a voltage null line produced by exciting the other feed, a strategy which produces low mutual coupling. In this paper, the two-port Y-shaped patch antenna is re-examined by characteristic mode analysis (CMA). It is shown that, in general, the feed positions are not restricted to only two points, but to two spatial regions. Furthermore, another pair of regions can be used for probe feedings to achieve low mutual coupling and correlation.

II. ANTENNA PORTS DETERMINATION ANALYSIS

Figure 1 shows the geometry of a Y-shaped patch [1] where the three spokes are folded downward towards a ground plane. Antenna miniaturization is then achieved through the meandered structure, as well as the resulting capacitive loading [1]. The method of moments solver of Altair FEKO [2] was used to perform CMA of the Y-shaped patch. An infinite ground plane was used in this analysis to eliminate radiation modes contributed by the finite-size ground plane. The eigenvalues of the characteristic modes (CMs) are shown in Fig. 2. It is noted that only three modes are visible since other modes are insignificant in the frequency range of interest. Modes 1 and 2 resonate at around 2.35 GHz and 2.25 GHz, respectively. By definition, the electric far-field patterns of modes 1 and 2 at 2.35 GHz are orthogonal and they can be found in [3].

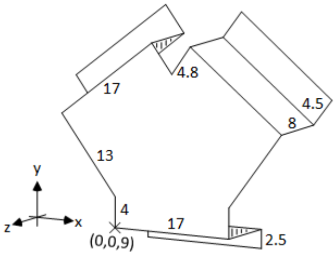

Fig. 1. Geometry of Y-shaped patch (ground plane not shown). (units: mm)

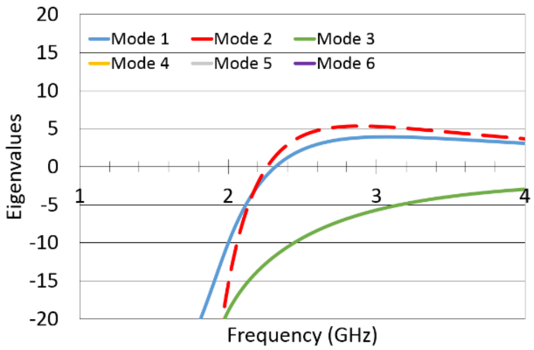

Fig. 2. Eigenvalues of first six characteristic modes of Y-shaped patch.

From the theory of characteristic modes (TCM), the current **J** at any port of a multiport antenna system can be given as [4,5]

$$\mathbf{J} = \sum_{n=1}^{N} \alpha_n \mathbf{J}_n \tag{1}$$

where n denotes the modal number, α_n denotes the modal weighting coefficient of the nth characteristic mode when ports 1 and 2 are excited; $\mathbf{J}_n$ denotes the eigencurrent of the nth CM. If only two CMs are dominant, then (1) can be written as

$$\mathbf{J}_{p1} = \alpha_1 \mathbf{J}_1 + \alpha_2 \mathbf{J}_2 \tag{2}$$

$$\mathbf{J}_{p2} = \alpha_1' \mathbf{J}_1 + \alpha_2' \mathbf{J}_2 \tag{3}$$

To generate orthogonal far-field radiation patterns, the inner product of the port current distributions should become zero, i.e.,

$$\oiint_S \mathbf{J}_{p1} \bullet \mathbf{J}_{p2}^* \, ds = 0 \tag{4}$$

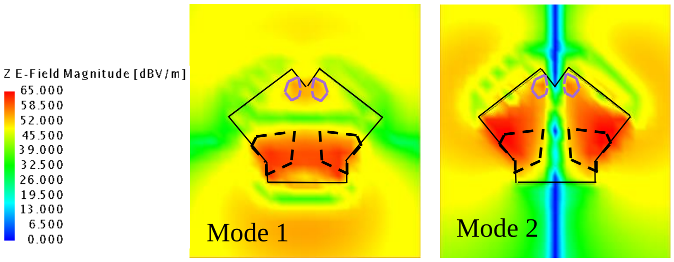

Fig. 3. Amplitude distribution of *z*-directed characteristic electric fields at 1 mm under the top plate of Y-shaped patch at 2.35 GHz.

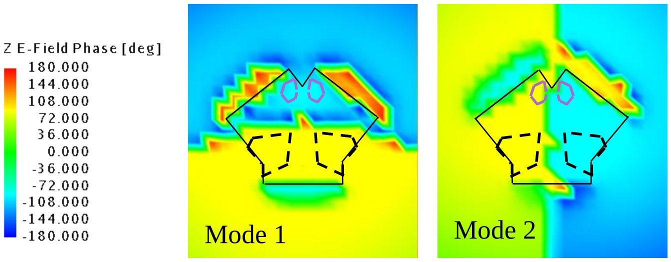

Fig. 4. Phase distribution of *z*-directed characteristic electric fields at 1 mm under the top plate of Y-shaped patch at 2.35 GHz.

TABLE I

EXAMPLES OF PORT LOCATIONS

Port Locations	**Coordinates (units: mm)**
#1 and #2 (black dashed line regions)	(-0.8, 7.4, 9.0) and (17.8, 7.4, 9.0)
#1′ and #2′ (purple dashed line regions)	(6.0, 21.8, 9.0) and (11.0, 21.8, 9.0)

This means that the following three criteria need to be satisfied

$$\alpha_1' = \alpha_1 \,, \tag{5}$$

$$\alpha_2' = \alpha_2 \, e^{-j\pi} \,, \tag{6}$$

$$|\alpha_1| = |\alpha_2| \,, \tag{7}$$

when $\alpha_1, \alpha_2, \alpha_1', \alpha_2'$ are all nonzero. Similarly, the electric field **E** generated by **J** can be also used to evaluate port orthogonality.

Figures 3 and 4 show the amplitude and phase distributions of the *z*-directed characteristic electric fields at 1 mm under the top plate of the Y-shaped patch. Based on the three criteria (5)-(7), two pairs of regions were identified for (*z*-oriented) probe excitations of the two modes to give orthogonal patterns. They are around the waist (regions within the black dashed lines) and around the top notch (regions within the purple dashed lines) of the Y-shaped structure. It should be noted the two ports in [1] are located in two specific points within the two regions within the black dashed lines. However, it did not discover the regions around the points as possible feed locations. Moreover, another possible pair of regions for probe feeding (i.e., regions within the purple dashed lines) has been identified.

III. VALIDATION

To confirm the results from CMA on possible feeding locations in Section II, two sets of probe feeds are placed in the regions within the black and purple dashed lines, respectively, for exciting the Y-shaped patch. The actual coordinates of the probe feeds are listed in Table I. The size of the ground plane used is 140 × 140 mm^2, which is large enough to minimize its effect on CMA. The corresponding *S*-parameters, antenna gains and efficiencies calculated in the time-domain solver of CST Microwave Studio [6] are given in Figs. 5 and 6. It is verified that the Y-shaped patch antenna can be excited at different locations to generate resonances at around 2.35 GHz and exhibit low mutual coupling. The envelope correlation coefficients between the two ports at 2.35 GHz, as calculated from the far-field patterns, are 0.00044 and 0.00039, respectively.

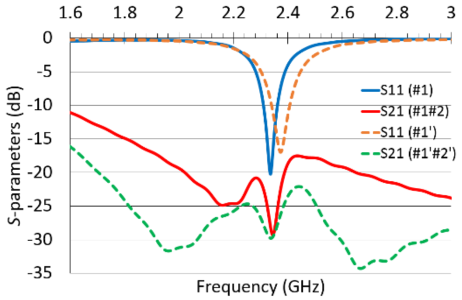

Fig. 5. *S*-parameters of Y-shaped patch with different feed locations.

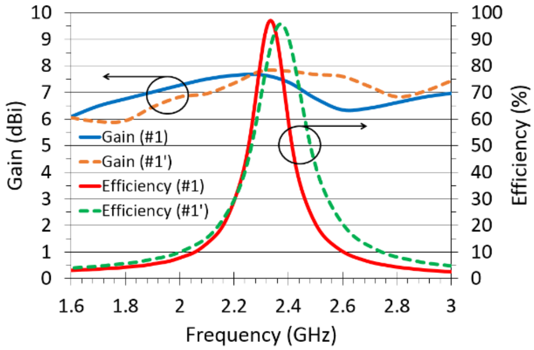

Fig. 6. Gains and efficiencies of Y-shaped patch with feeds at locations #1 and #1′.

IV. CONCLUSION

In this paper, a compact 2-port Y-shaped patch antenna has been revisited from the CMA point of view. Regions of possible port locations are found for joint excitation of the two dominant CMs, while maintaining low correlation and coupling.

ACKNOWLEDGMENT

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