2022 International Conference on Smart and Sustainable Technologies in Energy and Power Sectors (SSTEPS) | 978-1-6654-6414-7/22/$31.00 ©2022 IEEE | DOI: 10.1109/SSTEPS57475.2022.00087

Splitting of Degenerated Modes on Patch Structure Using Characteristic Mode Analysis

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***Abstract*— This study presents the characteristic mode analysis (CMA) on different patch shapes for circular polarization (CP) conditions. Through the use of various geometrical slots, a simple square patch orthogonal modes are divided. By doing a systematic modification of various slots on a square patch, a CP condition is achieved. This condition is identified with the help of CMA parameters such as modal significance and characteristic angle. In addition to these parameters, the surface current and radiation are also analyzed at CP condition frequency. These parameters are analyzed by etching three different slots such as slot, slit, and corner truncation on a square patch. These slots are etched on a simple square patch of 20×20mm^2 dimensions.**

***Keywords*— characteristic angle, characteristic mode analysis (CMA), modal significance**

I. Introduction

The Circularly polarized antenna are extensively used in multiband wireless communication systems to provide less sensitivity, suppress polarization mismatch, reduction in propagation loss and mismatching effects. Two orthogonal characteristic modes on the conductor plate can produce a circularly polarized radiation field [1-3].

It is typically possible to achieve circular polarization (CP) by using two types of feeding schemes: single-feed and multiple-feed. In the literature, there have been many techniques, including diagonal feeding, embedding cross slots in metallic patches, square patches with different slots, fractal boundaries, stake antennas, annular rings with strip lines inside inner rings, and truncated edge patches. Most of these designs are achieved by full-wave simulation and optimization based on engineering experience and intuition with little physical insight.

To achieve physical insight into antenna radiation, characteristic mode analysis (CMA) is more attractive for antenna designs in recent years. CMA is a systematic modal analysis that highlighted the natural resonance behavior [4]. CMA provides both the physical understanding of the radiation behavior of the structures and the reliability of the numerical simulations.

In 1965, Robert Garbacz [5] created the CMA, which was later combined with Turpin's in 1968[6]. Roger Harington and Mautz improvised the statement in 1971. It was initially used with conducting objects [7], but later it was implemented on dielectric and magnetic ones [8]. CMA helps enhance antenna parameters such as bandwidth, polarization [9], etc.,

By taking the advantage of CMA, this paper analyses the Characteristic modal parameters of a simple patch without considering any substrate and feed. The analysis mainly focuses on splitting the orthogonal degenerate modes of a simple patch to achieve uniform magnitude and quadrature phase for the CP condition. In the analysis, various structures such as a slit, slot, and truncated structures are considered to achieve the CP condition without substrate.

II. CMA Parameters

This section discusses the three standard parameters of CMA. There are three parameters: eigenvalue (λn), modal significance (MS), and characteristic angle (CA).

Depending on the frequency determined by the method of moments (MOM)[10], eigenvalues indicate fields or currents supported by a structure. If the eigenvalue becomes zero, then the resonance mode appears throughout a frequency range.

Using another parameter called MS is an easy way to analyze resonant behavior across a wide frequency range. The MS is defined as follows:

$$MS = \frac{1}{|1 + j\lambda_n|} \tag{1}$$

This equation describes significant and non-significant modes depending on the MS values. Also, according to equation (1), if a mode is stated to be resonance (λn= 0), then the MS=1. Another parameter also obtained from the eigenvalue equation to acquire the resonance frequency is called CA. It provides qualitative information about the phase lag between the two characteristic currents. It can be determined from the eigenvalue ( ) as follows:

$$\varnothing_n = 180^0 - \tan^{-1}(\lambda_n) \tag{2}$$

From equation (2), if λn=0, the CA is 1800. The CA may vary in the range of [90°, 270°].

To achieve the CP radiation of any structure, the two orthogonal modes must be uniform in magnitude and 900 phase difference. These conditions can be observed using MS and CA.

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DOI 10.1109/SSTEPS57475.2022.00087

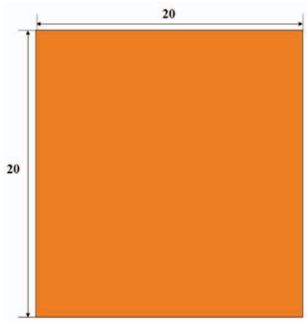
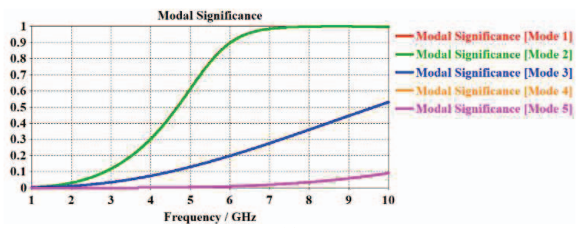


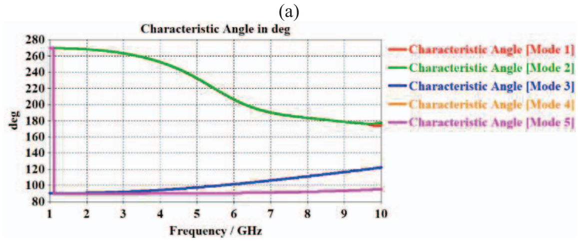
Fig. 1. Symmetric square patch configuration.

III. Design Configuration and Description

To understand the CMA, a simple square patch of the perfect electric conductor (PEC) has been introduced with a size of 20×20 mm^2 with zero thickness as shown in Fig.1. The first five characteristic Modes (CMs) such as MS and CA are illustrated in Fig.2. Due to symmetric square patch, one pair of degenerate modes are generated at 8.7 GHz.



(a)



(b)

Fig. 2. Symmetric square CMs (a) MS and (b) CA.

To split the degenerate modes, the symmetric square patch (Fig.1) is modified to excite two orthogonal modes with equal amplitude and 90^0 phase difference. The patch shown in Fig.1 is modified using different slots and they are considered as slot structure, slit structure, and corner truncated structure. The detailed study of these structures is described in the following sub-section.

A. Slot Structure

Once the CMs are analyzed, the next step has been analyzing the orthogonal properties of the lower-order modes by considering the surface current distribution and radiation behavior of the slot structure. Fig.5 represents the current distribution and Fig.6 shows the radiation pattern of the slot structure at 5.3 GHz for the first two modes. From Fig. 5, it is observed that the maximum surface current is distributed at the center of the patch for mode 1 in the vertical direction. While in mode 2, it is on the top and bottom center edges of the patch in the horizontal direction. This will indicate the modes are orthogonal to each other. Also, the radiation pattern from Fig. 6 shows that mode 1 is providing Omni directional pattern with null in the y-axis and mode 2 is radiating a broadside pattern with null in the x-axis.

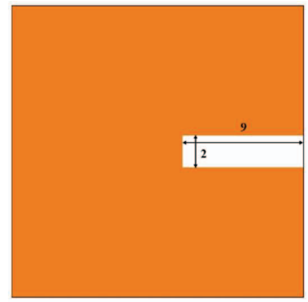
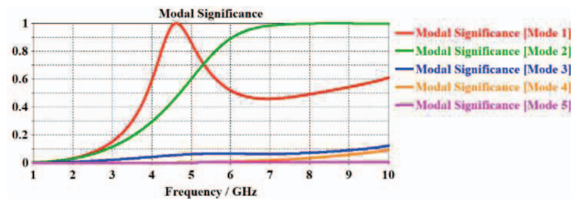
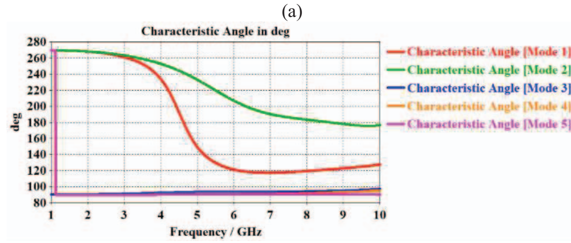


Fig. 3. Geometry of slot structure.

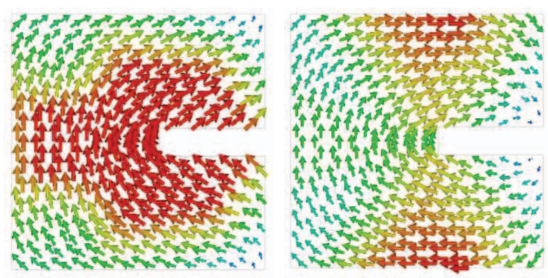


(a)



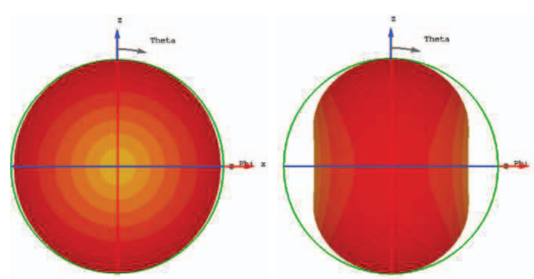
(b)

Fig. 4. CMs parameters of slot structure (a) MS and (b) CA.



(a) (b)

Fig. 5. Surface current distribution of slot structure (a) Mode 1 and (b) Mode 2.



(a) (b)

Fig. 6. 3-D radiaiton pattern of slot structure (a) Mode 1 and (b) Mode 2.

B. Slit Structure

In another structure, to split the degenerate modes, two modifications are done on the square patch. An asymmetric rectangular slot on the corner edges of the patch splits the lower modes. A 4 × 4 mm triangular slit at the top right side and bottom left side, as shown in Fig.7 is introduced as the second step to achieve additional modes. From the MS in Fig. 8 (a), the resonance modes are observed at 4.38, 5.73, 5.60, and 9.19 GHz from modes 1, 2, 3, and 5 respectively. The first two modes such as modes 1 and 2 are intersected at 4.90 GHz. From CA shown in Fig. 8(b) provides a 90^0 phase difference at an intersecting point.

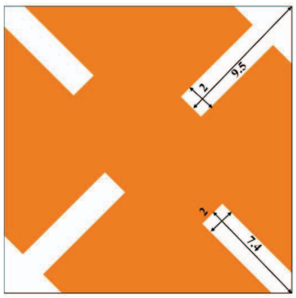
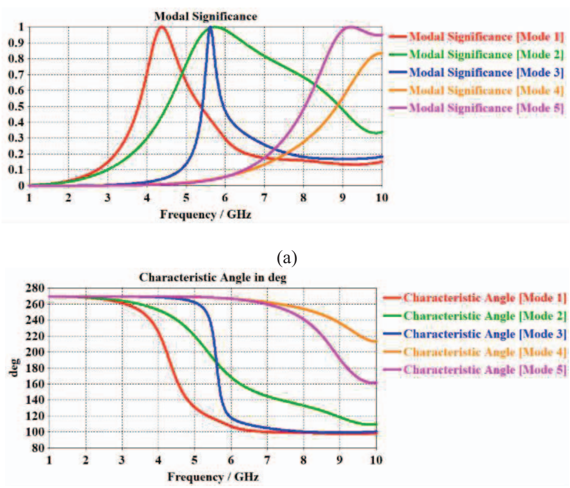
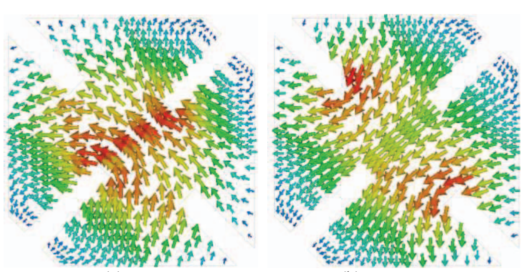


Fig. 7. Geometry of slit structure.



(b)

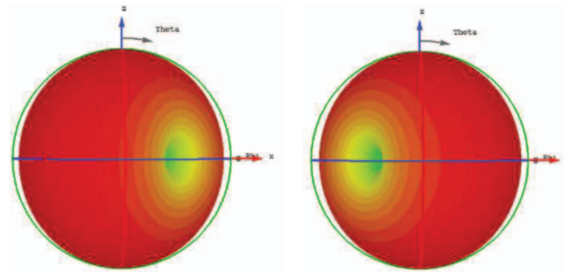
Fig. 8. CM parameters of slit structure (a) MS and (b) CA.



(a) (b)

Fig. 9. Surface current distribution of slit structure (a) Mode 1 and (b) Mode 2.

To understand the orthogonal properties of the modes, again the surface current distribution and radiation behavior of the slit structure are shown in Fig.9 and Fig.10. From Fig.9, the maximum surface current is distributed rotationally symmetric with quadrature phase from mode 1 to mode 2. Also, the radiation pattern from Fig. 10 shows that mode 1 provides an omnidirectional pattern with null in the x-axis.



(a) (b)

Fig. 10. 3-D radiaiton pattern of slit (a) Mode 1 (b) Mode 2.

C. Corner Truncated Structure

In the third stage, a corner truncation approach is used to split the degenerate modes. This is the most common method used for CP in antenna design. Fig.11. shows the corner truncated structure for splitting the modes. Corner truncation sizes influence the orthogonal modes. To split the degenerate modes, the modification on a square patch is introduced by etching a square slot with 11.6 × 11.6 mm^2 dimensions.

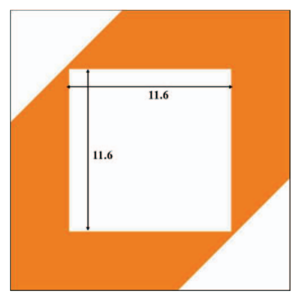
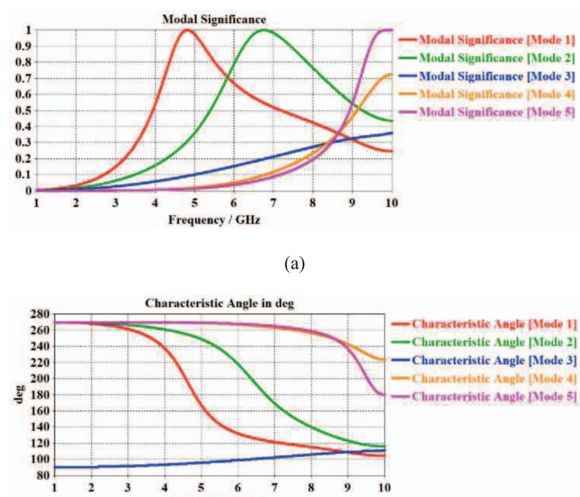


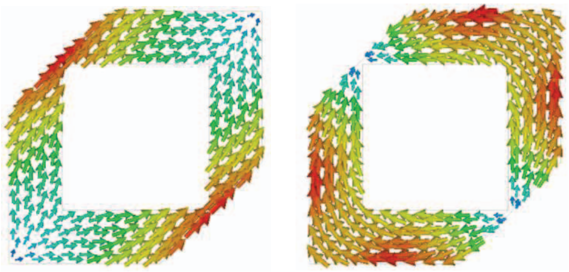
Fig. 11. Geometry of corner truncated structure.



(b)

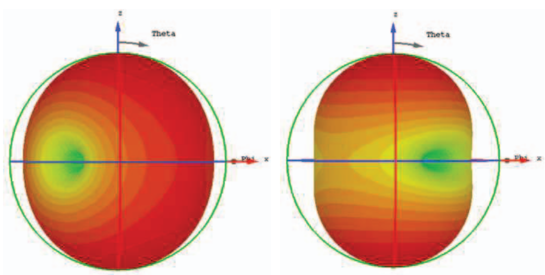
Fig. 12. CM parameters of corner truncated structure (a) MS and (b) CA.

As observed from MS shown in Fig. 12(a), the first two modes are split and intersect at 5.84 GHz with their resonant frequencies at 4.82 and 6.75 GHz, respectively. Also, from CA shown in Fig.12(b), it provides a 90^0 phase difference at the intersecting frequency. Further, it is also observed that the other modes such as mode 4 and mode 5 are also significant modes in the specified range compared to the slotted structure. However, mode 3 is again nonsignificant in the specified frequency range.



(a) (b)

Fig. 13. Surface current distribution of corner truncated structure (a) Mode 1 and (b) Mode 2



(a) (b)

Fig. 14. 3-D radiation pattern of corner truncated structure (a) Mode 1 and (b) Mode 2.

Further to understand the orthogonal properties of this structure, lower-order modes of surface current distribution and radiation behavior are shown in Fig.13 and 14 respectively. From Fig. 13. it is observed that the maximum surface current is distributed at the top right and bottom left corners of the patch for mode 1. For mode 2 the surface current is distributed at the left and right center edges of the patch. Also, Fig. 14 shows that mode 1 is providing an omnidirectional pattern with null in the y-axis and mode 2 is radiating a broadside pattern with null in the x-axis. This will indicate the modes are orthogonal to each other resecting points of the first two modes.

IV. Conclusion

In this study, a modified patch of various shapes is analyzed to split the degenerate modes with uniform magnitude and quadrature phase shift. The three different structures provide their resonance frequencies at different frequencies. This indicates that the slots/truncation greatly influence the resonance frequency for CP performance. The CMs of these structures give an intuition for the extension of antenna designs to achieve CP radiation along with feed optimization. Based on this analysis, the structures can be extended by considering the substrate and ground plane in future studies.

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