A MoM/FEM HYBRID ANALYSIS OF CIRCULARLY POLARIZED SLOT ELEMENTS WITH COMPLEX SHAPES

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ABSTRACT

Circularly polarized slot elements with complex shapes on the shorted end of a rectangular waveguide are analyzed and designed by the method of moments analysis based on the numerical eigenmodes derived by the edge-based finite element method. In this paper, a crossed slot, a notched annular ring slot and an elliptical annular ring slot are analyzed and designed. Potential of this method is fully demonstrated by clearly extracting the mechanism for circular polarization in each slot. The analysis is confirmed by experiments.

INTRODUCTION

The method of moments (MoM) analysis based on the numerical eigenmodes derived by the edge-based finite element method (FEM) was developed by the authors for the coupling analysis of arbitrary shaped slots on the waveguide [1]. It has several unique advantages in terms of applicability to complicated shapes, computational efficiency and accuracy and so on. This paper utilizes this hybrid method for designing various types of slot elements cut on the shorted end of the waveguide for circular polarization. It includes a crossed slot, a notched annular ring slot and an elliptical annular ring slot. Potential of this method is fully demonstrated by clearly extracting the mechanism for circular polarization in each slot. The mechanism of circularly polarized wave radiation is revealed by the decomposition into two linearly polarized waves associated with those two eigenmode basis functions. The analysis is confirmed by measurements of VSWR, axial ratio and patterns.

ANALYSIS MODEL

Fig. 1 shows a crossed slot, as an example, on the shorted end of a rectangular waveguide with a TE10 excitation. A dielectric layer is inserted in the waveguide to support inner conductors of slots (see Fig. 2 (b), (c)). A crossed slot, a notched annular ring slot and an elliptical annular ring slot are used as the slot in Fig. 1. All of them are typical radiator of circularly polarized wave.

A crossed slot shown in Fig. 2 (a) consists of two straight slots which have different lengths and cross at the center of each slot with an arbitrary angle. Design for the circularly polarized wave can be performed for wide range of crossing angles. To achieve a good circularly polarized wave, the length of one slot is shorter than the resonant one while that of the other is longer so that the appropriate phase difference may be realized.

A notched annular ring slot shown in Fig. 2 (b) is also cut on the center of the shorting plate of a rectangular waveguide. Two notches are extended from the inner ring of the annular ring in the symmetrical place to decompose degenerate two modes. Then notches are rotated to control coupling factor for those two modes.

Fig. 2 (c) shows an elliptical annular ring slot cut on the center of the shorting plate of a rectangular waveguide. The axial ratio varies with the separation of two degenerated modes; the slot is rotated to control coupling factor for those two modes.

ANALYSIS

MoM based on the numerical eigenmodes proposed by the authors [1] is used for the analysis. The basis functions in MoM are the eigenmode functions derived numerically by the edge-based FEM. Magnetic current basis functions for the complicated aperture of the slot can be obtained accurately and two dominating eigenmode basis functions are taken into the analysis because other modes are negligible for these slots since they are hardly excited by the TE_{10} standing wave excitation. The reaction in the wall-thickness region of a shorting plate can also be simply and accurately evaluated because of the orthogonality of mode functions.

NUMERICAL RESULTS AND MEASUREMENTS

Fig. 3 shows two dominant eigenmode basis functions in each shape, which are derived numerically by the edge-based FEM, used in MoM analysis. The decomposition into two linearly polarized waves associated with those two eigenmode basis functions reveals the mechanism of circularly polarized wave radiation. The sum of two linearly polarized waves results in a circularly polarized wave when the amplitude of the linearly polarized waves is the identical and the phase difference of them is 90 degrees. It is confirmed that two linearly polarized waves associated with two eigenmode basis functions satisfy the above conditions.

In the design, the frequency and waveguide size are specified first. Then some parameters of the slot are fixed and the others are varied iteratively until the desired small axial ratio at boresight is obtained. Parameters to be fixed and designed are listed in Table 1 for three types of slots. Usually, the reflection cannot be suppressed only by the slot. Designed slot parameters and their characteristics are listed in Table 2.

Fig. 4 shows frequency characteristics of the reflection and the axial ratio at boresight. In the measurement, frequencies where the axial ratio becomes minimum are slightly shifted from calculated ones. For a notched annular ring slot, the reflection is suppressed below –15dB over a 14.2% bandwidth and the axial ratio is suppressed below 3dB over a 3.0% bandwidth. The calculated and measured spin-linear radiation patterns for notched annular ring slot are shown in Fig. 5. Three types of slots have almost identical patterns in prediction. Radiation patterns for the crossed slot and the elliptical annular ring slot will also be presented.

CONCLUSION

Circularly polarized slot elements with complex shapes are analyzed and designed by a MoM/FEM hybrid analysis. A crossed slot, a notched annular ring slot and an elliptical annular ring slot are considered in this paper. The mechanism of circularly polarized wave radiation is revealed by the decomposition into two linearly polarized waves associated with those two eigenmode basis functions. The calculated frequency characteristics of the reflection and

the axial ratio are compared with the measured ones and they are in reasonable agreement except the small frequency shift.

REFERENCES

[1] T. Hirano, J. Hirokawa, M. Ando, "Method of moments analysis of a waveguide crossed slot by using the eigenmode basis functions derived by the edge-based finite-element method," IEE Proceedings - Microwaves, Antennas and Propagation, vol. 147, no. 5, pp. 349-353, Oct. 2000.

Table 1 Slot parameters to be fixed and designed

	Crossed slot	Notched annular ring slot	Elliptically annular ring slot
Fixed parameters	w	r, w	w
Varied parameters	ℓ_1, ℓ_2, θ_x	c, θ_r	r_a, r_b, θ_r

Table 2 Designed slot parameters and characteristics

	Crossed slot	Notched annular ring slot	Elliptically annular ring slot
Frequency	4.0GHz		
Waveguide	WRJ-4 ($58.1\text{mm} \times 29.1\text{mm}$), $t = 33.0\mu\text{m}$		
Dielectric layer	$d = 3.2\text{mm}$, $\varepsilon_r = 2.17$		
Slot parameters	$w = 4.0\text{mm}$ $\ell_1 = 37.0\text{mm}$ $\ell_2 = 32.0\text{mm}$ $\theta_x = 120.0\text{deg}$	$w = 4.0\text{mm}$ $r = 11.0\text{mm}$ $c = 5.4\text{mm}$ $\theta_r = 56.0\text{deg}$	$w = 1.5\text{mm}$ $r_a = 14.2\text{mm}$ $r_b = 7.7\text{mm}$ $\theta_r = 59.6\text{deg}$
Calculated Characteristics	$\lvert S_{11} \rvert = -5.4\text{dB}$ Axial ratio= 0.33dB	$\lvert S_{11} \rvert = -22.5\text{dB}$ Axial ratio= 0.20dB	$\lvert S_{11} \rvert = -3.6\text{dB}$ Axial ratio= 0.18dB

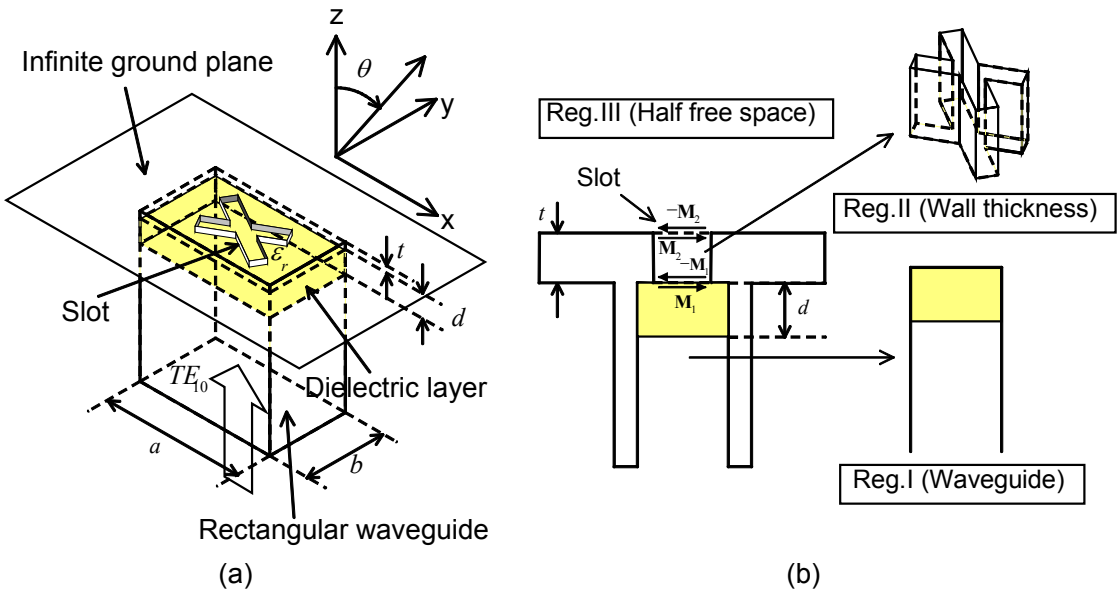

Fig. 1 (a) A crossed slot on the shorted end of a rectangular waveguide (b) Three canonical regions in MoM

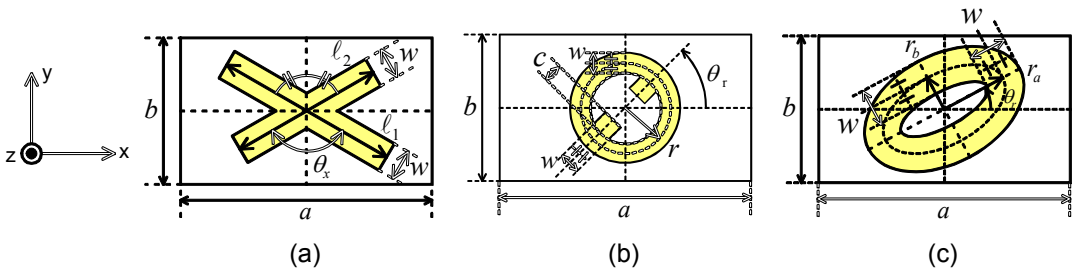

Fig. 2 Slots and parameters (a) crossed slot (b) notched annular ring slot (c) elliptical annular ring slot

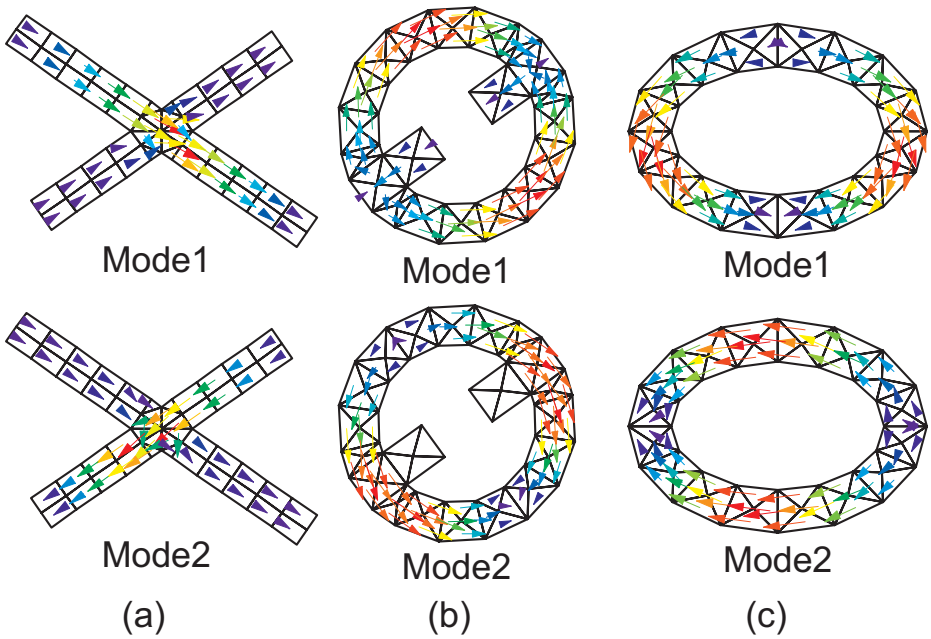

Fig. 3 Eigenmode basis functions (a) crossed slot (b) notched annular ring slot (c) elliptical annular ring slot

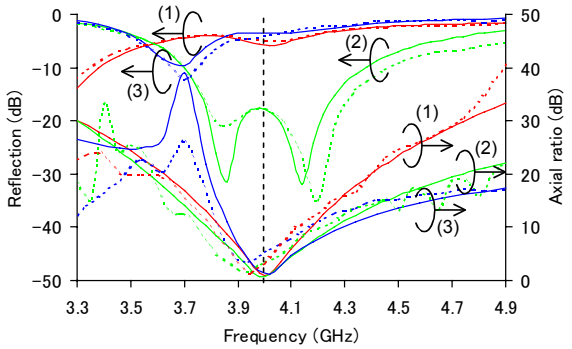

Fig. 4 Frequency characteristics of the reflection and the axial ratio at boresight. (1), (2) and (3) are results of crossed, notched annular, and elliptical annular ring slot, respectively. Solid and dotted lines are calculated and measured results, respectively.

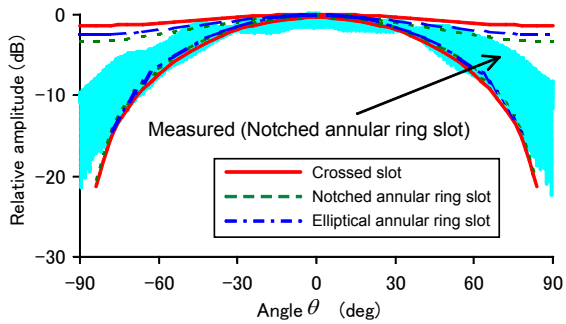

Fig. 5 Radiation patterns of a notched annular ring slot at boresight in x-z plane (Calculated: the semi-major and the semi-minor axes, Measured: spin-linear)