A MOM ANALYSIS USING NUMERICAL EIGENMODE BASIS FUNCTIONS FOR A NOTCHED ANNULAR RING SLOT ON A SHORTING PLATE OF A RECTANGULAR WAVEGUIDE

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1. Introduction

A notched annular ring slot [1] on a shorting plate of a rectangular waveguide as shown in Fig. 1 is analyzed for circular polarization at the boresight. Eigenmode functions of electric field for a waveguide with the cross section of the slot shape are derived numerically by the edge-based finite element method (FEM), and are utilized as basis functions of the magnetic current in the method of moments (MoM) [2]. The reactions of the magnetic currents in the wall-thickness region can be expressed in terms of the wall thickness and the propagation constant without taking the mode summation due to the orthogonality.

Predicted frequency characteristics of the reflection coefficient and the axial ratio, and the radiation pattern at 3.96GHz are compared with the measurements and good agreements are obtained. 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 mechanism for circular polarization is clearly explained in terms of excitation of two leading eigenmodes.

2. Analysis model

The analysis model of a waveguide notched annular ring slot is shown in Fig. 1 (a). The slot is placed at the center on a shorting plate of a rectangular waveguide (width: a, height: b, wall thickness: t). A dielectric layer (thickness: d, relative permittivity: ε_r) to support the inner conductor of the slot is included inside the waveguide just under the shorting plate. An infinite ground plane is assumed in the analysis to regard the outer region as a half free space. A TE_{10} wave is incident in the waveguide.

The configuration of a notched annular ring slot is shown in Fig. 1 (b). Two identical notches (depth: c, width: w) are cut in the annular ring (radius: r, width: w) as shown in this figure to separate two degenerated modes.

3. Numerical results and measurements

3.1 Model antenna

A model antenna is manufactured by using a standard waveguide WRJ-4 (58.1mm× 29.1mm) at 3.96GHz. The antenna parameters are listed in Table 1. A rectangular conducting plate (560mm along the x axis by 400mm along the y axis) is attached around the model antenna in the measurements, which is large enough to suppress the diffraction effects from its edges.

3.2 Eigenmode basis functions

Fig. 2 show the flow of the two lower eigenmode basis functions of the magnetic current for MoM as vectors, in the cross section of the shape of a notched annular ring slot derived by the edge-based FEM. They are referred as Mode1 and Mode2. Other higher modes are not included in the MoM since their excitation coefficient is negligibly small. In Mode1, the magnetic current flows from one notch to the other. In Mode2, the current is the maximum near the notches and it does not penetrate into the notches. The notches do not affect on the distribution in Mode 2. Fig. 3 (a) shows cutoff wavenumbers in the cross section for each mode, which are related with resonant frequencies of the slot. They are normalized by the cutoff wave number of a straight slot with a length ℓ_h defined in the figure b, and are expressed as a function of a notch length normalized by ℓ_h for $r:w=11:4$. Fig. 3 (b) describes the definition of ℓ_h. When $c=0$ (without notches), Mode1 and Mode2 are degenerated. As c becomes larger, the degenerate cutoff wavenumbers get separated and the cutoff wavenumber of Mode1 becomes smaller while that of Mode2 is unchanged because its distribution is almost independent of notches as shown in Fig. 2 (b). In rough approximation, $\pi/(\ell_h+w/2+c)$ and π/ℓ_h are cutoff wavenumbers for Mode1 and Mode2, respectively. The design for circular polarization and reflection suppression is achieved at 3.96GHz for the normalized notch length of 19.1% and the resonant frequencies for Mode1 and Mode2 of 3.74GHz and 4.47GHz, respectively.

3.3 Reflection coefficient

The frequency characteristic of the reflection coefficient is shown in Fig. 4. The calculated value and the measured one are in good agreement. The reflection is suppressed below –15dB over a 14.2% bandwidth.

3.4 Radiation pattern

Fig. 5 shows the radiation pattern at the design frequency. The observation plane is on $x-z$ plane ($\phi=0$) in Fig. 1 (a). The calculated and the measured axial ratio at the boresight are 0.98dB and 1.5dB, respectively. Ripples are observed in the spin-linear radiation pattern because of small diffraction effects.

The frequency characteristic of the axial ratio at the boresight is shown in Fig. 4. The axial ratio is suppressed below 3dB over a 3.0% bandwidth in the measurement. The agreement between the theory and the measurement is good.

Each eigenmode basis function of the magnetic current radiates a linear polarized wave since it is a real function as an eigenfunction solved in an eigen value problem.

Circular polarization can be regarded as a combination of two linearly polarized waves radiated by Mode 1 and Mode 2. E_θ radiated by Mode2 and E_φ radiated by Mode1 are $0\text{dB}\angle 32.4^\circ$ and $-0.2\text{dB}\angle -57.5^\circ$, respectively, at the boresight. The differences in amplitudes and phases between E_θ and E_φ are 0.2dB and 89.9 degrees. These E_θ and E_φ produce circular polarization with a good axial ratio.

4. Conclusion

A notched annular ring slot is designed at 3.96GHz. The axial ratio is 1.5dB at the boresight. Frequency characteristics of the reflection coefficient and the axial ratio, and the radiation pattern are compared with the measured ones and reasonable results are obtained. The reflection is suppressed below –15dB over a 14.2% bandwidth and the axial ratio is suppressed below 3dB over a 3.0% bandwidth. Circularly polarized wave radiation is interpreted as a combination of two linearly polarized waves associated with eigenmode basis functions.

References

[1] A. K. Bhattacharyya, and L. Shafai,“ A wider band microstrip antenna for circular polarization,” IEEE Trans. Antennas Propagat., vol. AP-36, no. 2, pp. 157-163, Feb. 1988.

[2] T. Hirano, J. Hirokawa, and 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, pp. 349-353, no. 5, Oct. 2000.

Table 1 Antenna parameters (at 3.96GHz)

Ring radius: r (mm)	11.0
Slot width: w (mm)	4.0
Notch length: c (mm)	5.4
Rotation angle: θ_r (deg)	56.0
Thickness of a dielectric layer: d (mm)	3.2
Relative permittivity: ε_r	2.17
Wall thickness: t (μm)	33.0
Rectangular waveguide	WRJ-4 (58.1mm×29.1mm)

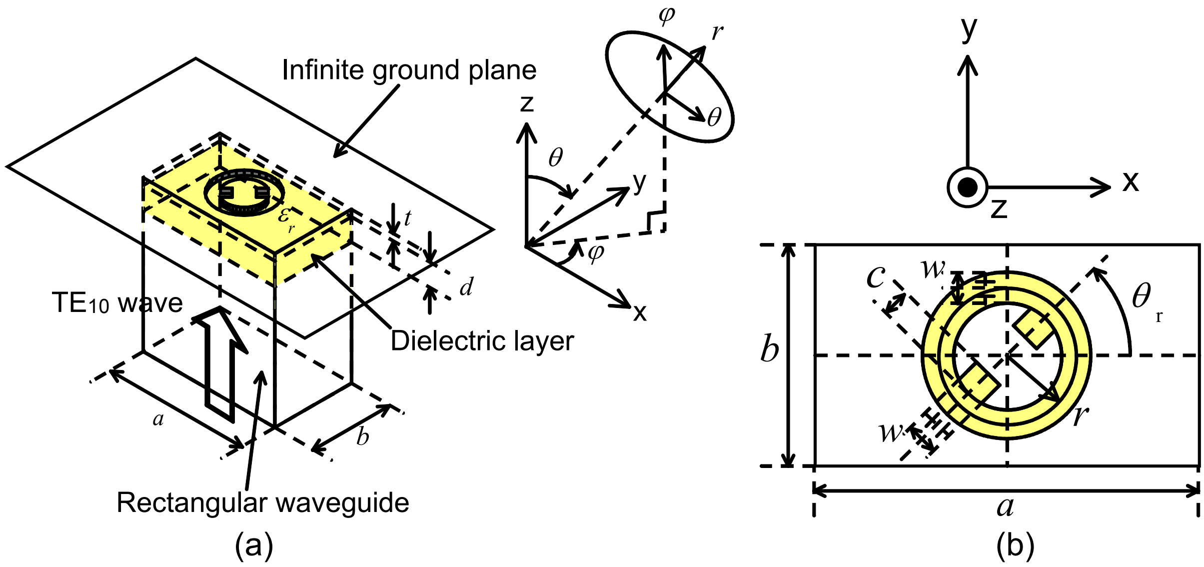

Fig. 1 (a) A waveguide notched annular ring slot, (b) Slot configuration

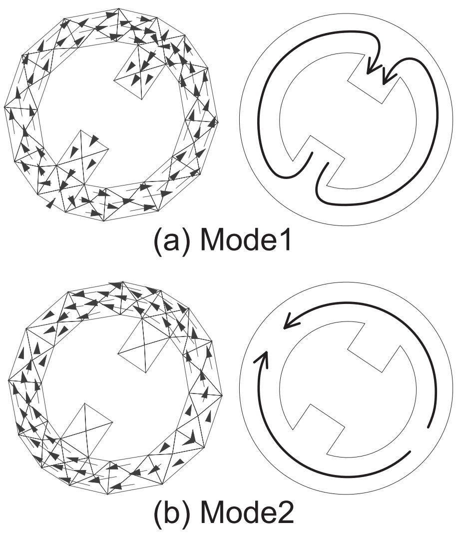

Fig. 2 Eigenmode basis functions

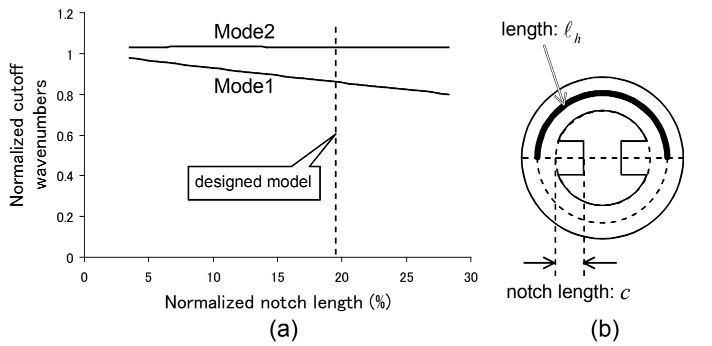

Fig. 3 Cutoff wavenumbers as a function of notch length

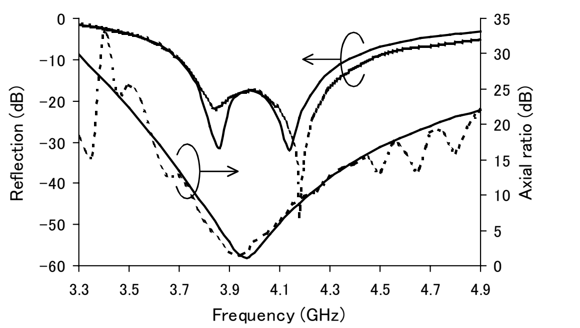

Fig. 4 Frequency characteristics of the reflection and the axial ratio (solid lines: calculated, dotted lines: measured)

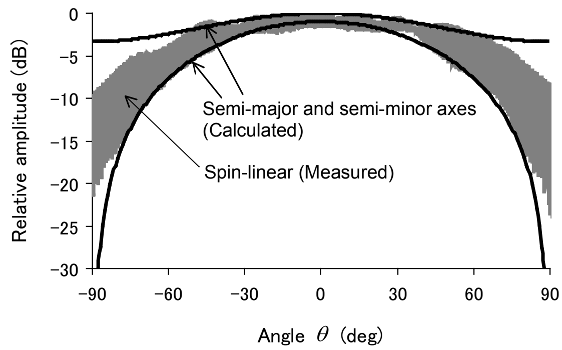

Fig. 5 Radiation pattern