PROCEEDINGS OF ISAP2005, SEOUL, KOREA

Reduction of amplitude ripples in the circumferential direction in a radial waveguide by using a crossed dog-bone slot

Kaoru Sudo*, Toru Oizumi, Jiro Hirokawa and Makoto Ando
Department of Electrical and Electronic Engineering, Tokyo Institute of Technology
S3-19, 2-12-1, O-okayama, Meguro-ku, Tokyo, 152-8552, Japan
E-mail: ksudo@antenna.ee.titech.ac.jp

1 Introduction

A radial line slot antenna (RLSA) is a high-gain, high-efficiency and low-cost planar antenna, which was originally proposed for satellite TV reception at 12 GHz band [1]. The slot design for realizing uniform aperture illumination and maximizing antenna efficiency is the key feature of RLSAs. A rotating mode uniform in amplitude and linearly tapered in phase in the circumferential (ϕ-) direction in a radial waveguide is required to get a pencil-beam in the boresight in a concentrical-array RLSA (CA-RLSA) [2]. A rectangular-to-radial waveguide transformer through a crossed slot was proposed [3]. The measured ripple of the amplitude was 3.0 dB in the ϕ-direction and the rotating mode with the ripple less than 6 dB was excited in wide bandwidth of 7.0%.

In this paper, a rectangular-to-radial waveguide transformer through a crossed dog-bone slot is proposed. A transformer with a crossed dog-bone slot can realize a more symmetric rotating mode, because of the wider beam width of dog-bone slots than that of rectangular slots. The calculated and measured amplitude ripple in the ϕ-direction are 0.76 dB and 1.5 dB, respectively. The amplitude ripple of the crossed dog-bone slot is lower than that of the crossed slot by 1.5 dB.

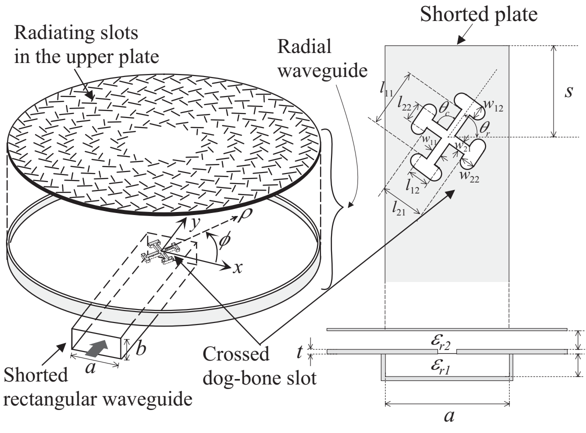


Figure 1: Structure of the rectangular-to-radial waveguide transformer through a crossed dog-bone slot with a CA-RLSA.

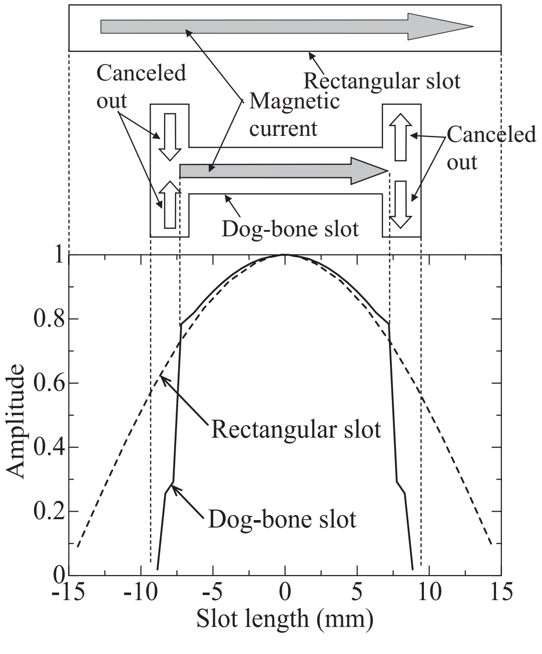


Figure 2: Magnetic current distributions of a rectangular slot and a dog-bone slot.

ISBN: 89-86522-79-9 94460©KEES

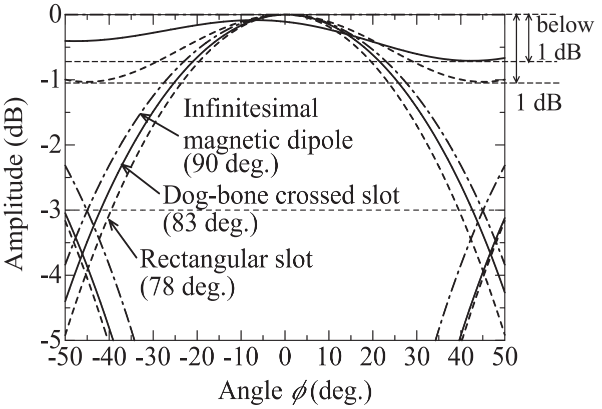


Figure 3: Field patterns of an infinitesimal magnetic dipole, a half-wavelength dipole and a crossed dog-bone slot.

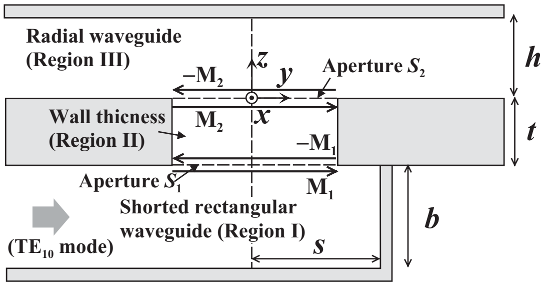


Figure 4: Analysis model of the transformer through a crossed dog-bone slot.

Table 1: Parameters of the transformer.

Frequency		5.8 GHz	**Radial waveguide**	h	6.00 mm
Crossed dog-bone slot	l_{11}	13.3 mm		ε_{r2}	1.00
	l_{12}	7.0 mm	**Rectangular waveguide**	a	40.0 mm
	l_{21}	10.6 mm		b	6.70 mm
	l_{22}	5.4 mm		t	1.50 mm
	$w11$, $w21$	2.70 mm		ε_{r1}	1.00
	$w12$, $w22$	3.30 mm		s	28.7 mm
	θ_r	55.0 deg.			
	θ_c	90.0 deg.			

2 Structure

Figure 1 shows the structure of a crossed dog-bone slot transformer with a CA-RLSA. A shorted rectangular waveguide is placed on the lower plate of the radial waveguide, which is common to the broad wall of the rectangular waveguide. In this transformer, the position of the shorted plate and the waveguide height are the leading design parameters for matching.

A crossed dog-bone slot is composed of two slots with different lengths. The length of one slot is shorter than the resonant length whereas the other is longer so that the excited amplitudes from each slot are equal and the phase difference is 90 degrees. The dog-bone crossed slot realizes a rotating mode ($\exp(-j\phi)$) in the radial waveguide in principle.

Since the half beam width of an infinitesimal magnetic dipole is 90 degrees, two crossed infinitesimal magnetic dipoles with excited phase difference of 90 degrees realize an ideal rotating mode. However amplitude distribution in the ϕ-direction is not actually uniform because the beam width of a magnetic dipole of finite length is narrower than that of an infinitesimal dipole. Two rectangular slots of a conventional crossed slot can be regarded as half-wavelength dipoles with the half power width of 78 degrees; therefore, the amplitude ripple in the ϕ-direction of the crossed slot becomes 1.0 dB at the minimum. Figure 3 shows the magnetic current distributions of a rectangular slot and a dog-bone slot. The amplitude is normalized by its maximum. The magnetic current of the rectangular slot decays smoothly near its edges. On the other hand, the magnetic current of the dog-bone slot decays rapidly near its edges because the magnetic currents in the edges are canceled out. Since the effective length of the dog-bone slot is shorter than the length of the rectangular slot, the beam width of the dog-bone slot becomes wider than that of rectangular slot.

Figure 4 shows the field patterns of an infinitesimal magnetic dipole, a half-wavelength dipole and a crossed dog-bone slot. The fields are amplitude of E_z at the height $h/2$ in a radial waveguide. The half power width of the dog-bone slot is 83 deg. The beam width of dog-bone slots is wider than that of rectangular slots; therefore, crossed dog-bone slots have the potential of the amplitude ripple below 1.0 dB in the ϕ-direction.

3 Analysis model

Numerical eigenmode basis functions are applied in the method of moments (MoM) [4]. Figure 5 shows the model for the MoM. The basis functions of the magnetic current in the MoM are eigenmode functions of a waveguide with a cross section of the crossed dog-bone slot. They are derived numerically by edge-based FEM. The reactions in the wall thickness (region II) are simply expressed in terms of the slot thickness and the propagating constant without taking mode summations due to the orthogonality of the eigenmode functions. The region of radial waveguide (region III) can be replaced with an equivalent model, which includes the original magnetic currents and their images due to the parallel plates all in a free space [5]. In this model with the images, fast convergence of the sum is obtained by using Poisson's formula.

4 Design and experimental results

A crossed dog-bone slot transformer in the 5.8 GHz band is designed by using the analysis described in the previous section. The design objectives are to suppress the reflection below -15 dB and to minimize the ripples of the amplitude in the ϕ-direction at the design frequency. Figure 1 shows the parameters and Table 1 summarizes their values. In the design, the frequency f, the height h of a radial waveguide, the permittivity ε_{r1} and ε_{r2} of the waveguides, the broad-wall width a of a rectangular waveguide, and the crossed angle θ_c are given. The other parameters are determined by the following steps. (1) The position s of the shorted plate is determined to minimize the reflection at the design frequency. (2) The height b of the narrow wall is given to suppress the reflection. (3) By changing the parameters of the crossed slot l_{11}, l_{12}, l_{21}, l_{22}, and θ_r, the ripple of the amplitude in the ϕ-direction is minimized. (4) The above numerical investigation (1)-(3) is repeated until the lowest ripple of the amplitude and the reflection is achieved. As a result of the iterative design for matching, the rectangular waveguide becomes thinner (a:b=6:1) than that of a standard one and the shorted position s is about $\lambda_g/2$. In the crossed dog-bone slot, the lengths $l_{11}+l_{12}+w_{12}$ and $l_{21}+l_{22}+w_{22}$ of the magnetic currents are longer and shorter than the resonant one, respectively, and the rotating angle θ_r is 55.0 degrees. The calculated ripple of the amplitude and the deviation of the phase in the ϕ-direction are 0.76 dB and 6 degrees.

Inner field is measured to confirm the quality of a rotating mode in a radial waveguide. By using the measurement set-up shown in Fig. 6, the inner field is picked up by a probe azimuthally moving along slots on the top plate of the radial waveguide. In this measurement, parallel slot pairs are adopted instead of orthogonal slot pairs. By using the parallel slot pairs, we can measure the field distribution in high precision, because the parallels slots do not disturb the field in the ϕ-direction than the orthogonal ones. In a slot pair, the coupling is controlled by the length of one slot and the reflection suppression is realized by choosing the length and the distance of the other slot. Figure 7 shows the experimental and calculated results of the circumferential distribution of the inner fields in the radial waveguide. The measured results are shown by removing the unwanted oscillated components by the radiating parallel slot pairs in order to demonstrate clearly the variation due to only the feeding crossed dog-bone slot. As an experimental result, the ripple of the amplitude in the ϕ-direction is suppressed to 0.8 dB at 5.55 GHz. The measured phase is linearly tapered with a deviation of 6 degrees.

5 Conclusion

A rectangular-to-radial waveguide transformer through a crossed dog-bone slot has been proposed and analyzed by using the MoM. The calculated and measured amplitude ripples in the circumferential direction have been 0.76 dB and 0.8 dB, respectively in the 5.8 GHz band.

References

[1] N. Goto and M. Yamamoto, "Circularly polarization radial line slot antennas," IEICE Technical Report, AP80–57, Aug. 1980.

[2] M. Ueno, M. Takahashi, J. Hirokawa, M. Ando, and N. Goto, "A rotating mode radial line slot antenna – concentric array–," IEICE Technical Report, vol.AP93-43, Jun. 1993.

[3] K. Sudo, T. Hirano, J. Hirokawa and M. Ando, "A radial line slot antenna fed by a rectangular waveguide through a crossed slot," IEICE Trans. Electron., vol.E86-B, no.10, pp3063–3070, Oct. 2003.

[4] 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," IEE Proc. Microwaves, Antennas Propagat., vol.147, no.5, pp.349–353, Oct. 2000.

[5] M. P. Sierra, Maria Vera-Isasa, Antonio Garcia-Pino, and Manuel C. Sierra, "Analysis of slot antennas on a radial transmission," International J. of Microwave and Millimeter-Wave Comput.-Aided Eng., vol.6, no.2, pp115–127, Feb. 1996.

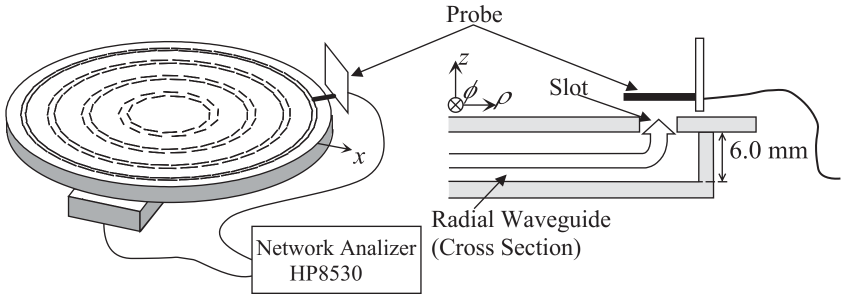
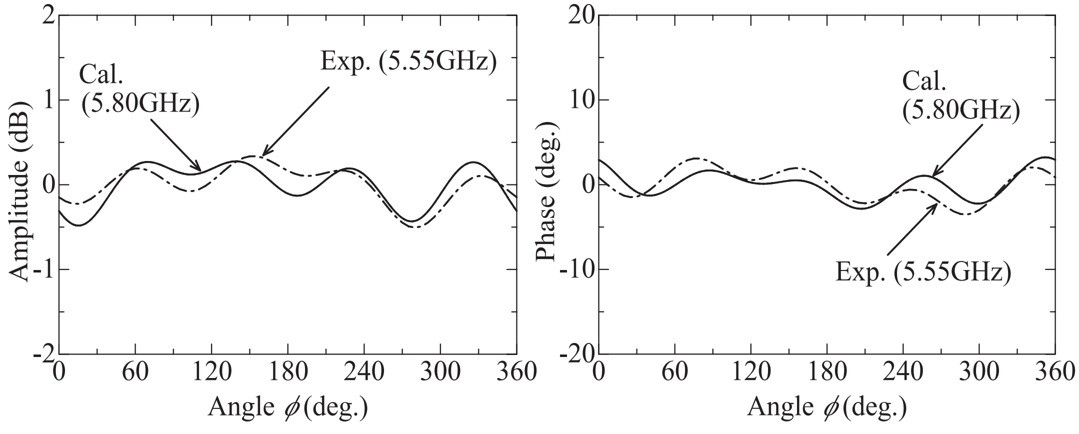


Figure 5: Measurement method of the inner field.



(a) (b)

Figure 6: Inner field distribution in the ϕ-direction.