Grating-Lobe Suppression in a Linear Array of a Hollow Waveguide Transverse Slots by a Layer of Parasitic Dipole-Quartets

Mitsuru Kirita, Jiro Hirokawa, Makoto Ando
Dept. of Electrical and Electronic Engineering, Tokyo Institute of Technology
S3-19, 2-12-1 Ookayama, Meguro-ku, Tokyo 152-8552, JAPAN,
kirita@antenna.ee.titech.ac.jp

Abstract

A linear array of transverse slot on the broad-wall of a hollow waveguide suffers the grating lobe problem because the element spacing is longer than the free-space wavelength. Addition of a parasitic dipole pair just above each slot was proposed to suppress the grating lobes. However the calculation of the three-dimensional radiation pattern of the slot and the dipole pair reveals that they have unwanted radiation to oblique directions. In order to solve this problem, a parasitic dipole quartet is introduced for each slot in this paper. This configuration can suppress the unwanted radiation to -13dB on $\phi = 90^o$ and -15dB on $\phi = 50^o$ in the experiment.

1. Introduction

A broad-wall transverse slot array on a hollow waveguide is important because it radiates linear polarization parallel to the waveguide axis. The transverse slot array requires the slot spacing of a guided wavelength which is always greater than the free space wavelength for the boresight radiation, hence the array suffers from unwanted grating beam radiations. The authors proposed a new way of grating-lobe suppression by installing a parasitic dipole pair layer over the slot array [1]. A dipole pair is placed at a height of half free-space wavelength from each slot as shown in Fig.1 to generate a Dual Parasitic Beam (DPB) [1] that suppresses the radiation of the slot in the directions of the grating lobes less than -15dB in the E-plane ($\phi = 90^o$ and $\theta \cong \pm 50^o$). However there may be some unwanted radiations in other oblique direction since the spacing between the elements is larger than the free-space wavelength.

In this paper, the authors calculate the three-dimensional radiation pattern of this element consisting of a slot and a dipole pair. The calculation reveals we have unwanted radiations in oblique directions ($\phi = 50^o$ and $\theta \cong \pm 90^o$). This paper proposes new configuration consisting of a dipole quartet and a slot to suppress it. The dipole quartet is referred as two dipole pairs or four dipoles in this paper. This configuration gives about -13dB suppression in the E-plane ($\phi = 90^o$), and -15dB suppression in the oblique directions ($\phi = 50^o$) in the experiment.

2. Three-Dimensional Radiation Pattern of a Slot and a Dipole Pair

The configuration of a slot and a dipole pair is shown in Fig.1. The integral equations for the excitation coefficients of the currents on the slot and the dipoles are obtained by the continuity conditions of the magnetic fields on the slot apertures and the null conditions of the electric fields on the dipoles. The mutual coupling is taken into account in the unit. The integral equations are solved using the Gelarkin's MoM (method of moments). Radiation patterns are calculated based on the far field approximation of Maxwell's equations and Fourier transform method [2-3]. The three-dimensional radiation patterns will be expressed as functions of the wave-number components k_x and k_y. The k_x and k_y are given in eq.(1),

$$\frac{k_x}{k_o} = \cos\phi \sin\theta, \quad \frac{k_y}{k_o} = \sin\phi \sin\theta \qquad (1)$$

as functions of the radiation direction (θ, ϕ) as shown in Fig.1. The offset y_d and height h_d of the dipole pair is usually 0.0mm and $\lambda_0/2$ to keep its symmetric property and to generate DPB. The other parameters are determined to minimize the radiation in the direction towards the grating lobes in the E-plane. The parameters are listed in Table 1. The design frequency is 12.0GHz. A WR-120 waveguide is used. Fig.2 shows a six-element array. Fig.3 shows the three-dimensional radiation pattern of the array factor of a uniformly-excited six-element array spaced by the guided wavelength. The grating lobes exist around $-0.65 < k_x/k_0 < 0.65, k_y/k_0 = \pm 0.75$. Fig.4 shows the three-dimensional radiation pattern of the element. Fig.5 shows the pattern of the six-element array, which is obtained by multiplying the element pattern in Fig.4 with the array factor in Fig.3. Two dot lines indicate the cut-planes on $\phi = 50^o$ and $\phi = 90^o$ in each figure. In the element patterns, the radiations to $\theta \cong \pm 50^o$ on $\phi = 90^o$(in the E-plane) are suppressed to -20dB, so that the radiations in these directions suppress well in the array even though the array factor has the grating lobes there. However, the element pattern has radiation in directions of $\theta \cong \pm 90^o$ on $\phi = 50^o$, so that the grating lobes of the array factor cannot be suppressed by the element pattern there. This confirms by the measured radiation patterns shown in Fig.6. The thick line represents the experimental result and the dot line represents the calculated results by MoM. The grating lobe level around $\theta \cong \pm 90^o$ on $\phi = 50^o$ is -3dB.

3. Configuration of a Slot and Four Dipoles(Dipole quartet)

To suppress the unwanted radiations to $\theta \cong \pm 90^o$ on $\phi = 50^o$, a new configuration is proposed to consist of a slot and four dipoles as shown in Fig.7. The dipoles are not placed above the slot. Two dipole pairs are spaced by a half guided wavelength in the longitudinal direction. The common height of the dipoles and the spacing in the transverse direction between two dipoles in a pair should be determined to suppress in the directions not only to $\theta \cong \pm 50^o$ on $\phi = 90^o$ but also to $\theta \cong \pm 90^o$ on $\phi = 50^o$. The parameters are listed in Table 1. Fig.8 shows the six-element array. Fig.9 shows the three-dimensional radiation pattern for the unit element. Two dot lines indicate the cut-planes on $\phi = 90^o$ and $\phi = 50^o$. Fig. 10 and Fig. 11 show the experimental patterns in the cut planes on $\phi = 90^o$ and $\phi \cong 50^o$, together with the simulated results by MoM, HFSS and array factor in each cut-plane. The sidelobe level is -13dB around $\theta \cong \pm 50^o$ on $\phi = 90^o$ and about -15dB around $\theta \cong \pm 90^o$ on $\phi = 50^o$ in the experimental results. The HFSS results have good agreement with the experimental results. The disagreement with the MoM calculation could come from the insufficient assumption of the dipole currents only using the first-order sinusoidal function because the dipoles have separation from the slot in the longitudinal direction. Higher-order basis functions would need to be taken into account in the MoM. Fig.12 shows the pattern of the six-element array, which is obtained by multiplying the element pattern in Fig.9 with the array factor in Fig.3. The grating-lobes level is under -15dB at MoM calculation.

4. Conclusion

The three dimensional radiation patterns have been introduced to verify the validity of the grating lobe suppression by placing a dipole pair above each transverse slot array on a hollow waveguide. The radiations in the directions for the grating lobes are suppressed but the unwanted oblique radiations exist. New configuration that consists of a slot and four dipoles has been proposed to suppress the unwanted radiation. In the measurement of the radiation pattern of the unit, the sidelobe level is -13dB around $\theta \cong \pm 50^o$ on $\phi = 90^o$ and about -15dB around $\theta \cong \pm 90^o$ on $\phi = 50^o$.

Acknowledgments

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Table 1: Parameters Unit: *mm*

Type	L_s	W_s	L_d	W_d	x_d	y_d	h_d
Dipole pair	11.52	1.0	11.8	2.0	6.5	0.0	12.5
Dipole quartet	12.5	1.2	12.0	2.0	7.0	8.0	14.0

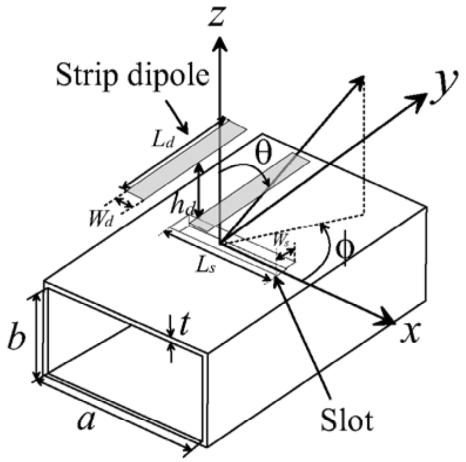

Fig. 1: Structure of a slot and a dipole pair

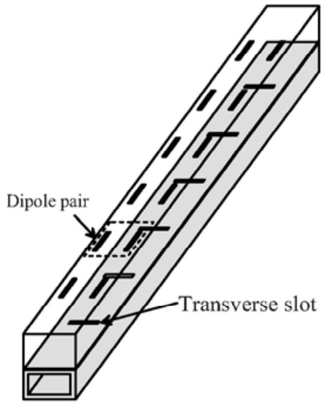

Fig. 2: 6-element array of 6 slots and 6 dipole pairs

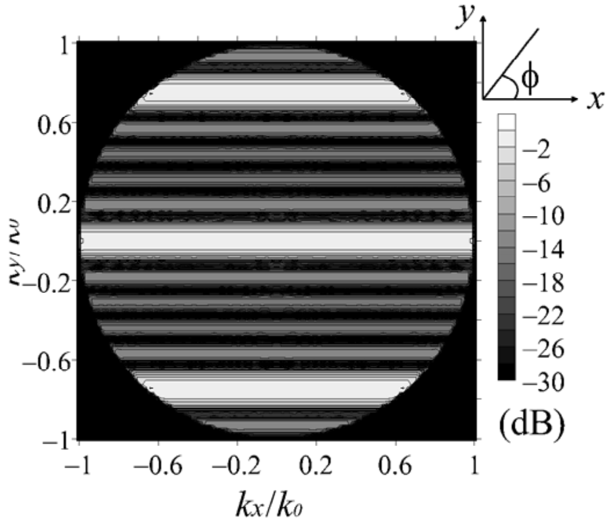

Fig. 3: Array facotor of a uniformly-excited six-element array

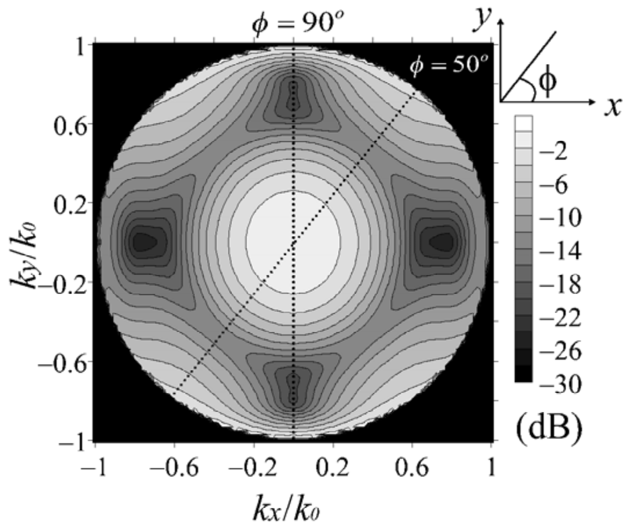

Fig. 4: Three-dimentional radiation pattern for the unit of a slot and a dipole pair

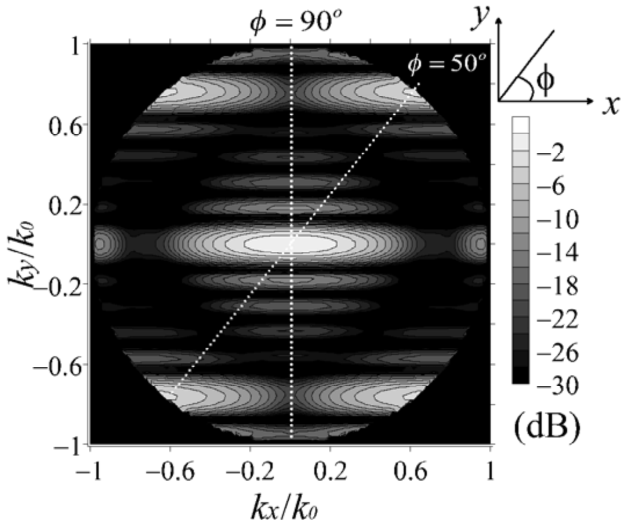

Fig. 5: Three-dimentional radiation pattern for 6 slots and 6 dipole pairs array

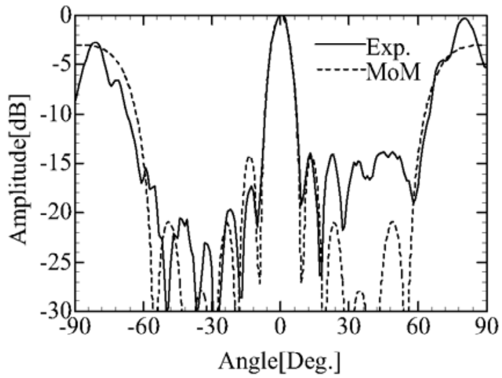

Fig. 6: Radiation pattern for 6 slots and 6 dipole pairs array on $\phi = 50^o$

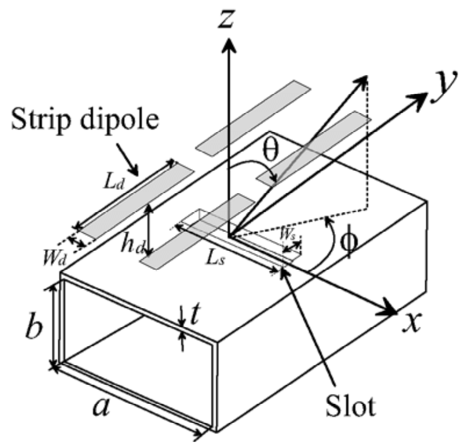

Fig. 7: Structure of a slot and a dipole quartet

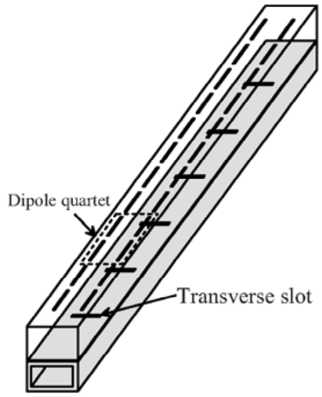

Fig. 8: 6-element array of 6 slots and 6 dipole quartets

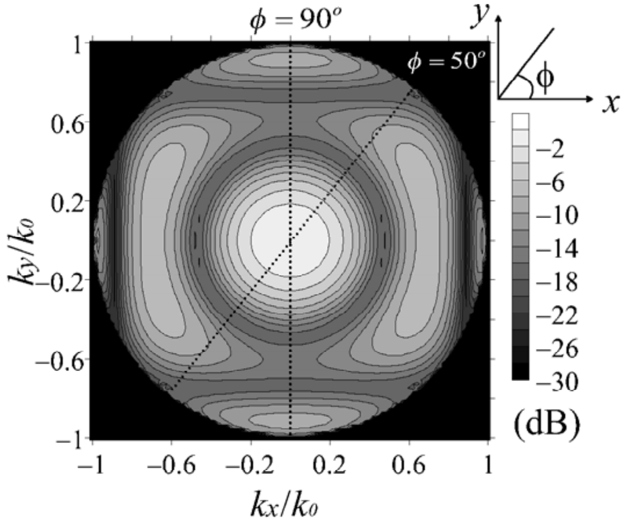

Fig. 9: Three-dimentional radiation pattern for the unit of a slot and a dipole quartet

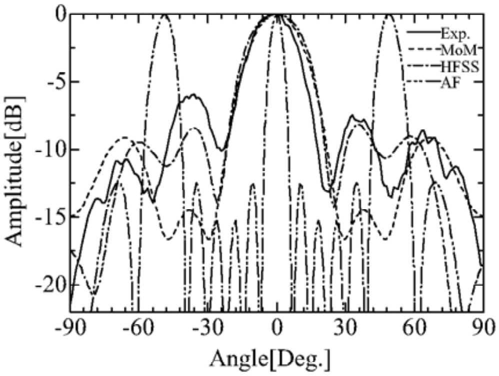

Fig. 10: Radation pattern for the unit of a slot and a dipole quartet on $\phi = 90^o$

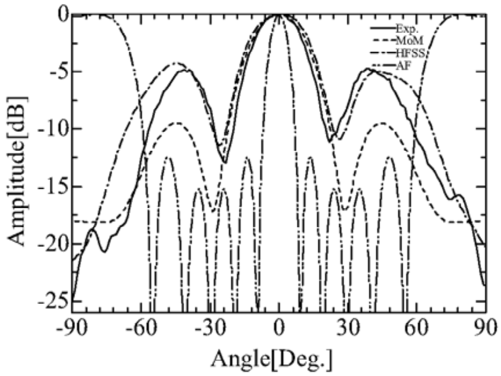

Fig. 11: Radation pattern for the unit of a slot and a dipole quartet on $\phi = 50^o$

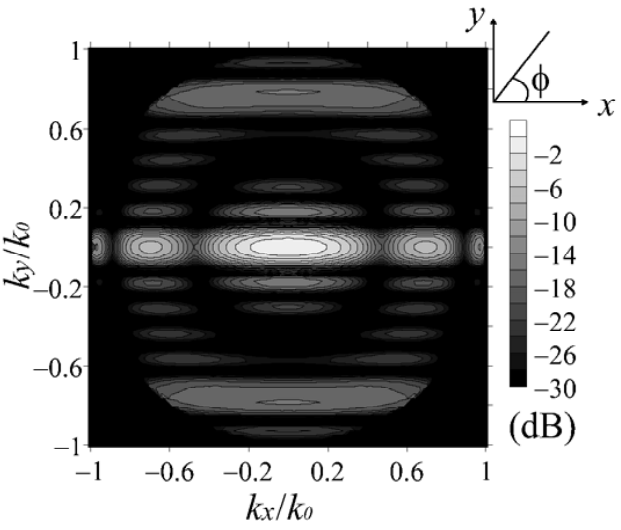

Fig. 12: Three-dimensional radation pattern for 6 slots and 6 dipole quartets array