Non-Iterative Design of a Waveguide Slot Array with Baffles to Realize Admittance of an Isolated Slot

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1. Introduction

In design of a waveguide slot array, it is important to take the effect of the external mutual couplings into account because they are large [1], [2]. The analysis including the mutual couplings has received much attention in literatures for more than fifty years [3]. Control of the mutual couplings is so difficult that various kinds of the analysis and design methods have been proposed. In [1] and [2], the design procedures were iterative, where the slot parameters were modified by calculating active admittances in the presence of mutual couplings in order to produce a desired far field pattern . The evaluation of mutual couplings was more time-consuming for a larger number of the slots. In [4], the design procedure with fast convergence was proposed to design a planar array with the feeding part of the tilting slots. This procedure had an advantage of the low variations of the mutual couplings between shunt slots for the offset and the length. In the design of the radiating parts for the single-layer slotted waveguide array antennas [5], [6], the slot unit model to simulate the mutual couplings for an two-dimensional infinite periodic array, was used to determine the initial values of the slot parameters for a desired distribution [7]. The slot parameters were compensated iteratively until realizing the desired excitation by introducing a finite number of magnetic currents at the both sides of the one-dimensional array in the external region. The iterations were required because the situation of the external mutual couplings was different between the infinite periodic array for the initial values and the finite one for the compensations.

This paper proposes the non-iterative design of a waveguide slot array with baffles [9] or cavities, shown in Figs. 1 and 2, where their sizes are determined so that the active admittance of each slot is equal to the admittance of an isolated slot with same dimension. In other words, the baffles or the cavities are designed not to affect the external mutual couplings to the slot(s) inside them at all. The baffle region or the cavity region acts as a choke and its surface is open-circuited. Furthermore, we find the size of the baffles or the cavities which is independent on the slot coupling except very strong one. The size is not needed to be changed for the slot coupling, which makes the design simple. This non-iterative design can realize a desired excitation easily. This method is adopted for two types of excitations; a uniform distribution and a Taylor one with -35 dB sidelobes.

2. Baffles and cavities to realize active admittance of an isolated slot

We design two-dimensional slot arrays with alternating-phase feed between adjacent waveguides. The sizes of the baffles or the cavities are found to realize the active slot admittance equal to that of the isolated slot with same slot dimensions in half-free space, as shown in Fig.3. Fig.4 shows the model of two slots with the baffles. The slots are assumed to have the equal amplitude and phase and a spacing of half guided wavelength. The slot drawn by a dashed line is assumed only in the external periodic region to include the external mutual coupling with the slot drawn by a solid line. The scattering matrix for the slot drawn by the solid line will be derived. This model has two discontinuities. One is due to a slot between the radiating waveguide and the baffle region and the other is the aperture or the step between the baffle region and the exterior periodic region extracting one radiating waveguide considering the alternating-phase feed. The scattering matrix of each discontinuity is separately derived. The matrices of the two discontinuities are connected. The scattering matrix for the slot is obtained by the method of moments. The matrix for the aperture is derived by the mode matching method, where only TEM mode propagates in the region because of the in-phase excitation of the two slots. Fig.5 shows the slot unit model surrounding with PEC walls, for the cavity. The exterior region is introduced by periodic boundary walls to simulate the periodicity of field in the longitudinal direction and PEC walls to reflect the alternating-phase feed in the transverse direction. The model is analyzed by HFSS.

Fig. 6 shows the active admittances for small offset with weak coupling in (a) and large offset with strong coupling in (b), as functions of the baffle size. The real parts of the admittance of an isolated slot for corresponding coupling in half-free space are 0.13 and 0.53, respectively. The solid and dotted lines indicate the real and the imaginary part of the admittance, respectively. The baffle width is 0.52 λ (6.2mm) and the height is 0.14 λ (1.7mm) to get the admittance of the isolated slot with the same slot dimension. This size is irrespective of the slot coupling except very strong one (more than 35%). For the cavity, the size is determined similarly to the baffles, independent on the slot coupling. The cavity width c_1 is 0.42 λ (5.0mm), the length c_2 is 0.57 λ (6.78mm) and the height c_3 is 0.38 λ (4.5mm).

3. Design for a uniform distribution and a -35dB-Sidelobe Taylor Distribution

The design frequency is 25.3 GHz. The parameters are shown in Table 1. The beam tilting is used to suppress the reflection. The admittance for each slot is determined in order to realize uniform distribution for 16 waveguides and 18 slots per waveguide, and Taylor distribution with -35 dB sidelobes and $\bar{n}$ =5 for 24 waveguides and 27 slots per waveguide. The uniform distribution is designed both for the baffles and the cavities, while the Taylor one is achieved only for the cavities. The slot offset and length are derived for the determined admittance for the sizes of the baffles or cavities given in Section 2. The full structure of the array models are simulated by HFSS. Fig. 9 and 10 show the far-field pattern and the directivity, respectively. The first sidelobe levels are -13.3 dB on the side toward the feeding waveguide and -15.3 dB on the side toward the matching slot in H-plane, and are -13.3 dB in the both sides of E-plane. The directivities are 32.6 dB for the baffles and cavities.

The gain of a regular antenna without the baffles or the cavities is 32.1 dBi at 25.33GHz for 16 waveguides and 19 slots per waveguide by the conventional iterative design [10]. The proposed design with the baffles or cavities gives almost equal aperture efficiency in comparison with the conventional one. Fig. 9 shows the amplitude and phase of the excitation of each slot on one radiating waveguide assuming the periodic boundary walls in the transverse direction in the exterior region, by using the spectral domain approach. The deviation of the amplitude and phase in the antenna with the baffles are 4.8 dB and 15.7 degrees, while those without the baffles are 10.4 dB and 23.3 degrees. Uniformity along the waveguide axis is improved by the baffles. The 1dB-down bandwidth for the directivity of the antenna with the cavities is 1.12 times wider than that with the baffles because each cavity is separated from each other and the cavities can be more stable or tolerable against perturbation than the baffles.

Fig. 11 and 12 show the far-field pattern and the directivity for the Taylor distribution, respectively. The main lobes have shoulders around -30dB level in the radiation patterns both in the E and H planes. The active admittance for very strong coupling near the end of the waveguide could not be the desired one. The other sidelobes are suppressed below -35.0dB in H-plane and -33.1dB in the E-plane.

4. Conclusions

We find the sizes of the baffles or cavities for the active slot admittance to be equal to that of an isolated slot with same slot dimensions in half-free space. We propose the non-iterative design of a waveguide slot array with the baffles or cavities for a uniform and a -35dB Taylor distributions. This method can drastically simplify the design procedure of the waveguide slotted array in comparison with the conventional iterative design. The proposed design can realize almost equal aperture efficiency in comparison with the conventional one for uniform excitation. For the Taylor distribution, the sidelobes can be suppressed below -35.0 dB in H-plane and -33.1dB in E-plane even though the main lobe has shoulders around -30dB level.

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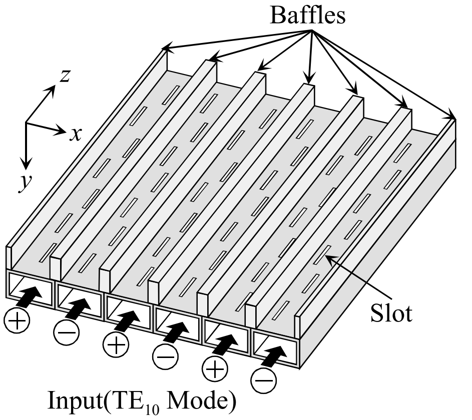


Fig. 1 Alternating-phase feed waveguide slot array model with baffles.

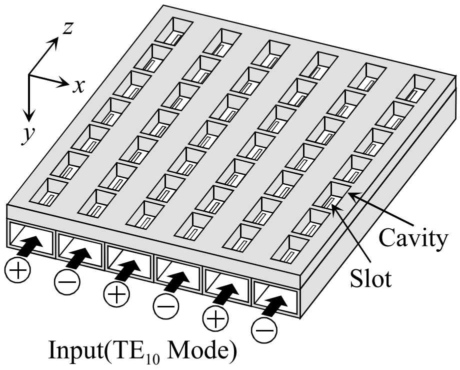


Fig. 2 Alternating-phase feed waveguide slot array model with baffles.

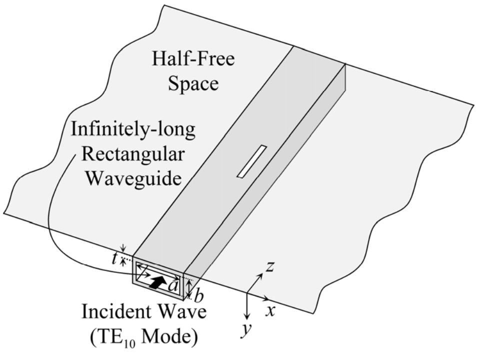


Fig. 3 Isolated slot in half-free space.

Table 1 Antenna Parameters.

	Uniform Excitation With Baffles	Uniform Excitation With Cavities	Taylor Exciation With Cavities
Center Frequency	25.3 GHz		
Waveguide Width *a*	8.0 mm		7.9 mm
Waveguide Height *b*	3.0 mm		
Slot Width *w*	0.5mm		
Slot Plate Thickness *t*	0.5 mm		
Perfect Electric Conductor Wall Width p_x	10.0 mm		9.4 mm
Periodic Boundary Walls Width p_z	15.68 mm	7.84 mm	7.63 mm
Beam tilting angle	-4.82 deg.		-6.61 deg.

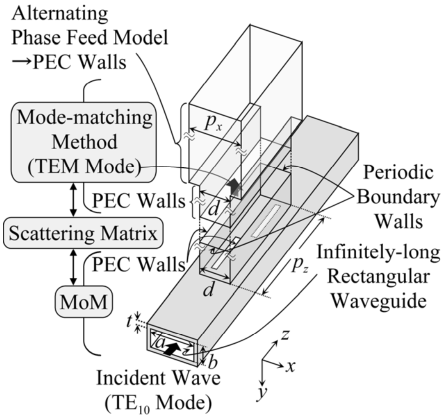


Fig. 4 Model for the unit design of baffles

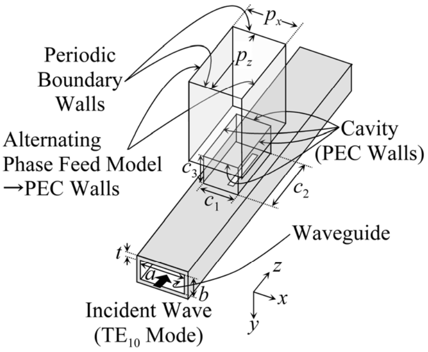
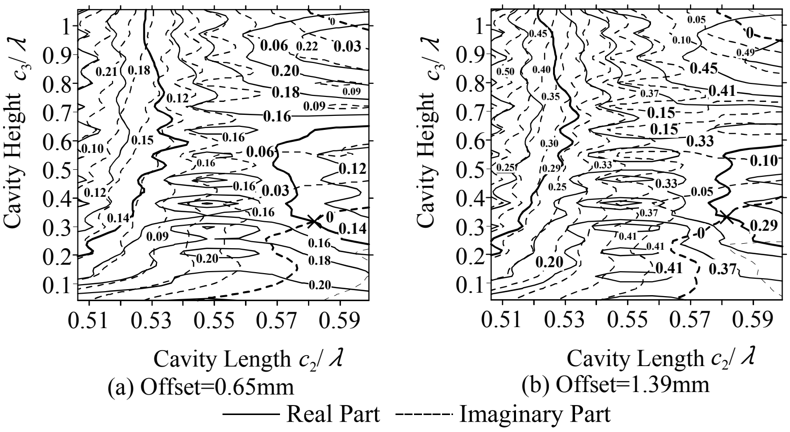


Fig. 5 Model for the unit design of baffles



(a) Offset=0.65mm (b) Offset=1.39mm

Fig. 6 Normalized slot admittances

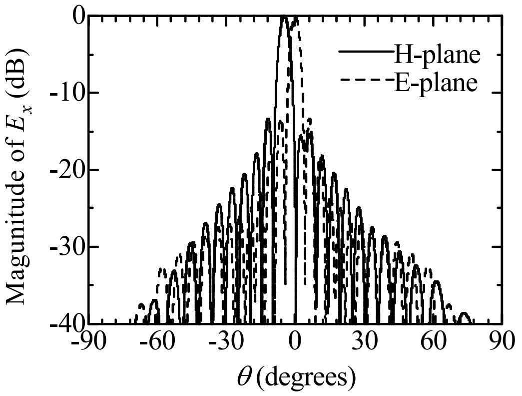


Fig. 7 Radiation pattern for
the uniform distribution at 25.3 GHz

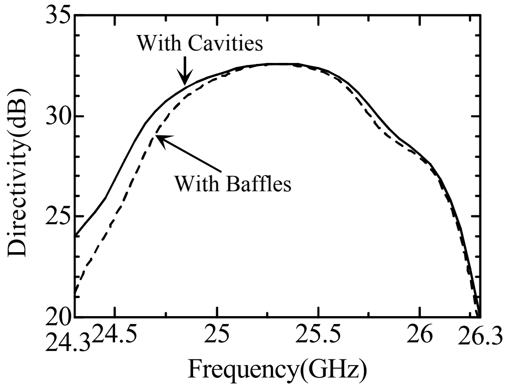


Fig. 8 Directivity for the uniform distribution

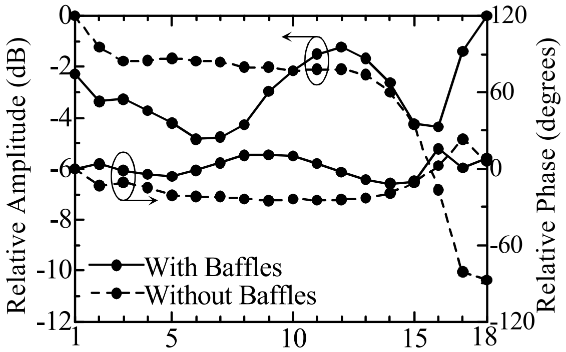


Fig.9 Amplitude and phase of
the electric far-filed from each slot

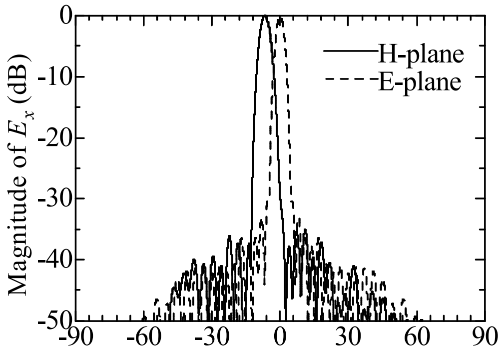


Fig.10 Fig. 7 Radiation pattern for
the Taylor distribution at 25.3 GHz