Aperture Illumination of a Circular Polarization Oversized Rectangular Waveguide Slotted Array

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Abstract

A circularly polarized slotted oversized waveguide array is designed and antenna characteristics such as aperture illumination, radiation patterns and axial ratio are predicted. The approximate model reflecting the reflection-canceling feature of slot pairs dispenses with the full analysis of practical structure with thousands of slots.

1. Aperture illumination of slotted oversized waveguide arrays

Rectangular parallel plate slotted arrays using dielectric substrate, named a post-wall waveguide array shown in Fig.1are attractive candidates for high efficiency and mass producible planar array antennas in millimeter wave applications[1-5]. A large parallel plate is shorted by densely arrayed metal-surface via-holes and works as the antenna aperture with slots on it. A TEM-like wave is excited at one end of the parallel-plate by a feed waveguide through the coupling windows, which consist of posts as well. The dimension of the plate in transverse direction is very large compared with the wavelength. So the structure is fully oversized. The two-dimensional array consists of radiation units as element, each one of which satisfies the reflection canceling design rule [6]. The unit consists of slots and depends upon the polarization requirement as shown in Fig.2 As an example, number of radiation units is 24x20 units that are 960 slots (480 pairs) in 0-deg linear and circular polarization antenna, 1440 slots in 45-deg linearly polarization antenna with the aperture 19 $\lambda\varepsilon$ x 19$\lambda\varepsilon$. Since the reflection from units is negligible, traveling wave operation is expected in the oversized guide. As the first approximation in the design of slot, we assume the infinite arrays and impose the periodicity of the inner field distribution in parallel plate waveguide; slot length, width, angle and position is determined using the linear array model with periodic boundary walls shown in Fig.3. In the real structure of the arrays, on the other hand, the aperture size is large but is still finite (10-40 wavelengths). So several strange behaviors have been observed, which are unique and inherent to the oversized waveguide arrays. For an example, Figure.3 (a) shows measured result of aperture illumination of 45-deg linearly polarized parallel plate slotted array. The aperture field uniformity suffers from a triangular area of low illumination, in the left bottom part in the aperture. For enhancing the quality and the accuracy of the array design, an accurate model of the inner field and aperture illumination in the oversized waveguide arrays. However, it is not realistic to conduct the full wave analysis of large two-dimensional slotted array with thousands of slots. The authors proposed effective and easy analysis method for determining the inner field, subsequent slot excitation coefficients and aperture illumination that dispenses with the matrix calculation in the full wave analysis [7]. As the result, we succeed in explaining the illumination defects in left bottom for 45 deg polarization antenna as shown in Fig.3 (b)

In this paper, the authors design a circularly polarized rectangular slotted array and apply this simplified model for the prediction of antenna characteristics.

2. Scattering Field due to Radiation Units

Figures 4(a) and (b) show two examples of scattering fields from one and 24 slot pair(s) respectively. It is found that the scattering toward –z direction or the reflection is canceled in a pair and fields are directed only in the lower

(+z) direction. The above reflection-canceling feature of circular polarization slot pair suggests us the following approximation.

3. Basic Procedure of Analysis

Excitation field for a radiation unit at some points consists of the two contributions, that is, unperturbed oversize waveguide field and scattering fields from all the slots. For the latter, the rigorous analysis is not practical for larger arrays with thousands of slots and perturbation approximation is introduced here. The oversize waveguide field after propagation in the oversized waveguide [8] and scattering fields from slots result in non-uniform excitation field for slots arrayed in the x-direction. The slots in the lower position in the waveguide in the traveling wave operation would be seriously perturbed. Figure 5 shows the analysis model of oversized waveguide as well as the calculation procedure. The periodic boundary wall model used for slot design is also included in the bottom. The aperture has M (row) x N (column) radiation units while the periodic model has 1 x N units. As for the scattering field from slots observed at (p_m,q_n), the contribution from units only in the upper (n=#1, #2 ...#n-1) region is important since reflection canceling units radiate only in forward direction as is shown in Figs 4(a) and (b). We determine slot excitation coefficients using the following procedures. <1> Calculate the TEM-like dominant mode (total field arrived at the unit #n) I_n and slot excitation coefficient V_n of slots at #n radiation units in the design model with periodic boundary wall. <2> Calculate incident field I_{mn} at column n and row m (=1, 2 ...M) by the sum of unperturbed oversize waveguide field $H^{inc.}_{mn.}$ in an oversized waveguide and the scattering fields from all the slots in the upper position (p_m,q_n) (m=1, 2,…M, n=1, 2,…n-1). Perturbation ratio of incident field k_{mn} is defined by the incident field I_{mn} at the position (p_m,q_n) in the oversized waveguide and that (I_n) at position q_n in the design model with periodic boundary wall.

This ratio is not uniform for m and accounts for perturbation due to narrow wall and slots in the finite array. This defect has been neglected in the periodic boundary wall model assuming infinite size of the array and the parallel plate. Excitation coefficients of unit at (p_m,q_n) with this perturbation taken into account are given by

$$V_{mn} = k_{mn} V_n\ , \qquad n = 1,2,3,....N \qquad m = 1,2,...M \quad (1)$$

Aperture illumination in the plane of slots is calculated by Fourier transform of plane wave spectrum of the array in visible region and is compared with the illumination calculated from near field measurement data.

4. Analysis Result

Figure6 shows predicted result of excitation coefficients of slots at the lower column (n=15) position for uniform excitation source. Points show estimated excitation coefficients of slots normalized by that of periodic boundary wall model, while the line shows the distribution of oversize waveguide field without perturbation due to slots. Deviation from the unity corresponds to perturbation. Distribution of excitation coefficient agrees with that of oversize waveguide field almost everywhere; it implies the perturbation due to the narrow walls is dominant. Figure 7 shows calculated aperture illumination. As the perturbation due to the narrow wall is dominant aperture illumination has ripple around the center of waveguide and low amplitude near the side wall.

Figure8.shows calculated radiation pattern in the plane parallel to the feed waveguide (x-direction). The solid line shows calculated radiation pattern without perturbation. The dotted line shows that with perturbation .The wide angle sidelobes are lower for radiation pattern with perturbation than that without perturbation, since the edge illumination is tapered down in Fig.6.

5 Conclusions

In this paper, the authors discussed about circular polarization oversized waveguide array to evaluation effect of slot arrangement based on internal traveling-wave field in an oversized rectangular slotted array. As the result, we found that the perturbation due to the narrow walls is dominant in this slot arrangement. Aperture illumination is similar to that of arrays for 0 deg linear polarization. Experiments are now conducted and the comparison between measured and calculated results will be presented.

6. Reference

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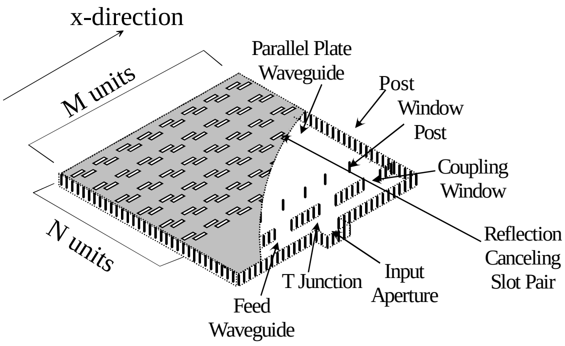
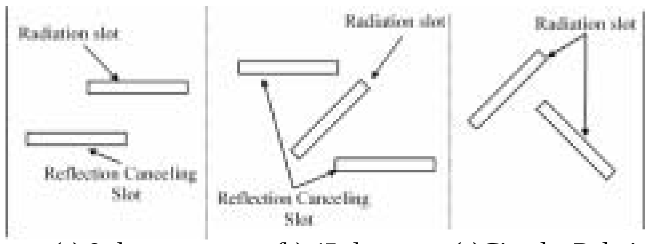


Fig.1 Parallel Plate Slotted Array



(a) 0-deg Linearly Polarized
(b) 45-deg Linearly Polarized
(c)Circular Polarized

Fig.2 Slot Arrangement for Polarization

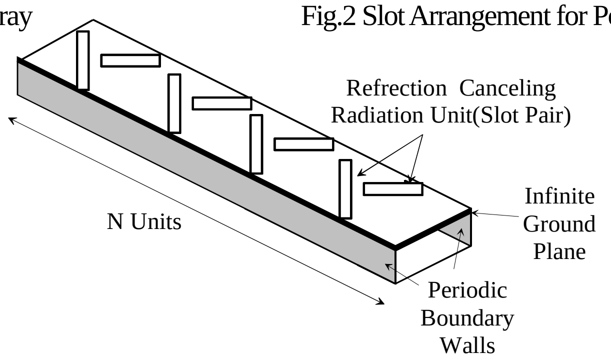
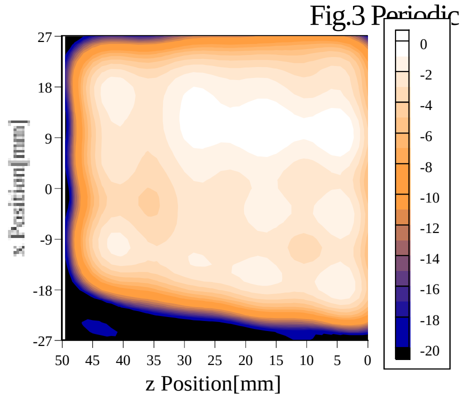
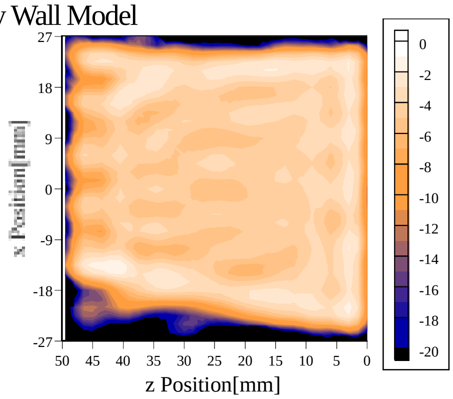


Fig.3 Periodic Boundary Wall Model

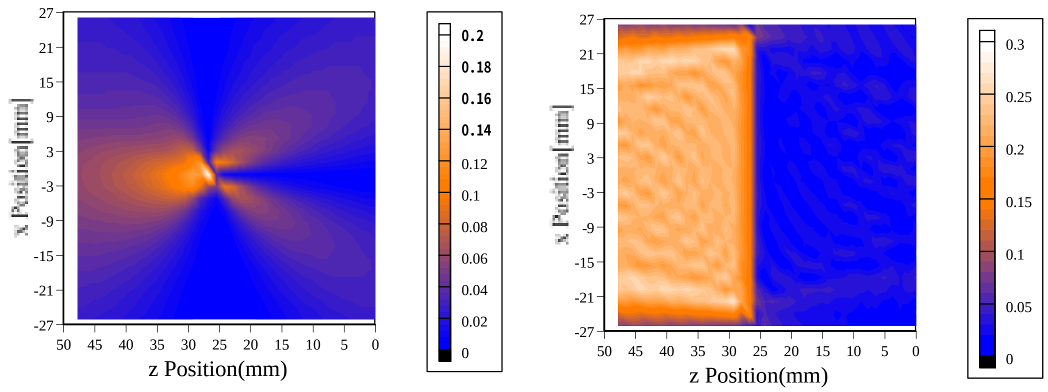


(a) Measured Result



(b) Calculated Result

Fig.3 Aperture Illumination of 45-deg linearly Polarized Parallel Plate Slotted Array



(a) 1Unit (b) 24 Units

Fig.6 Scattering Field due to Radiation Units

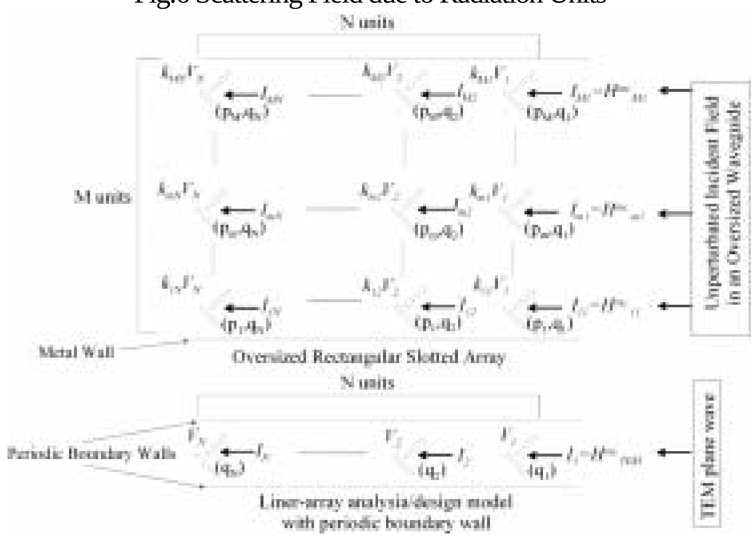


Fig.5 Estimation of Excitation Coefficient

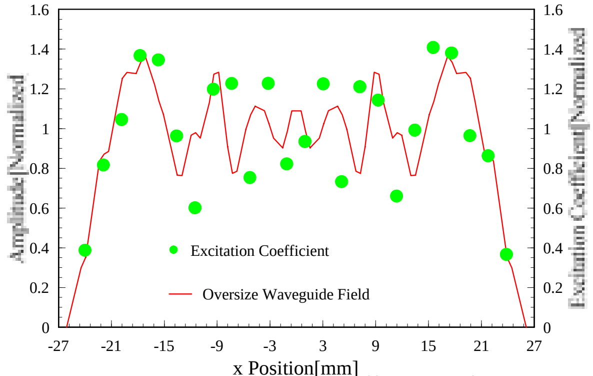


Fig.6 Estimated Excitation Coefficients of Slots

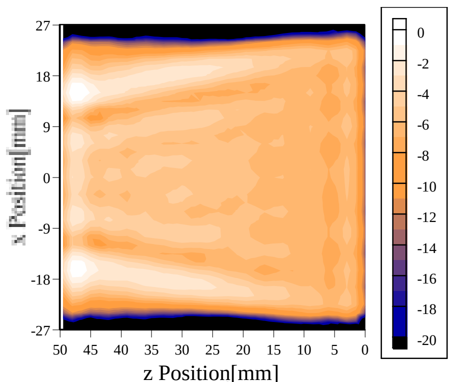


Fig.7 Calculated Result of Aperture Illumination

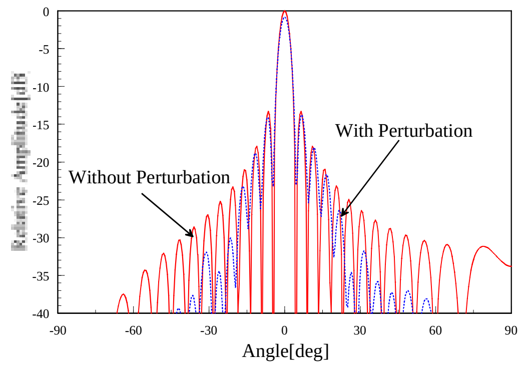


Fig.8 Calculated Result of Radiation Pattern to the Feed Waveguide