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Mechanical Phase Shifting by Moving the whole Sidewall in Single-Layer Slotted Waveguide Arrays with Obliquely-Arranged Feed Waveguide

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1. Introduction

Single-layer slotted waveguide arrays shown in Fig. 1 are high efficiency and high gain antennas. The simple structure is attractive for mass production as well. They have been developed for several applications in microwave and millimeter wave frequency bands [1][2]. The fully theoretical design method has already been available for basic specification of high efficiency, arbitrary polarization, low sidelobes etc. However, bandwidth widening, multibeam and beam scanning are still difficult demands for these unique slotted arrays. Amongst all, antennas with beam scanning are desired in various systems such as anti-collision car radars [3]-[5] for an example. The final goal is electrical scanning but mechanical scanning is still an attractive choice in terms of cost, heat-radiation and reliability, provided the antennas or the movable parts in it are light in weight and small in size. Single layer slotted waveguide arrays with beam scanning are the candidates in this respect.

In the conventional structure for mechanical phase shifting, a part of the side wall between two π-junctions [6], which is for co-phase feed, with spacing of one guide wavelength is movable [7]. In the alternating-phase feed, T-junction [8] [9], which is for alternating-phase feed, with spacing of a half the guide wavelengths is used, and it's difficult to obtain phase shifting by moving the part of the side wall. In this report, the whole side wall in the feed waveguide is moved to obtain phase shifting. The beam is scanned by controlling the guide wavelength in the feed waveguide, which can be changed by the feed waveguide width. When the feed waveguide width a is varied, the reflection from each T-junction increases because the T-junctions are designed to suppress the reflection only for a certain width. In addition, the reflection from each T-junction is accumulated at the input, and which is not negligible. The obliquely arranged feed waveguide [10] can reduce the overall reflection by shifting phase of reflection from each T-junction, and whose characteristics are also investigated in this report. The possibility of beam scanning by varying the narrow wall width a of the obliquely arranged feed waveguide is expected to have the reflection canceling effect. The reflection and beam scanning property of the array fed by a cascade of T-junctions is surveyed.

2. Principle

The reflection canceling mechanism in the obliquely arranged feed waveguide in Fig.1 (b) is summarized qualitatively in Fig. 2 for a case of six coupling windows as an example, which compares the reflection in the conventional type in Fig.1(a). The phase of the radiating waveguides at the same y-coordinate is alternating between adjacent ones in both arrangements. The mechanism of accumulation or cancellation of reflection from a series of coupling windows in the feed waveguide is explained. The reflection from the radiating waveguides is assumed to be negligibly small since one of the methods such as beam tilting technique [11] or the reflection canceling units as the array elements [12], [13] is adopted; only the reflection from the coupling windows is considered and suppressed here. In principle, each T-junction is designed to be reflection-free at the design width a by introducing a reflection canceling post or an inductive wall,[8] [9]. However, in the conventional T-junctions, small reflections due to frequency shift and/or manufacturing errors are accumulated in phase at the input port for the window spacing is $(1/2)\lambda_f$ as shown in Fig.2(a). This causes large reflection and small bandwidth. This problem can be solved by obliquely arranged T-junctions by setting the window coupling to be $(11/12)\lambda_f$ as shown in Fig. 2(b). The reflection from each coupling window has 60-degree phase difference, it is canceled out to each other because of the phase difference and the overall reflection can be reduced.

In this report, at first, each T-junction is designed to suppress the reflection in the phase condition of reflection from each coupling window for the window spacing is $(7/8)\lambda_f$ to have 90-degree phase

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difference as shown in Fig.3(b). Then, the width of the feed waveguide is changed so that the window spacing takes between $(11/12)\lambda_f$ for 60-degree difference in Fig. 3(a) and $(5/6)\lambda_f$ for 120-degree difference in Fig. 3(c). Even if the reflection from each coupling window increases for Figs. 3(a) and (c), the overall reflection is cancelled out. As a result, the overall reflection keeps small for the range of the window spacing.

3. Analysis and Design

The overall structure of the feed waveguide consisting of several T-junctions is too large for EM analysis and design; the approach adopted here is to characterize a unit T-junction in the form of an S-matrix for the dominant mode and then to cascade this matrix with its neighbors to obtain the composite S-matrix of the complete feeding structure. T-junctions are analyzed by 2D edge-based Finite Element Method (FEM) [14]. Fig.4 shows the FEM analysis model, parameters and meshes. The coupling is controlled by the width of the coupling window w and the reflection is cancelled by wall height q.

4. Numerical Example

As an example, a feed waveguide with six T-junctions are designed at 4.0GHz. The T-junctions are designed for a=58.1mm. The designed parameters for the oblique T-junctions are listed in Table 1. Fig.4 shows the analysis model. Fig.5 shows amplitude and phase dividing in each radiating waveguide with variation of the waveguide width a. At 43.1mm, the phase shift at one T-junction is about 100 degree though amplitude uniformity degrades. Fig.6 shows the overall reflection at the input port as a function of the feed waveguide width a. The overall reflection of the oblique feed waveguide is better (below -20 dB for a 18mm range) than that of the conventional waveguide (below -20 dB for a 6mm range) for various width a. Fig. 7 shows the array factor, in which radiating waveguides are regarded as elements for various feed waveguide width a. When $a = 73.1$ mm, a large gratinglobe of -3.75dB is observed. About 15degree beam-scanning is estimated.

5. Conclusion

The mechanical phase shifting by moving the whole side wall is proposed in the alternating-phase fed slotted waveguide array. The side wall is moved to change the guide wavelength, which finally causes beam scanning. The accumulated reflections from each junction in the mechanical scanning are canceled by using the obliquely arranged feed waveguide technique. As an example, a feed waveguide with six T-junctions are designed. About 15degree mechanical beam-scanning is observed with reflections below -20dB.

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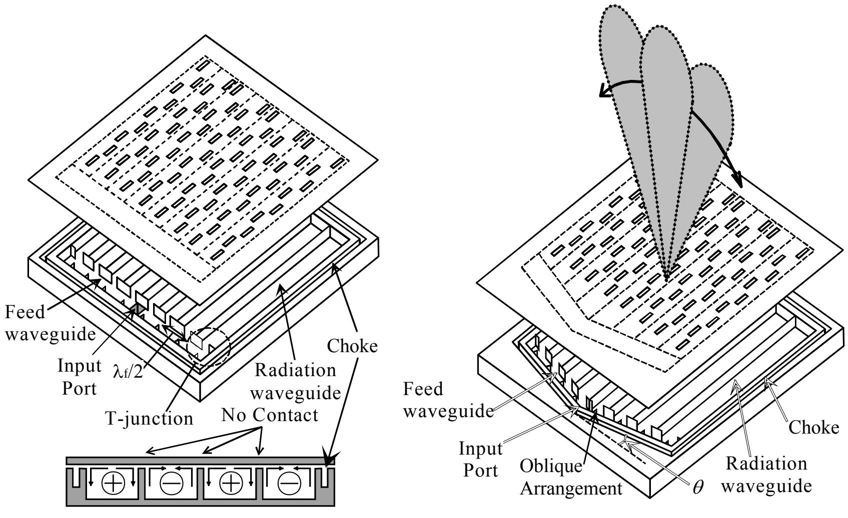
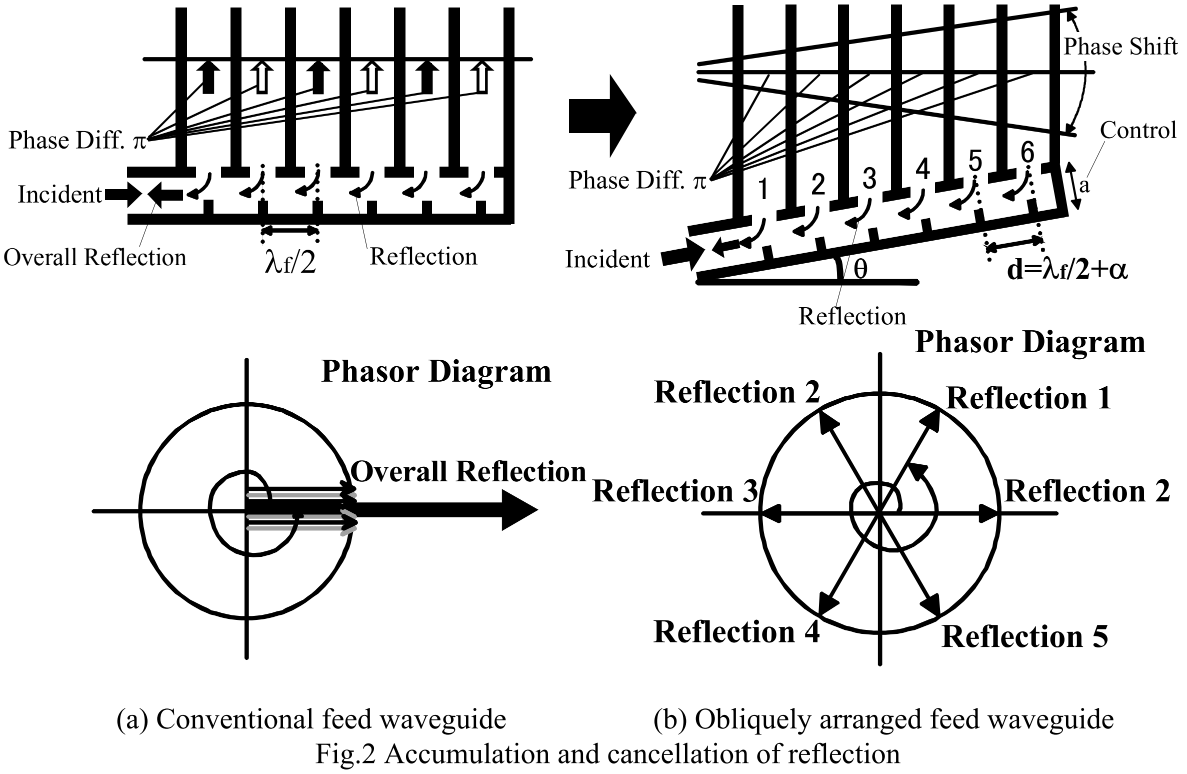


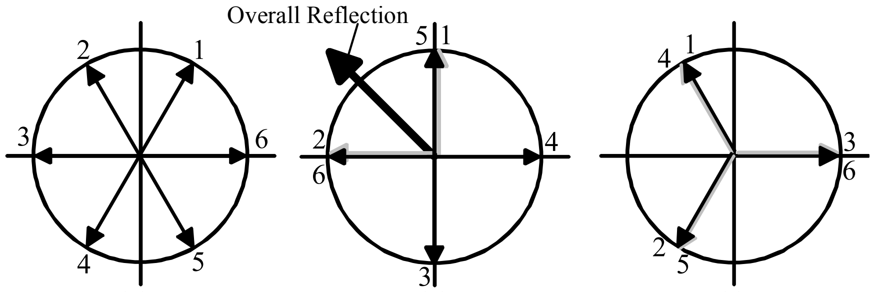
(a) Conventional arrangement (b) Oblique arrangement

Fig.1 Alternating phase fed single-layer waveguide slot arrays.



(a) Conventional feed waveguide (b) Obliquely arranged feed waveguide

Fig.2 Accumulation and cancellation of reflection



(a) (b) (c)

Fig. 3 Overall reflection at the input port

Table.1 Design parameter

T-j No.	1	2	3	4	5	6
Coupling	1/6	1/5	1/4	1/3	1/2	1
w(mm)	28.5	29.5	31.0	33.0	37.5	47.0
q(mm)	14.5	15.5	16.5	18.5	21	24.5
p(mm)	4.0	4.0	4.5	5.5	8.5	7.0

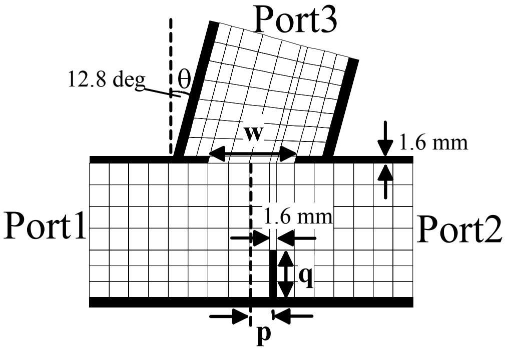
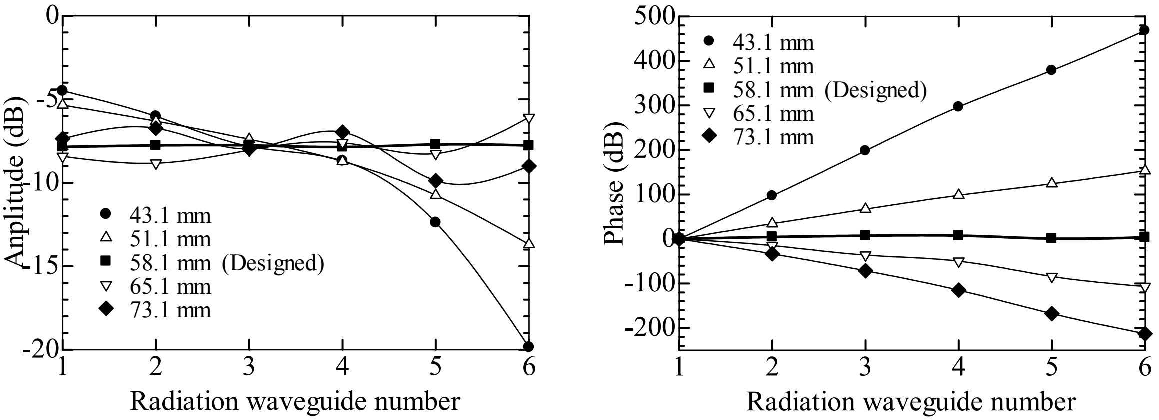


Fig. 4 FEM analysis model.



(a) Amplitude (b) Phase

Fig.5 Amplitude and phase dividing in each radiating waveguide.

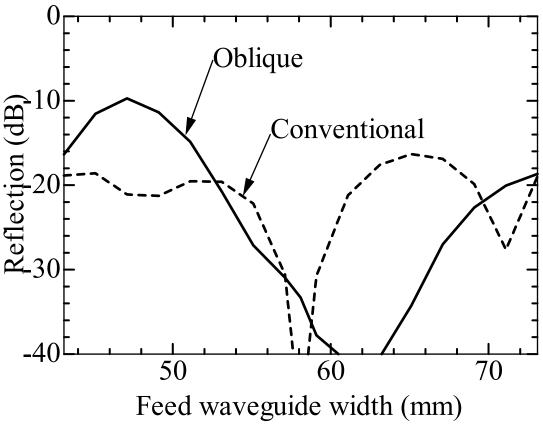


Fig.6 Overall reflection at the input port
as a function of the waveguide width

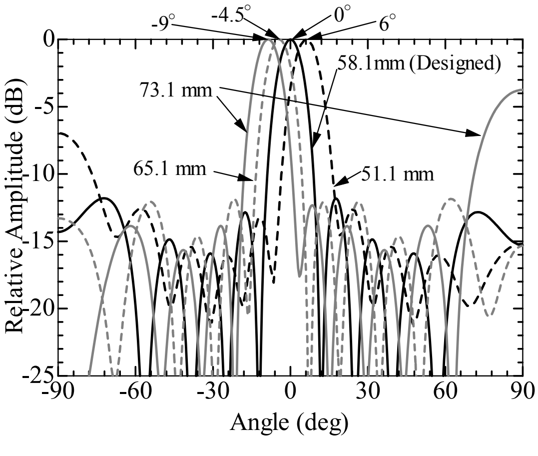


Fig.7 Array factors
(E-plane)