A Circularly Polarized Waveguide Narrow-wall Slot Array using a Single Layer Polarization Converter

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Summary

This paper describes the characteristics of a one dimensional narrow-wall slotted waveguide array with a single-layer linear-to-circular polarization converter consisting of a dipole array. An external boundary value problem of one slot and three dipoles, which approximates the mutual coupling between the dipole array and an edge slot extending over three faces of a rectangular waveguide, is formulated and analyzed by the method of moments; design of polarization conversion is conducted for this model as a unit element. If every unit element has perfect circular polarization, grating lobes appear in the array pattern due to the alternating slot angle: these are suppressed in this paper by changing the dipole angle and degrading the axial ratio of the unit element. The validity of the design is confirmed by the measurements. The dipole array has negligible effects upon slot impedance; the polarization conversion for existing narrow-wall slotted arrays is realized by add-on dipole array.

Key words : Single Layer, Polarization Converter, Dipole array, Narrow-wall, Slot, Waveguide

1. Introduction

Developments of a linearly polarized radar antenna with good performance in high frequency are actively advanced for mobile station such as shipborne application, car-collision avoidance system and railroad communication system[1][2]. Most of these radar antennas are fabricated by a rectangular waveguide with a negligible transmission loss in high frequency system. Recently, a radar antenna for the circular polarization is increasingly required[3][4]. The authors have proposed a single layer polarization converter[5] which perfectly switches the polarization of an existing broad-wall slotted waveguide array from linear to circular polarization by mounting dipole array upon it.

This paper proposes a circularly polarized radar antenna composed of a slot array on narrow wall

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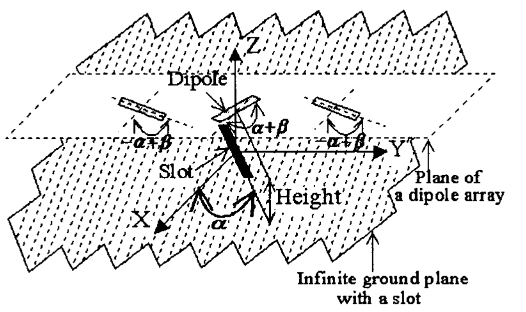
of waveguide and a single layer dipole array mounted on it as a polarizer. From the experience in the design of broad-wall slotted waveguide arrays, circular polarization is realized by optimizing the length, the height and the angle of the dipoles for a given magnetic current instead of a slot; only the external problems are analyzed. In a narrow-wall slot array, each slot has the same phase but different angle with respect to the waveguide axis to control the radiation power[6]. This variation in the slot angle results in large phase difference in the circularly polarized wave, when each dipole mounted on the inclined slot is designed to optimize the axial ratio of the element pattern and is making the constant angle with each slot. The grating lobes of -14 dB and -20 dB appear in the -35 dB Taylor distribution design of 1.2 m (47 elements) and 3.6 m (150 elements) in 9.41 GHz band, respectively. The phase correction is realized by changing the angle between the slot and dipole though the axial ratio of the element in the boresight direction is degraded up to 4.0 dB in the worst case. The array pattern still has perfect circular polarization. The level of the grating lobes after the phase control is about -18 dB and -26 dB for the circularly polarized antenna with 47 elements and 150 elements, respectively. In order to confirm the validity of the dipole design on the assumption of an external boundary value problem, the measurements of an element with 1 slot and 3 dipoles are performed at 12 GHz band. The optimum dipole parameters in terms of the axial ratio are independent of the slot length and reasonable agreement with the moment method prediction is observed.

2. Analysis

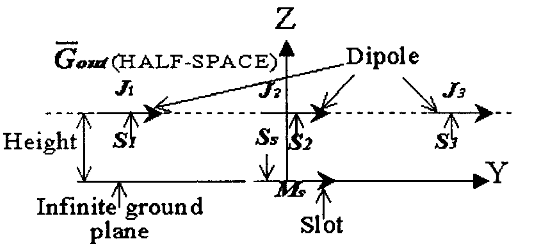
We deal with only the external boundary value problem in the analysis, where a slot, corresponding dipole and the adjacent two dipoles are placed in the half free space. The geometry of one slot and three dipoles in the model is illustrated in Fig. 1 (a). All the dipoles are assumed to be perfectly conducting, and its thickness is negligibly thin. An analysis of the dipole excitation is conducted by using Galerkin's method of moments[7]. The electric fields in the slot aperture have only a transversal component, since the slot width is assumed to be narrow enough in comparison with both the wavelength and the slot length. As shown in Fig. 1 (b), the electric fields on the slot aperture Ss are replaced with a given equivalent magnetic current Ms with sinusoidal distribution, while the unknown equivalent electric currents $Jd(d=1$ to $3)$ are assumed on the dipole surface Sd. The boundary condition requires that the tangential electric fields equal to zero on all the dipoles in the half free space. In external region, the simultaneous integral equations for Jd by using the Dyadic Green's functions in the half space [8], [9] are obtained. For an example, the integral equation on the dipole surface S1 is as below:

$$\begin{aligned}\int\int_{S_1} \overline{G}^{ee}{}_{out}(r_0 \mid r_s)\cdot J_1 dS \\ +\int\int_{S_2} \overline{G}^{ee}{}_{out}(r_0 \mid r_s)\cdot J_2 dS \\ +\int\int_{S_3} \overline{G}^{ee}{}_{out}(r_3 \mid r_s) \\ =-\int\int_{S_s} \overline{G}^{em}{}_{out}(r_o \mid r_s)\cdot M_s dS\end{aligned} \qquad \text{..............(1)}$$

where r_o and r_s are an observation point and a source point, respectively. The same equations are also satisfied on the other dipoles S_2 and S_3. The dyadic Green's functions $\overline{G}^{ee}{}_{out}(r_o \mid r_s)$ and $\overline{G}^{em}{}_{out}(r_o \mid r_s)$ represent the electric fields produced by the electric- and magnetic- currents in the half space, respectively. For the reduction of eq. (1) to a system of linear equations, Galerkin's method of moments with the piecewise sinusoidal



(a) Geometry of one slot and three dipoles model



(b) A given magnetic and unknown electric currents in integral equations

Fig. 1 A Simplified analysis model for the design of a dipole array

basis functions is adopted on the dipole surfaces [10]. Once the unknown coefficients for Jd (d=1 to 3) are solved in linear equations, a radiation pattern and an axial ratio can be calculated straightforwardly.

3. Design

3-1. Narrow-wall slot array

An existing linear polarization narrow-wall slotted waveguide array in X-band is considered for the polarization conversion. Generally, the radar antennas with a long array of 3.6 m with 150 elements are often used for the commercial requirements. To clarify the appearance of grating lobes, a short slot array of 1.2 m with 47 elements are considered in this paper. Each slot cut on the narrow wall has different angle, designated i as shown in Fig. 2 (b), with respect to the waveguide axis in order to control the radiation power.

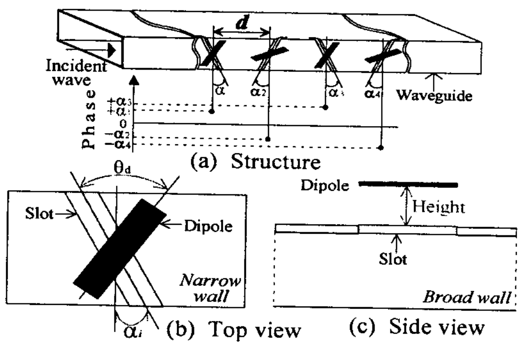


Fig. 2 Structure of a circularly polarized radar antenna

This antenna has the beam tilting angle of about 4.5 degree to reduce the reflection at the feed point. The spacing d between each slot is uniform and 0.7815 λ for a 47 slot array at 9.41 GHz. They are all in resonance and are excited in phase; the slot length covers both the narrow wall and the broad wall to realize the resonance. In the external problem in this paper, these folded slots are replaced by a straight magnetic current with the average length.

3-2. Dipole array

The dipoles are arranged with the spacing of d which equals to that of the original slot array in the longitudinal direction. Fig. 2 (b) and (c) show the relative position between a slot and a dipole. A dipole is placed above a slot. The dipole parameters such as the height, the length and the angle are determined by solving an external boundary value problem, where a single slot, the corresponding dipole and the adjacent two dipoles are placed in the half space[5]. The height and the length of the dipoles are commonly given independent of the variation of slot length.

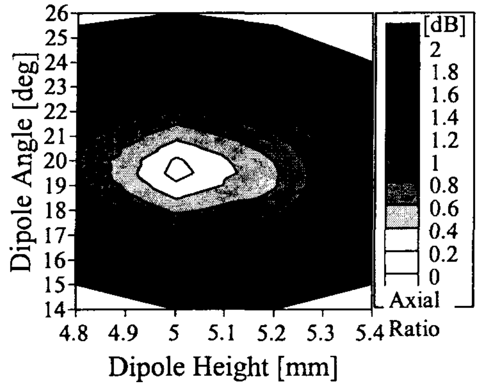


Fig. 3 The design to determine the optimum dipole angle for the slot angle of - 10.675° at 9.41 GHz

Fig. 3 shows an example of the contour map to determine the optimum dipole angles. This figure shows the axial ratio as a function of the dipole heights and the dipole angles, for the dipole length of 12.55 mm, the slot length of 17.0 mm and the slot angle of -10.675° at 9.41 GHz. The dipole angle with the axial ratio below 0.2 dB is obtained around 19.5° for the dipole height of 5.0 mm.

The dipole angle measured from the slot can control the axial ratio in the boresight direction of an element pattern and the phase of the circularly polarized wave. The optimum angle, designated θ_d as shown in Fig. 2 (b), between the slot and the dipole is almost the same for all the slots.

3-3. Phase control

The variation in the slot angle results in the same amount of the phase difference of the circularly polarized wave as is shown in Fig. 2 (a). Fig. 4 (a) shows the phase distribution for a slot array of 1.2 m with 47 elements at 9.41 GHz.. Each dipole is designed to optimize the axial ratio of the element pattern. This design produces -14 dB grating lobes in the radiation pattern denoted by Circular Polarization element

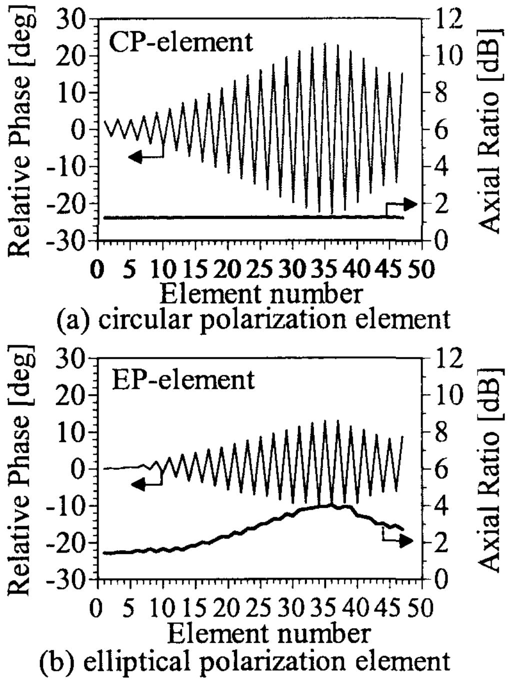


Fig. 4 Phase and axial ratio for a 47 element array at 9.41 GHz

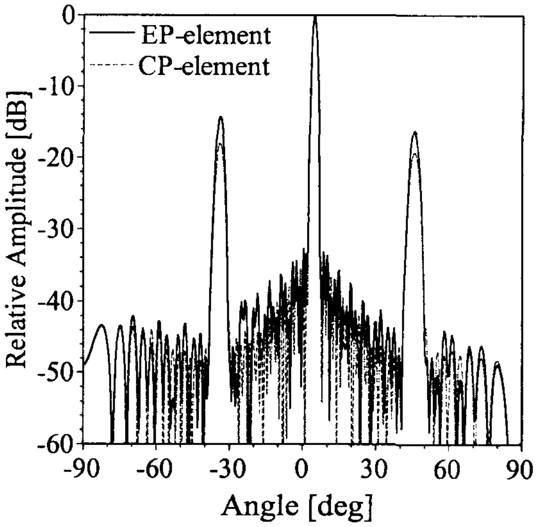


Fig. 5 The Calculated radiation pattern for a 47 element array

(CP-element) as shown in Fig. 5. In order to suppress the level of the grating lobes, we halve the phase difference as shown in Fig. 4 (b), by changing the angle of each dipole. The axial ratio of the element is degraded up to 4.0 dB and the element has the elliptical polarization (EP). This phase control reduces the level of the grating lobe to -18 dB. The axial ratio of the array is not so degraded in the boresight direction.

4. Experimental results

A standard rectangular waveguide for 12 GHz band is employed to fabricate a test antenna which is composed of 1 inclined slot and 3 dipoles. The common parameters used in the measurements are listed in Table 1.

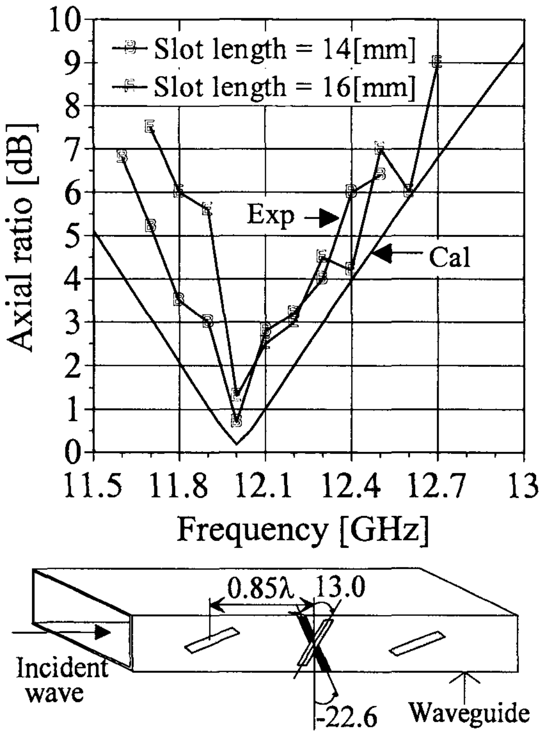


Fig. 6 Comparison between the theoretical and the experimental axial ratio in the main beam direction for the variation of slot length

Fig. 6 shows the comparison between the theoretical and the experimental axial ratio in the main beam direction for two types of slots with different length. Both measured axial ratios are below 0.8 dB at 12.0 GHz and show reasonable agreement with the prediction. It is confirmed by the experiments that some extension of the slot length can be simulated by the straight magnetic current with average length.

Fig. 7 shows the measured transmission (S_{21}) and reflection (S_{11}) coefficients for 1 slot only as well as 1 slot and 3 dipoles. Their characteristics are not sensitive for the mounted dipoles. As the rough approximation, we may say that S_{21} and S_{11} are almost the same as those without the dipoles. One slot model indicates that the perturbation of slot impedance due to waves excited by the very slot and reflected by the dipole array is negligible.

It is natural to assume that the perturbation of impedance caused by other slots is much smaller than the above. If this observation is acceptable,

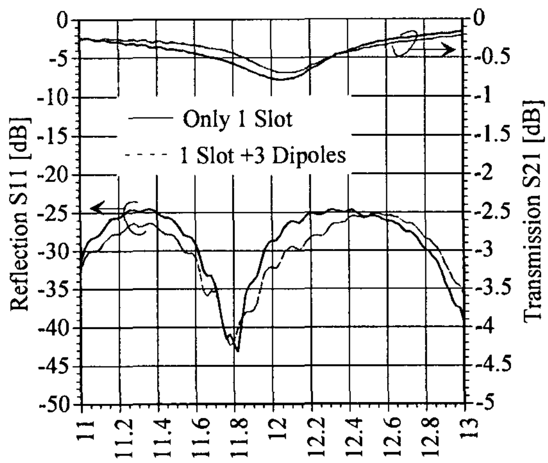


Fig. 7 The measured transmission and reflection coefficients for only 1 slot (length of 16 mm) as well as 1 slot and 3 dipoles

the impedance of all the slots or aperture illumination of the array antenna would remain unchanged by the printed dipole array; so the single layer polarization converter with the dipole array can be used for existing slot arrays without disturbing the characteristics of the original array. This will be verified by experiments in near future.

5. Conclusion

A circularly polarized radar antenna by using a printed dipole array polarization converter and the existing slot array on the narrow wall of a waveguide is proposed. The grating lobe of the proposed antenna with 47 elements is suppressed below -18 dB by the phase control of the elements patterns utilizing the relative dipole angle at 9.41 GHz. The validity of the dipole parameters determined by solving an external boundary value problem is confirmed by the measurements using a test antenna with 1 slot and 3 dipoles. It is experimentally confirmed that the slot length extended into the broad wall for resonance has very small affects in the design of dipoles. The effects of dipoles upon VSWR are also observed at 12 GHz band; the perturbation of slot impedance due to the reflection by the dipoles is negligible.

Table 1 Parameters for design and measurement

	Design	Measurement
Frequency (GHz)	9.41	11-13
Dipole length (mm)	12.55	10.2
Dipole width (mm)	2.0	1.0
Dipole height (mm)	5.0	4.0
Dipole angle (deg)	varied	13.0
The number of the used dipoles	47	3
Slot length (mm)	17.0	14.0 & 16.0
Slot width (mm)	2.0	1.0
Slot angle (deg)	-22.6 ~ 22.6	-22.6
The number of the used slots	47	1
Beam Tilting Angle (deg)	4.5	4.5
Spacing between dipoles (mm)	25.0	21.2

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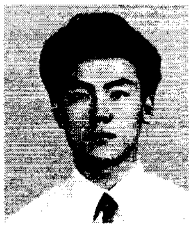

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