A Novel Single Layer Polarizer for An Existent Linearly-polarized Slotted Waveguide Array

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1. Introduction

Various applications of slotted waveguide array antennas are actively progressed in high performance radar, and advanced mobile and personal satellite communication systems and so on. Antennas with high gain and high efficiency in high frequency are the key elements in these systems. Generally, most of slotted waveguide planar arrays are used in the linear polarization with the exception of some special design for the circular polarization[1]. Two independent approaches have been conducted to realize the circular polarization. One is the design of elements for the circular polarization. Another approach is the design of linear-to-circular polarization converters. The design objective of the conventional polarizers has been the realization of transparency (no reflection and no insertion loss) and the minimization of an axial ratio (perfect circular polarization) for the plane wave incidence. Electromagnetic coupling between the polarizers and the antennas has not been taken into account in the design; the antennas and the polarizers are designed independently. This design for the conventional type imposes a multi-layer structure and a large spacing between the antennas and the polarizers in principle, and a triple layer meander-line polarizer has been the most popular[2].

This paper proposes a novel single layer linear-to-circular polarization converter for an existing linearly polarized slotted waveguide array as shown in Figure 1. A novel polarizer has much lower profile than the conventional one. The original array has resonant slots with the longitudinal spacing of half the guide wavelength. The polarizer is composed of a planar array of the uniform dipoles and is mounted closely above a slot array. The number of dipoles is the same as that of slots and each dipole locates above the corresponding slot. The dipoles are etched on a very thin polyethylene sheet which is neglected in the design throughout this paper. The space between the slot array and the dipole array is filled with an expanded polystyrene sheet which has the permittivity almost equal to that of free space.

The method of moments is conducted to clarify the mutual coupling between the dipoles and the slots on the waveguide. Two important observations are obtained. One is that the optimum parameters of the dipoles for circular polarization are independent of the slot length or the slot offset on the waveguide broad wall. Another is that the slot impedance viewed from the waveguide is not much affected by the dipoles and is almost the same as that without the dipoles. These promise the use of a uniform and parallel dipole array as an add on single layer linear-to-circular polarization converter for an existent linearly polarized slotted waveguide array[3]. The measurements using a 22.0 GHz band linearly polarized slotted waveguide array confirm the prediction; the linear polarization is converted to the circular one with a negligible insertion loss. The aperture illumination as well as the resultant radiation patterns is not affected by the polarizer.

2. Linearly polarized slotted waveguide array

An existing linear polarization slotted waveguide array in 22 GHz band [3] is adopted for confirming the design of a single layer polarizer. Design parameters for a slot array of 280 mm by 260 mm are given in Table 1. As shown in Fig. 1, 24 radiating wave guides with 25 slots each are arranged perpendicularly to the feed waveguide. The feed waveguide consists of series of π-junctions. Twelve π-junctions are cascaded to compose a multiple way power divider[4] and each radiating waveguide is excited in equal amplitude and phase. One bottom plate with corrugations realizes all these wave guides. In order to decrease the reflection at the feed point, the beam tilting angle of about 6.2 degrees is adopted. The resonant shunt slots are employed and are placed parallel to the longitudinal direction. The fabricated slot edges are round and the equivalent rectangular slot length is used in the analysis. To realize the uniform aperture illumination of the planar array, the slot length and the slot offset from the center of the waveguide are increased gradually toward the termination. This slot position data is copied for the position of dipole elements in the polarizer. Figure 2 shows the variation of the resonant slot length and the slot offset along the radiating waveguide. The slot number 1 in Fig. 2 indicates the nearest slot position from the feed point and the slot number 25 is that from the termination. This antenna has the gain of 33 dBi in 600 MHz bandwidth at 22 GHz band and an antenna peak efficiency of about 58 % .

3. Dipole parameters

The dipole parameters are designed for one slot and five dipoles model[5] at 22.0 GHz. The dipole parameters are optimized for the 18-th slot (length : 6.65 mm, offset : 0.74 mm) in Fig. 2. Figure 3 shows an example of the contour map to determine the optimum dipole parameters. This figure shows the axial ratio as a function of the dipole lengths and the dipole heights, for the given dipole angle of 68.5° at 22.0 GHz. The dipole height with the axial ratio below 1.0 dB is 2.5 mm and the dipole length is 5.3 mm. The optimum dipole angle with the minimum axial ratio is also determined by the same above iteration with the given dipole parameters. After determining the dipole parameters, we arrange them above each slot; the slot position data is copied and used in the etching of the dipole array.

4. Experimental results

Based on the design parameters of the dipoles listed in Table 1, a single layer printed dipole array polarization converter is fabricated to confirm the radiation of the circular polarization. The polyethylene sheet employed to support the dipoles has the thickness of 50 μm, the relative permittivity of 3.0 and the loss tangent of 0.008. The key feature of the proposed polarizer is to convert the polarization without affecting other characteristics of the original linearly polarized planar antennas.

A. Reflection coefficients

As for the internal phenomena, the change in slot impedance is discussed, which determines slot excitation coefficients or the aperture illumination of the array. Figure 4 compares the reflection measured at the antenna input. The thickness of the expanded polystyrene sheet is only about 2.5 mm. The measured results of an existing linear polarization slotted waveguide array are almost the same as those with the dipole array. It means that the impedance of all the slots or aperture illumination of the array is not changed by the add on polarizer; so the dipole array can be adopted for existing slot arrays without disturbing the aperture illumination of original array. It is also confirmed that the reflection due to the polyethylene sheet can be neglected.

B. Radiation patterns

Figure 5 (a) and (b) show the measured radiation patterns in the fresnel region in the y-z plane at 22.0 GHz, where the latter is presenting the spin-linear pattern. The radiation pattern of the circular polarization show reasonable agreement with that of the linear polarization as a whole. Both have about 6.2 degrees beam tilting angle from the boresight direction and the large grating lobes of about -17.5 dB appear at $\theta \cong -34°$ and $\theta \cong +45°$ directions as shown in Fig. 5 (a). The measured axial ratio in the main beam direction is about 0.8 dB at 22.0 GHz.

C. gain

Figure 6 shows the measured gain as a function of the frequency for both polarization. The peak gain of the circularly polarized planar array is 34.5 dBi. The antenna efficiency of the circularly and the linearly polarized planar array is about 57 % and 58 % in the peak point as shown in Fig. 6, respectively. The frequency bandwidth with a gain of more than 33 dBi is observed about 600 MHz.

5. Conclusion

A single layer polarization converter with the dipole array is proposed for the slotted waveguide array. It can be attached to existing linearly polarized arrays and linear-to-circular polarization conversion is performed without affecting other array performances. An extremely low insertion loss and a small spacing between the dipole array and the slot array is the advantage of the single layer and the strongly coupling structure. The dipole parameters are independent of the slot length and the offset; a single layer uniform dipole array can cover all the aperture provided that the slot position should be copied upon the dipole array. The design is fully verified by measurements using the existing linearly-polarized slotted waveguide array in 22 GHz band. Another important result is that the antenna characteristics, such as antenna input VSWR, the aperture field distributions, the radiation patterns and the gain are almost unchanged from those of the original array.

References

[1] A. J. SANGSTER, "Polarisation diversity techniques for slotted waveguide array antenna," Mikrowellen Mag., vol. 15. pp. 237-243, June 1989.

[2] D. S. LERNER, "A wave polarization converter for circular polarization," IEEE Trans. Antennas & Propagation, vol. 13, no. 1, pp. 3-7, Jan. 1965.

[3] K. SAKAKIBARA, J. HIROKAWA, M. ANDO and N. GOTO, "A linearly polarized slotted waveguide planar array using single layer feed circuit for 22 GHz band radio system," 1994 Asia-Pacific Microwave Conference, Chiba, Japan, vol. 2, no. 12-1, pp. 307-310, Dec. 1994.

[4] J. HIROKAWA, M. ANDO and N. GOTO, "A single-layer multiple-way power divider for a planar slotted waveguide array," IEICE Trans. Commun., vol. E75-B, no. 8, pp. 781-787, Aug. 1992.

[5] K. S. MIN, J. HIROKAWA, K. SAKURAI, M. ANDO and N. GOTO, "An experimental estimation of an effect of mutual coupling on a circularly polarized radiator with a slot and dipole for a waveguide array," National Convention of IECE, Tokyo, Japan, B-42, pp. 42, Sept. 1995.

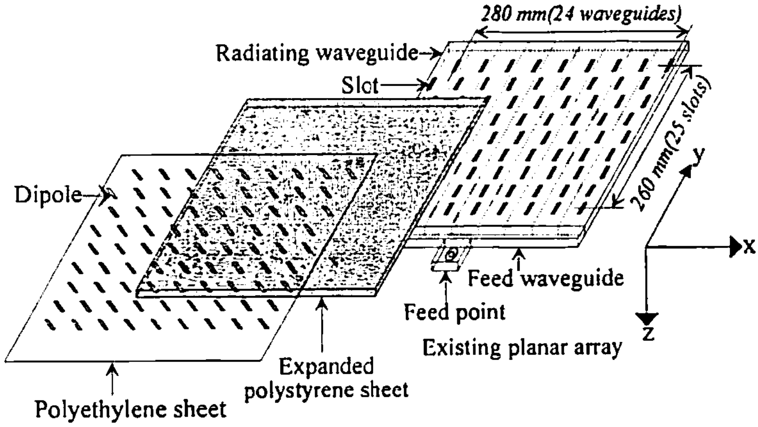


Fig. 1 The structure of a linearly polarized waveguide array and a single layer polarization converter

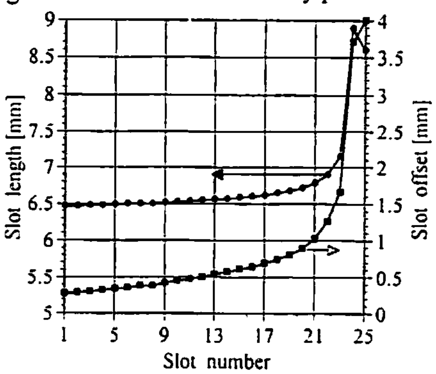


Fig. 2 The relations of the resonant slot length and the slot offset as functions of the slot number at 22.0 GHz

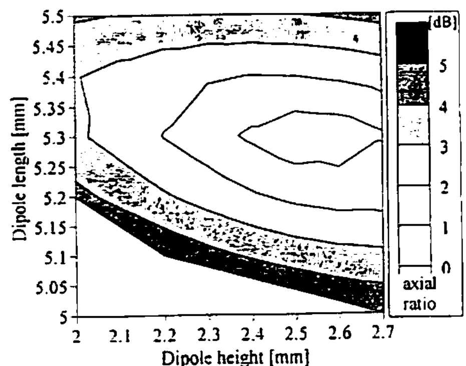
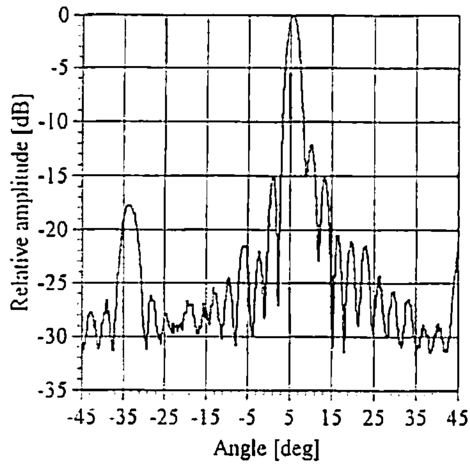


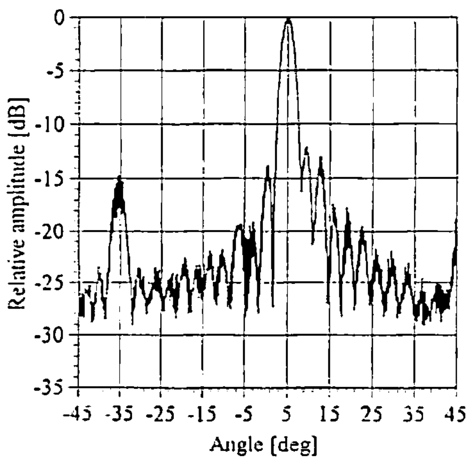
Fig. 3 The predicted axial ratio as functions of the dipole lengths and the dipole heights

Table 1 Design parameters for the slots and the dipoles

Design frequency	22.0 [GHz]
Broad wall width of the waveguide	10.0 [mm]
Narrow wall width of the waveguide	2.0 [mm]
Slot width	1.0 [mm]
Spacing between the slots in the x direction	12.0 [mm]
Spacing between the slots in the y direction	10.6 [mm]
Number of the radiating waveguide	24
Number of the slots on one waveguide	25
Number of the slots (all)	600
Dipole length	5.3 [mm]
Dipole width	1.0 [mm]
Dipole angle	68.5 [deg]
Dipole height	2.5 [mm]
Number of the dipoles (all)	600



(a) linear polarization



(b) circular polarization

Fig. 5 The measured radiation patterns of both polarization in the y-z plane at 22.0 GHz

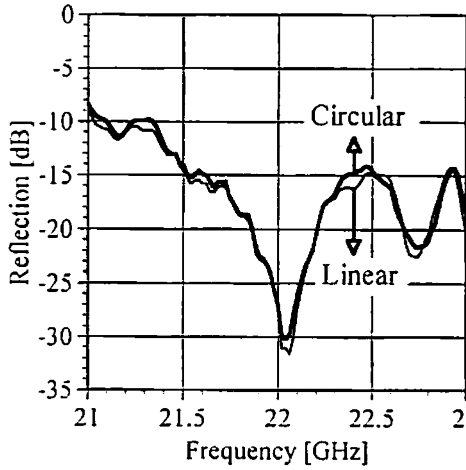


Fig. 4 The measured reflection coefficients as a function of the frequency for the linearly and the circularly polarized planar array

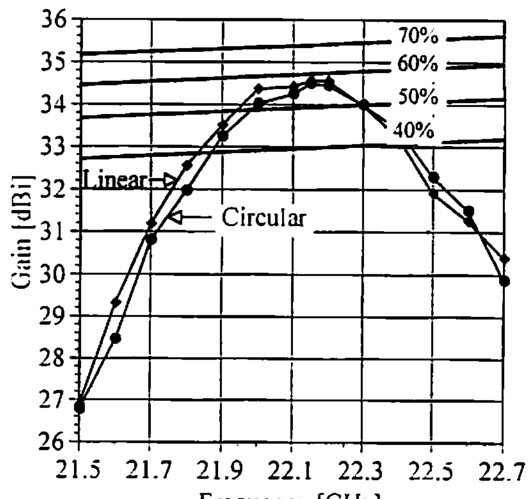


Fig. 6 The measured gain as a function of the frequency for both polarization