A Design of Slotted Waveguide Antenna Array Operated at X-band

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ABSTRACT

This paper presents a design of X-band slotted waveguide antenna array that has a linear polarization and exhibits high directivity for a long-distance communication. Especially we present a procedure that is very useful in a realistic implementation. The design is validated by numerical simulation using HFSS, and measurement results will be presented in the conference presentation.

I. INTRODUCTION

High power efficiency and capability with a simple geometric structure make slotted waveguide antenna arrays (SWAA) [1-3] very attractive for many applications of communication and radar system [4]. This paper presents a large array design that has a linear polarization and exhibits a high directivity, and is very useful in a long-distance communication. In particular, a procedure is presented, which provides simple steps in a realistic implementation at X-band. This procedure is based on a numerical modeling of antenna to realize an equivalent circuit in terms of self-admittances that are dependent on waveguide size, type of radiating slot and position of slots. The changes of slot admittance relative to its configuration parameters in a waveguide are studied. A realistic implementation is presented and validated by numerical simulation using HFSS at 9.25GHz. Experimental results will be presented in the conference presentation.

II. WAVEGUIDE SLOT'S CHARACTERISTICS

The antenna array is formed by cutting slots on the top surface of perfectly conducting rectangular waveguides in the longitude direction as illustrated in Figure 1(a). The slots are displaced from the central line of waveguide to the right- and left-sides alternatively. The width of slots is less than $\frac{\lambda}{20}$ (λ is the wavelength of free space). In the design we use the following formulations derived by [3] to predict the values of slots' resonant resistance and conductance, which were normalized to the waveguide impedance, and were obtained based on transmission line theory and waveguide modal Green functions. The conductance of the longitude shunt slot can be expressed as

$$g = g_1 \sin^2(d\pi/a)\,;\; g_1 = \left(2.09a\lambda_g/b\lambda\right)\cos^2(\lambda\pi/2\lambda_g) \tag{1}$$

where λ and λ_g are the wavelengths of free space and waveguide. In (1), d is the slot displacement from waveguide centerline, and a and b are the width and height of waveguide. The resistance of the centered inclined series slot is given by

$$r = 0.13\left(\frac{\lambda^3}{ab\lambda_g}\right)\left[I(\varphi)\sin\varphi + \left(\frac{\lambda_g}{2a}\right)J(\varphi)\cos\varphi\right]^2 \tag{2}$$

where

$$\begin{Bmatrix} I(\varphi) \\ J(\varphi) \end{Bmatrix} = \frac{\cos(\pi\alpha/2)}{1-\alpha^2} \mp \frac{\cos(\pi\beta/2)}{1-\beta^2}\;;\; \begin{Bmatrix} \alpha \\ \beta \end{Bmatrix} = \frac{\lambda}{\lambda_g}\cos\varphi \pm \frac{\lambda}{2a}\sin\varphi, \tag{3}$$

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and φ is the slot's tilted angle measured from the longtitude direction of centerline. It is noted that the susceptances and the reactances of the slot equivalent circuits vanish at the center frequency when all slots are resonant in the array. Therefore, all the concerns are about the conductance and resistance. Using (1)~(3), the conductance of the longitudinal shunt slot and resistance of the centered series slot at X-band are shown in Figure 2 and 3, where the curves are plotted with respect to the variations of displacement, d, and tilted angle φ, respectively. In this case, $a = 22.86$mm and $b = a/4$, respectively. The results shown in Figure 2 and 3 are the values normalized to waveguide impedance. It is found that the conductance increases with the increase of displacement while the resistance decreases with the increase of tilted angle. To further complete the required information in the design, Figure 4 shows the variation of waveguide impedance versus waveguide width a. In this case, the waveguide height is assumed to be $b = a/4$.

III. THE DESIGN OF ANTENNA

The design of slotted waveguide antenna array is accomplished by using the information shown in Figure 2-4. The structure of antenna is shown in Figure 1(b), which is consisted of three layers of waveguide structure. The top layer is consisted of 18 short waveguides, in which each waveguide is cut with 8 longtitude slots to radiate fields fulfilling the need of beam width in the H-plane. The number of waveguides (18 in this case) is selected to control the beamwidth in the E-plane. Each waveguide is shorted at the termination with a separation distance of $\lambda_g/4$ from the closeby slot. The dimension of the waveguide is selected to have a fundamental TE_{10} mode with a cutoff frequency below X-band. Using the information in Figure 4, one selects $a = 22.86$mm , which is same to the width of WR90 standard waveguide, and gives a waveguide impedance of 164.5Ω. The displacement of the slot is selected that the overall shunt slots' impedance may perfectly match with the waveguide's impedance. In this case, $d = 1.6$mm.

The waveguides on the top layer are fed by a waveguide on the second layer through a tilted slot coupling. The dimension of the waveguide is selected that its waveguide wavelength is $2(a + 2\Delta)$ where Δ is the thickness of waveguide wall, which is required to accommodate the waveguides of sub-arrays on the top layer. In this case, the width of waveguide is 21.5mm. The adjacent slot is tilted in an opposite direction to make sure equal-phase feeding for each sub-array. In order for impedance to be matched, this title angle is found to be 16 degrees. In this case, 18 slots were cut on this waveguide.

Similarly the second layer waveguide is fed by the waveguide in the third layer through a slot coupling. Applying same concept gives the dimension of the waveguide. In this case, the width is 21mm. The tiled angle is 36 degrees. Those values are also labeled on Figure 2-4. This waveguide is probed with a coaxial transmission line.

IV. NUMERICAL RESULTS

Numerical results of reflection coefficients and radiation patterns are shown in this section. In particular, Figure 5 shows the return loss that exhibits an operation band at X-band centered at 9.25GHz. The bandwidth is about 500 MHz, which exhibits 6% bandwidth. Simulation result of normalized radiation pattern is shown in Figure 6. The antenna directivity is 28.75dB at the center frequency and exhibits beamwidths of 9.5 and 3.5 degrees at x-z and y-z planes.

V. CONCLUSION

This paper provides a design of slotted waveguide antenna array. Characteristics and variations of conductance and resistance of slots at X-band are presented, which is useful for practical implementations. Numerical results have shown the characteristics of a realistic antenna design, which can be used for a long-distance communications.

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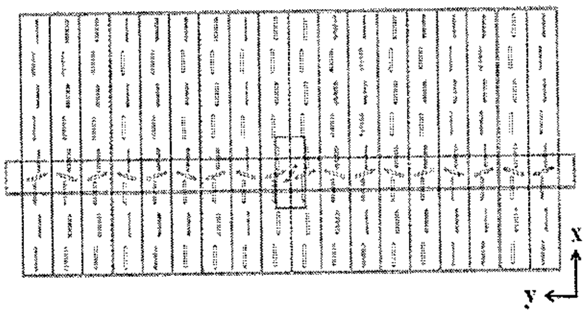
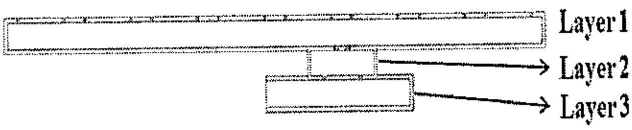


(a) Top view



(b) Side view

Figure 1: Structure of 8 by 18 slotted waveguide antenna array

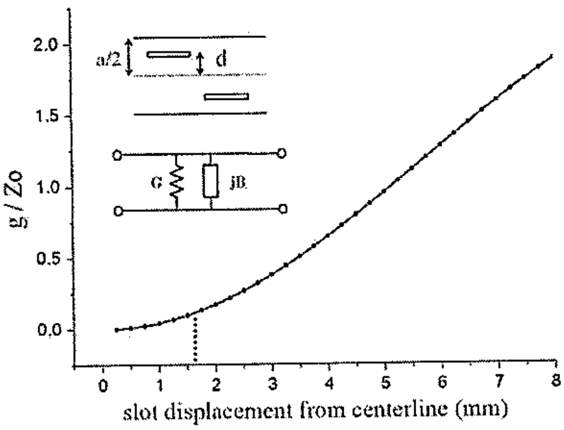


Figure 2: Conductance of the longitudinal shunt slot

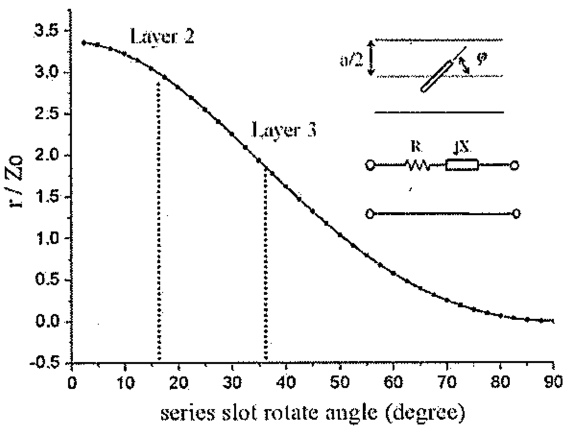


Figure 3: Resistance of the centered series slot

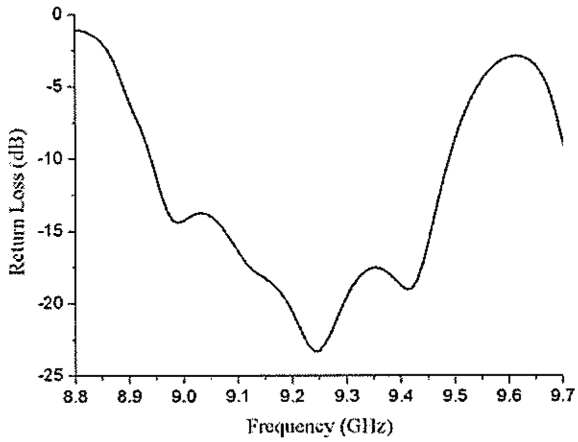


Figure 5: Return loss

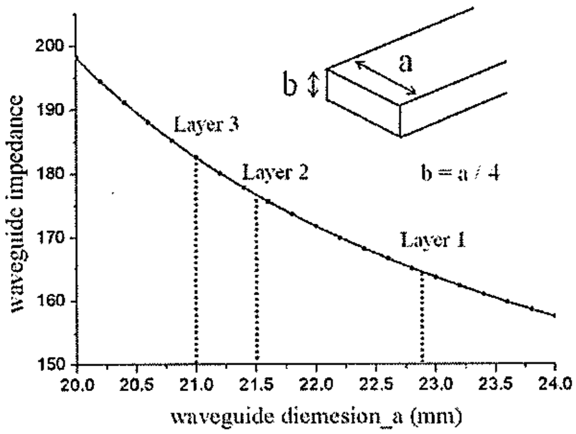


Figure 4: Input impedance of waveguide

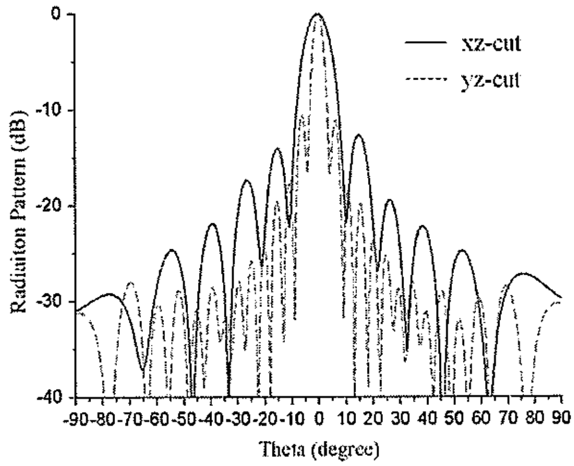


Figure 6: Radiation pattern

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