Design of Waveguide Shut Slot Arrays Formed on Copper-plated Dielectric Sticks in Millimeter-wave Band

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***Abstract* – A dielectric-filled waveguide shunt slot array antenna is designed to manufacture the dielectric rectangular stick with printed pattern of shunt slot array on the copper plate. In contrast to the hollow waveguide, the guided wavelength is shorter than one wavelength in free space because the dielectric is filled in the waveguide. Therefore, grating lobes do not appear even if the slots are spaced by one guided wavelength for in-phase excitation of travelling-wave operation. The radiation characteristics of the shunt slot arrays with spacing one guided wavelength and a half guided wavelength by interleave arrangement for in-phase excitation are compared in this work.**

***Index Terms* — Dielectric-filled waveguide, Slot antenna, Array antenna.**

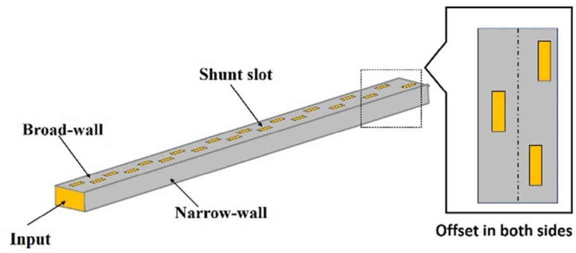
1. Introduction

Low cost technologies to manufacture waveguide slot arrays have been developed without spoil the high-efficiency property. The authors have been in the development of waveguide arrays composed of plated plastic. Two parts with grooves are assembled at the center of the broad wall of the hollow waveguide, where the contact plane does not cut high frequency current flowing on the inner walls of the waveguide. The electrical contact is not important to reduce transmission loss caused by leakage from the gap [1]. However, slots are restricted to be cut on the narrow wall of the waveguide. The design freedom is limited due to the narrow-wall slot arrangement. Then, we develop the broad-wall slotted waveguide array plated on the rectangular dielectric stick. The guided wavelength is shorter than the wavelength in free space. Therefore, grating lobes do not appear even if the slots are spaced by one guided wavelength for in-phase excitation of travelling-wave operation. The radiation characteristics of the shunt slot arrays [2] with spacing one guided wavelength and a half guided wavelength by interleave arrangement for in-phase excitation are compared in this paper.

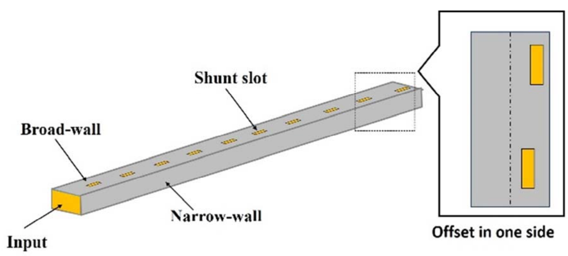
2. Structures of Two Shunt Slot Arrays

A dielectric-filled waveguide is created by metal plating to a rectangular resin stick [3]. Slots are placed on the broad-wall of the waveguide. The guided wavelength in the dielectric waveguide is shorter than the wavelength in free space. Therefore, it is possible to arrange the elements in one guided wavelength interval without growing grating lobes. Fig. 1 (a) shows a 20-element ordinary shunt slot array with spacing a half guided wavelength in interleave arrangement [4]. Fig. 1 (b) shows a 10-element shunt slot array with spacing one guided wavelength in one-side offset shunt slot arrangement. Thus, the array length of the 10-element one-side offset slot array is almost the same with the array length of the 20-element ordinary both-side offset slot array.

The dimensions of the waveguide are 2.054 mm x 1.016 mm which is almost equivalent with waveguide WR-12 (3.1 mm x 1.55 mm) filled with dielectric of permittivity 2.17. Both arrays are designed for uniform aperture distribution by traveling-wave operation at the design frequency 75 GHz. Both antennas have shunt slots which radiate by cutting current perpendicular to the tube axis. By cutting slot near broad-wall center where current perpendicular to the tube axis is zero, the radiation is small. On the other hand, by



(a) Array antenna with shunt slots offset in both sides.



(b) Array antenna with shunt slots offset in one side.

Fig. 1. Dielectric-filled waveguide shunt slot array antennas.

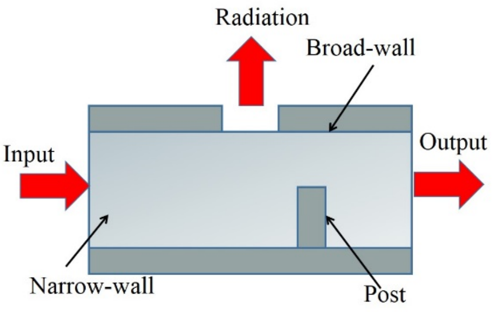


Fig. 2. One element with slot and post.

cutting slot near broad-wall edge where current perpendicular to the axis is large, the radiation is large. Therefore, it is possible to control radiation by changing the slot offset from the center of the waveguide. The magnetic currents on the slots located at the opposite place from the waveguide center flow in opposite directions out of phase. The slot spacing of a half guided wavelength compensates 180 degrees out of phase. The radiation slot reflects input wave in the waveguide. The all reflections sum up in phase. Thus, the overall reflection characteristic of the array becomes worse. A post is provided in the waveguide just next to the slot as shown in Fig. 2. The post is designed to cancel the reflection from the slot with the reflection from the post out of phase. Furthermore, the radiation from the slot can increase because the power density concentrates around the slot by the post, simultaneously.

3. Simulated Performance

The performances of the antennas were simulated by the electromagnetic simulation of the finite element method. Fig. 3 shows the radiation patterns of the two antennas. Both mainlobes direct to 0 degrees in elevation. All in-phase excitation was confirmed. The sidelobe levels were lower than −13dB. Almost uniform aperture amplitude distribution was confirmed. The sidelobe level of the 10-element array was higher in wide angle than the 20-element array because the grating lobe is closer to the mainlobe in invisible region for the 10-element array. Almost similar radiation patterns and directivities were obtained because of the same array length. Fig. 4 shows reflection characteristics of the two antennas. The bandwidth of reflection lower than −20 dB for 20-element array was 3.05 GHz which was 6 times wider than 0.48 GHz of the 10-element array. This is because the radiation from each slot of the 20-element array is smaller than that of the 10-element array. Therefore, overall reflection characteristic is more superior than the 10-element array. However, resonant frequency shifts to lower due to the mutual coupling between the slots, since the slot spacing is small.

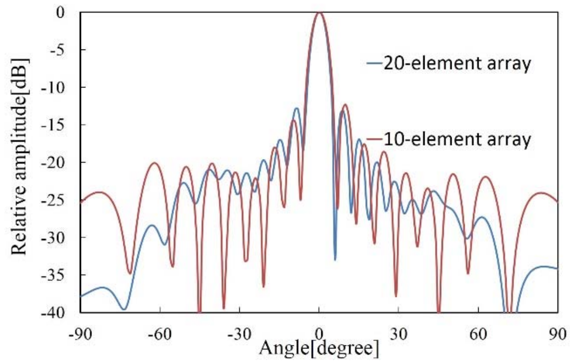


Fig. 3. Radiation patterns.

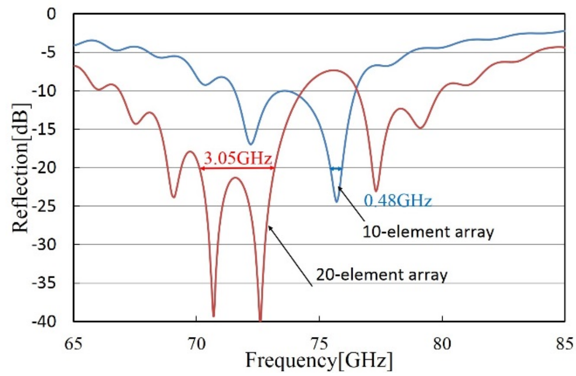


Fig. 4. Reflection characteristics of array antennas.

4. Conclusion

Two dielectric-filled waveguide shunt slot arrays were designed. The performances of the arrays with 10 elements spaced by one guided wavelength in one-side offset and with 20 elements spaced by a half guided wavelength in both-side offset were compared. The 20-element array was wideband composed of the 10-element array. However, the resonant frequency shifts lower in the 20-element array. This is caused by the mutual coupling between the slots which are spaced by a half guided wavelength.

References

[1] A. Mizutani, “Grating lobe suppression of narrow-wall slotted hollow waveguide millimeter-wave plannar antenna for arbitrarily linear polarization” *IEEE Trans. Antennas and Propagation*, vol. 55, no. 2, pp. 313-323, Feb. 2007.

[2] R. C. Johnson and H. Jasik, *Antenna Engineering Handbook.* New York: McGraw-Hill, 1984, ch. 9.

[3] S. Ishino and N. Shinohara, “Examination of a sloted resin waveguide using a low dielectric loss material,” *IEICE Techical Report.*

[4] K. Sakakibara, J. Hirokawa, M. Ando and N. Goto, "Periodic boundary condition for evaluation of external mutual couplings in a slotted waveguide array," *IEICE Trans. Commun.*, vol. 79, no. 8, pp. 1156-1164, Aug. 1996.