A New Technique for Suppressing The Sidelobe Due to Reflected Wave in The Traveling-Wave Slot Array

진행파 슬롯 배열 안테나에서 반사파에 의한 부엽을 억제하기 위한 새로운 기법

Bierng-Chearl Ahn
Chungbuk University
bician@cbu.ac.kr

안 병 철
충북대학교

Abstract

A new techique is proposed for suppressing sidelobes due to the wave reflected from the waveguide end in the traveling-wave slot array. In this approach we use multiple waveguide steps intead of the conventional matched load. To show the validity of the proposed method, a Ku-band slotted waveguide is fabricated and tested. Measurements confirm the excellent sidelobe suppressing capability of the proposed method.

요 약

진행파 슬롯 배열 안테나에서 반사파에 의한 부엽을 억제하기 위한 새로운 방법을 제안한다. 이 방법에서는 통상적으로 사용되는 정합부하 대신에 다단 도파관 계단구조가 사용되었다. 제안된 방법의 타당성을 보이기 위해 Ku-대역에서 동작하는 도파관 슬롯 안테나를 제작 시험하였다. 측정결과로부터 제안된 방법을 사용하여 반사파에 의한 부엽을 억제할 수 있음을 확인하였다.

I. ntroduction

Arrays of radiating slots in the rectangular waveguide are employed in many military and commercial systems due to such advantages as compactness, high-power handling capability and flexibility of beam shape design [1]-[2]. When the number of slots in the array is large, it is often advantageous to feed slots by traveling wave rather than by standing wave. In a traveling-wave array, slots are fed with progressively increasing or decreasing phases to avoid in-phase accumulation of waves reflected from each slot. It is customary to connect a matched load or matchin slots at the end of the array [3]-[4]. The matched load, however, n takes up a considerable amount of space so that an alternative approach is desirable where the space is a premium, for example, aboard the aircraft.

In this paper, we propose a new method of suppressing the sidelobe due to reflecgted wave. The concept is similar to matching slots but a special design of matching slots are not required in the proposed method. To verify the validity of our approach, we designded, fabricated and tested a sample Ku-band slot array.

II. Sidelobe Suppression

Fig. 1 shows a typical traveling-wave slot array in a rectangular waveguide. Design of such an antenna is well known [5].

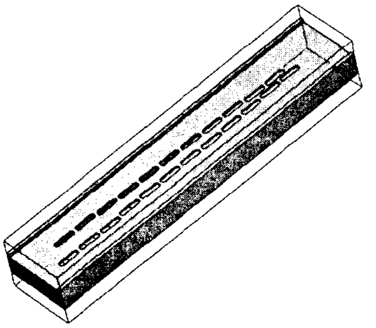

Fig. 1 An example of a traveling-wave slot array.

In a resonant array, the distance between two adjacent slots is exactly one half of the guided wavelength. Slots are placed alternatively at the opposite side of the waveguide center line to compensate for the 180-degree phase shift arising from the half-wavelength spacing. A shorting plate is placed at a 1/4-wavelength from the last slot. Impedance matching is obtained by making the sum of slot conductances be equal to the characteristic admittance of the waveguide. The resonant slot array shows a narrow bandwidth so that it is usually employed in small arrays.

When the number of elements is large, a traveling-wave array is preferred. In this case, the slot spacing is either greater than or less than a half wavelength. The phase of the radiated field from the slot is either decreasing or increasing so that the main beam is tilted from the array normal direction. A matched load is usually placed at the end of the waveguide. Reflections from individual slots are effectively cancelled by each other so that the array shows a wideband performance.

Consisting of a section of waveguide containing tapered lossy material, the waveguide matched load, however, makes the construction of the waveguide array rather complicated. When a matched load is replaced by a shorting plate, there arises a large sidelobe resulting from a reflected wave. The sidelobe due to the reflected wave is tilted in the directoin opposite to that of the main beam. The level of sidelobe due to the reflected wave usually ranges from -20 to -10 dB depending upon the number of slots and the array aperture distribution.

As an alternative way of suppressing the sidelobe due to the reflected wave, we suggest multiple waveguide steps. Fig. 2 shows an example of waveguide steps for suppressing the sidelobe.

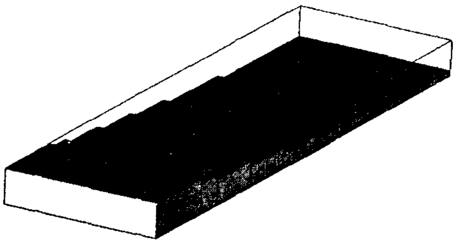

Fig. 2 Waveguide steps for suppressing the sidelobe due to the reflected wave.

The resonant conductance of a longitudinal slot in the broad wall of a rectangular waveguide is given by [5]

$$\frac{G_r}{Y_0} = 2.09\,\frac{ak}{b\beta_{10}}\,\cos^2\frac{\pi\beta_{10}}{2k}\,\sin^2\frac{\pi x}{a} \qquad (1)$$

where

G_r : resonant conductance of the slot

Y_0 : characteristic impedance of the waveguide

a, b : waveguide broad and narow wall dimensions.

k, β_{10} : free-space and guided wave number

x : slot offset

In Eq. (1) we find that reducing the waveguide height b gives higher values of slot conductance. With a properly reduced height, one can, therefore, expect the slot conductance to match the waveguide impedance. For example, with a=16mm, b=2.5mm, f=16.25GHz, x=5.5mm, we obtain $G_r = 1.03\,Y_0$, a nearly matched condition.

From the above discussion one can see that a proper reduction of the waveguide height around end slots will match the conductance of the slot to the waveguide impedance resulting in no reflected waves even when the waveguide is terminated with a short circuit.

To verify the theory we designed a 23-element slot array operating at 16.25GHz with the main beam tilted by 34 degrees toward the source. The distance from the first slot to the last slot is 165mm. We placed 7 steps with a constant height (0.5mm) spanning 54mm over last 7 slots. Step lengths are optimized (15, 10, 6, 6, 6, 3, and 8mm).

Fig. 3 shows the H-plane pattern of the array without matching steps and that of the array with matching steps. One can observe that the sidelobe due to the reflected wave is completely removed in the array with matching steps.

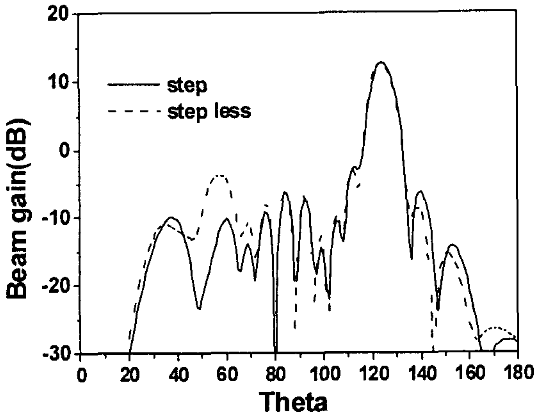

Fig. 3 The sidelobe reduction in the array with matching steps.

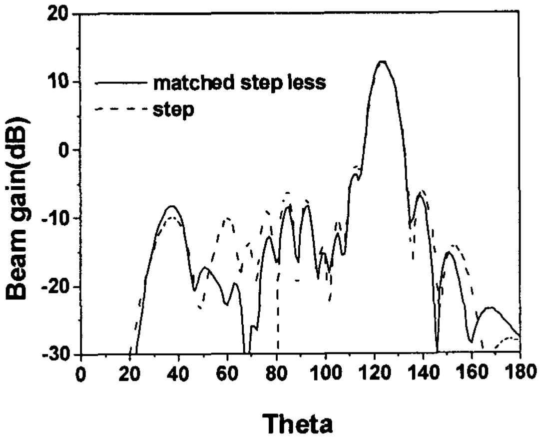

Fig. 4 The sidelobe performance of the array with matching steps compared to that of the array with a matched load.

As an another way of verifying the operation of matching steps, we computed the radiation pattern of an array terminated with a matched load. Fig. 4 shows radiation patterns of the array with matching steps and those of the array with a matched load, where one can again confirm the sidelobe reducing performance of the array with matching steps.

As another way of verifying the operation of impedance matching steps, we computed the reflection coefficient of arrays of last 7 slots with matching steps (Fig. 5).

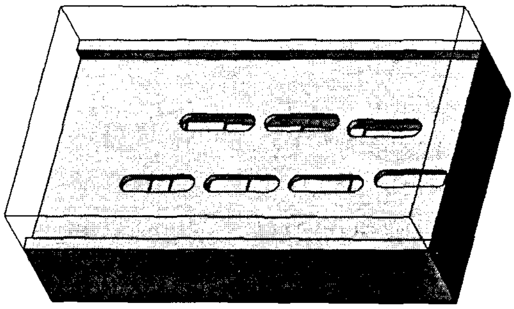

Fig. 5 An array of last 7 slots used in verifying the operation of impedance matching steps.

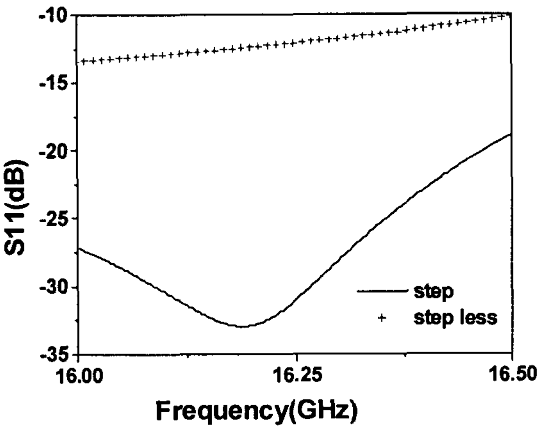

Fig. 6 The reflection coefficient of last 7 slots with impedance matching steps.

Fig. 6 shows the computed reflection coefficient, where one can see a significant reduction in reflection performance.

III. Experimental Verification

To experimentally verify the proposed method, we fabricated and tested a Ku-band slot array described above. The antenna is manufactured using a numerically controlled machining center. The rectangular waveguide is splitted along the H-plane. The height *b* of the waveguide cross section is 5mm, where a height of 3.5mm is assigned to the lower half of the waveguide block and the remaining 1.5mm height is taken up by the top plate where slot openings are precisely machined. Fig. 7 shows the photograph of the fabricated antenna.

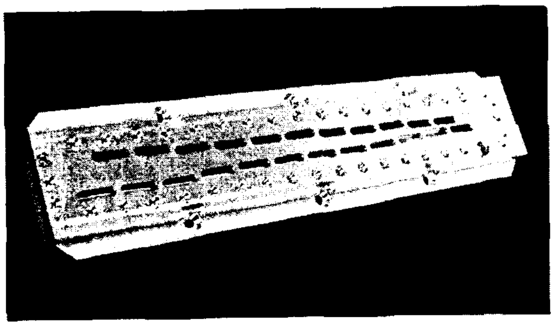

Fig. 7 The Ku-band slot array used in the proof of the principle.

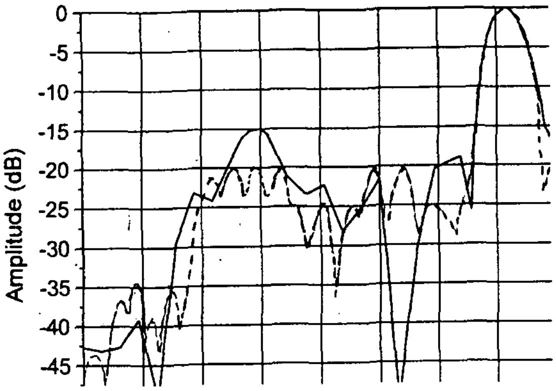

Fig. 8 Radiation patterns of the array with impedance matching steps (broken line) and that without them (solid line).

Fig. 8 shows radiation patterns of the antenna. The sidelobe suppressing ability of the array with impedance matching steps can be clearly seen.

IV. Conclusions

A new technique is presented for suppressing the sidelobe due to the reflected wave in the traveling-wave slot array. It is shown theoretically and experimentally that properly designed waveguide steps can be used in the slot array instead of a bulky and costly matched load.

References

[1] S. R. Rengarajan, L. Josefsson and R. Peterson, "Recent developments in broad wall slots in rectangular waveguides for array applications," *Proc. 1991 IEE 7th Int. Conf. Antennas Propagat. (ICAP 91)*, 15-18 Apr. 1991, pp. 729-731.

[2] K. W. Brown, "Design of waveguide slotted arrays using commercially available finite element analysis software," *1996 IEEE AP-S Int. Antennas Propagat. Symp. Dig.*, 21-26 July 1996, pp. 1000-1003.

[3] J. Hirokawa, K. Sakurai, M. Ando and N. Goto, "A matching slot pair for a circularly-polarized slotted waveguide array," *1990 IEEE AP-S Int. Antennas Propagat. Symp. Dig.*, 7-11 May, 1990, pp. 926-929.

[4] T. Hirano, J. Hirokawa and M. Ando, "Analysis of a waveguide matching crossed slot by the method of moments uising numerical eigenmode basis functions," *2001 IEEE AP-S Int. Antennas Propagat. Symp. Dig.*, 8-13 July 2001, pp. 258-261.

[5] R. S. Elliott, *Antenna Theory and Design*, Englewood Cliffs, NJ: Prengtice-Hall, 1981.