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

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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 sections of reduced-height waveguide with the final section terminated with a short circuit instead 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 여러 단의 높이가 감소한 도파관과 마지막 단에 연결된 단락회로가 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.

Key words : Matching Sections, Waveguide Slot Array Antenna, Reflection Cancelling, Antenna Efficiency Enhancement

Ⅰ. Introduction

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. When a matched load is employed at the termination, the radiation efficiency is lowered especially in small arrays[3]. Furthermore the matched load takes up a considerable amount of space so that an alternative approach is desirable wherever the space is a premium, for example, aboard the aircraft.

Recently the concept of matching slots is applied in the design of planar waveguide slot arrays and in radial line slot arrays[4]~[7]. Hirokawa and co-workers studied

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the design of a matching slot pair with circular polarization for use in the slotted waveguide array[4]. Hirano and co-workers proposed a matching crossed slot in the rectangular waveguide[6]. Yamamoto and co-workers applied the concept of matching elements in the design of a radial line slot array with improved efficiency[5]. Very recently Hirano and co-workers studied the optimized design of a crossed slot array in the presence of a matching element[7].

In this paper, we propose a new method of suppressing the sidelobe due to reflected wave. In this method, multiple stages of reduced-height waveguide together with terminating short circuit are employed to greatly reduce the reflection from the short-circuited waveguide end. The concept is similar to matching slots but a special design of matching slots are not required. To verify the validity of our approach, we designed, fabricated and tested a sample Ku-band broad wall shunt slot array in the rectangular waveguide.

Ⅱ. Sidelobe Suppression

To demonstrate the sidelobe suppression capability of the proposed method, we employ an array of broad wall shunt slots in the rectangular waveguide. Fig. 1 shows a typical example, where two of metallic plates(so-called "baffle") are placed along the waveguide edge to suppress the second-order beam. Design of such an antenna is well known[8].

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. All the slots in the array operate at their resonances so that slot admittances are pure real. 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.

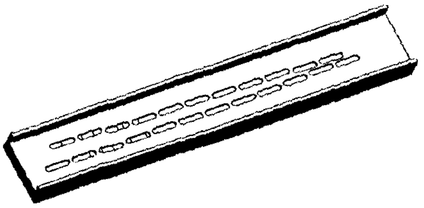

Fig. 1. An example of a traveling-wave slot array.

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 waveguide section 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 direction 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 stages of reduced-height waveguide. Fig. 2 shows an example of waveguide steps for suppressing the sidelobe. According to the classical theory of waveguide slot, the resonant conductance of a longitudinal slot in the broad wall of a rectangular waveguide is given by [8].

$$\frac{G_r}{Y_0}=2.09\frac{a\lambda_g}{b\lambda_0}\cos^2\left(\frac{\pi\lambda_0}{2\lambda_g}\right)\sin^2\left(\frac{\pi x}{a}\right)$$

where

G_r : resonant conductance of the slot

Y_0 : characteristic impedance of the waveguide

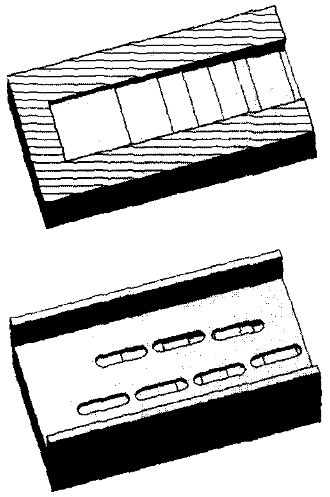

Fig. 2. Matching sections. Top: reduced-height waveguides. Bottom: slots with reduced-height waveguides.

a, b : waveguide broad and narrow wall dimensions

λ_0, λ_g : 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=16 mm, b=2.5 mm, f=16.25 GHz, x=5.5 mm, 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. One can, of course, use a single slot in the reduced-height waveguide. In this case, the bandwidth will be much narrower.

To verify the theory we designed a 23-element slot array operating at 16.25 GHz with the main beam tilted by 34 degrees toward the source. The distance from the first slot to the last slot is 165 mm. We placed 7 steps with a constant height(0.5 mm) spanning 54 mm over last 7 slots. Starting from the quarter wavelength, step lengths are optimized for minimum reflection over wide frequency range.

Reducing the waveguide height modifies the original design of the slot array so that iterative optimization is required. At first we place a short circuit 1/4 wavelength beyond the center of the last slot. The traveling-wave array is designed assuming that a matched load is placed beyond the last slot. The use of a short circuit instead of a matched load gives rise to a reflected wave so that the performance of the array will be altered. The next step in the design procedure is the introduction of optimized sections of reduced-height waveguide, which will also modify the array performance.

The entire array including multiple sections of reduced-height waveguide is optimized by adjusting slot offset and slot length. For the array tested in our study we were able to simulate the entire array with CST Microwave Studio^{TM}. Fig. 3 and Table 1 show the structure and dimension of matching sections, respectively. The width and length of slots all are 3.0 mm and 12.0 mm respectively. The thickness of the waveguide wall containing slots is 1.0 mm.

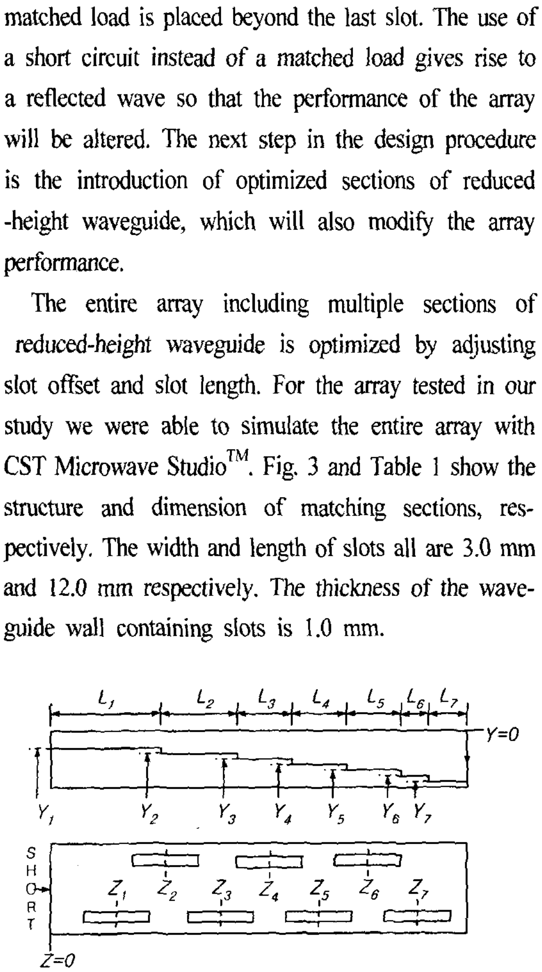

Fig. 3. Structure of matching sections.

Table 1. Dimension of matching sections.

Waveguide length (mm)	L_1	L_2	L_3	L_4	L_5	L_6	L_7
	15	10	6	6	6	3	8
Waveguide height (mm)	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7
	1.5	2	2.5	3	3.5	4	4.5
Slot position from short circuit (mm)	Z_1	Z_2	Z_3	Z_4	Z_5	Z_6	Z_7
	8.1	14.6	21.1	27.6	34.1	40.6	47.1

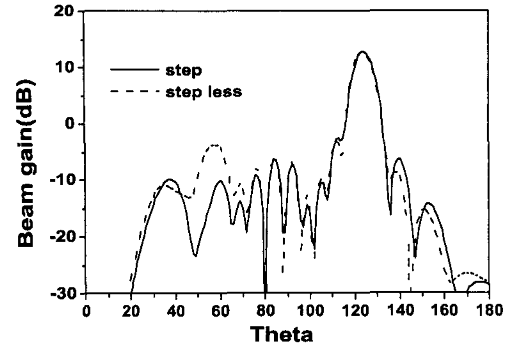

Fig. 4. The sidelobe reduction in the array with matching steps.

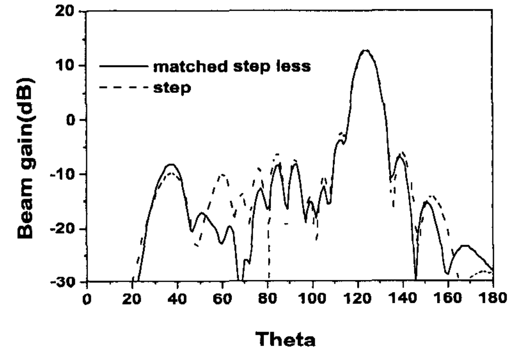

Fig. 5. The sidelobe performance of the array with matching steps compared to that of the array with a matched load.

Fig. 4 shows the H-plane pattern of the array without matching sections and that of the array with matching sections. One can observe that the sidelobe due to the reflected wave is greatly reduced in the array with matching sections.

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. 5 shows radiation patterns of the array with matching sections and those of the array with a matched load, where one can again confirm the sidelobe suppressing capability of the array with matching sections.

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

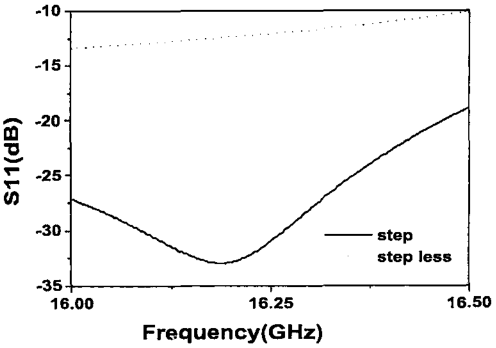

Fig. 6. The reflection coefficient of last 7 slots with impedance matching sections.

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 to facilitate the fabrication of slots. The height b of the waveguide cross section is

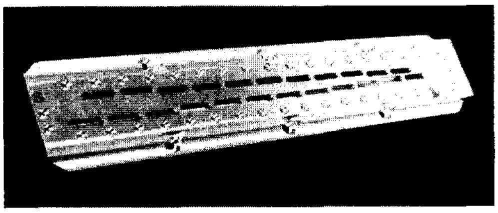

Fig. 7. A Ku-band slot array used in the proof of the principle.

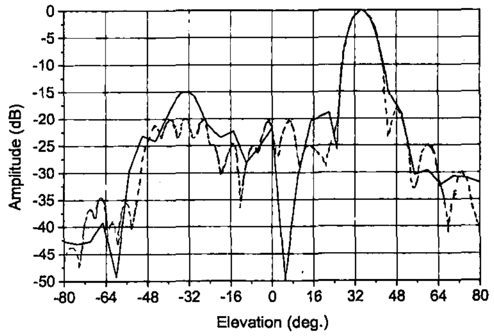

Fig. 8. Radiation patterns of the array with impedance matching sections(broken line) and that without them(solid line).

5 mm, where a height of 4.0 mm is assigned to the lower half of the waveguide block and the remaining 1.0 mm height is taken up by the top plate where slot openings are precisely machined. Fig. 7 shows the photograph of the fabricated antenna. Fig. 8 shows the radiation pattern of the antenna. The sidelobe suppressing capability of the array with impedance matching sections can clearly be 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.

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