Design of Inclined and Displaced Slotted Waveguide Array Antennas

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1. Introduction

Slotted waveguide array antennas are attractive because of their low loss characteristics in high frequencies. Several type of slotted arrays whose polarization angles are inclined to the waveguide axis have been reported [1]- [5]. In this paper, we propose a design procedure for the inclined and displaced slotted waveguide array antennas and verify its effectiveness through experiments.

2. Antenna configuration

The schematics of both inclined and displaced slotted waveguide array antennas are shown in Fig. 1. The radiating slots are cut in the broad wall of a rectangular waveguide (radiating waveguide), these slots are inclined to the longitudinal axis at an angle α and alternately displaced with respect to this axis. The slot spacing is equal to one-half guide wavelength ($\lambda_g/2$). The radiating waveguides are shortened at both ends at a distance of $\lambda_g/4$ from the last slot. A feeding waveguide is positioned in parallel behind the radiating waveguides, and the coupling slots are cut in the common broad wall between the two waveguides.

3. Equivalent circuit of a slot element

In this section, we present the characteristics of a slot element, as shown in Fig. 2. In Fig. 2, a is the width of the broad wall of the rectangular waveguide ($a \times b$), D is the displacement of the slot from the center of the axis, and L is the slot length. This type of slot is called a “compound slot” [4], and its equivalent circuit is expressed by an antisymmetric T-network, as shown in Fig. 3 [5]. The T-network parameters (Z^-, Z^+, and Y) can be derived from the 2×2 S parameters of the slotted waveguide.

Examples of T-network in X-band (frequency: f_0, wavelength in freespace: λ_0) are shown below. An electromagnetic field simulator, HFSS, was used for the calculation. As mentioned above, D and L are the parameters of the slotted waveguide with $a = 0.76\lambda_0$ and $b = 0.17\lambda_0$. The following are the fixed parameters; α is 45 degrees, the slot width is $0.04\lambda_0$, the slot thickness is $0.02\lambda_0$.

Figs. 4 and 5 show the case of the parameter L when $D = +0.20\lambda_0$. Fig. 4 reveals that $Re[Y]$ is predominant and $Re[Z^-] = Re[Z^+] \simeq 0$. Therefore, the consumption of power (that is, radiation to space) is represented by parameter Y. On the other hand, Fig. 5 reveals that $Im[Z^-]$ and $Im[Z^+]$ are almost constant, although $Im[Y]$ changes in proportion to the slot length; moreover $Im[Z^-] = -Im[Z^+]$.

Figs. 6 and 7 show the case of the parameter D when $L = 0.53\lambda_0$. On the basis of the changes in the real part, the following points can be considered. (i) $Re[Z^-]$ and $Re[Z^+]$ are predominant near the center axis (here, $|D| < 0.08\lambda_0$). (ii) $Re[Y]$ gradually becomes predominant as $|D|$ is increased. (iii) $Re[Y]$ suddenly decreases when $|D|$ is further increased. This is because the edge of the slot begin to exceed the waveguide wall. When we design the slots array, point (ii) will be mainly considered. For the imaginary part, the values of $Im[Z^-]$ and $Im[Z^+]$ decreases with an increase in $|D|$ but do not become equal to 0.

In conclusion, based on the dimensions of L and D, Y might be only the pure resistance; however, since Z^- and Z^+ have the reactances, the entire slot element cannot be represented by a real number.

4. Design of array antennas

In this section, it is shown that the ideal characteristics can be obtained by appropriately combining L and D. Fig. 8 shows the configuration of the slotted waveguide array and its equivalent circuit. The structure of one side of the radiating waveguide in the antenna shown in Fig. 1 can be observed here. The waveguide is fed from one side and the other side is shortened. The relation between the excitation distribution (amplitude A_i, phase P_i, slot number i) of each slot and the correspondence of T-network equivalent circuit parameters are as follows.

$$A_i = Re[Y_i|V_i|^2] \quad P_i = Arg[Y_i V_i]$$

If all the slots have to be excited equally and have to be in phase, they must be designed in such a manner that A_i and P_i are equal. For example, the design results of L_i and D_i for uniform distribution in 3-element arrays and the value of A_i and P_i in that case are shown in Table 1. It is found that all the distributions are almost uniform. Here, the input impedance at the feed point is $Z_{IN} = 0.99 - j0.02$.

Table 1: Design results obtained by using the equivalent circuit

Slot	L [λ_0]	D [λ_0]	Amp [dB]	Pha [deg]
1	0.52	+0.13	0.00	0.00
2	0.48	-0.13	0.05	-0.54
3	0.60	+0.14	0.01	-4.91

We verified the results shown in Table 1 by using the HFSS simulation. Fig. 9 shows the return loss performance versus frequency (normalized by f_0), and Fig. 10 shows the radiation pattern at f_0. Low reflection characteristics are observed at the center frequency. Moreover, a boresight beam is realized, and a symmetrical pattern shape is obtained. Thus, it can be said that the three slots are almost excited equally and in phase.

5. Experimental Results

We designed the entire antenna combined with the feeding waveguide by using a HFSS, and actually fabricated the 12-element arrays shown in Fig. 1. Fig. 11 shows the return loss performance versus frequency, and Fig. 12 shows the radiation pattern at f_0. In both cases, good agreement was obtained between measured and calculated ones. In this manner, the effectiveness of the design result for the entire antenna was confirmed.

6. Conclusions

We have proposed a design method for inclined and displaced slotted waveguide array antennas. We discussed the characteristics of a slot element and showed the design results by using an equivalent circuit. Moreover, we verified its performance by experiments and confirmed its effectiveness.

References

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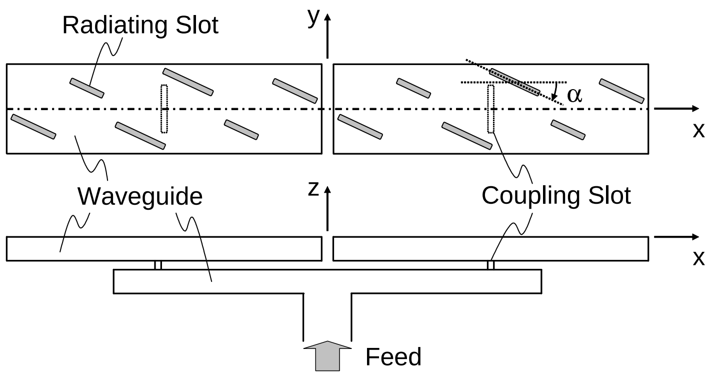

Figure 1: Antenna configuration

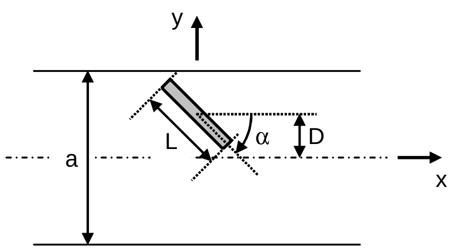

Figure 2: Slot element

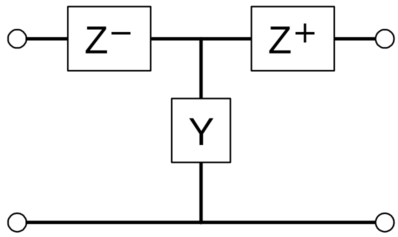

Figure 3: T-network equivalent circuit representation of slot element

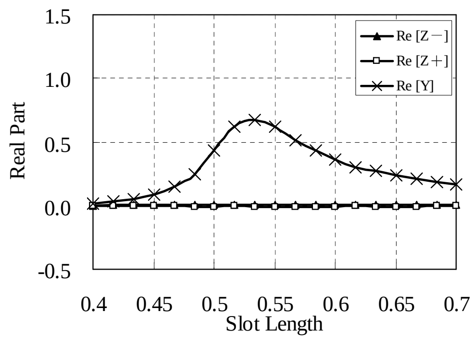

Figure 4: Real part of T-network components as a function of the slot length L ($D = +0.20\lambda_0$)

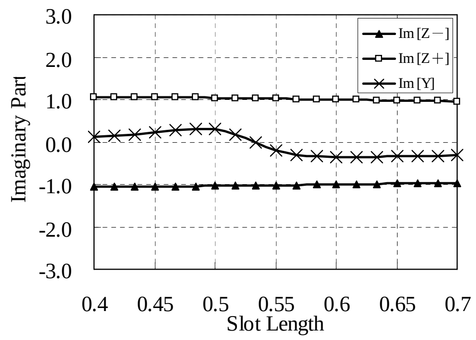

Figure 5: Imaginary part of T-network components as a function of the slot length L ($D = +0.20\lambda_0$)

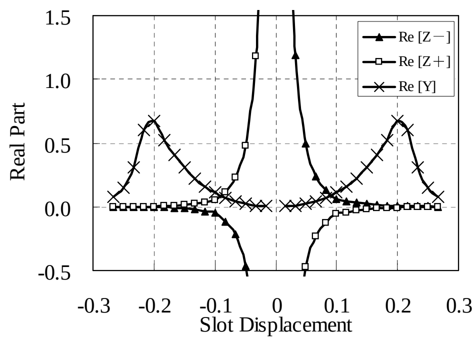

Figure 6: Real part of T-network components as a function of the slot displacement D ($L = 0.53\lambda_0$)

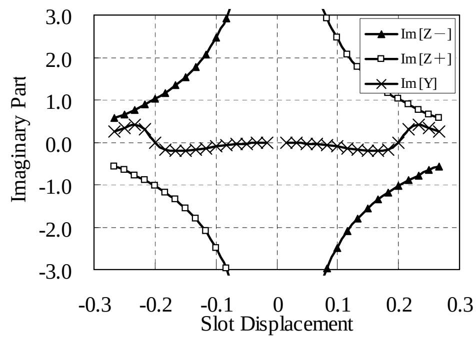

Figure 7: Imaginary part of T-network components as a function of the slot displacement D ($L = 0.53\lambda_0$)

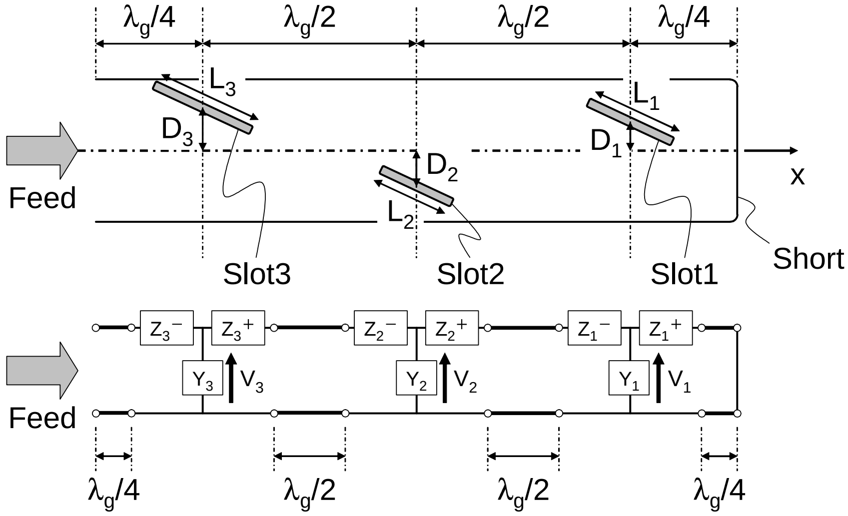

Figure 8: Equivalent circuit of one side of the radiating waveguide

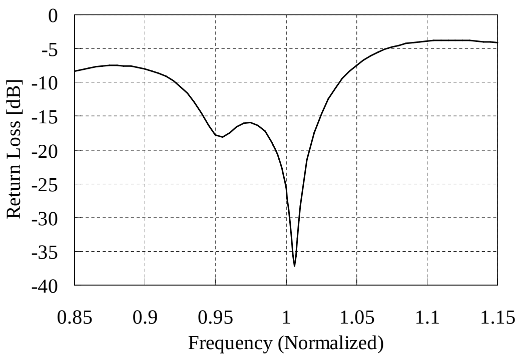

Figure 9: Return loss of 3-element arrays

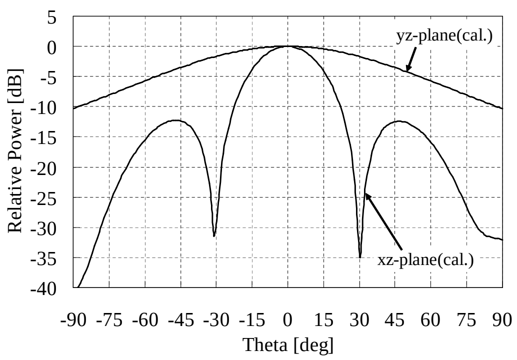

Figure 10: Normalized radiation pattern of 3-element arrays at f_0

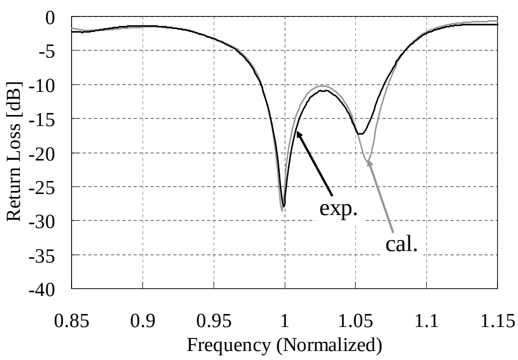

Figure 11: Return loss of 12-element arrays

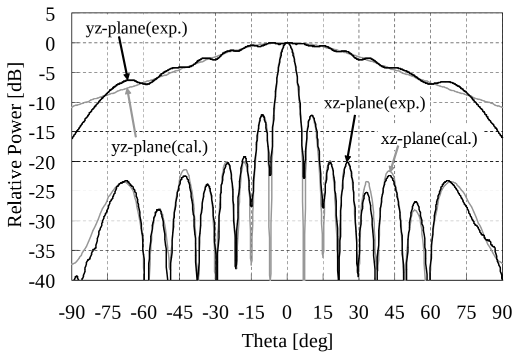

Figure 12: Normalized radiation pattern of 12-element arrays at f_0