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Design of Hollow Waveguide Slot Antenna Using Quite Thin Narrow-Wall Waveguide for Grating-Lobe Suppression

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1. Introduction

One-dimensional slotted waveguide array and feeding circuit are designed for two-dimensional waveguide antenna with no gratings lobes. Since a guided wavelength of waveguide is essentially longer than a wavelength in free space, grating lobe is serious problem in the design of a slotted waveguide broadside array with slot spacing of one guided wavelength for traveling-wave excitation. Alternating phase feeding circuit has proposed to reduce slot spacing to half in the direction of the guide axis [1]. In this case, in order to suppress grating lobes in the diagonal direction due to the triangular lattice arrangement, slots are cut on the narrow wall of the waveguide and open ended cavity is used on each slot [2]. Since 45-degrees diagonal polarization is required for automotive radar applications, narrow wall width of the waveguide can not be reduced in narrower than limit to locate slot and cavity on the waveguide narrow wall. This paper proposes the way to reduce two-dimensional slot spacing by using a waveguide with extremely small narrow-wall. Horizontal-polarized slot array with low grating lobes is designed for applications which do not require the inclined polarization. Simulated performance of the designed antenna is reported in this paper.

2. Slot Arrangement and Design

The slotted waveguide planar antenna is composed of 24 radiating waveguides which are connected on the broad wall of the feeding waveguide, as is shown in Fig. 1. Twelve longitudinal radiating slots are cut on the narrow wall of each radiating waveguide. Spacing of slots in x-direction is approximately one guided wavelength λ_g of the radiating waveguide. Since it is larger than a wavelength λ_0 in free space, grating lobes appear in zx-plane for one dimensional array. Therefore, adjacent waveguides are spaced in a half guided wavelength of the feeding waveguide. The radiating waveguides are fed in alternating 180 degrees out of phase. Slots are arranged with a half guided wavelength shift alternately in x-direction on each waveguide in order to compensate the feeding phase difference between the adjacent waveguides. Consequently, the grating lobes do not appear in zx-plane because the slot spacing becomes about a half guided wavelength in x-direction. The slot arrangement is designed to minimize the slot spacing in kk'-direction shown in Fig. 1 because it becomes a triangular lattice arrangement.

Slot spacing in x-direction can be short by using wide broad-wall a of the waveguide since a guided wavelength becomes short. The broad-wall width a is determined to be large within the limit that only TE_{10} mode propagates. Design frequency is 24.15 GHz. Broad-wall width in which cut-off frequency of TE_{20} mode is 24.15 GHz is 12.4 mm. The spacing in kk'-direction is chosen to be 0.8 λ_0 (9.9 mm) so that grating lobes would be suppressed. Admitted maximum spacing of radiating waveguide in y-direction is 6.8 mm for no grating lobes in kk'-direction. The size of radiating waveguide is determined to be 11.8 mm × 3.8 mm including some margin for manufacturing point of view where wall thickness

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between the waveguide is 3.0 mm. The guided wavelength is 14.6 mm which is shorter than the guided wavelength 15.4 mm of standard waveguide (10.7 mm × 4.3 mm). In this case, radiation from slot decreases significantly when the broad-wall width is large. In order to increase the radiation from slot, post is located at the opposite side of the waveguide. Reflection characteristic is also improved because the reflection from the slot is designed to be canceled with that from the post as well as the case of T-junctions, as is shown in Fig. 2(a) and (b). Each slot element and each T-junction with post is designed to obtain the desired radiation and reflection lower than −30 dB at the design frequency. Required coupling power from slots of radiating waveguide and from T-junctions of feeding waveguide are assigned for Taylor distribution in both directions on the aperture to be a sidelobe level lower than −20 dB. Spacings of slots and T-junctions are designed for in-phase excitation including the phase perturbation into account. Performance is evaluated by calculation of electromagnetic simulator.

In the design of feeding circuit, mutual coupling between the adjacent T-junctions is significantly large because the spacing between the T-junctions is quite short in order to suppress grating lobes. Figure 3 shows influence of mutual coupling in S-parameters. For example, 1st and 2nd T-junctions are optimized in the single-element analysis to minimize reflection at 24.15 GHz as shown in Fig. 3(a). Figure 3(b) shows S_{11} and S_{21} simulated in the two-element analysis with variation of spacing of two T-junctions. When spacing of T-junctions is large as 14 mm (λ_g), resonant frequency is still the same with the case of single-element analysis shown in Fig. 3(a). However, when the spacing between two T-junctions is short, resonant frequency shifts to higher frequency. In the case of 6 mm ($\lambda_g/2$) for alternating-phase feeding applied to the proposed antenna, the resonant frequency shifts to 25.3 GHz. This shows that mutual coupling between T-junctions must be taken into account in the array design. We optimized all the parameters of the feeding circuit in the array design using electromagnetic simulator.

3. Simulated Performance

Radiation pattern in xz-plane is shown in Fig. 4(a). Sidelobe is set to be −20 dB. Grating lobes decrease due to the triangular lattice arrangement obtained by alternating phase feeding. Reflection characteristic is below −30 dB at the design frequency, as is shown in Fig. 4(b). Next, the simulated results of feeding waveguide are shown in Fig. 5. Sidelobe level of design is less than −20 dB in the radiation pattern shown in Fig. 5(a). However, sidelobe level in the simulated radiation pattern is −17.5 dB which is 2.5 dB higher than the design. This is because two center T-junctions are very close to the input port. Coupling power to these two waveguides become smaller than the design. Reflection characteristic is completely optimized for S_{11} to be lower than −30dB including the effect of mutual coupling. Characteristics for over all configuration of the planar antenna composed of 24 radiating waveguides and a feeding circuit are analyzed. Figure 6 shows radiation pattern of kk'-plane in which the slot spacing is maximum for all the directions of the triangular lattice arrangement. It is confirmed that grating lobes are suppressed to −38.2 dB in the proposed design.

4. Conclusion

We proposed the way to reduce two-dimensional slot spacing by using the waveguide with extremely small narrow-wall. Horizontal-polarized slot array with low grating lobes was designed for applications which do not require inclined polarization. It is confirmed that grating lobes are suppressed to −38.2 dB in the proposed design.

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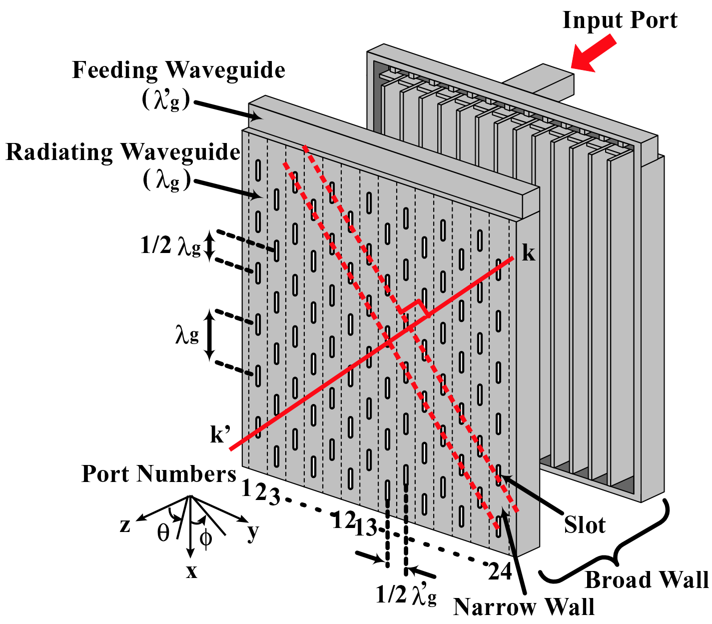


Figure 1: Planar Antenna

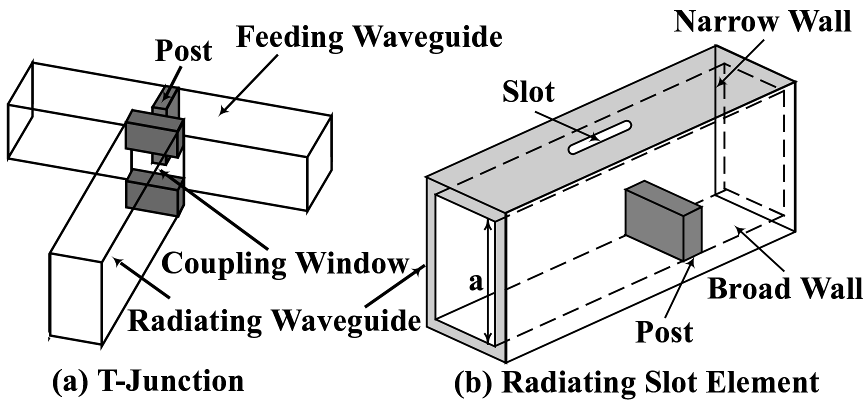


Figure 2: Structure of Radiating and Feeding Waveguide

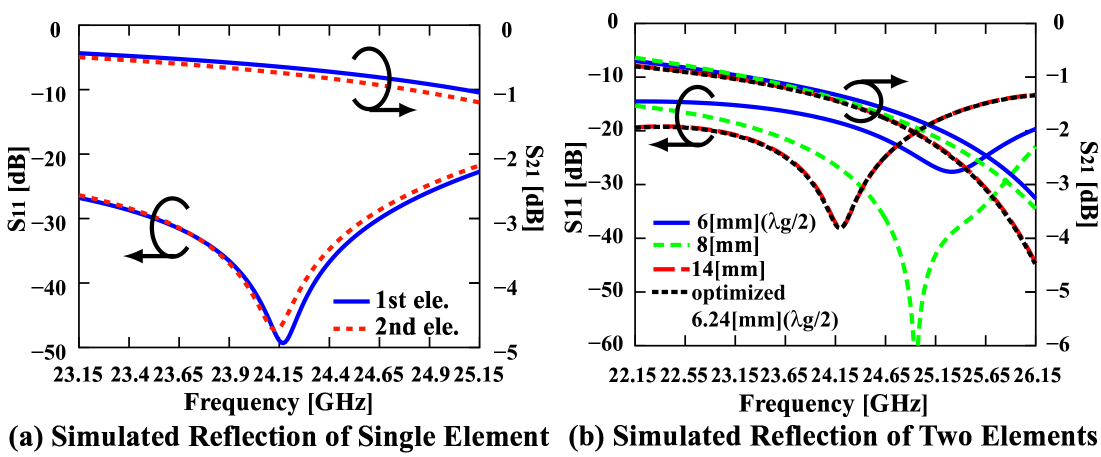
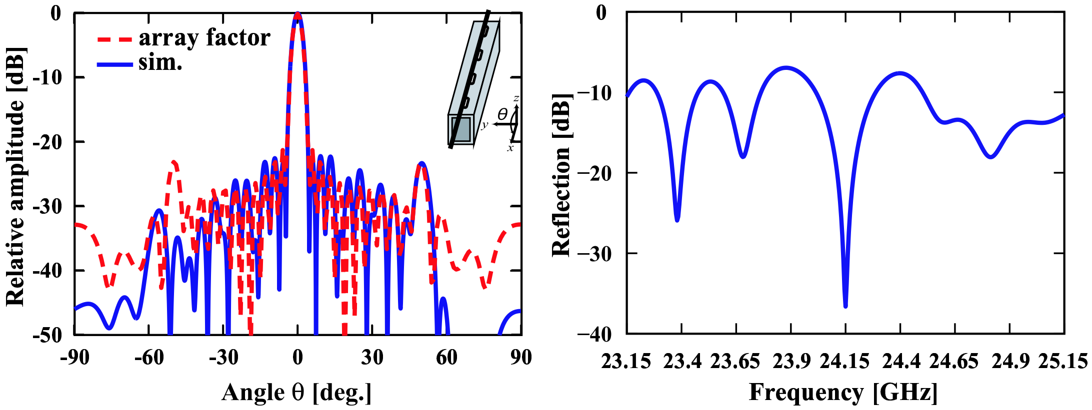


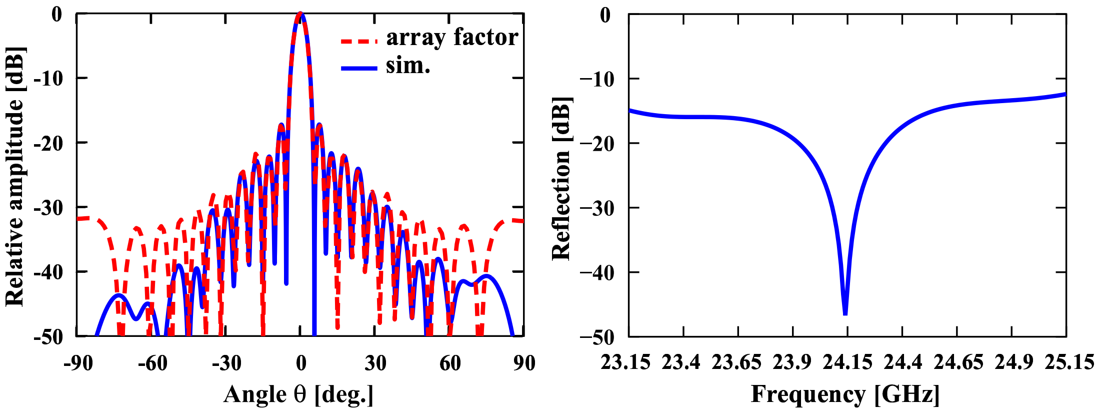
Figure 3: Influence of Mutual Coupling in S-parameters



(a) Array Factor and Simulated Radiation Patterns (xz-plane)

(b) Reflection Characteristic

Figure 4: Characteristics of Radiating Waveguide



(a) Array Factor and Simulated Radiation Patterns (yz-plane)

(b) Reflection Charactristic

Figure 5: Characteristic of Feeding Waveguide

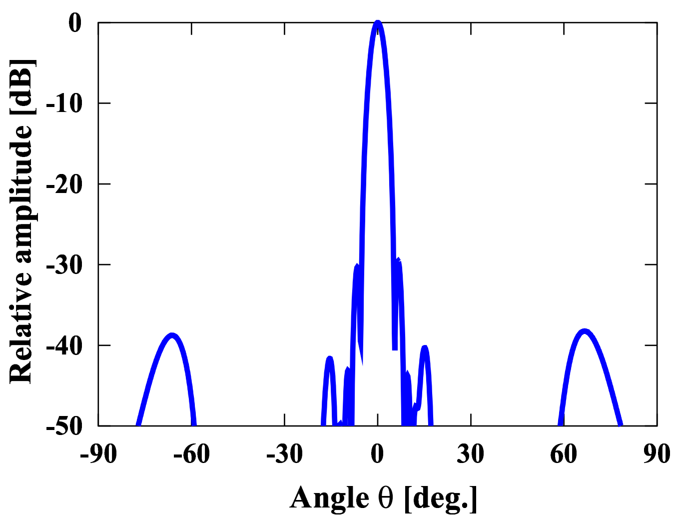


Figure 6: Simulated Radiation Pattern of Plannars Antenna in kk’-Plane (phi=31°)