

Height Reduction in a 2x2-element Sub-array for a Corporate-feed Plate-laminated-waveguide 45-degree Linearly-polarized Slot Array

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Abstract

We propose a new configuration for the height reduction. The radiation element is modified for lower quality factor and lower height. The 2x2-element sub-array is analyzed for wider reflection bandwidth. The height is reduced by 1.5mm but the reflection bandwidth becomes 1.9 % narrower in the 60GHz-band model.

Keywords : Plate-laminated-waveguide; 45-degree linearly-polarization; Slot array antenna; Millimeter wave band; Corporate-feed;

1. Introduction

Hollow-waveguide slot array antennas have been widely used in the millimeter band since they do not have radiation loss or dielectric loss either [1]. They have been developed especially for military application such as radars. For commercial application such as the fixed wireless access system, mass production at low cost has been required. A double-layer corporate-feed waveguide slot array [2] was proposed and achieved a wide bandwidth of high gain and high aperture efficiency. It can be mass-produced at low cost by diffusion bonding of laminated thin metal plates [3]. We proposed a 45-degree linearly-polarized configuration, where 45-degree inclined radiating slots were placed on the feeding circuit and fabricated 16x16-element array antenna [4]. In this paper, we propose a new configuration for the height reduction and low quality factor (denoted as Q) and design the 2x2-element sub-array considering wider reflection bandwidth.

2. Configuration and Operation Mechanism

Figure 1 shows the proposed 45-degree linearly-polarized hollow-waveguide slot array antenna with corporate-feed. The antenna is composed of the feeding part in the lower layer and the radiating part in the upper layer. It is fed through a feeding aperture by a WR-15 standard waveguide from its backside. The feeding circuit is a corporate-feed and a combination of H-plane T-junctions. The radiating part is fed through a coupling aperture located at each end of the feeding circuit. Figure 2 shows the exploded perspective view of the conventional and the proposed 2x2-element sub-array. Exciting slot excites 45-degree inclined radiating element in the xy-plane. The radiating element is a slot backed by a cavity for the proposed model while it was an aperture for the conventional model. The cross polarization in the conventional model was suppressed by the height of the radiating apertures and the total thickness of the antenna becomes large. In contrast, the cross polarization in the proposed model is suppressed by the width of the radiating slots. Therefore, the total height of the antenna will be reduced. Even though another layer is added for the proposed model, the complexity of fabrication by the diffusion bonding of laminated plates does not change.

3. Design of Radiation Element

The radiation element composed of a radiating slot and an exciting cavity is designed at 61.5 GHz. The analysis model of the radiation element is shown in Fig. 3 and is simulated by

"Ansoft HFSS". Two pairs of periodic boundary walls are assumed to take mutual coupling into account. Eigenvalue analysis is conducted to obtain Q . PML (Perfect Matching Layer) and 377Ω impedance boundary are assigned on the feeding plane and the radiation boundary, respectively. At first, it is shown that cross polarization can be suppressed by the width of the radiating slot against several exciting cavity height. Next, its dimension is determined for low Q keeping cross polarization below -30 dB.

3.1 Cross polarization suppression by radiating slot width

Cross polarization of a 16×16 -element array is calculated by Array Setup of HFSS for four different exciting cavity height. The cross polarization at the design frequency is shown in Figure 4. As the radiating slot width becomes narrower, the cross polarization is suppressed. For a lower exciting cavity height, a narrower radiating slot width is required to have equal cross polarization level.

3.2 Optimization of cavity dimension for low Q by eigenvalue analysis

The radiating slot width and the exciting cavity dimension are determined for low Q . For several exciting cavity dimensions, the radiating slot width is adjusted so that the cross polarization at the design frequency is -30 dB. The Q is calculated by the eigenvalue analysis.

The Q and the radiating slot width for the exciting cavity height are shown in Figure 5. As the exciting cavity height becomes larger, the slot width becomes wider to have -30 dB cross polarization. Even though the minimal Q is obtained when the exciting cavity height is 1.8 mm, the exciting cavity height is determined as 1.2 mm considering the reduction of the antenna height. The Q and the radiating slot width for the exciting cavity length are shown in Figure 6 where the ratio of the exciting cavity length to the width is kept to 0.6 . The Q becomes lower as the exciting cavity length longer, and therefore the exciting cavity length is preferable as longer as possible. The exciting cavity length is determined as 3.7 mm not to interfere neighbor exciting cavities.

4. Design of 2×2 -element Sub-array

The analysis model of the 2×2 -element sub-array is shown in Figure 7. Two pairs of periodic boundary walls are assumed to take mutual coupling into account and the element spacing is 4.2 mm. Impedance matching is conducted by two parameters: d and l_{CP} , the length of the wall in the coupling cavity and the length of the coupling aperture. Frequency characteristic of the reflection coefficient on complex plane (Smith chart) is shown in Figure 8 and draws a loop around the origin. The loop corresponds to double resonance characteristic and double-tuned frequency characteristic of the reflection is obtained as shown in Figure 9.

4.1 Optimization of double resonance frequencies

It is observed that the circumference of the loop is adjustable by the length of the exciting slot. This means that the length of the exciting slot affects the resonance frequencies. Lower and higher frequencies where the loop crosses are defined as f_l and f_h , respectively. The center frequency between f_l and f_h is defined as f_c . The circumference of the loop can be expressed by the ratio of $(f_h - f_l)$ to f_c . For several length of the exciting slots, the impedance is matched and the bandwidth is calculated as shown in Figure 10. The impedance matching is conducted so that VSWR is 1.2 at the center frequency f_c and the bandwidth is defined so that VSWR is less than 1.5 . The figure reveals that reflection bandwidth can be enhanced by the circumference of the loop. The widest bandwidth is 5.3% when the length of the exciting slots is 2.51 mm.

The frequency characteristics of the cross polarization and the directivity of the 16×16 -element array are calculated by Array Setup and shown in Figure 11. The aperture efficiency is also shown in the same figure and basis aperture area is 67.2 mm square. The cross polarization is less than -26.6 dB from 59 GHz to 64 GHz. The directivity is 33.7 dBi and the corresponding aperture efficiency is 98.3% . The radiation patterns in the $\phi = 0$ deg. plane and 45 deg. plane (E-plane) are shown in Figure 12. The first side lobe level is -13.3 dB and -26.6 dB in the $\phi = 0$ deg. plane and 45 deg. plane, respectively. Any grating lobes are generated on the planes.

5. Conclusion

We propose a new configuration for the height reduction. At first, it is shown that the cross polarization can be suppressed by the width of the radiating slot. Then, the radiation element is designed for lower height with low Q . Finally, the 2×2 -element sub-array is analyzed for impedance matching. The impedance characteristic shows double resonance and its bandwidth becomes wider by adjusting the spacing of the double resonance frequencies. Compared to the conventional model, 1.5 mm height reduction is realized but the bandwidth for VSWR less than 1.5 is 5.3 % whereas the conventional model has 7.2 % bandwidth.

References

- [1] R. C. Johnson, and H. Jasik, Antenna Engineering Handbook, 3rd ed. New York: McGraw-Hill, 1984, Chap.9.
- [2] Y. Miura, J. Hirokawa, M. Ando, Y. Shibuya, G. Yoshida, "Double-layer Full-corporate-feed Hollow-waveguide Slot Array Antenna in the 60GHz-band," accepted in IEEE Trans. Antennas Propagat.
- [3] J. Hirokawa, M. Zhang, and M. Ando, "94GHz single-layer slotted waveguide array by diffusion bonding of laminated thin plates," 2008 Intl. Symp. Antennas Propagat., TP-C03-3, Oct. 2008.
- [4] T. Tomura, M. Zhang, J. Hirokawa, M. Ando, "Plate-laminated-waveguide Corporate-feed 45-degree Linearly-polarized Aperture Array Antenna in the 60 GHz-Band," 2011 IEEE AP-S Int. Symp., TH-PM.8.7, Jul. 2011.

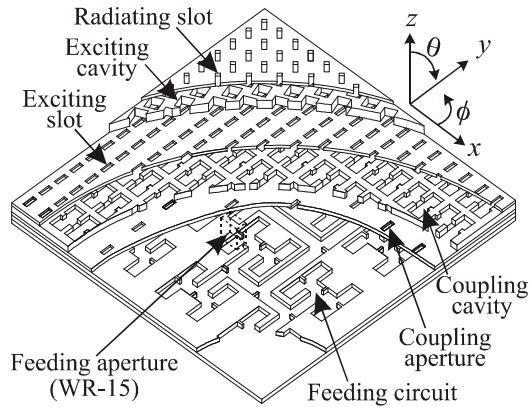


Figure 1: Plate-laminated-waveguide Corporate-feed 45 degree Linearly-polarized Slot Array Antenna

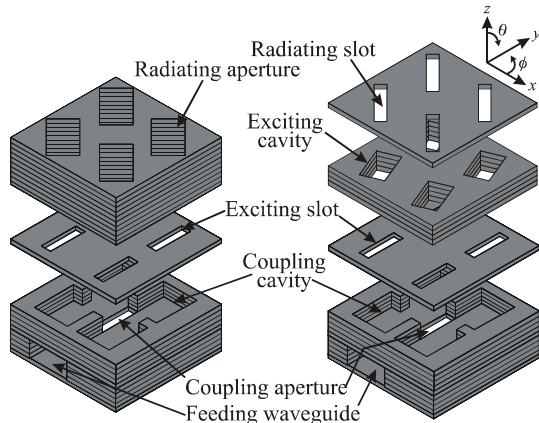


Figure 2: Exploded perspective view of the conventional(left) and proposed(right) 2×2 -element sub-array

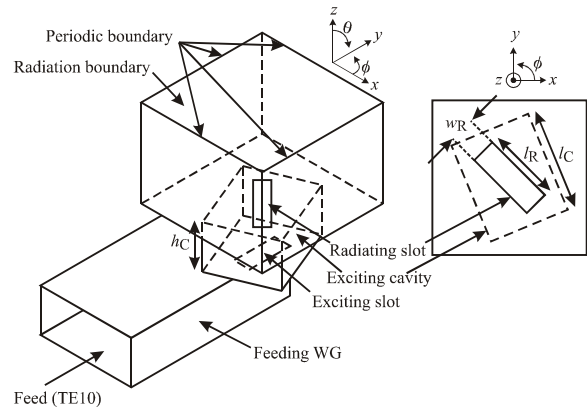


Figure 3: Analysis model of the radiation element

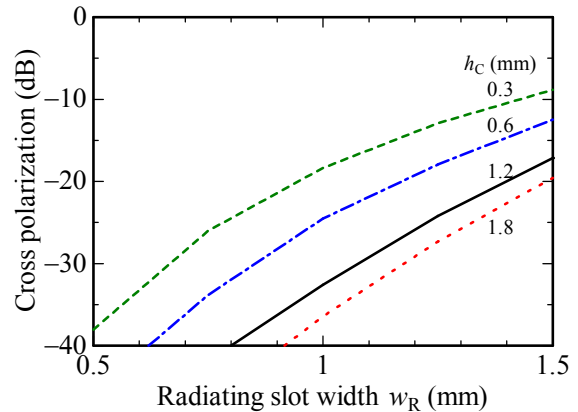


Figure 4: Cross polarization characteristics by radiating slot width

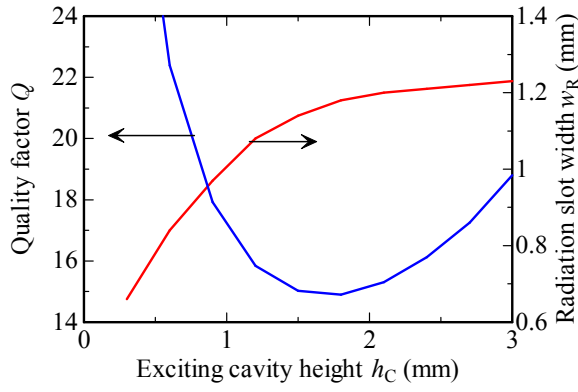


Figure 5: Cavity height characteristics of Q

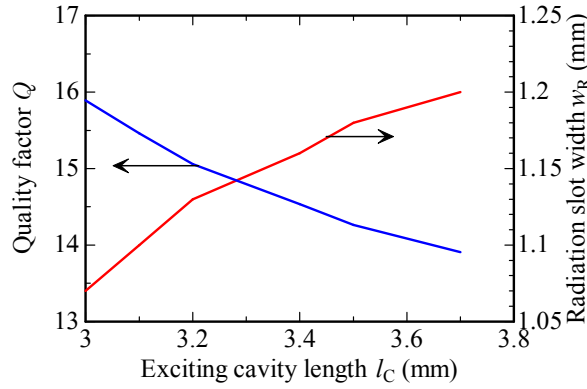


Figure 6: Cavity length characteristics of Q

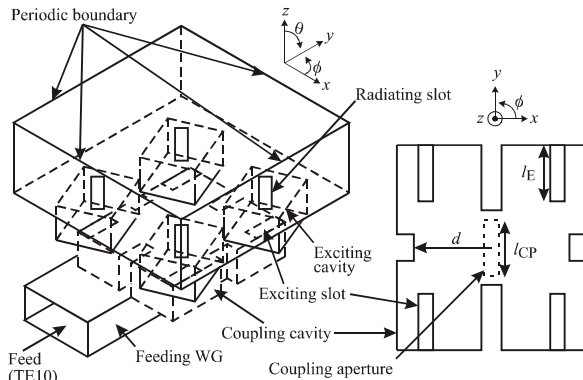


Figure 7: Analysis model of 2x2-element sub-array

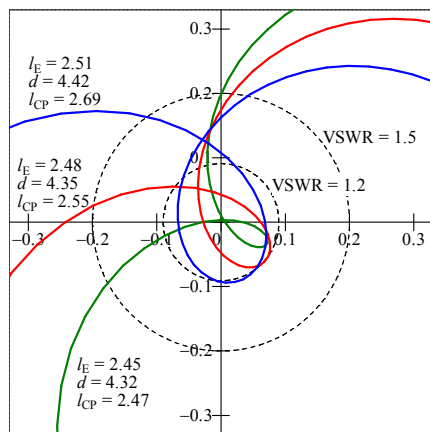


Figure 8: Reflection coefficient on complex plane

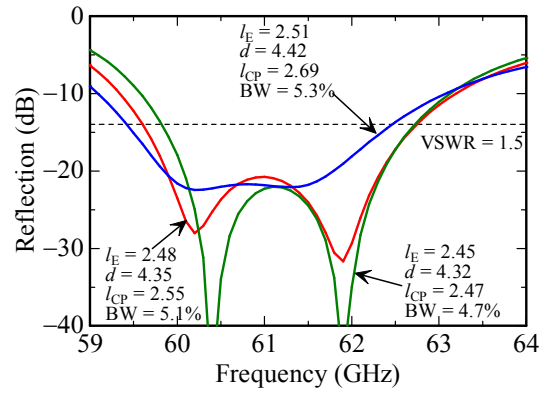


Figure 9: Frequency characteristic of reflection

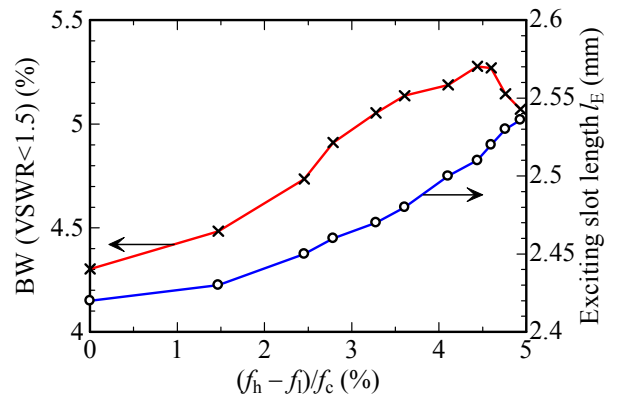


Figure 10: Bandwidth enhancement

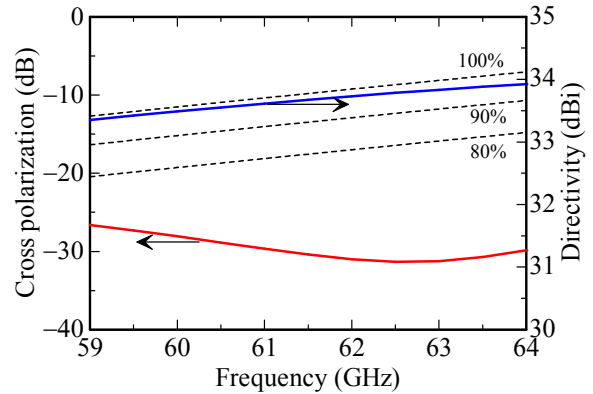


Figure 11: Frequency characteristics of cross polarization and directivity

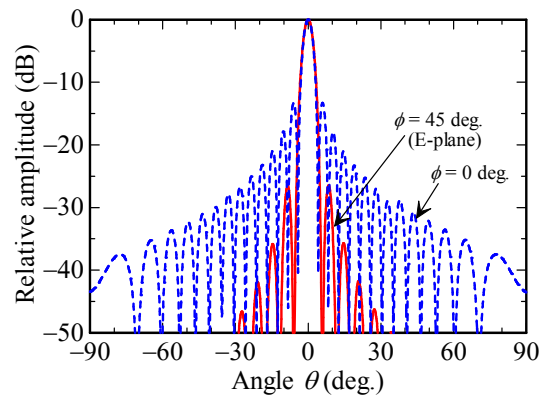


Figure 12: Radiation pattern in the $\phi = 0$ deg. plane and 45 deg. plane (E-plane)