Design of Partially Parallel-Fed Hollow Waveguide Nallow-Wall Slot Array Antenna in Millimeter-Wave Band

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1. Introduction

High-gain and low-profile antennas are required for high-speed wireless communication systems and mechanically-scanning automotive radars in the millimeter-wave band. Waveguide antenna is one of the most attractive planar antennas for such millimeter-wave systems because of its low loss and high efficiency characteristics in high frequency band. Travelling-wave excitation is more effective for array feeding than parallel feeding systems. However, array antenna with travelling-wave excitation essentially possesses a significant problem of long line effect that gain is degraded by beam shift due to frequency changes when the array antenna is fed from the edge of radiation waveguide [1]. This paper proposes the way to reduce the gain degradation due to frequency change by using partially parallel feeding of radiation waveguide. A wideband slotted waveguide broadside array is designed in the millimeter-wave band. Simulated performance of the designed antenna is reported in this paper.

2. Antenna configuration

2.1 Feeding circuit

We propose the way to reduce the long line effect due to travelling-wave excitation of waveguide slot array antenna. Figure 1(a) shows three different feeding systems for waveguide antenna. Partially parallel feeding in radiation waveguide decreases the long line effect. The long line effect for edge feeding is the largest in three-different feeding systems. Center feeding system supplies RF power from the center of the waveguide by using four-way power divider. Four parallel feeding system is composed of two asymmetrical four-way power divider fed from the center H-plane T-junction. Lengths of travelling-wave feeding parts in center and four parallel feedings are shorter than edge feeding. Figure 1(b) shows frequency dependency of directivity in 0 degree direction. Directivity reduction in center and four parallel feeding is much smaller than edge feeding. Thus, the long line effect is reduced by using partially parallel feeding.

Two types of partially parallel feeding systems are designed as shown in Fig. 2(a) and (b). Array design is implemented for Taylor distribution with sidelobe lower than –20dB. Figure 2(a) shows four-way power divider for center feeding. This circuit is designed as symmetrical structure for feeding equal power. Post and iris are designed for impedance matching. Transmission phase difference between port 2 and 3 and between port 4 and 5 are designed as alternating 180 degrees out of phase. Figure 2(b) shows asymmetrical four-way power divider for four parallel feeding from the centers of both half array. This circuit is designed to be asymmetrical structure with power-split ratio of 7:3 for Taylor distribution. Desired reflection characteristic and power-split ratio would be obtained by adjusting dimensions of post, iris and coupling window.

2.2 Slot design to suppress grating-lobes

Two-line slotted waveguide planar array antenna is developed for broadside beam. Nallow-wall slot waveguide array antenna for travelling-wave excitation is shown in Fig. 3. Total number of

elements is 24. Array design is implemented for Taylor distribution with sidelobe lower than –20dB. Slot arrangement shifts by a half guided wavelength in x-direction on adjacent waveguides. 6 slots cut on the narrow-wall are inclined with 45 degrees for automotive radar application. In this design for broadside beam, slot spacing is one guided wavelength that is larger than a wavelength in free space. Consequently, grating lobes appear in the radiation pattern. Following ideas are supplied to the antenna in order to reduce the grating lobe.
(1) Grating-lobe suppression in x-direction
Interleave slot arrangement excites all slots in phase since the power divider feeds adjacent two waveguides with 180 degrees out of phase [2]. Consequently, grating-lobe does not appear in xz-plane. On the other hand slot spacing is maximum in kk'-direction.
(2) Grating-lobe suppression in kk'-direction
In order to shorten the guided wavelength, the broad wall width of the waveguide is designed to be large. In order to shorten slot spacing in y-direction, slots are cut on narrow-wall. Grating lobe level is reduced more by element radiation pattern of the cavity on the slot. Therefore, grating-lobes are suppressed by the design of narrow-wall slot waveguide array antenna in the millimeter-wave band.

3. Designed antenna and simulated performance

Figure 4(a) and (b) shows array antennas partially parallel-fed by symmetrical and asymmetrical four-way power dividers. Design frequency is 76.5 GHz. Total number of elements is 24 in two-line slotted waveguide planar array antenna. Array design is implemented for Taylor distribution with sidelobe lower than –20dB. Grating-lobe is suppressed in the design of two antenas. Center-fed array antenna is fed by symmetrical four-way power divider. Four partially parallel-fed array antenna is fed by two asymmetrical four-way power dividers.

Performances of two-line slotted waveguide planar array antennas composed of 24 slots are calculated by electromagnetic simulator of finite element method. Figure 5(a) shows reflection characteristics. Since the resonant frequency corresponded to the design frequency 76.5 GHz, reflection level was lower than –20 dB at the frequency. Figure 5(b) shows radiation patterns in the plane parallel to the waveguide axis at the design frequency 76.5 GHz. Although array design is implemented for Taylor distribution with sidelobe lower than –20dB, the sidelobe level is –17.1 dB for center-fed array antenna and –15.1 dB for four partially parallel-fed array antenna. This is because slot spacing is slightly large on the feeding circuit shown in Fig. 2. Figure 5(c) shows directivity in 0 degree direction in three types of array antennas. Directivity reduction in frequency change of center-fed and four partially parallel-fed array antenna is smaller than edge feeding array antenna. Figure 5(d) shows radiation patterns of four partially parallel-fed array antenna when frequency changes by ± 3 GHz from 76.5 GHz. The main beam direction does not shift from 0 degrees.

4. Conclusion

Narrow-wall slot waveguide array antenna is designed to obtain broadband and low loss by using partially parallel feeding in the millimeter-wave band. Comparing the three types of feeding circuit method for waveguide antenna, center-fed and four partially parallel-fed array antennas are more effective for broadband operation than edge feeding array antenna.

References

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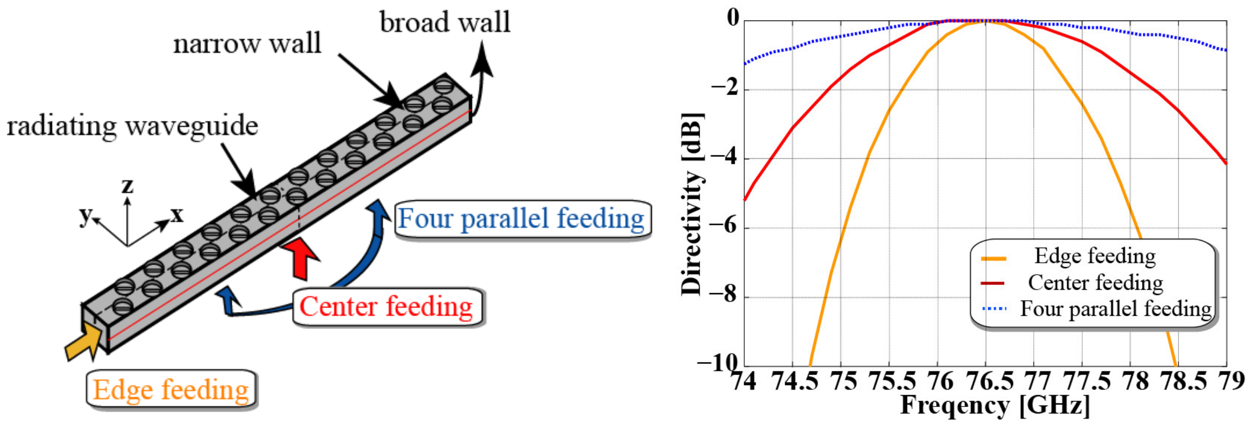
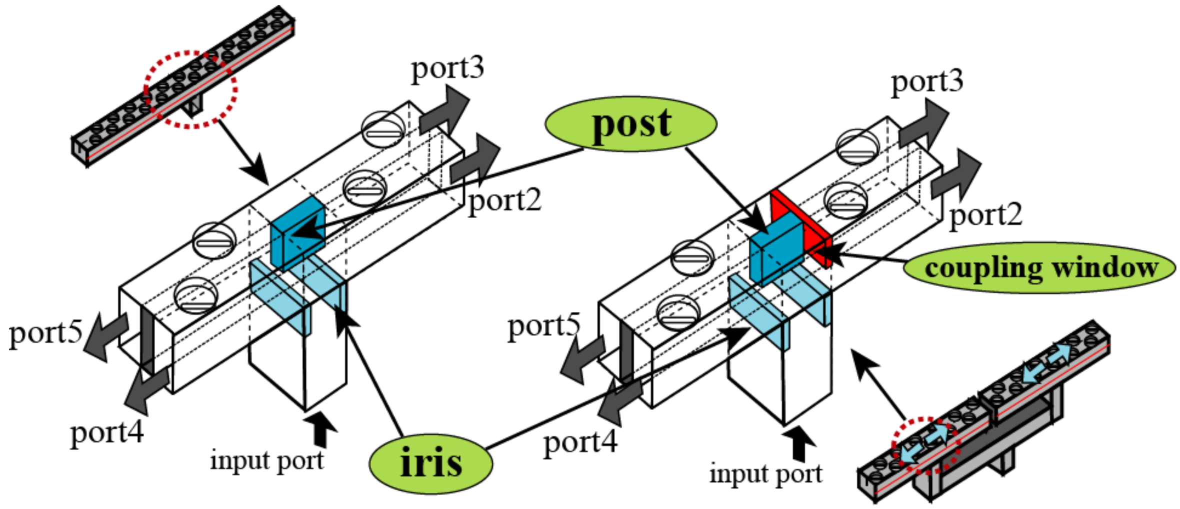
[2] K.Sakakibara, Y.kimura, A.Akiyama, J.Hirokawa, M.Ando, and N.Goto, "Altenating Phase-Fed Waveguide Slot Array with a Single-layer Multipe-Way Power Divider," IEE Proc. Microwave, vol.79, NO.12, pp.1765-1772, Dec.1997.



(a)Three types of feeding system **(b) Directivity of 0 degree direction**

Fig. 1. Characteristic of feeding system



(a) Symmetrical four-way power divider for center feeding **(b) Asymmetrical four-way power divider for four parallel feeding**

Fig. 2. Structure of feeding circuit

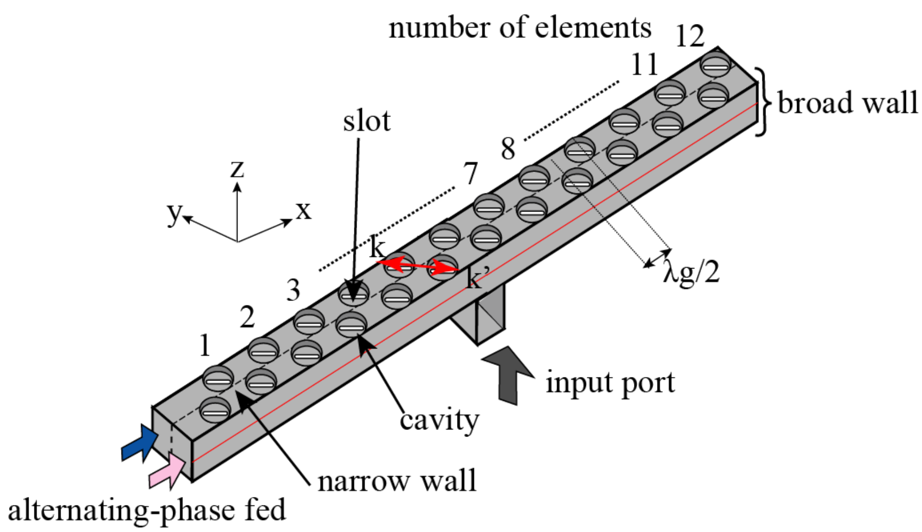
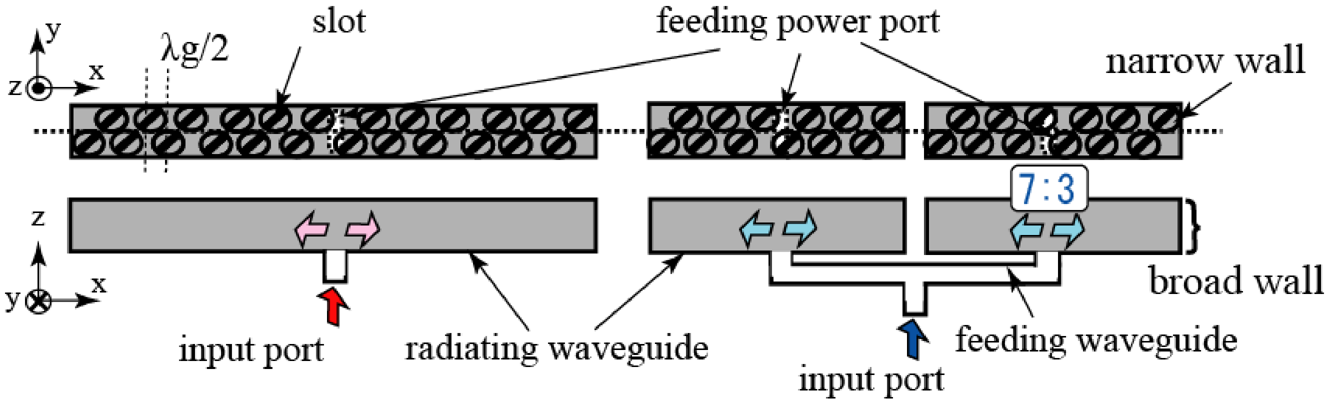


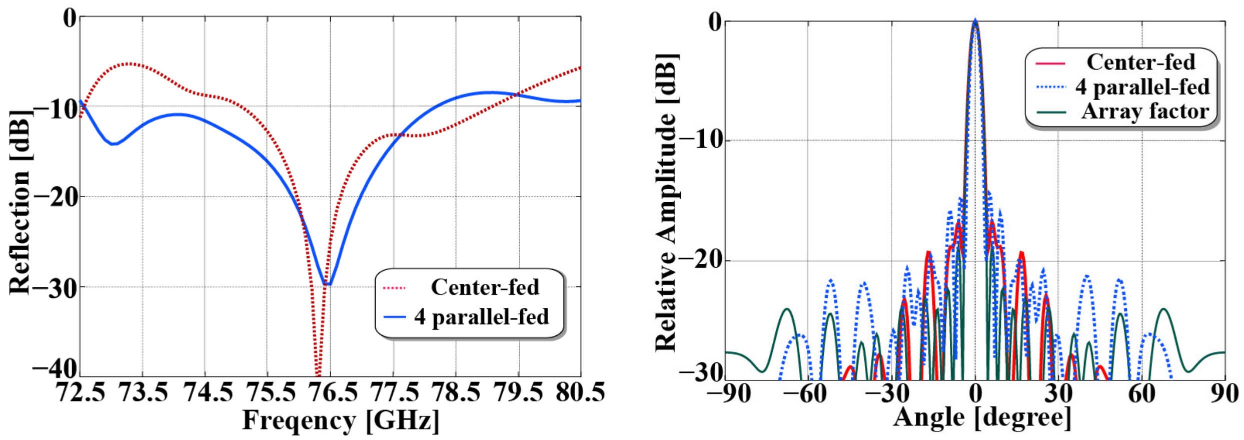
Fig. 3. Two-dimensional waveguide slot array antenna



(a)Array antenna fed by four-way power divider

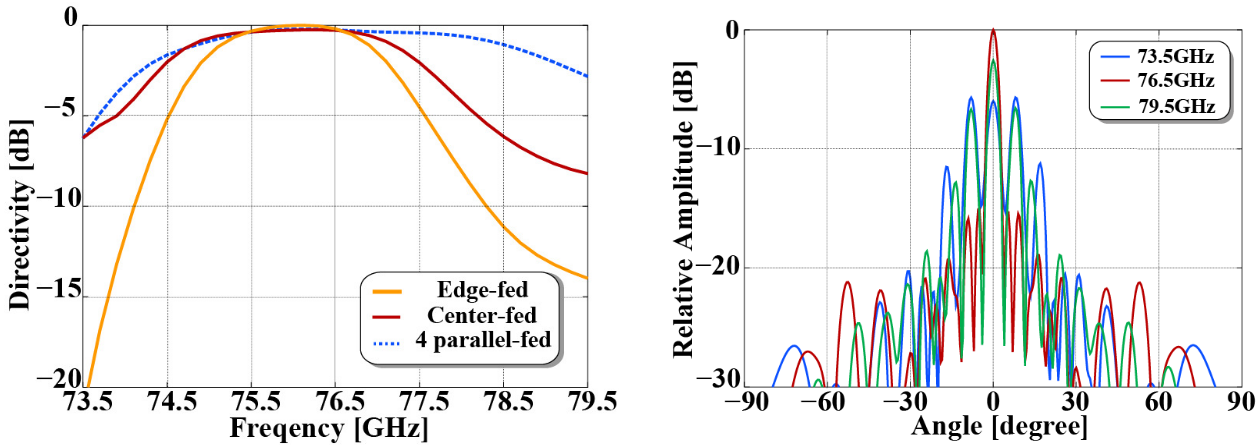
(b) Array antenna fed by asymmetrical four-way power divider

Fig. 4. Structure of the array antenna



(a) Reflection characteris

(b) Radiation patterns of array antennas for different feeding systems



(c) Directivity of 0 degree directi

(d) Radiation patterns of four partially parallel fed array antenna

Fig. 5. Simulated characteristics of array antenna