Efficiency of 76-GHz Post-Wall Waveguide-Fed Parallel-Plate Slot Arrays

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***Abstract*—We design and fabricate various sizes of 76-GHz post-wall waveguide-fed parallel-plate slot arrays. The post-wall waveguide is an array of metalized via-holes with a narrow spacing in a grounded dielectric substrate. The antenna can be easily made at low cost by conventional PCB (printed circuit board) fabrication techniques such as via-holing, metal plating, and etching. We have obtained 40–50% efficiency for various sizes from 26 mm × 24 mm to 104 mm × 100 mm. We have measured 35.3 dBi gain with 39.3% efficiency at 77.0 GHz in an antenna sized 104 mm × 100 mm.**

***Index Terms*—Millimeter-wave, parallel-plate waveguide, planar antenna, post, slot antenna.**

I. Introduction

A PARALLEL-plate slot array [1]–[9] is an attractive candidate for high- efficiency and mass-producible planar phased-array antennas [10], [11] for millimeter-wave applications for car warning radar system (76–77 GHz) and wireless LAN system (60–61 GHz). We investigate the efficiency characteristics depending on the Gain or the size in 76 GHz post-wall waveguide-fed parallel-plate slot arrays [9], [12]. We extract the loss factors from the efficiency in this antenna. Five model antennas sized from 26 mm × 24 mm to 104 mm × 100 mm are designed and fabricated. The structure and the configuration are briefly described at first. Next, we discuss loss measurement in straight post-wall waveguides and loss estimation by simulations. Then, the experimental results of the model antennas are presented. Finally, we summarize the conclusions. We give the high potential of this antenna in terms of the efficiency at millimeter waveband.

II. Model Antennas

Fig. 1 shows the structure. A post-wall feed waveguide is located at the edge of a parallel-plate waveguide. Coupling windows are placed with a spacing of the guide wavelength in the feed waveguide to be excited in phase [13], [14]. An input aperture is cut on the bottom of the parallel-plates at the center of the feed waveguide. Reflection-canceling slot pairs are arrayed with one-wavelength spacing to be excited in phase and to radiate a main beam in the boresight [15]–[17].

Five sizes of 76-GHz-model antennas are designed and fabricated. The aperture sizes are 26 mm × 24 mm (A), 39 mm × 37 mm (B), 52 mm × 49 mm (C), 78 mm × 74 mm (D), and 104 mm × 100 mm (E). An array of the coupling windows and that of the slot pairs are designed for uniform excitation both in amplitude and phase [18], [19]. The design frequency is 76.5 GHz. A dielectric substrate of PTFE and glassfibers is used with 18-μm-thickness rolled copper on the both surfaces. The dielectric constant is 2.17 and the loss is $\tan\delta = 0.00085$ at 10 GHz. The height is 0.762 mm, 0.29 wavelength including the dielectric constant. Many metal-surface via-holes with 0.3-mm diameter are arrayed with narrow spacing of 0.6 mm in the maximum. Slots with 0.2-mm width are etched on the upper plate. The antennas can be easily produced by via-holing, metal plating, and etching.

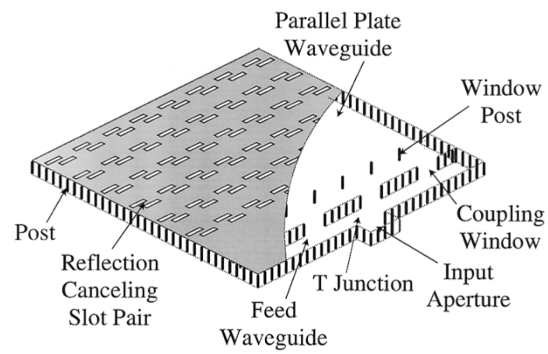

Fig. 1. Post-wall waveguide fed parallel-plate slot array.

III. Measured Loss in Straight Post-Wall Waveguides

Various length of straight post-wall waveguide is fabricated. The spacing a_f of the two post-walls is 2.625 mm. The other parameters are the same as those in the model antennas as listed in Section II. Each post-wall waveguide is terminated by a few posts at the both ends and two input apertures are placed as the ports there. The transmission loss between the two ports as well as the reflection at each port is measured by a vector network analyzer. Fig. 2 shows the frequency dependence of the measured transmission of each waveguide and the loss per millimeter. We confirm that the reflection at the input aperture is below -15 dB in the worst case and generally around -20 dB. The thin lines are the transmission eliminating the reflection loss of the input aperture, since we compensate the difference in the reflection loss among the waveguides and evaluate purely the increase of the loss, as the waveguide becomes longer. The thick line is the loss per millimeter by approximating linearly the measured transmission as a function of the waveguide length. The loss of the post-wall waveguide is 0.023 dB/mm at 76.5 GHz. A parallel-plate waveguide in the radiating part of the antenna should

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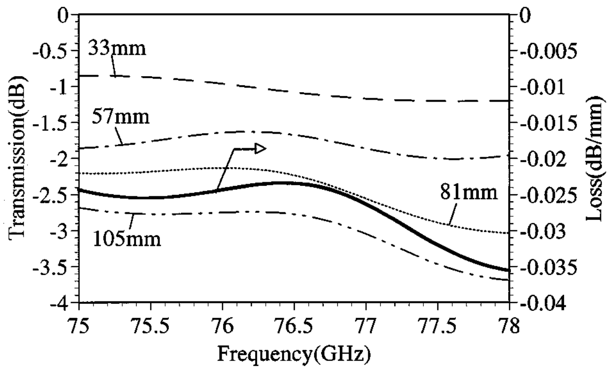

Fig. 2. Measured transmission and loss per millimeter of straight post-wall waveguide (thin lines: measured transmission; thick line: loss per millimeter).

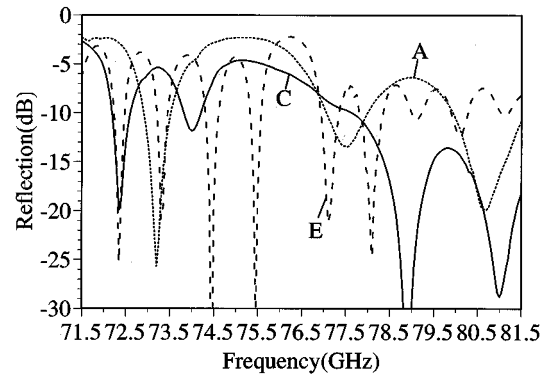

Fig. 3. Frequency dependence of the overall reflection at the input port.

have smaller loss than a post-wall waveguide because the wavelength is shorter and the posts are eliminated in the parallel-plate waveguide.

IV. Experimental Results

A. Reflection

Fig. 3 shows the frequency dependence of the overall reflection at the input port. It is found that the input aperture itself has −11-dB reflection due to its position error of 0.2 mm in the antennas expect (C). In these antennas, furthermore, the period of the frequencies minimizing the reflection locally decreases, as the aperture length becomes large. This may come from the mutual effect between the reflection at the input port and that of the match junction at the ends of the feed post-wall waveguide. The post walls in the parallel-plate region are not included in the analysis and the design of the matching junction. Full size of the feed post-wall waveguide will have to be analyzed in the future study to reduce the reflection.

B. Near-Field Distributions

Experimental results are shown at the center frequencies where the maximum gain is obtained in each antenna. The frequencies are 76.75 GHz in (C) and 77.0 GHz in the others. The center frequencies are slightly different with the designed one due to the manufacturing errors of about 5–10 μm in the length of the radiating slots.

Fig. 4 shows the amplitude distribution of the near field in (C) at 76.75 GHz. The horizontal axis is perpendicular to the feed waveguide while the vertical one is parallel to it. This means that the feed post-wall waveguide is placed at the right side along the vertical axis and a plane TEM wave in the parallel-plates propagates from the right to the left. The amplitude has about 4 dB deviation over almost of the aperture. The phase has about 80° taper perpendicularly to the feed waveguide due to the etching error of the slots but it is almost uniform along the feed waveguide. Around the periphery of the parallel-plates, the amplitude becomes weak and the phase has some progression due to the truncation of conductor post-walls.

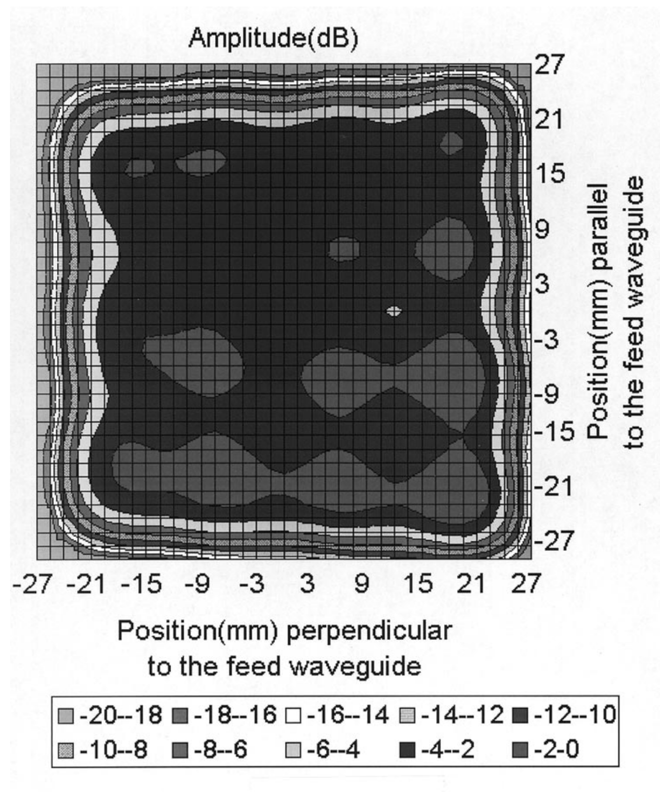

Fig. 4. Amplitude distribution of near-field in antenna (C) at 76.75 GHz.

C. Radiation Patterns

Fig. 5 shows the radiation patterns in the *H*-plane of the model antennas around the boresight. The *E*-plane patterns are quite similar to the *H*-plane ones. The sidelobes in the both planes are suppressed below −13 dB due to the uniform aperture field distribution. However, the first sidelobe level of (E) in the *H*-plane is −6.6 dB because of the strong aperture field around the periphery of the parallel-plates. The sidelobes in a wide-angle range are suppressed well. The 3-dB beamwidth decreases proportionally to the aperture length. The measured values agree well with the predicted one given as 50.6/d (degrees, d is the aperture length in wavelength) for uniform aperture field [20].

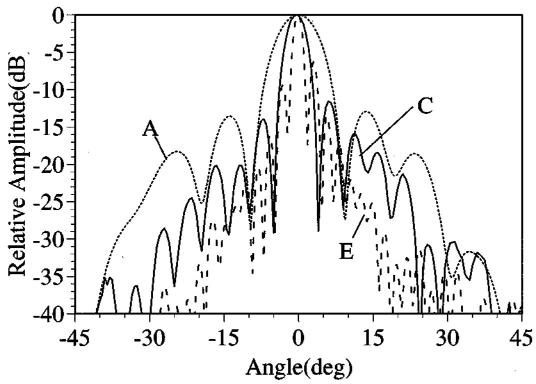

Fig. 5. Radiation patterns in the *H*-plane of the five model antennas around the boresight [frequency: 76.75 GHz for (C) and 77.0 GHz for the others].

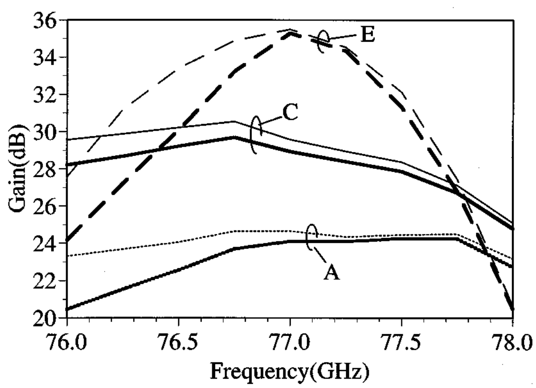

Fig. 6. Frequency dependence of gain (thick lines: measured; thin lines: eliminating the reflection loss).

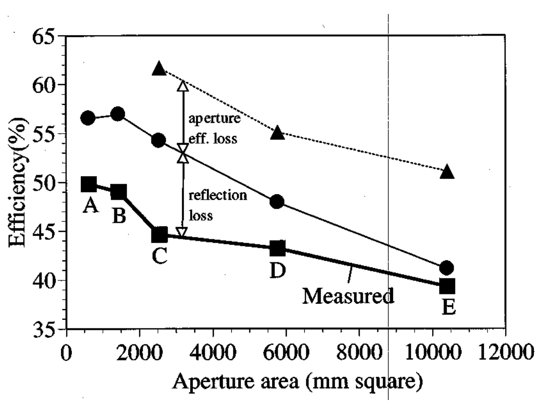

Fig. 7. Efficiency as functions of the aperture area of the antenna [frequency: 76.75 GHz for (C) and 77.0 GHz for the others] (thick line: measured; thin line: eliminating the reflection loss; dotted line: eliminating the reflection loss and the aperature efficiency loss).

D. Gain and Efficiency

Fig. 6 shows the frequency dependence of the gain. Fig. 7 shows the efficiency for various aperture area of the antenna. The thick lines indicate the measured gain while the thin lines are the gain eliminating the reflection loss. When the aperture size becomes larger, the peak increases. However, the bandwidth decreases due to the long line effect of the series arrays of the coupling windows and the slots. The peaks of the measured gain are 29.7 dBi with 44.6% efficiency at 76.75 GHz in (C) and 35.3 dBi with 39.3% efficiency at 77.0 GHz in (E). The range of the measured efficiency is from 39.3% in (E) to 49.8% in (A) for various sizes of the antennas. The aperture efficiency estimated by near-field distribution is 87.9% in (C), 86.9% in (D), and 80.5% in (E). The thin solid and dotted lines in Fig. 7 are the efficiencies eliminating the reflection loss and/or the aperture efficiency loss. These results reveals that the antenna has the potential to improve the efficiency up to 50% to 60% after suppressing the losses associated with the reflection and the aperture efficiency.

V. Conclusion

We have designed and fabricated various sizes of 76 GHz post-wall waveguide-fed parallel-plate slot arrays. We have found the loss of the straight post-wall waveguide to be 0.023 dB/mm in measurements. The peaks of the measured efficiency are obtained 39.3% to 49.8%, in the five arrays sized from 26 $\times$ 24 mm to 104 $\times$ 100 mm. These antennas have potential to enhance the efficiency up to 50% to 60% after the suppression of the reflection and the aperture efficiency losses.

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