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Waveguide Slot Antennas with Different Aperture Sizes Developed for the MMW Short Range Wireless Access Gate System

#Miao Zhang, Jiro Hirokawa, Makoto Ando
Dept. of Electrical and Electronic Engineering, Tokyo Institute of Technology
S3-19, 2-12-1 O-okayama, Meguro-ku, Tokyo, 152-8552, Japan, miao@antenna.ee.titech.ac.jp

1. Introduction

Recently, a cloud computing system is widely expected to realize a free and high-capacity data transfer between the high-performance mobile wireless terminals and the servers. The high-speed multi-Gbps short range wireless access gate system in millimeter-wave band is under development in Japan. Figure 1 illustrates the wireless access gate to be established in stations and other public areas. Many researches and activities on antenna packages for 60 GHz WPAN (Wireless Personal Area Network) terminals have been reported [1-3]. The antenna gain for those mobile wireless terminals about 3 ~ 9 dBi is relative low, and the HPBW (Half Power Beam Width) around 40 ~ 60 degrees is preferred to realize high access performance. However, the suitable antenna aperture size remains an issue for the wireless access gate. The communication distance between the mobile wireless terminal and the wireless access gate is relative short from tens of centimeters to several meters. Those far-field evaluation indices as represented by Friis Transmission Equation as well as the antenna gain and HPBW can not be easily applied as before. In this paper, the suitable antenna aperture size will be investigated first to enlarge the reception in a wireless access gate system. After that, the circularly-polarized waveguide slot arrays with different numbers of slots are designed for demonstration. The 2×2, 4×4, 8×8 and 64×64-element arrays are fabricated and evaluated especially from the conventional viewpoint of far-field radiation.

2. Investigation of Suitable Antenna Aperture Size

The suitable antenna aperture size is investigated first, to enlarge the reception area in a wireless access gate system. As the initial approach, the radiation in a free space is considered. For simplicity, the uniformly distributed magnetic currents with different aperture sizes are assumed on the aperture of a grounded metal plate. The radiated electromagnetic fields from the source including all the near-field and far-field components are precisely calculated. It is well known that the directivity for the uniform distribution is given by $D_0 = 4\pi\ (b/\lambda)^2$, where b the side length of a square aperture. The electric field intensities evaluated in the neighborhood of source for different aperture sizes are summarized in Fig. 2 (*a*) for comparison. Here, the total input power is fixed at 10 mW. For the small aperture size of 2.51 mm square (5 dBi equivalence), the electric field is very strong in its neighborhood similar to the low gain antenna. The radiated field intensity wanes fast with the increment of propagation distance. On the other hand, for the large aperture size of 251 mm square (45 dBi equivalence), the electric field intensity keeps almost unchanged in short range regardless of the propagation distance. A larger reception area for the wireless terminal would be achieved by adopting a large aperture antenna in the access point compared with the small one. In addition, the maximum electric field density in close vicinity to the source can also be favorably suppressed with the consideration of SAR (Specific Absorption Rate). It should be noted that the conception of a larger aperture as well as a high gain antenna with narrow HPBW and small reception area in the far-field is not applicable in the short range wireless access gate system. As the second step, the propagation environment involving multi-path, where the reflected waves happen due to the metal plates and the concrete walls existing around the transmission path, is also investigated. For a simple simulation, five image sources with same amplitude and phase are assumed on each side of the original antenna aperture, with a periodicity of 400 mm. The total electric field intensity is summed up under the same condition with Fig. 2 (*a*). As illustrated in Fig. 2 (*b*), the small aperture antenna is susceptible to the reflected waves. You can well imagine that the transmission between the access point and the mobile terminal becomes unstable due to the presence of standing wave. On the other hand, the large aperture antenna provides wide and stable reception area regardless of the reflected waves, to which a similar result is obtained in Fig. 2 (*a*).

3. Design of Waveguide Slot Antennas

To demonstrate the effectiveness of the reception area enlargement by using large aperture antennas, the waveguide slot arrays with different aperture sizes are to be designed. The user-friendliness and access performance can also be enhanced by adopting a circular polarization, since the users are not necessary to intentionally adjust the posture of mobile terminal. A 16×16-element circularly-polarized double-layer waveguide slot antenna as illustrated has been successfully developed with the center frequency at 61.5 GHz [4]. A high antenna efficiency of about 90% and a good axial ratio are realized at the center frequency. However, the 1 dB down bandwidths of antenna gain is 4.4% and the bandwidth of axial ratio less than 3 dB is 4.4%. These bandwidths are not large enough to cover a whole frequency channel in 60 GHz band WPAN system [5]. To demonstrate the antenna performance in a real WPAN system, this type of antenna will be redesigned at 60.5 GHz to cover the frequency range of 59.40 ~ 61.56 GHz. At first, the basic composing structure as illustrated in Fig. 3 that is a 2×2-element subarray with PBWs (Periodic Boundary Walls) existing in the external region will be redesigned at 60.5 GHz. Following the conclusion obtained in [4], the element design method assuming the PBWs is effective for the array antennas with the number of elements larger than 16×16. That is, even a 64×64-element array can be easily realized by just arranging 16 16×16-element arrays properly connected by a corporate feeding circuit. However, specific consideration has to be given to the design of 2×2, 4×4 and 8×8-element arrays, where the axial ratio has large dependence on the finite ground plane size. The dimensions of hexagonal apertures in radiation are optimized again to improve the axial ratio at the center frequency. The structural parameters and axial ratios after optimization are summarized in Table 1. It can be easily observed that, the axial ratios for the 2×2 and 4×4-element arrays are not so good and they could be improved further by increasing the aperture height, which is fixed at 3 mm in our design. As the design results by applying HFSS, the reflections for all antennas are suppressed below -17 dB over the desired frequency channel. It should be noted that, the bandwidths of antenna gains are same to each other, because all antennas are fed by a corporate feeding circuit and there is no long line effect. The axial ratios are suppressed below 2 dB over the desired frequency range.

4. Antenna Fabrication and Measurement

Now, the designed antennas are ready for fabrication by diffusion bonding of thin copper plates [4, 6]. Totally, four types of antennas with different numbers of slots, they are 2×2, 4×4, 8×8 and 64×64, are fabricated. A bottom plate with the thickness of 6 mm is adopted for the 2×2, 4×4 and 8×8-element arrays with large stableness. With the consideration of antenna weight, the 64×64-element array adopts a 0.6 mm bottom plate instead. However, four composing 2×2-element subarrays at the center area have to be removed sacrificially, and four through-holes penetrating the antenna are produced to connect with the standard waveguide from bottom for feeding. The antenna size of 64×64-element array is as large as 290×290 mm^2. The flatness and stableness especially in the feeding circuit are remained as the issues. The photograph of the test antenna is shown in Fig. 4. The aperture illuminations for all test antennas are measured under a near-field measurement system. Uniform distributions are realized at the center frequency of 60.5 GHz for the 2×2, 4×4 and 8×8-element arrays. On the other hand, mosaic-like patterns with 8×8-element areas are observed in the 64×64-element array as illustrated in Fig. 5. The degradations its aperture illumination may result from the deformation in the layer of feeding circuit. The antenna gains are measured in an anechoic chamber as summarized in Fig. 6, by comparing a standard gain horn. Due to the degradation in the measured reflections of test antennas, the antenna gains with the matching loss excluded are also included in Fig. 6 denoted as the dashed lines. Furthermore, the directivities calculated from the measured aperture illuminations are denoted as solid lines with circles in Fig. 6. By comparing those values of antenna gain and directivity for each antenna, it is easily observed that the degradation in the antenna gain of 2×2-element array mainly results from the reflection loss. On the other hand, about 2 ~ 3 dB conductor loss is observed in the 4×4 and 8×8-element arrays. The investigation on its reason is remained as an issue. On the other hand, the aperture size for the 64×64-element array is too large to be measured in an anechoic chamber. The degradation in its directivity compared to the calculated value is also observed at about 2 ~ 3 dB. Even though the measured antenna performances are not perfect, but those waveguide slot antennas with different numbers of elements are ready for the evaluation in a wireless access gate system in the future.

5. Conclusion

The adoption of waveguide slot arrays with different aperture sizes has been investigated to enlarge the reception area in millimeter-wave short range wireless access gate system. A larger reception area in short range can be achieved by using the large aperture antenna compared with the small one, even though the high gain antenna has narrower HPBW in the far-field. In addition, the large aperture antenna provides wide and stable reception area regardless of the reflected waves. The circularly-polarized corporate-fed waveguide slot array antennas with 2×2, 4×4, 8×8 and 64×64 elements are designed at 60.5 GHz. They are fabricated by diffusion bonding of thin copper plates. Those antennas have been evaluated especially from the conventional viewpoint of far-field radiation. Now, they are ready for the evaluation in a short range wireless access gate system.

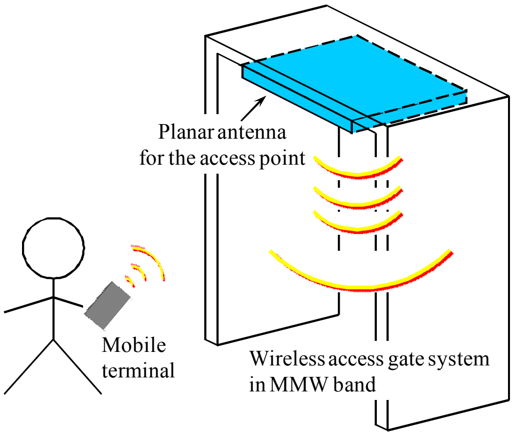
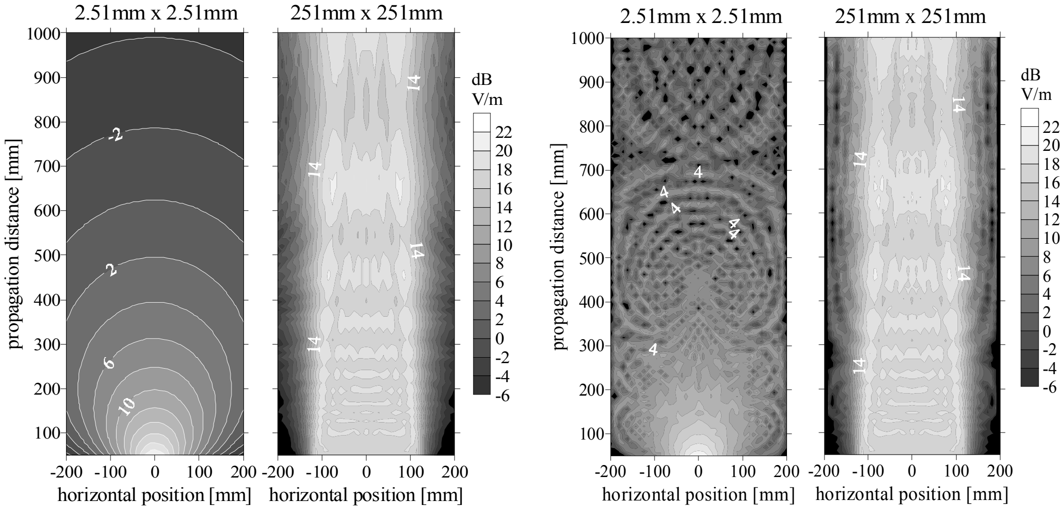


Figure 1: Wireless Access Gate System in the Millimeter-Wave Band



(*a*) w/o image sources (*b*) w/ image sources

Figure 2: Near-Antenna Electric Field Density

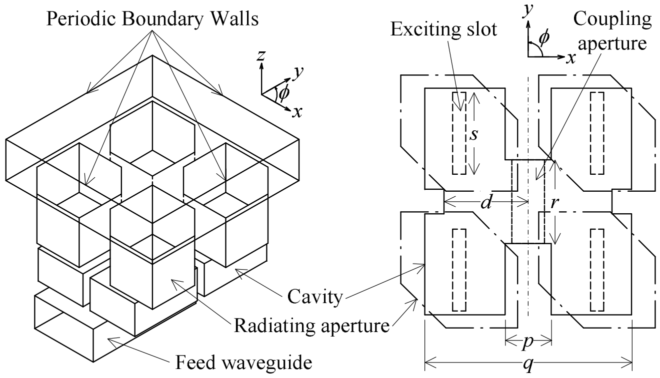


Figure 3: Composing 2×2-Element Subarray

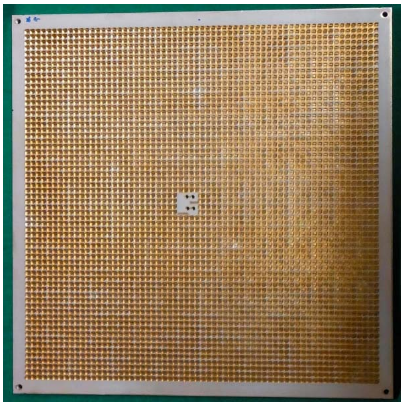


Figure 4: 64×64-Element Test Antenna

Table 1: Design Parameters for the Hexagonal Apertures

Number of Elements	Hexagonal Aperture		Wall Distance	Antenna Size	Axial Ratio
	a [mm]	*c* [mm]	*d* [mm]	[mm^2]	[dB]
2 × 2	3.9	1.68	2.66	33 × 40	1.52
4 × 4	3.8	1.58	2.66	33 × 40	0.81
8 × 8	3.65	1.41	2.64	42 × 43	0.69
2 × 2 (PBWs)	3.65	1.41	2.64	N/A	0.21

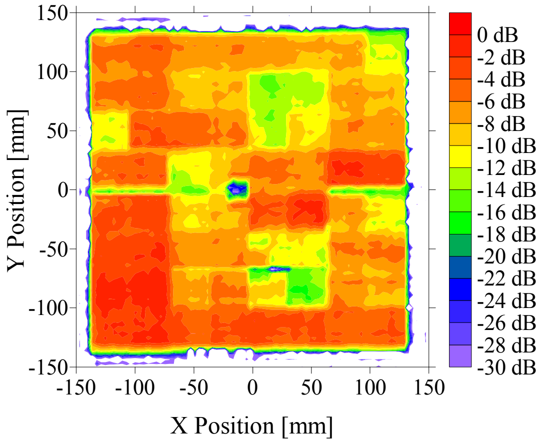


Figure 5: Aperture Illumination (64×64)

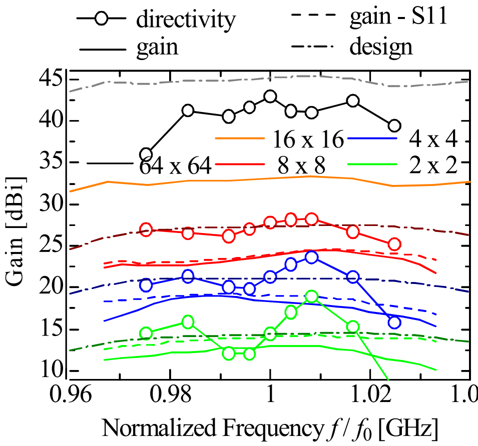


Figure 6: Measured Antenna Gain & Directivity

References

[1] R. Suga, H. Nakano, Y. Hirachi, J. Hirokawa and M. Ando, “Cost-effective 60-GHz antenna-package with end-fire radiation for wireless file-transfer system,” IEEE Trans. of Microwave Theory and Techniques, vol.58, no.12, pp.3989-3995, Dec. 2010.

[2] Y.Tsutsumi, T. Ito, S. Obayashi, H. Shoki and T. Morooka, “Bonding wire loop antenna built into standard BGA package for 60 GHz short-range wireless communication,” IEEE MTT-S Int. Microw. Symp. Dig., pp.1-4, June 2011.

[3] de la Torre, J. Kunisch, C. Oikonomopoulos-Zachos and M. Martínez-Vázquez, “Comparison of 60 GHz Low and High Gain Antennas for Coverage Analysis of Aircraft In-Cabin Radio Links,” 2011 European Conference on Antennas and Propagation (EuCAP), pp. 2354-2358, EUR Congressi, Rome, Italy, Apr. 11-15, 2011

[4] Y. Miura, J. Hirokawa, M. Ando, K. Igarashi, and G. Yoshida, "A high-efficiency circularly-polarized aperture array antenna with a corporate-feed circuit in the 60 GHz band," IEICE Trans. Electron., vol.E94-C, no.10, pp.1618-1625, Oct. 2011.

[5] [Online]. Available: http://ieee802.org/15/index.html

[6] M. Zhang, J. Hirokawa and M. Ando, “Fabrication of a slotted waveguide array at 94GHz by diffusion bonding of laminated thin plates,” IEICE Trans. Commun., Vol.E93-B, No.10, pp. 2538-2544, Oct. 2010.