Single-layer slotted post-wall waveguide array with compact feed-line structures for 77 GHz automotive radar

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***Abstract*— A single-layer antenna composed of four subarrays and compact low-loss feed-line structures connecting to an RF-module for 77 GHz automotive radar systems is presented. This antenna is based on a slotted post-wall waveguide array, which is integrated in a ceramic-filled PTFE substrate. The antenna gain is higher than 16 dBi relative to the maximum available directivity of 20.4 dBi at 76.5 GHz. The proposed compact feed-line structures achieve the low transmission loss of less than 3.2 dB.**

I. INTRODUCTION

Automotive radars are put into practical use for Adaptive Cruise Control (ACC) and easier stop-and-go driving [1]. Recently, automotive radar with a wider azimuthal coverage, for collision mitigation as well as the observation of driver's blind spots, has been desired. Many research groups are being developed the antennas for automotive radars in the millimeter-wave band [2-8]. Subarrays with the wider beam width in the radiation pattern are spaced closely to avoid a grating lobe for the wider azimuthal coverage in digital beam forming (DBF) systems. Thus, the antenna aperture is relatively narrower than that of the antenna for a long range and a narrower azimuthal coverage, and the antenna gain is lower. The problem to achieve not only wider azumuthal coverage but the long range is transmission losses in feed lines between multiple RF ports in an RF module and multiple subarrays. A single-layer slotted post-wall waveguide array (shown in Fig. 1) composed of four subarrays and compact low-loss feed-line structures connecting to the RF ports in the RF module is presented. The post-wall waveguide can also be manufactured at low cost by conventional printed-circuit board (PCB) fabrication process. It should be noted that the post-wall waveguide, a laminated waveguide and a substrate integrated waveguide (SIW) have the same propagation mechanism as described in [9,10]. The slotted post-wall waveguide array is suitable for the automotive radar because of its low transmission loss characteristics. Also, this antenna achieves short feed lines to reduce the transmission loss in the feed line.

II. FEED-LINE STRUCTURE

An RF-IC for 77 GHz automotive radar systems is packaged in the RF module whose RF-signal lines are connected to coplanar waveguides (CPW) and transformers between the CPW and a hollow metal waveguide as the standard waveguide port (WR10). The size of the standard waveguide (WR10) is 2.54 mm x 1.27 mm and chokes are cut between RF ports. Thus the RF module with the multi-channel RF ports becomes large when the multiple RF ports are arranged next to each other.

Assuming the azimuthal coverage from -40 degrees to 40 degrees, spacing between the subarrays is required to be less than 0.6 λ_0 to avoid the grating lobe where λ_0 is a wavelength in free space; that is 3.9 mm in 77 GHz. Compact feed-line structures are presented to connect between the four subarrays and the four-channel RF ports in the RF module as shown in Fig. 2. The spacing between the subarrays is 2.3mm. In the figure, RF port 2 and RF port 3 are arranged next to each other with the spacing for the choke. RF port 1 and RF port 4 are arranged so as not to interfere with the feed lines for port 2

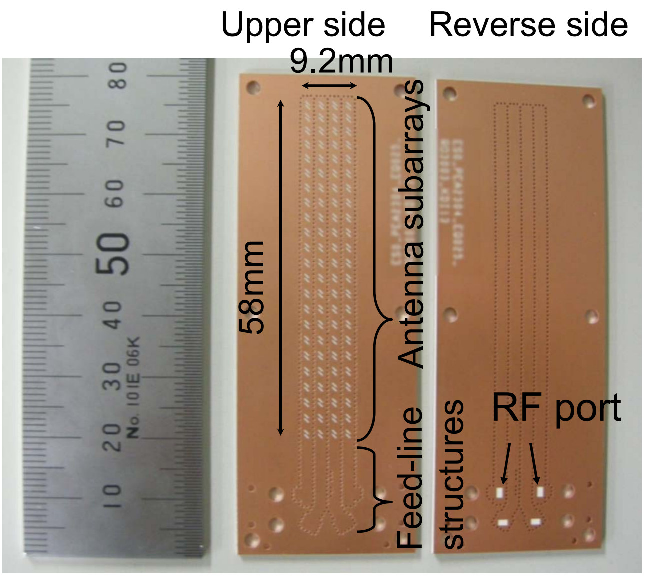

Fig. 1. Fabricated slotted post-wall waveguide array with the compact feed-line structures for 77GHz automotive radar

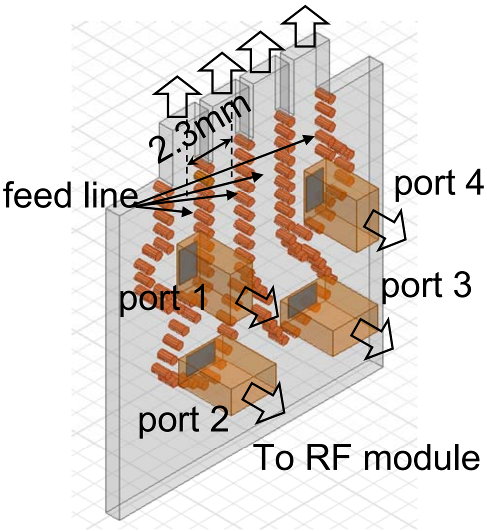

FIG. 2. THE COMPACT FEED-LINE STRUCTURES CONNECTED BETWEEN THE FOUR ANTENNA SUBARRAYS AND THE FOUR-CHANNEL RF PORTS IN THE RF module

and port 3, which are turned to right angles for port 2 and port 3 for the compact RF module and for the shorter CPW in the RF module.

Here we discuss transformers between the hollow metal waveguide connected to the RF module and the post-wall waveguide in the subarrays for port 1 and port 4. The standard transformer between the hollow metal waveguide and the post-wall waveguide is shown in Fig. 3, which is like an E-bend structure. On the other hand, in port 1 and port 4, the H-plane of the hollow metal waveguide and the E-plane of the post-wall waveguide are parallelized. In this case, some transformers use resonance coupling slots such as a longitudinal slot and a cross slot, as shown in Fig. 3. Fig. 4 shows the simulated reflections for various transformers between the hollow waveguide and the post-wall waveguide. The bandwidth of the reflection of less than -20 dB of the cross-slot transformer is narrower than that of the standard transformer. The proposed transformer structure is shown in Fig. 5. The EM wave from the hollow waveguide is coupled to a "coupling waveguide" in this transformer and then is reflected at the edge of the coupling waveguide. The EM wave reflected at the edge of the coupling waveguide can be coupled to the post-wall waveguide with the slotted subarrays like an H-plane bend. The bandwidth of the reflection of less than -20 dB of the proposed transformer is wider than that of the cross slot in Fig. 4. The reflection of the transformer for port 2 is shown in Fig. 4. The reflections of all ports in these feed-line structures are suppressed below -25 dB at 76-77 GHz.

III. MEASUREMENT OF ANTENNA

As shown in Fig. 1, the fabricated antenna has the four subarrays in the horizontal axis, which is a one-dimensional slot array composed of 24 slot pairs along the vertical axis. A "45-degree linear polarization slot pair" is utilized for each element, and thus the main polarization is tilted at 45 degrees from the vertical axis. Fig. 6 shows the measured reflections

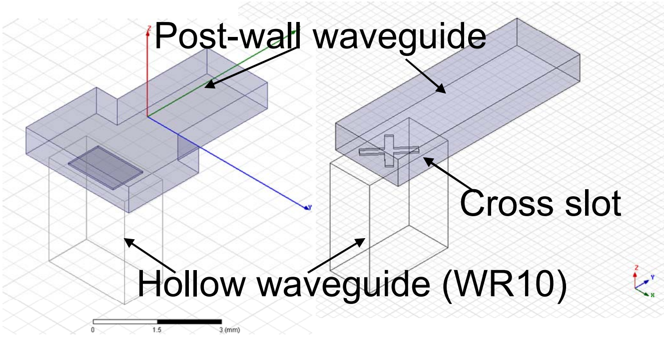

Fig. 3. A standard transformer and a cross-slot transformer between the hollow waveguide and the post-wall waveguide

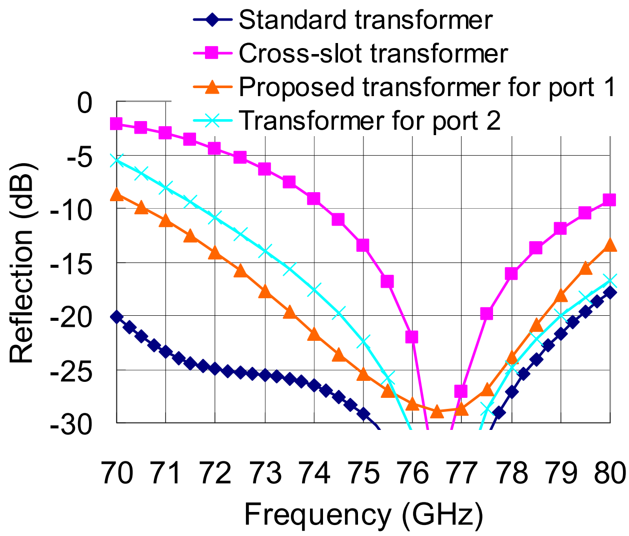

Fig. 4. Simulated reflections of the transformers from the hollow waveguide to the post-wall waveguide

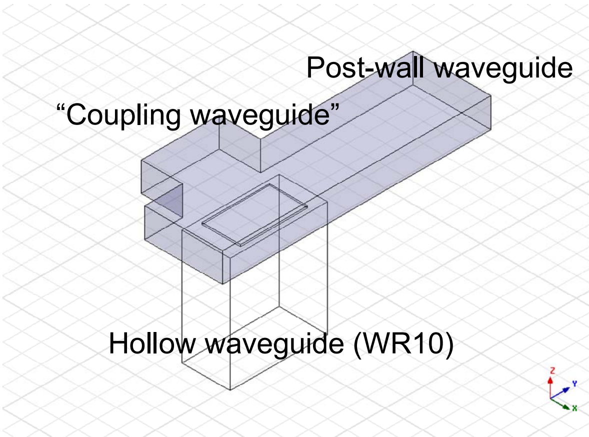

Fig. 5. Proposed transformer

of all ports in the fabricated antenna. The reflections are less than -10 dB, even if the measured reflections include all the reflections from the slot array and the feed-line structure. Fig. 7 shows the measured results of the relative amplitude of the radiation pattern in the elevation (EL) plane. This antenna is designed to have a shaped beam for the EL plane to suppress the side lobe level. Fig. 8 shows the antenna gain for each

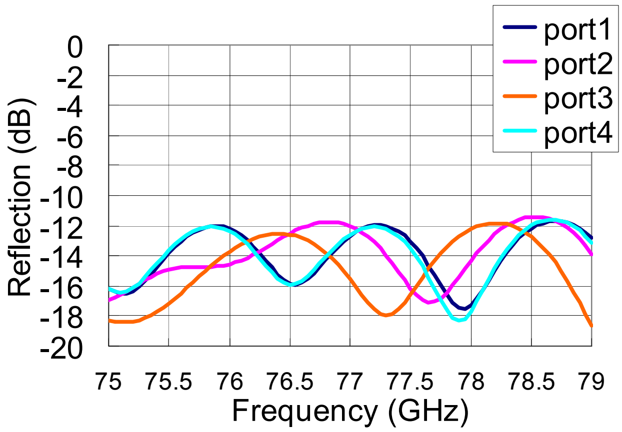

Fig. 6. Measured reflections of the fabricated antenna

port of the fabricated antenna. The antenna gain of the main lobe is higher than 16 dBi relative to the maximum available directivity of 20.4 dBi for the aperture size of 58 mm x 2.3 mm. The measured transmission loss in the 77-GHz post-wall waveguide integrated in the ceramic-filled PTFE substrate at 77 GHz is 0.40 dB/cm. The rough breakdown of the losses in this antenna is the beam shaping loss in EL plane of less than 1 dB, the reflection loss of less than 0.5 dB and the transmission loss of less than 3.2 dB in the post-wall waveguide of the 8cm included the radiation part and feed line.

IV. Conclusion

A single-layer slotted post-wall waveguide array composed of four antenna subarrays and four feed-line structures connecting to an RF module for 77 GHz automotive radar is presented. This antenna is integrated in a ceramic-filled PTFE substrate. The antenna gain of each subarray of the fabricated antenna is higher than 16 dBi relative to the maximum available directivity of 20.4 dBi for the aperture size of 58 mm x 2.3 mm at 76.5 GHz. The proposed compact feed-line structures achieve the low transmission loss of less than 3.2 dB.

Acknowledgment

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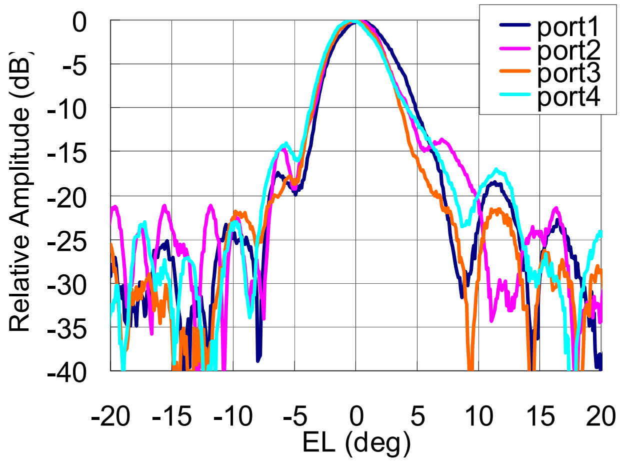

Fig. 7. Measured results of the relative amplitude of the radiation pattern in the EL plane for the fabricated antenna

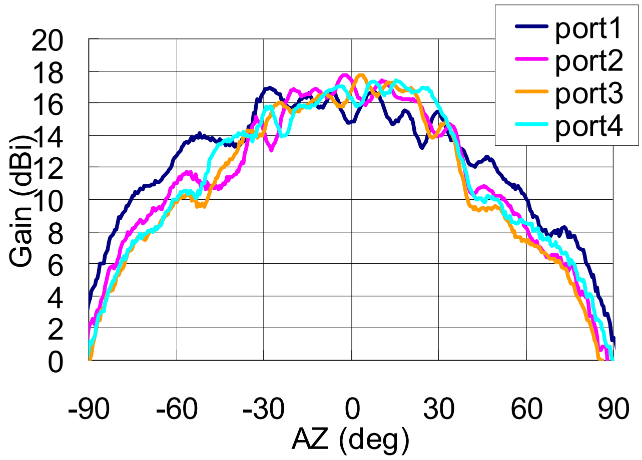

Fig. 8. Measured results of the antenna gain for the fabricated antenna in the AZ plane

References

[1] M. Schneider, "Automotive radar – status and trends," *GeMiC 2005*, 5-3, pp. 144-147, April 2005.

[2] T. Binzer, M. Binzer, and V. Gross," Development of 77 GHz radar lens antennas for automotive applications based on given requirements," *INICA '07*, pp. 205-209, March 2007.

[3] M. Ohta, , H. Ishizaka, R. Kose, T. Saito, N. Okubo, and M. Haneishi, "Radiation properties of circularly polarized triplate-feed-type patch antennas at 60 GHz band," *IEICE Natl. Conv. Rec.*, B-115, Sept. 1994.

[4] J. Hirokawa, "Analysis and fabrication of millimeter-wave slotted waveguide array antennas," *URSI Intl. Symp. Electromagnetic Theory (EMTS)*, Tutorial 4, Aug. 2010.

[5] K. Sakakibara, Y. Ikeno, N. Kikuma, H. Hirayama, "Millimeter-wave slotted waveguide planar array using partially-parallel feeding with traveling-wave excitation," *IEEE APSURSI*, Jul. 2010.

[6] K. Sakakibara, S. Sugawa, N. Kikuma, H. Hirayama, "Millimeter-wave microstrip array antenna with matching-circuit-integrated radiating-elements for travelling-wave excitation," *Proceedings of EuCAP*, April 2010.

[7] J. Hirokawa and M. Ando, "Single-layer feed waveguide consisting of posts for plane TEM wave excitation in parallel plates," *IEEE Trans. on Antennas and Propagation*, Vol.46, No.5, pp.625-630, May 1998.

[8] T. Shijo, S. Obayashi, and T. Morooka, "Design and development of 77-GHz pair-slot array antenna with single-mode post-wall waveguide for automotive radar," *IEEE APS URSI Int. Symp. Dig.*, pp.476-479, 2011.

[9] H. Uchimura and T. Takenoshita, "Development of a laminated waveguide," *IEEE Trans. Microwave Theory Tech.*, vol. MTT-46, no.12, pp. 2438–2443, Dec. 1998.

[10] D. Deslandes and K. Wu, "Integrated transition of coplanar to rectangular waveguides," *IEEE MTT-S Int. Microwave Symp. Dig.*, pp. 619–622Feb. 2001.