Millimeter-Wave Tapered Slot Array for Automotive Radar Applications

Meijiao Li1, Paul Schmalenberg2, and Jae Seung Lee2
1Electrical and Computer Engineering, University of California Davis, One Shields Avenue, Davis, CA 95616, USA
2Toyota Research Institute – North America, 1555 Woodridge Avenue, Ann Arbor, MI 48105, USA

***Abstract* – To support advanced driving and vehicle safety applications such as semi-autonomous and autonomous vehicle modes, a growing variety of high performance sensors for object detection are under development. These sensors include millimeter-wave radars. To extend the performance of passenger vehicle radars to true volume scan capability, end fire antenna arrays are explored. In this paper, we present a planar 76-81 GHz corrugated tapered slot antenna array. Over all designs, return loss within 76-81 GHz is better than -15 dB, and gain is 19 dB with a beamwidth of 8.5° when used in an 8-element array. Results of simulation and pattern measurement in anechoic chamber are shown. Additionally, integration of this end fire design into possible packages for automotive radar with true volume scan are presented.**

***Index Terms* — end fire, phased array, automotive radar.**

1. Introduction

Usage of millimeter wave radar in passenger vehicles has become common [1]. These sensors support driving assistance features such as auto-cruise control and automatic braking. Generally, they track targets on road then calculate time to collision, which is then utilized for system level decisions. To extend these features to full autonomous vehicle functionality, radars must output thorough scene information. Target type, the context of the target in the scene, and scene structure are some required outputs for these new sensors. However, in current commercial systems data is distilled into target tracks, typically vehicles, and scene information is filtered out. These radars scan only a horizontal plane with limited unique channels by broadside radiating patch or slots [2]–[4]. Instead, a radar that can scan a volume with high resolution is needed. To realize this new radar with broadside arrays is difficult due to routing of millimeter-wave signals from RFICs to individually addressed patches in a two dimensional array while maintaining small array spacing. Outside of very small arrays, the routing area soon outgrows the aperture area and is not appropriate for the stringent sensor requirements in passenger vehicles. Instead, we propose end fire antennas to make up a compact two dimensional array and investigate one design at the automotive frequency of 76 GHZ to 81 GHz.

In [5], a Fermi Tapered Slot Antenna (TSA) array was proposed for a 20–40 GHz band. This paper proposes a design of similar geometry and adds curved structure to the end of antenna for improving the matching between the edge of the substrate and air to increase the gain. For frequencies higher than 60 GHz, most of TSA's width is larger than λ_0 [6], where λ_0 is a wavelength in free space. However, spacing between the antennas is required to be less to avoid grating lobes appearing in the scan area. In this paper, a 0.6λ width antenna is proposed which avoids gating lobes when scanned from about -40 degrees to 40 degrees. Using this proposed design, an eight element array has high antenna gain (19 dB), low sidelobe levels (-15 dB), and narrow beamwidth (8.5°). The compact size, simple structure and microstrip feed are beneficial for circuit integration.

2. Design

Fig. 1 shows the designed antenna and its optimized parameters. The antenna is designed on RO3003™ substrate with thickness of 0.127 mm and a relative permittivity of 3.00. It is fed by a microstrip transmission line through a balun. The bottom metal layer is a cut microstrip ground. Fig. 2 shows the simulated return loss for the antenna. The simulations are performed using CST STUDIO SUITE®. In Fig. 2, the return loss of the antenna is better than 10 dB from 74 GHz to 84 GHz which covers the entire automotive radar band.

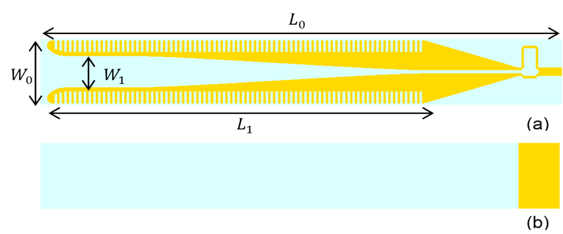

Fig. 1. Antenna geometry (W_o = 2.4 mm, W_1 = 1.4 mm, L_0 = 21.75 mm, and L_1 = 16.05 mm). (a) top view, (b) bottom view.

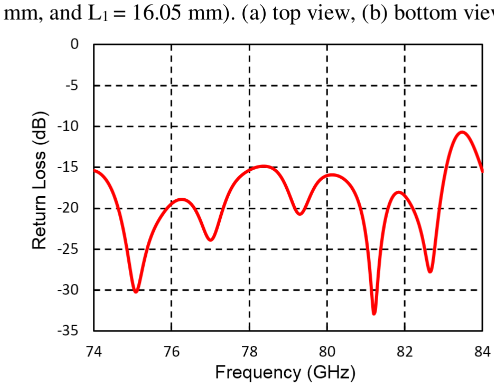

Fig. 2. Simulated return loss versus frequency of antenna in Fig 1

3. Experimental Results

Photographs of the fabricated tapered slot antenna array are presented in Fig. 3. The fabricated board contains an eight elements array, a one to eight T-junction power divider and a waveguide to microstrip transmission line transition. The four holes at the corners are used for mounting the board. Boards are mounted into a semi-anechoic room and scanned by a standard W-band horn antenna. A Gunn diode is used to excite the antenna under test and power is recorded on a spectrum analyzer hooked into the automated testing system.

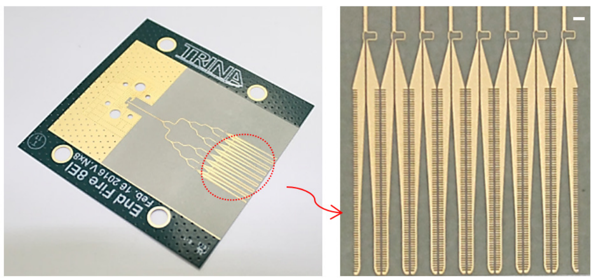

Fig. 3. Photograph of fabricated array and zoom of 8 element section

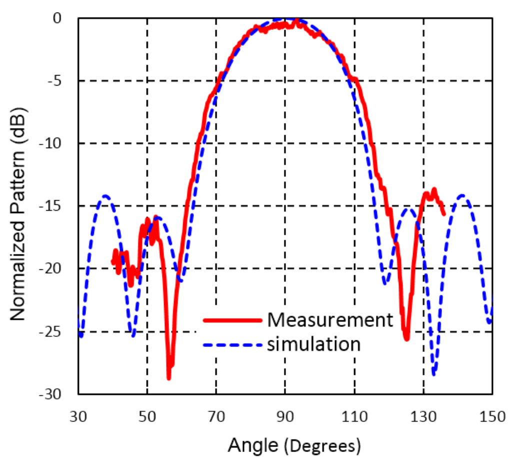

Fig. 4. Single element E-plane far-field pattern at 78 GHz

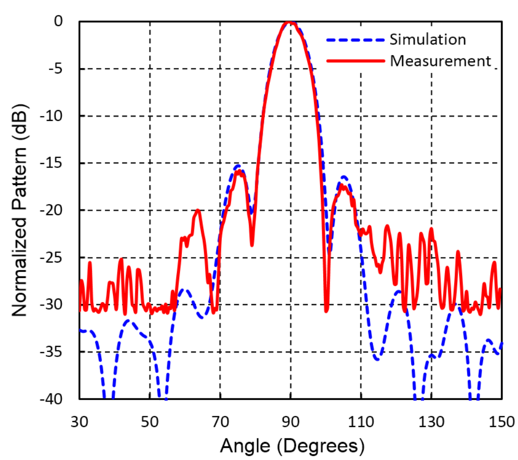

Fig. 5. Eight element array E-plane far-field pattern at 78 GHz

Fig. 4 illustrates the measured E-plane pattern of single antenna comparing with the simulation result at 78GHz. The dashed curve corresponds to the simulation result while the solid curve is for the measurement result. The main lobe power is approximately 15 dB larger than the highest side lobe power. An angle of 90° corresponds to the board edge normal.

The measured E-plane pattern of eight elements array comparing with the simulation result at 78GHz is presented in Fig. 5. The dashed curve corresponds to the simulation result while the solid curve is for the measurement result. At off axis angles, the measurement values are much higher than the simulation due to the noise limitation of the testing environment. The gain of the antenna is about 19 dBi. The side lobe level is better than -15 dB and the HPBW is 8.5° while maintaining a total array size of 22 by 20 mm^2.

4. Conclusion

An end fire antenna design was presented and measurement results shown. This type of end fire antenna is appropriate for a compact volume scan radar for automotive applications, the concept of which is shown in Fig 6. This concept has a small forward facing profile of just 70mm by 20mm despite having a 16 by 5 individually addressed phased array antenna. mmW-ICs would be mounted in the shielded area on each individual board, with each board slotted into a backplane. In future work, coupling between channels will be studied and coupling mitigation proposed.

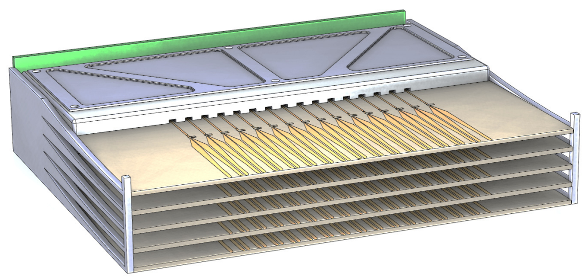

Fig. 6. Concept of utilizing end fire antenna for volume scan

References

[1] J. Dickman, J. Klappstein, M. Hahn,. M. Muntzinger et al. "Present research activities and future requirements on automotive radar from a car manufacturer's point of view." Microwaves for Intelligent Mobility (ICMIM), IEEE MTT-S Int'l Conf. on, 2015

[2] B. H. Ku, P. Schmalenberg, O. Inac, O. D. Gurbuz, J. S. Lee, K. Shiozaki, et al. "A 77–81-GHz 16-element phased-array receiver with beam scanning for advanced automotive radars." Microwave Theory and Techniques, IEEE Trans. on 62.11, pp. 2823-2832, 2014

[3] T. Shijo, K. Hashimoto, S. Obayashi, H. Shoki, "Single-layer slotted post-wall waveguide array with compact feed-line structures for 77 GHz automotive radar," URSI International Symp. on. IEEE, 2013

[4] A. Abdellatif, M. Ghassemi, M. R. Nezhad-Ahmadi, S. Safavi-Naeini, N. Ghassemi, "Low cost low loss waveguide-fed patch antenna array for automotive radar system." In Millimeter Waves Global Symp. 2015

[5] Y. Lu, N. Ito, C. W. Domier, N. C. Luhmann, and A. Mase, "20 to 40 GHz beam shaping/steering phased antenna array system using fermi tapered slot antennas." IEEE/MTT-S Inter., pp. 1887-1890, 2007

[6] I. Mohamed, Z. Briqech, A. R. Sebak, "High-gain dielectric-loaded antipodal Fermi tapered slot antenna for MM-wave applications." Antenna Technology and Applied Electromagnetics (ANTEM), 2014