Millimeter-Wave Printed Circuit Antenna System for Automotive Applications

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Abstract **— An antenna system for automotive intelligent cruise-control application contains two separate printed circuit antennas: wide beam transmit antenna and three narrow beam receive antenna. The Rotman lens beamforming network is used to provide multibeam operation of receive antenna. The design of antenna system is discussed and test results are presented.**

I. INTRODUCTION

The creation of an automotive intelligent cruise control (ICC) is under wide discussion from the beginning of nineties [1], [2]. The radar scheme with three switching beams providing the observation of own lane and two neighboring lanes is the most popular. Two types of antenna: quasioptical voluminous three beam antennas (Cassegrain, lens-horn, *etc.*) [3], [4] or radiating arrays with beam-forming network (BFN) are usually used in such radars. There are three inputs in these antennas according to the beam number. First type antennas are more simple and cheap, but their principal demerit is relatively long depth of about 60-80 mm. Second type antennas are planar. The printed [5]-[7] or slot [2], [8] radiators are usually used. We developed antenna system containing three beam receive (*Rx*) antenna and one beam transmit (*Tx*) antenna. Transmit beam covers all three receive beams.

We selected the following concept of *Rx* antenna: subarrays with patch radiators, BFN based on Rotman lens, combination of these units through waveguides. The *Tx* antenna is simpler than receive one, it consists of the array of patch radiators.

The printed circuit arrays were used because of their aptitude for mass production and low cost. This choice was adventurous in the great extent because of the optimal interrelation between dimensions of radiators and striplines and dielectric substrate parameters that usually fulfilled in dm and cm frequency bands can't be implemented in the automotive ICC band of 76-77 GHz. Moreover there is no any considerable worldwide experience of creation of patch antennas in this frequency band, so we had to solve many problems first time.

BFN based on Rotman lens was selected because of reasonable combination of high technical performances and relatively simple design. The following development confirms the propriety of this choice. The combination of BFN and radiating structure through waveguides provides the low loss. But these waveguides are complicated: each waveguide contains the 180° bend and twist.

II. ANTENNA SYSTEM SPECIFICATION AND DESIGN

The technical performances of antenna system are presented in Table 1.

TABLE I
PERFORMANCE SPECIFICATION

Parameter	*Rx* antenna	*Tx* antenna
Frequency Band	76-77 GHz	
Polarization	horizontal	
Azimuth Beam Number	3	1
Beam Overlapping Level	-3 dB	-
Azimuth Beamwidth	3°	9°
Elevation beamwidth	3.0-3.2°	
Gain	29.0 dBi	25.7 dBi
Side Lobe Level (SLL)	SLL(*Rx*)+SLL(*Tx*)≤-27 dB	
Tx-Rx Isolation	≥70 dB	

The diagram of developed antenna system is shown in Fig. 1. The antenna system includes *Tx* antenna, *Rx* antenna, and isolation structure. All components are installed on common supporting frame. The *Rx* antenna contains 6 printed circuit subarrays, BFN, radome, waveguide sections between subarrays and BFN, and output waveguide lines. The spacing of subarrays is about 3λ, that provides the absence of grating lobes within radar field of view. The subarray output is of waveguide type. The *Tx* antenna contains only one printed circuit array and radome. The radomes protect the antenna elements against

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environment. We also used the radomes to improve the antenna performances due to the gain depends on thickness and position of radome.

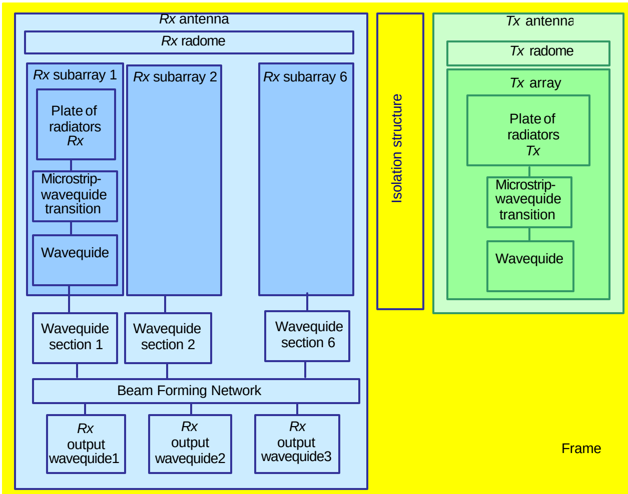

Fig. 1. Antenna system block diagram.

Fig. 2 shows the antenna system assembly. The load-carrying part of the construction is frame, which is made of aluminum by mechanical processing. *Rx* subarrays and *Tx* array are attached on the frame face. The radomes of both antennas are made of polystyrene. In the frame construction some special metal barriers, separating the radomes of *Rx* and *Tx* antennas are available. They are necessary for providing the specified isolation. The special dielectric isolation structure is placed between these barriers. On the backside of the frame there is BFN attached at. The *Tx* and *Rx* radiating apertures are of 22×70 mm and 72×70 mm dimensions. The overall dimensions of antenna system are following: the width is 158 mm, the height is 110 mm, and the depth is 33.5 mm. The mass of antenna system is about 900 g.

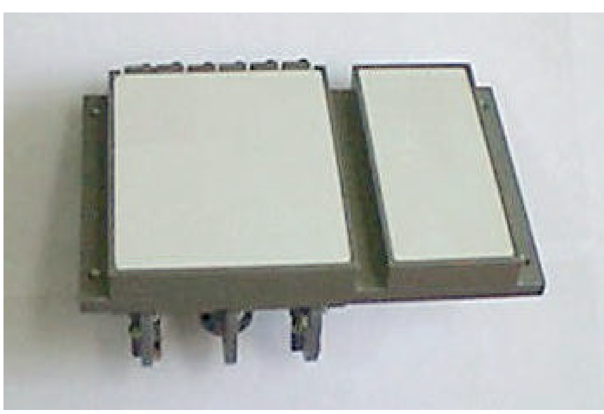

Fig. 2. Antenna system assembly.

III. Printed Circuit Arrays

We used two types of printed circuit arrays in antenna system: *Rx* subarray and *Tx* array. Both arrays consist of printed board with radiators and combiner, bed, feeding waveguide, and microstrip-to-waveguide transition. The feeding of radiators is sequent in elevation plane and parallel in azimuth plane. Different printed circuits were simulated, fabricated and tested. Two basic structures are shown in Fig. 3. The RT duroid and CuFlon substrates were used. Finally the best results were obtained for structure shown in Fig. 4 for *Rx* subarray.

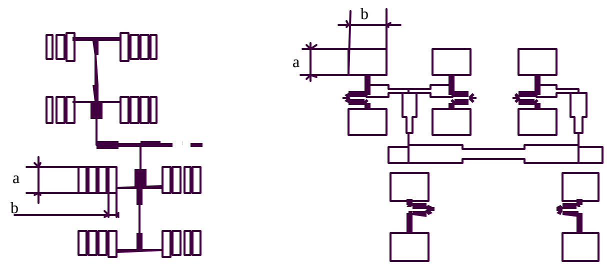

Fig. 3. Microstrip printed circuit board fragments.

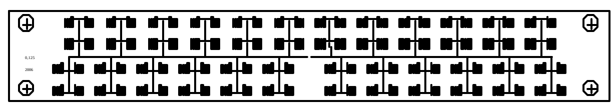

Fig. 4. *Rx* printed circuit board.

The *Rx* subarray is performed on the basis of printed radiators having no lines laid to the radiating edges. The stripline comes in the *H*-plane, not in the *E*-plane. This has allowed eliminating the parasitic influence of the stripline on the antenna performance, as well as considerable reduction the length and number of bends of the stripline. The phasing of the radiators is provided at the expense of their asymmetry. We used CuFlon substrate of 0.125 mm and 0.25 mm thickness. The performances were acceptable in both cases. The array feed point is placed in the center of printed board. In *Tx* subarray the microstrip combiner provides tapering amplitude distribution in both planes to suppress sidelobes. In *Rx* subarray the amplitude distribution is uniform in *E*-plane and tapering in *H*-plane. We tested amplitude and phase distribution over printed board area with use of near-field measurement technique.

The beds of *Rx* subarrays and *Tx* array are made of brass to provide easy soldering printed boards and feeding waveguides to them. The bed thickness is 4mm that provides all the necessary mechanical firmness. The production process of subarrays is difficult, it contains multi-step soldering and testing of the technical performances on the different steps of assembling.

IV. BEAMFORMING NETWORK

BFN must form *Rx* antenna three beams, overlapping at the level of about –3 dB. At the same time insertion loss and mass and dimensions of BFN must be minimum. In our opinion, among other possible kinds of BFN Rotman lens is simplest in spite of rather high technical performances. Radiophyzika has a considerable experience in working out such systems. The first of them are related to the beginning of the sixties [9]. The diagram of developed BFN is shown in Fig. 5.

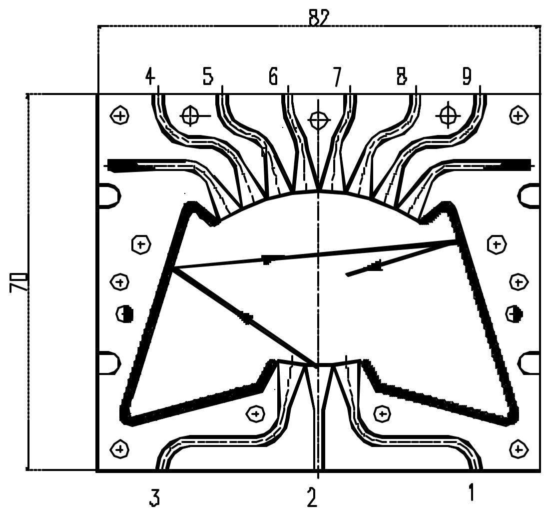

Fig. 5. Diagram of the beamforming network.

BFN contains three output channels 1-3 and six input channels 4–9. All channels are *E*-plane sector horns, those are situated on the arcs. Constructively input and output horns are placed between metal parallel planes forming flat waveguide. Radiation is happening in this artificial environment. During the operation the signals received by six subarrays of *Rx* antenna are lead up through the waveguides to the flange of BFN in the section of inputs 4–9. These signals are reradiated by input horns into the cavity of lens. Depending on the direction of the received signal the energy is focused in one of output horns 1–3. The side walls of cavity are covered by absorbing material to suppress the horn side lobes and are shaped to reradiate them to another wall as Fig. 5 shows. The photo of BFN is presented in Fig. 6.

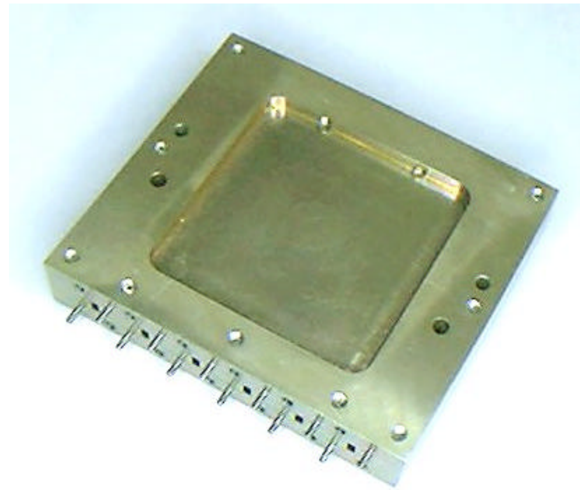

Fig. 6. Beamforming network package.

BFN provides the following technical performances in specified bandwidth: VSWR of output channels is no more than 1.12; input channel isolation is no less than 27 dB; loss for central beam is no more than 1.4 dB; losses for side beams are no more than 1.5 dB; angle between central beam and side beams is 3.0°. Simulation and experimental results are coincided with good exactness: divergence in amplitude is no more than ±0.4 dB, in phase is no more than ±6.5°. BFN is made of aluminum, its mass is 192 g.

V. TEST RESULTS

The azimuth *Rx* antenna (for all three beams) and *Tx* antenna patterns are presented in Fig. 7. The elevation *Rx* and *Tx* antenna patterns are presented in Fig. 8.

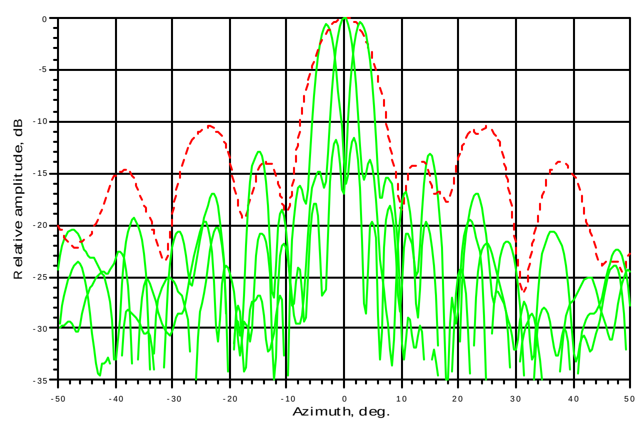

Fig. 7. Azimuth *Rx* (green lines, three beams) and *Tx* (red line) antenna patterns at 76.5 GHz.

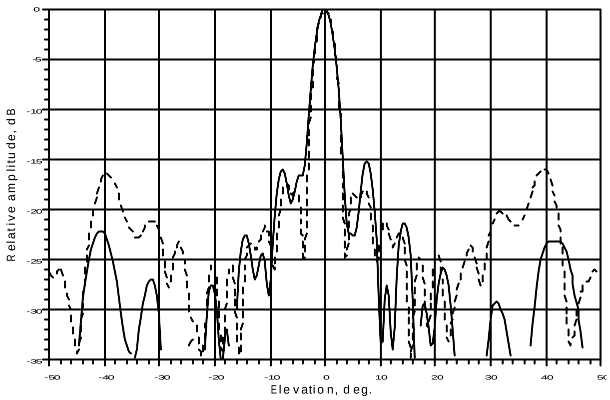

Fig. 8. Elevation *Rx* (solid line) and *Tx* (dotted line) antenna patterns at 76.5 GHz.

Fig. 9 shows the frequency dependence of gain for *Tx* and *Rx* antennas. Both gains achieve maximum value at 76 GHz.

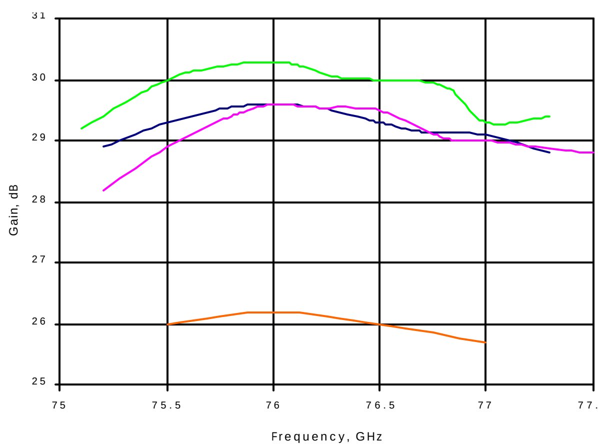

Fig. 9. Frequency dependence of gain for *Rx* antenna (upper curve for central beam, two middle curves for side beams) and *Tx* antenna (lower curve).

V. CONCLUSION

The directivities of *Rx* and *Tx* antenna are 36 dBi and 31 dBi correspondingly. Thus total loss is about 6 dB in *Rx* antenna (including loss in BFN) and 5 dB in *Tx* antenna. These values are rather small for this type of antennas, so we consider the efficiencies of *Tx* and *Rx* antennas as high. For example, the total loss in analogues multibeam antenna described in [5] is 10 dB. We obtained high efficiencies due to central feeding of printed arrays, relatively thick substrate, waveguide feeding, and quasioptical BFN. The another merits of the antenna system are high *Tx-Rx* isolation and low cost production technology.

The demerit of our antenna system is high sidelobe level. There are high (about –12 dB) sidelobes in *Rx* pattern within *Tx* main beam. They are caused by different gain of *Rx* subarrays and will be removed in the next antennas. The grating lobes caused by 3λ spacing of *Rx* subarrays are available in the side beam patterns. But their amplitude is not too great, and they can be suppressed by minimums of *Tx* pattern in radar. The high *E*-plane sidelobe level in *Tx* pattern should be reduced by the use of more sharp tapering amplitude distribution.

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REFERENCES

[1] D. A. Williams, "Millimetre Wave Radars for Automotive Near Obstacle Detection", *IEEE MTT-S Digest*, pp. 721-724, 1992.
[2] S. A. Zelubowski, "Low Cost Antenna Alternatives for Automotive Radars", *Microwave J.*, vol. 37, no. 7, pp. 54-63, July 1994.
[3] Crash Avoidance FLR Sensors, Millitech Corp., *Microwave J.*, vol. 37, no. 7, pp. 122-126, July 1994.
[4] C. Cranet, V. Dyadyuk, "Compact Potter-Type Horns for a Traffic Management Radar", *Millenium Conference on Antennas & Propagation AP2000, Davos Switzerland, Abstracts*, vol. 1, p. 570, April 2000.
[5] M. E. Russel, A. Crain, A. Curran, R. A. Campbell, C. A. Drubin, and W. F. Miccioli, "Millimeter-Wave Radar Sensor for Automotive Intelligent Cruise Control (ICC)", *IEEE Trans. Microwave Theory and Tech.*, vol. MTT-42, no. 12, pp. 2444-2452, December 1997.
[6] D. D. Li, S. C. Luo, and R. M. Knox, "Millimeter-Wave FMCW Radar Tranceiver/Antenna for Automotive Applications", *Applied Microwave & Wireless*, pp. 58-68, 1999.
[7] T. Teshirogi, A. Yamamoto, Y. Schine, and N. Baba, "Novel Millimeter-Wave Planar Arrays with High Radiation Efficiencies", *Millenium Conference on Antennas & Propagation AP2000, Davos Switzerland, Abstracts*, vol. 1, p. 267, April 2000.
[8] K. Sakakibara, T. Watanabe, K. Sato, and K. Nishikawa, "Slotted Waveguide Array Antenna for Automotive Radar Systems", *Millenium Conference on Antennas & Propagation AP2000, Davos Switzerland, Abstracts*, vol. 1, p. 598.April 2000.
[9] A. G. Shubov, V. V. Denisenko, A. V Majorov, A. A. Shalyakin, and A. V. Shishlov, "Development of Rotman's Lenses for Various Frequency Bands in Russia", *Nordic Antenna Symposium, Lund Sweden, Conference Proceedings*, pp. 219-224, September 2000.