High-Efficiency Injection-Molded Waveguide Horn Antenna Array for 76-81 GHz Automotive Radar Applications

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Abstract **—A high-efficiency waveguide horn antenna array for 76-81 GHz automotive medium-range MIMO radar is designed, fabricated, and tested. The antenna consists of a linear array with eight elements and is realized by assembling two injection-molded plastic layers metalized using physical vapor deposition (PVD) and electroplating. Excellent free-space performance is achieved in the 76-81 GHz band, with measured impedance bandwidth of 20.8% and a maximal measured realized gain of 17.1 dBi at 78.5 GHz. With a measured efficiency of 91% (-0.4 dB), the built prototype represents an attractive alternative to conventional PCB technology.**

Keywords **— metalized plastic, injection molding, waveguide technology, horn antenna array, millimeter wave, medium-range radar (MRR), automotive radar, MIMO radar, 76-81 GHz, E-Band.**

I. Introduction

Over the last years, the development of reliable driving assistance systems has drawn considerable focus from the automotive industry. Owing to their robust performance in adverse environmental conditions and their competitive pricing compared to LiDARs and cameras, radar sensors have established themselves as key components for autonomous driving [1].

The performance of a radar front-end is directly affected by the applied antenna topology and technology. Antennas are critical components in radar systems and come with advanced requirements in terms of performance, size, weight, and compliance with environmental standards [2]. In terms of performance, broadband matching, antenna pattern, and efficiency are crucial parameters since they directly affect the overall system performance (angular estimation performance, range resolution, or maximum detection range) [3].

Printed circuit board (PCB) antennas, such as microstrip patch arrays [4] or substrate integrated waveguide slot arrays [5], have been widely applied in automotive radar thanks to their simplicity and high integration capabilities. However, since the electromagnetic signal propagates within a dielectric material, they typically exhibit low efficiency and small bandwidth, which results in lower detection range and resolution.

Waveguide antennas overcome these drawbacks since the electromagnetic signal is propagated in free air and only ohmic losses are present. However, although they were considered as a possible alternative to PCB antennas [6], [7], their high production cost and non-straightforward integration within the radar front-end made them less attractive then. Most of these drawbacks have been solved today since new technologies such as injection molding and electroplating allow large antennas to be produced at a lower cost. Furthermore, novel interfaces with the electronics [8] simplify the integration of the components. Hence, a new generation of radar sensors, including waveguide technology, is possible [9], [10].

This work presents an injection-molded waveguide horn antenna array suitable for medium-range 77 GHz automotive MIMO radar. Section II addresses the antenna design. In Section III, the manufacturing process of the measured prototype is described. Later, in Section IV, the measurement results are presented. Finally, conclusions are summarized in Section V.

II. Antenna design

The proposed antenna is sketched in Fig. 1. It consists of a linear array of eight horn antenna elements. The apertures, as well as the internal waveguide beamformer, are horizontally polarized.

The linear array is fed through a combination of corporate and serial power dividers. In particular, a power splitter (19) is connected to two horizontally polarized branches, which feed serially two pairs of radiating horns, or doublets (11). Finally, the doublets split the incoming signal into two radiating elements (14).

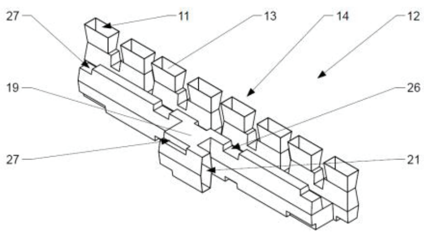

Fig. 1. Sketch of the antenna architecture [11]

It is crucial for the pattern stability over frequency and minimizing the beam squint that the first power splitter separates the signal into two different branches with equal amplitude and phase. Additionally, the serial divider feeds both doublets in phase. Therefore, a guided wavelength (λ_g) distance between both outputs, equal to 5.7 mm at the frequency of 76.5 GHz, is required. However, to reduce such distance and obtain a uniform spacing between the horn antenna elements, an inductive step (26) is added to the horizontal branches, which modifies the propagation constant of the waveguide. Over frequency, this distance varies, creating a phase tapering in the elevation pattern.

The signal division in the doublets is asymmetric to create illumination with a low side-lobe level. For this purpose, a septum and irises are integrated into the doublet. These features also contribute to creating broadband impedance matching. In this design, for simplicity, all doublets are similar. As a result, only two variables control the illumination of the linear array the power-phase relation within the doublet and the power-phase relation in the serial divider.

Besides the illumination characteristics, the radiators' position also influences the pattern. In the final design, the distance between the antenna array elements ranges from 0.85 to 0.9 wavelength in free space (λ_0) at the frequency of 76.5 GHz, mainly driven by limitations of the minimum size for waveguides (cut-off frequency) and manufacturing constraints, obtaining a total aperture of 6.8 λ_0. The excitations of the elements target a side-lobe level of -20 dB over the complete band of operation.

Finally, a groove is added at both sides of the horns to tune the azimuth pattern (see Fig. 3). This increases the size of the azimuth aperture by modifying the electrical currents on the surface of the antenna, as such, acting as a soft surface [12]. As a result, the antenna radiation pattern in azimuth focuses more. Different azimuth pattern characteristics are achieved by tuning the depth of the groove and its distance to the horn. A distance of 0.25 λ_0 and a depth of 0.17 λ_0 are applied in the design. Additionally, if positioned between different linear antenna arrays, the grooves help reduce radiation coupling, which is beneficial for the operation of, e.g., Multiple Input – Multiple Output (MIMO) radars, which typically feature multiple closely spaced antenna elements [13].

III. Manufacturing

The prototype consists of two metalized plastic pieces, each manufactured by means of plastic injection molding and coated employing particle vapor deposition (PVD) and electroplating. The two metalized plastic layers were finally soldered together [14]. The complete process, sketched in Fig. 2, was carried out at Huber+Suhner AG.

Fig. 2. Schematic of the complete manufacturing process.

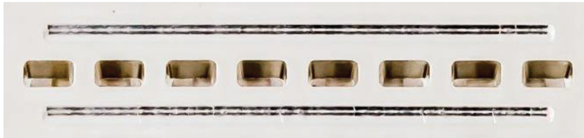

Fig. 3. Fabricated prototype. Grooves are visible above and below the horn antennas.

IV. Measurement Results

In order to measure the prototype, an internal routing from the radiator to a waveguide opening is also implemented into the antenna. Since such opening does not use a standardized waveguide dimension, an adaptor waveguide component that transforms the opening to a standard WR-12 is required for the measurements, manufactured in brass to avoid excessive additional losses. Hence, the measurements include the designed linear antenna array, the internal routing, and the waveguide adaptor.

A setup consisting of a VNA with frequency converters and a waveguide flange as output was used for the reflection coefficient measurements. Then, a TOSM (Through – Open – Short – Match) algorithm was applied for the calibration. The prototype's simulated and measured reflection coefficients are shown in Fig. 4. Notice that the measured prototype achieves excellent matching across a broad frequency band, with a reflection coefficient below –15 dB in the 76-81 GHz band and below -10 dB between 71.1 to 87.6 GHz. The discrepancy between simulation and measurements is due to the tolerance of the manufacturing processes.

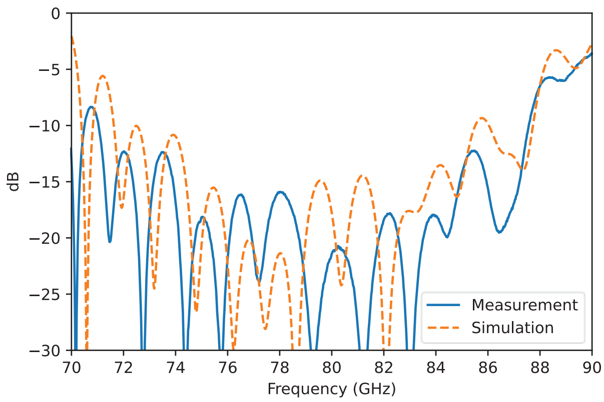

Fig. 4. Reflection coefficient of the fabricated antenna.

The prototype's radiation characteristic was measured through a near-field planar scanner (see Fig. 5), which allows measuring the antenna radiation pattern within +/- 70° in both azimuth and elevation. A low gain probe was used as a receiver antenna at a distance of 3 wavelengths at 76.5 GHz from the antenna under test (AUT). An absorbing material was placed around both AUT and near-field probe to avoid interferences and reflections from the surrounding elements of the measurement setup.

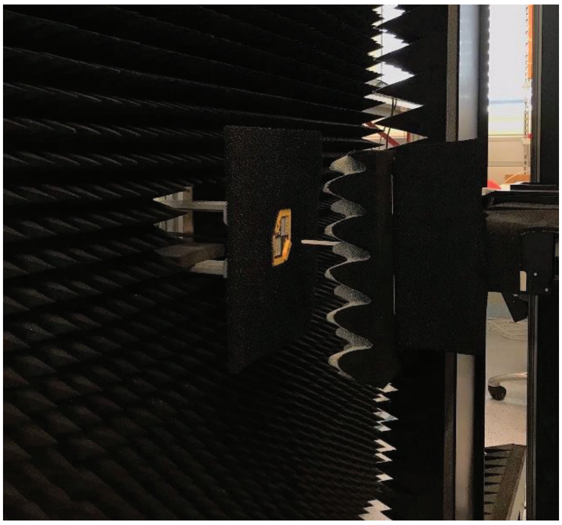

Fig. 5. Setup for the radiation pattern measurements.

The normalized measurement and simulation results of the primary radiation planes at 78.5 GHz of the fabricated prototype are shown in Fig. 6. Excellent correlation is achieved between the measured and simulated radiation pattern in both elevation and azimuth. The elevation plane presents a narrow beam with a half-power beamwidth (HPBW) of 9.1° and a side-lobe level lower than 20 dB. A wider field of view with an HPBW of 80° is obtained in the azimuth plane. The measured realized gain and the directivity at 78.5 GHz are 17.1 dBi and 17.5 dBi, respectively. Therefore, a very high-efficiency value of -0.4 dB is achieved — which includes the internal routing of 43 mm, and the approximately 0.1 dB losses of the waveguide adaptor. Fig. 7 shows the antenna performance for the elevation pattern over different frequencies in the whole 76 to 81 GHz frequency band. As explained in Section II, a stable pattern without beam squint is achieved thanks to the center feeding. Furthermore, notice that the pattern shape is stable over frequency.

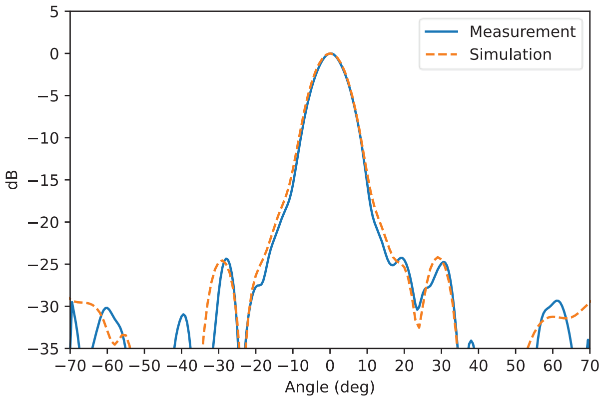

Fig. 5. Co-polar radiation pattern of the fabricated antenna at 78.5 GHz in the Elevation plane.

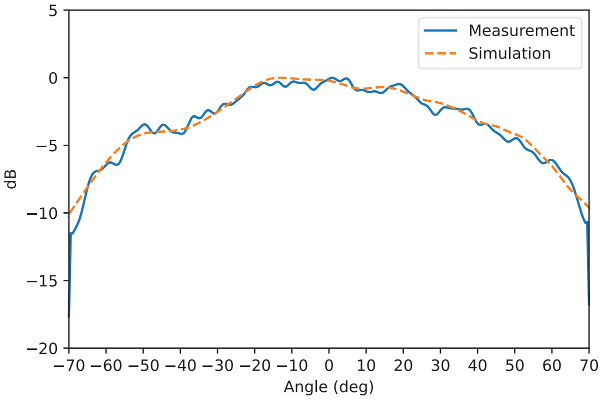

Fig. 6. Co-polar normalized radiation pattern of the fabricated antenna at 78.5 GHz in the Azimuth plane.

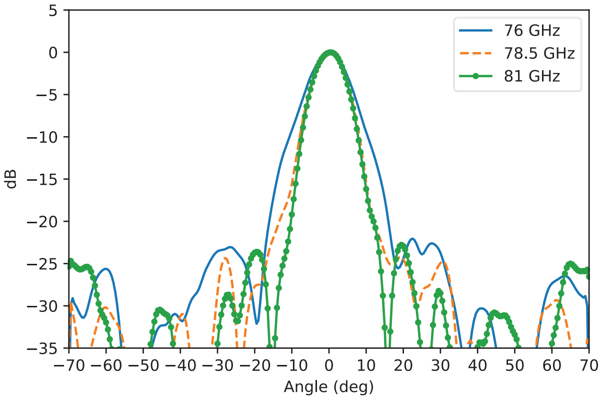

Fig. 7. Co-polar normalized radiation pattern of the fabricated antenna across the 76-81 GHz band in the Elevation plane.

V. Conclusion

An injection-molded waveguide horn antenna array for 76-81 GHz automotive medium-range radar is presented. The prototype was built by assembling only two plastic layers manufactured with injection molding and coated utilizing PVD and electroplating.

The antenna exhibits a wideband matching of 16.5 GHz, a high realized gain of 17.1 dBi, and a very high efficiency of -0.4 dB at 78.5 GHz. Thanks to its feeding structure, a stable radiation pattern over frequency is achieved, with a side-lobe level below -20 dB in the 76-81 GHz frequency range. As such, the proposed antenna is well suited for automotive MIMO radar applications.

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