

# Design and Fabrication of High-Gain 3-Dimensional Printed Reflectarray Antenna for W-Band Millimeter-Wave Radar Applications

Shunichi Futatsumori, Kazuyuki Morioka, Akiko Komura Nobuhiro Sakamoto, and Naruto Yonemoto  
Surveillance and Communications Department, Electronic Navigation Research Institute, 7-42-23, Jindaiji-higashi, Chofu, Tokyo, 182-0012 Japan

**Abstract** -W-band 3-dimensional (3D) printed reflectarray antenna for the millimeter-wave radar systems are designed and fabricated. The advantages of the reflectarray antenna so far are the simple and the flat structure. In addition to that, the low-cost fabrication can be achieved with fabrication by the 3D printer. The purpose of the paper is to achieve the 3D printed reflectarray antenna, which antenna gain is more than 30 dBi at 78.5 GHz. Firstly, the reflection signal phase of the different thickness dielectric plate is analyzed by the FDTD analysis to obtain the characteristics for the reflectarray design. Then, the eight-zone Fresnel reflectarray, which each zone has 45 degree steps phase difference, is analyzed and fabricated. The analyzed result shows the 31.6 dBi antenna gain at 78.5 GHz.

**Index Terms** — 3-dimensional printer, FDTD, Millimeter-wave radar, Reflectarray, W-band

## 1. Introduction

As the quasi-optical approach, the reflectarray antenna has the advantage of the simple, the small volume and the flat structure [1]-[3]. We have been a developing a millimeter-wave radar system for the civil aviation areas such as the helicopter collision avoidance on-board radar and the foreign object debris detection radar on the runways [4], [5]. For the millimeter-wave radar application, the reflectarray antenna is one of the important options to realize the high-performance radar system [3].

In this paper, the design and the fabrication of the high-gain reflectarray antenna for W-Band millimeter-wave radar applications are discussed. The 3-dimensional (3D) printed reflectarray which gain is less than 30 dBi is demonstrated [2]. On the other hand, the novelty of this paper to obtain the more than 30 dBi antenna gain with 3D printed fabrication. Firstly, the reflection signal phase of the different thickness dielectric plate is numerically investigated at W-band. Then, the 150 mm diameter reflectarray is designed at 78.5 GHz and analyzed to evaluate the antenna characteristics.

## 2. Analysis of reflection signal phase at W-band

To obtain the quantitative value of the phase shift of the dielectric material, the FDTD analysis of the dielectric plate is carried out. Fig. 1 shows the FDTD analysis model of the reflection signal phase. The reflection signal phases of the plane incident wave are analyzed at the different thickness of the dielectric plate. Assuming the infinite periodical space,

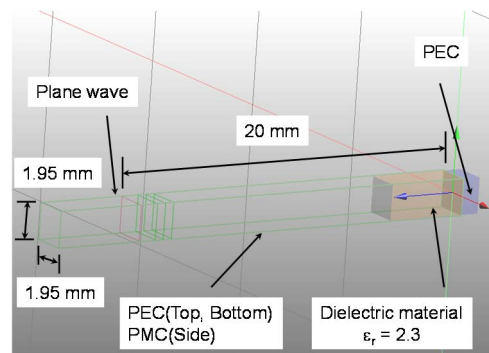


Fig. 1. FDTD analysis model of reflection signal phase due to the dielectric plate.

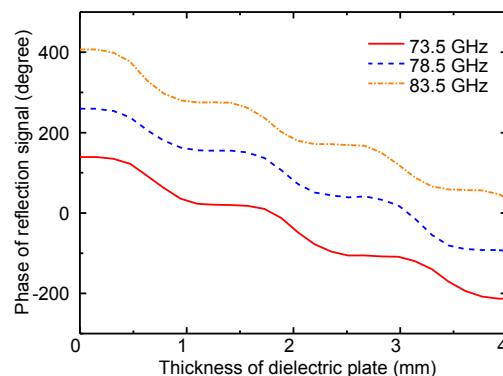


Fig. 2. FDTD analyzed reflection signal phase of the different thickness of the dielectric plate.

the top and the bottom walls consist of the perfect electric conductor (PEC). In addition, both the side walls consist of the perfect magnetic conductor (PMC). The PEC is attached on the back of the dielectric plate. The commercial available FDTD analysis software (SEMCAD X, Schmid & Partner Engineering AG) is employed. To fabricate the reflectarray by the 3D printer, it is used the dielectric constants of the acrylonitrile butadiene styrene (ABS) plastics. The relative permittivity and the loss tangent are 2.3 and 0.1, respectively.

Then, Fig. 2 shows analyzed reflection signal phases of the different thickness of the dielectric plate at 73.5 GHz, 78.5 GHz and 83.5 GHz. It is confirmed that the phase shift is proportional to the frequency. Since the center frequency of the reflectarray is 78.5 GHz, the 360 degrees phase shift is obtained by about 3.6 mm dielectric plate thickness.

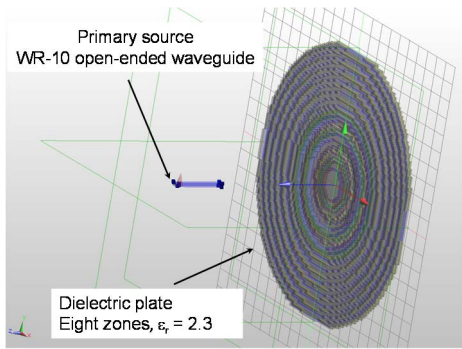


Fig. 3. Eight-zone reflectarray antenna analysis model.

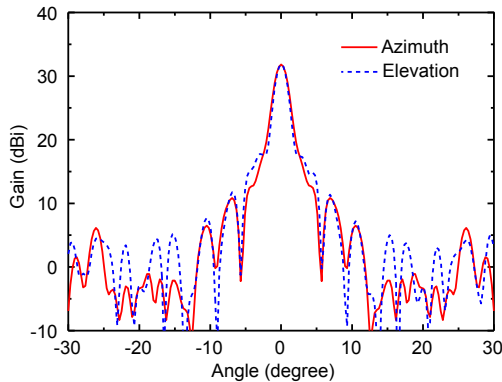


Fig. 4. Analyzed radiation patterns of the eight-zone reflectarray antenna at 78.5 GHz.

### 3. Design and fabrication of reflectarray antenna

The W-band high-gain reflectarray antenna is designed and fabricated based on the analysis results of the dielectric plate reflection phase. Regarding the reflectarray design, the following Fresnel equation is employed:

$$r_n = \sqrt{\frac{2nf\lambda}{P} + \left(\frac{n\lambda}{P}\right)^2} \quad (1)$$

where  $r_n$  and  $f$  are the  $n^{\text{th}}$  radius and the focal length, respectively. In addition,  $P$  and  $\lambda$  are the number of Fresnel zone and the wavelength of the incident wave, respectively. To compare with the conventional reflectarray fabricated by the metallic patch on the dielectric substrate [3], the number of Fresnel zone  $P$  and the focal length  $f$  is determined to eight and 75 mm. Then, the outer diameter of the reflectarray is 150 mm. The designed center frequency is 78.5 GHz.

Based on the FDTD analysis results of the dielectric plate described in the previous section, the thickness of the each zone is determined to realize the eight-zone reflectarray, which phase shifts are 0, 45, 90, 135, 180, 225, 270, and 315 degrees at 78.5 GHz. For example, the dielectric thickness to have 45 degrees and 90 degrees are 3.3 mm and 3.1 mm, respectively.

Fig. 3 and Fig. 4 show the eight-zone reflectarray antenna analysis model and the analyzed radiation patterns of the reflectarray antenna at 78.5 GHz. The primary source is WR-10 open-ended waveguide. The maximum antenna gain is 31.6 dBi. In addition, the azimuth and elevation half-power beamwidth are 1.8 degrees and 1.6 degrees, respectively. Then, Fig. 5 and Fig. 6 show the overview of the printing

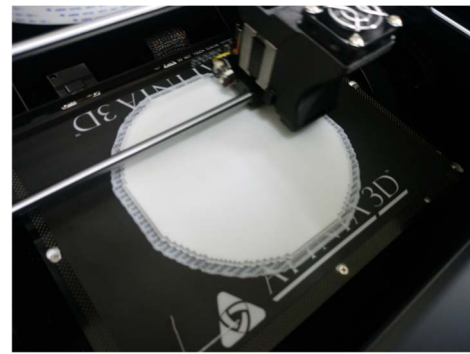


Fig. 5. Overview of the printing process of the eight-zone reflectarray using the 3-dimensional printer.

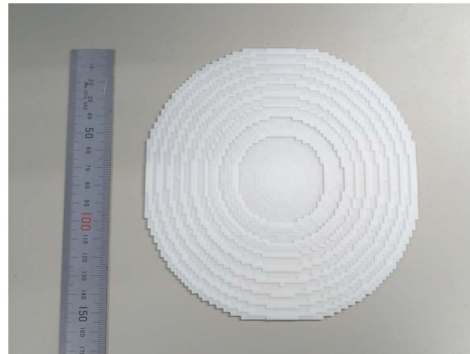


Fig. 6. Overview of the fabricated reflectarray.

process of the eight-zone reflectarray using the 3D printer (Afina H800, Afina) and the fabricated reflectarray, respectively.

### 4. Conclusion

The design and fabrication of the 3-dimensional printed reflectarray antenna, which has more than 30 dBi gain at W-band, was discussed in this paper. The analysis results of the dielectric plates showed the reflection phase shifts at the different thickness. Then, the 150 mm diameter eight-zone reflectarray is analyzed and fabricated. The measured results of the reflectarray antenna will be shown in the conference.

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