Study on Evaluation Method for FMCW Radar Using EM Simulation

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***Abstract*—This paper proposed the test setup for performance evaluation of an FMCW radar. The test setup includes multiple targets with different velocities, which represents the boundary of a certain detection region. The surrounding environments, such as the position and direction of the antenna arrays and ground conditions are also included in the test setup. The metric for evaluation of the detection performance is then defined as a cost function that utilizes the amplitude of each boundary target on a range-Doppler image. Using the proposed test setup and the cost function, the antenna HPBW is optimized and the results demonstrate the method is suitable for performance evaluation of the FMCW radar.**

Keywords—component; FMCW radar, vehicle, antenna, performance evaluation, evaluation method

I. INTRODUCTION

In recent years, many sensors, such as cameras, lidar, and radar have been used in vehicles to provide the driver with information about the driving environment, including pedestrians, traffic lanes, traffic signs, and other vehicles [1, 2]. Among them, a frequency-modulated continuous wave (FMCW) radar system has been widely used as a main sensor because of its low costs, simple implementation, and high reliability under weather conditions [3]. The FMCW radar system generally consists of antenna arrays, radio frequency (RF) devices, and signal processing modules. The signal-to-noise ratio (SNR) of the system is then determined by the strength of the transmitted and received signals that are radiated through the antenna arrays. Therefore, the characteristics of antennas, such as a bore-sight gain, radiation pattern, and half-power beam width (HPBW) are properly determined to maximize the detection performance of the radar for a given specific environment. To optimize the antenna characteristics for such an environment, a systematic evaluation method to measure the detection performance of the radar is essential. However, most previous studies have focused mainly on improving the gain of antenna arrays and the signal processing methods, and in-depth studies of radar evaluation methods have not been fully conducted yet [4, 5].

In this paper, we propose a novel test setup for evaluating the FMCW radar using a full-wave electromagnetic (EM) simulator (FEKO EM Software and Systems) [6]. The proposed test setup includes multiple targets with different velocities, representing the boundary of a certain detection region. The setup also includes surrounding environments, such as the position and steering angle of antenna arrays with a ground condition. A metric for evaluating detection performance is defined as a cost function that uses the amplitude of each boundary target on a range-Doppler image. Using the test setup with the cost function, we optimized the antenna HPBW, and the results verified that the proposed method is suitable for use in evaluating and optimizing the performance of the FMCW radar.

II. PROPOSED TEST SETUP AND COST FUNCTION

Fig. 1 shows the proposed test setup, which includes one antenna and nine boundary targets. We determine the specific detection region with a rectangular shape to take into account real driving environments; the detailed parameters are listed in Table I. Individual boundary targets have a spherical shape in order to minimize simulation resources, and they are located at four corners, four sidelines, and the center of the detection region. The velocities of the targets are varied to recognize all of the targets separately on a range-Doppler image. Then the transmitting antenna radiates the EM wave to the boundary targets, and the received signal is obtained by the receiving antenna. The antenna characteristics, such as antenna gain, HPBW, height, and steering angle with a ground condition are considered in the test setup. The antenna and boundary targets are located at 1 m above the ground, and the diameter of the boundary targets is 0.05 m. We also assume that the FMCW radar

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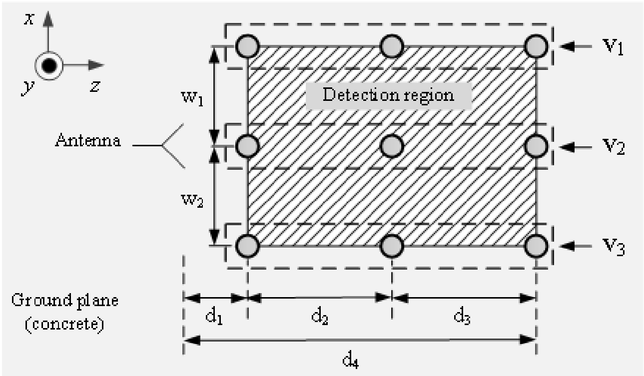

Fig. 1. Proposed test setup.

operates at a frequency of 77.5 GHz with a bandwidth of 200 MHz. The vertical and horizontal HPBWs of the antenna are 50° and 20°, respectively. The ground material is concrete with a relative dielectric constant of 7 and a conductivity of 0.08 S/m [7].

Fig. 2 shows the obtained range-Doppler image for the specific detection region. All of the boundary targets appear in the image with their range and velocity values. A cost function is then defined as a metric to evaluate this range-Doppler image.

$$Cost = \frac{Standard\ deviation\ of\ target\ amplitude}{Average\ of\ target\ amplitude + \alpha} = \frac{\sigma}{mean + \alpha} \quad (\alpha = 25) \tag{1}$$

Using the test setup with the cost function, we conducted a parametric search to find the optimum HPBW of the antenna for the specific detection region. The results are shown in Fig. 3; the lowest cost of 1.23 is observed when the vertical and horizontal HPBWs of the antenna are 10° and 50°, respectively.

Fig. 4 shows the range-Doppler image using an antenna with the optimized HPBWs. The amplitudes of the boundary targets at the edge are improved compared with the amplitudes shown in Fig. 2.

III. CONCLUSION

A novel test setup with a cost function to evaluate the detection performance of an FMCW radar, was proposed. The test setup included multiple targets with different velocities, and it considered the surrounding environment of antenna positions and angles with a ground condition. We optimized the HPBWs of the antenna and obtained the optimum vertical and horizontal HPBWs of 10° and 50°, respectively. These results verified that our test setup is suitable for use in evaluating and optimizing the performance of the FMCW radar.

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TABLE I. PARAMETERS OF THE DETECTION REGION.

v_1	v_2	v_3	d_1	d_2	d_3	d_4	w_1	w_2
-10 m/s	0 m/s	10 m/s	5 m	20 m	25 m	50 m	10 m	10 m

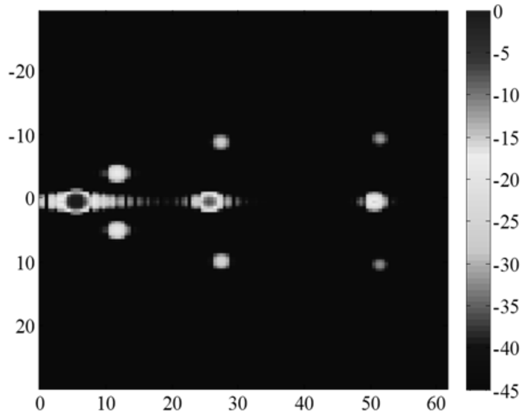

Fig. 1. Range-Doppler image with vertical and horizontal HPBW of 50° and 20°.

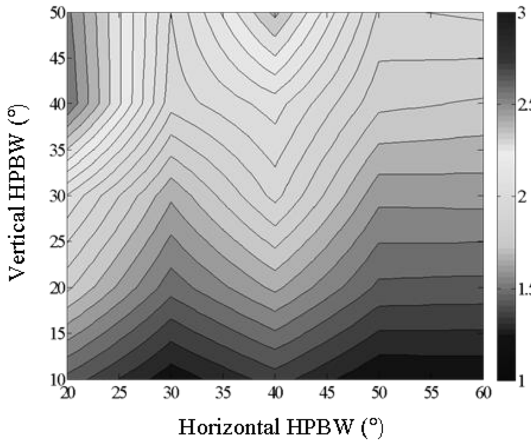

Fig. 2. Contour plot of the cost function.

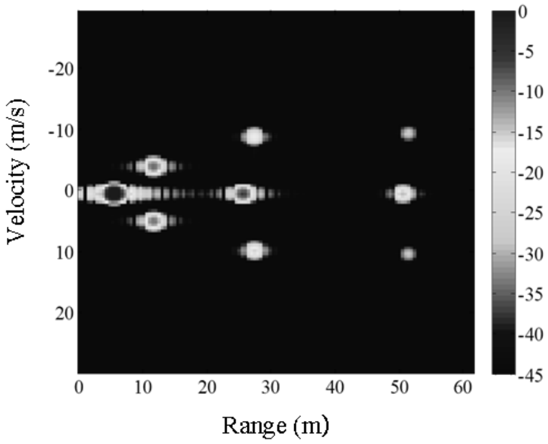

Fig. 3. Range-Doppler image with vertical and horizontal HPBW of 10° and 50°.

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