

Investigation to Recognize Target Width using Millimeter Wave Radar

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ABSTRACT

In recent years the number of vehicles equipped with millimeter wave radar has been increasing due to the popularization of driving assistance systems such as adaptive cruise control (ACC) and forward vehicle collision warning (FCW) systems. Consequently, high performance millimeter wave radar must be developed to support even more advanced driving assistance systems. The investigation described in this paper confirms that it is possible to use high range resolution radar to recognize the width of a target. In tests, a simulated radar signal was transmitted and received by a millimeter waveband network analyzer using a 1.6 meter-wide aluminum foil board as the target. When the range resolution was low, only one point of reflection from the board could be detected. However, when the range resolution was improved, then multiple points of reflection from the target could be detected. The high range resolution radar improves the separation performance of the target and also improves the detection performance of close range targets. In addition, the results of the tests indicate that the high range resolution radar contributes to recognizing the width of the target by grouping together the multiple detected points.

INTRODUCTION

As its name implies, radio detection and ranging (radar) is a sensor that transmits and receives radio waves for the primary purpose of measuring the range to a target. It also detects the relative speed and azimuth direction of the target. Radar is employed in a wide range of uses, including weather monitoring, atmospheric observation, air traffic control, harbor control, and in military uses.¹

In recent years the practical application of vehicle-mounted radar has been promoted for the purpose of utilizing it in driving assistance systems such as vehicle speed and vehicle-to-vehicle distance control systems (adaptive cruise control (ACC)) and forward collision warning systems (forward vehicle collision warning (FCW)).² Camera and laser radar sensor systems that monitor the area around the vehicle also exist, but the advantage of radar is that the target detection performance does not deteriorate in bad weather, such as rain or fog. Another advantage of radar is that it can directly measure the speed of the target from the Doppler shift effect, whereas camera and laser radar systems calculate speed as a derivative of range.³

In the future, even more advanced driving assistance systems will be developed with precise vehicle-to-vehicle distance control compatible with vehicles entering and exiting from several lanes of traffic, and even more accurate collision detection that will reduce collision damage. Sensors that monitor the area around the vehicle in such advanced driving assistance systems must identify both the position of the detected target and the area in which the target exists. In other words, the sensor must detect the width of the target. Camera and laser radar systems have superior azimuth resolution to radar, and this higher resolution enables the detection of target width. In contrast, to improve the azimuth resolution of radar, it is necessary to make the beam of the antenna narrower and the size of the antenna larger. However, if the size of the antenna is increased, then the size of the radar itself becomes larger and it becomes more difficult to mount the system on the vehicle.⁴

In response, this paper describes how it is possible to detect target width using high range resolution radar without having to enlarge the size of the antenna. Section 1 explains how

high range resolution radar contributes to width recognition. Section 2 introduces the results from tests conducted in a radio anechoic chamber to confirm the principle. In these tests, a corner reflector (CR) with a radar cross section of 15 dBsm and a 1.6 meter-wide board attached with aluminum foil were used as the targets. Then, a comparison was made of the results obtained from both targets when normal and high range resolution radars were used. The final section of this paper presents the conclusions of the research and tests.

1. CONTRIBUTION OF RANGE RESOLUTION TO WIDTH RECOGNITION

As explained in the previous section, target width is usually detected based on azimuth direction, including in the case of camera and laser radar sensors that monitor the area around the vehicle. In this method of detecting width, a narrow beam is used to scan back and forth on a wide target from one edge to the other, and it detects the difference in the angle from the radar. To precisely detect the width of the target, it is necessary to make the width of the beam as narrow as possible, and consequently the size of the antenna larger. Therefore, this method is not realistic if the radar is to be mounted on a vehicle. Stated another way, the key point is the spread of this angle from the radar, which is produced by the width of the target (Fig. 1). However, a target with width possesses both an angle and a range spread (Fig. 2). From this fact it is shown that angle detection is not the only method for detecting the width of the target. Therefore, this paper focuses on the spread of the range that is produced by a target that has a width.

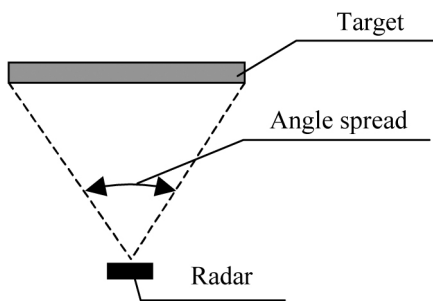


Fig. 1. Angle Spread

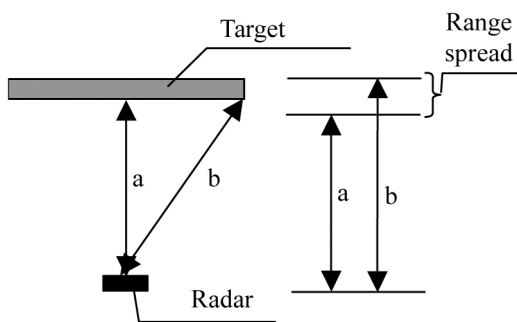


Fig. 2. Range Spread

This range spread becomes even more pronounced when the target is tilted in respect to the radar (Fig. 3) and also when the target is not located directly in front of the radar (Fig. 4).

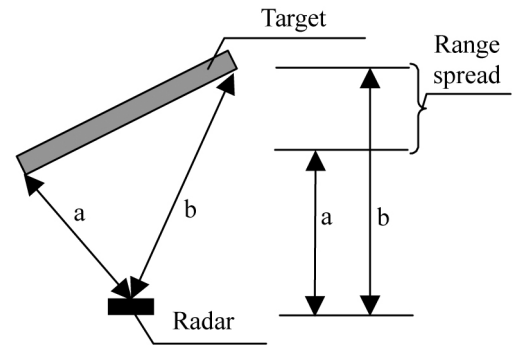


Fig. 3. When Target is Tilted

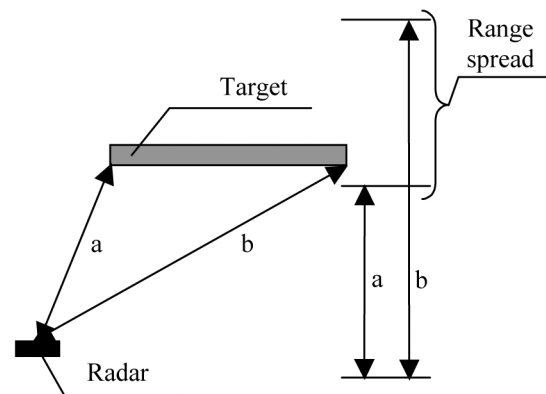


Fig. 4. When Target is Positioned Off-Center

The radar discretely calculates the range to the target in accordance with the range resolution. This discretely calculated range information is then stored in the recording location (range bin) in accordance with that range. The presence or absence of a target is confirmed via the level of the stored signal. When the detected target is comparatively wide, the spread information from the range produced by the target width is placed in the range bin that is equivalent to the range where the detected target exists. When the range resolution is low, the spread from the width of the target fits into one range bin and it is not possible to detect the spread using the range (Fig. 5). However, if radar with superior range resolution is used, the target information spans multiple range bins due to the range difference produced by the target width (Fig. 6). In other words, the radar can make a judgment on whether the target has a certain width or is a comparatively narrow target by confirming whether the target information is included in multiple range bins. Whether the target information is included in multiple range bins can be confirmed by azimuth detection processing on each of the range bins. The results of the tests conducted to confirm this principle are presented in the next section.

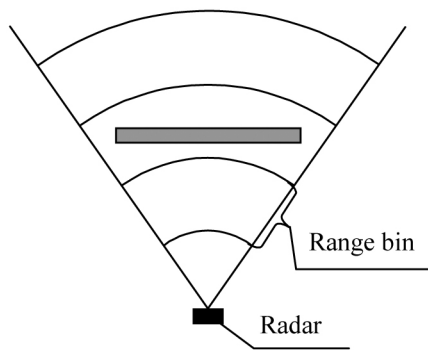


Fig. 5. When Range Resolution is Low

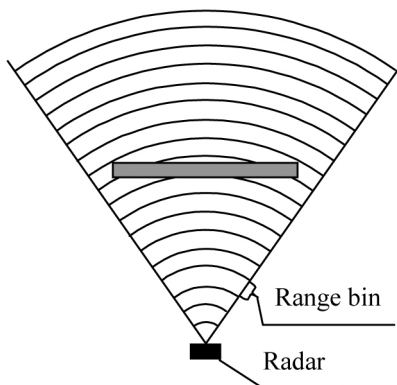


Fig. 6. When Range Resolution is High

2. PRINCIPLE CONFIRMATION TESTS

Tests were conducted using a millimeter waveband network analyzer to transmit and receive a simulated radar signal. The antenna was a standard gain horn antenna. The targets were a CR with a radar cross section of 15 dBsm and an aluminum foil board with a width of 1.6 m and a height of 0.6 m. Measurements were made after placing the targets 12 m from the antenna. The tests were conducted with the antenna at a height of 1.25 m above the ground. The horn antenna was

connected to the network analyzer and transmission measurements (S21 measurements) were conducted. The horn antenna that was connected to the network analyzer was then placed as shown in [Fig. 7](#) so that it faced toward the target aluminum foil board. In the S21 measurements, the signal sent from port 1 passes through the horn antenna and is transmitted. This signal then reflects off the target and is received by the horn antenna connected to port 2 and enters port 2. At this time, both the amplitude ratio and phase difference of the transmitted signal and the received signal are obtained. In these tests the center frequency was 79 GHz and measurements were made at 801 data points with a bandwidth of 3.2 GHz in intervals of 4 MHz. The amplitude ratio and phase difference data at ports 1 and 2 was then obtained at each of the frequencies. A digital beamforming receiver (DBF) with six channels is assumed. The channel spacing was 6mm. To realize a DBF receiver, the port 2 antenna was moved to each channel location, and a measurement was stored for each channel. The range to the target and the azimuth direction was computed using the signal processing method described in the [Appendix](#).

[Figure 7](#) shows the arrangement of the room used for the tests. The network analyzer was placed at the upper left corner. The target was placed on the right side to suppress reflections from the walls as much as possible. When the target was the aluminum foil board, it was placed at an angle of 5 degrees from the antenna. Given the conditions described above, the spread of the range, as shown in [Fig. 3](#), was approximately 0.14 m.

As explained previously, when high range resolution radar is used with a target that has width, the target information is stored in multiple range bins. Consequently, the information for a target with width is extracted by conducting signal processing using the amplitude and phase information of the bins surrounding the range bin where the peak appeared. In this case, first, element i (where the peak appeared) is used from the elements of the vector in [Eq.\(3\)](#) of the [Appendix](#) to detect the range and azimuth direction. After this, the next element $i+1$ is used to detect the range and azimuth direction.

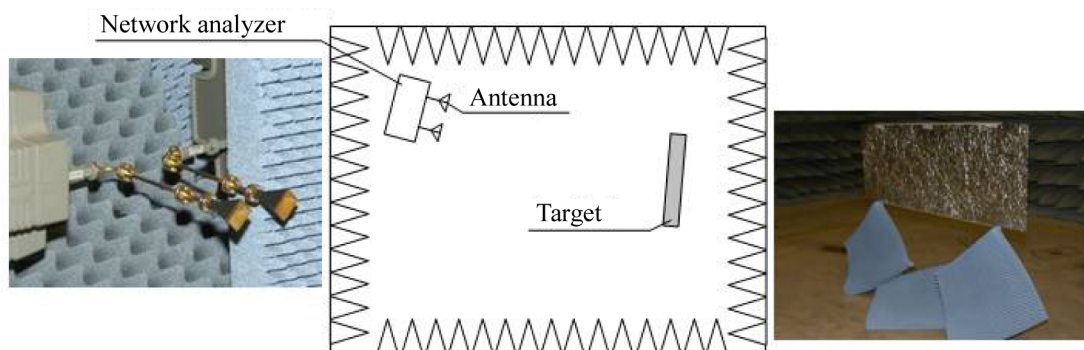


Fig. 7. Diagram of Test Setup