79 GHz-Band High-Resolution Millimeter-Wave Radar

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High-resolution millimeter-wave radar that operates in the 79 GHz band is expected to achieve a significant increase in the distance resolution of radar systems because of the availability of a wide frequency bandwidth of 4 GHz as compared with 0.5 GHz of the existing 77 GHz-band millimeter-wave radar. For this reason, it has the potential to distinguish between a vehicle and a human, which was conventionally difficult, and recognize their movements. Therefore it raises expectations for use as a surrounding monitoring radar in driving safety support and automatic driving. As one of FUJITSU TEN's efforts regarding sensing technologies for driving safety support and automatic driving, it has been developing 79 GHz-band high-resolution millimeter-wave radar. This paper presents specifications of radar for application to systems that assist in safe driving and automatic driving and the results of testing a prototype for a wider bandwidth that is required to accomplish the technology's purpose. This radar increases the ability to detect a pedestrian in the surroundings of a vehicle, which was difficult to do with the existing 77 GHz-band radar. Furthermore, this paper also describes how the newly developed radar offers the possibility of improving the performance of a sensor for automatic driving and systems to assist in safe driving.

1. Introduction

Traffic deaths are on the increase globally. The United Nations General Assembly has proclaimed the Decade of Action for Road Safety,[1] as an effort to be pursued between 2011 and 2020. Countries and automobile manufacturers across the world are beginning their unique initiatives to stabilize and then reduce global road traffic deaths.

Through their respective efforts in ensuring road safety, automobile manufacturers are developing and launching a diverse range of safety technologies. Presently, various automobile manufacturers market anti-collision vehicles equipped with the technology to minimize damage from collisions, raising expectations for being an effective means to reduce traffic accidents. The technology will be included in the New Car Assessment Programme (NCAP) in the near future, which then would encourage further market expansion.

Progress is also being made in the field of automatic driving; for example, Google Inc. has developed a system that links up omni-directional sensors and a data center. While image sensors and laser radars are often deployed on autonomous cars, these are likely to be affected by the elements such as rain and the surrounding conditions. Therefore, millimeter-wave radar is a promising medium since its high detection performance is robust over weather conditions.

In this paper, we will explain the efforts at FUJITSU TEN to develop high-resolution millimeter-wave radar that operates in the 79 GHz band, for driving safety support and automatic driving. This radar has the potential to enhance detection of pedestrians and other objects in the surroundings of a vehicle, which has been difficult to do with a conventional 77 GHz-band millimeter-wave radar so far.

2. Millimeter-wave radar

A millimeter-wave radar utilizes radio waves in the millimeter-wave band, and the operation on electromagnetic waves makes it less affected by climatic elements such as rain, snow and fog as well as a vehicle's rear lights than image sensors and laser radars, which have used visible light or infrared so far. The sensing mechanism involves utilizing the time difference between transmitted and received waves to calculate the distance to objects, and the Doppler effect and changes in the distance to obtain the speed of the objects. It also uses the amplitude and phase of the received wave to identify orientation.

There are 77 GHz-band and 24 GHz-band radars already commercialized for in-vehicle applications, but higher performance is in demand as the systems continue to become more sophisticated as in driving safety support and automatic driving, which require wider detection areas and enhanced resolution to be operable in more complex environments such as on urban roads. To enhance the resolution requires wider bandwidth. In Japan, the available bandwidth is limited to 0.5 GHz by law, and thus the existing 77 GHz-band millimeter-wave radar[2)-5)] cannot have the resolution necessary for automatic driving.

This is why there are high expectations for the development of 79 GHz-band radars, which are capable of achieving high resolution in the ultra-wide 4 GHz bandwidth. We have developed a high-resolution radar that operates in the ultra-wide 79 GHz band, and verified that its resolution is enhanced compared to 77 GHz-band radars. Furthermore, surroundings detection tests yielded stable successes in detecting pedestrians in the surroundings of a vehicle apart from other vehicles.

3. Consideration on radar specifications

This section describes the specifications of FUJITSU TEN's millimeter-wave radar, which is adapted to driving safety support and automatic driving. The driving safety support system (DSSS) includes Adaptive Cruise Control (ACC) and Autonomous Emergency Braking (AEB), as well as lane-changing assistance and automatic collision avoidance. In order to meet the requirements of the above-mentioned systems, a radar system as shown in **Figure 1** must be developed. Long- and mid-range radars are installed in the front and rear of a vehicle, and short-range radars are mounted on both sides. Currently we are considering the use of Multi-Mode Radar (MMR) for both long- and mid-range radars, or 77 GHz-band for long-range and 79 GHz-band high-resolution millimeter-wave radar for mid-range radars. The actual selection will depend on the required applications, e.g., ACC, AEB, and so on. For short-range radars, we adapted 79 GHz-band millimeter-wave radar.

The radar specifications required by the applications are shown in **Table 1**. ACC does not require high resolution because it monitors vehicles, which are large and normally there is some distance between them, and are unlikely to make a sudden change in

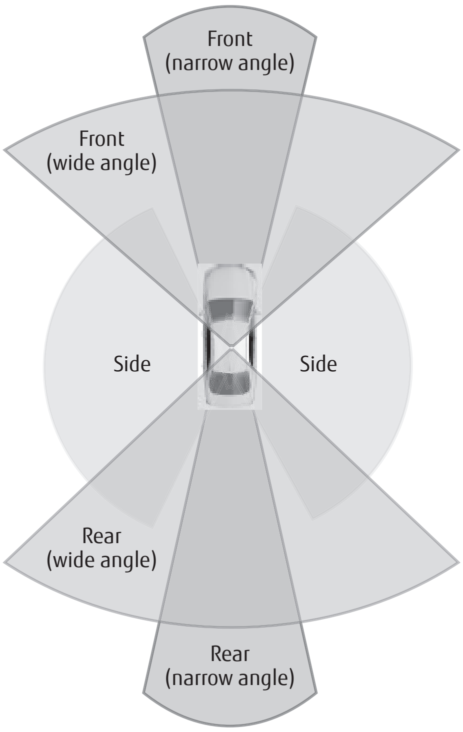

Figure 1
Radar system structure.

Table 1
Major system requirements and radar's detectable range.

Specifications \ System		ACC	AEB	BSD	ERBA
Maximum detection range (m)		160	50	40	15
Minimum detection range (m)		2	2	0.5	0.2
Range resolution (m)		0.5	0.2	0.5	0.2
Object	Vehicle	○	○	○	○
	Pedestrian		○		○
Direction	Front	○	○		
	Rear		○	○	○
	Side		○	○	○

BSD: Blind Spot Detection
ERBA: Extended-range Backing Aid System

the direction of their motion. Monitoring humans is different, in that they may suddenly change the direction of their motion, and may come up very close to surroundings objects. For this reason, a high resolution is required. For example, a 77 GHz-band millimeter-wave radar, if applied to short-range monitoring, would need angular resolution to supplement the distance resolution in order to achieve the required resolution. In order to enhance the angular resolution, the radar will need more antenna elements. This means not just an increase in its size, but also a rise in cost due to an increase in the number of signal processing circuits. Meanwhile, the 79 GHz-band millimeter-wave radar enhances the range resolution through wider bandwidth, allowing for downscaling and lower costs.

It is also important to widen the detectable range, thereby reducing the number of radars to be mounted and reduce the system cost. If the system shown in Table 1 were to be realized in the system configuration depicted in Figure 1, the radars need to cover a range of more than 130 degrees.

As such, a high-range resolution of distance and wide detectable angle is needed for the 79 GHz-band millimeter-wave radar. Therefore, what needs developing is enhanced range resolution and antennas with a wide angle of detection capability. We will explain the range resolution in the following section.

4. Consideration on radar method

The methods of detecting targets are mainly categorized into the modulation method (detecting the distance and relative velocity) and the arrival angle estimation method. The Frequency Modulated Continuous Wave method and pulse processing method, among others, fall in the category of the modulation method. The performance of the arrival angle estimation method is determined by the number of antenna arrays and calculation methods as it utilizes digital signal processing. These methods have their advantages and disadvantages, which affect the performance and required system configurations. Thus, it is necessary to grasp the difference in the characteristics of these methods, and develop not only the method to resolve distances and detect arrival angles, but also the methods of detecting targets.

We conducted performance tests on the 79 GHz-band millimeter wave radar to clarify the difference in fundamental performance with the wider bandwidth instead of the difference between the detection methods. For this reason, we employed the FMCW method, the same as the 77 GHz-band millimeter-wave radar that has already been commercialized. The range resolution of a FMCW method is obtained by the following equation:

$$\Delta R = A \frac{c}{2\Delta F} . \quad (1)$$

In the above equation, ΔR is the range resolution, c is the speed of light, ΔF is the modulation frequency bandwidth, and A is the constant of detection performance deterioration due to signal processing such as a window function. Equation (1) indicates that the wider frequency bandwidth allows for a greater value of ΔF, to enhance the range resolution (smaller ΔR value). The conventional 77 GHz-band millimeter-wave radar operated in the bandwidth of 0.5 GHz, whereas the 79 GHz band high-resolution millimeter-wave radar has 4 GHz, an eight-fold increase. Thus, we estimated the resolution could be improved in the range from 1.5 m to 0.18 m.

We experimented with the developed 79 GHz-band millimeter-wave radar to verify the above. The method and results of the experiment are described in **Figure 2**. In the experiment, we changed the distance between two corner reflectors (standard reflection medium to return the radio wave back in the direction it came from), and measured the distance between them at which they could be distinguished. The results represent the frequency analysis of received signals, and the peaks of the received signal power indicate the positions of the objects. At the interval of 0.2 m between the corner reflectors, the radar detected only one peak in the 0.5 GHz bandwidth, being unable to distinguish the two reflectors. By contrast, they are clearly distinguished in a bandwidth of 4 GHz. This result fully supports the equation, confirming the theory.

5. Detection of pedestrians and distinguishing from vehicles

We investigated whether improving the range resolution made it possible for the system to detect a person in the surroundings of a vehicle, which had been difficult to do with the 77 GHz-band millimeter-wave

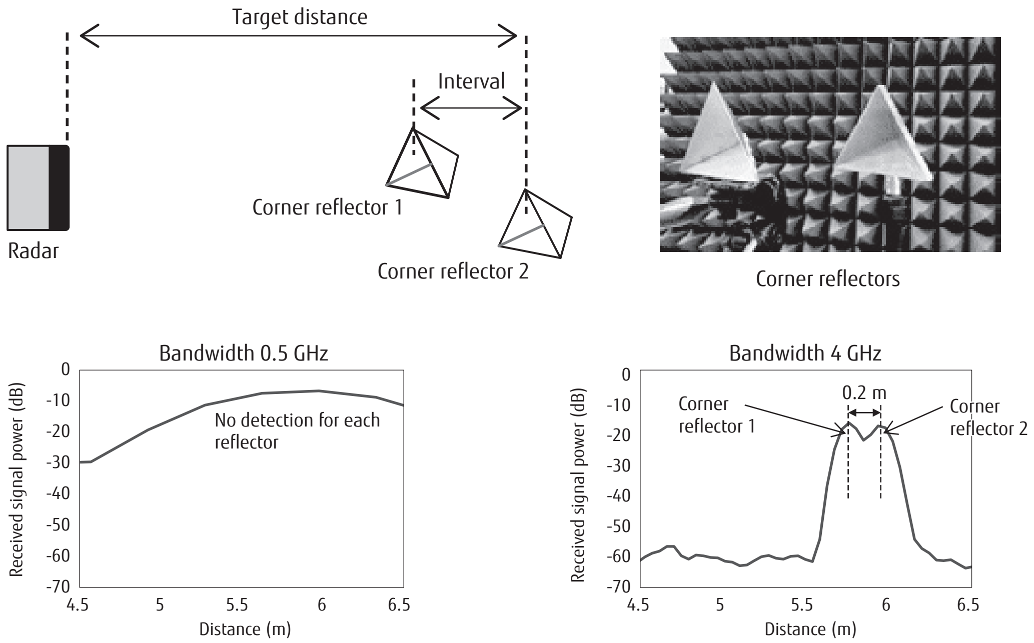

Figure 2
Outline and results of the range resolution tests.

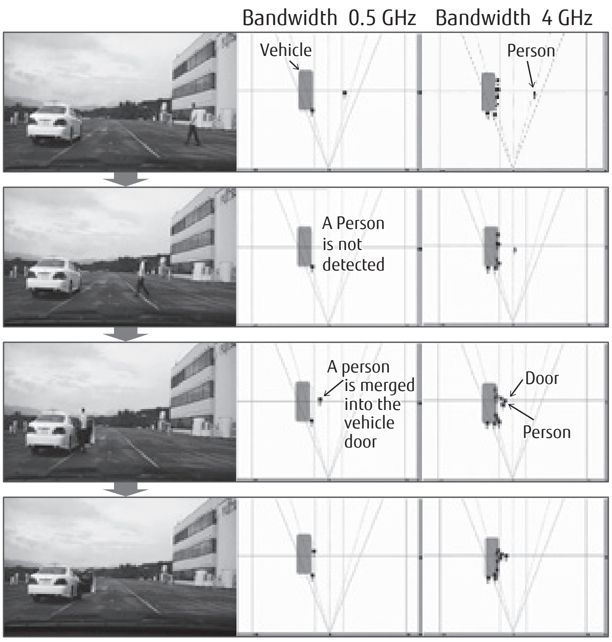

Figure 3
Detection of a person getting into a vehicle.

radar. We conducted a comparative experiment of different bandwidths using a situation in which a person is getting into a car, as shown in **Figure 3**.

1) Bandwidth of 0.5 GHz (frequency of 77 GHz)
- The person could be detected while he was away from the vehicle, but it became difficult to detect the person as he approached the vehicle, and it was impossible to detect him as he got into the car.
- While the person was away from the vehicle, the angle resolution helped to distinguish him from the car. But it could not help to detect or distinguish the person when he comes close to the vehicle and the distance between him and the vehicle exceeds the limit of the angle resolution, due to the low-range resolution of the radar.
- As there were only a few detection points, the vehicle was detected but not clearly enough to determine its shape.

2) Bandwidth of 4 GHz (frequency of 79 GHz)
- With the high resolution in distance, both the vehicle and person were detected separately and stably.
- It successfully detected the opening/closing of the side doors, which the 77 GHz-band millimeter-wave radar could not do.

The experimental results thus suggest that the 79 GHz-band millimeter-wave radar has the potential to detect pedestrians near a vehicle, the shape of a vehicle, and operation of side doors, through the enhanced range of resolution operating in a wider bandwidth of 4 GHz.

6. Conclusion

This paper described FUJITSU TEN's project to develop a high-resolution millimeter-wave radar that operates in the 79 GHz band, and it explained the results of performance tests using an actual radar. We verified that the radar was able to detect a pedestrian in the surroundings of a vehicle distinctly. We also confirmed that the radar's performance level was high enough to identify the shape of a vehicle. However, the higher resolution resulted in detecting many signals from one object. Thus, our future challenges include the development of algorithms to aggregate these signals and recognize one object as one, and of the filtering process to enable continuous detection. Widening the detectable angle potentially results in catching more signals from the surroundings. Therefore, this must be addressed in the future by adapting the technology to distinguish irrelevant signals from vehicles and pedestrians. Technology for high-speed signal processing will also be needed.

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