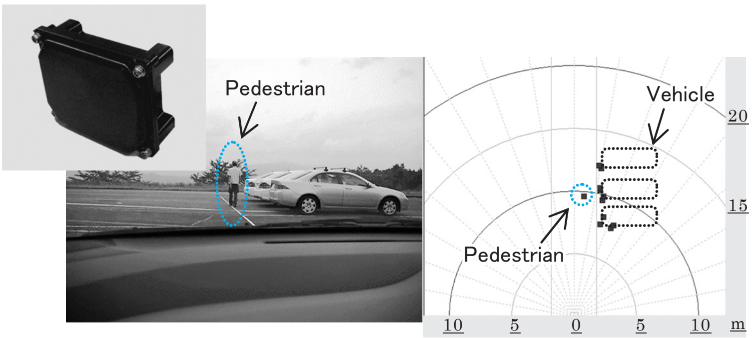
79GHz Band Ultra-Wideband Automotive Radar

Katsuyuki OHGUCHI
Masayoshi SHONO
Masayuki KISHIDA



Abstract

Fujitsu Ten has been developing millimeter-wave radar that can accurately measure, for example, the distances between the host vehicle and other vehicles by using millimeter-wave. Recently we have developed 79GHz band radar with higher resolution and wider-angle detection than existing 77GHz band radar and have confirmed that the new radar realizes high-resolution separation ability, and we report it. It is composed of an ultra-wide band FMCW modulator and a sector antenna, and is realized by sophisticated signal processing technology. This paper describes: the configuration of a peripheral monitoring radar system and study of its detection area; the concept of the radar system and the theoretical and simulation verification of advantages of wider bandwidth; and the concept of antenna development and the configuration of its prototype model. Furthermore, we present the test results of the prototype model. This radar enables the detection of a pedestrian and the like around vehicles which are difficult to be detected by the existing 77GHz band radar so that more advanced safety system will be able to be materialized.

1 Introduction

The death toll from traffic accidents shows a trend to increase year by year in the world. UN General Assembly declares the period from 2011 to 2020 "Decade of Action for Road Safety." Country and automakers also set individual goals and promote the efforts to curb the increase in death toll from traffic accidents and to reduce it in the world.[1)]

Each automaker develops various advanced safety technologies as an approach to traffic safety and markets its products. Currently, vehicles equipped with the technology for preventing a collision accident are launched on the market as a collision avoidance vehicle by various manufacturers and attract attention due to a great effect in reducing traffic accidents. Furthermore, this technology is decided to be introduced into "New Car Assessment Programme (NCAP)" in the future and its market is expected to grow. Recently, safe-driving assist systems have been developed. Those systems include: functions, such as parking assist, that improve convenience; and functions that detect a vehicle approaching from behind the host vehicle or from blind spots and that enhance the effects of collision prevention and collision mitigation by expanding the monitoring area from the front alone to the periphery of the host vehicle. In fact a system equipped with 77GHz band radars or 24GHz band radars on a vehicle is put into practical use. Such a safe-driving assist system designed for collision mitigation is required to evolve into a more sophisticated system for collision avoidance and further into the autonomous driving system in the future, and an automotive radar is required to have more advanced performance, such as wider detection area and higher resolution used in complicated environments like city traffic. Though wider bandwidth of the frequency needs to be used for higher resolution, conventional 77GHz band radars[2)-5)] cannot have enough resolution because the available bandwidth is limited to 0.5GHz by the standard. Thus, the development of a 79GHz band radar having a wider usable bandwidth of 4GHz and a possibility of higher resolution is expected. We have developed a 79GHz band ultra-wideband radar having high resolution and wide-angle detection area and have confirmed its higher resolution in experiments as compared to a conventional 77GHz band radar. In addition, better results are also confirmed in pedestrian detection test around a vehicle.

2 Consideration of Detection Area

The configuration of our proposed radar system is shown in **Fig. 1**. Long-range and middle-range radars are installed on the front and the rear portions of a vehicle and short-range radars are installed on the both sides. Our envisioned system-configuration for a long and middle range is to install; 77GHz multi-mode radars (MMR) for both ranges, or 77GHz band radars for a long range and 79GHz band radars of more advanced detection ability for a middle range. These radars are selected according to the required application such as Adaptive Cruise Control (ACC) or Autonomous Emergency Braking (AEB). And for short-range use, a 79GHz band radar is installed. Detection area of each radar type is shown in **Table 1**. For cost reduction, it is also so important to reduce the number of installed radars by expanding detection area of each radar in a manner of broadening detection angle that very wide-angle radar of detection angle of 130° is required for a short range.

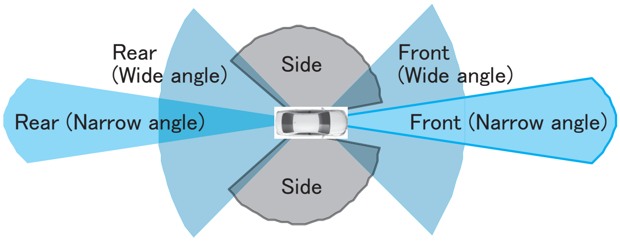


Fig.1 Configuration of Radar System

Table 1 Detection Area of Each Radar Type

	Front-Rear (Narrow angle)	Front-Rear (Wide angle)	Side
Usage	Long Range	Middle Range	Short Range
Range	250m	70m to 100m	40m
Angle	18°	90°	130°

3 Approach to Developing 79GHz Band Ultra-Wideband Radar

The 79GHz band radar which is used for a middle and short range is required to have high resolution and wide detection-angle performance. Therefore, the key elements of the development are a modulation method, a target detection method, such as DOA estimation, and an antenna technology as the base of DOA operation. An approach to each development is described below.

3.1 Radar System

The target detection method is divided broadly into modulation scheme to detect a range and a relative speed, and DOA estimation scheme to detect an angle. The modulation scheme consists of various systems, such as FMCW system and Pulse system, and the detection performance is determined by a selected modulation system. The performance of DOA estimation operated by digital signal processing is defined by operation type. Each system or the type has its own merits and demerits, and the produced system performance and the required system configuration is changed. With an understanding of the characteristics of those different systems or types, it is necessary to develop a radar system which satisfies not only wide angle and high resolution, but also high accuracy, high speed processing and low cost. We have developed and evaluated a 79GHz band ultra-wideband radar adopting FMCW system and high-resolution DOA estimation algorithm developed for the 77GHz band radar. We selected the FMCW system because it is our well-used key technology and we have lots of relevant technological resources. The range resolution of the FMCW system is defined by the formula (1).

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

In the above formula, ΔR is range resolution, c is light velocity, ΔF is bandwidth of modulation frequency, and A is integer which decreases the range resolution affected by signal processing such as window function. The formula (1) represents that the wider frequency bandwidth is, the higher range resolution is. The frequency bandwidth of the developed radar is given 4GHz, which is 8 times the bandwidth of a conventional 77GHz radar. **Fig. 2** shows the outline of the simulation and the simulation results of range resolution, using 0.5GHz bandwidth and 4GHz bandwidth. These results represent that the 79GHz band radar has high range resolution of 0.2 meters.

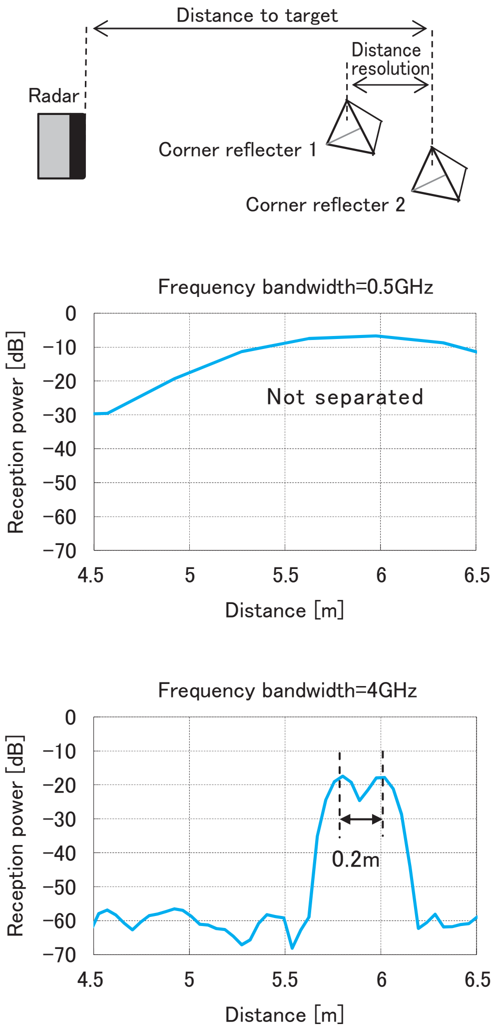


Fig.2 Simulated Results of Range Resolution

3.2 Antenna

The 79GHz band radar needs to have a very wide detection angle of 130° in a short range. Therefore, accordingly, the antenna needs to have a wide detection angle. It is also important to increase detection angle and gain concurrently, to suppress side lobes, and further to reduce grating lobes*(1) produced by DOA estimation.

In order to solve these problems, we have developed an antenna including M pieces of transmitting antennas whose beam directions are changed respectively. This antenna is configured as a sector antenna whose transmitting antennas change their beam directions respectively. As a result, the antenna covers a wide range, suppresses side robes, and produces antenna gain which satisfies the required detection range. The image of the wide-angle antenna is shown in **Fig. 3**. The image of DOA estimation is shown in **Fig. 4**. The DOA estimation is used to detect an arrival angle by computing the reflected radio waves which are transmitted from an arbitrary transmitting antenna and received by N pieces of receiving antennas. Hence, the N pieces of the receiving antennas cover the same detection area. Also, for the countermeasures against grating lobes, an algorithm which utilizes M pieces of the transmitting antennas having different detection areas is employed. The number of M or N is set to 4 for the developed antenna.

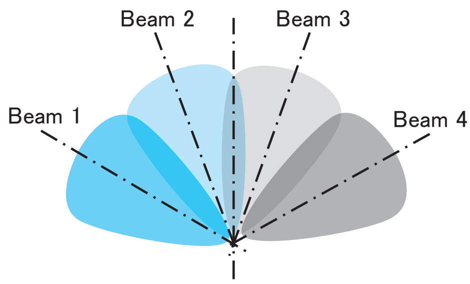


Fig.3 Image of Wide-Angle Detection Method

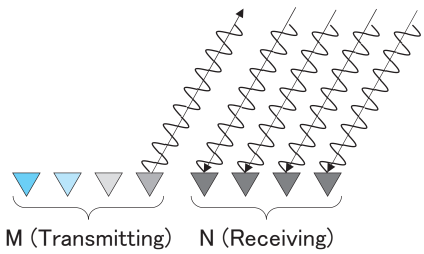


Fig.4 Image of DOA Estimation

＊(1) Grating lobe: It refers to unwanted emission generated in a different direction from the main lobe which is formed in the arriving direction. When the distance between receiving antennas is wider than the wavelength, it appears at the angle where its phase condition is the same as one of main lobe.

4 Results of Range Resolution Test

Using the developed 79GHz radar, the range resolution was tested. This test was conducted with changing the distance between the 2 corner reflecters[(2)]. The outline and results of the test are shown in **Fig. 5**. The results show that the range resolution performance of 0.2m obtained in the simulation was confirmed by real world test using an actual system. Also, as compared with the test results to the simulation result, both range resolutions were nearly equal. The result of the comparison is shown in **Fig. 6**.

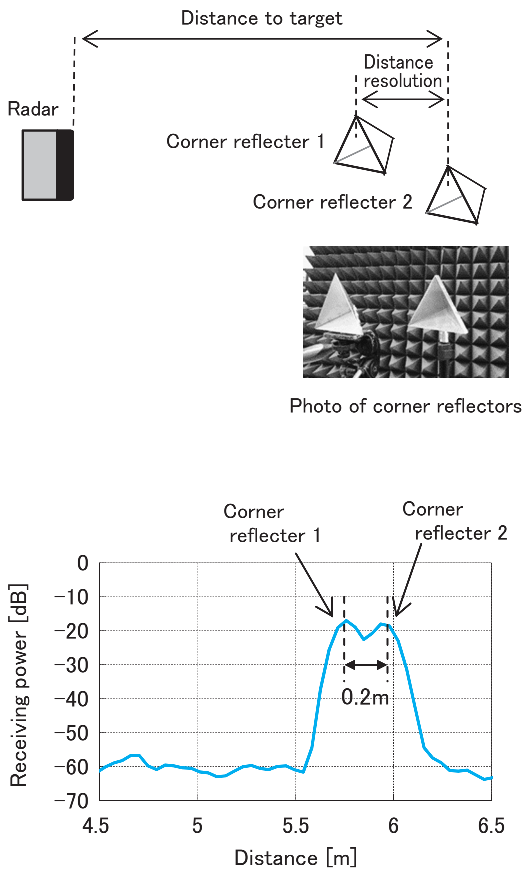


Fig.5 Outline of Range Resolution Test and Test Result

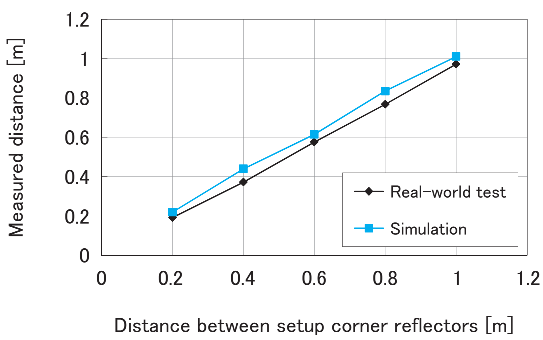


Fig.6 Comparison of Results between Real-World Test and Simulation

5 Detection Test of Pedestrian around Vehicle

We have checked whether it is possible to detect a man standing in front of a vehicle who is difficult to detect by the conventional 77GHz band radar. An outline and results of the test are shown in **Fig. 7**. By this test results, it was confirmed that the developed 79GHz band radar can detect a pedestrian separately from a vehicle and also capture the shape of the vehicle. It is thought that the improved resolution enables the slight differences of reflecting points of a vehicle to be detected separately.

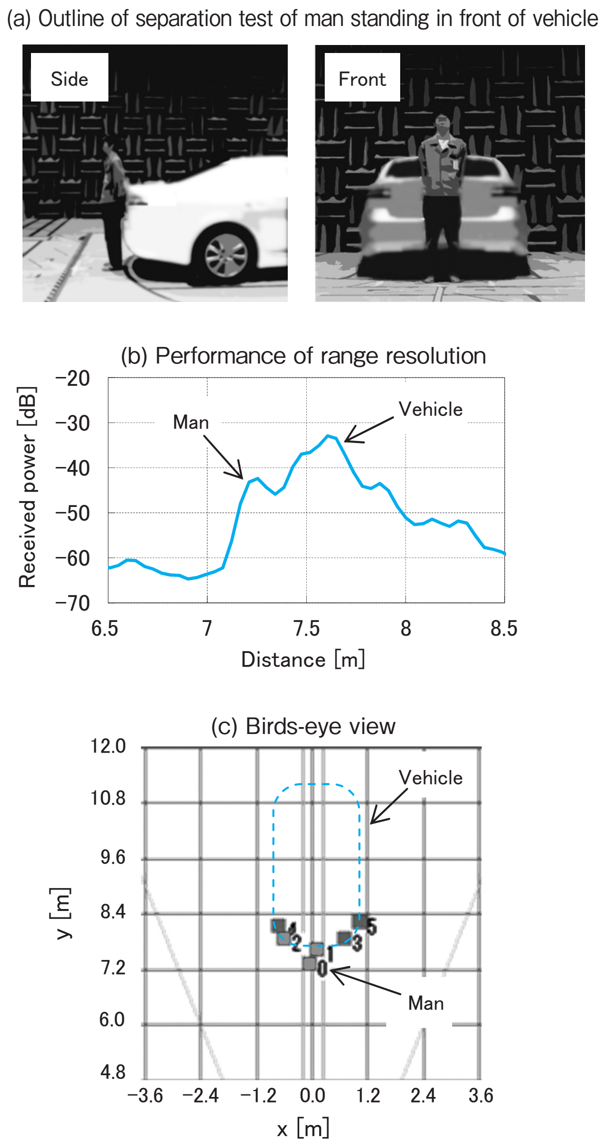


Fig.7 Results of Separation Test of Man Standing in Front of Vehicle

＊(2) Corner reflecter : Reflecter to reflect a coming radio wave in its incident direction

Next, a detection test of a pedestrian around vehicles shown in **Fig. 8** was conducted. In this test, detection performances were also compared between 0.5GHz bandwidth and 4 GHz bandwidth. The test results of 0.5GHz bandwidth are shown in **Fig. 9** and ones of 4 GHz bandwidth are shown in **Fig. 10**. In the case of the 0.5GHz bandwidth, the pedestrian could not be detected continuously and was sometimes lost. On the other hand, in the case of the 4GHz bandwidth, the pedestrian was detected continuously without losing sight of him. It is thought that the vehicle and the pedestrian were detected separately thanks to the improved range resolution of the radar.

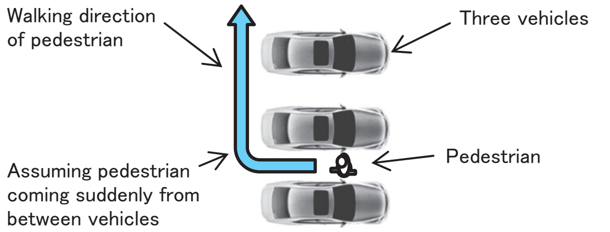


Fig.8 Outline of Detection Test of Pedestrian Walking around Vehicles

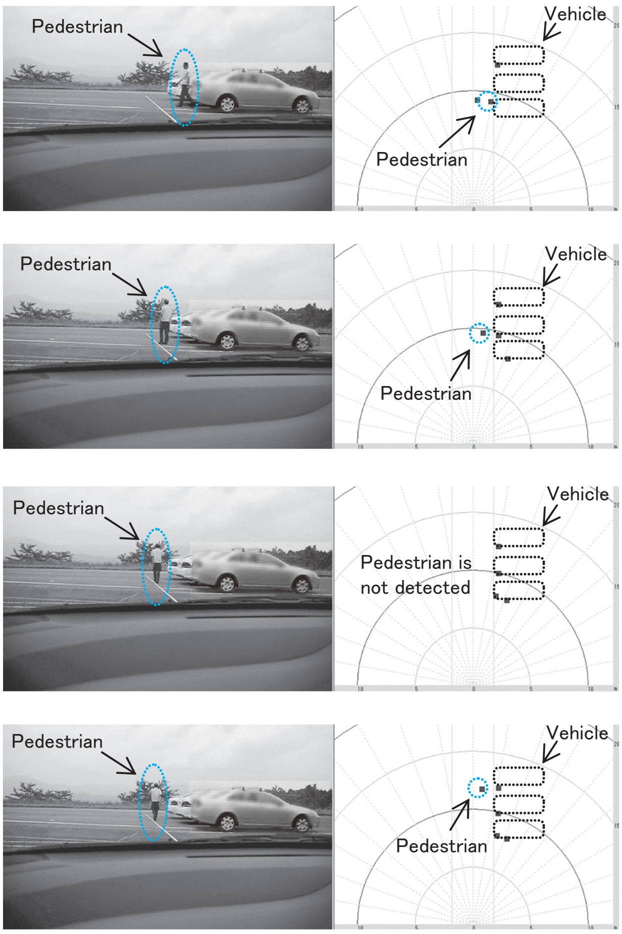


Fig.9 Detection Test of Pedestrian Walking around Vehicles (bandwidth=0.5GHz)

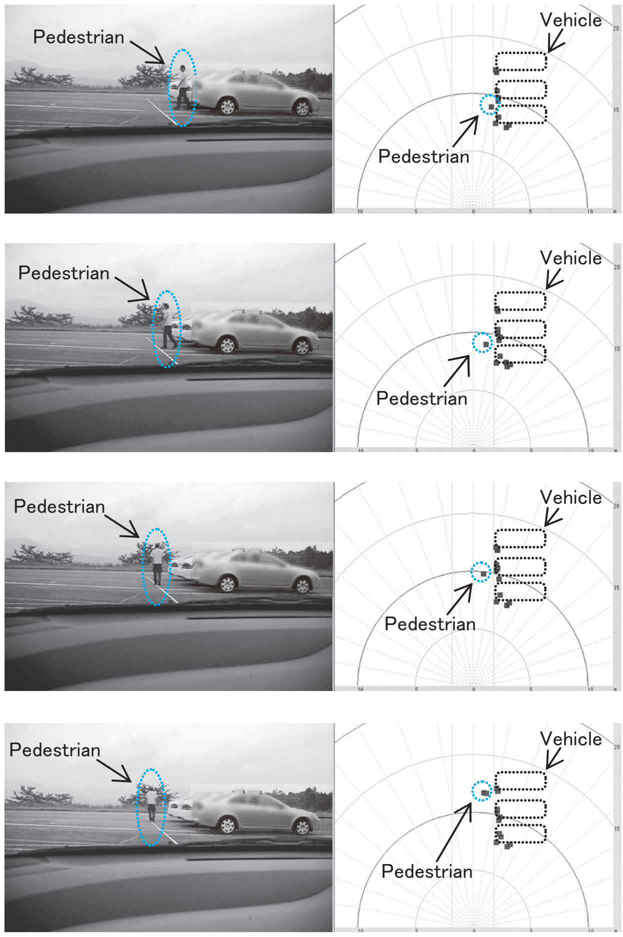


Fig.10 Detection Test of Pedestrian Walking around Vehicles (bandwidth=4GHz)

6 Conclusion

In this paper, we have presented the configuration of our radar system, detection areas, the approach to developing the 79GHz band ultra-wideband radar, and the results of the test using the prototype. In this radar test, it is confirmed that the developed radar has the capability of not only detecting a pedestrian around vehicles separately, but having a performance like an imaging function which captures the shape of a vehicle. We also confirm that this radar is effective to upgrade the safe-driving assisting system. We are willing to make a contribution to realizing the automobile society of no traffic accidents through this radar development.

Reference

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Profiles of Writers

Katsuyuki OHGUCHI
A Project Promotion Dept.
AS Engineering Group.

Masayoshi SHONO
A Project Promotion Dept.
AS Engineering Group.

Masayuki KISHIDA
Manager of Advanced Sensor Development Dept.
AS Engineering Group.