Development of 24 GHz-band High Resolution Multi-Mode Radar

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ABSTRACT In recent years, Advanced Driver Assistance System (ADAS), which has sensor devices mounted and avoids vehicle accidents by detecting objects in surroundings, started to be popular. Using the radar technology and detecting attenuation characteristics based on the weather and the Doppler Effect of the radio waves make possible the higher more reliable sensing over the sensing based on cameras and lasers. For this reason, it is expected that the demand will increase more and more in the future. Furukawa Electric has developed the multi-mode radar, based on pulse method radar which is in compliance with radio equipments specified for low power radio stations or for mobile detection sensors and is suitable for various applications. Since this radar is compact, has a lot of flexibility in mounting on vehicles and can be mounted inside the bumpers, it is suitable to various applications such as a front side monitoring and a rear side monitoring. Here, we introduce its development concept, its fundamental performances and its considerations for mounting on vehicles.

1. INTRODUCTION

Automobile safety technologies for decreasing fatalities from traffic accidents are classified roughly as preventive safety technologies and as crash safety technologies.

For the crash safety technologies, the development of the technologies such as a seat-belt or an air-bag is mainly advanced. In recent years, the development of the preventive safety technologies is advanced with the progress in electronics technologies, and various sensors such as laser radars, millimeter-wave radars and image sensors are commercialized to date. The sensors already put into production are assumed to be applied for the systems which are designed to reduce and prevent head-on collisions or rear-end accidents.

Here, we recently created a new concept for the development from the analysis of the events and the characteristics of each accident pattern and from the condition of the types of road shape extracted from the database of the number of traffic accidents in Japan, and we designed and developed the new sensor which meets this concept.

2. THE CONCEPT OF THE DEVELOPMENT

2.1 The Required Performances

Based on, “The classification of the events and the characteristics of each accident pattern in Japan” shown in “The conditions of occurrence of traffic accidents”, the accidents between vehicles account for more than 80% and, in particular the accidents of cars having bumped into each other and those which turned to right/left have a high percentage. The accidents between vehicles and pedestrian walking across the street have also a high percentage. In addition, based on “The classification of the conditions and the characteristics of the types of road shape in the database of the number of traffic accidents in Japan” shown in “The conditions of occurrence of traffic accidents”, it can be confirmed that more than half of the traffic accidents occur at intersections[1]. Therefore, we have developed a sensor for the systems which reduce the accidents of cars having bumped into each other and those which turned to right/left at intersections. The typical requirements for each application are shown in Table 1 and 2.

Table 1 Requirements to avoid the accident of cars having bumped into each other.

Item	Value	Unit
Main detection target	Vehicle	—
Detection direction	Front side of vehicle	—
View angle	60	deg.
Detection distance	50	m
Relative velocity	60	km/h

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Table 2 Requirements to avoid the accident of cars turning to right/left.

Item	Value	Unit
Main detection target	Human	—
Detection direction	Front side of vehicle	—
View angle	120	deg.
Detection distance	30	m
Relative velocity	60	km/h

2.2 Specifications

For the sensor that realizes the required performances of the system reducing accidents of cars having bumped into each other and those which turned to right/left, we select a radio wave type radar in consideration of its mounting positions. The specification of the multi-mode radar which can be applicable to various applications is shown in Table 3. Since there are radars which use millimeter-wave (76 GHz band, 79 GHz band) or quasi-millimeter wave (24–29 GHz band), we decided to develop the radar with the quasi-millimeter wave ISM band (24.05–24.25 GHz)[2] from the viewpoints of cost and detection distance.

Table 3 Specification of the 24 GHz-band high resolution multi-mode radar.

Item	Value	Unit
Modulation method	Pulse	—
Frequency band	24.05–24.25	GHz
Minimum detection distance	0	m
Maximum detection distance	72	m
Horizontal angle range	120	deg.
Size	100 x 100 x 30	mm

2.3 Radar Configuration and Characteristics

The radar configuration is shown in Figure 1. The antennas, the quasi-millimeter module and the signal processing section are placed on both sides of the main board. The power supply unit is placed on the sub-board. A radome, the main board, a shielding case, the sub-board and a base plate are stacked to configure the radar. The radar has a waterproof construction because it will be mounted in the bumpers.

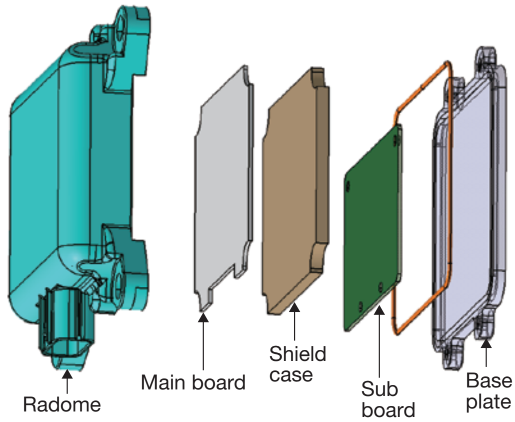

Figure 1 The radar configuration.

The shape of the developed radar is shown in Figure 2. The projected area is within 100 mm squares including the bracket fixing unit and the connector unit for the connection to the power supply/CAN (Control area network), and the thickness is 25 mm, so that it achieves the size that can be mounted easy in the limited space in the bumpers.

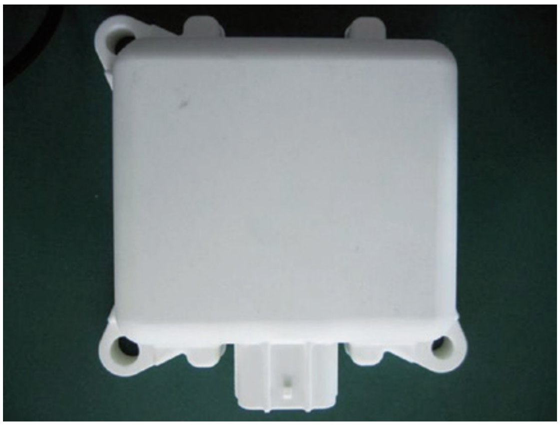

Figure 2 The shape of the radar.

The basic block diagram of the radar with a monopulse method is shown in the Figure 3. The main high frequency components consist of a local oscillator, a power divider which divides the signals from the oscillator into the transmission line and into the reception line, a switch for the transmission line, a transmission antenna, reception antennas, a selector switch for the reception antennas, a low-noise amplifier and a down converter mixer. There are also the control/signal processing unit and the power supply/communication unit. The angle measurement is done by the configuration of one antenna for the transmission and two antennas for the reception.

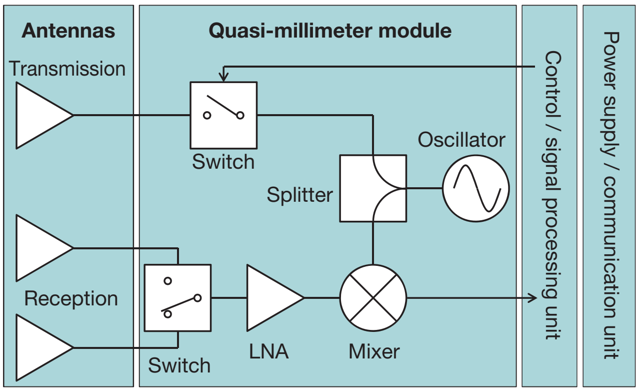

Figure 3 The block diagram of the radar.

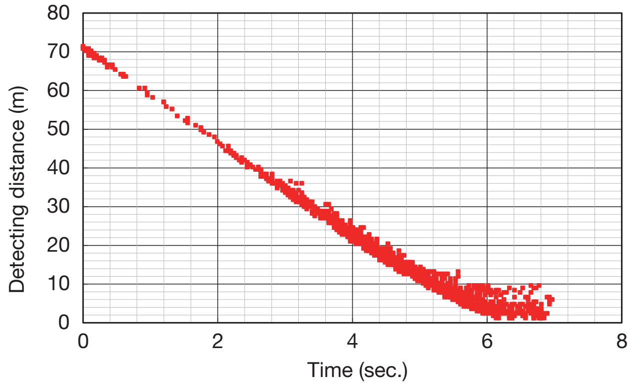

Figure 4 An automobile's detection performance.

Next, we describe its performance. In the transmission circuit, the switch in the transmission line is opened/closed by the signal which is time-adjusted in the control/signal processing unit, and the transmission pulse signal is generated. The signal which is reflected on the target is received by two reception antennas. With the selector switch of the reception antennas, the signal from either reception antenna is selectively transferred to a low-noise amplifier. After amplification at the low-noise amplifier, the RF signal is converted to the base band signal at the down converter mixer and then converted to the digital value by the analog-to-digital (A/D) converter in the control/signal processing unit. The digital signal will have a target detection decision after averaging and Fast Fourier Transform (FFT) processing. The processing after the target detection decision will be discussed in another paper.

2.4 The Basic Performance of the Radar

Figure 4 shows the detection performance which shows the event when a vehicle (sedan) is approaching to the radar with respect to its detecting distance and its time. It is found that the radar starts detecting a vehicle approaching from far at the distance of 72 m (time 0 sec.) and keeps detecting until the distance of 0 m (time 6 sec.). In the immediate vicinity of the radar, the target is detected at several distances at same time. This is because that there are multiple reflection points on the vehicle. This data has no signal processing after target detection decisions, so that the improvements in the target number of identifications and in the positional accuracy will be possible by the signal processing of the application. From this data, the radar has the detection performance of 50 m or more toward a vehicle, and it can be confirmed that the radar meets the requirements shown in Table 1 to avoid the accident of cars having bumped into each other and a maximum detection distance shown in Table 3.

Next, a pedestrian (adult male) detection performance is shown in Figure 5. This figure shows the measurement results of the event where a pedestrian gets away and then comes close in front of the radar, with respect to its detecting distance and its time. It is found that the radar is detecting a pedestrian who starts to walk from the immediate vicinity of the radar (2 m) and keeps detecting until the distance of 38 m(time 24 sec.). From the above, it can be confirmed that the radar has a detection distance of 30 m or more toward a pedestrian and meets the requirements shown in Table 2 to avoid the accident of cars turning to right/left.

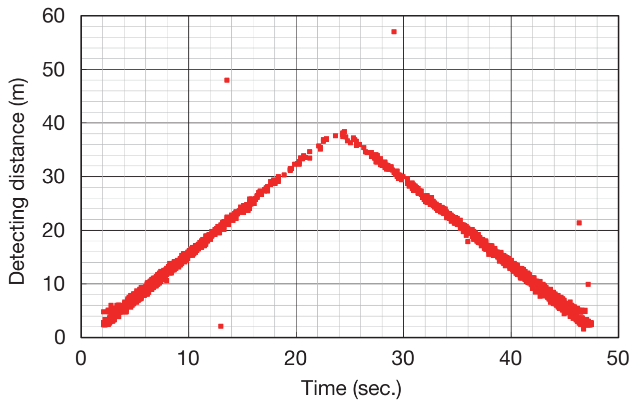

Figure 5 A pedestrian's detection performance.

Next, the accuracy of the detected angle performance of the radar is shown in Figure 6. If the angle is detected in the range from the center of the radar to 120 deg., an accuracy within ±1 deg. is achieved over the whole angle range, and it can be confirmed that the radar meets the requirements shown in Table 2 to avoid the accident of cars turning to right/left and the horizontal angle range shown in Table 3.

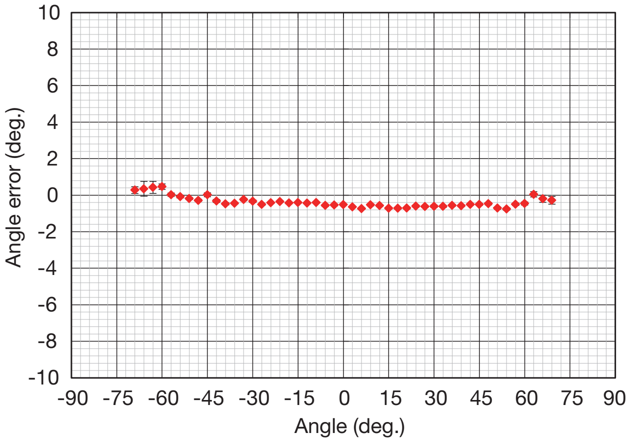

Figure 6　Accuracy of the detected angle performance.

3. CONSIDERATION OF VEHICLE MOUNTING

3.1 Analysis by the Electromagnetic Simulation

To reduce the degradation of the detection performances and the risk of the false alarm of the radar under practical operating condition, the understanding and the designing of not only the characteristics of the radar itself but also the ones under the condition that the radar mounted in bumpers is required. Although the quasi-millimeter wave band is less influenced by the bumpers than the millimeter wave band, the influences in the characteristics of the mounting on the vehicles are noticeable comparing to the characteristic of the radar itself.

With respect to the vehicle mounting consideration, the radiation direction of the radio wave, for example the electromagnetic field analysis with bumpers or emblems mounted, is well-known. On the other hand, it is getting obvious that structures out of the main radiation direction may have contribution to the analysis.

3.2 Influences of Bumpers and Vehicles

Figure 7 shows the pattern of the electromagnetic analysis in the model where the bumper or structures of the vehicle around the radar are simplified as a flat plate.

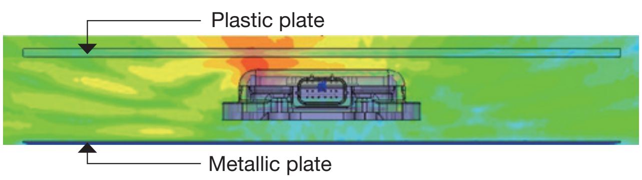

Figure 7　EM simulation model.

Figure 7 shows the electric field distribution when the radio wave emits from the transmission antenna, while installing a plastic plate as a simulation of a bumper in the front side of the radar and a metallic plate as a simulation of a vehicle in the rear side of the radar. In this result, the electric field distribution can be seen not only between the front side of the radar and the plastic plate but also between the plastic plate and the metallic plate.

In Figure 8, the emission patterns of the transmission/reception antennas are shown when comparing:

a. the radar itself
b. the plastic plate and the radar, and
c. the plastic plate, the radar and metallic plate (correspond to Figure 7).

The existence of the vehicle structure behind of the radar contributes to the characteristics, and it is found that the structure out of the radiation direction has an influence to the main direction of the radiation.

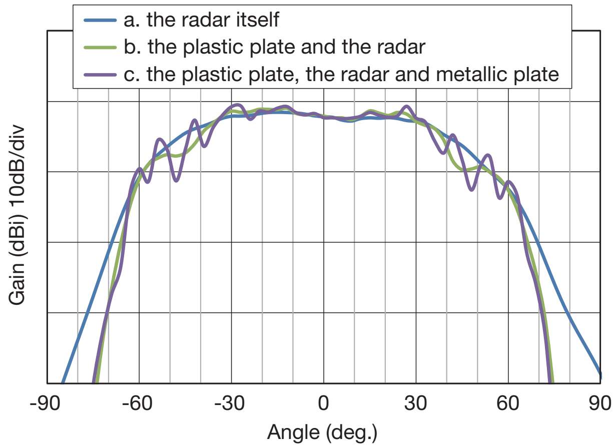

Figure 8　Radiation patterns.

Figure 9 shows the calculated results of the gains in the directions of 45deg. and 60deg. from the radar front, when the gap between the plastic plate in the front and the radar of Figure 7 is changed.

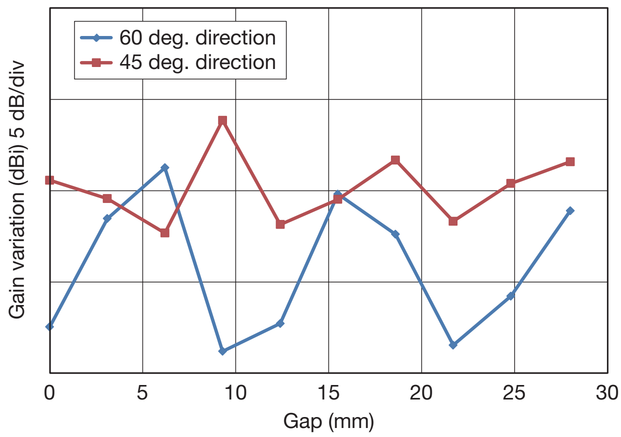

Figure 9　Change of the radiation pattern by the gap to a bumper.

From the results so far, it is found that the position of the radar greatly contributes to the characteristics when the radar is mounted on a vehicle. The actual bumper configuration has a curved surface and there are many structures of the vehicle around the radar. Therefore the appropriate mounting condition can be easily found out by downsizing and increasing the flexibility of the installation of the radar. Especially for the wide-coverage radar which is discussed in here, it is necessary to give a good-consideration with respect to the influence of the vehicle structure and the mounting position and to design so as to reduce the influence of the mounting on the vehicle.

4. CONCLUSION

We have developed a high-resolution multi-mode radar which is compact as fitting inside of the bumpers and has a wide-coverage. This radar is considered for the applications of monitoring front side and rear side of the vehicle. We will pursue improving the performances of the radar itself to improve safety furthermore and contribute to the decreasing of fatalities from traffic accidents, and pursue a size reduction and a cost reduction for expansion into applicable types of vehicles.

REFERENCES

1) "The Conditions of Occurrence of Traffic Accidents in Japan in the Fiscal Year 2012", The Metropolitan Police Department
2) "Sensors for Detecting or Measuring Mobile Objects for Specified Low Power Radio Station", ARIB-STD-T73