Development of a 24 GHz Band Peripheral Monitoring Radar

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ABSTRACT In recent years, the safety technology of automobiles has evolved into the collision avoidance and the mitigation measures to prevent the occurrence of accidents. Among them, an Advanced Driver Assistance System (ADAS) that secures safety by utilizing various sensors is expected to lead the future automated driving. In this ADAS, the peripheral monitoring radar is required to detect the obstacles behind the vehicle and the blind spots in the night time and in the bad weather. In this paper, we introduce the outlines of the “24 GHz band peripheral monitoring radar”, which full scale mass production was realized in Japan for the first time.

1. INTRODUCTION

Currently, ADAS is widely recognized in the worldwide society, especially the “peripheral monitoring radar” which searches for the dead angle detection in the lane change, the object information around the vehicle, etc. has been rapidly spreading. Figure 1 shows the main applications of the peripheral monitoring. Although only one application is described in each beam, the beam arrangement of the same function is assumed for each direction of front, rear, left, and right.

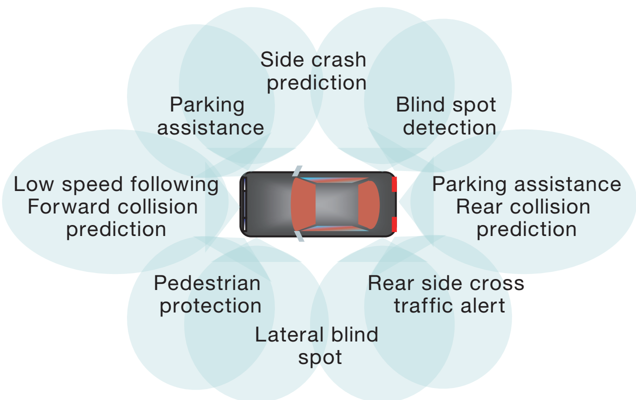

Figure 1 Main applications of the peripheral monitoring radar.

The radar (RAdio Detection And Ranging) is a device that detects the existence of the object, the distance, the relative speed, the angle, etc. from the propagation time by sending a radio wave and receiving a reflected wave from the object.

A camera, a lidar, an ultrasonic wave, etc. besides a radar, have been put into practical use in the peripheral monitoring system. Table 1 shows the comparison of these sensors. The radar is in conformity with the requirements as the peripheral monitoring sensor such as wide coverage, weather resistance, night time correspondence, speed detection, etc. It is agreed that the radar is the most compatible.

Table 1 Comparison of the peripheral monitoring sensors.

system	Radar	Lidar	Ultrasonic	Camera
Relative speed direct detection	○	×	×	×
Weather resistance (fog, rain)	○	△	×	△
Night time (darkness) correspondence	○	○	○	△

○: Suitable △: Possible ×: Impossible

2. OUTLINES OF THE AUTOMOTIVE RADAR

2.1 Legislation Trend

Table 2 shows the legislation trend of the automotive radar band. As far as the band that is available for the vehicle radar, two frequencies bands in the quasi-millimeter wave band (24.05 to 24.25 GHz, 24 GHz band) and the millimeter wave band (76 to 81 GHz) are common. In particular, the quasi-millimeter wave band has already been legislated in many areas of the world and it has been widely adopted mainly for the backward applications. From the ease of installation, the environmental robustness, the compliance to the legislation, the utilization of the quasi-millimeter wave is expected in the future also. In addition, the development of the 79 GHz band is being promoted to further expand the use of the radar

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such as in the automated driving. It is expected that this wave band will be used as a band for the future peripheral monitoring radars around the world in the future.

Table 2 Legislation trend of the Radio frequency allocation for the automotive radar.

Country/region		Operation Frequency		
		Quasi-millimeter wave band	Millimeter wave band	
		24 GHz band	76 GHz band	79 GHz band
		24.05-24.25 GHz	76-77 GHz	77-81 GHz
Operation bandwidth	Europe	200 MHz	1 GHz	4 GHz
	USA	100 MHz or 200 MHz	1 GHz	Regulation in progress
	Japan	200 GHz	1 GHz	4 GHz
	China	250 MHz	1 GHz	–

2.2. Comparison of the Characteristics for Each Radio Frequency Band

Table 3 shows the characteristics for each frequency band. In general, in the quasi-millimeter wave band (24 GHz band), the attenuation due to the rainfall, the transmission loss of the bumper painting including the surface deposit near the radar mounting and the spatial propagation loss are small in comparison to the millimeter wave band (78-81 GHz). Therefore, the robust sensing is possible. On the other hand, since the allocated bandwidth is as narrow as 200 MHz, the radar mutual interference and the distance resolution are inferior. For the peripheral monitoring radar, it is mainly used in the 24 GHz band and the 79 GHz band and it is considered that the band will be appropriately selected according to the required timing, the cost, the performance and the regional restriction.

Table 3 Performance comparison of the automotive radar for each frequency band.

		Quasi-millimeter wave band	Millimeter wave band	
Frequency		24.05-24.25 GHz	76-77 GHz	77-81 GHz
Main applications		Peripheral monitoring	Forward sensing automatic brake	Peripheral monitoring
Rain attenuation coefficient γ (dB/km)[1]	Strong rain 10 mm/h	1.42	5.65	
	Weak rain 3 mm/h	0.40	2.23	
Bumper permeability[2] (triple coating, 2 ways)		About 1 dB	About 7 dB	

3. DEVELOPMENT OF THE PERIPHERAL MONITORING RADAR

In developing the peripheral monitoring radars, we have selected the 24 GHz band and promoted its development from the advantages of the environmental resistance, the installation, etc. Figure 2 shows the outlines of the main systems. “Fast-Chirp Modulation” (FCM) system is based on “Frequency Modulated Continuous Wave” (FMCW) system and it continuously sends the signal to be transmitted while sweeping at high speed in the units of several to several tens of microseconds and the measurements of the distance, the speed and the angle are carried out by analyzing the difference in frequency with the reflected wave. On the other hand, the “pulse system” is the one that sends radio waves intermittently, purely measures the round trip time of the pulses for the distance and measures the speed and the angle from the frequency analysis. Conventionally, FCM and FMCW are common for the automotive radars, but this product emphasizes the object detection performance and adopted a “pulse system”.

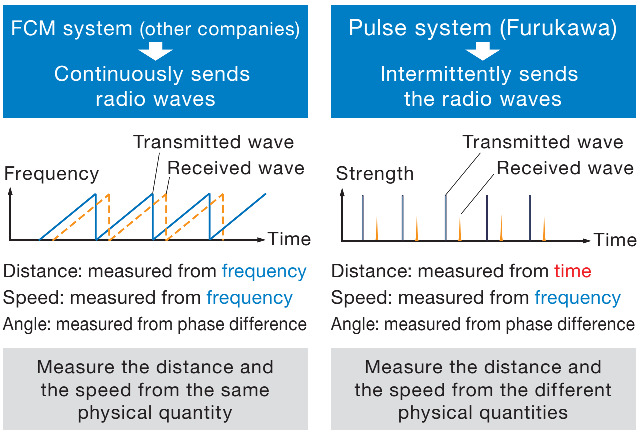

Figure 2 Outlines of the radar system.

This radar realizes the high resolution signal processing compared to the ordinary narrowband radar by means of the signal processing and the circuit technology of the ultra-wideband radar which has been developed conventionally. When a scene as shown in Figure 3 (a) is assumed, it is a concept that makes it possible to separate 2 cars behind and to detect each car reliably.

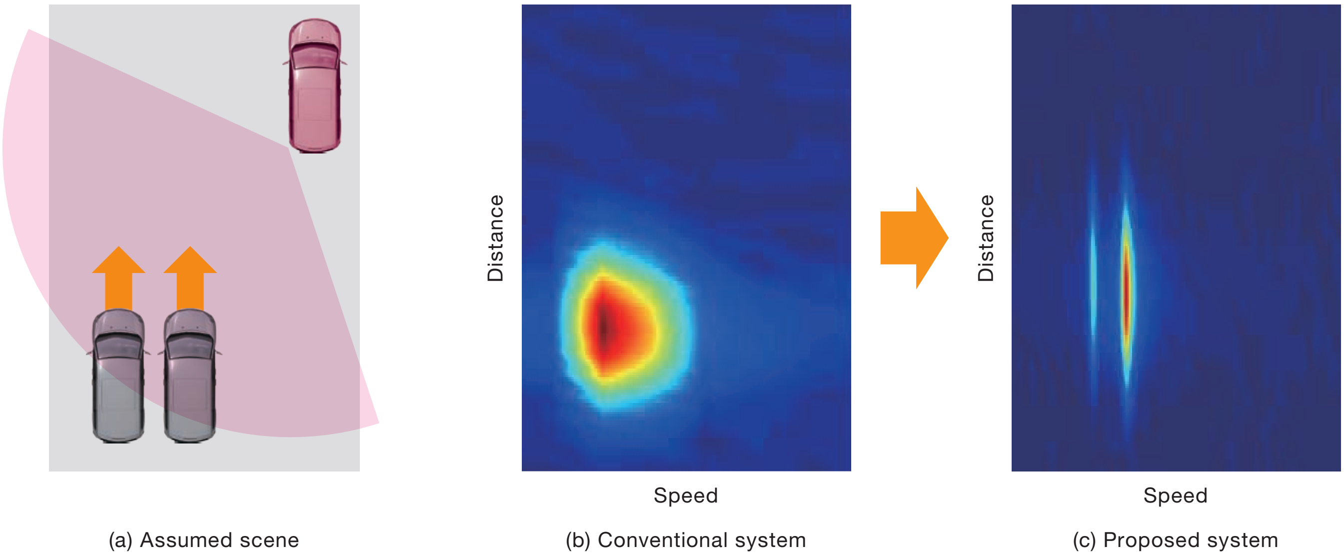

Figure 3 Concept of the high resolution signal processing.

3.1. Specifications

The picture is shown in Figure 4 and the main specifications are shown in Table 4. Considering the space in the back of the bumper, it is a thin and lightweight housing. The angle measurement system further improves the stability of the data by adopting the digital beam forming which calculates the angle from the phase information of 4 beams.

Figure 4
The picture of the automotive radar.

Table 4 Main specifications.

Item	Specification value (reference)
Detection system	Pulse Doppler with Digital Beam Forming
Operating frequency	24.05-24.25 GHz
Operating temperature range	-40℃ to +85℃
Operating voltage range	DC +9 V to +16 V
Outer dimension	W131 x D129 x H23 (mm)
External communication I/F	CAN

Figure 5 shows the configuration of the radar. The main circuit parts are composed of an antenna, a quasi-millimeter wave module, a signal processing part and a power supply part and are configured by stacking a radome, a main board, a shield case and a base plate. The radar is waterproof structure because it is installed behind the bumper.

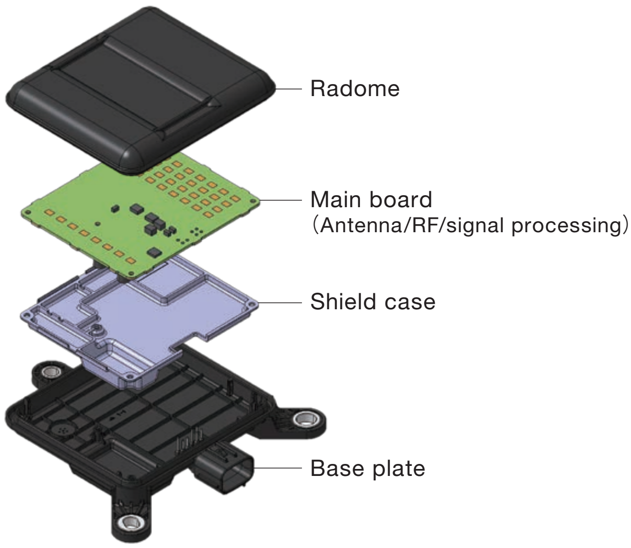

Figure 5 The configuration of the automotive radar.

Furthermore, the performance improvement has been made for this radar in order to cope with the various environments in comparison to the conventional FM type radar. This radar has the following features.

1) The separation performance
Even if a strong reflector is present, the detection performance for a plurality of objects such as a vehicle, a bicycle, a pedestrian can be improved because there is possibility to limit the situation where a weak received signal is buried at the hem of the same peak (Figure 6).

2) The robust installation
Since the detection performance can be adjusted for each distance, it is less susceptible to the influence of the strong reflector in the vicinity and is excellent in installation. In the vehicle bumper, there are many reflecting objects. In the conventional FCM system, when the balance of the mounting is broken due to the bumper deformation, etc., the continuous wave satu-

rates the analog/digital converting unit and the detection becomes unstable. However, in the pulse system, the influence is limited and the overall detection is stable (Figure 7).

3) The detection in the ultra-vicinity

In the FCM system, it is necessary to suppress the large reflection (wraparound) around 0 m and avoid the saturation of the receiving circuit. For this reason, a high pass filter is connected immediately before the analog/digital converter. In principle, a dead band generates around 0 m due to this side effect [3], but in the pulse system, since the detection processing can be performed for each distance, it is possible to detect the object in the ultra-vicinity by adjusting the sensitivity in the ultra-vicinity independently from the far distance detection performance (Figure 8).

In order to confirm these features, an example of measurement in the urban area using a pulse type radar (one each on the right and left, inclined at ± 45 degrees) mounted on the front side of the vehicle is shown in Figure 9. It can be shown that the pedestrians can be detected without being buried in the strong reflectors such as a metal shutter (right side) and a truck (front side).

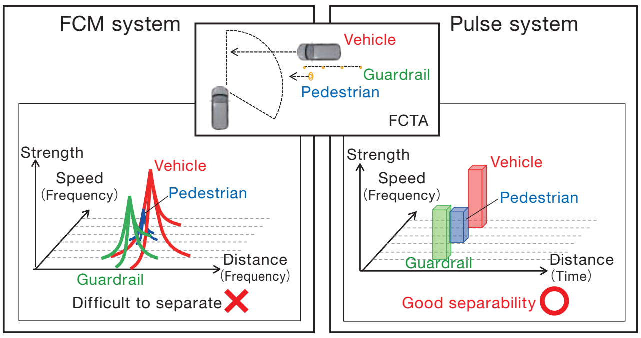

Figure 6 Comparison of the separability.

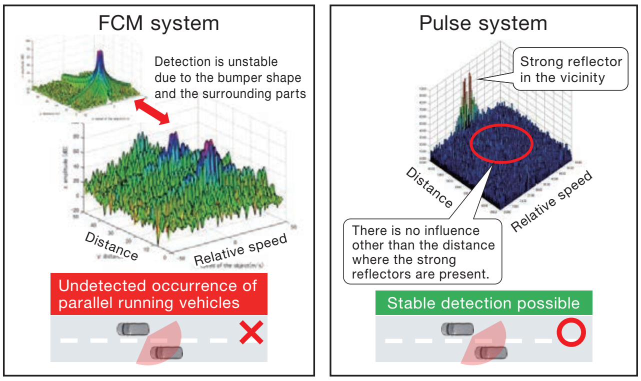

Figure 7 Comparison of the mountability.

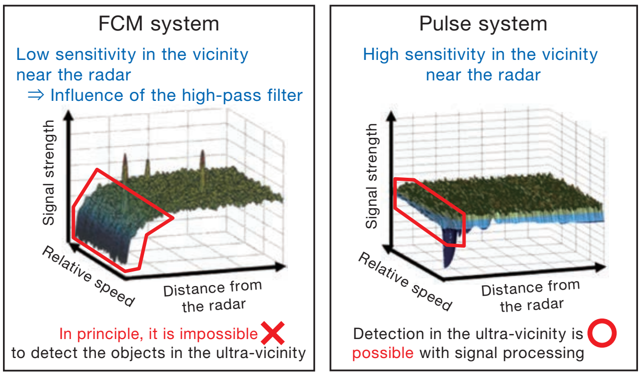

Figure 8 Detection in the ultra-vicinity.

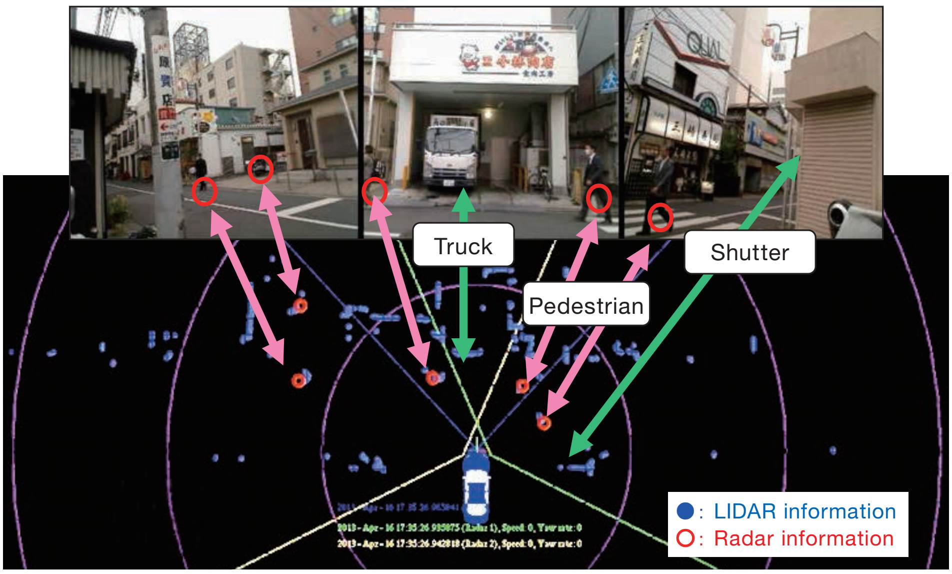

Figure 9 Example of the measurement result.

4. THE DEVELOPMENT OF THE PREVENTIVE SAFETY SYSTEM

So far, we introduced only the detection of objects up to the previous chapter, but as shown in the basic operation as in the automotive preventive safety system constituted of the radar alone of Figure 10, the function of predicting the danger judgment in this radar is incorporated and the function of notifying the degree of danger to the driver or the host vehicle system is added. Furthermore, it is possible to build a preventive safety system by connecting to the vehicle network and making it to read the vehicle speed information, the yaw rate, the gear state, the turn signal state, etc. from the controller area network (CAN). Also, in order to operate the left and right radars in cooperation, the side connected to the host network becomes the master and it is possible to make a danger judgment. The criteria for the danger judgment complies to the application specifications and as the notifying means, a circuit that drives the LED built in the door mirror from the user connector was mounted (Figure 11). Figure 12 shows the applications (LCDAS, RCTA) applied to the preventive safety system.

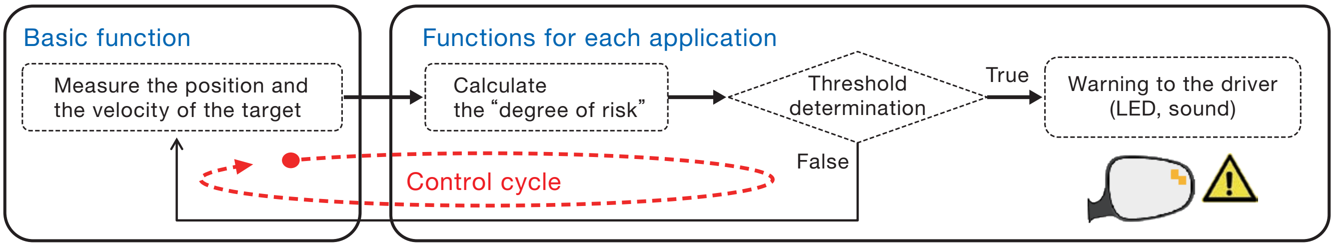

Figure 10 The basic operation as implemented in the automotive preventive safety system composed of the radar alone.

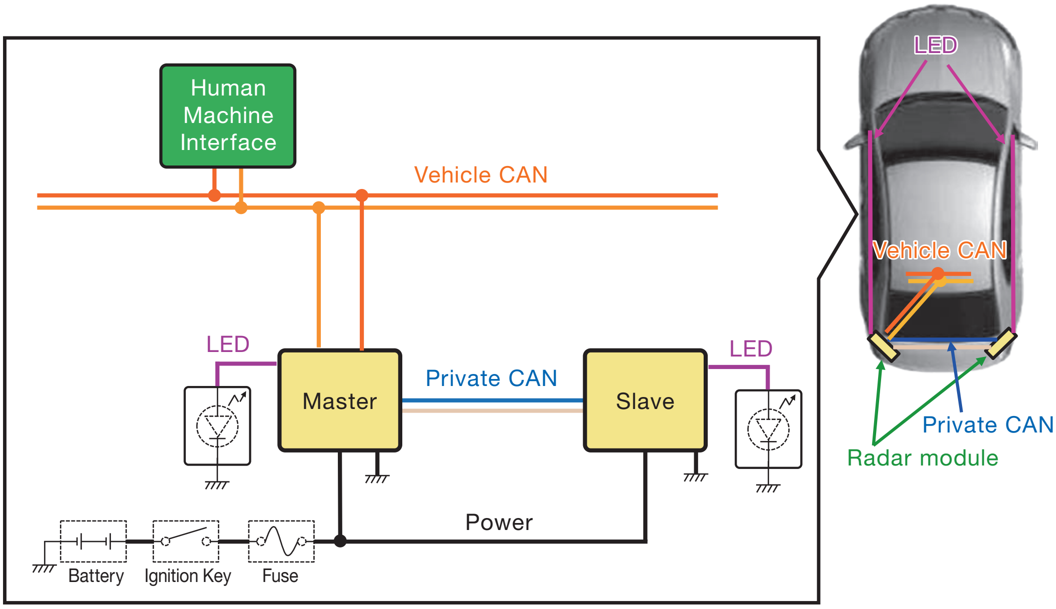

Figure 11 The configuration of the vehicle system.

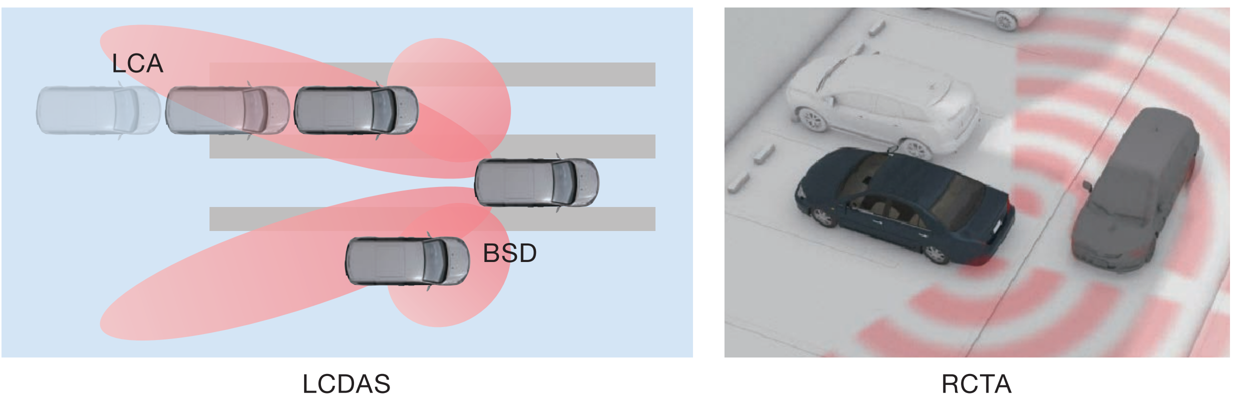

Figure 12 Applicable applications.

Vehicle status information	Gear state	Reverse			Forward	
	Vehicle speed	High speed	Low speed	Stopping	Low spee	High speed
Application state		Standby state	RCTA		Standby state	LCDAS (BSD/LCA)
		The radar detects the vehicle status and changes the mode				

Figure 13 The linkage between the application and the vehicle status.

Lane Change Decision Aid System (LCDAS)[3] is a function to support the safe lane change, which alerts the driver by detecting the existence of another vehicle diagonally behind. LCDAS Type III is the one that equips both Blind Spot Detection (LCDAS Type I) which detects other vehicles entering the blind spots around the vehicle (right and left adjacent lanes and a range of about 10 m behind) and Cruising Vehicle Warning (LCDAS Type II, also called Lane Change Assist (LCA)) which detects another vehicle that rapidly approaches the adjacent lane in addition to the blind spots.

Rear Cross Traffic Alert (RCTA) is an application that detects a vehicle or a pedestrian existing in a blind spot and prevents the serious accidents such as injuries in the accident when taking a car from the parking lot in reverse.

Although these applications need to be switched, as described above, using the vehicle information (vehicle speed, turn signal ON/OFF, gear) obtained by connecting to the body CAN of the vehicle, the radar is configured to select the operation mode automatically (Figure 13).

5. CONCLUSION

In this paper, we introduced the positioning of the peripheral monitoring radar and the characteristics of the frequency band. Also, we introduced the outlines of the “24 GHz band peripheral monitoring radar” that makes it possible to detect the obstacles behind the vehicle and the blind spots even in the night time or in the bad weather and realized the full-scale mass production for the first time in Japan. In the future, in order to cope with the next-generation ADAS and the automated driving, we will promote the radar high reliability and the expansion of its functions.

REFERENCES

1) Takada, “Basic theory of radio wave propagation” MWE, 2005. [On line]. Available: http://www.apmc-mwe.org/mwe2005/src/TL/TL05-01.pdf
2) R. Lachner, “Development Status of Next Generation Automotive Radar in EU,” ITS Forum, 2009. [ON line]. Available: http://www.itsforum.gr.jp/Public/J3Schedule/P22/lachner090226.pdf
3) M. Fujimoto, “76/79 GHz band millimeter wave radar system solution for realizing Advanced Driver Assistance System (ADAS),” [On line]. Available: http://cache.freescale.com/ja/files/FTFAUT-F0736.pdf
4) ISO, “ISO17387 :Intelligent transport systems - Lane change decision aid systems (LCDAS) - Performance requirements and test procedures,” 2008.