NOTE

Development of 76GHz Millimeter-Wave Radar for Rear Short Range

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Abstract

The system applying millimeter-wave radar is now widely used for monitoring rear direction and the periphery as well as front direction. In June 2006, we developed the radar for PCS (Pre-crash safety system), which aims at protecting passengers from neck injuries, the most frequent type of injury in traffic accidents. This radar, our first product with monopulse system, has characteristics of compact, wide-angle detection, and high-speed processing. This paper describes three-channel monopulse principle that we applied, and our challenges.

1 Introduction

The millimeter-wave radar, first used on systems for convenience such as ACC (Adaptive Cruise Control)*(1), is now widely used on systems for safety such as the PCS (Pre-Crash Safety) system*(2). In 2006, TOYOTA marketed the world's first rear PCS system on LS460 (refer to Fig.1).

FUJITSU TEN has marketed these radars for ACC system and front PCS system since 2003, and provided the rear millimeter-wave radar (Fig.2) for rear PCS system installed on LS460 described above.

This paper introduces this rear radar.

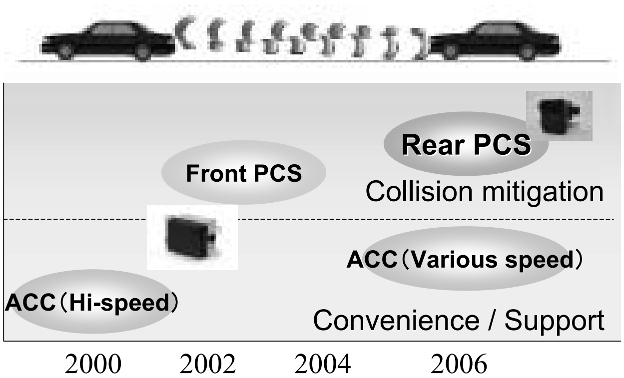


Fig.1 History of Systems Applying Millimeter-Wave Radar

Fig.2 Rear Millimeter-Wave Radar

2 Development of PCS

The PCS system was commercialized as a front PCS system responding to frontal collisions with a focus on fatalities. Meanwhile, with a focus on injuries, it is rear-end collisions that happen most often, and thus, the most injuries are on the cervical part caused by collisions from behind (Fig.3-1, Fig.3-2).

With this result, we assured that our target application should be the rear PCS system for the next step of the safety system, and started developing the radar for this system.

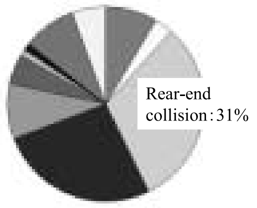


Fig.3-1 Proportion of Traffic Accidents by Type

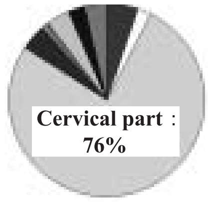


Fig.3-2 Proportion of Casualties (on Board) by Main Injured Part

3 Rear PCS System and Requirements on Radar

The rear PCS system has functions as to

(1) detect by radar any vehicles approaching with danger of crashing from behind,

(2) warn with flashing hazard lights,

(3) reduce the risk of neck injuries by moving the headrests to an optimum position, in an unavoidable accident.

This system requires the following performance by the radars.

①Wide-area detectability for detecting any vehicles approaching from behind.

②High-speed response for moving headrest with appropriate timing.

③Compactness to enable installation in the restricted area such as in a bumper

Fig.4 Image of Rear PCS(2)

4 Main Specifications for Radar

Here are the main specifications for radar we developed in Table 1, satisfying the requirements described above.

∗(1) Adaptive Cruise Control (ACC):
Refers to the system controlling acceleration or deceleration of vehicles so as to maintain a fixed range from the preceding vehicle using radar. When no preceding vehicle, it works as normal cruise control system on speed control (keeping the speed set by a driver).

∗(2) Pre-Crash Safety system:
A type of safeguard system.
This system predicts potential hazards using a radar and other devices in advance, and controls collision mitigation (breaking assist, etc.), passenger protection (retracting seatbelt, etc.), functioning in advance of passenger protection system after the collisions, such as airbag system.

Table 1 Main Specifications

Item		Specifications
Frequency band		76GHz
Range measurement		FM-CW system
Angle measurement		Monopulse system
Detection performance	Range	2 to 45m
	Angle	View angle 30 °
	Relative velocity	0 to 100km/h
Size		87×67×46mm

5 Radar System

This radar requires instant detectability in wide-angle area as described in Section 3, and compactness. So, we have adopted phase monopulse system as the angle measurement system for the first time. In this system, with setting two antennas, arriving wave direction is obtained by the phase difference between signals received at the two antennas. This system, covering wide area at a time, enables the antenna size to be compact, and requires less processing-load with less numbers of antennas.

Here is the principle of this system in Fig.5.

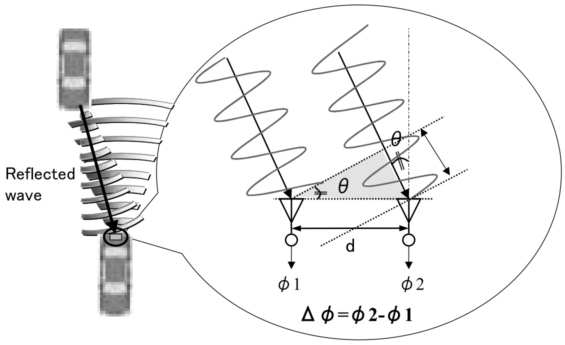


Fig.5 Principle of Monopulse System

The phase difference φ is obtained by arrival angle: θ, antenna intervals: d, carrier wavelength: λ in the following formula.

$$\Delta\phi = 2\pi * (d * \sin\theta / \lambda)$$

Fig.6 shows this relation. In this occasion, to eliminate repeated phases, the antenna intervals d must be λ/2 or less.

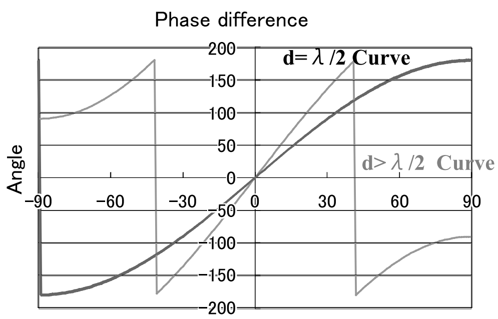


Fig.6 Angle vs. Phase Difference

The spatial wavelength λ is 4mm for 76GHz band. While, as the elements used in planar array antenna of the conventional system are in the size of approx. 2mm square, it is difficult to make the antenna intervals into λ/2.

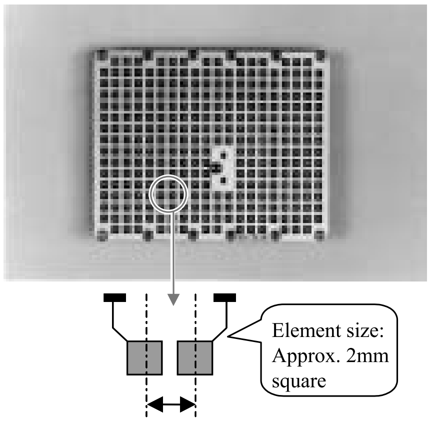


Fig.7 Image of Planar Array Antenna

To solve this problem of the antenna arrangement restriction, we made a 3ch structure using three antennas. Fig.8 shows this concept. When three antennas detect respective phase differences (● mark in Fig.8), the angles detected at respective antennas are in variety (▲ mark in Fig.8). In this case, we solved the problem of repeated phase by regarding the angle where those three angles match as a real angle.

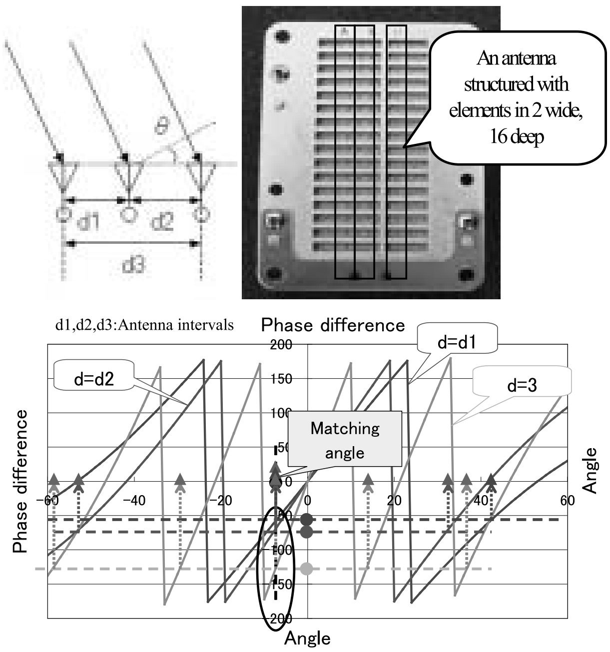


Fig.8 Relation of 3ch Monopulse Antenna and "Angle vs. Phase Difference"

For detecting range and velocity, we adopted conventional FM-CW(Frequency Modulation Continuous Wave)system, capable of measuring the both information at a time. Fig.9 shows the principle.

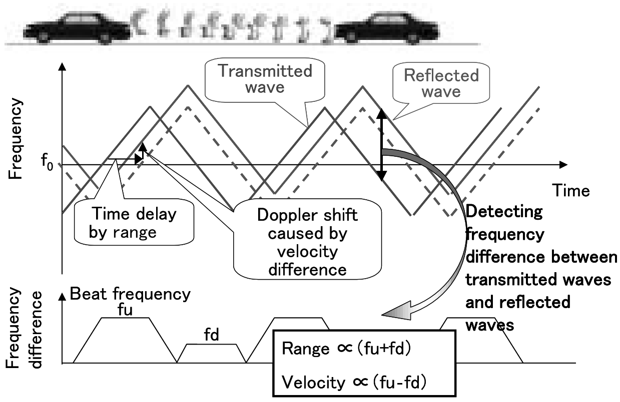


Fig.9 Principle of FM-CW Radar

In this system, the radio wave transmitted by radar is modulated with setting the frequency f0 as a center frequency using triangular waves. As the frequencies of signals that have hit the target and received contain information of time delay by range and Doppler shift components by velocity difference, it is possible to obtain the range and velocity of the target, using the difference between the transmitted waves and the reflected waves.

Where setting the frequency on the ascending slope of the triangular waveform: fu, the frequency on the descending slope of the triangular waveform: fd, range frequency: fr, and velocity frequency: fv, these relations are as follows:

$fu=fr-fv$

$fd=fr+fv$

*) The velocity in upcoming direction is assumed to be positive.

Where setting modulation frequency: FM, modulation width with a central frequency (f0): Δf, velocity of light: c, range: R, and relative velocity: V, these relations are as follows:

$fr=((4 * \Delta f * FM)/c) * R$

$fv=(2 * f0/c) * V.$

So, the range and velocity can be obtained using these four formulas.

6 Radar Structure

Fig.10 shows this radar structure. We developed the new antenna and DP3T-SW (Swtich with two to three system) MMIC to realize the monopulse system, and for other devices, adopted the existing technology, which was developed for the front radar.

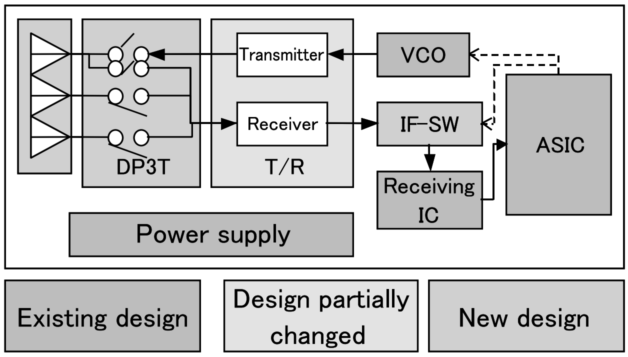


Fig.10 Configuration Diagram

7 Signal Processing Part

To realize the 3ch monopulse system, the signals were measured in the following manner: with switching three antennas within three FM (triangular wave) cycles at a timing of each FM cycle, assigning two signals to the two channels respectively, as the signal control timing shown in Fig.11. To explain more details, the process is as follows:

- Assigning signals of the two antennas to the two channels, receiving 1 and 2
- Switching antennas by time series and respectively
- Identifying the range and velocity of the target by processing ADC (AD converter) and FFT (fast Fourier transformation) during both of the ascending slope and the descending slope of the triangular wave, respectively
- Identifying the angle of the target by comparing the phase difference of signals from one target, naturally with the same range and same velocity, received at receiving 1 and 2.

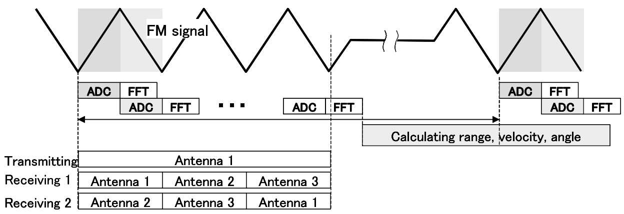


Fig.11 Control Timing

We succeeded in making the processing time in 20ms, with shortening the time for complicated calculation, by synchronizing the control of triangular waves and ADC / FFT processes inside the ASIC as hardware processing.

In these processes, DC level variation generated at the time of switching respective antennas becomes problematic.

As the DC levels between antennas (channels) differ by FM cycle, low frequency (DC) noises are generated whenever switching. As a short-range target tends to be hardly detected with these noises, rejecting these DC noises becomes a task.

We solved this problem by processing cancellation; setting the signal at no-targeted condition (stopping transmission) as a reference, and then deducting the reference values from respective FFT results.

Fig.12 shows the FFT results before and after the cancellation.

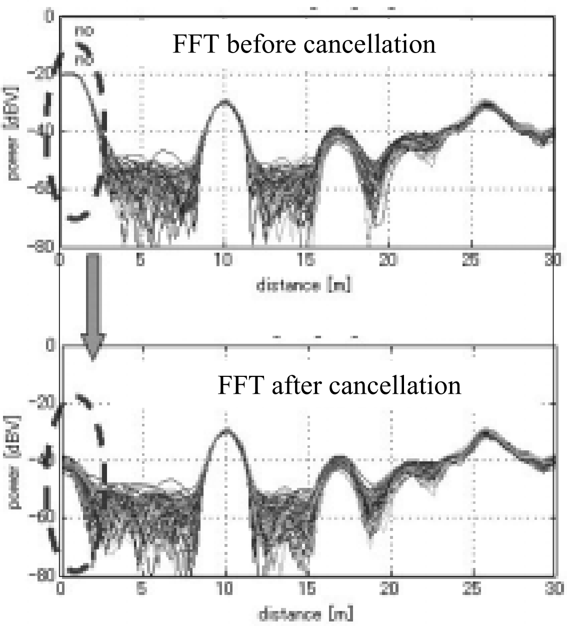


Fig.12 Results of Processing Cancellation

As this figure shows, the DC noise components are eliminated and the noises in short range are lowered.

9 Detected Results by Radar

Here is the detected state (video screen tested by actual vehicle) by this newly developed radar in Fig.13. On the right side of the screen, it shows the vehicle positions detected by the radar in bird-eye view and with range, velocity, and vertical position by target, corresponding to the targets framed in each composite box on the rear view. On this screen, respective vehicles approaching from behind and on the adjacent lanes are detected in their correct positions.

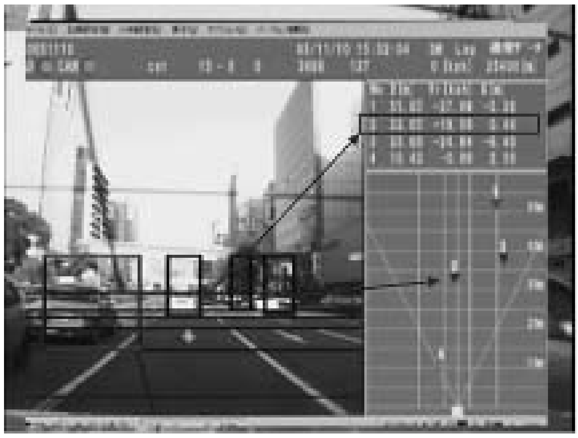


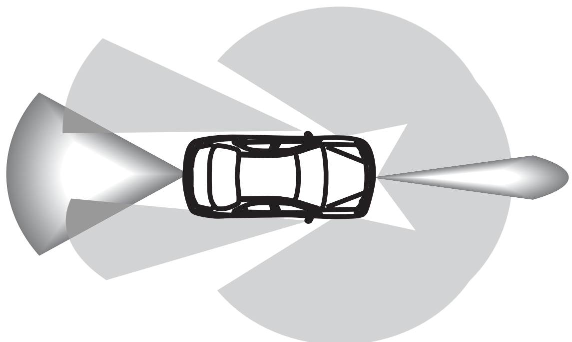
Fig.13 Detected State

Composite display part	Framed in red : Static target	
	Framed in blue : Moving target	
Bird-eye view	Red : Static target	
	Blue : Moving target	
	▼ : Negative relative velocity (Approaching)	
	■ : Zero relative velocity	

10 Conclusion

The future application of radars seems to be developed for all direction detection.

We, FUJITSU TEN, are willing to make a further contribution towards a safer society with no casualties and no accidents by providing radar devices developed for these systems.



Reference:

(1) Institute for Traffic Accident Research and Data Analysis
According to traffic statistics of 2004 fiscal year

(2) Rear pre-crash safety system described on TOYOTA Website (http://lexus.jp/models/ls/facts/thought.html)
TOYOTA Technical Review Vol.45 No.1

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