Front-Side- Looking Millimeter Wave Radar for Front-Side-Pre-Crash Safety System

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Abstract

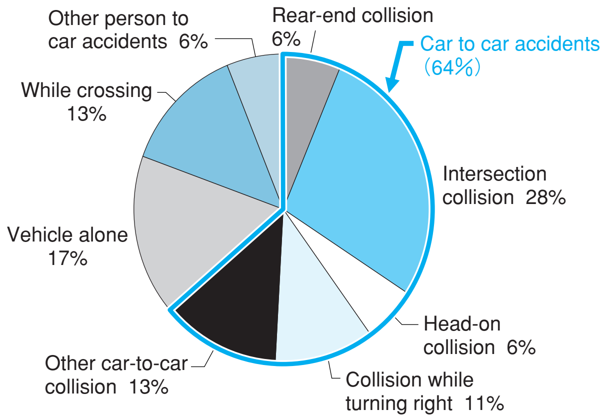
Fujitsu Ten has developed millimeter wave radars for various collision judgment systems for reducing traffic accidents by using radar mounted in the front or the rear.

Now we developed the front-side-looking radar for the collision mitigation system for traffic accidents of intersection. This radar is designed to provide a wide field of view (FOV) by using the phase shifted mono-pulse method and it detects an oncoming target not only movement of back and forth but any direction movement. And in the principle of the phase shifted mono-pulse method, the falsely detected target "ghost" is generated by having a wide FOV without changing a hardware basic composition.

We invented phase difference ratio algorithm as a countermeasure against this ghost. We achieved in dealing with the ghost by simulating the countermeasure and verifying its effectiveness in a real environment.

1 Introduction

These years, various systems to reduce the increased number of traffic accidents with fatal and serious injuries have been developed. **Fig. 1** shows the breakdown of fatal and serious injury accidents in Japan. According to **Fig. 1**, car-to-car accidents account for 64% out of total accidents. Among them, the most common accident is an intersection accident, which accounts for 28% out of the total. For the head-on / rear-end collisions, the collision reduction systems using a front-looking radar or a rear-looking radar have already been developed. However, there was the lack of development of a pre-crash safety system for intersection accidents. Therefore, Fujitsu Ten has launched the development of a front-side-looking radar based on the commercialized rear-looking radar.



(Statistics reported by Traffic Bureau, National Police Agency)

Fig.1 Statistics of Fatal and Serious Injury Accidents in 2008

2 Requirements

Table 1 shows the comparison of required performances between the conventional rear-looking radar and the front-side-looking radar. The front-side radar is designed to detect targets of the side and front-side directions from the car in order to mitigate collisions including intersection collisions, head-on collisions caused by a car straying from its lane. Thus, the radar must detect cars at their side or front-side parts with lower reflection performances; concretely, the reflection level of the front-side radar is 10dB lower than that of the rear radar (refer to **Fig. 4**). As in **Table 1**, the front-side radar requires higher sensitivity (SNR) for wider FOV for preparing intersection collisions. Besides, the front-side radar requires as fast response as the rear radar so that it can be used for Pre Crash System (PCS).

3 Radar System and Construction

Fig. 2 shows the construction of this radar. We decided to divert the technology of phase mono-pulse system capable of high-speed angle measurement, which is used in FM-CW radar that we mass-produce, so as to develop the new radar efficiently.

We had to design radar in the following points different from the technology of rear radar.

(a) To redesign antenna for wider detection range for the preparation of an intersection collision.

(b) To develop adaptable algorithm for various movements of targets to be detected in every direction for front-side radar.

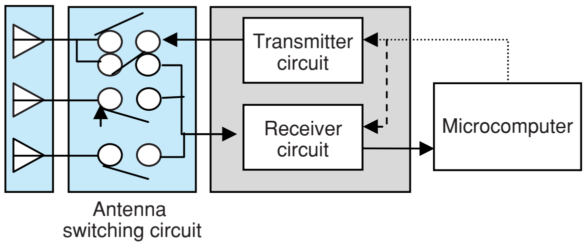


Fig.2 Construction

4 Phase Mono-Pulse Radar System

Fig. 3 shows the principle of mono-pulse angle measurement. Usually it is formed by two antennas; however the replication of phase difference occurs due to the limited intervals of antenna elements.

The replication of a phase difference is a principle phenomenon of mono-pulse system in which multiple phase differences are calculated to one direction. We adopted 3-antenna-mono-pulse system for wider angle detection, in which the reliability of angle calculation is improved as the replication of phase difference can be recognized.

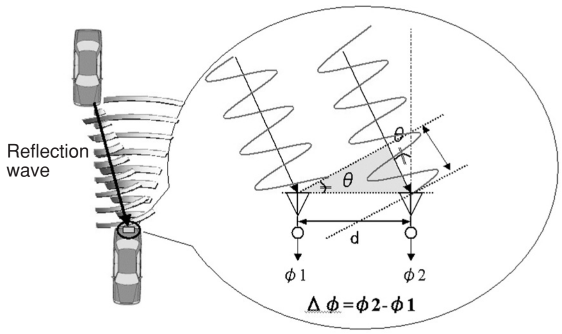


Fig.3 Radar Construction

Table 1 Comparison of Required Performance

Item	Rear-looking radar	Front-side-looking radar
Main target and its direction	Car, mainly front part	Car, omni-direction
Field of view	30°	52°
Detecting range (car)	45m	50m
Relative speed range	±100km/h	±180km/h
Installed place	In rear bumper	In both corners of front bumper

5 Problems on Algorithm and How to Deal With Them

By diverting the rear-looking radar as mentioned above, and besides by changing the processing algorithm with no change in a principle hardware construction, we succeeded in developing front-side-looking radar emitting radio waves in the front-side direction.

As a result of evaluation, the following three problems appeared.

(a) Fluctuation of detected target position depending on reflection point
(b) Detection impossible due to environments
(c) False detection of target position caused by item with high reflectivity outside detection area (Ghost)

Here are these phenomena and their countermeasures.

5.1 Fluctuation of Detected Target Position Depending on Reflection Point

Fig. 4 shows the radar cross section area of a car, representing reflection degrees by scale markings on a series of concentric circles and directions by scale markings on a series of radial lines. In the case of detecting the front or rear of a car, reflecting points are around the front surface or the rear surface constantly. However, in the case of detecting the front-side of a car, the car surface where the radar is monitoring varies as in **Fig. 5**, which means the reflection waves from the car varies in strength as a physical phenomenon. Naturally, higher-reflection points are processed preferentially, and thus the detected points vary (**Fig. 6**). This makes an incorrect calculation in the collision prediction due to the judging system using radar output results, and leads to a control error or no control in the system. So, we took a countermeasure as follows. When a moving distance that the radar detected is too far for an actual car to move, the radar judges it is an incorrect prediction and then eliminates the predicted values by implementing filtering processes. As a result, now we stably obtain the movement detection of targets, compared to the conventional process (**Fig. 7**).

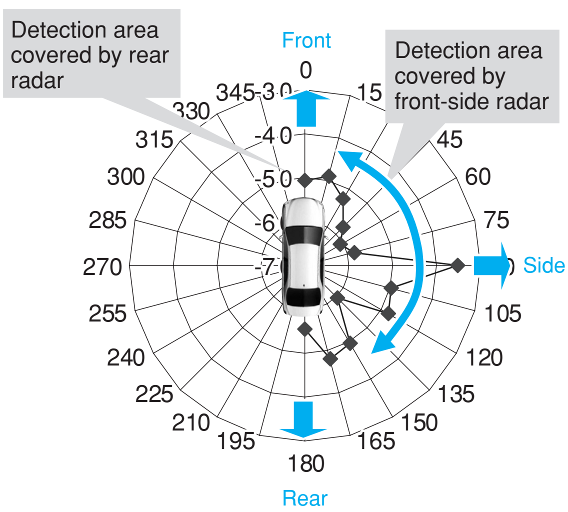


Fig.4 Radar Cross Section of Car

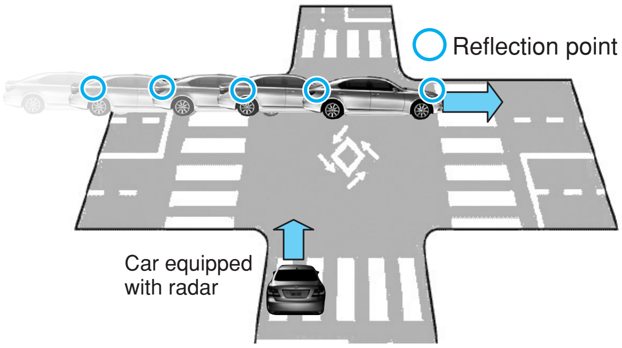


Fig.5 Movement of Reflection Point of Car

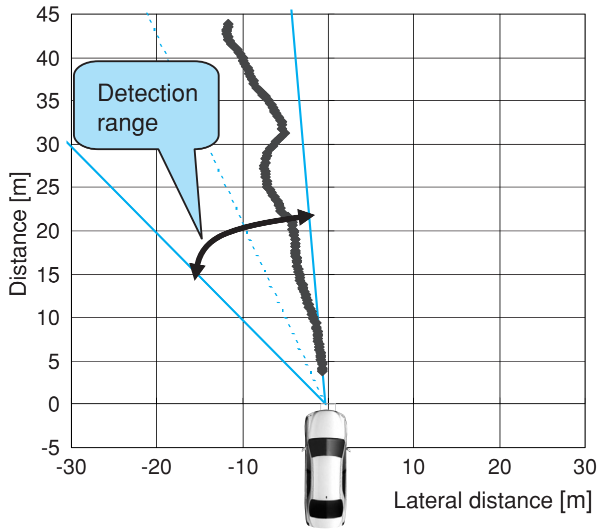


Fig.6 Target Detection for Collision at Intersection

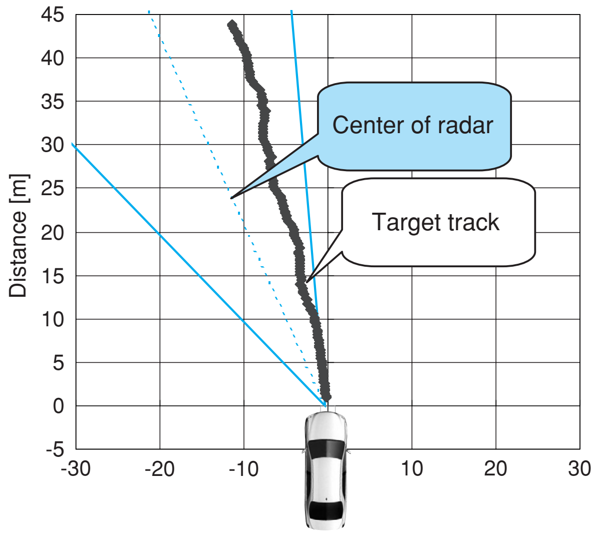


Fig.7 Improved Target Detection

5.2 Detection Impossible Due to Environments

The front-side-looking radar is susceptible to the environments detected at radar head-on due to the diagonally directed radar axis. **Fig. 8** shows the situation of an oncoming car and its FFT result.

The radiation from diagonally directed radar makes higher-reflection signals from guardrails. Thus, the signals from the oncoming car cannot be detected as those signals are mixed up with the signals from the guardrails. Besides, in principle, it is difficult to detect respective angles from a FFT result mixed up with multiple target results in phase mono-pulse system. So, in order to improve the separation capability of multiple targets, we took the methods of improving the separation capability in frequency. In the FM-CW system, the methods to improve the separation capability in frequency are as follows:

(a) To lengthen monitoring time (To increase the number of FFT points)

(b) To widen modulation width of frequency

As the method (a) above requires longer time for processing, we adopted the method (b) above of widening modulation width of frequency to solve this problem.

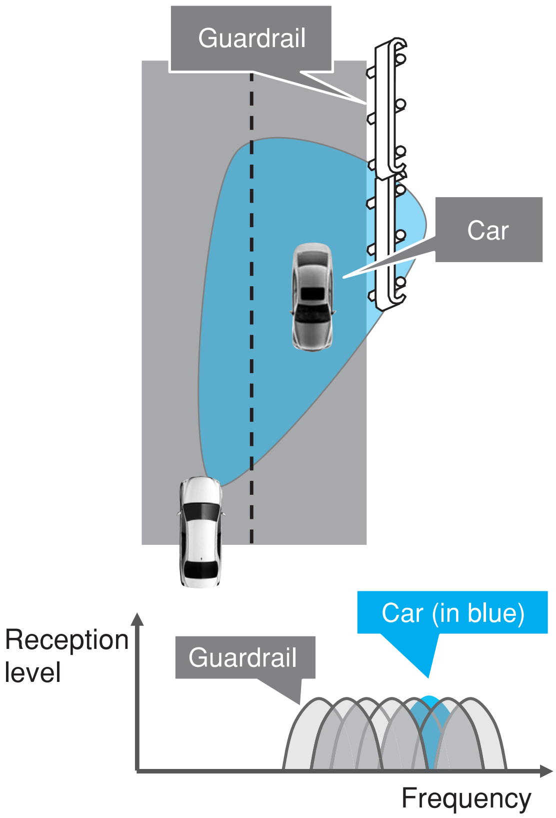


Fig.8 Situation of Oncoming Car and Its FFT Result

Fig. 9 shows the result of FFT by widening the modulation width of frequency. The interval between the two peaks of frequencies from guardrails was expanded and the desired target was detected in between.

5.3 Ghost Caused by Target Outside Detection Area

This radar uses a phase mono-pulse system for angle measurement. Here is the explanation of algorithm for angle calculation used in this phase mono-pulse system. In this algorithm, as in **Fig. 10**, the direction of a target is calculated using mapped phase differences that are calculated with the combinations of three antennas. The figure represents directions in its horizontal axis and phase differences in its vertical axis, and FM1, 2 and 3 represent the respective intervals of antennas.

(FM1: $5/4\lambda$, FM2: $11/4\lambda$, FM3: $6/4\lambda$, λ: 4mm)

As for the rear-looking radar, after calculating directions from phase differences, the matching combination of FM1 and FM3 in the monitoring range of $\pm 15^\circ$ shown as the area without hatching in **Fig. 10** is selected among three points of FM2 as the detected target.

However, the front-side-looking radar has to cover the wider range of $\pm 26^\circ$, which requires the detection range of $\pm 30^\circ$ or more as in **Fig. 11**. In this case, the replications in FM1 and FM3 are generated, and thus two targets could be output due to multiple combinations including these replications. It is difficult to distinguish the real target from the false ones, and a display shows these targets including the false targets output by the right and left radars as in **Fig. 12**.

Here is our countermeasure against the replications of phase. The relation between phase differences and angle depends on the element intervals between antennas.

$\theta = \sin^{-1}(\phi \times \lambda \div (2\pi \times d))$

[d: antenna distance, ϕ: phase difference, θ: angle, λ: wave length (approx. 4mm)]

The phase differences of respective element intervals are proportional to the element intervals. As the antenna element intervals in this case are $5/4\lambda$, $6/4\lambda$ and $11/4\lambda$, the ratio among these phase differences in principle is "5:6:11." By implementing a process using this theoretical ratio of the phase difference as a true value, the combination with a ratio closest to this 5 : 6 : 11 was judged as a real target (**Fig. 13**).

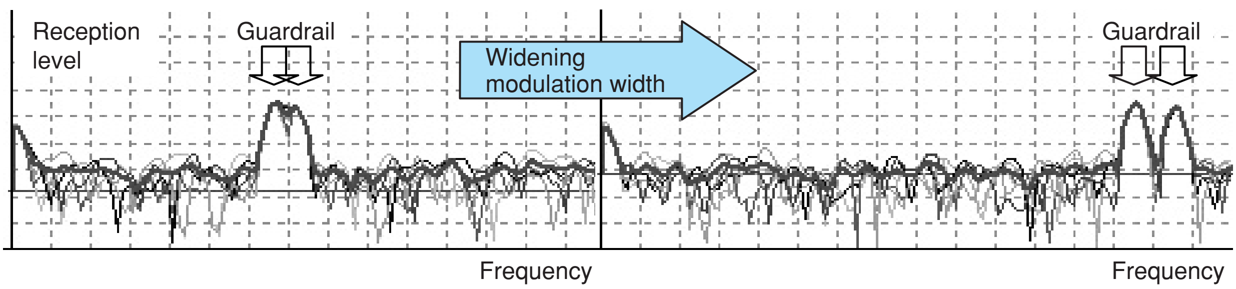


Fig.9 Detected Result of Changed Modulated Width (FFT Wave Form)

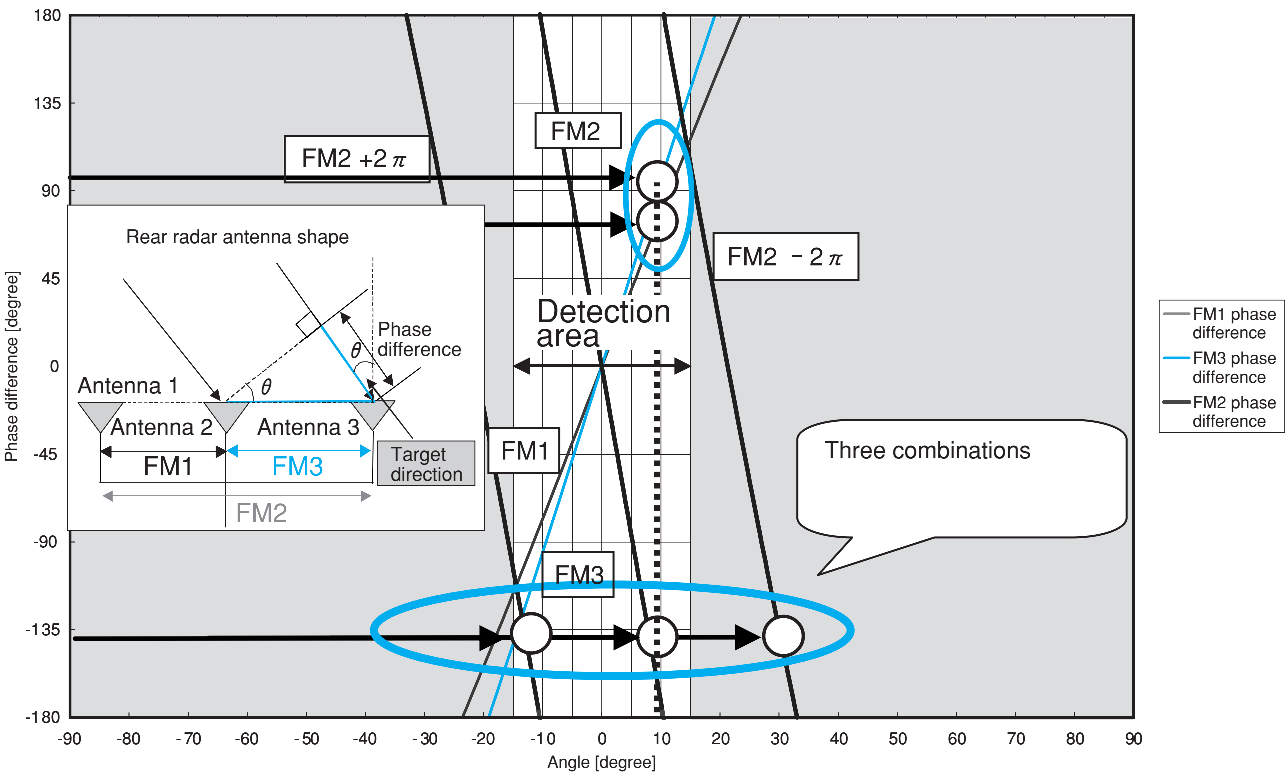


Fig.10 Phase Difference Mapping of Rear Radar (Theoretical Value)

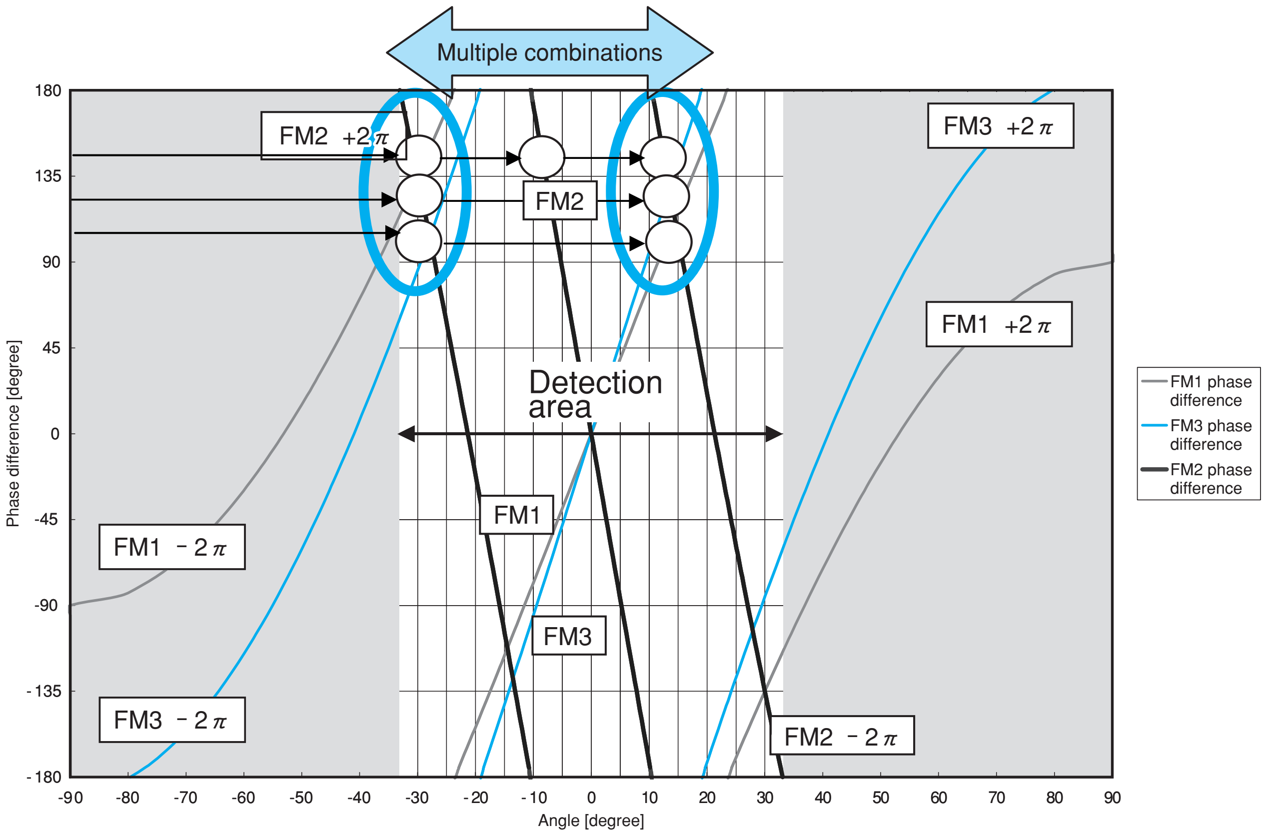


Fig.11 Phase Difference Mapping of Front-Side Radar (Theoretical Value)

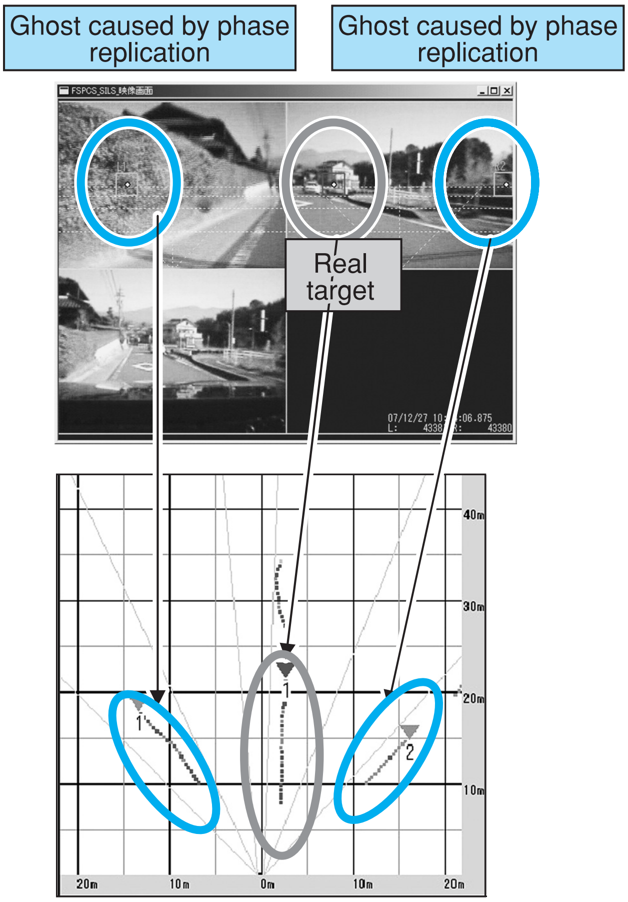


Fig.12 Ghost Caused by Replication of Phase
(Oncoming Car Shown in Yellow and Ghost Shown in Red)

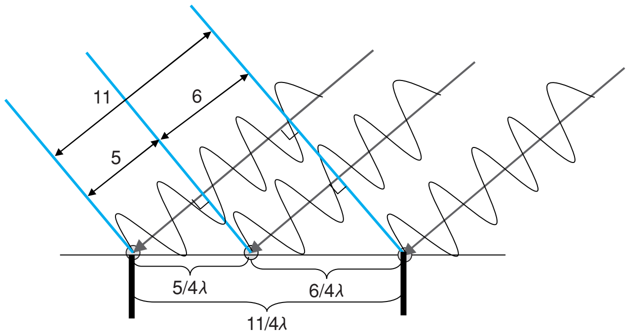


Fig.13 Explanation of Ratio Relating to Path Intervals of Millimeter Wave

In principle, the process of ghost judgment using the ratio of phase differences to the phenomena as in **Fig. 12** is effective to detect targets in right locations in spite of replication generation. However, the ratios used in this process are not always in 5:6:11 as the actual phase differences are uneven. This sometimes raises false ghost judgment.

So, using a linear approximation method to the relations between real phase differences and directions to bring the relations closer to the theoretical ratio, we succeeded in improving the judgment accuracy against ghost. We verified the effectiveness of the countermeasure by driving a car with this radar on heavy traffic roads where phase replication tends to occur.

6 Conclusion

As above, although widening detection area caused big problem of generating ghosts, to solve the problem in this development, we took an ultimate measure of ghost judgment in the upper recognition step of calculating phase differences without changing any hardware.

We will keep developing algorithms for further widening detection or for improving performances so as to correspond to various applications.

Profiles of Writers

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