DEVELOPMENT OF MILLIMETER WAVE AUTOMOTIVE SENSING TECHNOLOGY IN JAPAN (Invited)

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ABSTRACT

The Ministry of Posts and Telecommunications in Japan organized a committee to study millimeter wave sensing technologies in 1984. Sensors for automotive vehicles have been mostly studied as appropriate applications of millimeter waves. This paper presents the outline of three types of radars e.g. FM-CW, 2D-imaging, and pulse Doppler, and also presents the study results and a lot of fundamental data measured through the laboratory and road tests. Among those, the FM-CW system shows good performance on freeway test and under adverse environmental conditions.

INTRODUCTION

Automobiles are becoming an increasingly important means of transport in Japan, where there are now over 50 million automobiles on the roads. The increase in the number of vehicles has complicated the traffic situation and safety depends to a large extent on the capability of the driver. It is, therefore, vital that drivers can react quickly to the changing traffic situation and make sound judgments. Just one mistake may lead to a major accident. In the last few years, there has been a marked increase in the number of traffic accidents, particularly on highways.

In order to reduce the burden imposed on the drivers and increase the safety of driving, an automotive sensing system is being developed as a means of supplementing the driver's senses of sight and hearing. However, unlike airplanes and ships, in which radar devices are already in use as safety sensors, it is vital in the case of automobiles to grasp the complicated situation of the road and surrounding area. Consequently, the radar technology has been only introduced to a collision warning system for professional driver use, or a backward warning sensor.

As Fig. 1 shows, the history of the development of automotive sensing technology began in the 1970's and until the 1980's the mainstream was electromagnetic wave (e.g. millimeter-wave, microwave) sensors. However, since it was difficult to obtain suitable microwave and millimeter-wave devices and because of their complexity and high-cost, optical pulse radars with infrared laser diodes were first developed as automotive sensors. However, safety standards concerning vision organ restricts the output power of optical radars with laser diodes, and adverse condition, such as foggy or snowy weather, reduces the maximum operating range of radars. On the other hand, millimeter-wave automotive radar must be an appropriate substitute. Furthermore, millimeter wave devices may, as a result of advances in compound semiconductor technology and processing techniques, be supplied as MICs and MMICs in the near future, removing one of the obstacles to development.

The Ministry of Posts and Telecommunications in Japan, which administers radio frequencies, commissioned the Millimeter-Wave Sensing System Study and Research Committee to conduct various experiments in order to collect the basic data to develop new automotive millimeter-wave radar systems. This paper outlines some of the test results described in the committee's report and clarifies what has to be done to put automotive millimeter-wave sensing technology into practice.

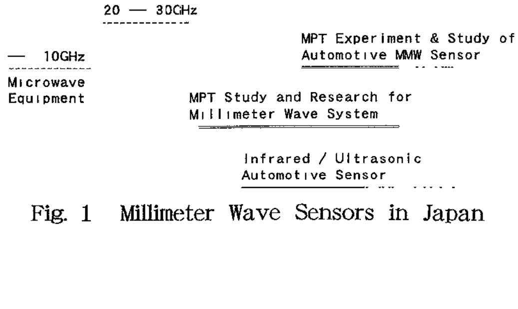

Fig. 1 Millimeter Wave Sensors in Japan

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OUTLINE OF EXPERIMENTAL SYSTEMS

The basic experiment was conducted using two modulation systems – FM–CW and Pulse–Doppler – at three frequencies – 50, 60, and 70GHz – as shown in Table 1. The homodyne reception method, which facilitates the setting up of the system hardware, was adopted for the receiver.

The configuration of the 50GHz sensor system is shown in Fig. 2. To simplify the structure, the millimeter–wave electronic circuit was integrated and installed in the base of the V–shaped antennas. Each antenna forms an angle 2 x 6 degree fan beam, with a cylindrical parabola for a reflector and a slot array antenna for a radiator. The transmission and reception beams form a combined beam angle of 2 x 2 degrees, thus forming the target beam angle. By configuring the transmission and reception antennas in a V–shape, 45 degree polarization is realized, thus avoiding radio interference from vehicles coming from the opposite direction.

The configuration of the 60GHz sensor system is shown in Fig. 3. It is constructed so that scanning can be performed in the directions of the X and Z axes in order to obtain 2–dimensional image data. A pyramidal single horn antenna is used so that the polarization of the received signal can be measured. The Pulse–Doppler modulation system is also adopted so that scattering patterns are measured with carrier waves.

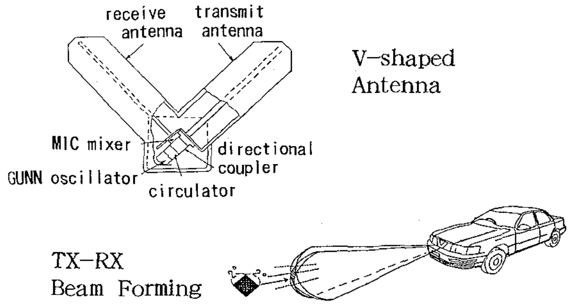
The 70GHz sensor system employs multiple beams in order to pick up direction component signals as well as distance component. The modulation system is FM–CW, same as in the 50GHz sensor system. The multi–beam antenna is realized with a primary multi–horn radiator and a parabola reflector.

OUTLINE OF EXPERIMENT

Using the 50GHz, 60GHz, and 70GHz sensor systems as shown in Table 1, basic data necessary to develop an automotive sensing system were

ITEM	SYSTEM A	SYSTEM B	SYSTEM C
FREQUENCY	50GHz	60GHz	70GHz
RADAR System	FM-CW	Pulse Doppler	FM-CW
ANTENNA	Fixed single, Mill's Cross	Scanning Single, Horn, Parabola	Multi-Beam, Multi-Horn, Parabola
ALARM LOGIC	Vehicle Speed, Closing Speed, Relative Distance	2D Image Processing, Image Recognition	Combination of Speed, Distance, Target-Direction
EXPERIMENTS	Scattering Pattern, On-Road Drive Test, Atomospheric Cond.	Scattering Pattern, X-Y Scanning Data, Detection on the Curved Road	2 Channel Beam, Target Angle Det. Detection on the Curved Road

Table 1 Study and Experiment of Automotive Sensor



Fig, 2 50 GHz Sensor System

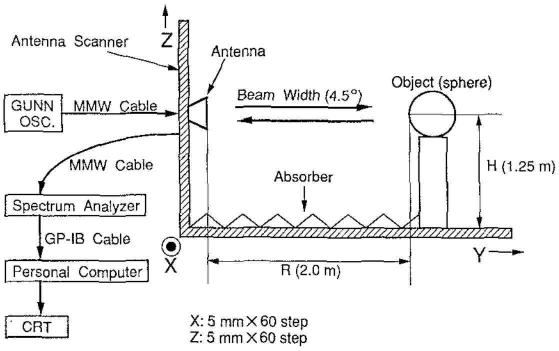


Fig. 3 60 GHz Sensor System

collected. These data include the basic characteristics of each system, radio wave propagation characteristics, characteristics of detected objects, radio interference, evaluation of system functions, target object image data, curved road simulation, and directional angle signal processing. The most important results of the experiments are summarized below.

(1) Experiment to Determine Scattering Patterns

Detected objects such as vehicles and guard rails take many different shapes and forms. Measuring different scattering patterns according to shape is very important for distinguishing between target objects. Fig. 4 shows the cross sectional scattering patterns measured for four vehicles and objects set along roadsides. The cross sectional scattering pattern of the passenger vehicles are large in the front and rear directions but diagonally very small. The scattering patterns of the truck and motorcycle are almost the same in every direction, but those of the motorcycle are smaller. Since the angle for detecting flat target objects such as guard rails and traffic control signs is narrow, reflection signal power of such objects while driving are expected to be small. However, as cylindrical objects like metal pipes are nondirectional and have a relatively high reflectivity, reflections from poles such as roadside street lights may be obstacles to radar detection.

(2) Radio Interference

In the future, when radar systems are installed in a large number of vehicles, mutual interference between similar types of radar system installed in vehicles is expected to occur. In order to assess radio interference, 50GHz sensor systems were installed in two vehicles and the level of interference was measured in one of the vehicles as the distance between it and the other vehicle coming from the opposite direction (R) and the angle at which they faced each other (θ) changed. (See Fig. 5.) The experiment demonstrated that when two vehicles approached each other from opposite directions the interference level was well suppressed by the effect of a polarization of 45 degrees. When the two vehicles ran parallel to each other, the necessary separation ratio was attained by sharpening the directivity of the beam.

(3) Road Test

To determine how well the radar system works in actual road conditions, a 50GHz sensor system as shown in Fig. 2 was installed in a vehicle and a road function evaluation test was performed. (See Fig. 6.) When the vehicle ran on straight roads close to the guard rail the system did not malfunction, but on winding roads the guard rail or roadside objects were sometimes detected. On uphill roads, the system lost the target at the start and finish of the incline. The system could detect a concrete wall in front, but not trees.

In addition, the system was tested on ordinary roads over a distance of over 1,000 kilometers and the number of times the alarm worked and the false alarm rate were recorded. The results of the test are shown in Table 2. The frequency with which the driver judged the alarm to have worked mistakenly was low, ranging from 1.5% on highways to 7–10% on other roads. Most of the false alarm occurred on winding roads and were mostly caused by roadside objects such as the guard rail, walls and poles. These false alarms can be overcome by adopting extensive techniques such as steering or scanning the beam and by minute alterations such as improvements in the signal processing method and alarm logic. The current system is proved already sufficient for use on highways.

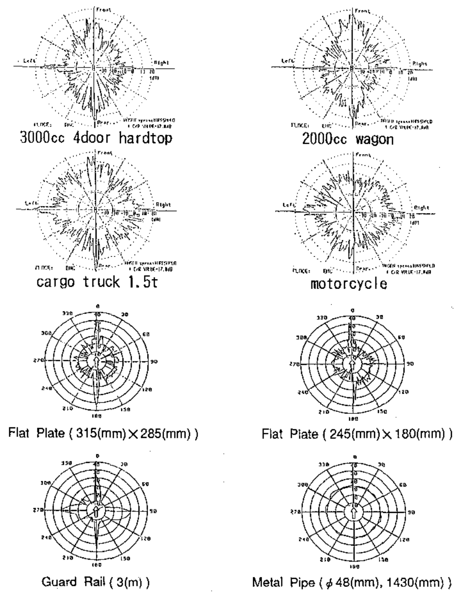


Fig. 4 Cross-Sectional Scattering Patterns

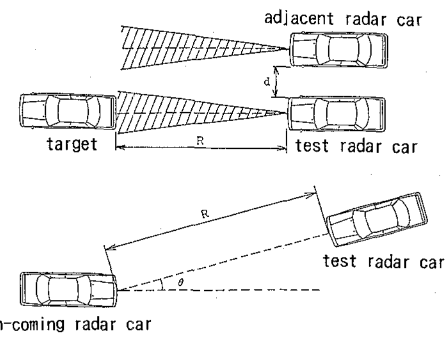


Fig. 5 Radio Interference Between Vehicles

(4) Collection of Image Data

A spherical object and a flat plate were used as target objects since their shape is comparatively simple and their characteristics easy to extract, facilitating comparison between them. The experiment shown in Fig. 3 was conducted using the 60GHz CW system. Measurement results are shown

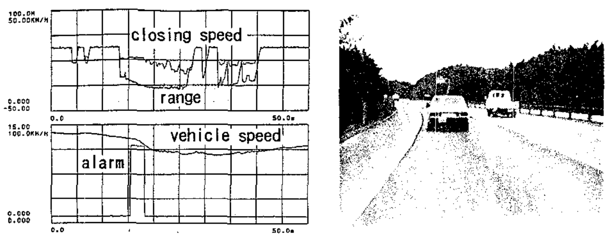


Fig. 6 Road Test of 50GHz Sensor

Road	Driving Distance (km)	Driving Time (hr.)	Total Alarm (times)	Alarm Rate (times/km)	Alarm Rate (times/hr.)	Total False Alarm (times)	False Alarm Rate (%)
Downtown	215.0	10.4	310	1.4	29.8	22	7.1
Rural	482.5	14.5	314	0.7	21.7	32	10.2
Freeway	378.0	4.8	135	0.4	28.1	2	1.5
Total	1075.5	29.7	759	0.7	25.6	56	7.4

Table 2 Alarm Data of the Road Test

in Fig. 7. As the main beam is wide (4.5 deg.) and the resolution is poor, the edges are blurred, but the shape of the object is comparatively well displayed. The distribution of reflection intensity of the flat plate and the spherical object were compared. In the case of the flat plate, the distribution is unimodal, the maximum intensity being almost at the central position and monotonously decreasing from this point outwards in all directions. The maximum intensity of the sphere's reflection is also almost at the central point, but there is no monotonous decrease, the intensity decreasing and increasing alternately.

This experiment shows that comparatively good image data can be obtained for objects with a simple shape from reflection intensity measurement.

DISCUSSIONS OF AUTOMOTIVE SENSORS

There are several points that have to be solved in the implementing automotive sensing systems for practical use. Some of the more important ones are discussed below.

(1) Downsizing of Antenna

The size of antenna is almost entirely determined by the frequency used and the required beam width. On the basis of the characteristics of reflections and malfunction rate, a beam width of approximately 2 degrees is considered most suitable. In order to have such a sharp beam, a millimeter wave frequency must be used. It is also necessary to use array antenna with a small surface area which have an electronic scanning function.

(2) Improvement of Reliability

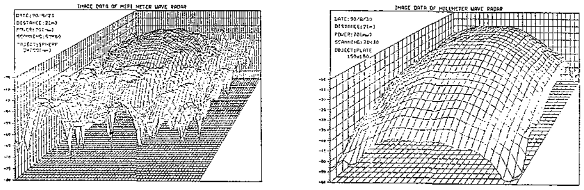
Devices and equipment used in automotive systems must be able to withstand the rigors of various environments and must be equipped with diagnostic and fail-safe functions to ensure that breakdowns do not lead to accidents. As the radiator grille where this sensor is installed is relatively close to the engine, the system must be made vibration-proof and heat resistant.

(3) Influence of Climatic Factors

The greatest difficulty in using the millimeter wave system is its susceptibility to precipitation. However, tests showed that the system is sufficiently effective even in strong rain of 10mm/hr. The problem caused by rain is rather the decreased effectiveness which occurs when raindrops on the surface of antenna form a water screen. It is therefore necessary to design a radome which does not permit water screen formation.

(4) Radio Interference

It seems possible to solve the problem of radio interference by using antenna with sharp directivity, adopting 45 degree polarization, and encoding transmission signals. In fact, these tests revealed hardly any radio interference problem caused by equipment in vehicles or between vehicles with radar systems without encoding.



(a) Sphere (ϕ 200(mm))　　(b) Flat Plate (150(mm) × 150(mm))

Fig. 7　Imaging Data

(5) Frequency Band

To install the antenna with a narrow beam width, it is necessary to choose a frequency of 50GHz or more. Since sensor systems are expected to be used in many vehicles, the 60GHz and 120GHz frequency bands, at which much radio power is absorbed by oxygen molecules in the atmosphere, are suitable from the viewpoint of avoiding mutual interference.

CONCLUSIONS

In view of the high level of precision and the compactness of system, there are great hopes for using millimeter wave systems as visual sensors for road vehicles. The experiments show that the millimeter wave sensor system performs very well under adverse environmental conditions such as rain and fog, and it is likely that they will become increasingly important as traffic accident prevention and driving safety systems.

REFERENCES

"Report of the Millimeter-Wave Sensing System Study and Research Committee" (Japanese), Radio Equipment Inspection and Certification Institute, Tokyo, March 1990, and March 1991,