76GHz Millimeter Wave Automobile Radar using Single Chip MMIC

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Abstract

In the latter half of the 1990s, auto manufacturers released driving assistant "Adaptive Cruise Control (ACC) Systems" that utilized Millimeter Wave radar. Then in 2003 this technology started being applied to safe driving support in the form of "Collision Mitigation Systems." In the future, Millimeter Wave radar is expected to undergo performance improvements that will enable it to be adapted to all driving situations, and continued reduced pricing is expected to lead to an expansion in a wide variety of models that adopt it.

As an approach to price reduction aimed at expanding the use of Millimeter Wave radar, FUJITSU TEN LIMITED developed a single chip for Monolithic Microwave Integrated Circuit (MMIC) modules in Millimeter wave transceivers and also developed radar that utilizes that technology. This report describes a 76GHz Millimeter Wave radar using such single-chip-MMIC. This low-cost radar will be produced on a commercial basis from this point forward.

1 Introduction

Safe driving support technology is an important field of development for ITS, and automobile radar a key component of this elemental technology.

The development of automobile radar began around 1970, followed by the marketing of the Adaptive Cruise Control (ACC) System, a basic driving support system, by auto manufacturers in the late 1990s.

Both laser radars and Millimeter wave radars have been released. However, the development and expansion of Millimeter wave radars have progressed globally, because of their resistance to fluctuation due to dirty cars and weather conditions (rain, snow and fog).

This report introduces the trends in the development and application of 76GHz Millimeter wave radar for automobiles, as well as an example of the latest developments in this field.

2 Trends in the application of Millimeter wave radar

Recent trends in the application of Millimeter wave radar by various auto manufacturers are shown in Table 1. The first Millimeter wave radars measured distance from and range rate compared to the preceding vehicle. They were used with a convenient system called the Adaptive Cruise Control (ACC) system, which automatically accelerated and decelerated the vehicle to maintain an appropriate distance from the preceding vehicle while driving. However, there have been indications of changes in this use since last year.

【In addition to such systems, of which the ACC system is merely a single example, the use of collision mitigation systems sold by Honda and Toyota has also begun. These safety support systems detect and warn the operator of potential hazards, and automatically apply the brakes to reduce damage in the event of a collision.】

The development of this collision mitigation system progressed within the Advanced Safety Vehicle (ASV) project promoted since 1990 by the Ministry of Land, Infrastructure, and Transport of Japan. Recent improvements in the stability and performance of the sensing of Millimeter wave radars, which are the "eyes" of the vehicle, have allowed these developments to progress to the actual installation of these systems in automobiles.

The collision mitigation system utilizes Millimeter wave radar to detect the preceding vehicle and warn of the potential of rear-end collisions. If the distance from the preceding vehicle becomes too close, the system uses a warning alarm and display to instruct the driver to reduce vehicle speed. However, if the system determines that deceleration is insufficient to prevent a collision, it is designed to reduce damage by automatically and strongly applying the brakes to reduce the collision speed, while simultaneously tightening the seat belts to restrain passengers.

The predicted evolution of radar application is shown in Figure 1. In the future, we expect an enlargement in the applicable speed range, for the application of a convenient system to be used at slow-speeds only for tracking congestion.

Although the collision mitigation system currently functions to simply caution the driver and assist in braking to reduce collision damage, we expect it to evolve into a hazard evasion system avoid in the future, to avoid by detecting peripheral hazards and assisting in steering.

For the further proliferation of Millimeter wave radar in the future, improvements in function and performance are required, such as the monitoring of the entire periphery of the vehicle, to achieve a system that is applicable in all situations and driving conditions, whether driving on expressways or city streets, at high speeds or in congestion.

In addition, it is necessary to reduce the cost of such a system so that it can be utilized as a safety device in a wide variety of models in the same manner as airbags and Anti-lock Braking Systems (ABS).

Table 1 Trends in the Application of Millimeter Wave Radar

(Current as of October 2003.)

Market Date	Manufacturer	System	Features
1998/11	Daimler Chrysler	･ACC	Low G Braking Control
1999/07	Nissan (CIMA)	･ACC	Low G Braking Control
1999/09	Jaguar	･ACC	Low G Braking Control
2001/10	BMW	･ACC	Low G Braking Control
2002/10	Honda (Accord)	･ACC	Low G Braking Control
2003/02	Toyota (Harrier)	･ACC ･Collision mitigation system	High G Braking Assistance
2003/06	Honda (Inspire)	･ACC ･Collision mitigation system	High G Strong Braking
2003/08	Toyota (Celsior)	･ACC ･Collision mitigation system	High G Strong Braking
2003/10	Honda (Odyssey)	･ACC ･Collision mitigation system	High G Strong Braking

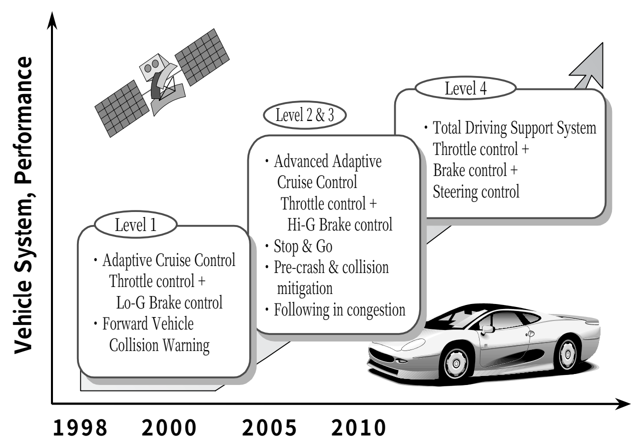


Fig.1 Prediction of the Evolution of Radar Application

3 Requirements for automobile radars

Automobile radars require the stable detecting of distances to a variety of vehicles, from small motorcycles to large trucks, at distances from a few meters to well over 100 meters, as well as speeds from 0km/h to 200km/h, regardless of weather conditions or time of day.

It is necessary to set the radar beams to scan a certain range of angles, so that, regardless of whether the road is straight or curves, the relative side positions (angles) can be tracked to determine whether the preceding car is in your lane (where operation of the system may be necessary) or an adjacent lane.

In addition, since radar is installed in the limited space at the front of the automobile, it must be contained within dimensions that will not affect the design or cooling performance of the vehicle or hinder safety with respect to collisions.

It is important to make radars available at low cost to promote their proliferation in the market.

4 Development trends in automobile radars

A comparison of recent automobile radars from both Japanese and other manufacturers is shown in Table2.

There are a variety of modulation methods for Millimeter wave radar, such as FM-CW, 2-frequency CW, pulse, and Spread Spectrum (SS). However, FM-CW (Frequency-Modulated Continuous Waves) is utilized most often, since the high-frequency band has a comparatively simple structure, it can measure both distance and range rate simultaneously with a high degree of precision and it can also measure range rates of zero.

There are two types of methods used for detecting angles in the right and left directions: one is electronic methods, such as beam conversion and monopulses, and the other is mechanical antenna scanning methods. There have been reports of 3-beam and 9-beam conversions for the beam conversion method. By increasing the number of beams, angle resolution is increased and a wider angle is achieved. There have also been reports of monopulse methods that detect angle with the reception of two signals, as well as a phased array method in which the beam shape can be modified.

Mechanical scanning with antennas allows comparatively simple in wide angles with sharp beams and increased angle resolution.

There have been reports of radars with horizontal detecting angles from ±4° to ±10°, showing a trend toward wider angles.

Millimeter wave devices, which are used as 76GHz transceivers have shifted from the use of Gunn diodes to the use of Monolithic Microwave IC (MMIC), which are easier to mass-produce. Developments are underway to take advantage of the characteristics of MMIC.

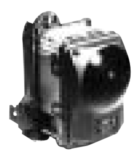
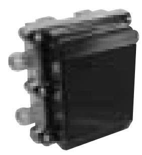
5 Outline of FUJITSU TEN LIMITED Millimeter wave radars

Millimeter wave generally refers to the frequency range from 30GHz to 300GHz, which consists of extremely short wavelengths (from 10mm to 1mm).

FUJITSU TEN LIMITED uses 76GHz for its Millimeter wave radars, because this is the frequency selected by the governments in the principal markets of Japan, the United States, and Europe.

Our current Millimeter wave radar systems use the FM-CW radar method, which has a simple structure and allows the measurement of the distance to and range rate compared to the target vehicle.

Table 2 Comparison of Millimeter Wave Radars from Various Manufacturers

Manufacturer	Our company	ADC	Delphi	Bosch	Honda elesys	Denso	Hitachi
Appearance							
External Dimensions (mm)	89×107×86	136×133×68	137×67×100	91×124×79	123×98×79	77×107×53	80×108×64
Modulation Method	FM-CW	FM Pulse	FM-CW	——	FM-CW	FM-CW	2- frequency CW
Detection Range	4m to 120m or greater	Approx. 1m to 150m	Approx. 1m to 150m	2m to 120m or greater	4m to 100m or greater	Approx. 2m to 150m	Approx. 1m to 150m
Horizontal Detection Angle	±8 °	Approx. ±5 °	Approx. ±5 °	±4 °	±8 °	±10 °	±8 °
Angle Detection Method	Mechanical Scan	Beam Conversion	Mechanical Scan	Beam Conversion	Beam Conversion	Phased Array	Monopulse
EHF Device	MMIC	GUNN	GUNN	GUNN	MMIC	MMIC	MMIC

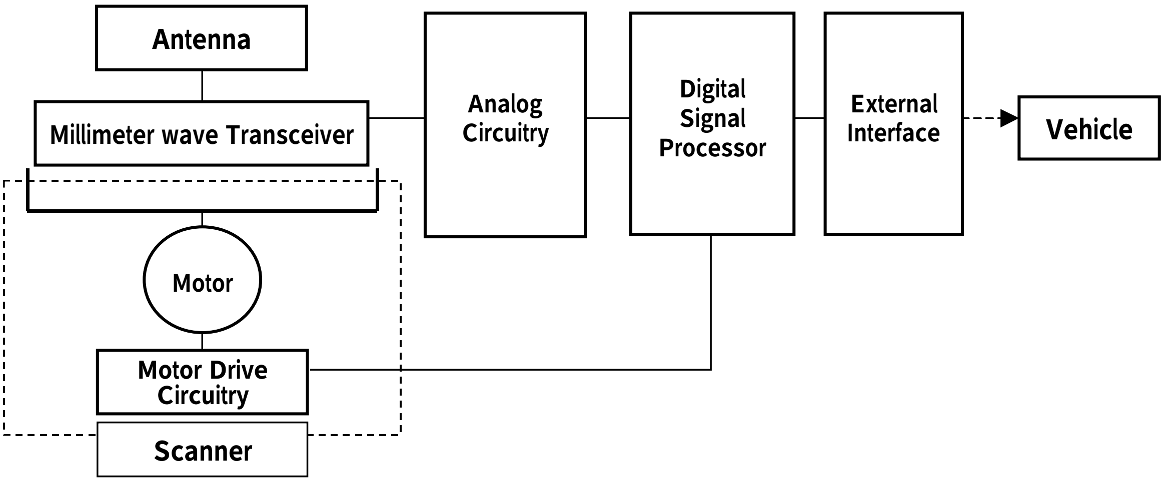


Fig.2 Radar System Block Diagram

The system configuration for Millimeter wave radar is shown in Figure 2. Millimeter wave radar consists of an antenna, Millimeter wave transceiver, scanner, analog circuitry, digital signal processor, and an external interface. The antenna is connected to the Millimeter wave transceiver, and the locations of obstacles are calculated in the signal processor. The results of these calculations are relayed through the transmission interface and output to the vehicle's control computer.

The radar system is shown in Figure 3, and the primary specifications are listed in Table 3.

With this Millimeter wave radar system, a planer antenna is connected to an Millimeter wave unit using a waveguide, and an actuator is used to perform left to right scanning. The radar beat signals are converted to AD in the signal processor, the frequency is analyzed in the DSP circuitry, and distance, range rate, and angle information are calculated to detect the positions of obstacles.

The sensor must be able to instantly detect the position and speed of a variety of vehicles, from small motorcycles to large trucks, regardless of time of day or weather conditions. Therefore, the antenna and Millimeter wave unit must have a dynamic range that can detect large and small obstacles, as well as being compact enough for installation on vehicles and to reduce scanning load.

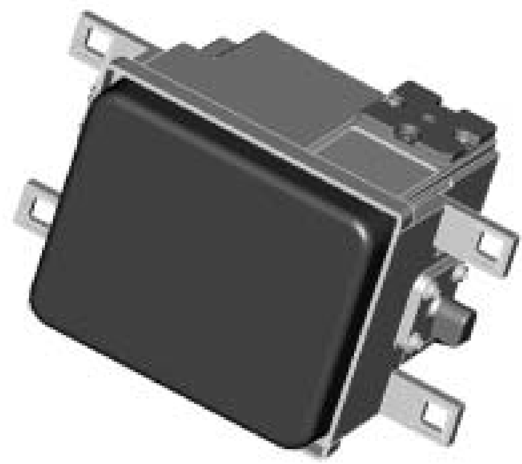


Fig.3 76GHz Millimeter Wave Radar

Table 3 Primary Specifications of Millimeter Wave Radar

Item	Specifications
Radar Method	FM-CW
Central Frequency	76 - 77GHz
Transmission Power	10mW or less
Antenna Polarized Wave Characteristics	45 °linear polarized wave
Maximum Detection Range	Approx.120m

6 Millimeter wave transceiver

The Millimeter wave transceiver is the most important component in a 76GHz Millimeter wave radar, as well as the component whose technology has made the most rapid progress. In order for automobile radar to proliferate in the future, the cost needs to be reduced. Development is progressing in making Millimeter wave transceivers, called the heart of Millimeter wave radar, more compact and economical.

Specifically, there have been reports of MMIC chips mounted directly onto multilayer ceramic circuit boards, to develop multilayer boards with built-in via hole construction for 3-dimensional multilayer wiring structures with 3-dimensional wiring layouts, as well as Millimeter wave signal connections between MMIC and antennas.

As one approach toward creating compact, low-cost radar, we have developed a method for mounting MMIC modules inside Millimeter wave transceivers, as well as a single-chip integrated MMIC module applicable to the integrated IC.

The configuration of the Millimeter wave transceiver is shown in Figure 4.

We developed a 2-module construction for MMIC. Excluding VCO, all transceiver functions are contained on 1 MMIC chip. The single-chip integrated MMIC module is sealed in an airtight package to maintain reliability. It consists of an integrated MMIC for transmission and reception which includes frequency multiplier (MLT), mixer (MIX), and amplifier (AMP) functions.

Although the configuration of this transceiver system is the same as our conventional products, the use of a single-chip integrated MMIC module achieves both a unit volume and weight that are 75% that of our conventional products. In addition, the formation of a high-frequency transmission line inside the chip allows a reduction in the number of connections, allowing simplified production and more stable performance.

6.1 Single-chip MMIC (integrated MMIC)

A photograph of an integrated MMIC chip is shown in Figure 5. The process used a P-HEMT (Pseudomorphic HEMT) with an InGaP/InGaAs heterojunction as the base. The P-HEMT performance is as follows: gate length of 0.15 μm, transition frequency of 90GHz, and maximum frequency of oscillation of 170GHz. The capacitor has a Metal-Insulator-Metal (MIM) structure using SiN. The resistance uses an epitaxial activated layer. The area of the integrated MMIC chip is 8.46mm^2, 1/3 of that for our conventional MMIC chips. In addition, as shown in the photograph of the chip in Figure 5, a gold pillar with over 250 earths is arranged on the MMIC chip to prevent interference due to unnecessary radiation between circuits.

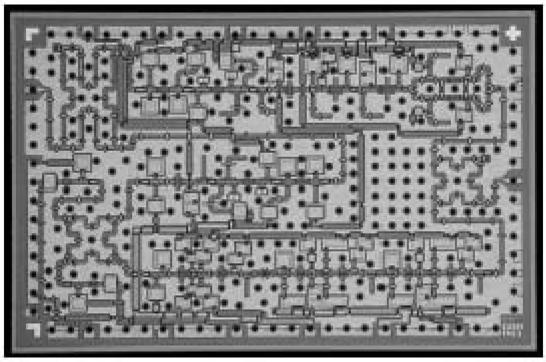


Fig.5 Single Chip Integrated MMIC

The performance of the newly developed single-chip MMIC module is shown in Table 4. The transmission performance and reception performance are shown in Figure 6 and Figure 7. This new module achieves the same performance as combinations of for our conventional MMIC modules.

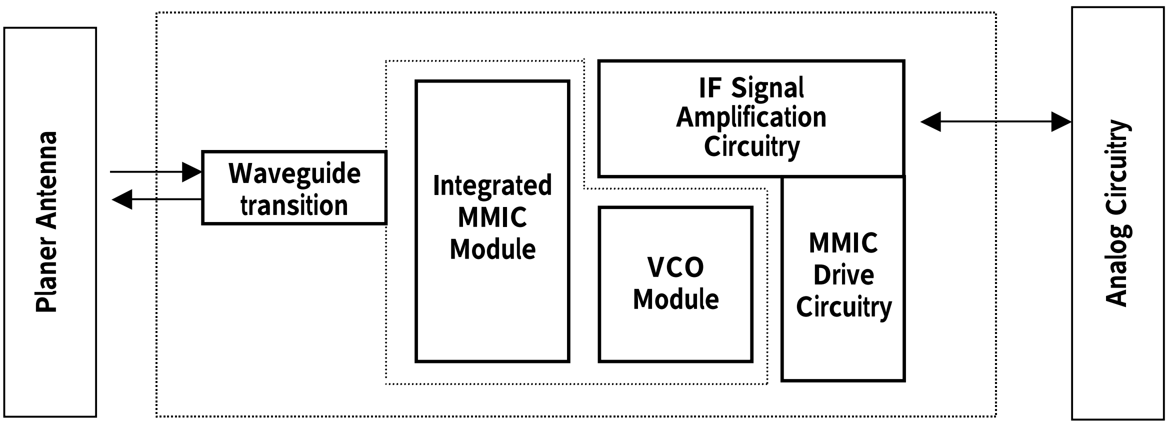


Fig.4 Millimeter Wave Transceiver Block Diagram

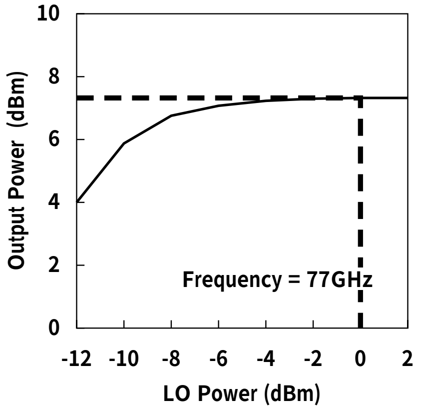


Fig.6 Output Power of Single Chip Integrated MMIC

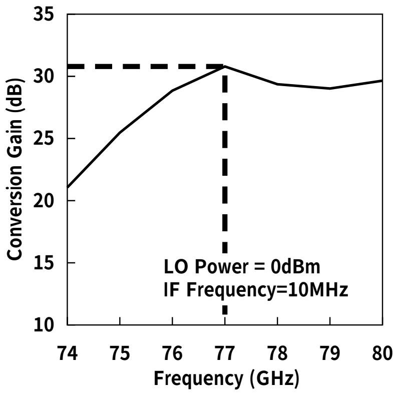


Fig.7 Conversion Gain for Single Chip Integrated MMIC

Table 4 Performance of Single Chip Integrated MMIC

Item	Transmission Performance	Reception Performance
High-frequency Characteristics	Transmission Power 7.3dBm (0dBm@38GHz in)	Gain 30.8dB (0dBm@38GHz in)
		Noise Figure 11dB (@IF 1MHz)
Consumed Power	0.54WDC	0.3WDC

6.2 Circuit operation in single-chip integrated MMIC

A block diagram of a single-chip integrated MMIC module is shown in Figure 8. As explained in the previous section, four conventional MMIC chips have been integrated into a single MMIC chip.

The integrated MMIC module has a port for the input of external 38GHz VCO signals, a port for the input and output of 76GHz signals, and two IF signal output ports. The signal routes can be broadly classified into the following types: local signal route, transmission signal route, and reception signal route.

In transmission mode, the receiving route is turned off, and in reception mode the transmission route is turned off.

When switching between transmission and reception the drain bias voltage in the transmission amp and the reception amp is adjusted consecutively.

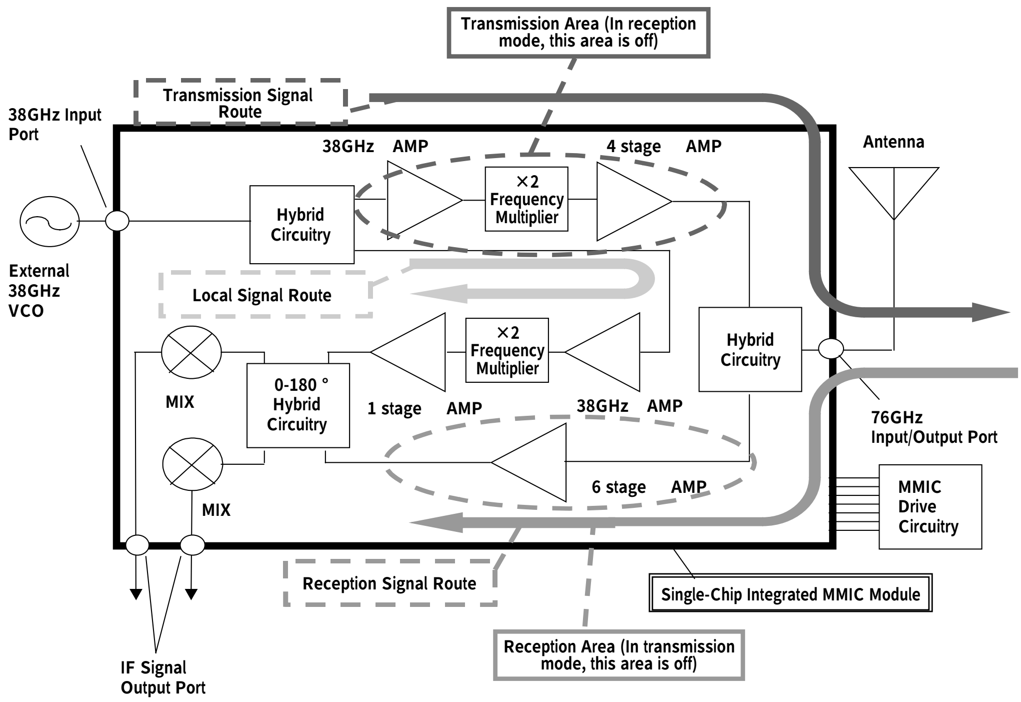


Fig.8 Block Diagram for Single Chip Integrated MMIC

The VCO module, which receives a triangular modulating signal, outputs an FM modulated signal. The signal from the VCO is divided into two by the 38GHz branch-line hybrid circuit. Of the two divided signals, one is a local signal amplified by the 38GHz amplifier. Then, it enters the frequency multiplier, is re-amplified by the 1st stage amplifier, and sent to the local port of the 76GHz mixer.

The other divided signal is amplified by the 38GHz amplifier. Then, it enters the frequency multiplier, is amplified by the amplifier, passes through the 76GHz branch-line hybrid circuit, and then output from the 76GHz input/output port as a transmission signal.

The reception signal passes from the 76GHz input/output port through the 76GHz branch-line hybrid circuit, and is then amplified by the amplifier. It is then downconverted from 0-180 degree hybrid circuitry by a single end mixer, and output from the IF signal output port.

In this formation of single chip MMIC, the level diagram of transceiver was designed so that it might have equivalent characteristics to the conventional transceiver. In addition, hybrid circuitry is also built on the chip to reduce cost and size.

7 Radar evaluation results

The tracking performance with this newly developed single chip MMIC is shown in Figure 9. The figure shows the detecting performance of distance and range rate while gradually approaching a stopped vehicle in the distance. The figure shows that the vehicle can be tracked in a range from more than 170m to 2m. The conditions for the tracking of the vehicle are shown in Figure 10. The square appearing on the target vehicle in Figure 10 indicates the position detected by the radar, indicating that the target has been acquired successfully. In addition, the right side of Figure 10 shows the radar detecting conditions from above. In this area of the figure, distance to the target is expressed on the vertical axis and the lateral position of the target is expressed on the horizontal axis. The target vehicle, enclosed in the dashed-line circle, is detected at the correct distance and lateral position.

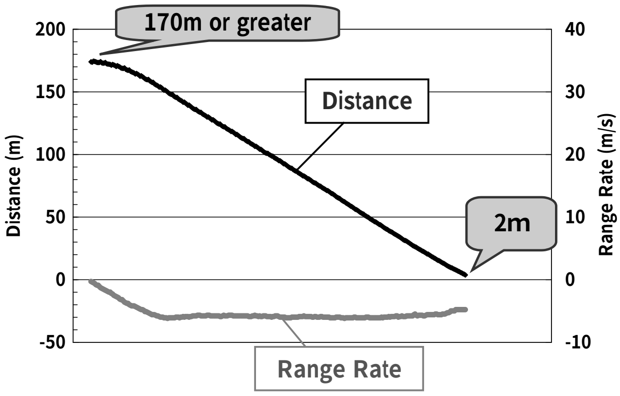


Fig.9 Actual Tracking Performance

Figures 11 and 12 show the accuracy for range and range rate measured using reflectors in fixed positions with a Radar Cross Section (RCS) value of approximately $10m^2$ (the size of a car). Good test results were achieved. The detection range error for various distances between 20m to 160m is less than 1m, and range rate error is less than 0.5m/s.

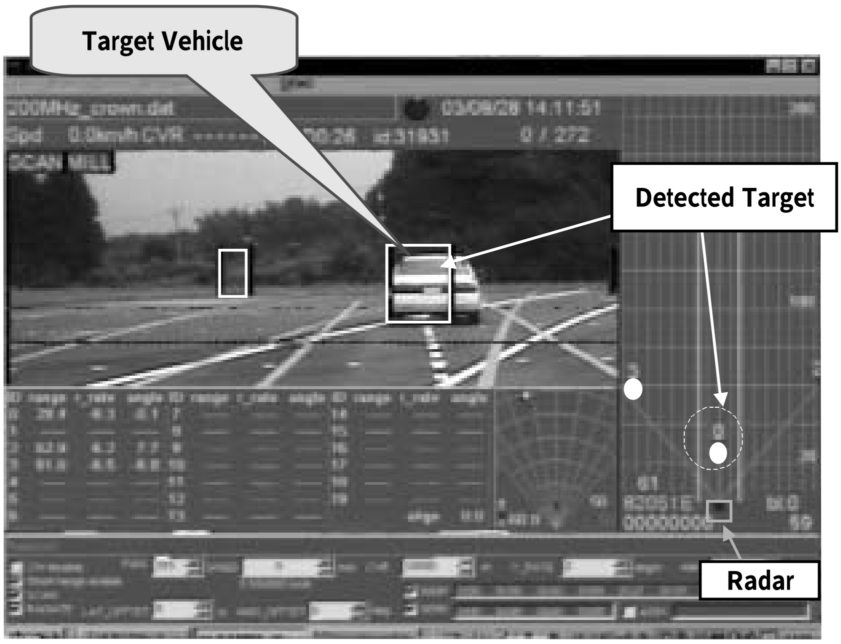


Fig.10 Test Condition

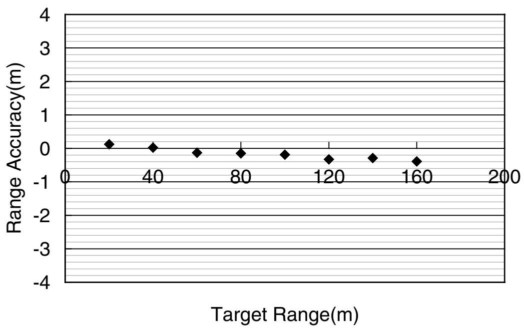


Fig.11 Range Accuracy

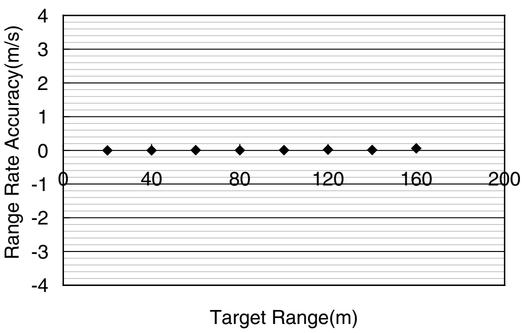


Fig.12 Range Rate Accuracy

8 Conclusion

Single-chip MMIC for use in Millimeter wave transceiver, as well as the radars in which these MMIC will be used, were developed and evaluated in an effort to reduce the cost of Millimeter wave radar.

We believe that there will be an increase in the number of vehicles with Millimeter wave radar installed as convenient systems, similar to current ACC systems, as well as for safety, similar to current collision mitigation systems. However, reductions in cost, as well as improvements in function and performance, will be necessary.

We hope to contribute to the enlargement of the Millimeter wave radar market, by promoting technological developments in MMIC, the key component of Millimeter wave radar, as well as developments in systems that include peripheral circuitry that utilize MMIC.

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