

Millimeter-Wave Radar Technology for Automotive Application

by Shinichi Honma and Naohisa Uehara*

Mitsubishi Electric Corporation has developed a millimeter-wave radar for automotive application. Monolithic microwave integrated circuits (MMICs), developed specifically for this application by Mitsubishi Electric, are used for the radio-frequency (RF) module to obtain outstanding radar performance. This millimeter-wave radar incorporates a signal-processing unit in the radar head, resulting in a more compact, light-weight radar system that is easy to install on vehicles.

The sensors for monitoring vehicle driving environments embody important technology for the Intelligent Transport System (ITS). Sensing devices employed include the ultrasonic sensor, image-processing sensor, infrared lidar, microwave radar and millimeter-wave radar. Compared with other types of sensors, a millimeter-wave radar has the advantage of providing stable detection of targets even under inclement weather conditions such as rain or snow. Recent remarkable advances in RF technology have facilitated production of highly functional and efficient radar sensors. Thus, millimeter-wave radar has been marketed as, a vehicular collision warning sensor.

The RF technology, semiconductor technology and radar technology that Mitsubishi Electric has developed over many years for space, defense and consumer electronics applications have been used to create a millimeter-wave radar for use on vehicles. One of the features of this radar is that all of its constituent elements, including the semiconductor devices, have been developed in-house specifically for automotive radar application.

Measuring Distance and Velocity

The method of measuring the distance from a radar to a target vehicle and the vehicle's relative velocity depend on the type of radar system employed. Millimeter-wave radar systems for automotive application include pulse radar, frequency-modulated continuous-wave (FM-CW) radar and spread spectrum radar. The newly developed millimeter-wave radar is based on the FM-CW radar system.

The FM-CW radar system allows a simple construction of the RF circuit. Moreover, this system has often been adopted for automotive millimeter-wave radars because it can measure both the distance to a target and the target's relative velocity simultaneously. The measurement principle of the FM-CW radar system is shown in Fig. 1. The radar transmits a frequency-modulated millimeter-wave signal, and the signal reflected by a target is received by the radar. By mixing the received and transmitted signals, the system obtains a beat signal having a fre-

quency of f_b . This beat signal features a time-delay due to the distance from the radar to the target and a Doppler shift due to the relative velocity of the target. The range to the target, R , and its relative velocity, V , are found with the following equations using the pair of beat signal frequencies, f_{b1} and f_{b2} . These beat signals are obtained from the pair of frequency-modulated waves having different time variations.

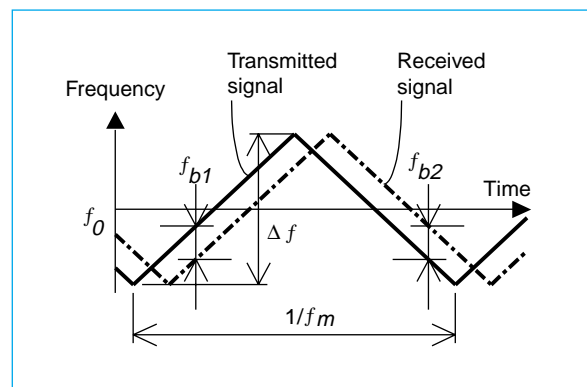


Fig. 1 Frequency-time relationships in FM-CW radar.

$$R = \frac{(f_{b1} + f_{b2})c}{8f_m\Delta f} \dots\dots\dots (\text{Eq. 1})$$

$$V = \frac{(f_{b2} - f_{b1})c}{4f_0} \dots\dots\dots (\text{Eq. 2})$$

where c is the velocity of light, f_0 is the center frequency, f_m is the modulation frequency and Δf is the maximum frequency deviation.

*Shinichi Honma and Naohisa Uehara are with the Automotive Electronics Development Center.

When two or more targets and objects exist, the beat signals obtained from them have multiple frequency components. Consequently, in order to detect the distance to a target and its relative velocity accurately, it is essential to select the pair of beat signals from the same object without error. In order to use a millimeter-wave radar as the sensor for an adaptive cruise control (ACC) system or an automated driving system, it is necessary to reduce the target misrecognition rate as much as possible.

Masuring the Azimuth

The monopulse method illustrated in Fig. 2 is often used to measure target azimuth. The reflected signals from the same target are received as two beams having different directions. The azimuth is determined according to the following procedure from the received field intensity of the two beams.

1. The difference and the sum of field intensities for the two beams are obtained for each angle. A discrimination curve that shows the relationship between the angular-error signal voltage ϵ and the azimuth θ is obtained. The angular-error signal voltage is obtained by normalizing the difference signal with the sum signal.
2. The reflected signals from the same target are received as two beams having field intensities of α and β . The difference δ between these two intensities, and their sum σ , are then calculated.
3. For these pairs of field intensities, the ratio of the difference to the sum (δ/σ) is compared with the angular-error signal voltage of the discrimination curve. And then the azimuth θ_t of the target is uniquely identified.

sities of α and β . The difference δ between these two intensities, and their sum σ , are then calculated.

3. For these pairs of field intensities, the ratio of the difference to the sum (δ/σ) is compared with the angular-error signal voltage of the discrimination curve. And then the azimuth θ_t of the target is uniquely identified.

Table 1 Technical Specification of the Millimeter-wave Radar.

Item	Performance
Frequency	76 ~ 77GHz
Output power	10mW max
Range	0 ~ 120m (Passenger car)
Range resolution	1m
Relative speed	-100 ~ +200km/h
Speed resolution	1km/h
Detection angle	± 8 deg.
Multiple target detection	Possible
Data refresh rate	100msec

In order to obtain two beams, a sequential lobing method is adopted in this radar for automotive use. For this purpose, a mechanical scanning method with an antenna radiating a single beam is adopted.

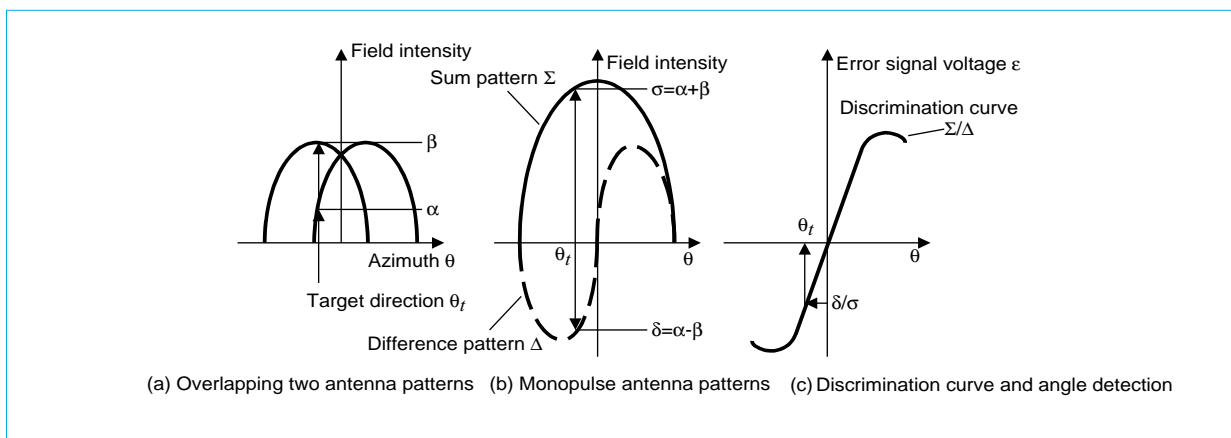


Fig. 2 Monopulse radar signal processing.

Overview of the Newly Developed Millimeter-Wave Radar

An example of the specifications of the millimeter-wave radar for automotive application is shown in Table 1. Assuming the radar is to be used in expressway driving, it must provide sufficient performance for detecting a forward vehicle at distances greater than 100m from the host vehicle. In addition, a millimeter-wave radar for automotive application must also satisfy the following requirements:

1. It must be capable of oscillating, amplifying, modulating and demodulating millimeter-wave signals stably.
2. It must be capable of radiating a millimeter-wave signal toward a target with a suitable level of power, beam width, number of beams and timing.
3. It must be capable of maintaining robust performance in the environment of the host vehicle temperature changes and vibrations.
4. Taking into account ease of installation on the host vehicle, it must be compact and lightweight.

In order to satisfy all of these requirements, Mitsubishi Electric has developed each of the elements constituting a radar head, including an RF module, antenna, antenna scanning mechanism, and radar signal-processing unit.

RF MODULE. The RF module consists of MMICs having functions such as millimeter-wave band oscillator, amplifier and mixer. The RF module also has an interface function with an antenna and a signal-processing unit. By using MMICs developed and manufactured for this automotive millimeter-wave radar, an RF module has been provided with the high output and sensitivity to achieve a maximum detection range greater than 100m. The performance stability of the RF module has been confirmed in the harsh vehicle environment.

ANTENNA. An offset paraboloidal reflector antenna is used to obtain high gain and antenna efficiency in order to provide the desired maximum

detection distance and detection angle range when combined with the RF module. A reflector-rotating mechanism has been adopted that rotates only the lightweight reflector to accomplish beam scanning. One feature of this antenna is that beam scanning can be performed while the RF module is kept stationary. Another advantage is that its radiation properties show virtually no change within a beam scanning angle of $\pm 10^\circ$.



Fig. 3 Radar head (prototype).

RADAR SIGNAL-PROCESSING UNIT. The radar system adopted combines pulse-Doppler radar with FM-CW radar. This combination reduces the rate of target detection error, which can be a problem with the FM-CW system, and thereby successfully improves target detection performance significantly. This signal-processing unit is housed in the radar head together with the RF module, antenna, reflector-rotating mechanism and power supply circuit. Fig. 3 shows a prototype radar head. The compact, lightweight radar that has been achieved is easy to install on vehicles.

A compact and lightweight millimeter-wave radar for automotive application has been developed. This radar is currently being tested under actual driving conditions as the sensor for an ACC system. □