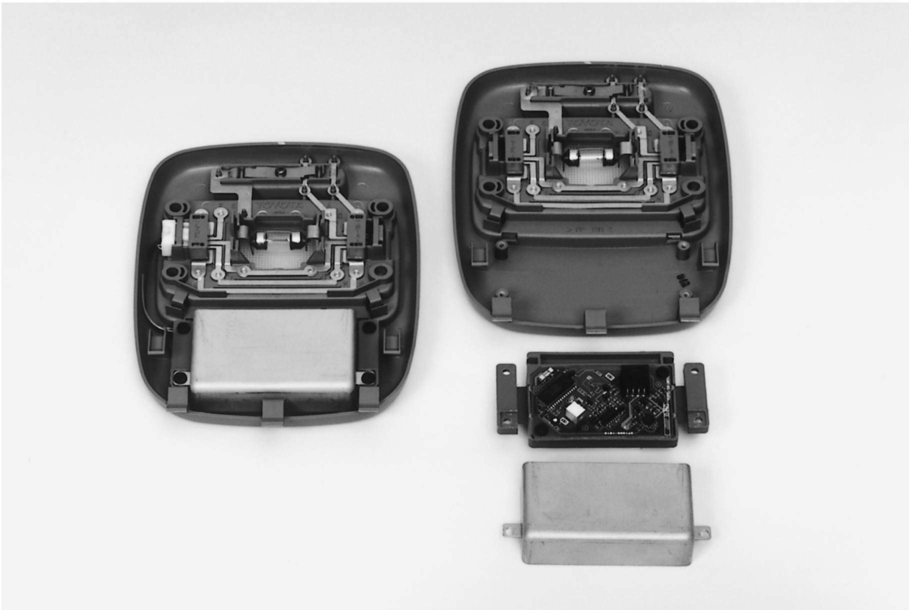
Development of Intrusion Detection Sensor for Vehicle Anti-theft Systems

● **Yoshijiro Hori** ● **Yoshihiro Sasaki** ● **Isao Miyamatsu**

● **Shinji Yakura**



Abstract

The demand for automobile security devices is high throughout Europe and North America, among other regions.Automobile insurers, especially in Europe, offer more favorable policies for vehicles equipped with a security device. To qualify, vehicle owners must meet insurers ' specific requirements, by, for example in UK, installing a warning siren with built-in batteries and an intrusion detector in the vehicle.

Fujitsu Ten has developed a security device that satisfies these requirements. In Europe, we market the device as an insurer-certified system.

This paper describes the application of the radio wave-type intrusion sensor (radar sensor that we adopt) to the system, and reviews the guarantee for this product.

1. Introduction

Demand for vehicle anti-theft devices (hereafter, security devices) is high throughout Europe and North America, where cases of automobile burglary are numerous. If a burglar tries to steal an automobile, a vehicle-mounted audio system or other vehicle-mounted components, or an article in the cabin, a security device helps to prevent the burglary by detecting it and sounding an alarm to notify people in the vicinity about the burglary. Europe, in particular, saw a sharp increase in automobile burglaries around such major developments as the reunification of East and West Germany (1990) and the collapse of the Soviet Union (1991). Statistical data on automobile burglaries in major European countries indicates that there were about 600,000 cases in 1990 and about 900,000 cases in 1993. Consequently, insurers in Europe suffered as a result of having to make payments on insurance claims for stolen cars. Since around 1991, these insurers have taken a number of measures to deal with this situation. One of these measures was to call on national governments and automobile manufacturers to enhance measures to prevent burglary. Insurance companies also began paying out less on insurance claims to owners of vehicles not certified by the insurers, and offering discounts on insurance premiums to owners of certified vehicles. Although the insurance policies vary among the insurance associations in a number of countries, in the U.K., a high percentage of vehicles have security devices installed because owners of such vehicles get to pay lower premiums.

Since 1990, Fujitsu TEN has been marketing optional security devices for European vehicles (devices that car owners can have installed in their cars at a dealer or at a port). The products first marketed were simple devices that blow the vehicle horn or blink the hazard lamps when the electronic control unit (ECU) detects the opening or closing of a door, etc. Because the techniques employed by burglars became more sophisticated, we began to ship in 1992 a system with a self-powered siren (with built-in batteries) for alarm purposes only and an intrusion sensor that can detect unauthorized entry into the cabin. In the U.K., where a high percentage of vehicles have security devices installed, demand for a line-installed device (to be installed on an automobile assembly line) has grown. We started developing this type of device in 1997 and began marketing it in 1998.

This paper primarily describes the vehicle conformance and performance assurance-related technologies applied to the development an intrusion sensor, one of the components of a line-installed product for the U.K.

2. Requirements and Features of an Intrusion Sensor

2.1 U.K. Insurers' Certification Requirements

For an intrusion sensor to be certified by an insurer in the U.K., it must pass two kinds of tests: an environment resistance test such as a temperature test, and the so-called attack test that tests the sensor's performance while it is actually installed in a vehicle.

Table 1 shows the test requirements of the attack test.

Table 1 U.K. insurers' certification requirements (attack test performed in a vehicle)

Requirement	Item	Assumed event
Detection requirement	Taking away a reference object on a seat, through a window	Stealing an article in the cabin or stealing the vehicle itself
	Hand movement near the ignition switch	
Erroneous detection prevention	Bringing an aluminum plate one meter square close to each window	Approach of a truck, etc.
	Walking around the vehicle	Environment in which the car is parked on a street
	Leaning over the vehicle	

The test requirements are classified into detection requirements and erroneous detection prevention requirements. The detection requirements simulate the theft of an article in the cabin or stealing the vehicle itself. The erroneous detection prevention requirements simulate erroneous detection triggering factors expected when the vehicle is actually parked.

2.2 Detection Technology and Features of an Intrusion Sensor

Two kinds of sensors that detect the entry of a burglar into the cabin are known: those that use radio waves and those that use ultrasonic waves. Fujitsu TEN

Table 2 Comparison of radio-wave-type sensors and ultrasonic-wave-type sensors

Item	Radio wave type	Ultrasonic wave type
Media used	Microwaves at 2.45 GHz	Ultrasonic waves at a few tens to hundreds of kHz
Effect on design	• Radio waves pass through resin, etc. - Can be installed in instrument panel. - Little effect on design	• Ultrasonic waves are reflected by resin. - An opening for a microphone is required. - Significant effect on design
Detection range	• Limited by distance and angle • Dead zone generated only by metallic objects	• A relatively large area can be covered using reflections. • Dead zone generated by objects (seats, etc.)
Malfunction	• Malfunctioning may be triggered by an object outside the cabin.	• Effect of an object outside the cabin depends on whether a window is open.

employs a radio-wave-type of radar sensor because it has no effect on the design of the cabin interior and can be installed inside the instrument panel or the console. Additionally, this sensor is advantageous because it does not easily generate a dead zone in the cabin as radio waves pass through any non-metallic object. Table 2 compares radio-wave-type sensors and ultrasonic-wave-type sensors.

3. Progress of Development

3.1 Operating Principles of the Radar Sensor

3.1.1 Detection principles

The radar sensor detects, when a moving object has entered the area where microwaves are irradiated, whereby a change takes place in the phase difference occurring between waves reflected from the object and the oscillation source. The sensor then uses this difference as an intrusion detection signal to perform system control.

Fig. 1 shows the system structure of a radar sensor. The RF block consists of a receiver, transmitter, phase difference detector, and oscillator. The low-frequency amplifier that includes a filter circuit amplifies a signal output from the RF block. The wave detector, upon detecting a signal over a certain level, assumes that an intrusion has occurred.

3.2 Features of Optional and Line-installed Products

Fujitsu TEN developed a radar sensor first as an optional device and then as a line-installed device. Table 3 shows the features of these two radar sensors.

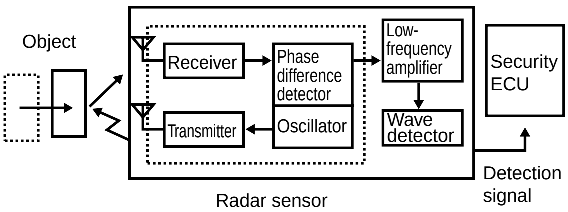


Fig. 1 System structure of radar sensor

3.3 Examining the Installation Location

To meet insurer certification requirements, the radar sensor needs to be installed where it can uniformly cover the cabin interior.

An optional device, which is retrofitted, is installed in the center console or the instrument panel where it can be easily installed and connected via harness wiring. However, a line-installed device that we have developed is integrated with the courtesy light and installed approximately in the center of the cabin. This is because the development of this device began during the vehicle design phase and, being standard equipment, can be connected via harness wiring even if it is installed in the roof space of the vehicle.

Table 3 Comparison of optional and line-installed products

Item	Optional product	Line-installed product
Installation requirement	Equipment to be retrofitted. In many cases, the installation location is determined after the vehicle design is completed. The installation location must be one that enables easy retrofitting.	Standard equipment. The installation location is determined in the design phase. This product is factory-installed by an automobile manufacturer.
Specific installation location	Inside the instrument panel, or inside the center console	Little effect is exerted on the vehicle design in the area near the centerline of the vehicle. Near the courtesy light, near the map light, inside the instrument panel, or inside the center console.
Sensitivity adjustment	The sensitivity must be adjusted on an individual-vehicle basis at a port or dealer because one product is used for many different car models.	The sensitivity is adjusted by Fujitsu TEN at the time of factory shipment because each product is used for a limited number of car models.

Before determining that the radar sensor is to be integrated with the courtesy light, however, we encountered a problem: the courtesy light installation position differs between vehicles with and without a sunroof, with the result that the radar sensor cannot cover the required detection area for the former vehicle type. In a vehicle with a sunroof, the existence of the sunroof causes the sensor to be positioned more toward the rear of the vehicle, compared with a vehicle without a sunroof. Additionally, the radar sensor capabilities are lower for the front seats of the vehicle because the space required to slide the sunroof somewhat makes the cabin ceiling lower, making it difficult for the sensor beam to reach the front part of the vehicle. Fig. 2 shows the actual sensor position and the detection area. As shown in this figure, coverage of the front seats of the vehicle is severely restricted. Additionally, the position of the sensor approximately in the center between the rear seat windows tends to cause malfunctioning for the area outside the rear seat windows.

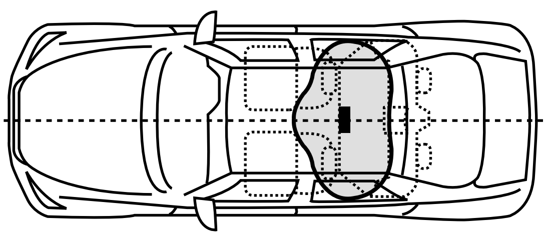


Fig. 2 Intrusion detection coverage of vehicle with sunroof

3.4 Improving the Detection Area

To improve the radar sensor detection area described above, we installed a metal reflector (hereafter, reflector) outside the sensor to change the directivity. Fig. 3 shows the shape of the reflector. Basically, the reflector is intended to minimize the leakage of radio waves to the rear and both sides of the vehicle and to extend the directivity toward the front of the vehicle. A reflector is shaped like a box with walls on the rear and both sides of the radar sensor and an opening on the front of the radar sensor.

Fig. 3 Shape of reflector

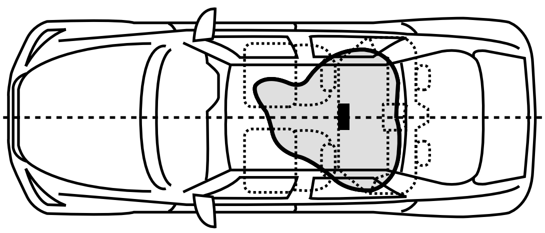


Fig. 4 Intrusion detection coverage following correction by reflector

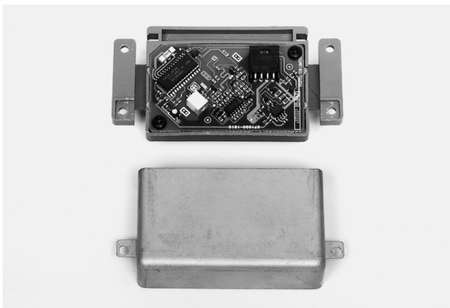


Fig. 5 Radar sensor (outside view)

Thus, we succeeded in improving the detection area to realize the coverage shown in Fig. 4, which can cover the front seats. Fig. 5 shows the outside view of the radar sensor.

3.5 Erroneous Detection Prevention Signal Processing

To improve the erroneous detection prevention performance, we focused our attention on the differences between radar sensor output waveforms. Fig. 6 shows the actual output waveform. As is apparent with these waveforms, a relatively clean sine wave is output if the erroneous detection prevention requirement for the area outside the cabin is implemented. In contrast, a sharply changing disordered waveform is output if an object is removed from the cabin. This is presumably because the electric field strength distribution in the cabin is disturbed due to reflection because the cabin interior is a metallic box. These two waveforms, when checked, have mainly a frequency content of around 4 Hz. However, we found that much harmonic content exists for activity in the cabin, and succeeded in facilitating the distinction between the cabin interior and exterior by emphasizing the signals containing much harmonic content among those at the same frequency. We employed the low frequency amplifier shown in the radar sensor block diagram in Fig. 1. This amplifying circuit, containing a filter circuit, demonstrates the clear characteristics of a band pass filter while no harmonic content exists, but demonstrates a transient response and then emphasizes signals at a specific frequency if a signal containing harmonic content such as a square wave is input. Using this characteristic to facilitate the detection of activity in the cabin, we have set the pass band lower limit of the filter to 4 Hz at which harmonic content can pass (Fig. 7).

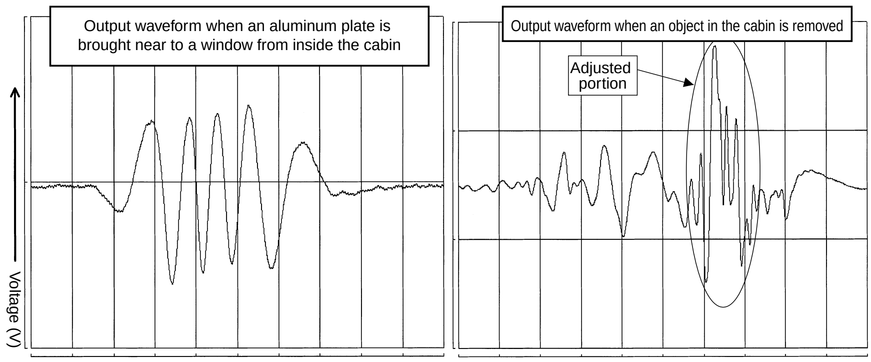


Fig.6 Output wave shape of radar sensor

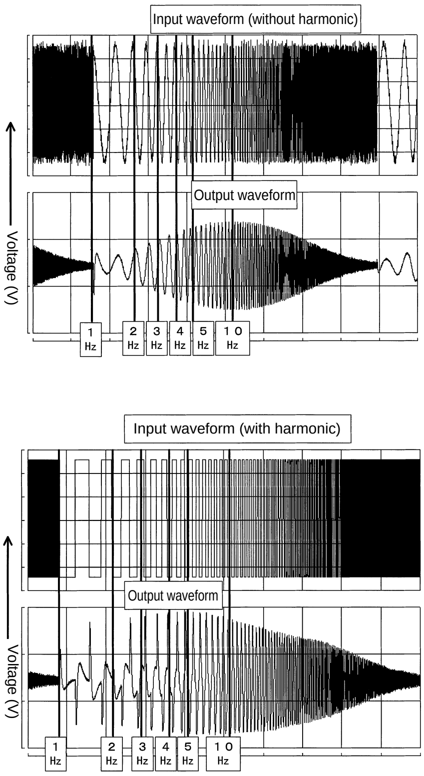


Fig. 7 Filter characteristic

4. Concept of Performance Assurance and Development of Adjustment Method

4.1 Performance Assurance Issues

The output characteristics of a radar sensor account for approximately a similar shape but includes some dispersion. Fig. 8 shows the output characteristics of a radar sensor at n=3. This graph represents the output characteristics of a radar sensor when a target object is moved at a certain distance from the radar sensor in a direction described by an angle that is inclined from the center of the radar sensor. When you adjust the sensitivity of the radar sensor, you must select the points used for correction because you cannot measure the output characteristics in all directions.

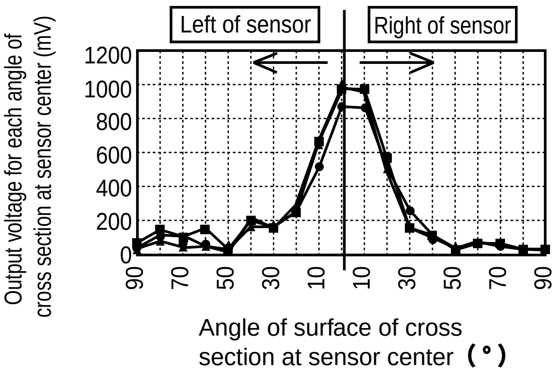


Fig. 8 Output characteristics of radar sensor crossing side for each angle

4.2 Adjusting the Sensitivity

A security device issues an alarm when a burglary occurs. However, if can also issue a false alarm if it malfunctions, which many users consider a serious problem. We therefore adjusted the sensor sensitivity for some selected points that are most susceptible to malfunctioning.

We examined the sensitivity adjustment by following the steps given below:

(1) Identifying the points outside the cabin for which the sensor is susceptible to malfunctioning
(2) Checking the propagation path taken by radio waves to the selected points
(3) Examining how to correct the sensitivity in production processes
(4) Taking measurements and checking the correlation between the detection requirements and the malfunction prevention requirements at the test facility

(1) Identifying the points outside the cabin for which the sensor is susceptible to malfunctioning

Fig. 9 shows, from among the detection requirements and the erroneous detection prevention requirements, the output distribution with excerpted requirements to which the voltage level that is output by the radar sensor is nearest when the certification requirements are implemented. The activity items that pose the greatest hurdle for the device (in this output distribution) are the removal of an object on the passenger's seat (hereafter, P seat) and leaning on the window near the left rear seat (hereafter, RrL seat), from outside the vehicle. We decided to focus our attention first on leaning on the RrL seat window, and then examining the removal of an object from the P seat, activity items most difficult for the device to detect, in terms of the detection requirements.

(2) Checking the propagation path taken by radio waves to the selected points

To check the propagation path of radio waves, we covered in turns various metal parts inside the vehicle with a piece of radio wave absorption material. Then, we had a person lean on the RrL seat window to identify as the propagation path the part accounting for the sharpest drop in the output voltage. In actuality, the path affected the most was the path in which radio waves reached the RrL seat window after being reflected by the vehicle underbody(Fig. 10).

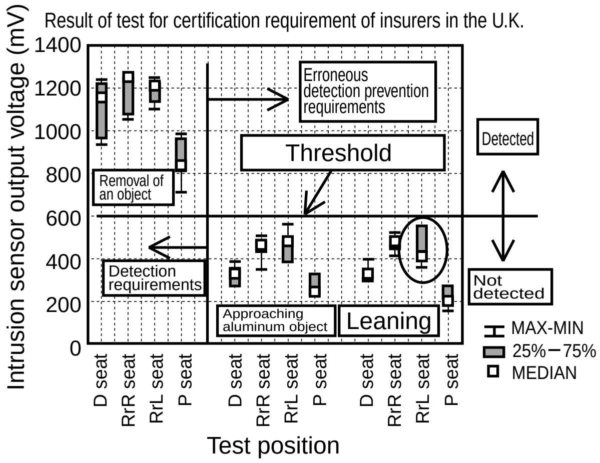


Fig. 9 Distribution of output when tested using regulation requirements

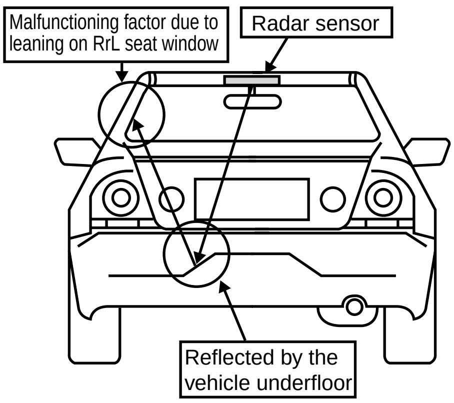


Fig. 10 Propagation path taken by radio wave to left of rear seat

(3) Examining how to correct the sensitivity in production processes

We worked on correcting sensitivity by following two steps:We set up a dipole antenna in the same position as that matching the angle of reflection from the sensor to the RrL seat and output interference waves at a certain level from this antenna. We then adjusted the sensor threshold voltage in accordance with the level of output voltage occurring at this time. Before employing this method, we checked the correlation between two types of data:individual characteristics of the sensor measured by minutely varying the angle and position of the dipole antenna near the propagation path roughly determined on the actual vehicle. data obtained by having a person lean on the RrL seat window of the actual vehicle. This allowed us to find the position with the highest correlation, for setting up the antenna. Additionally, we examined the correlation between this data and the data covering the act of removing an object on the P seat, an activity item most difficult for the device to detect, among the detection requirements in order to verify that a similar correlation exists and that there are no problems with correcting for positional change.

(4) Taking measurements and checking the correlation on an actual vehicle at the test facility

Lastly, we set up a dipole antenna inside the test facility and checked an already tested product on an actual vehicle to ensure that there were no problems in terms of correlation.

5. Conclusion

As a result of the development described so far, this radar sensor passed the examination conducted by the British Association of Insurers and obtained their certification for the first time as a line-installed device for Toyota Motors.

During the development process, we succeeded in establishing a procedure for conforming a radar sensor to the requirements of a specific vehicle model including:

(1) Changing the directivity,
(2) Filter matching, and
(3) Determining the correction factors.

Although the use of an intrusion sensor first become more widespread as a result of an increase in the number of cases of vehicle burglary in Europe, security devices are now penetrating the U.S. and Asian markets, and this tendency is expected to continue in the future. Also emerging on the market as a part of the ongoing development of security devices is a tracking system that detects the position of vehicles, enabling vehicles to be tracked if they are stolen. A security device is expected to play a major role in such a tracking system.

We expect that, under such an environment, demand will grow for products with better detection and malfunctioning prevention abilities.

6. Afterword

Anti-theft devices for vehicles are in the limelight overseas, especially in Europe and North America. Intrusion sensors, based on a variety of methods, are widespread in many countries.

Fujitsu TEN produces radio-wave-type intrusion sensors that do not affect the vehicle design when installed or easily generate dead zones in the cabin. We consider it our first priority to make the most of the characteristics of this technology to bring it closer to perfection. We intend to further accumulate know-how related to intrusion sensors during this process and use it to promote the more widespread use of security devices, probably employing also other technologies (including new detection methods).

Lastly, we would like to express our sincere thanks to Mr. Nishiwaki in the 12th Electronics Room, 1st Electronic Engineering Department, Toyota Motors and Mr. Toriyama in the Electronic Laboratory, both of whom provided us with guidance in marketing this product.

Profiles of Writers

Yoshijiro Hori

Employed by Fujitsu TEN since 1979. Engaged in developing electronic devices for automobiles such as cruise control and engine control. Currently an assistant department general manager in the 3rd Engineering Department, Vehicle Electronics Division.

Yoshihiro Sasaki

Employed by Fujitsu TEN since 1987. Engaged in developing electronic devices for automobiles. Currently in the 3rd Engineering Department, Vehicle Electronics Division.

Isao Miyamatsu

Engaged in developing electronic devices for automobiles since 1990. Currently in the 3rd Engineering Department, Vehicle Electronics Division.

Shinji Yakura

Employed by Fujitsu TEN since 1993. Engaged in developing design support tools for vehicle control systems and evaluating vehicle control systems. Currently in the System Engineering Department, Vehicle Electronics Division.