Development of a Seat Module for Automobiles

by Hirotomo Shiozaki [*], Akihito Yahara [*2], Toshikazu Doi [*3], Shigeki Motomura [*2], Atsushi Sasaki [*2], Toshihiro Kawazoe [*2], Takayuki Matsuoka [*4], Shoji Hara [*], Shigeki Itabashi [*2], Eiji Ichii [*] and Satoshi Kawai [*5]

ABSTRACT A seat module has been developed for a minor modification program of Toyota's Land Cruiser, which was put into quantity production in August 2002.

The core of a seat module is an electronic control unit with a memory function to memorize and retrieve the driver's seat position, and a number of peripheral components are integrated therein.

The developed product integrates the electronic control unit, wire harness, unit casing, and fixing bracket, thereby aiming at cost reduction, upgrading of ease of assembly, and weight reduction.

One of the features of the development is that it implements an infrared ray communication system for the control of the body system of vehicle --for the first time in the world. This paper reports on the development of the module, focusing on the development of the infrared ray communication system.

1. INTRODUCTION

Module-based production method has been introduced by many European and American car manufacturers since the 1980s as an effective method for cost reduction. In this method, the constituting modules such as doors, roofs, and instrument panels are respectively assembled from their parts, and subsequently they are assembled on the main line for vehicle assembly to complete a car. Recently, a number of domestic car manufactures have introduced this production method [1)].

On the other hand, the number of the equipment and subsystems mounted on vehicles is continuing to increase due to the technological trend of IT and electronics [2)]. With this trend, the wire harness (hereafter denoted as W/H) that supplies electric power and signals to each equipment grows in volume, resulting in the increase of vehicle weight [2)]. Because equipment to be installed in the limited space in vehicles increase in number and W/Hs are distributed threading between these equipment, designing equipment installation is becoming more difficult. On the vehicle assembly lines also, the swollen W/Hs cause big problems such that they are heavy, stiff, difficult to handle and hard to install. Thus, there is an increasing need for thinning W/Hs.

[*] Harness and Electric Components Engineering Dept., Electric Components Plant, Automotive Products Div.

[*2] Development Promotion Dept., Automotive Products Div.

[*3] Toyota Engineering Dept., Automotive Products Div.

[*4] Third Planning Dept., Plants and Facilities Div.

[*5] Production Engineering Dept., Electric Components Plant, Automotive Products Div.

Against this background, we have promoted the development of a seat module aimed at a minor modification program of Toyota's Land Cruiser. Various means for W/H thinning have been implemented such as accommodation of joint circuits into the circuit board of electronic control unit, reduction of wire-to-wire connectors through the use of board connector, and elimination of wire through the employment of an infrared ray communication system. This is the first time in the world that a wireless communication system using infrared ray has been adopted as a communication means for the body system control of a mass production car.

2. OUTLINE OF SEAT MODULE

2.1 Problems with Present Technologies

A seat adjuster of powered seat systems, in which a seat position is adjusted by electrical motors, has a number of components such as motors and links accommodated in a limited space. In the case of memory seat, an electronic control unit called "seat ECU" is additionally required to memorize and retrieve drivers' seat positions. Conventionally, much manpower was needed to assemble such systems comprised of W/Hs, seat ECU, and brackets because these were all independent components. Among others, the installation of W/Hs that were stiffened by increased circuits was known as one of the difficult works, so that earnest desires for workability improvement has been created. In particular, the part called "seat-adjuster transfer" involves careful considerations from the standpoint of product quality in terms of circuitry size and path design. This is where the W/H path transfers from the inside of a seat-adjusting rail to its outside on which a seat switch is located, whereby sometimes causing a problem such that the W/H is jammed between the seat-adjuster components as the seat changes its position in the vertical direction. Figure 1 shows the appearance of a conventional seat-adjuster assembly.

2.2 Development Goals

The development goals of the seat module are as follows.

1) Improving productivity: Reduction in installation man-hour through workability upgrading.
2) Improving product quality: Designing a W/H that eliminates jamming.
3) Weight reduction: Reducing weight through integration of components, use of resin to replace metal components, and circuit number reduction.

2.3 Module Configuration

Figure 2 shows the developed product installed on a seat-adjuster assembly. In order to reduce the component number and installation man-hour as well, the seat ECU, seat W/H, bracket, and casing have been integrated. The integration of the W/H with the seat ECU enabled a substantial reduction in the number of circuits.

Moreover, the integration with the W/H allowed an optimized module design embodying general design concepts such as accommodating circuit joints into a board and placing connectors near to the auxiliary equipment.

In addition, clamping holes for the W/H and fixing parts for the connectors were provided on the bottom face of the casing to reduce the number of components further.

Countermeasures against jamming of the W/H are known to be such that a path route is selected as far as to the back of the seat to avoid passing by the transfer part and that an opening for the W/H is provided on the seat adjuster to prevent jamming. However, problems still remain with these countermeasures such that the cost increases due to the additional wiring length for the former, and workability degrades for the latter.

At this time, we have investigated wire-reducing technologies to reduce the circuitry size. We have studied wireless communication systems based on electromagnetic wave as well as infrared ray communication systems, and decided to employ the latter for its advantageous cost.

As shown in Figure 2, a transmitter (LED) and a receiver (PD) are provided at the seat-control switch and the seat ECU, respectively, to effect unidirectional communication between them. The dotted line in the Figure shows the direct beam path of the infrared ray communication.

Figure 3 and Figure 4 show in comparison the components of the conventional and the developed W/H module, respectively. It can be confirmed that the number of components has been reduced together with the W/H size.

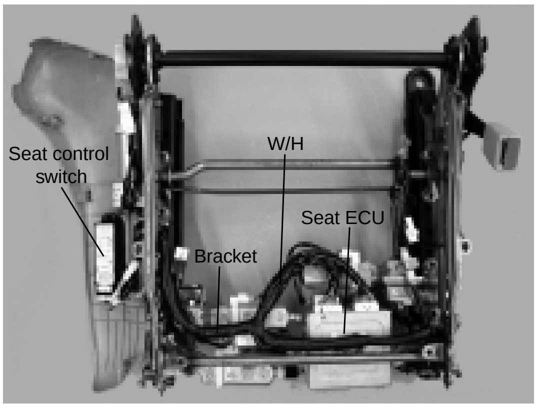

Figure 1 Appearance of conventional seat-adjuster assembly.

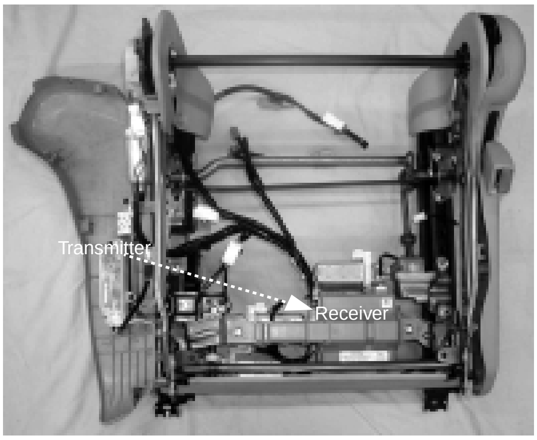

Figure 2 Appearance of seat-adjuster assembly using the developed module.

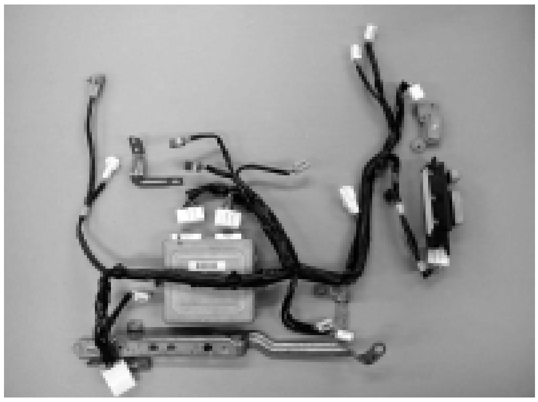

Figure 3 Components of conventional W/H module.

Figure 4 Components of developed W/H module.

The infrared ray communication system has been developed jointly with Tokai Rika Co., Ltd. since the seat-adjusting switch belongs to their products. Technologies for this in-vehicle, infrared ray communication system will be described in detail below.

3. DEVELOPMENT OF INFRARED RAY COMMUNICATION SYSTEM

Conventionally, application of in-vehicle infrared ray communication systems has been practically limited to such subsystems as remote control for audio systems and opener for door locking systems, which would give little influences to the vehicle should a failure occurs by any chance.

Because the seat-adjuster transfer part developed at this time for wire reduction belongs to a body control communication system, where the signals are transmitted from the seat-control switch to the seat ECU, the issue of ensuring reliability has been identified to be an important technological task.

3.1 Specifications for Infrared Ray Communication System

In order to implement an infrared ray communication system of high in-vehicle reliability sufficient for body control and also to make the system easily applicable, basic specifications have been set as shown in Table 1.

Illegal-signal processing of disturbing lights and the like has been incorporated in firmware to enhance communication reliability.

3.2 Infrared Ray Intensity Design

Below will be described the infrared ray intensity design with respect to the light intensity on the transmitter side and the light receiving performance on the receiver side.

It is supposed that light transmitting and receiving performance may change from their initial performance due to various factors besides original differences in the device performance, so that the Failure Modes and Effects Analysis (FMEA) was utilized to extract variable factors in the transmitting and receiving device performance, and the results were reflected in the system design.

Light intensity attenuating factors considered are: a) differences in device performance, b) changes in device performance over time, c) adhesion of dirt on to the PD cover, and d) others.

Table 1 Basic specifications for the infrared ray communication system.

Item	Content
Communication method	Unidirectional multiplex communication
Communication speed	1 kbps
Coding method	Pulse position modulation
Modulation frequency	38 kHz
Error check	CRC (8 bit)
Response	Latency time of 100 msec or less to be secured

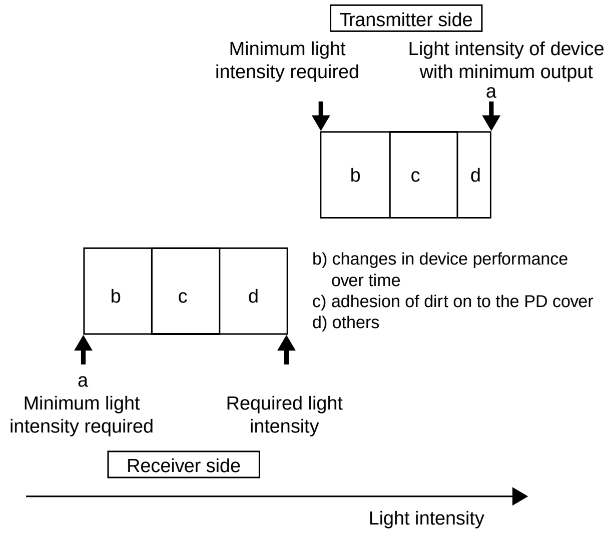

Figure 5 Design diagram for infrared ray intensity.

These factors were considered for the light transmitter and receiver respectively, and the light intensity at the transmitter was designed to meet the required light intensity at the receiver. Figure 5 shows the diagram used in the light intensity design.

The "a) minimum light intensity required" is a necessary design value of light intensity that has been specified based on the device data sheets for proper functioning of the receiving circuit, so that the intensity was determined by applying statistical processing on the measured results.

As for the device performance changes over time, the device performance data sheets were referred to. The "adhesion of dirt on to the PD cover" means a factor of light intensity attenuation resulting from adhesion of dirt on to a cover that is provided to protect the light receiving device and to prevent entering of foreign matters into the ECU. All these attenuation factors were taken into account to determine the light intensity required on the receiver side.

The upper limit of loading current for the light transmitting device, an LED, is determined from its durability taking its vehicle mounting conditions into consideration. The "light intensity of device with minimum output" means a minimum light intensity that is set based on the light intensity measurements at the loading current limit. The "minimum light intensity required" was determined considering, just like as for the receiver side, all the attenuation factors.

In order to reduce attenuation effects due to device directivity and also to make the transmitting light intensity meet the light intensity required at the receiver, both the LED and PD were installed arranging them face to face with each other.

Next will be described adhesion of dirt, which is one of the attenuation factors. Infrared remote controllers for TV sets and the like are easy to maintain by wiping out the dirt adhered on the light transmitter. In contrast, the present product has to be maintenance-free because it is installed under a seat thus making workability for wiping out very poor. Furthermore, the product has to be provided with some countermeasures against dirt because the place under a seat is, despite the fact that it is in a vehicle, likely to be dirty due to mud brought into by the shoes.

Following investigations were carried out to understand the adhesion conditions of dirt under the seats.

1) Investigation on Under-Seat Conditions of Aged Cars

The under-seat conditions of a car about 10-years aged were investigated for its pollution. It was found that dust deposited on the top surface of a duct for rear heater made of molded resin, while its side-walls had a relatively small amount of adhesion; differences in the degree of pollution arise depending on the resin material; and that the seat rail gathered dust regardless of position due to the grease applied.

Figure 6 shows the example of an RV that was driven 170 thousand kilometers.

2) Componential Analysis of Dust Adhered Under-Seat

Samples from the under-seat dust deposition were analyzed for their components and it was identified that sand and cellulose constituted most of them. Moreover, a test was conducted in which a sample of PD cover was set at the light receiving position of seat ECU for half a year. In this test, while sand was also detected, constituents of seat such as metal dust or fats and oils such as grease were not detected probably because of their low contents. We have therefore decided to develop countermeasures against dirt adhesion assuming such pollutants as sand and cellulose.

3.3 Design of PD Cover

The design level for attenuation due to pollution has been set to 70 % in view of other attenuation factors considered in the light intensity design. To begin the PD cover design, transmittance changes over two types of pollution were studied, i.e., grease adhesion and dust adhesion.

The attenuation is defined by the following formula.

$$\text{Attenuation}\,(\%) = \left(\frac{\text{Transmittance after pollution test}}{\text{Transmittance before pollution test}}\right) \times 100$$

Figure 6 Under-seat view of an RV.

Because grease is applied on the seat-adjuster rail, it is very likely that the grease adheres, during the time of seat module installation on to the seat-adjuster assembly, to the PD cover via working gloves. A small amount of grease was applied to a sheet sample simulating the assembly process, and its infrared transmittance was measured. It was found that the attenuation was as much as 46.4 %, whereas the design level had been set to 70 %.

We have decided, therefore, to provide a cylinder cover to prevent working gloves from touching the PD cover placed in the beam path.

In the evaluation of pollution due to dust adhesion, JIS D 0207 General Rules of Dust Test for Automobile Parts was adopted for the sake of dust adhesion with high repeatability.

In the preliminary evaluation where a cylinder was used as a PD cover, test particles were seen to deposit on the cylinder's interior. When dust deposits on the cylinder's interior, the reflectance for infrared ray changes decreasing light intensity.

We therefore devised a cylinder with a notch on its underside to prevent dust deposition, and a comparative evaluation was made with a cylinder having no notch.

In view of the fact that the transmitter position shifts as the seat position changes, a cylinder 7 mm in diameter was used to enable a direct reception of the beam in the full range of the transmitter position, and it was placed aslant along the lines of the infrared beam. The material is PMMA. Because of the fact that the PD was molded with a visible-light-cut resin and that the receiver was to be installed under the seat eliminating design considerations to conceal the board --as is the case with home appliances, a transparent and colorless material was selected giving preference to infrared transmittance. Figure 7 shows the structure of a PD cover.

Figure 8 shows the measured results of transmittance after dust tests using PD cover samples with different structures. Three types of samples, i.e., plate-type without cylinder, cylinder-type for beam path protection, and cylinder-type with a notch at the underside, were used. The cylinders were 7.5 mm in height. The initial value means the transmittance before the dust tests. The low density and the high density correspond to the transmittance at the low-density floating dust test (Section F3) and the

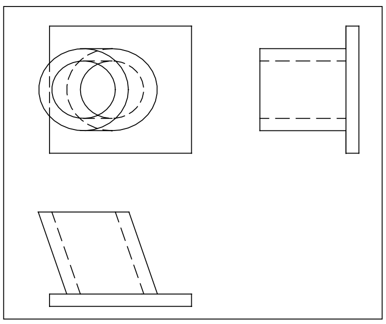

Figure 7 Structure of PD cover.

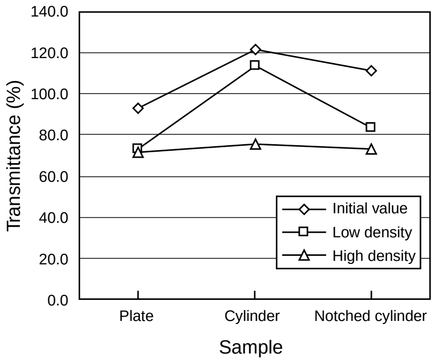

Figure 8 Comparison of transmittance between different PD cover structures.

high-density floating dust test (Section F1) both defined in JIS D 0207, respectively.

Basically, the seat module is an indoor component, so that it is required to meet the low-density floating dust test only. However, to ensure reliability against dust, the high-density floating dust test with severer test conditions was carried out, which is applicable to outdoor components. With respect to the test powder, the class 8 Kanto loamy layer powder specified in JIS Z 8901 Test Powders and Test Particles was used for the light-density test, and the class 11 Kanto loamy layer powder with finer particle size for the heavy-density test to make the test severer.

The transmittance obtained using no PD cover was defined to be 100 %, so that it exceeded 100 % due to the reflection at the inner surface of the cover when a PD cover was used.

Test samples of PD covers are shown in Figure 9. They are, from the left, plate-type without cylinder, cylinder-type for beam path protection, and cylinder-type with a notch at the underside. The beam passes through the cylinder. Kanto loamy layer powder adhered may be seen.

One of the test samples had a notch at the underside in anticipation of eliminating dust deposition on the beam window. However, it was found that such a structure tended to gather much dust on the beam path, and that a cylinder without a notch worked much more effectively against dust. It would appear that the notch caused some adverse changes in the airflow.

Figure 10 shows the results of cylinder height optimization.

The initial transmittance is seen to be higher the larger the height of the cylinders. This is presumably because of collimating effects due to the reflection at the cylinder's inner surface. Results of dust tests showed that, for the cases of both high-density and low-density dust tests, the optimal result was obtained with a sample 10 mm in height. It was supposed that, in the case of low cylinder, the transmittance for direct beam decreased due to the dust adhered on the beam window, while in the case of high cylinders, the reflection in the cylinder decreased due to the dust deposited on the cylinder's interior.

Based on these studies, it was decided to use a cylinder-type PD cover with a height of 10 mm.

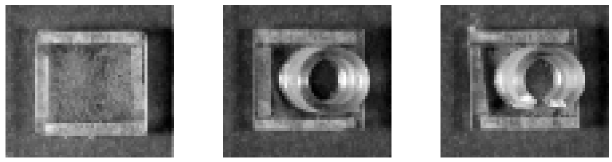

Plate-type Cylinder-type Cylinder-type with notch

Figure 9 Test samples of PD cover.

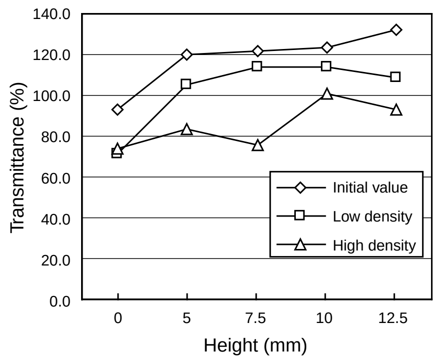

Figure 10 Comparison of transmittance between cylinders of different height.

3.4 Evaluation Methodology for Infrared Ray Communication System

We have developed and implemented evaluation methods to simulate the failure modes described in the FMEA, because our customer and we were lacking in any specifications or evaluation methods for this unprecedented system.

Evaluation items considered are: 1) influence of pollution, 2) influence of obstacles, 3) influence of other infrared ray communication equipment used in-vehicle, 4) influence of disturbing lights, and 5) endurance test using actual cars. The results of each evaluation are described below.

3.4.1 Influence of Pollution

Infrared ray attenuation under the influence of pollution on the PD cover window was evaluated. The criterion for attenuation at the window was set to 70 %.

In addition to the high-density as well as low-density dust tests mentioned before, a dust test using a type of textile fiber called cotton linter was also carried out simulating the cellulose found in the dust component analysis. A cotton linter contained in the class 15 mixed dust specified in JIS Z 8901 was used. The attenuation measurements were: 97.5 % for low-density floating dust, 88.2 % for high-density floating dust, 99.9 % for cotton linter; thus achieving the target of 70 % in all the cases.

3.4.2 Influence of Obstacles

To simulate an interruption of the direct beam by an accidental intrusion of obstacles, selected samples were used to screen the beam path, and proper operation of the system was checked. It was confirmed that the seat adjuster

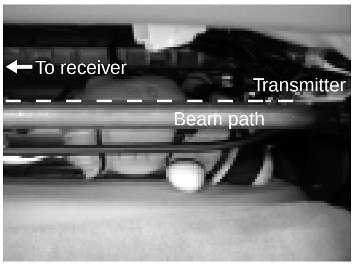

Figure 11 View of obstacle evaluation.

Table 2 Effects of seat module.

Item	Effect over conventional
Weight	40 % reduction
Installation time	57 % reduction
Number of transfer wires	39 % reduction
Number of total wires	47 % reduction

operated properly even when the direct beam was interrupted, thanks probably to light signals reflected from the seat-adjuster components. Figure 11 shows a scene of the test, where the direct beam represented by the broken line is interrupted by a stuffed toy.

3.4.3 Influence of Other Infrared Ray Communication Equipment

Influence of other infrared ray communication equipment in-vehicle on seat adjuster operation was evaluated. More specifically, another infrared remote controller was operated during the time when communication system was in operation for seat adjusting so as to confirm if there were any influences.

An infrared ray whose wavelength is within the wavelength band of the PD and whose modulation frequency is within the pass-band of band-pass filter in the receiving circuit had a chance of giving influences. It was found, however, ordinary use posed no problems.

3.4.4 Influence of Disturbing Lights

Influence of disturbing lights illuminating the receiver was evaluated. Disturbing lights considered include sunshine, lights from the outside such as road lighting, and in-vehicle lighting.

Because of the fact that a visible-light-cut resin is used for the PD and that the light-receiving amplifier has an automatic gain control function in response to the environmental brightness preventing saturation, the influence due to disturbing lights has been confirmed to be almost negligible.

3.4.5 Endurance Test Using Actual Cars

Prototype products have been installed on actual cars for endurance tests in Australia as well as in Japan, and long-term endurance was evaluated, posing no problems.

4. EFFECTS OF DEVELOPED PRODUCT

Table 2 shows the effects of the developed product excluding, because the comparison was made with conventional specifications, those on function improvement.

The installation time has been reduced to less than half the conventional, achieving a significant improvement due to modularization. The weight as well as the number of circuits have been improved. The use of infrared ray communication not only reduced the number of transfer circuits but also mitigated the problem of W/H jamming.

5. CONCLUSION

Integrating the ECU, W/H, and bracket for seat-adjuster, which have been separate components conventionally, into a module has proven to be effective in reducing installation time as well as circuit numbers. Further improvements can be expected if the range of modularization is expanded to design optimization including arrangement of seat adjuster and auxiliary equipment, connecting method, power supply, and communication system.

We intend to extend the knowledge concerning modularization acquired through this development to other modules of various parts of the vehicle. We also plan to mature the infrared ray communication technology in an effort to make it a differential technology.

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