Engine Control ECU Development for '05 Standard Model

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Abstract

Automobiles in recent years are becoming more electronically controlled in order to improve safety and environmental characteristics, and these control methods are becoming increasingly complicated.

Because of these reasons, the demand for standardization of electronic control units (ECU) and optimal placement within a vehicle has become higher since 2000. For the engine control ECU which has the largest number of functions out of all vehicle control ECUs, not only its standardization but the possibilities of mounting of the ECU in the engine room has been evaluated.

This document introduces fundamental technology that we developed in collaboration with the Toyota Motor Corporation and Denso Corporation.

1 Forward

The role of electronic control devices is growing steadily in recent years as a way of raising product value of automobiles. Engine control ECU functions and the range of control continue to be expanded. Figure 1 and Figure 2 shows the functions of microprocessors which are used as engine control ECUs, and the transition of the number of input/output in ECUs over the years.

The Toyota motor corporation is promoting development efficiency with standardization of ECU and vehicle control systems (creating an electronic platform) and optimal placement. But because engine control ECU generally employs high performance microprocessors, the passenger room where temperature and vibration conditions are generally good has been selected as an installation location.

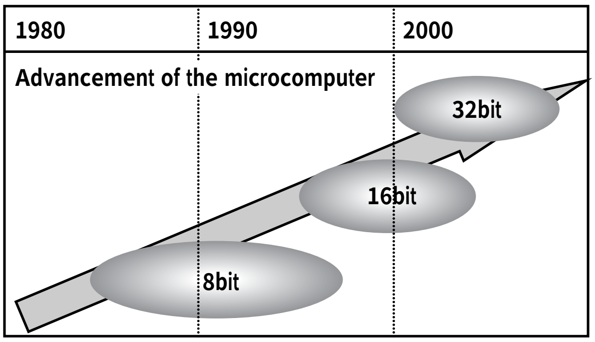


Fig.1 Advancement of the engine control microcomputer

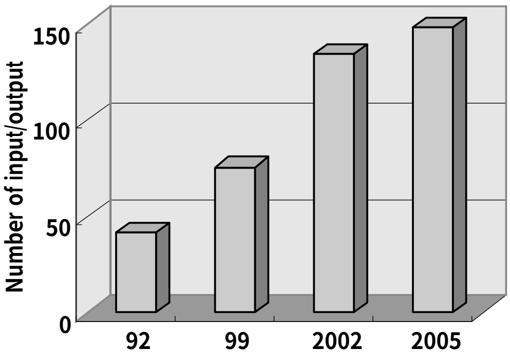


Fig.2 Number of input/output for four-cylinder engine ECU

However, the reduction of wires penetrating from the engine compartment to the passenger room, and the reduction of harness lengths to reduce vehicle weight have been promoted starting from '05 standard model. It was also decided to place the ECU in the engine compartment from the aspect of optimum engine control functionality (Figure 3).

To equip the ECU in the engine compartment, not only waterproofing but also the development of new techniques for securing reliability, heat dissipation and heat resistance design according to the heat environment of the mounting location is required. This document introduces fundamental technology that we developed in collaboration with the Toyota Motor Corporation and Denso Corporation.

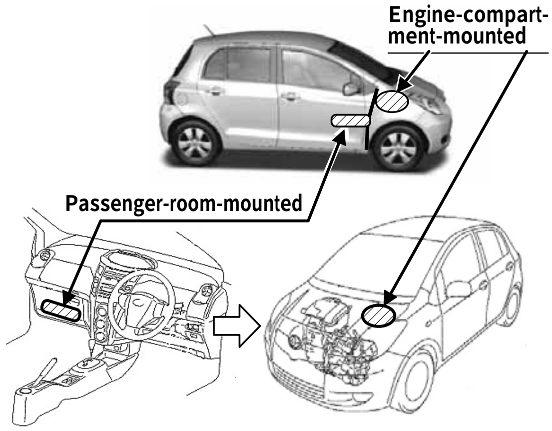


Fig.3 ECU mount location

2 Overview of the engine control system

In order to improve engine horsepower, fuel economy and emissions, the engine control ECU controls fuel injection, ignition timing, and throttle opening with precision and in an integrated manner, according to input signals from various sensors which show the status of the vehicle and engine.

For example, fuel injection control calculates the basic injection time from the amount of air intake to the engine and the engine rpm, and adding compensation for signals from various sensors, the total injection time is controlled.

The structure of engine control is shown below.

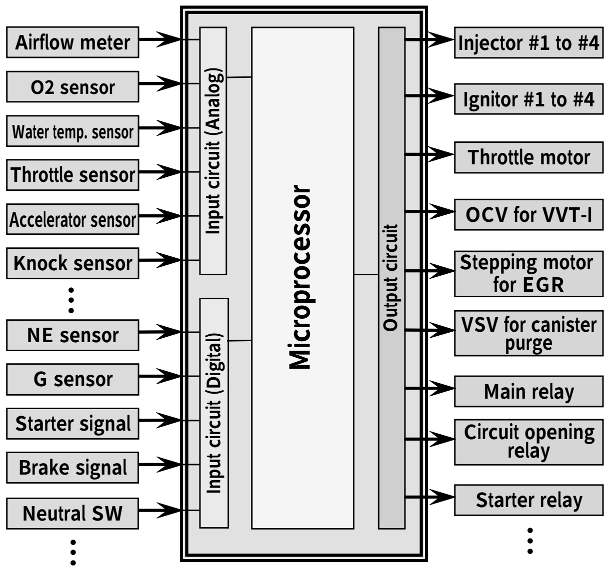


Fig.4 Structure of engine control ECU

In order to comply with advanced, complex systems, engine control ECU are also equipped with self diagnosis and failsafe functions.

3 Objectives of the development

Typically, the environment inside an engine compartment is very harsh in terms of heat, vibration, and moisture in comparison to the passenger room.

Table 1 Comparison of mounting environment

Item \ Mounting location	Passenger room	Engine compartment
Environmental temperature	−30 to 80°C	−40 to 120°C
Waterproofing	Protected	Shower-submerge
Vibration	Up to approx. 30m/s²	Up to approx. 45m/s²

Especially in a high performance engine control ECU, the balance between heat and miniaturization is a major issue. Based on the standard equipment in the initial stages of development, the target mounting environment and outer dimensions were set as follows.

Table 2 '05 standard ECU development objectives

Item \ ECU	Conventional (in pass. room)	05 Standard ECU (Engine compartment)
Operating temperature	Up to 80°C	Up to 110°C
Waterproofing	Protected	Temporary submerge
Vibration	Up to approx. 30m/s²	Up to approx. 45m/s²
Power consumption	7 to 13W	7 to 13W
Outer dimensions	193×170mm	189×148mm
Mass	Approx. 600g	600g or less

The passenger-room-mounted ECU is conventionally composed of a circuit board affixed to a die-cast box by screws, and the heat dissipation was mainly from the circuit board itself.

However for the 2005 standard model, The heat dissipation structure was fundamentally redesigned to accommodate the waterproofing required for mounting in the engine compartment, and for the ECU to operate in an operating environment that is approximately 30°C higher in temperature then previous models. The details of the fundamental technology used for this purpose are the following:

(1) Heat dissipation technology

By dissipating heat from the component to the die-cast case, the heat dissipation characteristic is improved, and the temperature surrounding the microprocessor is lowered.

(2) High reliability technology

Improvement of reliability through thinning of the circuit board.

(3) Waterproofing technology

Securing vehicle-mounting reliability through a waterproof seal with a ventilation function.

(4) Miniaturization/weight reduction technology

Compact and weight saving design using a resin outer case.

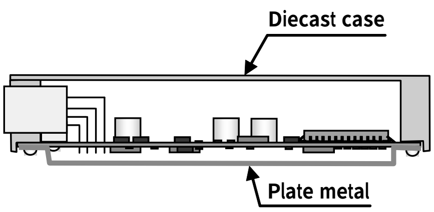


Fig.5 Conventional ECU structure

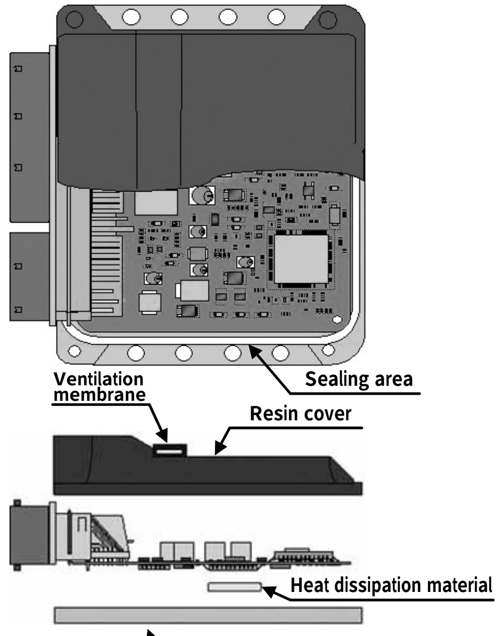


Fig.6 '05 standard model structure

4 Development Technology

4.1 Heat dissipation technology

1) Development objectives

In the 2005 model, the mounting location is changed to be inside the engine compartment. There is then an issue of reduced heat dissipation due to both a rise in ambient air temperature, and from the miniaturization of the outer casing, and a more aggressive thermal design is required. The reduction of the temperature surrounding the microprocessor, and the heat dissipation for the power IC which consumes the most electricity were the most important concerns.

As a method for improving heat dissipation, many types of forced cooling have been developed for consumer electronics products, such as for home game systems and personal computers. Heat pipes with high heat conductivity and heat sinks with fans are typical measures used for this purpose.

For automotive products, a metal with high heat conductivity is often used for the base metal to dissipate heat from the circuit board, but these methods above prevents the miniaturization of engine ECU's which has the largest number of functions, and they are often not cost effective.

In this development, the use of a multilayer resin circuit board that is effective in cost savings and mounting density, and the utilization of the existing package that is proven in reliability were set as prerequisites, and the following development targets were evaluated.

①Heat resistance of the Power IC section: 1/2 or less of previous models

②Temperature rise at the microprocessor: 15℃ or less

The following describes the actual measures that were used in each section.

2) Power IC Heat dissipation structure

As the ambient temperature of the passenger-room-mounted ECU is low, the heat dissipation is mainly through the heat dissipation to the circuit board. However, '05 standard model has such structure that the power IC required for heat dissipation is mounted on the opposite side from the microprocessor and the heat is dissipated from the back of the component to the die-cast case through a heat dissipating material.

For the heat dissipation material, thermal sheets, a rubber type heat dissipating material consisting of mainly silicone, and a gel type of heat dissipation material like thermal grease was evaluated, but because a reaction force will be applied directly to the part during assembly due to the structure shown in Figure 6, a gel type of heat dissipating material was applied to reduce stress through its fluid characteristics.

However on the other hand, the gel type material is inferior in heat conductivity in comparison to a heat dissipation sheet. It was therefore necessary to determine design values taking into consideration the level of effect that the application area of the thermal material has to heat dissipation characteristics of the ECU in a quantitative manner, and any possible variations, and include these in the design conditions.

Figure 7 is a specific example of this, and shows the relationship of the application area of the heat dissipation material and heat resistance.

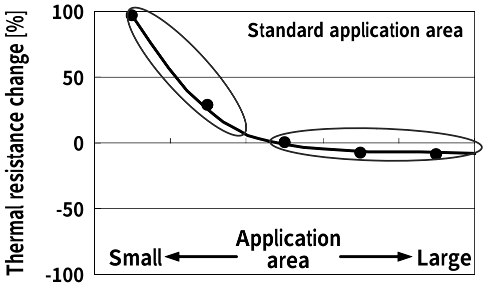


Fig.7 Relationship of the application surface area of heat sink material and heat

As can be seen in Figure 7, in the IC used in this development, it was confirmed that for a given application of heat dissipation material that is less than a certain standard surface area, the variation of the material amount greatly influences the heat dissipation characteristics of the component, while if the application area that is larger than a certain standard area is secured, the influence of the application amount to heat resistance is small regardless of the exterior shape of the mould.

As a result of this, the amount of heat dissipation material application was determined while taking into consideration the application precision of the heat dissipating material application facility.

3) Thermal measures for the microprocessor

Because the heat loss in a microprocessor used in '05 standard model is small in comparison to the power IC, no special heat dissipation structure is used, but the issue here is in avoiding the thermal interference from the surroundings, to maintain guaranteed operation temperatures.

As shown in Figure 6, the basic structure of the ECU consists of power ICs equipped on the opposite side of board from the microprocessor. By dissipating heat to the die-cast case side, the heat sources are separated from the front and rear sides of the circuit board, to reduce temperatures around the microprocessor.

Locating parts with high heat loss near the microprocessor can be expected to cause a localized rise in temperature. For this reason, the power IC locations were dispersed, and they were located near the edges of the case where added heat dissipation through the bracket can be expected.

The effect of this layout was confirmed through heat simulation in the initial design stage, as shown in Figure 8, and applied to the component layout and circuit pattern design. From an actual thermograph photo of an operating ECU shown in Figure 9, the effect of the heat source distribution can be confirmed in the image of the power IC equipped surface.

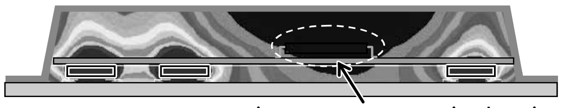


Fig.8 Heat simulation results

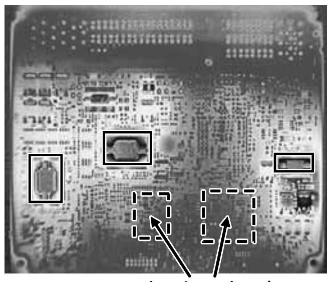


Fig.9 Thermography during ECU operation

4) Conclusion

The following targets were achieved as a result of the efforts described above.

①Heat resistance of the power IC section: Less than 1/2 of previous models

②Microprocessor ambient temperature rise: ΔT = 10℃ or less

4.2 High reliability technology

1) Securing connection reliability in a multilayer resin circuit board

To miniaturize through high-density mounting, a 6-layer circuit board and 0.3 to 0.4 mm via holes are utilized, but these presented a challenge of securing reliability in a wide temperature range on the high temperature side.

In regards to the symptom of circuit board thermal expansion and contraction causing reductions in connection reliability at via holes, it can be seen in Figure 10 that this is caused by the linear expansion rate in the thickness direction being greater than in the surface direction.

In order to achieve a high density design, the via holes are miniaturized from 0.5 mm dia. to 0.3 mm dia., and the resulting cyclic stress occurring per unit area is increased more than 1.5 times, posing an even more difficult condition.

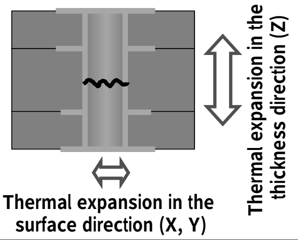
	Linear expansion coefficient	Destructive mode
Surface direction (X, Y)	Approx. 13ppm/°C	
Thickness direction (Z)	Approx. 60ppm/°C	

Fig.10 Physical properties of the circuit board and disconnected area of the through hole

In order to reduce the stress occurring at the via hole, the thickness of the circuit board was changed from the typical 1.6 mm to 1.2 mm. This is to reduce changes occurring in board thickness due to heat, so that connection reliability of via holes would be secured. Figure 11 shows the comparison of this board structure.

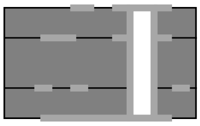
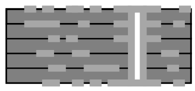
	Conventional product	Developed product
Configuration		
Layer structure	4 layer, t1.6mm	6 layer, t1.2mm
Via hole	φ0.5mm	φ0.3mm
Pattern width/Spacing	0.25/0.25mm	0.15/0.15mm

Fig.11 Comparison of circuit board structure

Figure 12 shows the relationship between through-hole connection life and hole diameter/circuit board thickness that was confirmed. It can be understood from this result that the reduction of via hole diameters for a circuit board of the same thickness leads to a reduction in reliability, but a change in the board thickness from 1.6 mm to 1.2 mm improves connection life by approximately double that of previous designs even when using 0.3 mm dia. via holes. This secures a lifespan for the part that exceeds previous designs.

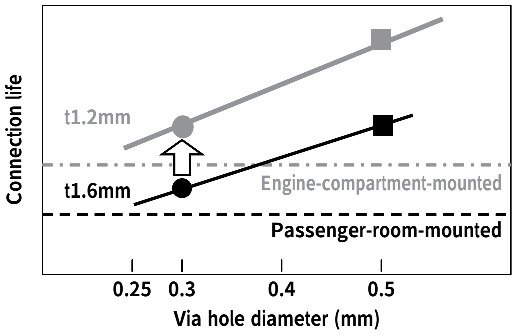


Fig.12 Relationship between hole diameter and connection life

There was a concern for a possible increase in board warpage, due to the reduced board thickness, but in this design, the ratio of remaining copper after etching was evaluated for this pattern design. By designing an equal remaining copper ratio for each layer, the board warpage during soldering was reduced.

Figure 13 shows the amount of remaining copper for each layer in the 2005 standard model, and it can be seen here that the layers are balanced well in their wiring patterns, from the center of the layers.

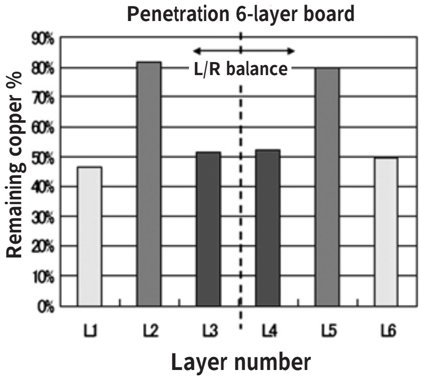


Fig.13 Ratio of remaining copper per layer

By thinking the board thickness, connection life was more than doubled, and the reliability of small diameter via holes in the engine-compartment-mounted environment was secured.

4.3 Waterproofing technology

1) Waterproofing performance

The waterproofing performance of automotive components is divided into three categories of shower, spray, and submerge. Typically, the highest mounting locations in an engine compartment where the fuse box is installed are subject to "shower", front headlights and other areas that are exposed to direct spray of rain and wind or are exposed to splashing water are subject to "spray", and components that can become temporarily submerged at the bumper height or lower, where many sensors are mounted in recent years, are subject to the "submerge" condition.

In the '05 model, development was performed to satisfy temporary submerge conditions in order to broaden the flexibility of mounting in the engine compartment.

Table 3 Water resistance performance comparison (JIS D 0203)

Classification	Division	Target product
Shower	R1	Components that may be exposed to water droplets
	R2	Components that may be indirectly exposed to rain water, or splashing.
Spray	S1	Components that are directly exposed to rain or splashing water
	S2	Components that are heavily exposed to water
Submerge	D1	Components that may be temporarily submerged in water
	D2	Components that are continually submerged, or those that are designed to be completely waterproof.
	D3	Special purpose waterproof components

2) Waterproofing structure

For methods of waterproofing structures, there is a "completely sealed" type, and "internal pressure adjustment" type.

For "completely sealed", it is a totally enclosed structure using soldering or adhesive of the mating surfaces, or through filling with resin, etc., and are used for sensors and igniters, etc. Though it is superior in waterproofing, those that are not filled with resin require consideration for stresses placed on the casing and seal area due to pressure or temperature changes.

On the other hand, those with "internal pressure adjustment" have a ventilation port or a ventilation membrane, and are used for headlights and ABS-ECU. For most ECU, a breather type structure with a ventilation membrane is utilized.

For this current unit, a waterproofing structure with an internal pressure adjustment function that can withstand submerging under fixed conditions, and that would not lose reliability due to cyclic stresses caused by temperature changes in the engine compartment was developed.

3) Sealing

The 2005 standard model structure requires waterproofing between the resin cover, connector, and die-cast case, and the waterproofing surface is not at the same level surface. The use of a typical O-ring was difficult, so a liquid silicone that can be applied to the sealing area in the assembly process was utilized.

As shown in Figure 14, the shape of the sealing area is a U-shaped groove along the seal application area formed by the resin cover and die-cast case. This shape allows an adequate seal contact depth and air tightness, even when the application amount of the seal was low in volume.

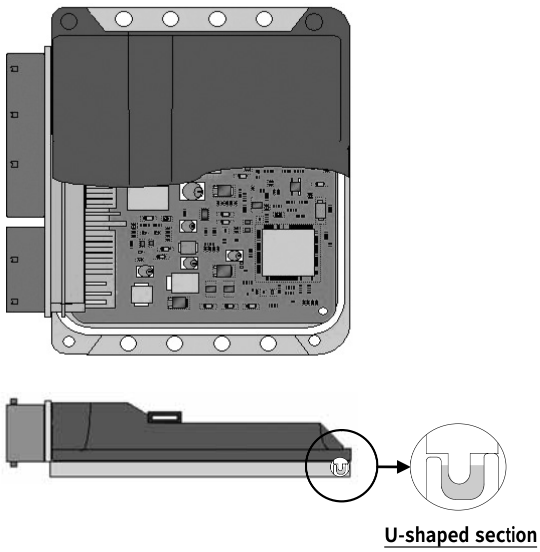


Fig.14 Configuration of the sealing area

4) Improvement of reliability by sealing

Figure 15 shows the internal vacuum created in the ECU due to temperature changes of the casing. If an ECU exposed to high temperatures is completely submerged, the ventilation membrane is covered by water and the internal pressure control function does not function. The ECU is cooled in tfhis condition by the water, and the air inside the unit will contract, and vacuum exceeding approximately 20 kPa will occur. On the other hand, the worst-case condition for a partial submerged condition was evaluated for a condition with the ECU submerged, excluding its ventilation membrane. Because the internal pressure adjustment function of the ventilation membrane will function in this condition, a temporary vacuum will occur, but the vacuum is less than 1/5 in comparison to the completely submerged condition, and the internal pressure of the ECU will revive to atmospheric pressure given time.

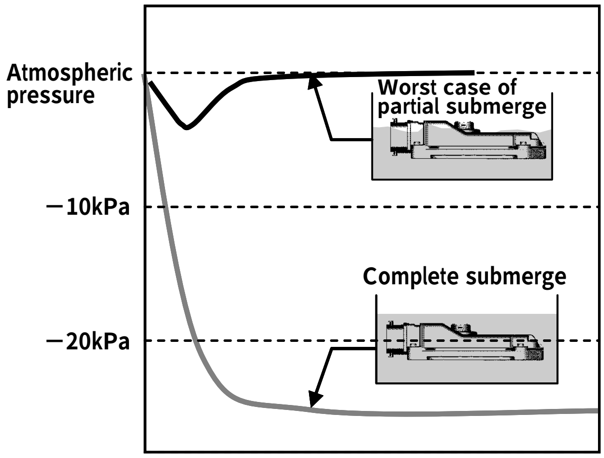


Fig.15 Differential pressure occurring from temperature change

Figure 16 indicates the evaluation results for waterproofing endurance in a temperature cycle testing. In a completely sealed model where the ventilation membrane was sealed, it could not maintain the waterproof seal for the target number of endurance cycles. The test unit with the ventilation membrane showed double the life of the sealed version. Therefore, the internal pressure adjustment function shown in Figure 15 is proven to reduce the stress applied to the seal area.

Figure 16 Relationship of sealing life to temperature cycle

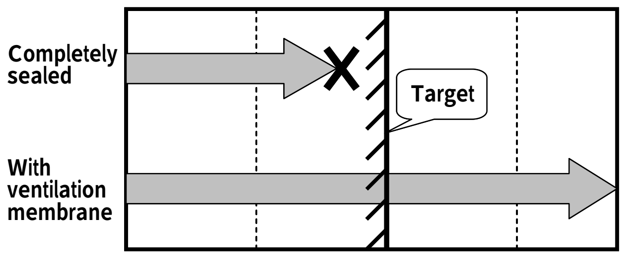


Fig.16 Relationship of sealing life to temperature cycle

Through this, a "temporary submerge", the objective of waterproofing, was secured with the long term reliability required for vehicle-mounted ECU.

4.4 Miniaturization/weight reduction technology

1) Weight reduction through application of a resin case

As described in the heat dissipation technology of section 4.1, it had become unnecessary to use metal materials for the cover side casing on the side where the microprocessor is located, through direct heat dissipation to the die-cast casing from the power IC, and separation of heat sources

So in order to reduce the weight of the ECU, we evaluated using a resin material for the casing on the cover side.

The leading types of engineered plastics used inside the engine compartment include PP (Polypropylene), PA (Polyamide), PBT (polybutylene terephthalate), and PPS (polyphenylene sulfide), but considering :

1. Endurance under high temperature, high humidity environments,
2. Solvent resistance against oil and other chemicals
3. Shock endurance due to falling tools, etc.
4. Compatibility with sealing materials
5. Matching with connector materials

for its function as an ECU, PBT was selected for use.

From various types of PBT, a material that contain some glass fibers was selected from a strength and heat resistance point of view, and for compatibility with sealing materials, a material that does not contain "adhesion preventing substances" that would affect internal mold-releasing agent and other adhesion characteristics, was utilized.

From the above, [PBT-GF30] was selected for the resin cover. This selection allowed for a cover that does not lose its seal under cyclic stresses of temperature and humidity, resists shock, and secures the target waterproof reliability.

For the size of the ECU, a reduction of 20% volume and 10% mass from previous passenger room model ECUs was achieved through high density mounting and reduction of space within the ECU, while still securing performance required for mounting inside the engine compartment.

5 In Closing

This document reported mainly on the effects of heat on an ECU, relating the major changes made for mounting ECU normally mounted within the passenger room, in the engine compartment.

However, vibration, solder life, and corrosion effects were still major issues for an ECU, and we have only succeeded in developing an engine control ECU that is possible to equip inside the engine compartment as a result of evaluating each of these issues one by one.

Another result of these efforts, was that by developing this structure, this 2005 standard ECU for the engine compartment enabled the creation of various ECU divided per function in the same structure.

Automobiles are relying more and more on electronic control. ECUs are required to be superior in performance and functions, compact, heat resistant to improve freedom of equipment location, and lesser in cost. We will be continuing our research and development hereafter to further contribute to the development of automotive technology.

Finally, we thank those at the Toyota Motor Corporation's Vehicle Engineering Group, Electronics Engineering DIV. I Electronics Laboratory, Electronics Engineering DIV. II, Product Development Group, Vehicle Electronics Engineering DIV, and the Denso Corporation's Electronics Engineering Department 1, Electronics Engineering Department 2, and all other related personnel including suppliers and those within and outside Fujitsu Ten.

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