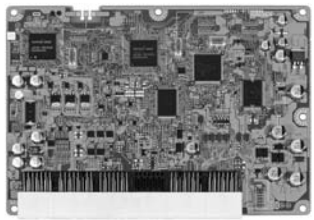
Development of Plug-in Hybrid Control ECU

Ryuichi KAMAGA
Hiroshi MORIGUCHI
Takaaki FUKUSHIMA
Satoshi FUKUI
Takuya HIBINO
Tsuyoshi TAKATORI



Abstract

Recently, as a growing number of hybrid vehicles are commercialized by automobile manufacturers to comply with environmental regulations, the market for hybrid vehicle control ECUs (HV-ECUs) is expanding. FUJITSU TEN has been manufacturing HV-ECUs to deliver to TOYOTA MOTOR CORPORATION for its GS Hybrid, LS Hybrid, Crown Hybrid, and Prius. Among hybrid vehicles, attentions are especially focused on plug-in hybrid vehicles (PHVs) of which battery can be charged through a cable being plugged into a household electric outlet to use them as electric vehicles for short distance driving. TOYOTA MOTOR CORPORATION has already launched sales of a PHV in December 2009 under the brand name of Prius Plug-in Hybrid Vehicle (hereinafter referred to as Prius PHV). FUJITSU TEN has manufactured and delivered the ECU that controls hybrid driving and plug-in battery charge (plug-in hybrid vehicle control ECU or PHV-ECU) for Prius PHV. This paper explains the outline of the ECU.

1 Introduction

With environmental efforts increasing across the global and oil price rising, car users become more interested in environmentally-friendly functions of cars such as fuel efficiency. In Japan, hybrid vehicles (HVs) have drawn attention and their sales have surged due to the introduction of a tax break for purchasing environmentally-friendly a vehicle, which became effective in fiscal year 2009. Tightening their environmental laws and regulations year after year, countries around the world demand car manufacturers to improve fuel efficiency and reduce CO_2 emission of their cars. Europe has established a CO_2 emission value to be satisfied, and CARB (California Air Resources Board) of the United States obliges car manufacturers to market ZEVs (zero emission vehicles) from 2012. In response to these regulations, some car manufacturers have announced electric vehicles (EVs) or when they will start selling EVs.

While EVs are environmentally-friendly, they have their own issues to be dealt with, such as battery capacity and cost, which do not allow the EVs to compete with gasoline vehicles in terms of traveling distance and selling price. Therefore, plug-in hybrid vehicles (PHVs) stand at the center of attention because it can be used as an EV when a user drives short distance. TOYOTA MOTOR CORPORATION started sales of Prius PHV with a limited quantity in December 2009.

FUJITSU TEN manufactures the ECU (plug-in hybrid ECU or PHV-ECU) that controls hybrid functions and battery charge from external power source (plug-in function) for Prius PHV. This paper explains the outline of the ECU.

2 System Configuration

2.1 Hybrid Vehicle (HV)

Before touching upon the PHV mentioned above, here is explained the system configuration of Prius HV, which is the base vehicle of Prius PHV. Generally, the HV is equipped with two or more different types of power sources and uses one or more of them to run, according to the situation. Among various power sources, Prius HV uses gasoline and electricity as power sources, and the engine and the motor supply power when driving force is demanded by pressing the accelerator.

HVs are excellent in quietness and fuel efficiency which are their well-known advantages. Their major functional characteristics are: idle stop; assistance by the motor during acceleration; EV driving, which means a vehicle runs only using power from the motor; and regenerative brake system that recovers electricity generated at braking.

The systems and their roles necessary to materialize those functions are explained below. The HV is added with the following systems that do not exist in the gasoline vehicle (**Fig. 1**).

①Transaxle including a motor, an electric generator and a power split device
②Power control unit (PCU)
③High voltage battery
④Computer that controls the hybrid system (Hybrid ECU: HV-ECU)

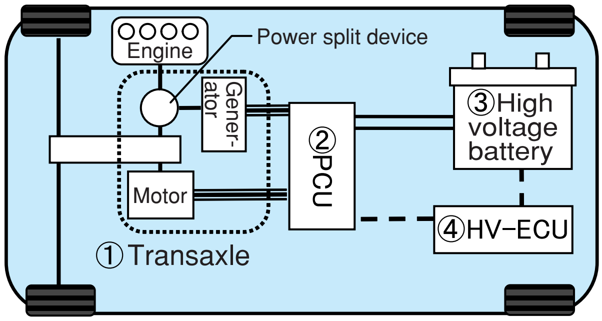


Fig.1 System Configuration for Prius HV

The HV enables "idle stop," using the generator as an engine starter. The HV "provides assistance during acceleration" and "runs as an EV" by driving the motor with power supplied from the high voltage battery. Moreover, the HV supplies electricity to the high voltage battery by adopting the "regenerative brake system" where the motor converts kinetic energy to electricity and a system where the engine drives the electric generator. The electricity generated in those systems are adjusted by PCU and distributed by the power split device. The HV-ECU controls the entire system of the vehicle based on various input signals.

2.2 Plug-in Hybrid Vehicle (PHV)

Here, the system configuration of Prius PHV is described. The high voltage battery of a HV is charged when its engine is working such as during traveling and idling. However, the PHV is the HV of which battery can be charged from an external power source when the PHV is stopping. A user can charge the PHV high voltage battery by plugging the battery charge cable installed with the vehicle into an electrical outlet at home as an external power source.

One of major characteristics of the PHV is to have functions of both the EV and the HV. The PHV can be an EV, when using charged electricity for short distance driving, leading to reduction in CO_2 and fuel cost. For long distance driving or driving on a freeway, the PHV can be used as a conventional HV. In other words, a user can drive a PHV in an area where the infrastructure for charging the battery of an EV has not been established.

Prius PHV is different from Prius HV in the following five points (**Fig. 2**).

①Inlet added in which the battery charge cable is plugged, on the area close to the door, of the left front fender
②Inverter added under the driver seat for converting AC for household use to DC to charge the high voltage battery
③Change of high voltage battery from nickel hydride to lithium-ion battery, installed under the luggage area, and enhancement of its capacity
④Change of the computer to control the hybrid system to a plug-in hybrid ECU (PHV-ECU) as the function of

battery charge is added

⑤Functions added to provide information to users by changing meter display and adding a battery charge indicator, etc.

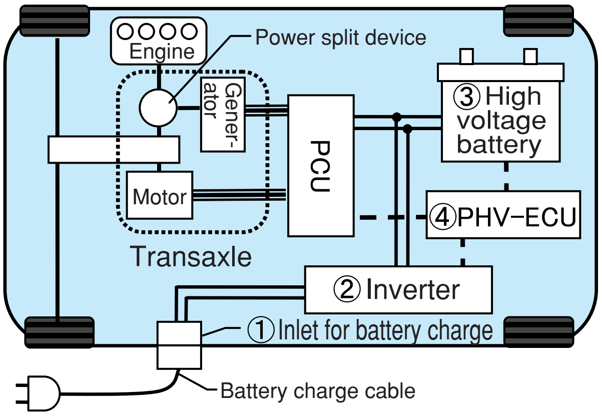


Fig.2 System Configuration for Prius PHV

With these system changes, Prius PHV achieved 23.4km of traveling distance as an EV powered by electric motor, a significant improvement from its base model Prius HV.

If only longer running distance had made a PHV different from an EV, the PHV could have been realized by adding a battery charger and an enhanced battery. However, actually, in order to realize a PHV, new ECUs need to be integrated into the PHV and the PHV is required to satisfy environmental and other standards and regulations. Therefore, FUJITSU TEN made various improvements to the conventional HV-ECU to materialize a PHV-ECU that controls the whole system of a PHV.

3 ECU Configuration

3.1 Difference from Conventional ECU

As mentioned above, the plug-in hybrid vehicle ECU (PHV-ECU) is added with the function of plug-in battery charge to the conventional hybrid vehicle ECU (HV-ECU). Due to the additional function, the capacity required for the control software of the PHV-ECU drastically increased and we decided the configuration with three CPUs, instead of the conventional configuration with two CPUs, to deal with the increased function.

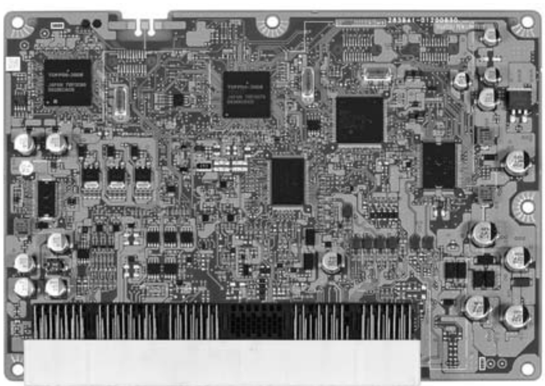


Fig.3 PHV-ECU Configuration

3.2 Use of Asset Gained from Previous ECU Designing

The discussion began in 2007 to develop a PHV-ECU and, we were required to launch the mass production of the ECU in about three years. The system of the ECU was so novel that there was a possibility that we developed it in the "scrap-and-build method." Therefore, we prioritized efficient development and tried to use a configuration that allowed us to develop the ECU based on our asset gained from previous HV-ECU designing.

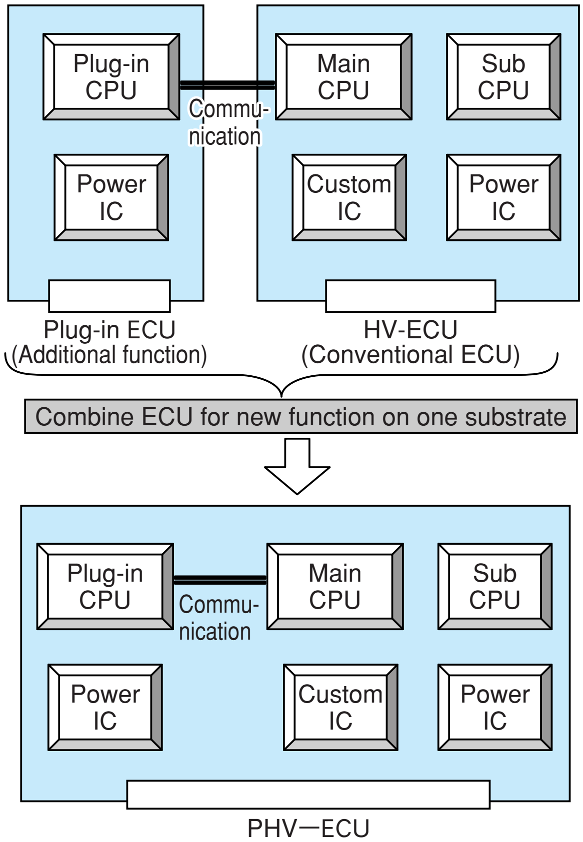


Fig.4 ECU Configuration

An initial configuration considered as the most effective was the one where a new ECU (plug-in ECU) to be developed for new functions was separate from the conventional HV-ECU. However, communication between the HV-ECU and the plug-in ECU did not satisfy requirements in terms of data capacity and speed as a system. Therefore, as shown in **Fig. 4**, new functions were added to the conventional HV-ECU and integrated into one substrate for faster communication. Moreover, the adopted ECU configuration had an advantage in designing and evaluation because we were able to use the accumulated assets gained from developing circuit and substrate configurations of the previous HV-ECUs. Furthermore, with the concept of the configuration where the main and sub CPUs and plug-in CPU are disposed on the same substrate, the points to be changed were minimized by using the control specifications and fail-safe methods used for the conventional ECUs.

3.3 Outline of Activation/End Process of ECU

As for the conventional ECUs, the system is turned on by pressing the start switch. However, as for PHV-ECU, battery charge is required to be turned on and controlled by plugging the cable, besides pressing the start switch. To that end, in addition to the input from the activation pathway of the conventional push-start switch, as shown in **Fig. 5**, a new function was added to detect the input representing the cable plugged in and turn on the battery charge system.

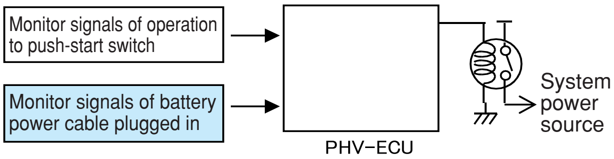


Fig.5 Flow Diagram of Battery Charge Activation

Moreover, when the battery is fully charged, the system is turned off and stands by for an activation command.

4 Battery Charge Control

4.1 Battery Charge Cable

The battery charge cable exclusive to Prius PHV is used when the battery is charged with a household electric outlet (**Fig. 6**).

Fig.6 Battery Charge Cable

The interfaces of the battery charge cable and the inlet on Prius PHV comply with the SAE standard "SAEJ1772: SAE Electric Vehicle Conductive Charge Coupler." Having the functions to "detect the connection status of the battery charge cable to the vehicle," "detect electric leakage," and "disconnect the vehicle from the household electric outlet," the interface on the battery charge cable side is housed in the square case (CCID box).

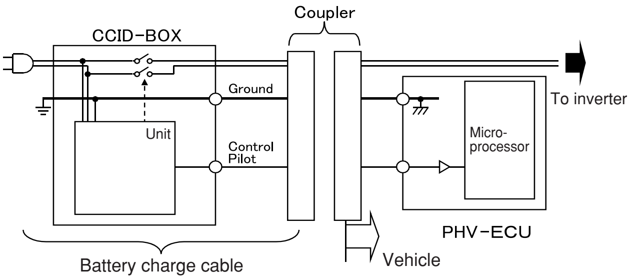


Fig.7 I/F between Battery Charge Cable and Vehicle

Fig.8 Battery Charge Case Lid on Vehicle

4.2 Battery Charge Procedure

The following steps show the battery charge operation procedure defined in the SAE standard.

Step 1: Detection of Connection with Vehicle

The unit in the battery charge cable detects connection of the cable to the vehicle by monitoring changes of signal voltage of control pilot (from V1 to V2).

Step 2: Notification of Rated Voltage

The unit in the battery charge cable notifies the PHV-ECU of the rated current of the power source (household electric outlet & cable) in the form of duty cycle of control pilot signals (square wave).

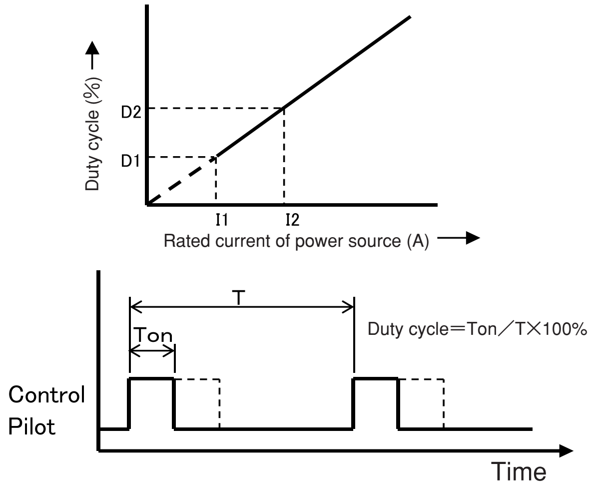


Fig.9 Wave Pattern of Control Pilot Signals

Step 3: Notification of Completion of Battery Charge Preparation on Vehicle Side

The PHV-ECU notifies, by changing the voltage of the control pilot signals (from V2 to V3), the unit in the battery charge cable of completion of battery charge preparation.

Some standards stipulate the necessity to inform the power source side of air ventilation when the variation of voltage change is increased (from V2 to V4). However, Prius PHV does not require the air ventilation so that the information is not notified.

Step 4: Connection of Contact Point in Cable

After detecting the notification that the preparation for the battery charge is completed, the unit in the battery charge cable connects the contact point to the vehicle for charge.

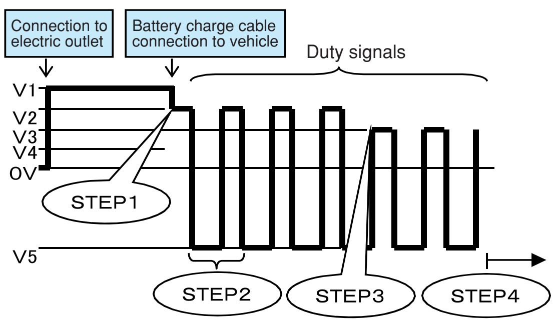


Fig.10 Control Pilot Signals Monitored from Battery Charge Cable

The unit in the battery charge cable is capable of cutting the electricity off at the contact point when detecting a problem such as electric leakage and a failure in ground connection to the power source side.

Prius PHV has a lamp on the dashboard on the passenger side to light while the battery is being charged. Therefore, people can see the battery being charged from the outside (**Fig. 11**).

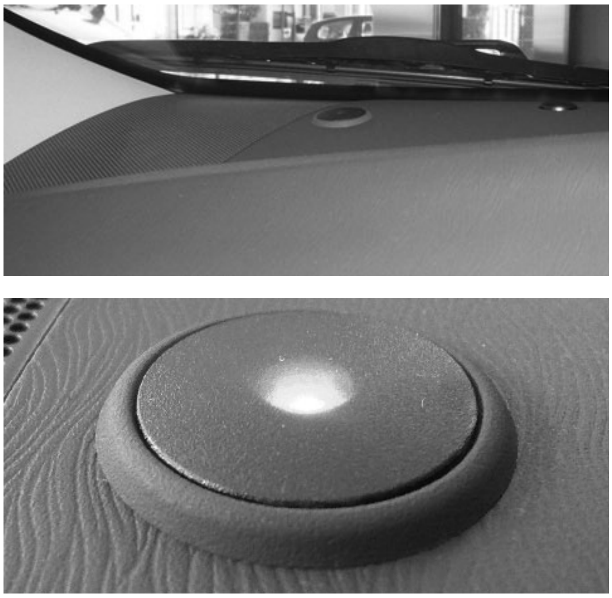


Fig.11 Battery Charge Lamp

4.3 Behavior of PHV-ECU

The following are the requirements for a PHV-ECU to be installed in Prius PHV.

- **It stands by in the case of power failure of the household electric outlet.**
- **It stands by after the battery is fully charged.**

In order to satisfy the above requirements, a change in control pilot signals mentioned above is set as the trigger to activate the PHV-ECU. When the control pilot signal becomes high, the microprocessor is activated and the system on the vehicle side is turned on. Moreover, the following improvement was made for the behavior of the control pilot signals for Prius PHV.

With **Fig. 12** below, the control pilot signals of Prius PHV will be explained.

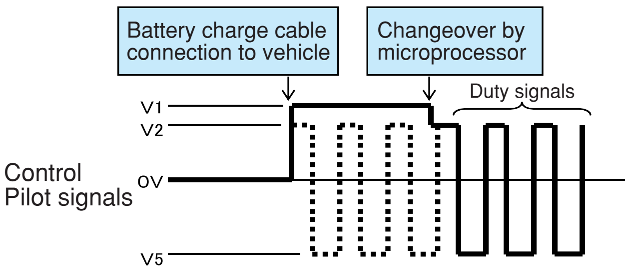


Fig.12 Control Pilot Signals Monitored from PHV-ECU

When the battery charge cable gets connected to the vehicle, the voltage of the control pilot signal would be

"V2" without the improvement, and the unit in the cable would start duty driving as shown in the broken line in **Fig. 12**. A circuit is added to Prius PHV to make the voltage to be "V1" when the cable gets connected to the vehicle. The voltage is changed to "V2" when the microprocessor of the PHV-ECU drives the circuit. Due to this improvement, the PHV-ECU is activated only by detecting the change from 0 volt to "V1" of DC voltage of the control pilot signals. This improvement makes stable activation possible.

The control pilot signal represents 0 volt when the power is not supplied late at night or the power is out, because electricity is not supplied to the battery power cable from a household electric outlet. When morning comes or the power is restored, the battery charge cable is turned on and the control pilot signal represents "V1." In other words, the PHV-ECU stands by when the control pilot signal represents 0 volt and, it is activated and starts to control the battery charge when the control pilot signal changes from 0 volt to "V1." Moreover, after the battery is fully charge, the PHV-ECU changes the control pilot signal to "V1." The unit in the battery charge cable detects the voltage of "V1" and then stops the duty driving. This whole process keeps the PHV-ECU standing by in stable condition after the battery is fully charge.

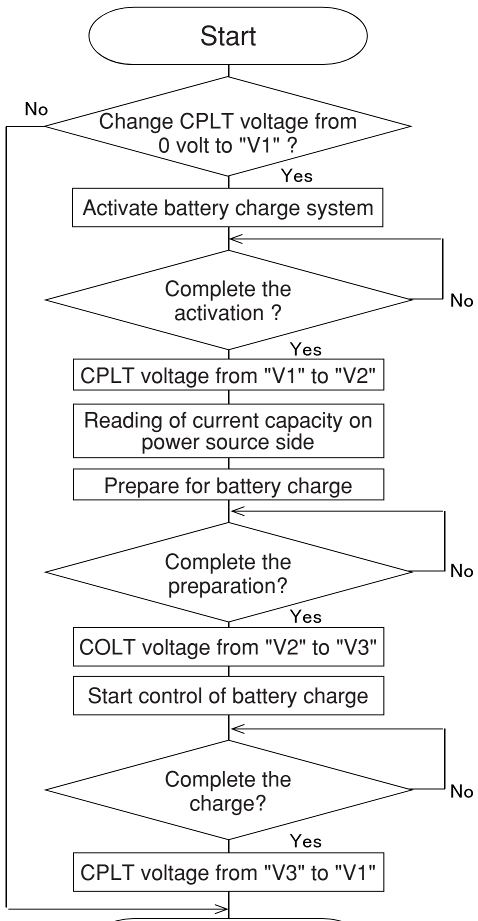


Fig.13 Flow Diagram of Plug-in Charge Control

4.4 Indication of Vehicle Status on Meter

On the assumption of various user operations to vehicle (turning on/off the push-start, putting the battery charge cable in, etc.), the PHV-ECU avoids risk and issues a warning (**Fig. 14**).

For example, in order to prevent damage to the battery charge equipment by a vehicle starting to move when the battery charge cable is connected to the vehicle, the PHV-ECU prevents drag of the battery cable. Concretely, if a user presses the push-start switch when the battery charge cable is connected to a vehicle, the PHV-ECU prohibits the vehicle from changing its status to the one for running (Ready-on status) and issues a warning to the user by displaying a message, on the meter panel, that the battery charge cable should be disconnected.

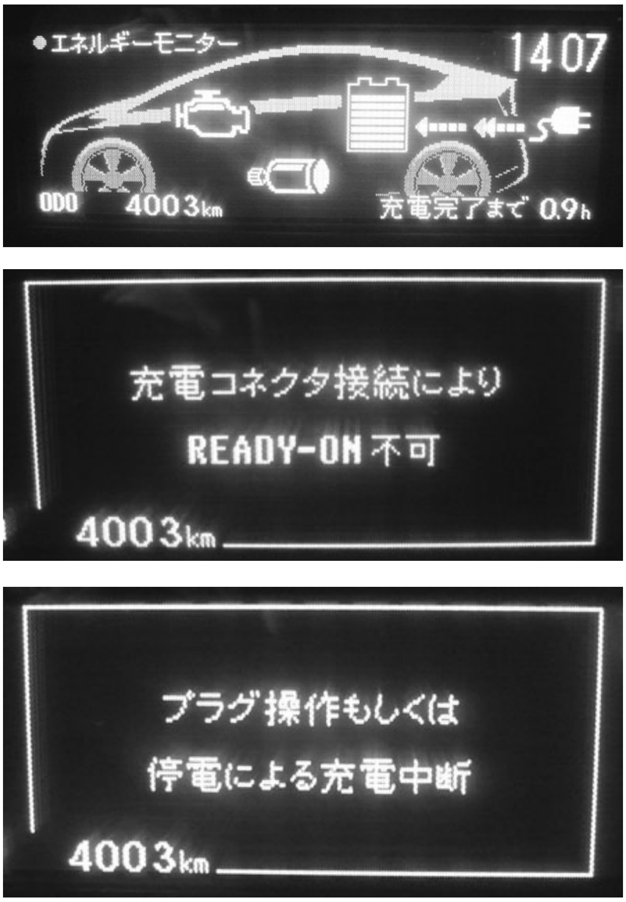


Fig.14 Message on Meter Panel of Vehicle

5 Conclusion

As for the current PHV-ECU, the following issues are left unsolved and we will make every effort to solve them in the future ECU development.

①Compatibility with rapid battery charge

The product explained in this paper is only compatible with household electric outlets and it takes about three hours to fully charge the battery in Japan. In addition to shorter battery charging time, it is necessary to improve the product to be capable of being charged at an electric station with the number of EVs increasing and infrastructure of electric stations in place in the future. The electric station provides service that users can charge the batteries of their vehicles rapidly on high power, which requires a control system different from the one for battery charge with a household electric outlet. This issue needs to be solved for user convenience.

②Smaller and lighter ECU

In order to address better fuel efficiency and smaller space for an ECU to be installed, in response to a larger fuel cell, the ECU must become smaller and lighter. We did not introduce a new smaller and lighter product because of the short development period this time. However, we will study miniaturization and integration of ECUs to satisfy requirements demanded in the future.

〈Reference〉

SAE Standard "SAEJ1772 : SAE Electric Vehicle Conductive Charge Coupler"

Profiles of External Writers

Ryuichi KAMAGA

Entered Toyota Motor Corporation in 1989. Since then, has engaged in the development of self-manufactured ECU such as ABS (Antilock Brake System) and the development of HV(Hybrid Vehicle) control electronic system. Currently the Group Manager of Electronics Development Div.2.

Profiles of Writers

Hiroshi MORIGUCHI

Entered the company in 1986. Since then, has engaged in the development of electronic devices for car. Currently the Team Leader of the Control Department 1, Power Train Engineering Division, AE Engineering Group.

Takaaki FUKUSHIMA

Entered the company in 2000. Since then, has engaged in the development of car electronics. Currently in the Control Department 1, Power Train Engineering Division, AE Engineering Group.

Satoshi FUKUI

Entered the company in 1987. Since then, has engaged in the development of car electronics. Currently in the Control Department 1, Power Train Engineering Division, AE Engineering Group.

Takuya HIBINO

Entered the company in 2002. Since then, has engaged in the development of car electronics. Currently in the Control Engineering Department, Power Train Engineering Division, AE Engineering Group.

Tsuyoshi TAKATORI

Entered the company in 1993. Since then, has engaged in the development of car electronics. Currently the Team Leader of the Software Engineering Department 1, AE Software Division, Software Engineering Group.