

Development of Inverter for 2006 Model Year CIVIC Hybrid

Hiroshi OHTSUKA*

Fumio ANRAKU*

Yoshinari TSUKADA**

ABSTRACT

Our goals in developing the inverter used in the CIVIC Hybrid Integrated Motor Assist (IMA) system were to reduce size and increase power. To increase the power, a C-Cu substrate was used to increase heat diffusion, resulting in a 6% rise at maximum power current compared with the former model. Several different technologies have been employed to reduce the size of the unit: A trench structure was used in the insulated gate bipolar transistor (IGBT) gates, the thickness of the chips was reduced, the diodes were spread out, a thin film capacitor was used and the control components of the motor and structural components were integrated. These changes resulted in a reduction of 47% in volume and 25% in weight compared with the former model.

1. Introduction

In light of the full remodeling of the CIVIC Hybrid, it was decided to develop an enhanced-performance inverter in-house. As shown in Fig. 1, the inverter is integrated into the Power Control Unit (PCU) in the Intelligent Power Unit (IPU), which is installed

on the back of the rear seat. Its role is power conversion between the motor and the battery. To enhance the power performance, fuel economy, and marketability of the vehicle, our goals were to increase the power and reduce the size of the inverter and other IPU parts. This paper describes the technologies used to accomplish those goals.

2. Technology for Achieving Increased Power

The maximum power current of the inverter is determined by the upper temperature limit of the semiconductor power chip (hereafter referred to as “chip”). In this development, the temperature rise of the chip was reduced and its maximum current value was increased by enhancing the heat radiation performance of the power module substrate.

2.1. High Heat Radiation Power Module Substrate

The power module substrate fulfills the functions of heat radiation, insulation, chip fixation and electric current conduction. Its heat radiation performance affects the temperature rise of the chip.

The temperature of the chip rises sharply when the vehicle is in motion such as engine starting that generates transient heat and continuous running that generates steady heat. The heat capacity

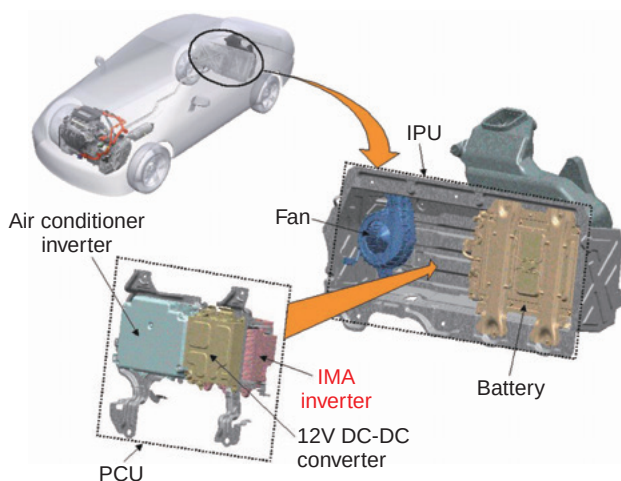


Fig. 1 Layout of IMA inverter

* Tochigi R&D Center

** Honda Engineering Co., Ltd.

and thermal conductivity of the material directly under the chip have a major influence on the temperature rise of the chip when transient heat is generated. As shown in the upper part of Fig. 2, the conventional power module substrate consists of a Direct Brazed Aluminum (DBA) substrate and a radiator plate (heat spreader), which are soldered together. The DBA substrate directly below the chip, in order from top down, consists of Al, AlN and Al layers. The relative thinness of the Al layers provides little thermal heat capacity. If the upper Al layer is made thicker, leading to increased thermal heat capacity, cracks are likely to occur in the soldering that connects the chip and the power module substrate. These cracks are possible because the coefficient of thermal expansion for Al is higher than that of AlN, which is made of ceramic, or of the chip, which is made of Si. Thus, the stress on the soldering increases if the thickness of Al is increased. As shown in the lower part of Fig. 2, the power module substrate developed is made of the following layers, beginning with the top: C-Cu, insulation and a heat radiator plate. C-Cu is a composite material made of a porous carbon substrate impregnated with Cu. It has a thermal conductivity equivalent to that of Cu, and a thermal expansion coefficient equivalent to that of Si. By arranging the thicker C-Cu layer directly below the chip, both a reduction in stress in the soldered section and high heat capacity were achieved. The heat generated in the chip is dispersed to the C-Cu, as shown in Fig. 3, and the transient thermal resistance is reduced in the area of the same chip, as shown in Fig. 4. At point A, when the engine is started, a reduction of

13% in transient thermal resistance was achieved in comparison to the conventional model.

In the case of steady heat generation, the heat radiation performance from a chip to the heat sink, which performs heat exchange, has a major influence on the temperature rise of the chip. The heat radiation performance in the power module substrate is determined by the thermal conductivity, distance and heat radiation area from the chip to the heat radiator plate, and can be expressed as thermal resistance. Equation (1) shows the thermal resistance equation.

$$R = \frac{L}{kA} \quad (1)$$

R is the thermal resistance, L is the thickness, k is the thermal conductivity and A is the area. The method of reducing the thermal resistance considering a single component is to use a material with high thermal conductivity, to increase the area through which heat passes and to decrease that area's thickness. However, the power module substrate is a multi-layered structure consisting of several materials, and the thermal resistance of the entire power module substrate can be reduced by dispersing heat to components with low thermal conductivity and by increasing the area through which heat passes. In this development, the C-Cu section, with high thermal conductivity, was made thicker to disperse heat, as shown in Fig. 5, and the area of insulating material with low thermal conductivity, through which heat passes, was made larger. High-

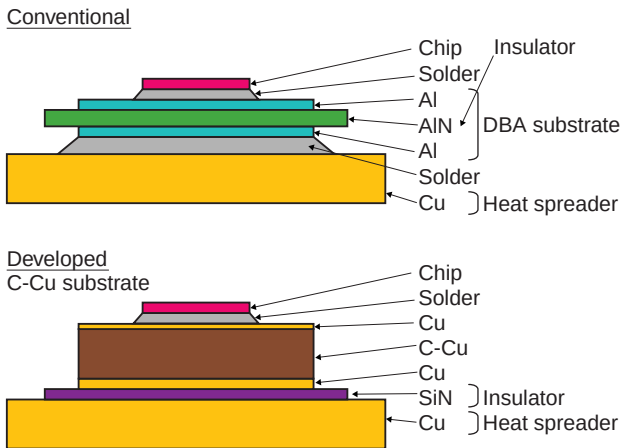


Fig. 2 Structure of power module substrate

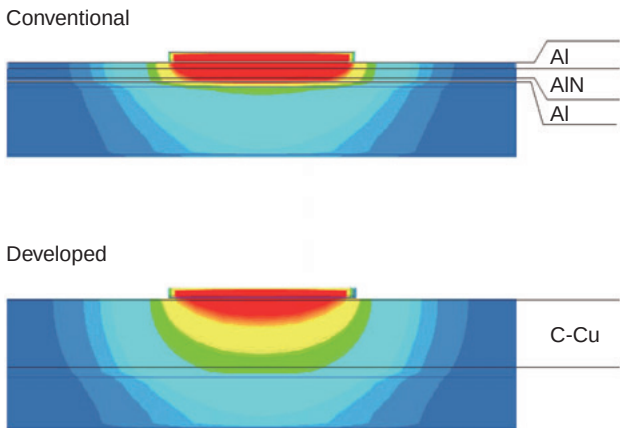


Fig. 3 Thermal simulation of transient conduction of heat

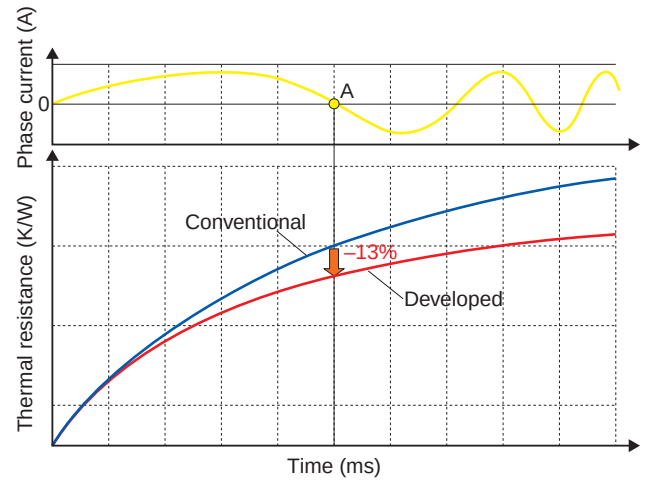


Fig. 4 Transient thermal resistance

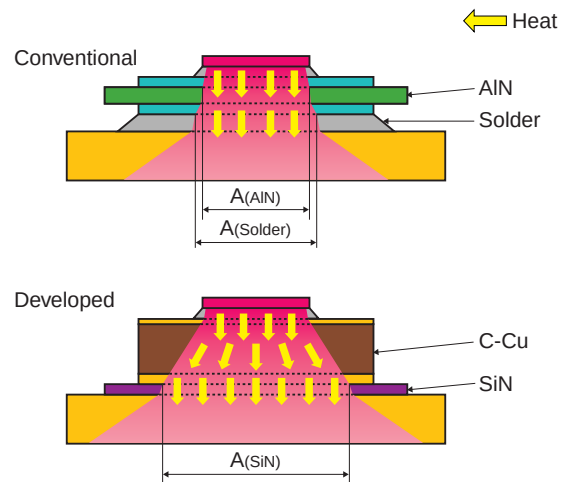


Fig. 5 Thermal diffusion

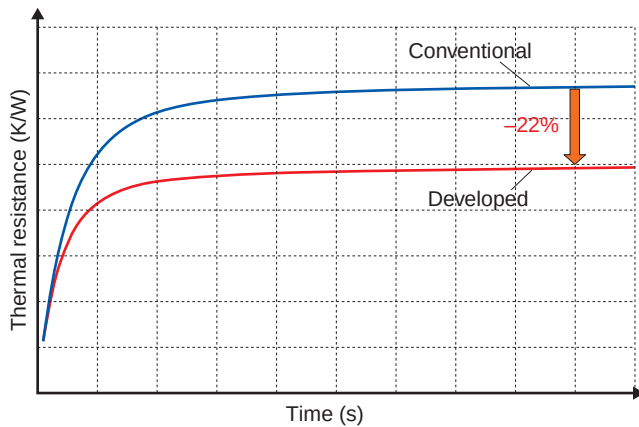


Fig. 6 Stationary thermal resistance

strength SiN was selected as the insulating material, and the section made of SiN was made thinner. The use of solder, which has low thermal conductivity, was avoided, and the C-Cu, insulating material, and heat spreader were brazed to form an integral body. Using these measures, as shown in Fig. 6, the steady state thermal resistance for the same chip area was reduced by 22% compared to the conventional structure.

3. Techniques for Achieving Compactness

Figure 7 shows the inverter and the functional components for motor control. Integration of components was the focus of attempts to achieve compactness. Individual items such as an inverter and other components have been made smaller in the past, but to achieve further compactness, functional components for motor control and inverter peripheral components were integrated, while at the same time eliminating connecting parts.

3.1. IGBT

The inverter uses IGBT as a switching device, allowing high power and high speed switching. The main current conducting section in the IGBT consists of pnp-type bipolar transistors, while the gates in the IGBT consist of Metal Oxide Semiconductor Field Effect Transistors (MOS FET). The IGBT possesses high speed switching characteristics in voltage drives of power MOS FET, and the high voltage and high current switching characteristics of a bipolar transistor.

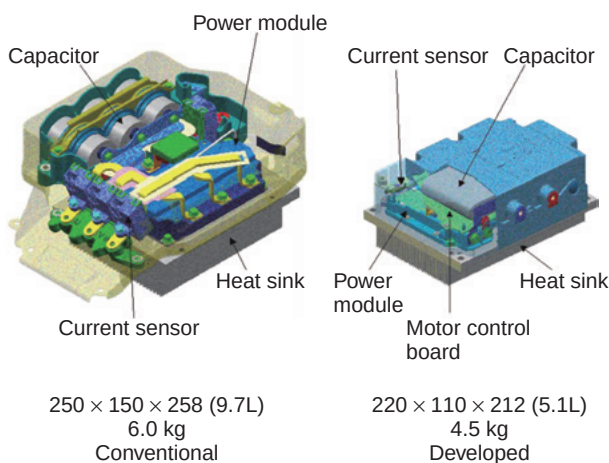


Fig. 7 Inverter configuration

Using techniques to reduce the size of the cells and the thickness of the chips and carrier accumulation technology, the loss per unit area in the IGBT was reduced and the chips were made more compact. The structure of the IGBT is shown in Fig. 8. In a conventional planar gate structure in which gates are formed on the surface of the chip, if the cells are made smaller, the current path narrows due to the expanded depletion layer, resulting in a steep increase in on-resistance. By adopting the trench gate IGBT structure, in which deep grooves of narrow width are made internally on the chip surface to form the gates on the side surface, the increase in on-resistance has been prevented and the cell size has been reduced. By arranging the gates with different spacing and by providing an insulating film in the wider spacing between gates, the carrier accumulation area was set in the N- layer and the modulation effect was enhanced⁽⁴⁾. On-resistance per unit area was reduced by reducing the resistivity due to the thinned chip and the adoption of the trench gate structure. The result was a reduction in chip surface of 46% compared to conventional structures.

The trench gate structure has several disadvantages, including a reduction in the short-circuit tolerance capability because of the increase in saturation current during short circuits, a delay in switching time and an increase in drive loss because of the increase in gate input capacity. By locally increasing the gate spacing in the adopted IGBT, the area of the MOS section is reduced, saturated current can be controlled and the input capacity can be reduced to the level similar to that found in a planar gate structure.

3.2. Diode

As shown in Fig. 9, a two-chip arrangement was used instead of the conventional one-chip arrangement, and heat was dissipated

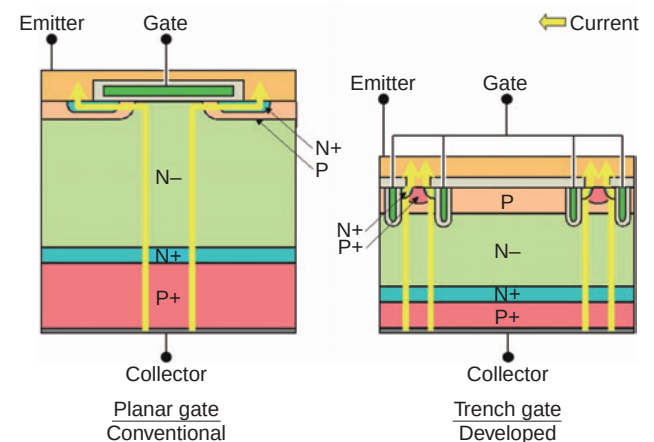


Fig. 8 Structure of IGBT

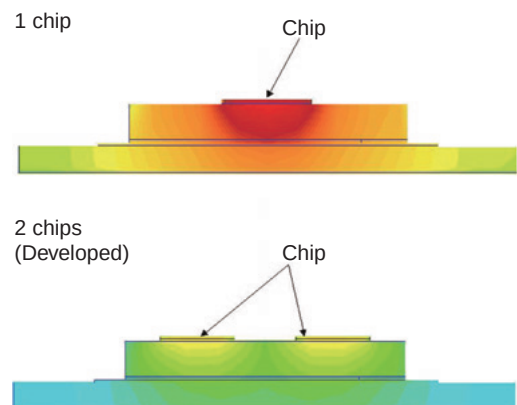


Fig. 9 Thermal simulation of conduction of heat

to enhance heat radiation performance. Thanks to the dispersed arrangement of chips, a reduction in thermal resistance of 50% was achieved in the same chip area, enabling a reduction in chip area of 44% compared to a conventional model.

3.3. Capacitor

Ways to reduce the electric capacitance were studied so that the capacitor could be made smaller. Usually, the IMA contactor is disconnected only when the current has been switched off, but sometimes it can be disconnected during current regeneration, as shown in Fig. 10, when the IMA system is in an unusual condition, and the voltage at inverter terminals rises abruptly⁽²⁾. Electric capacitance not only affects the voltage smoothing, but also the rise in voltage. If the electric capacitance is reduced, the voltage rise time decreases. In this inverter, the electric capacitance is reduced by compressing the response time for over-voltage protection by 90% compared to conventional models.

The electric capacitance of the conventional electrolytic capacitor was high, but since the equivalent series resistance (ESR) is high because of the electrolyte, the heat generated due to ripple current is large. The allowable ripple current and the electric capacitance are proportional to each other, as shown in Fig. 11. When the electric capacitance is reduced, the allowable ripple current of the electrolytic capacitor cannot satisfy vehicle requirements, and the capacitor cannot be made smaller than that of the conventional model. In contrast, the electric capacitance of the film capacitor is small, but since the ESR is also low, the allowable ripple current is high. A film capacitor with the minimum film thickness was used as the smoothing capacitor for vehicles in this inverter. As shown in Fig. 12, a reduction in capacity of 40% compared to conventional models was achieved by flattening the capacitor element shape.

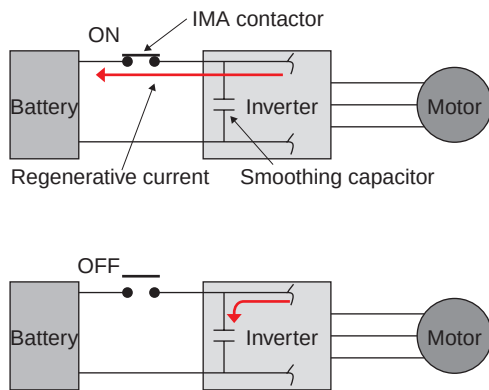


Fig. 10 IMA system diagram

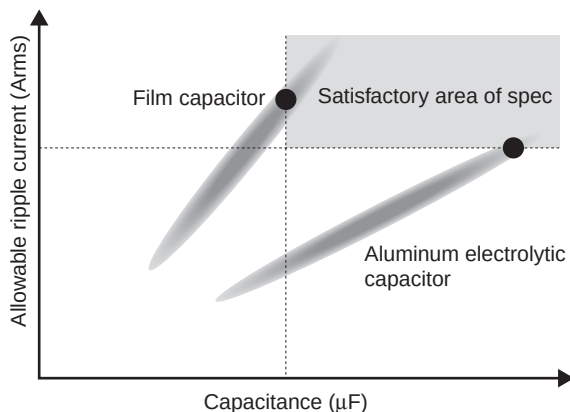


Fig. 11 Comparison of capacitor characteristics

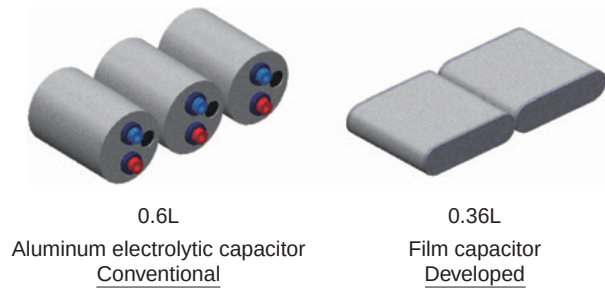


Fig. 12 Comparison of capacitor

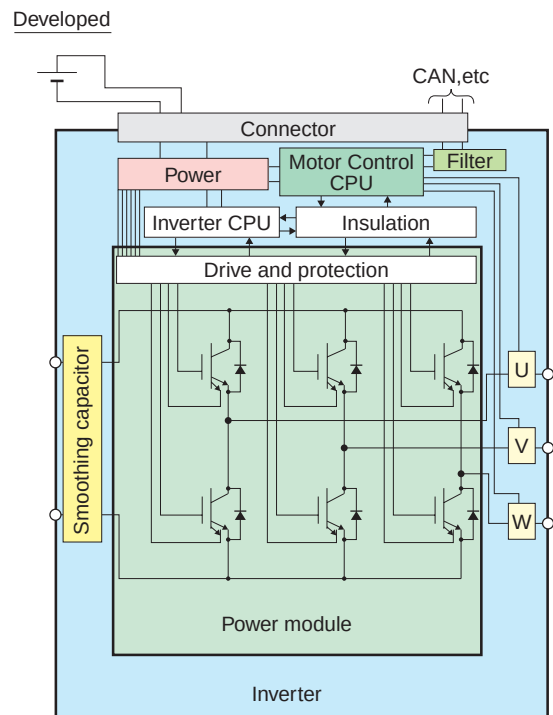
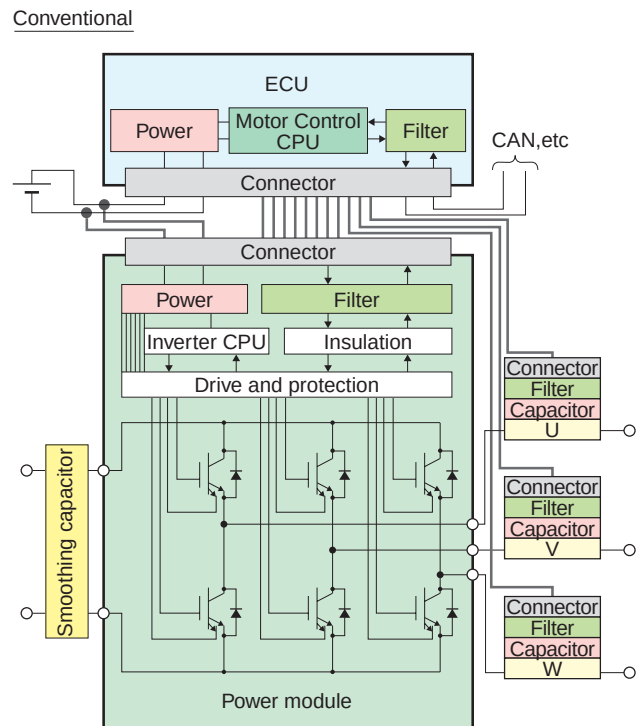


Fig. 13 Block diagram of inverter and peripheral parts

3.4. Integrating Motor Control Functions and Current Sensor

Figure 13 shows the block diagram of inverter and peripheral components. The motor control, battery control and cooling control functions were integrated in the conventional ECU, and many harnesses were used to connect the ECU and the components associated with motor control functions. To simplify the system components, the motor control functions and current sensors were integrated in the inverter, and the ECU and inverter were connected by CAN. The above measures enabled the elimination of harnesses and interface circuits, and allowed the sharing of the power source and filters.

Figure 14 shows the internal configuration of the inverter. The connectors and harnesses have been eliminated by changing from conventional connectors to pin terminals to connect the gate drive board, the motor control board and the current sensor board.

Figure 15 shows the structure of the connection between the gate drive board and the motor control board. The pin terminal assembly consists of a clamp housing, an adjustable housing and pin terminals. The adjustable housing is used to correct the offset in position between the gate drive board and the motor control board during assembly, and the pin terminal is normally inserted in the motor control board.

Figure 16 shows the construction of the connection between the motor control board and the current sensor board. The pin terminals are directly installed in the current sensor board, and connected to the motor control board by soldering. The offset in position of the motor control board and the current sensor board during assembly is corrected by adjusting the pin terminal position using the pin guide installed on the motor control board side. The current sensor volume has been reduced to 73% of that of the conventional model by sharing the power source and filters with the motor control board.

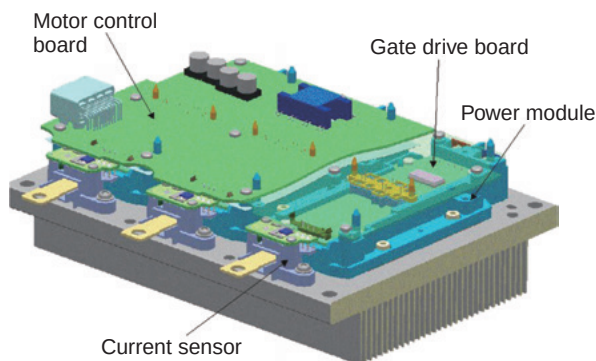


Fig. 14 Interior of inverter

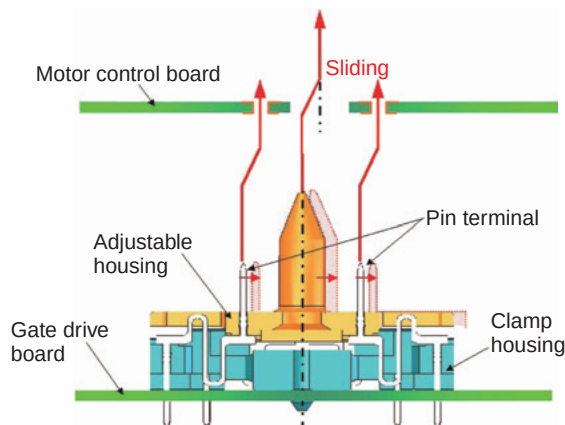


Fig. 15 Structure of pin terminal

3.5. Integration of Functional Components

Functions were concentrated in the capacitor unit to integrate electrical connections between components and fixation of components. Figure 17 shows the configuration of the capacitor unit. The capacitor and noise filters were fixed to the conventional inverter cover and connected to the same bus bar. The ground bus bar of the noise filter was extended up to the component to fix the capacitor unit in place, and is used for ground connection as well. The inverter cover was fitted with input and output terminal blocks, and the inverter output bus bar was extended, eliminating the conventional output bus bar. After adopting the measures above, the number of components was reduced, as shown in Fig. 18.

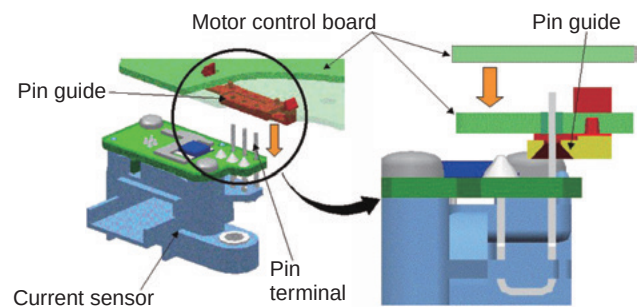


Fig. 16 Configuration of pin terminal

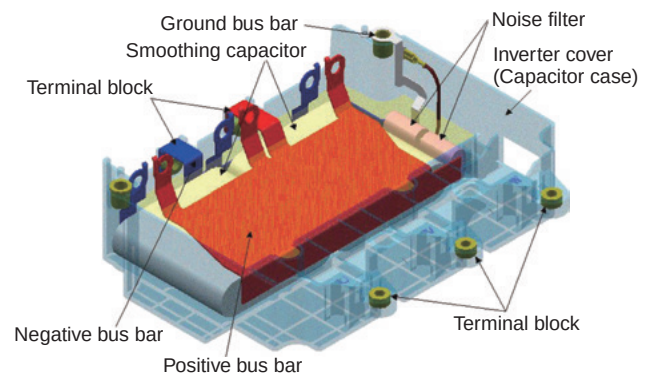


Fig. 17 Configuration of complete capacitor

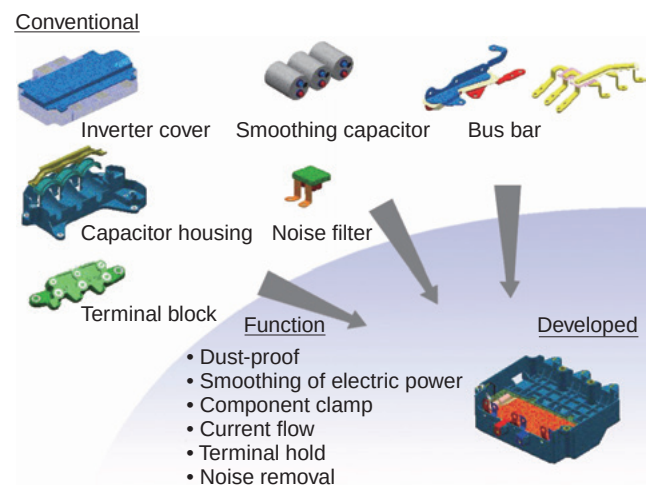


Fig. 18 Integration of capacitor components

4. Conclusion

An inverter for the new CIVIC Hybrid was developed, incorporating the modifications to conventional inverters listed below.

- (1) Inverter maximum power current was increased by 6% by adopting a C-Cu substrate with high heat radiation performance.
- (2) IGBT chip area was reduced by 46% by adopting IGBT trench gate structure and by using a thinner chip
- (3) Diode chip area was reduced by 44% by adopting a dispersed diode arrangement
- (4) Capacity of the capacitor was reduced by 40% by adopting a thin film flat capacitor
- (5) By integrating motor control function and the current sensor in the inverter, connectors and harnesses were eliminated, the number of components mounted on the board was reduced and the current sensor volume was reduced by 73%.
- (6) The number of components was reduced by integrating functional components.

As a result of adopting the measures above, the maximum power current was increased by 6%, the inverter volume reduced by 47% and the inverter weight reduced by 25%, meaning that target values were achieved. In this way, the technologies for achieving higher power and a more compact inverter have contributed to enhancing the power performance, fuel economy and marketability of the Honda IMA system.

References

- (1) Oyama, K., Kohno, Y., Sakano, J., Uruno, J., Ishizaka, K., Kawase, D., Mori, M., Hitachi Research Laboratory, Hitachi Ltd.: Novel 600-V Trench High-Conductivity IGBT (Trench HiGT) with Short-Circuit Capability
- (2) Yusaku, N., Kosaka, H.: Development of Intelligent Power Unit for the V6 Hybrid Midsize Sedan, SAE, 2005-01-0275

■ Authors ■



Hiroshi OHTSUKA



Fumio ANRAKU



Yoshinari TSUKADA