# Technological Development of Circuit Board with Built-in Bus Bar for Product with Large Amounts of Electric Current/Power

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## Abstract

As global $CO_2$ emmision control become more stricter, automobile manufacturers are being required to further improve fuel efficiency. The automobile manufacturers have been introducing various systems for improving fuel efficiency in conformity with the control.

To this end, our company has been developing the dual power supply management system, which comprises a DC/DC converter, lithium ion battery, and semiconductor relay that switches the charging/discharging routes. However, as a result of the measures taken in our study for suppressing the heat generated by the elements of the DC/DC converter, the structure of the product became large and complex.

To simplify the product structure and enable the system to carry a large amount of electric current, we decided to integrate the bus bar (sheet-shaped conductor with no insulation sheathing, and made of copper or aluminum) into a circuit board. Then We investigated the specifications and manufacturing process of the circuit board (circuit board with built-in bus bar) that can secure sufficient reliability as an on-vehicle device, and materialized it.

This paper introduces the efforts related to the technological development of circuit board that can be used for products with large amounts of electric current and/or power.

## 1. Introduction

Europe has been the global leader in carbon dioxide ($CO_2$) emission control. Furthermore, the emission control for passenger vehicles was set to be drastically stricter by 2030 in consideration of the future spread of electric vehicles (EV) and other low emissions vehicles. Meanwhile, Japanese automotive manufacturers, who are ahead in dealing with emission control by introducing hybrid vehicles (HV), have already taken measures to introduce systems operated by dual power supply system or the like. In addition, rapid innovation toward autonomous vehicles and electric vehicles has led the electronic control unit (hereinafter, ECU) for electric-powered systems to utilize high current and high power **(Fig. 1)**.

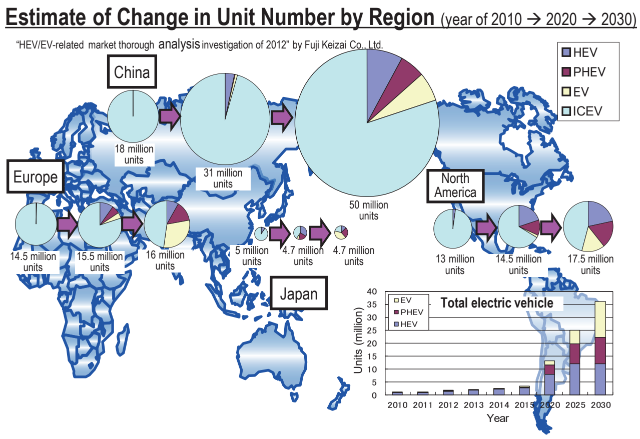



Fig. 1　Market Trends of Electrically Powered Vehicles

This increases the heating of parts associated with current/power as well as affects peripheral parts. Therefore, measures to control the heat of the entire product will be essential. In particular, printed circuit boards (hereinafter, PCB), which have sensitive parts mounted on them, are directly affected by this heat, which in turn impacts their reliability.

General countermeasures against heat include heat source dispersion and heat radiation using a suitable material with good thermal conductivity. It is, however, difficult to choose an optimal heat control measure because a product may be large and/or have a complicated structure. Accordingly, taking measures against heat while also simplifying the structure is necessary.

## 2. Concept of Development

**Fig. 2** shows the relationship between voltage/current used in products and product structures, where products with a maximum current of less than 10 A have simpler PCB and product structures.

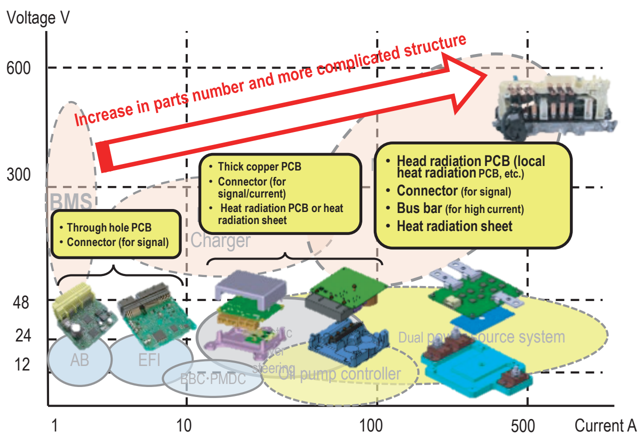



Fig. 2 Voltage/Current and Product Structures

On the other hand, product structures for maximum currents between 10-100 A, have PCB with thick copper foils (hereinafter, TC-PCB) or a combination of PCB based on metals with good radiative capabilities and heat radiation materials (gels or sheets). In the range over 100 A, product structures become so complicated that copper plates (bus bars) and other mechanisms for carrying current are necessary in addition to heat radiation PCB (local radiation, etc.) and materials having high heat radiation properties (**Fig. 3**).

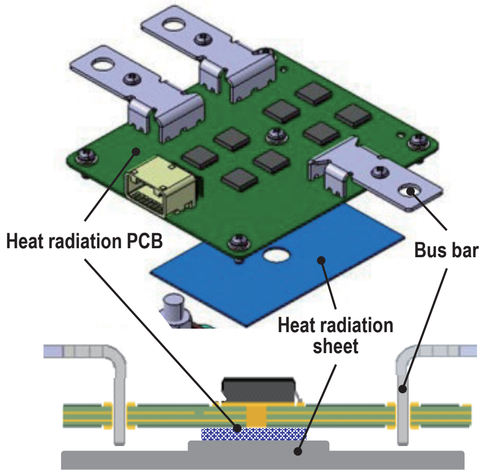



Fig. 3 Example of Product Structure (More Than 100 A)

For this reason, the development of a built-in bus bar PCB, as shown in **Fig. 4**, was undertaken based on the concept of a "PCB with good heat radiation property allowing both simple product structure and high current/power".

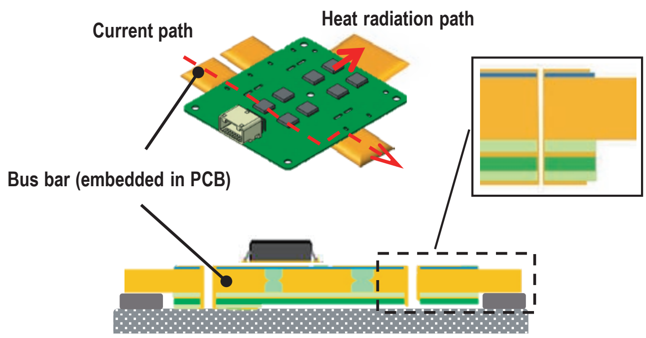



Fig. 4 Configuration of Built-in Bus Bar PCB

Such a PCB have the following four features:

- An internal copper plate of 1 mm thickness for carrying high current,
- Parts to connect to external terminals outside the PCB body,
- An insulating material of 50 μm thickness for improving heat conduction, and
- Current and heat radiation paths secured on the same layer.

Issues in the realization of this model and the efforts/results are described in the following sections.

## 3. Issues for Realization

The primary issues in the development of the built-in bus bar PCB are shown in **Fig. 5**.

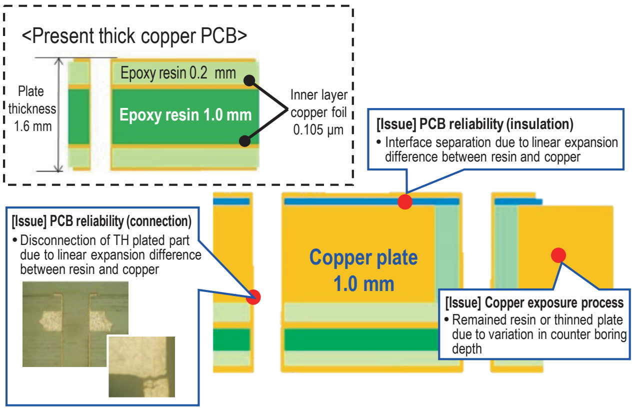



Fig. 5　Issues in Development of Built-in Bus Bar PCB

(1) PCB specifications for ensuring on-vehicle PCB reliability

Since a copper plate that is around ten-times as thick as that presently used in TC-PCB is built in the built-in bus bar PCB, the amount of expansion/contraction due to a change in temperature increases, resulting in larger stress generation on the interface with the insulating material, which affects the conductivities of the parts connected to the through holes and the insulation with the copper plate.

In addition, partially-thicker copper structures in the configuration of the built-in bus bar PCB may cause PCB deflection due to heat in the PCB manufacturing (laminating) or in-house mounting process. Therefore, layer configuration and insulation material selection that meet PCB reliability are required.

(2)PCB manufacturing process exposing copper plate

In order to directly attach a copper plate carrying current to the outside of a product, unnecessary insulating materials and copper other than that used in the copper plates must be correctly removed so as to minimize the variation in the thickness of the copper plates extruding from the footprint of the PCB. The depth of counter boring, however, varies depending on the router bit accuracy, plate thickness variation, and PCB deflection; hence, the establishment of machining conditions and processes enabling highly accurate removal of it will be important.

## 4. Efforts to Solve the Issues

(1)Examination of PCB specifications for ensuring on-vehicle PCB reliability

PCB reliability includes two electrical characteristics: connection reliability and insulation reliability. These types of reliability must be ensured to assure the quality of products. Among the types of connection reliability, the reliability of through holes is particularly important because product quality is remarkably affected by them, as they connect all layers and are used in large quantity. The connection reliability of through holes depends on stresses generated in the direction of the PCB thickness. If the stress exceeds a certain amount, the connection part cracks, which in the worst-case scenario can lead to disconnection (poor connection).

The dominant factor generating this stress is the linear expansion coefficient of the material. The linear expansion coefficients of copper (16 ppm/℃) and the insulation material (40 to 70 ppm/℃), which are constituent materials of the PCB, differ and the larger the difference (24-54 ppm/℃) becomes, the larger the stress is.

In order to select insulation material thickness (hereinafter, "resin thickness") and its linear expansion coefficient (hereinafter, "resin CTE"; coefficient of thermal expansion) to ensure connection/insulation reliabilities of through holes, stress analysis was performed using the model shown in **Fig. 6** to check the stress value and its concentration point.

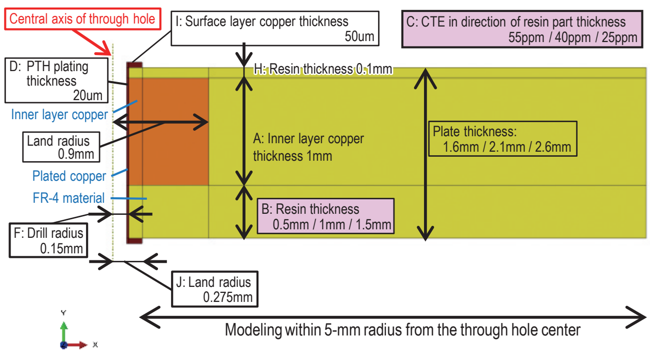



Fig. 6　Analysis Model and Parameters

As parameters, resin CTE of 25 ppm/℃, 40 ppm/℃, and 55 ppm/℃ as well as resin thickness of 0.5 mm, 1.0 mm, and 1.5 mm were applied (the copper thickness is constant at 1 mm). Some example results (contour figures) are shown in **Fig. 7**.

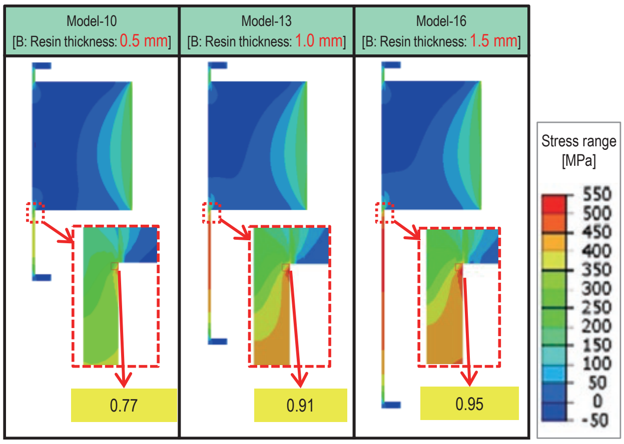
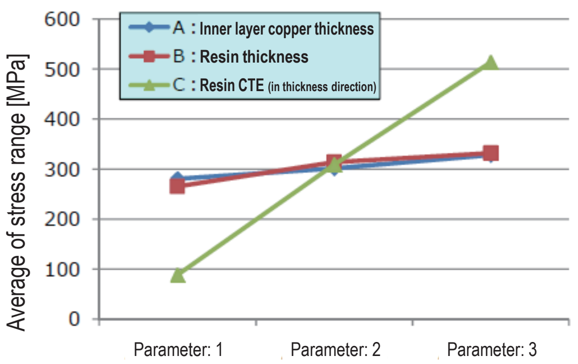



Fig. 7 Example of Stress Analysis Results (Resin CTE: 55 ppm/℃ )

The numerical values in the figures indicate the analyzed stress values in index numbers, where 1 represents the stress that causes poor connection based on past experience.

As shown in the results of the analyses, resin thickness and resin CTE that lowers the index of the stress concentration in the interface between the lower part of the copper plate and insulation material to under 1, have low probabilities of causing disconnections or interface separation.

**Fig. 8** also shows that the resin CTE has more effect than the copper plate thickness.




| | Parameter: 1 | Parameter: 2 | Parameter: 3 |
|---|---|---|---|
| A: Inner layer copper thickness | 0.5 mm | 1.0 mm | 2.0 mm |
| B: Resin thickness | 0.5 mm | 1.0 mm | 0.5 mm |
| C: Resin CTE (in thickness direction) | 25 ppm | 40 ppm | 55 ppm |

Fig. 8 Parameters and Effect on Stress

Examples of the reliability evaluation results with the PCB configuration selection based on the above results are shown in **Fig. 9** and **Fig. 10**.

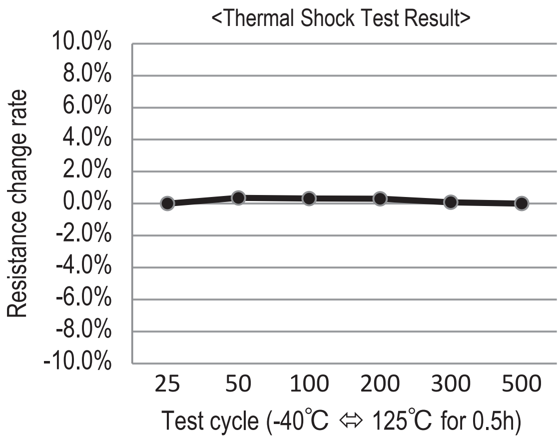



Fig. 9 Connection Reliability Test Results

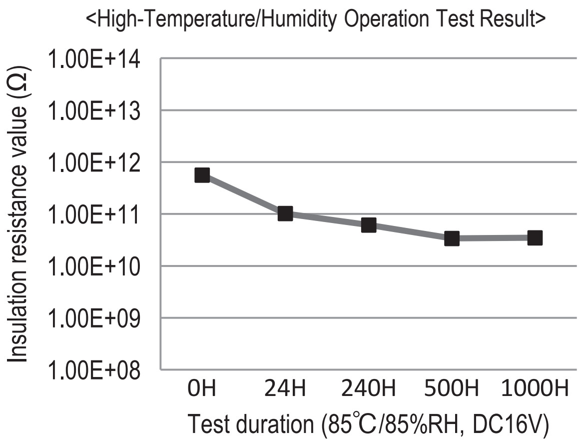



Fig. 10 Insulation Reliability Test Results

As both connection and insulation reliabilities satisfy the acceptance criteria, the target PCB specifications (configuration) ensuring on-vehicle PCB reliability has been able to be determined.

### (2)Establishment of PCB manufacturing process exposing copper plate

In order to directly attach a copper plate carrying high current to the outside of a product, it is necessary to accurately expose the internal copper plate of 1 mm thickness in a formed PCB. To achieve this, unnecessary objects such as surrounding insulation materials and copper foil must be removed to expose only the copper surface.

In general, machining with a router bit used for PCB outline machining **(Fig. 11)** is mainly applied. The depth of counter boring, however, varies, so that troubles such as a remained resin and an excessively-thinned plate may happen.

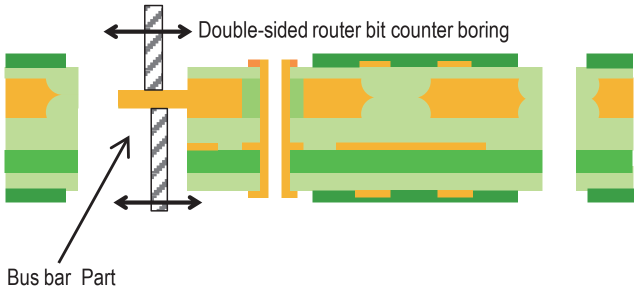



Fig. 11 Method to Expose Copper Plate

Facing this issue, we created, examined, and improved various processes, methods, and machining conditions repeatedly.

As a result, a stable counter boring depth was determined by establishing a manufacturing process with the following measures:

<Measures for stable counter boring depth (abstract)>
- Improvement of router bit accuracy
- Setting manufacturing conditions for reduction of plate thickness variation (pattern design, press conditions, etc.)
- Controlling loose PCB fixation on router table

After the above measures, the PCB specifications meeting on-vehicle reliability and capability of mounting as well as establishment of a manufacturing process were realized.

## 5. Conclusion

In this article, some of the issues and efforts for developing a PCB leading to simplified product structures are described by establishing the compatibility between response to high current/high power and good heat radiation property with the single PCB.

We intend to continuously investigate and make proposals for products requiring downsizing and structural simplification, which can then be applied to ECU handling high current/high power.

In autonomous vehicles and electric vehicles, automotive electronic equipment for ensuring appropriate environment, security, safety, and comfort are expected to change continuously. Hence, we will continue developing PCB technologies to keep pace with such changes and contribute to automotive technological development.

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