# Application of PowerBoard®, Large Current Composite Printed Circuit Boards in Automobiles

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**ABSTRACT** Many types of large-current composite printed circuit boards have been developed to meet various needs. The use of electronic circuitry in the automobile industry is growing too, and equipment that was mechanically driven and controlled is now operated more precisely by electronic circuitry. Furthermore, to cope with fuel shortages due to fossil fuel depletion and environmental problems such as acid rain, the development and marketing of electric and hybrid electric vehicles is proceeding apace, raising a need not only for conventional control circuitry but for power circuits as well. The structure and features of products that have been introduced for automotive applications are described.

## 1. INTRODUCTION

A variety of composite printed circuit boards for large current use, the PowerBoard®, have been developed to satisfy the requirements brought about by the introduction of inverter circuitry into such industrial fields as robots, working machinery, power supplies, and air-conditioners. PowerBoard features, while ordinary printed circuit boards (hereafter called PCB) use general purpose copper foils having a nominal thickness of 70$\mu$m or less, its circuitry structure consisted of copper foils having a thickness that is several times as much. This enables PowerBoard to integrate power circuitry with signal circuitry on a single PCB, permitting conduction of large currents, which was impossible for conventional PCBs.

Automobile industry, which is believed to be one of the most promising market areas for PowerBoard, has seen many cases where mechanical driving or controlling is replaced by electronic circuitry in search of more precise control. For instance, hydraulically powered steering including auxiliary equipment is actually shifting to electrically powered steering aiming mainly at fuel saving.

What is more, as represented by the PRIUS of Toyota, a hybrid-electric car mass-produced and commercialized for the first time in the world at the end of 1997, development and marketing of hybrid-electric or electric car is advancing rapidly to cope with fuel shortages due to fossil fuel depletion and environmental problems such as acid rain.

This report describes PowerBoard that has been commercialized so far with its structures and characteristics, focusing on its application to automobiles.

## 2. DEVELOPMENT TARGETS

PowerBoard has been developed to complete the following targets.

- To integrate the power circuitry, which users have hitherto been assembling using wire harnesses and busbars, with control circuitry thereby mitigating assembly work as well as inspection work. This will also lead users to easy process management by reducing the quantity of components to be taken care of.
- To be effective in making equipment compact and lightweight. Compared with wire harnesses, PowerBoard dissipates heat more efficiently, thereby reducing the cross section of conductors.
- To realize stabilization in electrical characteristics of equipment through the elimination of wrong wiring and fluctuations of power circuitry pattern.

In order to achieve the above mentioned targets, studies were conducted in terms of structure of components to be mounted as well as mounting method and current

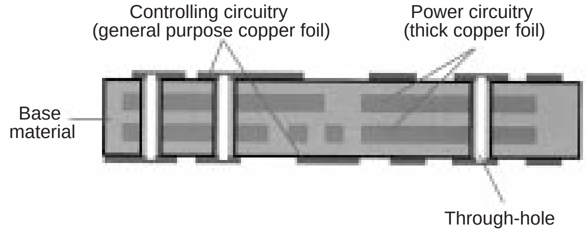


**Figure 1 Cross section of PB-L**

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Table 1 Current capacities of selected PowerBoards (board temperature rise = 10°C, conductor pattern width = 10 mm)

| Type of circuit board | PCB for general purpose | | PowerBoard | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| Type of conductor | General purpose copper foil | | PB-M | Thick copper foil (PB-F, PB-L) | | Short bar (PB-S), Bus bar (PB-B) | | | |
| Thickness of conductor (power circuitry) | 35 μm | 70 μm | 245 μm | 210 μm | 500 μm | 1 mm | 1.5 mm | 2 mm | 3 mm |
| Continuous current rating | 10 A | 14 A | 25 A | 25 A | 38 A | 54 A | 66 A | 76 A | 93 A |

capacity, and PowerBoard of five types have been developed as described below.

## 3. STRUCTURES AND FEATURES OF VARIOUS POWERBOARD

While each type has its own features, PowerBoard can be selected, as a rule, according to the current capacity and components to be mounted.

In determining the current capacity, two parameters, i.e., the steady conduction current (DC value or rms value) and the allowable temperature rise of PowerBoard at current conduction should be known.

Table 1 gives an example of the current capacity of PowerBoard, which assumes an allowable temperature rise at conductor of 10°C and a conductor width of 10 mm.

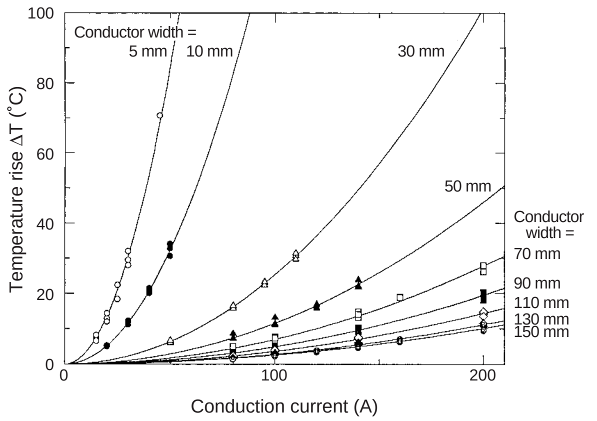


Figure 2 Measured temperature rise of inner conductor (thickness = 210μm, horizontal disposition)

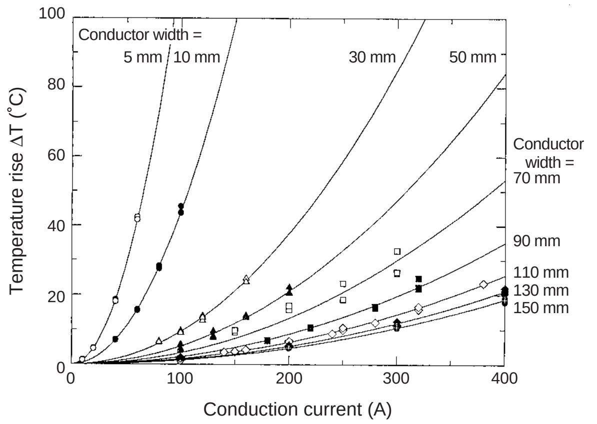


Figure 3 Measured temperature rise of inner conductor (thickness = 500μm, horizontal disposition)

Note that the table refers to a case of test pattern and that the current capacity changes depending on peripheral conductor patterns (for example, with or without a wide pattern).

### 3.1 PB-L (thick copper foil multi-layered type)

PB-L (thick copper foil multi-layered type)[1] consists of, as shown in Figure 1, inner layers of thin PCBs using 6 ounce electroplated copper foil (210μm nominal thickness) on which power circuit patterns are formed, and outer layers (four layers or more) of general purpose copper foil layered by using prepreg (semi-hardened composite sheet made of glass cloth substrate which is soaked with epoxy resin and dried), which subsequently undergoes such processes as through-hole forming, circuit patterning, solder-resist coating, and characters printing using silk screen.

For large current applications, another type is available that includes inner layers implemented by 500μm thick rolled copper foil, which is embedded by prepreg into layers of general purpose copper foil to make a multi-layered product.

One of the greatest merits of PB-L is that it enables not only conduction of large currents (typically 30~70 A) than conventional PCBs of general purpose copper foil due to its employment of thick copper foil for inner layers, but also mounting of surface mounting components due to its employment of general purpose copper foil for outer layers, thus ensuring readiness for use just like ordinary PCBs.

Moreover, since insulation between power circuits (large current conduction circuitry) of different voltages can be effected by using resin, the insulation distance can be decreased reducing the size of the substrate compared to the case where power circuitry is placed in the outermost layer. Similarly, circuits of different voltages can be brought near reducing inductive reactance that causes spike voltages (surge voltages).

PB-L eliminates soldered connection within the power circuitry, is manufactured in the same way as ordinary PCBs resulting in high reliability, enables mounting of surface mounting components, and thus is capable of downsizing of substrates. Because of this, for automobile applications, PB-L is best suited for various controlling and power circuitry such as electric powered steering and electric powered seats.

Figure 2 and Figure 3 show temperature rises of two types of PB-L respectively, namely with copper foil 210μm and 500μm thick, with conductor width taken as a parameter. At the time of pattern design, the conductor width given is normally multiplied by a factor of 1.5 to mitigate the current load.

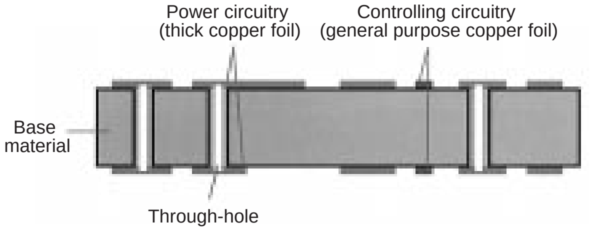


**Figure 4 Cross section of PB-F**

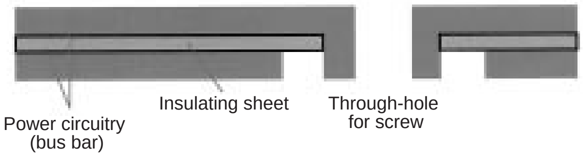


**Figure 5 Cross section of PB-B**

### 3.2 PB-F (thick copper foil double sided type)

Having a cross section as shown in Figure 4, PB-F (thick copper foil double sided type) is a double sided substrate based on copper clad laminate (CCL) which uses, like PB-L, 6 ounce electroplated copper foil. Since PB-F utilizes only the CCL of thick copper foil for circuit pattern formation, it has limitations in the attainable density of circuit patterns. Thus PB-F makes it suitable for power circuitry applications (application examples having continuous ratings of 15~30 A) which occasionally incorporates some signal circuitry.

One of the merits of PB-F is that it is economical because it saves material costs and layering costs. Moreover, its thick copper foil provides PB-F with a large heat capacity permitting it to be used as heat radiator (heat leveling), as well as a large conductor cross section compared to general purpose copper foil enabling the reduction of voltage drops within the circuit pattern.

In automobile applications, PB-F is suitable for the following purposes: to connect e.g. a plurality of relays using the power circuitry only; to equalize e.g. the line impedance of a bridge circuit that employs a plurality of FETs (field effect transistor).

### 3.3 PB-B (laminar bus type)

PB-B (laminar bus type), having a cross section as shown in Figure 5, consists of copper sheet conductors (tough pitch copper or oxygen-free copper) and such insulating sheets as mica, aramid paper, and PET, which are multi-layered through adhesive layers. The insulator material is determined considering the insulation requirements of the product in addition to environmental temperatures in use.

One of the advantages of PB-B is that, similarly for PB-L, insulation distances between different voltages are short and uniform thereby reducing spike voltages. This makes PB-B suitable for the high-speed switching and high frequency uses, enabling simplification of snubber circuit and heat sinks than conventional technologies.

What is more, PB-B is structurally suited for assembling such screw-fastened components as IGBT (insulated gate bipolar transistor), IPM (intelligent power module), diode module, and magnet switches as well as for connecting the circuitry between power supply terminals and the like.

In the area of automobile applications, PB-B has been employed in the inverter circuitry of the PRIUS of Toyota, a hybrid-electric car mass-produced and commercialized for the first time in the world at the end of 1997.

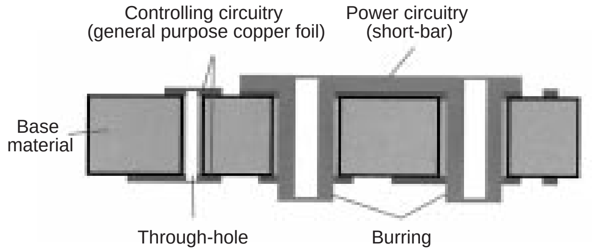


**Figure 6 Cross section of PB-S**

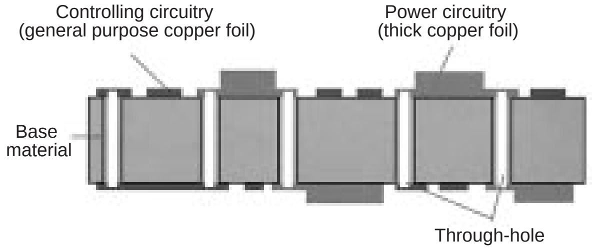


**Figure 7 Cross section of PB-M**

### 3.4 PB-S (short-bar type)

Having a cross section as shown in Figure 6, PB-S (short bar type)[2] consists of a double-sided or multi-layered PCB using general purpose copper foil and power circuitry. A copper sheet, stamped out to a required shape using press dies and bent if necessary, subsequently solder plated to make a short-bar, is fastened onto the pattern on PCB by soldering or riveting to constitute the power circuitry (application examples having continuous ratings of 30~70 A).

The fastening method by riveting has been developed to improve its vibration resistance considering installation on vehicles. Short-bars are fastened to the substrate by riveting, whereby conduction to substrate patterns is effected by inserting the short-bar ends into through-holes after bending and subsequently soldering it at the time when other components having leads are flow-soldered.

### 3.5 PB-M (components side/solder side composite thick copper foil substrate type)

While other PowerBoards pursue their own merits respectively, PB-M (components side/solder side composite thick copper foil substrate type)[3] has been developed with a major target of reducing costs under an assumption of mass production. Its cross section is shown in Figure 7.

PB-M features its automated manufacturing process, in which, thanks to the successful development of automatic machinery, copper foil is stamped out using dies, automatically mounted on general purpose substrates through the use of adhesive, thereby enabling continuous formation of partial power circuitry.

For automobile applications, PB-M is suitable for building up power circuitry (application examples having continuous ratings of 15~30 A) of small circuit quantities onto the signal circuitry made of general purpose substrates.

## 4. ENVIRONMENTAL TESTS

PowerBoards undergo various environmental tests since each type provides its own service, and major test items include thermal shock test, humidity test, hot-humid cycle test, and high temperature test.

Tests were carried out based on the methods specified in JIS, MIL, and the equivalent, in which appearance, electrical conductivity, insulation characteristics, and peel strength were evaluated in addition to other items specific to each type.

Test conditions and results are omitted from this report, but PowerBoard characteristics proved to have no abnormalities, like general purpose substrates.

## 5. CONCLUSIONS

We have described the outline of advantages of PowerBoard, composite printed circuit board for large current use, together with its applications in automobile industry. Realizing keen competition for lower costs in this business area, we plan not only to reduce costs of developed PowerBoard products, but also to develop new products suited for this industry, while maintaining product reliability comparable to that of conventional general purpose PCBs.

### REFERENCES


1) Composite printed circuit board for large current use (II), Furukawa Electric Review, No.87, 1990. (in Japanese)
2) Composite printed circuit board for large current use (I), Furukawa Electric Review, No.87, 1990. (in Japanese)
3) Composite printed circuit board for large current use, Furukawa Electric Review, No.101, 1998. (in Japanese)


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