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Laminated Bus Bars Eliminate Unmanageable Cabling in High Power Systems Cabinets

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Originally used to interconnect devices in high power modules, laminated bus bars are finding a home "inside the box" by interconnecting subsystems within high power systems cabinets.

Distributing power takes many forms in electronic systems. Depending on the industry, power (or high current) can be considered to be anything between 25 and 2,500A. Power distribution in this case means moving high current from the power supply to various components located throughout the enclosure: amplifiers, rectifiers, backplanes with routers, servers, etc. Multilayer circuit boards, heavy-gauge wire and cable, or copper bus bars are three of the more common methods used. Now, laminated bus bars that consist of a multilayer copper and dielectric insulator assembly offer significant advantage over the other power distribution approaches.

To describe fully how the laminated bus bar technique works, we have to look at the previous solutions to power distribution. Previously, most packaging engineers might distribute high current with one or more heavy copper bus bars, usually with tapped holes for connecting cables. The bars would typically be about four to six inches apart from each other and be isolated from the cabinet by red glastic (G-10 fiberglass reinforced plastic) spacers. Or, the packaging engineer might use another common sight: size 0000 cable. Those large unwieldy "snakes" could do the job, but not without a high degree of difficulty, because that mass of heavy cable made routing and bending within an enclosure a difficult,

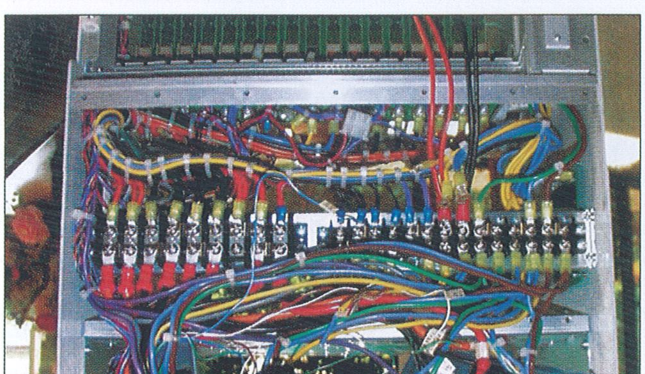

Figure 1. Typical wiring application with terminal blocks.

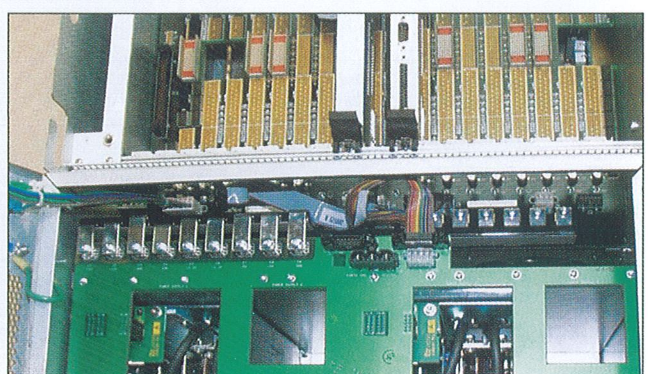

Figure 2. Same application as Figure 1 with multilayer laminated bus bar.

if not impossible, task.

Large copper (or aluminum) bus bars and cables have been used for years to distribute power within industrial control and telecommunication cabinets. They are big, relatively cheap, and can carry high power with ease. Just input power to one end and pull off power at the other end. It's simple, reliable and you can get them just about anywhere.

Until recently, power distribution was not considered something that packaging engineers would manipulate in their specific designs. Rather, the engineer would work around the physical limitations these bus monsters presented. That is, if they're hot from excessive current, then move more air within the cabinet to cool them down. If the bars were not insulated and thus dangerous to touch, then they located them away from everything else. Bus bars that delivered high power had to be located out of the way for safety, and the packaging engineers had to live with that.

Bar Connections

Because power bus bars remained fixed and remote, cable had to be run from them to components. Now, the laminated bus bar comes in. Originally developed in the 1960s, laminated bus bars were used for years in early computer systems, telecommunications and radar systems. A typical laminated bus bar consisted of multiple layers of fabricated copper separated by very thin dielectric materials and laminated together into a solid structure. The designs would include inputs for each layer and multiple output points using a number of different interconnection methods. In early designs, the input and output connections would use solder tabs or wire wrap technology. Connecting to wire wrap posts was fairly easy; however, the process of manufacturing bus bars with many posts and keeping them undamaged throughout gold plating and handling added to total system cost. Nonetheless, the physical size and electrical performance of laminated bus bars were considered beneficial and a reliable alternative to tap strips, which were used as a central meeting point for multiple wire connections. Because the laminated bus bar was a solid assembly of copper layers and did not contain crimped, screwed or soldered contacts (like wires), they provided lower resistance, could use less copper than wire and ran cooler. Lower voltage drop, low inductance and high distributed capacitance were also desirable features in low voltage telecom and computer systems. The ability to accommodate multiple currents and voltages into a single structure brought about greater packaging density, which gave the designer more freedom of space. *Figures 1* and *2* demonstrate packaging efficiency of laminated bus bars.

More Power, Less Space

History shows that technological innovations in electronic equipment take place in micron and submicron sized devices: higher power in smaller packages. Materials are now used that allow companies to engineer products that run hotter, which subsequently demands that more power be distributed within the system. This increased demand for power combined with some creative manufacturing and design concepts have brought the laminated bus bar to the forefront as a power distribution solution.

The packaging engineer must contend with EMI, airflow and ventilation, vibration, environment and efficient use of space. Also, the packaging engineer must develop solutions that can be easily assembled in the factory or in the field, and must be accessible to service personnel.

In today's modern IGBT-based motor drives and inverters, the laminated bus bar is used widely, and proven to provide the optimum power path for minimizing stray inductance, transient spikes and voltage overshoots[1]. Engineers continue to develop applications that feature laminated bus bars that can handle loads up to 1,000A and 5,000V or higher. Some of these applications also contain the added requirement of being corona-free, a long established feature in the electrical motor and transformer industries, but a new addition for bus bars. Use of laminated bus bars in traction drive systems is becoming more common and is moving the industry toward development of partial discharge-resistant (PD) bus bars for use in high power switching applications. While the interest for PD product grows, so do applications using laminated bus bars for dc power distribution in cabinet designs.

Multiple Supplies

Laminated bus bars continue to handle complex power distribution challenges, even as currents and voltages increase. Designers, in concert with manufacturers, are finding new ways to shape bus bars that maximize available space and improve airflow of these high power systems. Not only is there greater diversity in laminated bus bar geometry, they have also become mounting platforms for system components. For example, the laminated bus bar shown in *Figure 3* began as a conceptual alternative to heavy cables. The cables traversed throughout the enclosure and created a visual as well as an installation problem. The final solution replaced the cables with a contour hugging design.

Clever use of the rigidly laminated structure allowed the mounting of four circuit breakers directly onto the structure and at locations directly opposite their respective power supplies. Using a single input connection for low voltage dc power, the bus bar feeds four independent power supplies. The output from each power supply produces three different voltages. The U shaped bus bar was designed to fit snugly around and inside the door frame of an outdoor NEMA-grade enclosure.

This design concept called for the bus bar structure to minimize wire

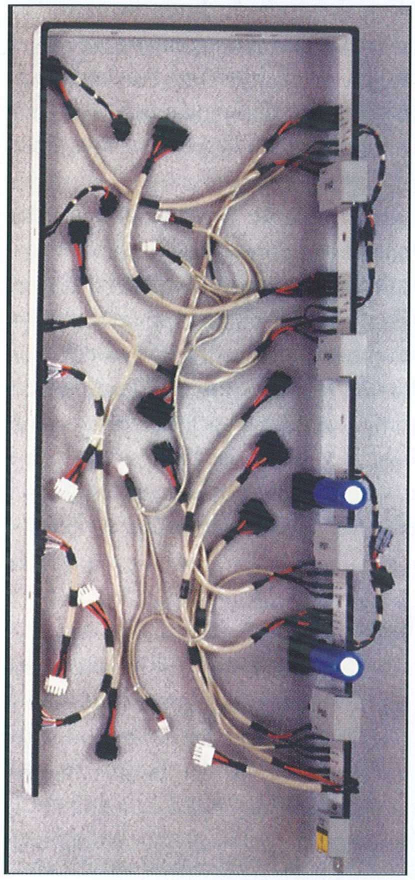

Figure 3. *U-shaped, 11-layer laminated bus bar includes connection cables, circuit breakers and capacitors.*

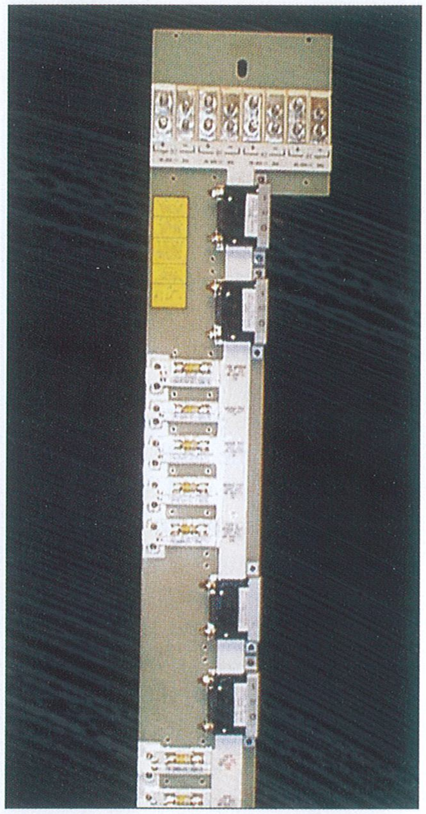

Figure 4. *Close-up of the input section of a six-foot-long, eight-layer, laminated bus bar with circuit breakers, fuses and plug outputs (covers removed for clarity).*

harness connections to each amplifier or power supply by providing connection tabs directly opposite their respective component. As the design process progressed, the customer/supplier design team determined that the four circuit breakers could be relocated closer to their respective power supplies, thereby shortening the power runs and making any necessary service more localized. Older designs would have used a central circuit breaker box or area where they all met; moving the power back and forth to the box required additional cabling. Not a difficult procedure, but done at the cost of clutter. Slowly but surely, the cables passed each other taking up more and more air space as they went. The concept of placing the circuit breakers at the point of use made more sense when working on fault detection, too. To compare this change in strategy to everyday experience, no more trips to the basement to reset the breakers. They're now located at the point of use. Electrical analysis of the entire system determined that the structure required the addition of electrolytic capacitors to handle possible power surges. Again, the rigid structure of the lamination allowed two capacitors to mount directly onto the bus bar.

Cabinet Power Distribution

Figure 4 shows a good example of a vertical bus bar assembly. The assembly distributes low voltage dc power and fits within an extremely tight physical envelope. The design distributes four 48V power circuits, each through its own 50A circuit breaker, to 30 cabinet outlets and power modules within a six-foot-tall enclosure. Each of the 30 outlets is fused. The power conductors are laminated directly onto a FR-4 board that serves as a structural frame. The structure is reinforced by a sheet metal cover, which mounts to the FR-4 board.

In operation, incoming power is attached at the top of the bus bar assembly via lugs onto heavy mounting pads. The four circuits run down the length of the bus bar assembly, which mounts along the side of the cabinet and distributes power to individually fused outputs positioned at typical rack mount locations. Once

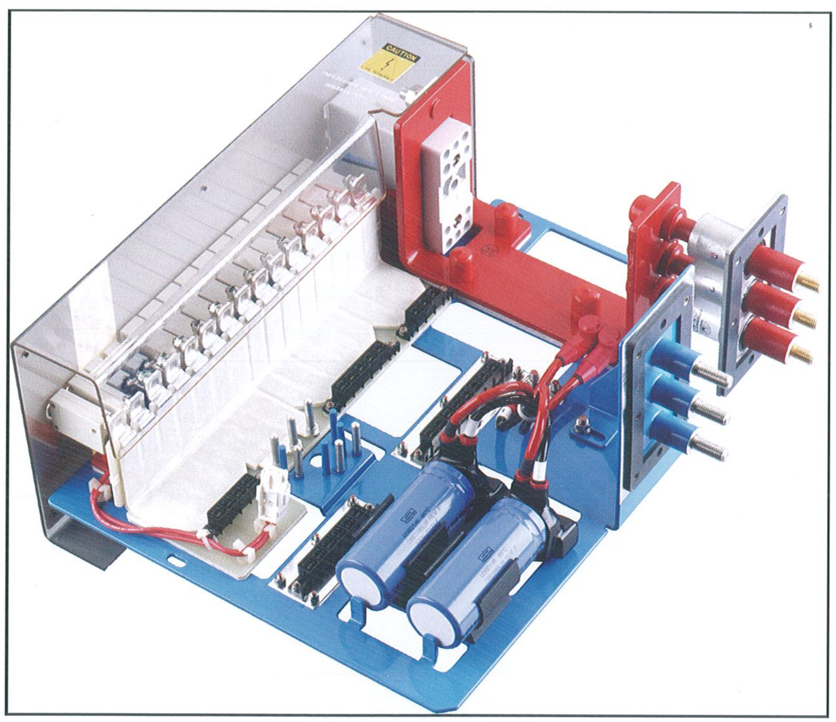

Figure 5. *Compact design strategy for complete power distribution network. Note circuit breakers, capacitors and plug outputs.*

installed into the cabinet, the long bus bar assembly allows for "plug and play" device integration.

In designing long bus bars for low voltage systems, it is important for the design and manufacturing team to provide sufficient cross sectional copper area to accommodate the system's voltage drop requirements. A good conservative design value is to size the copper conductors for 400 circular mils per ampere. The circular mil area is defined as the square of the diameter of a round conductor, measured in thousandths of an inch. Copper conductors sized to this value will have a temperature rise of 20°C above ambient.

Power Distribution Bus

A complete power distribution design in a more compact, centralized design style is shown in *Figure 5*. The bus bar assembly is one of a strategic family, and the design includes input filters, circuit breakers, capacitors and standard output connection points. Similar in value-added concept to the long bus bar assembly discussed earlier, this design approach locates all of the circuit breakers in a single area for easier troubleshooting and service. The blue sections of the bus assembly are the ground planes and all are insulated using a special epoxy powder coat, which provides a high dielectric strength and conforms well to irregular geometry. The power layers that feed the individual circuit breaker inputs as well as the power output bus bars are laminated using thin film insulation. The thin film insulation has high dielectric strength, is die cut to shape, and is excellent for production laminating. For added safety, a molded Lexan cover protects the circuit breakers from unwanted contact.

During the custom design process of these laminated bus bar assemblies, designers for both the manufacturer and customer spent additional design time to assure that the completed assemblies would meet the requirements of UL, CSA and other industry specifications.

The beauty of this value-added system approach to power distribution lies in the simplicity of use from the customer point of view. Installed directly into the cabinet, the manufacturer or assembly house merely plugs the appropriate components into the bus bar assembly, thus eliminating wiring errors and improving the overall system performance.

References

1. Dimino, C.; Dodballapur, R.; Pomes, J., "A Low Inductance, Simplified Snubber, Power Inverter Implementation," HFPC Proceedings, April 1994.