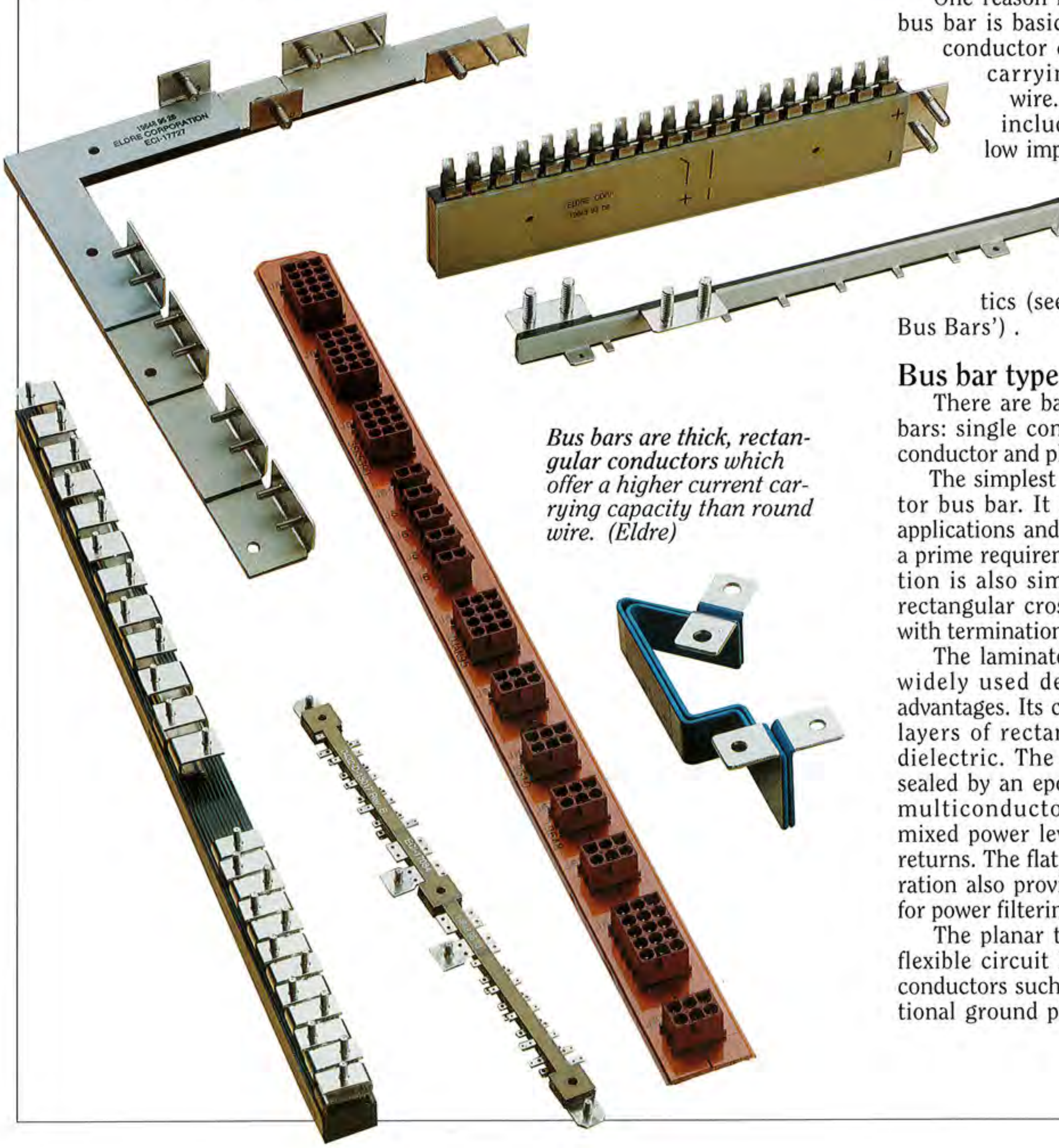
Bus Bars Optimize Power Handling

Laminated bus bars route power within cabinets while providing desirable electrical characteristics.

Howard W. Markstein, Western Editor



Bus bars are thick, rectangular conductors which offer a higher current carrying capacity than round wire. (Eldre)

Bus bars are widely used power distribution systems for such diverse applications as large computer systems, telecommunications, military ground-based and shipboard systems, avionics, banking and sorting systems, energy management systems, and industrial controls.

One reason for this wide use is that a bus bar is basically a thick, rectangular conductor offering a higher current carrying capacity than round wire. Other significant reasons include: reduced voltage drop, low impedance, inherent filtering, reduced EMI/RFI, elimination of wiring errors, and controllable and reproducible performance characteristics (see sidebar, 'Advantages of Bus Bars') .

Bus bar types

There are basically three types of bus bars: single conductor, laminated multiconductor and planar.

The simplest type is the single-conductor bus bar. It is used for high-current applications and when low voltage drop is a prime requirement. Its general construction is also simple: a length of a thick, rectangular cross-sectional bar of copper with termination tabs.

The laminated multilayer bus bar is a widely used design offering the most advantages. Its construction is of alternate layers of rectangular copper stock and dielectric. The exposed edges are often sealed by an epoxy resin. Because it is of multiconductor design, it can handle mixed power levels with integral ground returns. The flat, stacked, laminar configuration also provides a built-in capacitance for power filtering.

The planar type bus bar is basically a flexible circuit having thicker and wider conductors such as in the form of conventional ground planes. The planar bus bar design, however, has conductors as thick as 20 - 32 mils. These are spaced side-by-side and enclosed within an insulating film of polyester or polyimide.

Although pure copper or copper alloy is the most widely specified bus bar metal, aluminum is also specified when weight is a factor. Aluminum's conductivity is 60 percent that of copper. Other materials sometimes specified are brass, beryllium copper and phosphor bronze (see Table 1).

The insulating dielectric material for multiconductor, laminated bus bars can be chosen to tailor the capacitance and impedance. The materials differ in dielectric strength and dielectric constant. The most commonly used dielectric materials are polyester; epoxy/ glass; polyimide; and DuPont's Tedlar, Mylar, Nomex and Dacron (see Table 2).

Bus bar designs

Bus bars feature design flexibility in that they can be specified in many sizes and shapes. Some designs are mounted on printed circuit boards and backplanes, while the larger versions are integral to the enclosure structure. They may even be designed in as supporting members.

Fig. 1 shows a bus bar mounted to a card cage within a cabinet. Two conductors are laminated together, each capable of carrying 300 A. The I-shaped design measures 15 (l) x 10 in. (w).

The bus bar design in Fig. 2 is suitable to a variety of high-power applications. It is designed to provide low-inductance connections to individual insulated gate bipolar transistor (IGBT) modules and to a DC capacitor bank. The bus bar is constructed as alternating layers of tinned copper plates and epoxy/glass insulation, laminated into a multilayer assembly. The wide copper plates act to cancel parasitic inductance and suppress transient voltages in the power circuit.

Design factors

The allowable voltage drop is often the governing factor in selecting the bus bar cross-sectional area and material. Bus bar design involves minimizing the resistance with respect to the allowable voltage drop.

Resistance of a bus bar is given by:

$$R = \frac{\rho}{wt}$$

Figure 1. A cabinet-mounted card cage receives its power from the two-conductor, I-shaped bus seen at the center of the cabinet. (Eldre)

where:
R = resistance at 20°C, ohms/ft
ρ = conductor resistivity, ohms/sq mil/ft
w = conductor width, mils
t = conductor thickness, mils

For the higher in-service temperatures usually encountered, the resistance will increase according to:

$$R_2 = R_1 [1+\partial (T_2-T_1)]$$

where:
R_1 = resistance at 20°C, ohms/ft
R_2 = resistance at T_2, ohms/ft
T_1 = 20°C
T_2 = new temperature, °C
∂ = temperature coefficient of resistivity.

The voltage drop can then be calculated from:

$$V = RI$$

where:
V = voltage drop per foot, volts
R = resistance, ohms/ ft
I = current drawn by the load, amps.

Note that in determining the voltage drop, the total path length is considered, i.e., power source to load and back to power source.

Another goal in bus bar design is to

Table 1. Bus Bar Conductor Materials

	Resistivity at 20°C Metal ohms/sq mil/ft	α Temperature coefficient x10^{-2}
Copper alloy 110	8.09	0.393
Brass alloy 260	29.06	0.098
BeCu alloy 172	36.29	0.390
Phos. bronze alloy 210	54.27	0.160
Aluminum alloy EC	13.35	0.423

Table 2. Insulation Materials

Materials	Minimum thickness in.	K factor	Dielectric strength volts/mil
Tedlar*	0.002	9.0	3,500
Polyester	0.002	3.3	7,500
Epoxy/glass	0.0025	4.3	500
Dacron/Mylar/Dacron*	0.005	3.4	1,000
Polyimide	0.003	3.8	4,600
Nomex*	0.004	2.6	500
*Du Pont Trademark			

Busbars are an effective alternative to cabling

Figure 2. This multiconductor bus bar is designed for low inductance and transient voltage suppression in the power circuits for IGBT modules. (Eldre)

maximize capacitance and minimize inductance. The capacitance of a multiconductor, laminated bus bar can be determined from:

$$C = \frac{0.225KA\,(N-1)}{d}$$

where:
C = capacitance, picofarads
K = dielectric constant
A = conductor surface area, sq in.
N = number of conductors
d = dielectric thickness.

The inductance, L, in nanohenries, at a conductor length, 1, in inches, is given by:

$$L = \frac{0.385\,d\,1}{w}$$

Similarly as for capacitance and inductance, the characteristic impedance, Z, in ohms, is dependent on the bus bar geometry and dielectric material. For multiconductor bus bars—where d/w is always less than 0.1— the following applies:

$$Z = \frac{377d}{w\sqrt{k}}$$

From the above equations, it is seen that the bus bar conductor width, w, should always be maximized within the confines of the application, and the dielectric thickness, d, should be minimized. Also note that inductance is directly proportional to the length of the bus bar.

In essence, bus bars are an effective power distribution alternative to cabling. They would be the most advantageous choice in the following instances:

- When a system has sensitive electrical characteristics and low noise and crosstalk are requirements.
- When the cost of wiring harnesses and potential wiring errors are a consideration.
- When space is a concern.
- When it is necessary to provide a low-impedance route for high-frequency noise away from the load.
- When, for cost advantages, a bus bar can double as a supporting part of the enclosure.
- When large printed circuit boards need stiffening.
- For simplifying the layout and design of printed circuit boards and backplanes.
- For high-current applications.

To be effective, however, bus bars should be considered as a design option early in the design cycle, ideally as soon as the cabinet power, power supply and backplane requirements are established.

EP&P

Advantages of Bus Bars

In today's technological environment, electronic systems have become denser, thereby restricting the space available for power distribution. However, a bus bar requires significantly less space than does a comparable wire harness. Because of the difference in geometries, a bus bar may only require 1/2 to 1/10 the space required for a wiring harness.

In order to carry large currents, circular wire conductors must be large in diameter, which consumes space, and bending these wires within a cabinet can be a difficult task. Bus bar conductors, with a thickness of only 0.06 in. and a width of 1.0 in., can carry the same amount of current as a size #1 AWG wire having a 0.29-in. diameter. The thinner bus bar can also be easily constructed and insulated to meet demanding space requirements.

Most power applications require predicting the voltage drop characteristics of the distribution system. Bus bars, which display the lowest resistivity and inductance, can provide power to many different points within a cabinet with minimal voltage drop. Systems incur increased cost if larger wire is needed to compensate for undesirable voltage drop.

System electronic noise, including EMI/RFI and crosstalk, is another area where bus bars offer an advantage. Total system cost will increase if the wire harness requires shielding or external capacitance to provide sufficient performance. The reduced impedance, reduced inductance and increased capacitance of a laminated bus bar provides effective noise filtering and EMI/RFI suppression without added cost.

Where the enclosure contains a significant number of electrical connections, the installation labor involved for a wiring harness will often outweigh the labor involved in the installation of a bus bar. As the number of taps on a single voltage or ground level increases, the desirability of a bus bar conductor increases. Bus bars also reduce or eliminate wiring errors.

Another factor in choosing the type of power distribution system for an enclosure is the thermal management characteristics. Bus bars provide improved thermal management through better heat dissipation from the flat configuration. Also, airflow through the enclosure is enhanced because of the elimination of bulky power cabling. In some applications, bus bars can even function as air directors or baffles.

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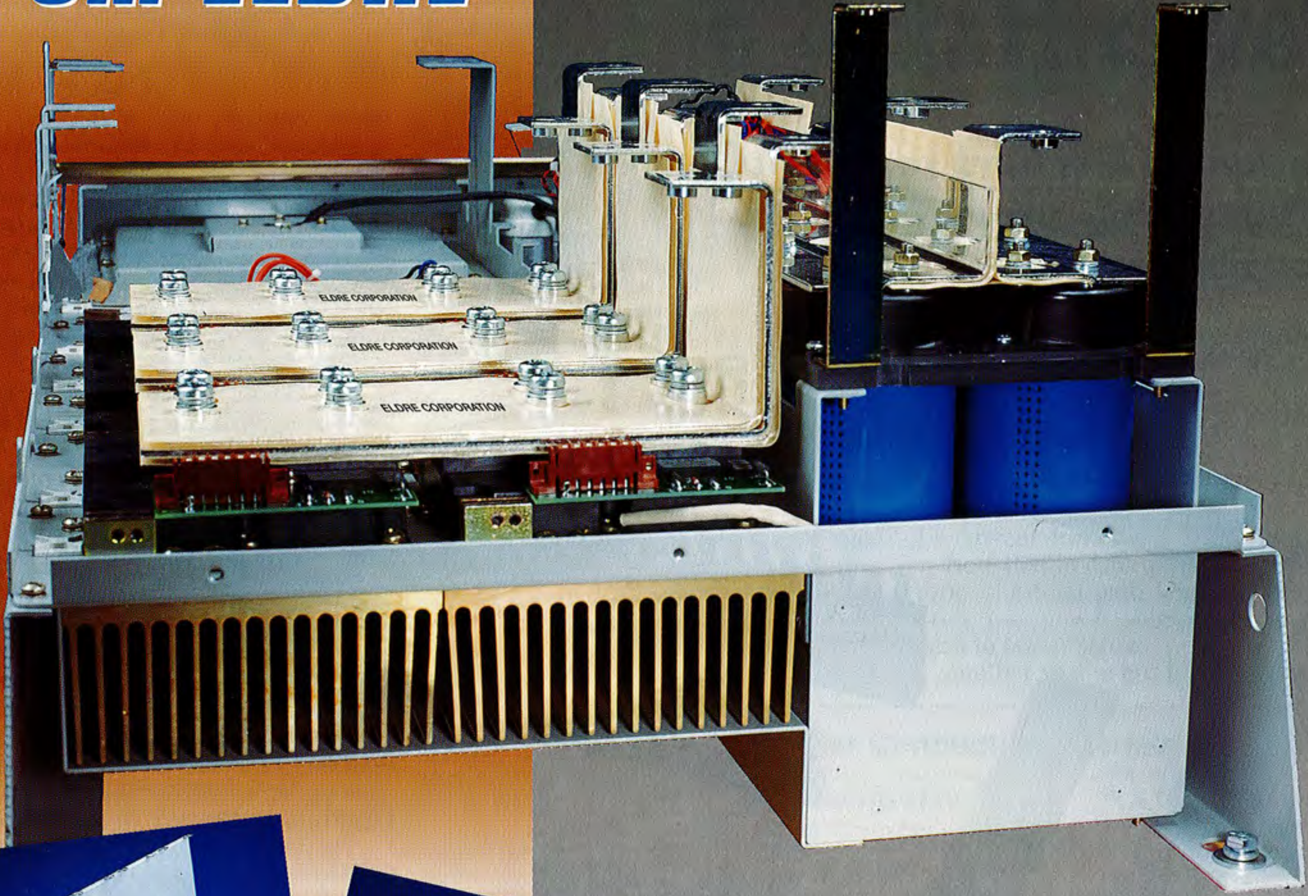

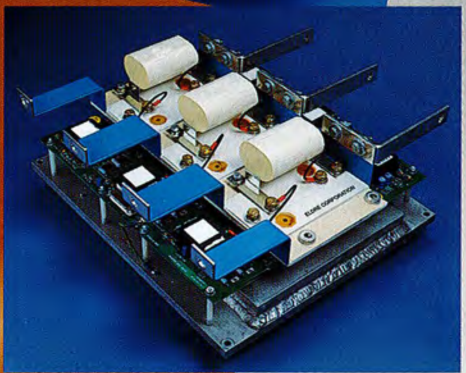

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