CCI
Circuit Components Inc.

Bussco Bus Bars

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TABLE OF CONTENTS

I. INTRODUCTION

A) About Circuit Components Inc. (CCI)

CCI has over 30 years of experience manufacturing Bus Bars in a variety of sizes and shapes that address a full range of electronic devices and systems. These innovative and cost effective, custom-engineered solutions are available in a choice of laminated, machined, and powder-coated products designed to improve electrical performance, simplify system packaging, save space, reduce system cost, and improve quality over conventional technology.

Laminated bus bars are precision-engineered assemblies consisting of alternating layers of conductor and insulator. They can be custom-designed to include virtually any connector, terminal, or interface method, while also serving to contain circuit elements including capacitors, resistors, circuit breakers, and solid-state devices, such as high-power switching transistors.

CCI also provides bus bar design services to its customers through its in-house Engineering Design Group. Not only can we create a production-ready design, we can quickly produce prototypes and provide production quantities of tested, ready-to-install bus bar systems.

At CCI, we aim to develop a lead position as a supplier of power distribution solutions to the markets we serve through a total focus on customer needs and customer satisfaction.

B) Bus Bar Benefits

The unique construction of Bus Bars consisting of laminar conductor layers, thin dielectric and a variety of planar or three-dimensional shapes, allows for superior overall performance when compared to the performance of wiring harnesses. The main benefits of bus bars include the following:

<u>Space Savings</u>: Significantly less space (as much as 50% less) is required for bus bars versus wire harnesses.

<u>Ease of Assembly</u>: Mounting and electrical terminals are integral parts of the Bus Bar and can be labeled using a variety of methods. This translates into faster assembly and easier repair, which result in lower manufacturing and field costs.

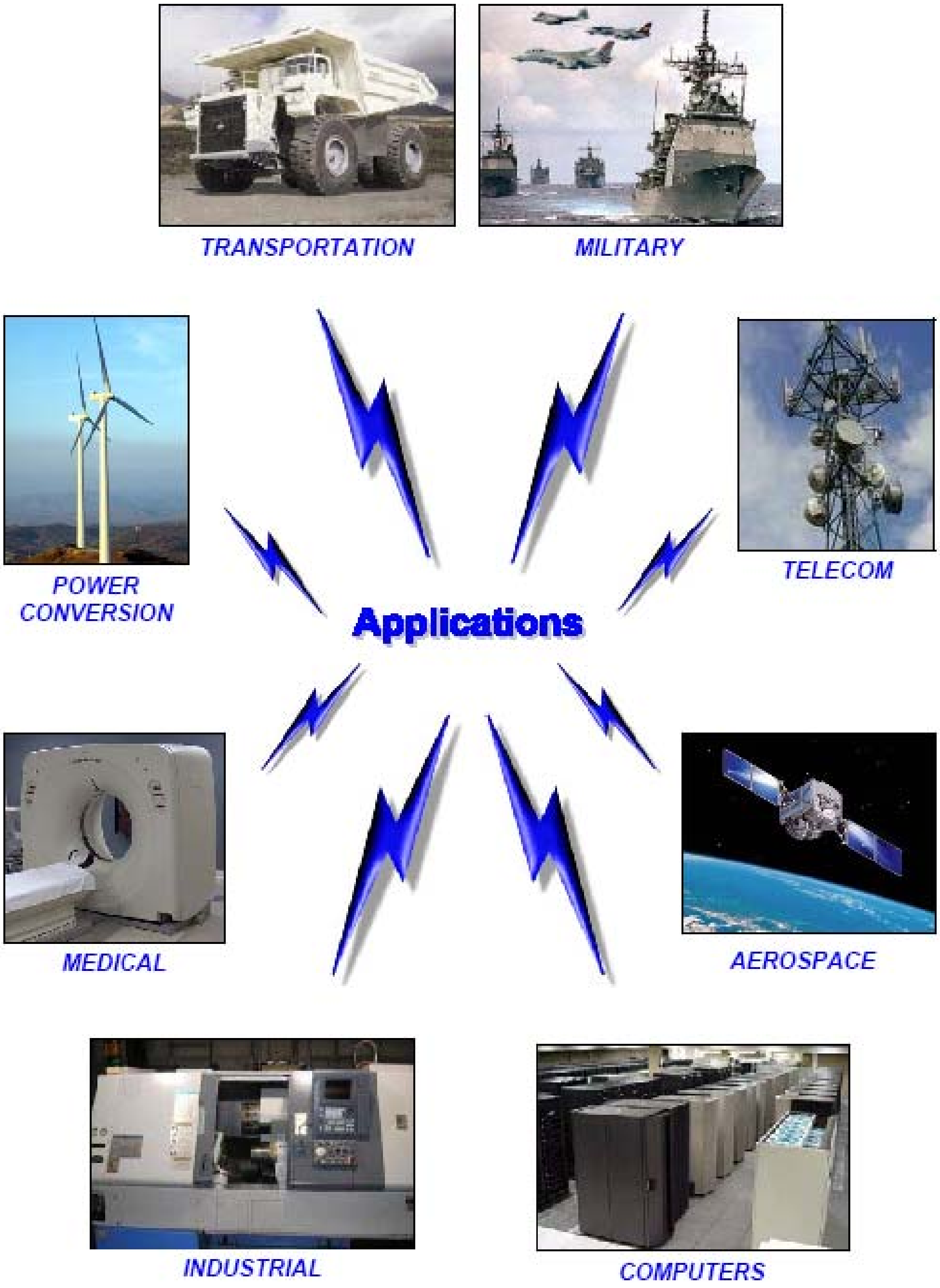
<u>Improved Electrical Performance</u>: A low characteristic impedance is attained due to high distributed capacitance and low inductance that result from larger surface areas and rectangular cross sectional areas.

<u>Higher Current Carrying Capability</u>: Larger cross sectional areas can be accommodated.

<u>Better Thermal Performance</u>: The larger surface area can allow for better heat dissipation and better airflow.

<u>Increased Long-term Reliability</u>:The bus bar construction allows for a more compact design. The product is easier to handle, easier to assemble and less prone to electrical or mechanical failures.

C) Common Bus Bar Applications



D) About This Design Guide

This Bus Bar Design Guide has been written to aid those who are involved in the design, specification, evaluation and procurement of bus bars for use in electronic systems. The information contained herein is provided as a general guide, with information covering design and product considerations, a typical design example, and support information. This design guide is not only intended in providing the user with the necessary information, formulas and material data to design a bus bar, but also to provoke the user into a thought process that will result in a thorough review of all aspects of the bus bar design.

II. DESIGN CONSIDERATIONS

Given a set of electrical, mechanical and environmental bus bar requirements, the focus of the design process is to find the optimum combination of materials, configurations and manufacturing processes that will yield a finished product that meets the requirements of the application.

A) Electrical

1) Delivering Voltage and Current

The starting point for bus bar design is identification of the voltage(s) and current(s) that the bus bar will be required to distribute. Then, a candidate cross sectional area can be selected and an initial conductor layout can be designed. The electrical properties of the conductor(s) must then be evaluated to determine if the voltage and current requirements will be met.

The most important electrical property is resistance, which applies to all types of voltages and currents. If the bus bar is carrying AC current or DC switching currents, two additional electrical properties need to be considered: capacitance and inductance. Each of these causes its own type of reactance (opposition to electrical change). Those reactances contribute to the impedance of the bus bar, which is resistance (to steady current) plus the total reactance

2) Resistance

Conductor resistance is calculated from the resistivity of the conductor material and the cross-sectional area of the conductor:

$$R = \rho / A \text{ ohms/foot} \qquad (2.1)$$

Where,

ρ = resistivity in ohms x sq mils per foot from Table 3

A = cross sectional area in sq mils calculated from formula (2.7) below

Current through the conductor will generate heat, and the resistance of the conductor will then increase proportionally to the heat. This sounds like an out-of-control spiral, but the system will eventually come to an equilibrium determined by the amount of heat dissipated by the surroundings of the bus bar. An allowable temperature rise will need to be determined, then the resistance recalculated at that temperature to check the impact on bus bar performance.

$R2 = R1\,[1+ \alpha\,(T2-T1)]$ ohms/foot (2.2)

Where,

R2=resistance at new temperature in ohms/foot

$R1$ = resistance at 20° C in ohms /foot
$T1$ =20°C
$T2$ = new operating temperature in °C,
α = temperature coefficient of resistivity of the material from Table 3

3) Voltage Drop Calculation

The voltage drop can be calculated using Ohm's Law.

$$\Delta V = R \; x \; \ell \; x \; I \qquad (2.3)$$

Where,

ΔV = voltage drop in volts in the entire conductor length
R = resistance in ohms /foot as calculated from formula (2.1) or (2.2)
ℓ =conductor length in feet
I = current in amperes given by the amperage requirements of the application

If the voltage drop does not meet the application requirements, consider increasing the cross sectional area to lower the conductor resistance.

4) Capacitance

The capacitance is directly proportional to the conductor area and the dielectric constant, and inversely proportional to the insulation thickness, as shown by this formula:

$$C = 0.224\,(k)(w)(\ell)\,/\,d\text{picofards} \qquad (2.4)$$

Where,

k = dielectric Constant of the insulation used
w = conductor width
ℓ = conductor length
d = thickness of dielectric
(ℓ, w and d are in inches)

5) Inductance

Low inductance is a critical element for controlled and efficient operation of the bus bar as it prevents excessive transient overshoots. The inductance of a two layer bus bar can be calculated by using this formula:

$$L = 31.9\,(\ell)\,d/w \quad \text{nano Henrys} \quad (2.5)$$

Where,

ℓ = length of conductor
d = dielectric thickness
w = conductor width
(ℓ,d & w are in inches)

6) Characteristic Impedance

Low characteristic impedance improves the bus bar performance for AC loads, or during the transition when load currents are switching.

$$Z_o = \sqrt{\left(\frac{L}{C}\right)} \quad \text{Ohms} \quad (2.6)$$

Where,

L= inductance
C= capacitance

Assumption: Effective loss less conductors and dielectric.

B) Physical

1) Cross Sectional Area Considerations and Determination

The required cross sectional area of a copper conductor for a given amperage requirement and a temperature rise of 30°C max from ambient can be determined by the following formula:

$$A= 300 \times I \times [1 + .075(N-1)] \text{ Sq. Mills} \qquad (2.7)$$

Where,

I = current in amperes
N = number of conductors

For multiple layer bus bars, the cross sectional area calculated for each conductor should be increased by approximately 7½% to account for the decrease in heat dissipation between conductors. This is already accounted for in formula (2.7) above

2) Conductor thickness and Width Calculations

The width calculation for a given cross sectional area can be determined by selecting an appropriate standard thickness and using the following formula:

$$w = A/(1x10^{6}) / t \text{conductor width in inches } (2.8)$$

Where,

A = cross sectional area as calculated from formula (2.7)
t = conductor thickness in inches selected from the list below

Available Standard Alloy 110 Thickness copper conductor:

0.020”, 0.032”, 0.40”, 0.062”, 0.093”, 0.125”, 0.187”, 0.250”, 0.375”, 0.500”, and 0.750”

For a given cross sectional area and taking into consideration the space and structural application requirements, the combination of a very thin and wide conductor, or having a maximum w / t ratio, has the following benefits:

- Inductance is minimized; See formula (2.5)
- Capacitance is maximized; See formula (2.4)
- Low characteristic impedance.

Table A (See Appendix) gives the width, per formula (2.8) for a given current, a given conductor thickness and a temperature rise of 30°C max from ambient A series of widths is calculated for the same current using all the available standard widths. The corresponding resistivity and inductance / length are calculated for each thickness and calculated width.

C) Mechanical

In addition to the electrical design characteristics of the bus bar, the mechanical design characteristics should also be addressed. The following are some aspects to consider.

1) Shapes

Bus bar shape will be affected by termination locations, enclosure constraints, operating environment, and mounted components. When determining overall dimensions for a laminated bus bar, allow for sufficient insulation extension beyond the conductor. The exact amount of extension depends on insulating material used, overall thickness of the bus bar, operating environment, operating voltage and method of sealing. Ultimately the final shape of the bus bar is a trade off between application requirements, manufacturing capability and cost.

Basic shapes:

- Planar conductors - square, rectangle, circular, or zigzag
- On-edge conductors - straight, “L”, “U”, “S”, “T”, and zigzag
- Formed conductors – flat or on-edge

2) External Stresses

Temperature and vibration are a couple stresses to consider that could affect the performance and reliability of the bus bar. Also note that for some applications, the bus bar can act as a reinforcement member or stiffening component for the assembled system.

3) Termination Methods

In some applications, termination options are fixed, such as for IGBTs. For other methods, consider the type of environment the connection will need to withstand. Ease of assembly and field service accessibility are issues to consider as well.

4) Mounting Methods

The mounting method used can depend on a number of factors that include the weight, size, ease of assembly, termination locations, enclosure constraint and accessibility to other system components. In most cases the bus bar is secured using fasteners through the bus bar body or by the terminations. Since holes through a conductor reduce the local cross sectional area, the designer must compensate for any reduction in current carrying capabilities.

5) Tolerances

Manufacturing capability and cost must be considered when specifying tolerances.

D) Environmental

The environment of the end application in which the bus bar operates will play a role in determining the type of materials and construction methods used for product fabrication. The main environmental factors are temperature extremes, moisture/humidity, and vibration, but many applications will impose additional concerns.

Another consideration, which is sometimes overlooked, is the type of environment the bus bar and assembled system will be subjected to during transportation. During the design phase the environmental suitability of the following should be considered: conductor material, out gassing, plating material and thickness, inner and outer insulation material, termination method, edge-sealing method, back filling of bushings and conformal coating if used. Choosing the right materials and construction methods will help to assure that the bus bar performs well under the specified environmental conditions.

III. PRODUCT CONSIDERATIONS

A) Product Configurations

Bus bars can be classified into two basic categories, **single layer** and **multi-layer**. A single layer bus bar consists of only a single conductor layer that is either insulated or un-insulated. Multi-layer bus bars contain two or more conductors that are separated by insulating layers. Multi-layer bus bars can also be insulated or un-insulated on the outermost conductor layers. A subcategory for both types of bus bars is that of added value. Basically, the bus bar will contain additional components such as fuses, breakers, cable extensions, support brackets and other devices as required by the application.

After making a decision to use a single layer or multi-layer bus bar, one must consider and choose from a variety of different insulation configurations and sealing methods. There are many construction options to choose from for both the insulation and sealing methods, and they somewhat depend on whether a single layer or multi-layer bus bar has been chosen.

For **outer insulation**, the options are:

- Flexible Dielectric Film
- Rigid Epoxy Glass Board
- Powder Coating

Selecting the right outer insulation option will depend on such factors as the operating environment, number of conductor layers and cost.

For **inner insulation** on multi-layer bus bars, the options are:

- Flexible Dielectric Film
- Rigid Epoxy Glass Board

Selecting the right inner insulation option can depend on capacitance and/or inductance requirements, voltage potentials and operating environment. It is also possible to powder coat several single layer bus bars and then stack them with an adhesive to form a multi-layer bus bar, but this is not typical as there are gross tolerance stack up issues to deal with.

The options for **edge sealing** are:

- Potting - filling the exposed area where the outer insulation extends beyond the conductors with an epoxy material. This option can be applied to thin as well as thick bus bars and is an excellent option when maximum protection from the environment is required.
- Pinch Off - the outer insulation is designed to overlap the conductor(s) by a specific distance. It is pinched and sealed together during the lamination process. This method is not recommended for bus bars in excess of 0.186” thick or in highly moist environments.

- Cavitation - a rigid epoxy glass insulation material with machined pockets for the conductors are used as inner and outer insulation layers which completely encapsulate the inner conductors when laminated together with an adhesive. This option is also employed in extreme environments.
- Powder Coating - all outer surfaces are completely coated with an epoxy that is cured to form a protective insulation. This option is well suited for extreme environments.

Table 1 summarizes the insulation and sealing configurations for a given bus bar type.

Table 1 - General bus bar configurations

	Single Layer				Multi-Layer				
Edge Sealing Outer Insulation	None	Pinch Off	Edge Potting	Powder Coating	None	Pinch Off	Edge Potting	Powder Coating	Cavitation
None	✓				✓		✓		
Flexible Film		✓	✓			✓	✓		
Rigid Epoxy Glass Board	✓		✓		✓		✓		✓
Powder Coating				✓					

B) Material Options

1) Conductor

Copper alloy 110 is the conductor material typically used in bus bar designs. It has lower resistivity than brass and aluminum, which are also used. Table 2 and Table 3 list some relevant physical and electrical properties of the most commonly used conductor materials in bus bar fabrication.

Table 2 - Relevant physical properties of conductor materials used in bus bar construction

Metal	Density @ 20°C (lb/in^3)	CTE @ 20°C (x10^{-6}m /m•°C)	Thermal Conductivity @ 20°C (W/m•K)	Specification
Copper 110	.323	17	388	ASTM B-152 QQ-C-576
Copper 101	.323	17	383 - 391	ASTM B-152 QQ-C-576
Brass 260	.308	19.9	120	ASTM B-36 QQ-B-613
Aluminum 6061- T651	.098	23.6	154	ASTM-B236

Table 3 - Relevant electrical properties of conductor materials used in bus bar construction

Metal	Resistivity (ρ) @ 20°C Ω • sqmil/ft	Conductivity % IACS @ 20°C	Thermal Coefficient of Resistivity (α) @ 20°C (10^{-2}/°C)
Copper 110	8.1	101	.393
Copper 101	8.1	101	.393
Brass Alloy 260	29.06	28	.098
Aluminum 6061- T651	13.35	62	.423

2) Insulation

A variety of materials can be used for insulation between conductors and for the outer covers. If the bus bar is to be edge-filled, a rigid material is recommended for top and bottom insulators. If the outer insulation is sealed by pinch bonding, we recommend the use of a flexible dielectric film. Table 4 shows some relevant specifications for the materials typically used. The data presented in Table 4 is for the base material without adhesive.

Table 4 - Insulation material general specifications

Material	Thickness Range (inches)	Dielectric Constant @23°C, 50%RH, 60Hz	Dielectric Strength @23°C, 50%RH, 60Hz (volts/mil)	Maximum Continuous Use Temperature (°C)	CTE 30 to100°C (x10^{-6}m /m•°C)	UL Rating	CTI (volts)
Epoxy Glass (FR4/G-10)	.010 - .125	4.3	1250	140	12-16	94V-0	388
Mylar(1)	.003 .005 .010	3.3	7,500	120	17	94VTM-2	400-600
Kapton(1)	.001 .002 .003 .005	3.9 (3)	6000 5000 4500 3000	200	17	94V-0	100-175
Nomex(1)	.002 - .030	1.6 - 3.7	430-840	220	16	94V-0	175-250
Mylar/Tedlar(1,2)	0.005	8.5	2860	105	NA	94HB	n/a

[1] Mylar®, Kapton®, Nomex® and Tedlar® are registered trademarks of Dupont.
[2] Mylar (.003”) bonded to Tedlar (.002”)
[3] Measured @ 23°C, 50%RH, 1kHz

3) Plating

The plating material used is dependent on environmental requirements as well as electrical requirements, see Table 5. If required, products can be processed with RoHS compliant plating.

Table 5 - Plating materials

Metal	Conductivity % IACS @ 20°C	Thermal Coefficient of Resistivity (α) @ 20°C $(10^{-2}/°C)$	Specification
Tin	13.6	.42	ASTM B545, MIL-T-10727
Nickel	11.8	.48	AMS 2403,AMS-QQ-N-290, QQ-N-290
Silver	105.8	.38	ASTM B700
Solder Alloy 60/40	10.0	.40	AMS-P-81728, MIL-P-81728

4) Potting

There are a variety of different electrical grade epoxy resins that can be used to edge fill bus bars. These materials are specifically chosen by the bus bar manufacturer to meet the physical, electrical and environmental requirements of the application and the limitations imposed during the manufacture of the bus bar. Each manufacturer may standardize on a potting compound that is suited to its own processing capabilities, therefore not all manufacturers use the same material.

C) Termination Options

There are many different options to terminate the bus bar for system connections. Some factors to consider when selecting a termination type are current requirements, assembly ease, and system vibrations. Table 6 describes some of the most common methods.

Table 6 - Most Common Termination Methods

No.	Termination Method	Typical current levels	Comments
1	Solder pin	≤ 11 A	Solder mounted directly on PCB
2	Faston tab	≤ 10 A	Depending on plug type, can restrict conductor overall thickness
3	Soldered wire	Wire gauge dependent	Typically, wire is solder attached to hole in tab
4	Wired lug	Wire gauge dependent	Connection is secured with screw, washer and nut. Can be suitable for high current applications
5	Threaded fastener	> 100 A	Extended tabs with threaded holes for bolt or screw attachment. Typically used in high vibration applications.
6	Threaded stud	> 100 A	Tabs or taps with secured studs for washer and nut attachment. Typically used in high vibration applications.
7	Threaded bushing	> 100 A	Tabs or taps with secured bushing for bolt attachment. Typically used in high vibration applications.
8	Mating connectors	As required	Various connector types can be implemented per request

D) Mounting Options

Considerations for mounting the bus bar are bus bar weight, system vibration, ease of assembly, enclosure restraints and field maintenance. Insulated thru-holes in the bus bar are most common for mounting. Depending on need, alternative methods include a separate mounting bracket or even cable ties with eyelets. When using insulated mounting holes, the hole in the conductor needs to be larger than the mounting hole diameter in order to accommodate the insulating washer, and placed a minimum of 0.030" from the conductor edge.

E) Marking Options

Parts are typically marked with a part number and date code by stamping or screen-printing. Parts can also include cage code and termination identifications per MIL-STD-130. For stamping, the standard character size is typically 0.060" to 0.130". For screen-printing, the character size is customer specified. Another option is to use a UL approved label, which offers the opportunity to use bar codes. A variety of label sizes are available.

F) Testing Options

When designing a bus bar, one must not forget to consider the issue of testing requirements. This can include initial qualification testing as well as production testing. Both environmental and electrical testing requirements need to be considered and specified, if not on the finished product print at least in a separate document that is referred to in the finished product print.

When considering initial qualification testing, it is a good idea to use Mil-Std-202 and Mil-Std-810 as guidelines for specifying test procedures for bus bars. Specified tests and condition levels should be carefully chosen in order to best qualify the bus bar for its intended application. Initial qualification testing can be quite expensive and can often take many months to perform, depending on the level and degree of testing. Therefore, one must be prudent in developing a qualification plan, being careful not to over-specify.

When considering production testing, the most commonly performed test is the dielectric voltage-withstand test (hi-pot test). This basically consists of applying a voltage potential across conductors not in common for a specific time period while sensing the leakage current that results through the dielectric separating the conductors. It is not unusual to test 100% of the manufactured bus bars for hi-pot. This test can be performed under DC (direct current) or AC (alternating current) conditions. The choice depends on the application and the decision is left up to the bus bar designer. The test voltage is usually chosen to be much higher than the specified continuous operating voltage that the bus bar will endure in operation. A common test voltage and test time for a DC hi-pot test is two times the continuous operating voltage for one minute. However, many designers will specify a minimum test voltage of 500Vdc for one minute, even if the continuous operating voltage is less than 250Vdc. In some cases, the test time can be shortened with an increase in the test voltage.

Another test, not so often specified or well known, is the partial discharge test. This test, generally performed on high voltage AC bus bars, is designed to detect localized ionization discharges across small insulation voids. If the voltage continuously rises and fall, such as with AC, the discharges occur over and over. The discharge energy can create micro damage to the insulation material, which can lead to the generation of discharge paths (treeing) and eventual catastrophic failure. Therefore, it is becoming more common, to see high voltage AC bus bars specified with a 100% partial discharge production test requirement.

G) Standard Capabilities and Tolerances

Table 7 lists CCI's standard capabilities and tolerances. If tighter tolerances are required, please contact us.

Table 7 - Standard Tolerances

Dimension	Standard Capabilities Tolerance
Maximum length:	96”
Maximum width	30”
Minimum single conductor bend radius	Equals conductor thickness
Mounting hole location	± 0.020”
Mounting hole diameter	± 0.010”
Mounting hole to conductor edge	± 0.030”
Tab to tab, single conductor	± 0.010”
Tab to tab, multiple conductors	± 0.030”
Tab hole diameter	± 0.005”
Tab hole to tab edge	± 0.010”
Formed angles	± 2°
Overall length, width	± 0.030”

IV. TYPICAL BUS BAR EXAMPLE

<table>
<tr><td colspan="3">Electrical Bus Bar Requirements:
Current Carrying : 300 Amps operating current @30°C max temp rise.
Application Dependent Parameters: Minimum Voltage drop Max. Capacitance, and Minimum Inductance.</td></tr>
<tr><td colspan="3">Mechanical and Physical Requirements:
Product Configuration: Two Layer, Rigid Epoxy Glass Board, Edge Potting;
Shape: Planar; Dimensions: 24” long by 1.5” wide max; Materials: Copper alloy 110, Mylar Tedlar Inner Insulation,;
Termination Method: Threaded Fastener; Mounting Method: Insulated thru holes Humidity: High humidity environment Vibration: Minimum.</td></tr>
<tr><th>Design Parameter</th><th>Design: Formulas and Tables Used</th><th>Results</th></tr>
<tr><td>Cross Sectional Area</td><td>$A = 300 \times I \times [1 + .075(N-1)]$ (2.7)
I= 300 Amps
N =2 layers
$A = 300 \times 300 \times [1 + .075(2-1)] = 96{,}750$ sq mils or 0.097 sq in</td><td>A = 0.097 Sq in</td></tr>
<tr><td rowspan="2">Conductor Width(w) & Thickness(t)</td><td>$w = A / t$ (2.8)
t= Selected thickness values from the available Std thickness to get the maximum w / t ratio and practical to the application
A=0.097 sq in
<table>
<tr><td>Thickness (t)</td><td>0 .125”</td><td>0.093”</td><td>0.062”</td></tr>
<tr><td>Width (w)</td><td>0.776”</td><td>1.043”</td><td>1.564”</td></tr>
<tr><td>w / t Ratio</td><td>6.20</td><td>11.21</td><td>25.23</td></tr>
</table>
The width requirement is 1.5” max therefore 11.21 (.093”/1.043”) is the max w / t ratio practical to the application</td><td>t=0.093”
w= 1.032”</td></tr>
<tr><td>(Optional method)
Use Ampacity Table A in the appendix and select the combination of w & t practical to the application and which will yield the lowest inductance (max w/t ratio)</td><td>t=0.093”
w= 1.040”</td></tr>
<tr><td rowspan="2">Resistance</td><td>$R = \rho / A$ ohms/foot (2.1)
$\rho = 8.1(\Omega \bullet \text{sqmil/ft})$ at Ambient Temp. 20 °C, Table 3
A=96,750 sqmil
$R = 8.1 / 96{,}750\ \Omega/\text{foot} = .084$ Milli Ω / foot @ 20 °C</td><td>R=0.08
Milli Ω / foot
@ 20 °C</td></tr>
<tr><td>$R2 = R1\,[1 + \alpha\,(T2-T1)]$ ohms/foot (2.2)
R1= 0.084 Milli Ohms, as calculated above,
$\alpha = .393$ from Table 3,
(T1-T2) =30 °C,
$R2 = 0.084\,[(1+0.393(30)] = 1.074$ Milli Ω / foot @ 50 °C</td><td>R2=1.074
Milli Ω / foot
@ 50 °C</td></tr>
<tr><td rowspan="2">Voltage Drop</td><td>$\Delta V = R \times \ell \times I$ (2.3)
ℓ (Conductor Length) = 2 ft
R = 0.084Milli Ohm / foot at ambient temperature
I = 300 Amps
$\Delta V = 0.084 * 2 * 300 = 50.4$ Milli Volts at ambient temperature</td><td>ΔV=48 Milli volts
@ 20 °C,</td></tr>
<tr><td>R2=1.074 Milli Ohm / foot at the 50 °C (The max allowed temperature),
$\Delta V = 1.074 * 2 * 300 = 644.4$ Milli Volts or 0 .644 Volts at 50 °C
(If this voltage drop is too large , increase cross sectional area)</td><td>ΔV=0.644Volts
@ 50 °C,</td></tr>
<tr><td>Capacitance</td><td>$C = 0.224\,(k)(w)(\ell) / d$ picofards (2.4)
K (Dielectric constant Mylar tedlar) =8.5 Table 4
w (width)=1.040”,
ℓ (length) =24”
d (dielectric thickness) = 0.005”
$C = (0.224)(8.5)(1.040)(24)/.005 = 9504$ picofards or
0 .0095 microfarads</td><td>C=0 .0095 microfarads</td></tr>
<tr><td>Inductance</td><td>$L = 31.9\,(\ell)\,(d/w)$ nano Henrys (2.5).
ℓ =24”
d=.005
w=1.040
$L = 31.9\,(24)\,(.005/1.040) = 3.68$ nano Henrys</td><td>3.68 nano Henrys</td></tr>
</table>

V. SUPPORT AND CONTACT INFORMATION

A) Technical Assistance

CCI’s bus bar design and manufacturing professionals stand ready to support your product requirements and work directly with you to find the right solutions to meet your technical and cost requirements. We have over thirty years of design and manufacturing experience providing power distribution solutions to a variety of markets. **Call 480-731-6202 or e-mail us at** info@bussco.com to contact a technical support representative.

B) Quality

Our commitment to meeting customer requirements and product specifications is the catalyst for providing superior product quality at competitive prices. We have established business relationships with many companies as an approved vendor and in various markets including military, aerospace, transportation, medical and others.

We have a well-established and documented quality system, which is ISO-9001 compliant. Product quality performance is well documented from incoming materials inspection to final outgoing inspection. Specific data requirements such as FAI (First Article Inspection) reports can be provided.

C) Customer Service

Beyond product quality is our long-term commitment to customer satisfaction. We work closely with our customers, responding promptly to their needs. Our staff is dedicated to making every customer a repeat customer. **Call 480-967-0624 or e-mail us at** sales@bussco.com to contact a customer service representative.

D) Electronic Data Format

We can receive customer drawings using .pdf files but prefer the use of AutoCAD's native .dwg format and .dxf type files.

E) Pricing

Prices quoted are in US funds and are FOB Tempe Arizona. Quotes are valid for 30 days from the date of the quote and subject to revision by notice to the buyer. Our terms are net 30 days for US and Canada customers and cash in advance for customers in all other countries. NCNR (Non-Cancelable & Non-Returnable) applies to all bus bar orders.

F) Lead Time

Lead times for bus bars can vary considerably and depend on many factors such as design complexity, materials used, tooling requirements, special testing or qualification requirements and quantities. Table 8 provides lead times that can be used as a rough guideline for planning purposes as it relates to the acquisition of bus bars from CCI.

Table 8 – Some typical lead times

Bus Bar Complexity	Prototypes	Production
Low	4 to 8 weeks	4 to 6 weeks
Medium	6 to 10 weeks	6 to 8 weeks
High	8 to 14 weeks	8 to 12 weeks

Low complexity bus bars would be of the variety encompassing low conductor layer count, planar with a couple of bends, pinch-off edge seal, no bushings, minimal hardware and simple fastener tabs.

Medium complexity bus bars would be of the variety encompassing two to four conductor layer count, planar, with several bends, pinch-off or potted edges, minimal bushings, some hardware, and slightly more sophisticated fasteners.

High complexity bus bars would be of the variety encompassing four or more conductor layers with possible partitions within each layer count, three dimensional with complex bends, pinch-off or significant potted edges, exotic insulation materials with possible routing involved, many bushings of different sizes, much hardware and sophisticated fasteners.

VI. GLOSSARY

Abrasion Resistance: The ability of a material to tolerate mechanically induced surface wear.

Admittance: The ratio of current to voltage, the reciprocal of impedance. The unit of admittance is the Siemens (S). Admittance is typically abbreviated as "y" or "Y."

Ambient Temperature: The temperature of the medium surrounding an object. The term is often used to denote prevailing room temperature.

American Wire Gage: (AWG): System of numerical designations for wire size, based on specified ranges of circular mil area. American Wire Gauge starts with 4/0 (0000) at the largest size, going to 3/0 (000), 2/0 (00), 1/0 (0), 1, 2, and up to 40 and beyond for the smallest sizes.

Ampere: Abbreviated A or amp. Practical unit of electrical current; the current flow rate (i.e., quantity of electrons passing a point in 1 second). Voltage of 1 volt will send a current of 1 ampere through a resistance of 1 ohm.

Bus Bar: Power distribution device consisting of single or multiple layers of rectangular conductors separated by insulation material and which may be laminated to form a single unit. Outer insulation may be used to isolate the bus bar form other components or to provide safety to end-users.

Capacitance: The property of an electrical nonconductor (dielectric in a capacitor) that permits the storage of energy as a result of electric displacement. The basic unit of capacitance is the Farad, however measurement is more commonly in microfarads or picofarads.

Capacitance Reactance: The opposition to alternating current flow presented by a capacitance. The symbol for capacitive reactance is XC. The unit is the ohm. The formula for capacitive reactance is XC = 1/(2πFC), where F is the frequency of the alternating current signal, and C is the capacitance.

Capacitive Coupling: Desired or undesired interaction between two circuits or conductors caused by the capacitance between them.

Capacitor: A device to store electricity and release it when needed - consisting of conducting plates or foils separated by thin layers of dielectric, the plates on opposite sides of the dielectric layers being oppositely charged by a source of voltage, and the electrical energy of the charged system being stored in the polarized dielectric. (See also capacitance).

Circular Mil: CMA - A unit of area equal to the area of a circle whose diameter is 1 mil (0.001 inch). Used chiefly in specifying cross-sectional areas of conductors. To obtain the number of circular mils in a round solid wire of a given diameter, express the diameter in mils then square it. The CMA formula for stranded conductor is to square the mil diameter of one strand then multiply by the number of strands. (One Circular mil is equal to 1/0.7854 Sq Mils or 1.2732 Sq Mils)

Clearance: The shortest distance through the air between two conductive elements.

Conductance: The reciprocal of resistance. The unit of conductance is the siemens, abbreviated as "S." The unit of conductance was the "mho," which was once shown as an upside down capital omega.

Conductivity: The capability of a material to carry electrical current, usually expressed as a percentage of copper conductivity (copper being 100%). Specifically, the ratio of the current flow to the potential difference causing the flow. The reciprocal of resistance.

Contact Resistance: The DC resistance of a pair of mated contacts.

Creepage: The conduction of electricity across the surface of a dielectric.

Creepage Distance: The shortest distance along the surface of the insulation material between two conductive parts.

Cross-Sectional Area: For planar bus bars, the cross-sectional area of a conductor is the product of the thickness times the width of the conductor. For wires the cross-sectional area is the sum of the cross-section areas (90^0 cut) of the individual strands in a conductor.

Cross Talk: A magnetic or electrostatic coupling that causes the unwanted transfer of energy from one circuit (disturbing circuit) to another circuit (disturbed circuit).

Current Carrying Capacity: The current a conductor can carry safely without exceeding temperature rise limits.

Derating: The reduction in a rating of a component or device to provide safety margins or to insure satisfactory performance when the parts are subjected to severe operating conditions for which normal ratings do not apply.

Dielectric: The insulating (non-conducting) material between two conductors.

Dielectric Constant: The property of an insulating material, which is the ratio of the capacitance of a capacitor with the given dielectric to the capacitance of a capacitor with an air dielectric (but otherwise identical).

Dielectric Strength: The voltage that an insulating material can withstand without failure. (Normally indicated in volts per mil).

Dissipation Factor: The ratio of the conductance of a capacitor to its susceptance. Also, the ratio of the parallel reactance of a capacitor to its parallel resistance

EMI (Electromagnetic Interference): Electro-Magnetic Interference - An unwanted electrical energy in any form. EMI is often used interchangeably with 'noise' and 'interference'.

Emissivity: The ratio of the radiant energy emitted by a radiation source to the radiant energy of a perfect radiator with identical dimensions under identical conditions.

Floating Ground: Any ground, or common current path, which is electrically isolated from earth ground or chassis ground.

Harness: A wire assembly involving two or more wires that are prepared and ready for installation into a unit or system.

Hermetic Seal: A gas-tight seal, which permits maximum gas leakage of 1.0-micron ft/hr at one atmosphere pressure.

Hertz: Term for cycles per second by international standard, adopted and now common in U.S. From the German physicist's name, Heinrich R. Hertz. In use we find that 60 cycles/second (or 60 cps) becomes 60 hertz (or 60Hz).

Impedance: The total opposition offered by a component or circuit to the flow of alternating or varying current at a particular frequency, including both the AC and DC component. Impedance is expressed in ohms and is similar to the actual resistance in a direct current circuit. In computations, impedance is handled as a complex ratio of voltage to current. The ohm is the unit of impedance. Impedance is typically abbreviated as "z" or "Z". The frequency-invariant, real component of impedance is resistance. The frequency-variant, imaginary component of impedance is reactance. The reciprocal of impedance is admittance.

Inductance: An electromagnetic phenomenon in which the expanding and collapsing of a magnetic field surrounding a conductor or device tends to impede changes in current. The effects of inductance become greater as frequencies increase. Inductance is measured in Henrys, and it is expressed by the equation: $L= E/(di/dt)$.

Inductive Reactance: The opposition to alternating current flow presented by an inductor. The symbol for capacitive reactance is X_L. The unit is the ohm. The formula for inductive reactance is $X_L = 2\pi FL$, where F is the frequency of the alternating current signal, and L is the inductance.

Inductor: A circuit component designed so that inductance is its most important property. Also called a coil.

Insulation Resistance: The property of a material that resists current flow through the material when a potential difference exists across the material.

IR Drop: The voltage measured across a circuit resistance R, when a current, I flows through that resistance.

Leakage Current: The undesirable current that flows through, or across the surface of an insulating material.

Loss Factor: The product of the dissipation and dielectric constant of an insulating material.

Mil: A unit equal to one one-thousandth of an inch (.001"), equivalent to 0.0254 millimeters or 25.4 micrometers; used in measuring the diameter of a conductor or thickness of insulation over a conductor.

Mho: Unit of conductance. Reciprocal of an ohm. One ampere of current passing through a material under a potential difference of one volt provides one mho of conductance. Also called siemens.

Noise: Random electrical signals, generated by circuit components or by natural disturbances.

RFI: (Radio Frequency Interference): Electromagnetic Interference (EFI) which exists in the frequency spectrum.

Reactance: The Imaginary part of the electrical impedance; a measure of opposition to a sinusoidal alternating current. See Inductive Reactance and Capacitive Reactance.

Resistivity: A physical property of a material to resist or oppose the movement of charge through the material. It is equal to the resistance of the material (in ohms) x (area of sample / length of sample). Typically expressed in ohm-cm, or ohm x Sq mm/m, or ohm x Sq mil/ft.

Shield: The metallic layer applied over or between dielectrics to prevent electrostatic or electromagnetic interference between the enclosed conductors and external fields.

Skin Effect: The tendency for alternating current to flow mostly near the outer surface of a solid electrical conductor, such as metal wire or rectangular bus, at frequencies above the audio range. The effect becomes more and more apparent as the frequency increases. At medium to high frequencies the skin effect essentially reduces the effective cross sectional area of the conductor and increases the resistance.

Square Mil: The area of a square, which measures one mil (0.001”) by one mil (0.001”). Thus one square mil is equal to 0.000001 in ^{2}, or 1x10^{-6} in (One Square Mil is equal to 0.7854 Circular mils).

Susceptance: The imaginary part of admittance

Temperature Coefficient of Resistivity: The ratio of the change in resistivity to the original resistivity value, for a unit change in temperature.

Temperature Rise: The difference between the initial and final temperature of the device. The increase in surface temperature of a component in air due to the power dissipation in the component.

Voltage Drop: The voltage developed across a component or conductor by the flow of current through the resistance or impedance of that component or conductor. Often simply called voltage. Also called "drop." The voltage across a resistor is usually called IR drop, while that in a conductor is usually called resistance drop.

Watt: The unit for power, abbreviated as "W," equal to 1 joule per second. The practical unit of electric power. In a dc circuit, the power in watts is equal to voltage multiplied by current. In an ac circuit, the true power in watts is effective voltage multiplied by effective current, then multiplied by the circuit power factor. There are 746 watts in 1 horsepower.

Wire Wrap: A method of connecting a wire by wrapping it tightly around a square, rectangular or V-shaped terminal

VII. APPENDIX

TABLE A

Ampacity Table

This table applies to a two-layer bus bar using a 0.005 dielectric. It gives the corresponding cross sectional dimensions, the resistivity and the inductance/inch for various amperage requirements at a 30°C max temperature rise.

Current Requirement at a 30°C max temp. rise	Required Cross Sectional Area in Sq. In.	Available Standard Conductor Thickness Inches	Calculated Conductor Width Inches	Resistivity Ohms/Inch at 20°C	Inductance Nanohenrys/Inch
I	A	T	W	R	L
50	0.016	0.020	0.806	0.042	0.198
50	0.016	0.040	0.403	0.042	0.396
50	0.016	0.062	0.260	0.042	0.613
50	0.016	0.093	0.173	0.042	0.920
50	0.016	0.125	0.129	0.042	1.236
50	0.016	0.187*	0.086*	0.042	1.850
100	0.032	0.020	1.613	0.021	0.099
100	0.032	0.040	0.806	0.021	0.198
100	0.032	0.062	0.520	0.021	0.307
100	0.032	0.093	0.347	0.021	0.460
100	0.032	0.125	0.258	0.021	0.618
100	0.032	0.187*	0.172*	0.021	0.925
150	0.048	0.020	2.419	0.014	0.066
150	0.048	0.040	1.209	0.014	0.132
150	0.048	0.062	0.780	0.014	0.204
150	0.048	0.093	0.520	0.014	0.307
150	0.048	0.125	0.387	0.014	0.412
150	0.048	0.187	0.265	0.014	0.617
200	0.065	0.020	3.225	0.010	0.049
200	0.065	0.040	1.613	0.010	0.099
200	0.065	0.062	1.040	0.010	0.153
200	0.065	0.093	0.694	0.010	0.230
200	0.065	0.125	0.516	0.010	0.309
200	0.065	0.187	0.345	0.010	0.462
250	0.081	0.020	4.031	0.008	0.040
250	0.081	0.040	2.016	0.008	0.079
250	0.081	0.062	1.300	0.008	0.123
250	0.081	0.093	0.867	0.008	0.184
250	0.081	0.125	0.645	0.008	0.247
250	0.081	0.187	0.431	0.008	0.370
300	0.097	0.020	4.838	0.007	0.033
300	0.097	0.040	2.419	0.007	0.066
300	0.097	0.062	1.560	0.007	0.102
300	0.097	0.093	1.040	0.007	0.153
300	0.097	0.125	0.774	0.007	0.206
300	0.097	0.187	0.517	0.007	0.308

*Cells with an asterisk indicate that the calculated width value is smaller than the thickness. These values are left for reference only but are not recommended choices.

VIII. OTHER CCI PRODUCTS

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