Mounting Bridge Rectifiers: Compliance Needs Make It Complicated

by Kevin Parmenter, Chair, and James Spangler, Co-chair, PSMA Safety and Compliance Committee

Among the various types of semiconductor devices, bridge rectifiers are somewhat unusual in that they are subject to safety agency certifications such as UL. These devices have agency approvals because they often connect to the ac mains in their applications. Additionally, some bridge rectifiers at larger power levels are mounted on a chassis or heatsink which can have contact with the chassis either directly or indirectly. That means the bridge rectifier is part of the isolation safety barrier and therefore subject to creepage and clearance considerations as well as hi-pot testing as part of qualification and/or production testing.

Another safety consideration stems from their high-power dissipation. Often regulatory agencies will set the maximum touch temperature of the product (depending on the applicable regulation) to something between 45°C and 60°C. In other words, no surface of the product can exceed that temperature. In many cases regulatory agencies will also limit the maximum component temperature within the product and, depending on what you are designing, this can range from no specification to a limit of 75°C max.

The requirements for isolation and heat removal are often in conflict when mounting bridge rectifiers. For example, if the bridge rectifier is suspended in air with no thermal contact to the chassis or surrounding metal surfaces, then the thermal conductivity to dissipate heat will be poor while the electrical isolation will be spectacular. So, there are tradeoffs to be made, and these must balance the safety agency requirements for isolation and temperature limits, while ensuring device reliability. In this article, we will discuss techniques and strategies for meeting these requirements—real world best practices—and highlight some of the pitfalls you will want to avoid when mounting bridge rectifiers.

In the interests of full disclosure, it should be noted that one of the authors (Kevin) works for a bridge rectifier manufacturer. However, the advice provided in this article applies equally to devices from any vendor.

Spacing Requirements

Much of this discussion will focus on satisfying thermal management requirements through the choice of hardware, materials, and mounting techniques. The isolation requirements can be viewed as something of a pre-requisite in the efforts to meet those thermal requirements. So, a good starting point in any bridge rectifier application is to ask how much spacing is needed between your device and any electrically conducting surfaces in the application.

There is a useful tool to help you answer that question based on your design at the website Creepage.com. Specifically, this site provides calculators for determining creepage and clearance distances according to IEC 60950. While that standard has been superseded by IEC 62368 and in the case of medical, IEC 60601, the results are for the most part still valid. However, I like to multiply the result by 1.5 to give some margin for applications that demand the ability to operate at higher altitudes (5000 meters seems to be the new defacto standard for altitude requirements).

Thermal Management Needs

For low-power applications, typically 70 W and below, innovative packages are now available which can be auto inserted in production at low cost yet provide sufficient cooling through the copper on the PCB. In other words, these packages do not require the rectifier to be mounted to a heatsink or the chassis. But above 70 W this type of heatsinking is commonly needed, and this is where the challenge of balancing isolation, thermal, and reliability concerns comes into play.

Historically the general approach to thermal management with bridge rectifiers has been to consider the device as a *module* that dissipates heat. However, recently this thinking has changed, and semiconductor companies are using thermal simulation systems to analyze the thermal characteristics of the bridge rectifier in more detail (Fig 1.)

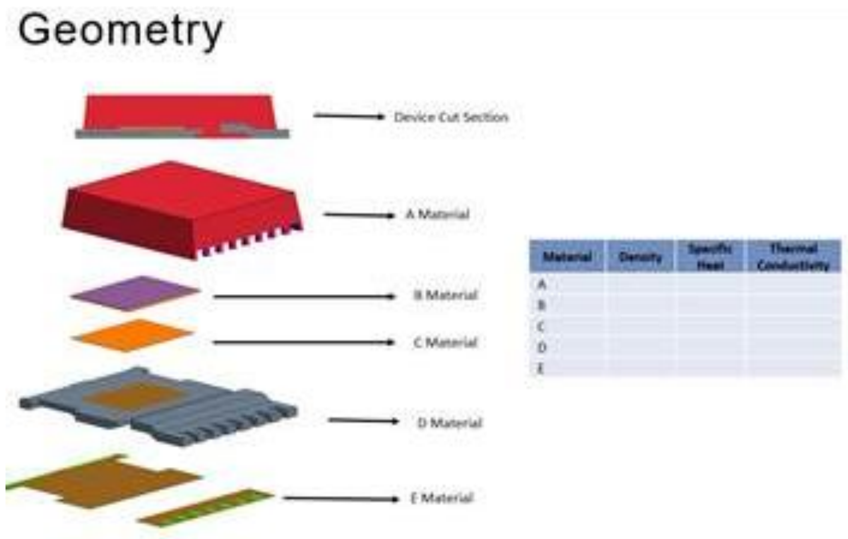


Fig 1. Thermal breakdown of a bridge rectifier (image courtesy of Taiwan Semiconductor).

Specifically, device makers are using thermal simulation to obtain a breakdown of the thermal conductivity of the lead frame, mold compound, clip, die and solder materials. This greater understanding can assist in the customer's efforts to cool the device. That includes removing heat from the device package as well as the leads. To perform a more accurate thermal simulation, it's good to know the density usually measured in kg/m^3, the specific heat measured in J/kg-K and the thermal conductivity W/m-K or thermal resistance for the device in more granularity as shown in Fig. 1.

This information is typically not on the datasheet or vendor website and you will probably need to ask your bridge rectifier supplier for it. If they do not have this type of data, they are either not the actual manufacturer of the device and/or you should be using a different supplier.

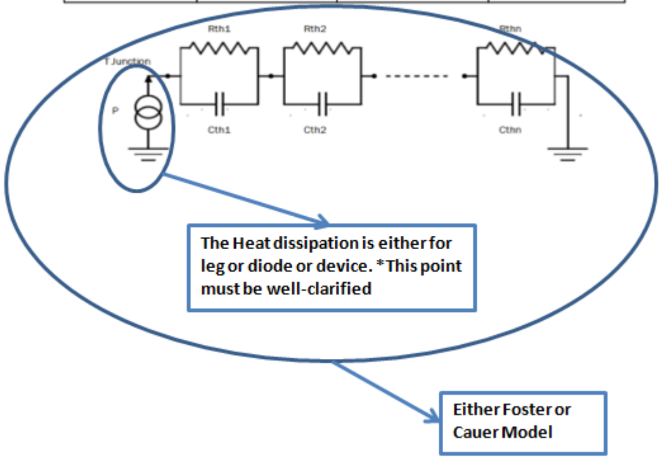
Cooling is important as the semiconductor industry's field history indicates that the failure rate of most silicon semiconductors decreases approximately by one–half for a decrease in junction temperature from 160°C to 135°C. Guidelines for designers of military power supplies impose a 110°C limit upon junction temperature.

Proper mounting of the device will support the highest possible thermal conductivity while not hurting the creepage and clearance, package integrity and zero-defect damage. We will get into the details of proper mounting techniques shortly in our discussion of mounting hardware. But before we get there, let us look further into thermal analysis.

The more information we have available, the better we can understand and predict device operation. In this regard, it is often useful to understand both the static thermal power dissipation model as well as the transient thermal response of the device. When designing with bridge rectifiers, it is often helpful to request from the supplier the Foster or Cauer models as shown in the example in Fig. 2a. Fig. 2b shows the importance of understanding the forward voltage drop of each diode in the module vs temperature. Some of this data is often provided in datasheets. But the Foster or Cauer models are usually not, so a dialogue with your supplier is needed to obtain this information.

Junction Temperature Thermal Model:

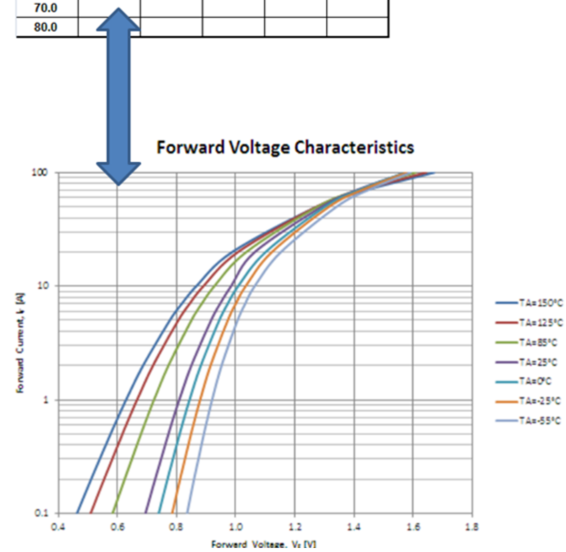
# of Leg	Rth [K/W]	Cth[Ws/℃]	Tau, τ[s]
1	8.99E-04	2.40E-03	2.15E-06
2	4.86E-03	2.06E-03	1.00E-05
3	8.30E-03	5.59E-03	4.64E-05
4	5.70E-03	3.78E-02	2.15E-04
5	1.11E-02	9.01E-02	1.00E-03
6	5.60E-02	8.29E-02	4.64E-03
7	1.90E-01	1.13E-01	2.15E-02
8	1.35E-01	7.38E-01	1.00E-01
9	7.06E-01	6.58E-01	4.64E-01
10	1.02E+00	2.12E+00	2.15E+00
11	9.01E-01	1.11E+01	1.00E+01
12	1.47E-02	3.16E+03	4.64E+01



Power Loss Model:

Bridge Rectifier Part Number					
VF@IF (V)					
IF	25℃	85℃	100℃	125℃	150℃
0.01					
0.03					
0.05					
0.08					
0.1					
0.3					
0.5					
0.8					
1					
2					
3.0					
5					
8					
10.0					
15.0					
20.0					
30.0					
40.0					
50.0					
60.0					
70.0					
80.0					

This range is well-desired to be more accurate



(a) *(b)*

Fig. 2 Foster or Cauer thermal models of a bridge rectifier module (a). Forward voltage drops versus current and temperature for a bridge rectifier module (b).

While understanding the modeling is great, it is essential to validate your modeling work with actual testing in the lab. Today I see too much reliance on modeling without lab verification to align simulations with actual performance. Just because a simulation says it is so, does not mean it is. Assumptions on any variable can make the model completely inaccurate and either give you overly optimistic or overly pessimistic results.

The goal is to have an accurate simulation of the actual use case. If you do not achieve that you really do not have anything useful. UL and other approval agencies will not be impressed with your pretty graphics and simulations if they do not agree with their worst-case testing. As a check on the thermal simulations, I find it very useful to use an IR thermal imaging camera to measure the temperatures on a bridge rectifier that is mounted as it would be in production and subjected to worst-case operating conditions. If the temperature readings match those predicted by the modeling, then we can have confidence in the simulations and know that we've met the design requirements.

Mounting Considerations

Now that you have thermally modeled the device with as much accuracy and precision as possible, it is time to examine the details of how the rectifier package will be mounted to the chassis or heatsink. Here, we must consider every piece of hardware and material type used to attach the rectifier, recognizing all the things that can go wrong with mounting.

If the mounting is not done properly then nothing else matters. Just consider, for example, that if you over-torque the mounting screw you can crack the rectifier package, which will surely cause a future defect and probably cause hipot failures in production. The latter is a good thing in a sense. It is far worse for the product to pass in production, only to fail later in the field. Keep this in mind as we discuss the different layers to our mounting assembly.

Thermal Interface Materials

If we start our hardware discussion at the interface between device and mounting surface, it brings us back to the issue of electrical isolation. Since many bridge rectifiers have electrically isolated packages the case of the semiconductor device must be electrically isolated from its mounting surface. The isolation material (that goes between device and mounting surface) is usually a thermal isolator as well as an electrical isolator which raises junction operating temperatures. In addition, the possibility of arc–over problems is introduced if high voltages are present.

Here is where those spacing requirements we discussed above are important. Various regulating agencies impose creepage distance specifications which further complicate the design requirements. Again, we are using IEC60950 as our time honored and proven guideline.

Before any type of interface material can be applied, first the mounting surface must be prepared. It must be flat and not curved. Unflat surfaces will bow the device and can crack the package. Additionally, the flatness minimizes voids which increases the thermal conductivity.

Then, the thermal path will be enhanced by applying a thermal grease or in the case of an electrically nonconductive bridge rectifier package, a thermal interface pad, which is thermally conductive. With these thermally conductive materials, you have a choice. You can specify either electrically isolating Sil Pad materials, or electrically nonisolating materials, as needed. Pay close attention to the Sil Pad thermal resistance specification as this will be a major contributor to device performance. Recall that the isolation is typically included in the package molding material. However, some semiconductors are nonisolated and thus a thermally conductive and electrically isolating pad material is needed.

Can you get by with no thermal interface? Possibly. It depends on the application and power dissipation. But thermal interface materials are cheap insurance. The makers of thermal compounds and pads should be consulted as their application engineers have a plethora of expertise and can assist designers in selecting the proper thermal interface materials.

Also consult your contract manufacturer (CM) or in-house manufacturing operations to see what they prefer. For example, silicone grease migrates and usually production engineering people do not like using it because it can contaminate manufacturing processes. It is best not to force fit something on them at the last minute—make sure what you have designed is manufacturable in your environment.

Fasteners

Fasteners are a science unto themselves. There are different styles of washers and screws to consider, different material choices, and a variety of assembly techniques.

Of course, these choices depend on the device. For example, Taiwan Semiconductor has auto insertable bridge rectifiers that range from surface-mount devices rated at 800 mA to devices with faston connectors to those higher power packages that bolt onto a chassis. Fig. 3 shows the range of device packages that are typically offered for bridge rectifiers. Each device package has its own mounting considerations. Surface-mount devices simply must have enough copper-heat-spreader surface area on the PCB to dissipate heat. Larger devices have other considerations of course.

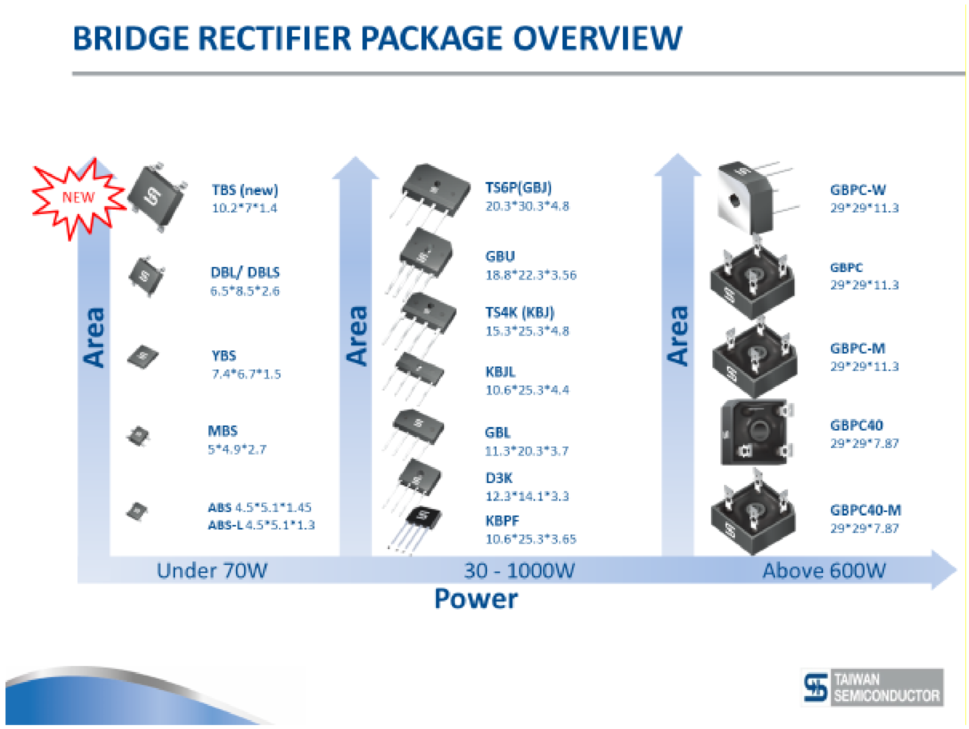


Fig. 3. Bridge rectifier packages. Above certain power levels, heatsink mounting is needed.

Washers

Notice that some of these rectifier packages have screw holes for mounting. Washers are often used when mounting these devices. It is very important to remain vigilant when selecting the size of the washer. The washer is usually electrically contacting the chassis or heatsink through the screw and thus the spacing (creepage and clearance considerations) between the washer and the leads (and the leads and chassis in general) must be considered. If proper spacings are not observed, arc over will happen during production hipot testing or during safety agency review and testing.

The size of the washer is also an issue because it affects how the force of compression is spread across the package. This must be considered along with the torque imposed on the screw so as not to crack the package. The higher the compression, the greater the thermal conductivity—to a point, that is. If the washer is compressed so far that the package cracks, then of course it is counterproductive. So, this torque and compression must be carefully controlled. Note that conical washers are a good choice in successful mounting of devices requiring strict control of the mounting force. More on these in a moment.

While we are thinking about issues that can stress the package, let us take a moment to consider materials. It is typically best to use nonferrous components for mounting hardware to prevent electrolytic corrosion or rust especially if your product will be deployed in humid environments. Stainless is a good choice, but brass or plated brass is fine as well–it depends what the heatsink is made of certainly.

Electrolytic corrosion develops between copper conductors and steel alloys or aluminum and copper in humid atmospheres. When it occurs, this corrosion can seize screws. Consequently, high-quality clamping parts are usually made of brass or stainless while screws use the same material. These materials are also particularly resistant to stress-corrosion cracking as the washer will absorb any cyclic expansion of the package and other materials caused by temperature changes.

Screws

Sheet–metal screws generally are acceptable. However, self–tapping screws are not generally recommended though we see it done sometimes in consumer products under carefully controlled conditions. Still, the danger with a standard self-tapping screw is that, during the tapping process, a volcano–like protrusion will develop in the metal being threaded. This protrusion can impede good contact and flatness and degrade the thermal interface. So, if you must use self–tapping screws please choose a screw type which roll–forms machine-screw threads.

Also screw heads should not directly contact the surface of plastic packages as the screw heads are not sufficiently flat to provide properly distributed force. In this case, Belville washers are highly recommended regardless of the other mounting hardware—they are just a great idea.

The size of the hardware depends on your preference and what fits well in the mounting hole without issues. Manufacturability is key and the best solution is a screw of the proper size with relation to the mounting hole in the device. Often the bridge rectifier manufacturer will recommend a screw size for a specific device. For example, Taiwan Semiconductor may recommend for a specific device a particular screw size and Belleville washer on the device top surface in combination with a flat washer and locking nut (the type with the plastic insert to prevent loosening with shock and vibration).

Nevertheless, if you are set on self-tapping screws into the mounting heatsink use the Belleville washer and prepare the heatsink by drilling a pilot hole. Then, use screws such as Taptite, which have a Torx drive that allows you to apply extra force with less slippage or damage to the recess. Taptite screws are made from steel and are zinc-plated steel to resist corrosion in wet environments. As with washer size, be mindful of the screw length and again, creepage and clearance between high-voltage points (leads) and the hardware.

Torqueing Down the Hardware

Normal split-ring lock washers are not the best choice for mounting power semiconductors including bridge rectifiers since you really need 150 to 300 lbs. of compression for good heat transfer at the interface. Again, a very useful piece of hardware is the conical washer, also called a Belleville or compression washer (see Fig. 5 and reference [3]).

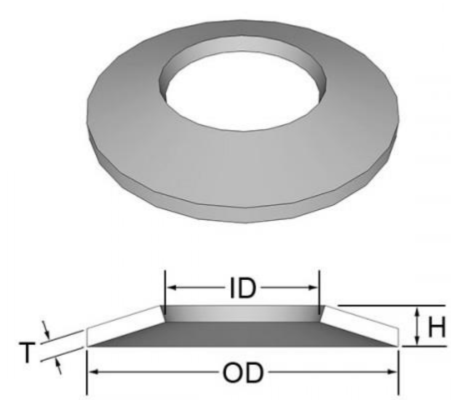


Fig. 5. Belleville compression washer (courtesy of Custom Thermoelectric).

When mounting power semiconductors, it is critical to follow the manufacturer's recommendation for torque. The properly selected Belleville washer has the added benefit of showing the operator in manufacturing, via a visual indication, when proper force is applied on the mounting of the bridge rectifier. When that visible sign is combined with a torque limit in the screw driver, it becomes easier to know when "not too much, not too little" force has been reached. In production always use a torque limited or torque wrench to avoid damage and insure consistency of manufacture.

Belville or conical washers can maintain a constant pressure over a wide range of their physical deflection (temperature excursions)—generally 20% to 80%. When installing them, the assembler applies torque until the washer depresses to half its original height. Tests should be run prior to setting up the assembly line to determine the proper torque for the fastener used to achieve 50% deflection of the washer. Then set the torque limit of the screwdriver to that level.

Consult Your Suppliers

The hardware selection must be made carefully to balance the best practices in thermal conductivity versus device manufacturability in production and the ability to meet thermal and electrical requirements of product safety certification agencies. It is highly recommended that you consult with the applications engineering staff at your bridge rectifier supplier, as well as the makers of your thermal interface products, mounting hardware, heatsink manufacturers, regulatory agencies and so forth.

The ability of suppliers to provide support should also be a consideration when choosing suppliers. In the case of the semiconductor supplier, recall also that the rectifiers themselves are subject to safety standards. So, make sure your bridge rectifier supplier has the proper agency approvals available before starting the design.

But once you have established your suppliers, take advantage of their knowledge. Do not struggle and suffer in silence when technical support staff are only a phone call or email away. Their experience with the various issues relating to bridge rectifier mounting and other expertise can save you time and money.

References

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3. Belleville Disc Spring Washers, a short tutorial from Lee Spring on Belleville washers
4. TAPTITE II FASTENERS product page by REMINC
5. Taiwan Semiconductor website
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About the Authors

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Kevin serves on the board of directors of the PSMA (Power Sources Manufacturers Association) and was the general chair of APEC 2009 (the IEEE Applied Power Electronics Conference.) Kevin has also had design engineering experience in the medical electronics and military electronics fields. He holds a BSEE and BS in Business Administration, is a member of the IEEE, and holds an Amateur Extra class FCC license (call sign KG5Q) as well as an FCC Commercial Radiotelephone License.

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For many years, he worked as a field applications engineer (FAE) for Motorola Semiconductor, On Semiconductor, Cirrus Logic, and Active Semiconductor, assisting customers in using semiconductors. He published numerous application notes and conference papers at a variety of conferences: APEC, ECCE, IAS, and PCIM. Topics included power factor correction, lighting, and automotive applications. As a FAE, he traveled internationally giving switch-mode power supply seminars in Australia, Hong Kong, Taiwan, Korea, Japan, Mexico, and Canada.

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For further reading on power supply-related safety and compliance issues, see How2Power's special section on Power Supply Safety and Compliance.