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A Guide To Second Sourcing Rectifiers

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Rectifiers are usually not very high on the priority list of most designers. Once designed-in on a PCB and qualified, the sources of these components are rarely changed to other suppliers. However, if problems happen in the supply chain or a supplier "end of lifes" parts then attempts will be made to second source them.

This article describes some of the problems that can occur when you second source rectifiers. Although testing is necessary in many cases, by better understanding the manufacturing processes, datasheets and technology, the testing can be more focused and failures in mass production can be avoided. Test programs and statistics provided by the manufacturer should also be considered.

We will start by discussing some general issues that arise when cross referencing standard rectifiers. Afterwards we will go into the details that apply when looking specifically at bridge rectifiers, fast recovery and fast efficient rectifiers, Schottky diodes, TVS diodes, small-signal products and zeners.

It is also important to understand that there is no such thing anymore as a mask exchange alternate source agreement. This went out in the 80s and now devices that are marked the same or indicated to be alternate sources may have widely varying construction and internal die when compared to the originally specified device.

Standard Rectifiers

With the term "standard rectifiers" we mean products like the S1 in an SMA package or the 1N4007 in a DO41. Please understand that these products are 55 and 30 years old, respectively. They are used as 50-/60-Hz ac-dc rectifiers or they provide reverse-polarity protection.

Surge Current And Breakdown Voltage Ratings

First, always compare the absolute maximum ratings on the two datasheets. There are really only two absolute maximum ratings in a rectifier datasheet: the surge current I_{fsm} and the breakdown voltage V_{rrm}. Exceeding them may result in catastrophic failures. (Another key specification, the maximum junction temperature will be discussed shortly.)

The breakdown voltage is 100% tested in production. So designers can take this parameter for granted. On the other hand, cross reference problems may arise if distributions of Vrrm are not considered. Most standard rectifiers are offered under numerous part numbers with ratings ranging from 100 V to 1000 V. But all the various part numbers may share the same die source (or possibly a vendor might use two die to cover the range).

These wafer sources may have a large spread in distribution of the breakdown voltage. If you are building prototypes or testing a few samples in the lab, you are only testing a small sample in a large population. It's recommended that you ask your supplier for essential details on device production data. A supplier who is set up for automotive AEC-Q products will have the ability in place to provide production parametric information as well as MTBF and FIT data and more.

Having only one wafer source means the electrical characteristics in the forward direction will be the same for all voltages. This information can be helpful in case of supply chain problems. However, different suppliers may have different test conventions, guard bands and distribution on breakdown voltages. This can lead to surprises.

Additionally, buyers if left unchecked will want to buy from whoever has the lowest-priced part without regard to any of the important technical details or the quality and reliability of the component or the integrity of the supplier. This can lead to production issues or field failures. God love them, buyers are salespeople in reverse and are evaluated on cost savings. They are not measured on the product working and lasting in the field or production yields.

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But returning to specifications, the I_{fsm} surge current rating is not tested in mass production but is guaranteed by design. It is determined by the die size as the inrush current in ac-dc converters usually is less than 1.5 ms. To save cost, different suppliers may reduce their die size. In addition, the manufacturing process may produce different amounts of solder voids—which impacts the surge current. So, if your design is marginal on surge, you may want to do some detailed testing when cross referencing including testing to destruction.

Different suppliers may also have different test conventions on delta V_f to eliminate worst-case solder voids.

Thermal Ratings

The maximum junction temperature T_j of a rectifier can be interpreted and used in three different ways: to determine the current rating, to set reliability testing and to determine long-term reliability using the Arrhenius equation. Semiconductor companies' marketing department usually determines the maximum T_j in the datasheet.

In the case of AECQ-qualified devices, testing is done by the manufacturer at the rated temperature and rated voltages and the definition of maximum T_j is clearly defined. In the case of non AECQ101 devices—there is a lot of freedom for the supplier in the datasheets and it may be beneficial to understand how a supplier determines the datasheet maximum T_j when cross referencing parts. If you are designing a product where reliability is paramount such as telecom/datacom, networking, radio communications and industrial equipment where uptime is crucial, it's good to use parts which are AEC-Q 101 qualified. You don't have to buy the automotive part however typically the difference is paperwork only from a reputable manufacturer.

In the case of Schottky diodes there is greater variety in processes and technologies (barrier materials) resulting in various T_j definitions. Standard rectifiers are manufactured using so called GPP (glass passivated pellet) processes. There are differences in quality between these processes. These differences can usually be observed by comparing leakage-current distributions. It's not out of the question to ask your supplier for this information and again, a quality supplier will make this available to you on request.

Rectifiers are temperature driven devices. The most important equation for a rectifier is $T_j = T_a + P_d*R_{thj-a}$ where T_j is the junction temperature, T_a is the ambient temperature, P_d is the power dissipation and R_{thj-a}, the thermal resistance from junction-to-ambient. In determining power dissipation, usually one can ignore leakage current and switching losses such that $P_d = I_f*V_f$. The current rating of a rectifier follows this equation. It's important to note that the supplier of the part can only really control the thermal resistance from the junction to the case, leads and thermal pads depending on the part. The engineer must consider the heat spreading and thermal resistance from the device to the PCB or heatsink. More on that in a moment.

It can be easily observed that marketing at semiconductor suppliers can change the current rating of a device or the current derating curve of a rectifier by changing the R_{thj-a} (sometimes to unrealistically low values) to make the datasheet more attractive. Take the derating curve of the 1N4007 as an example (Fig. 1).

Marketing determines the R_{thj-a} in this curve and the temperature at which the derating starts. The same rectifier can have a current rating x2 under different thermal circumstances. This can be avoided by using case temperature T_c on the x-axis and the R_{thj-l} is a fixed value in the datasheet.

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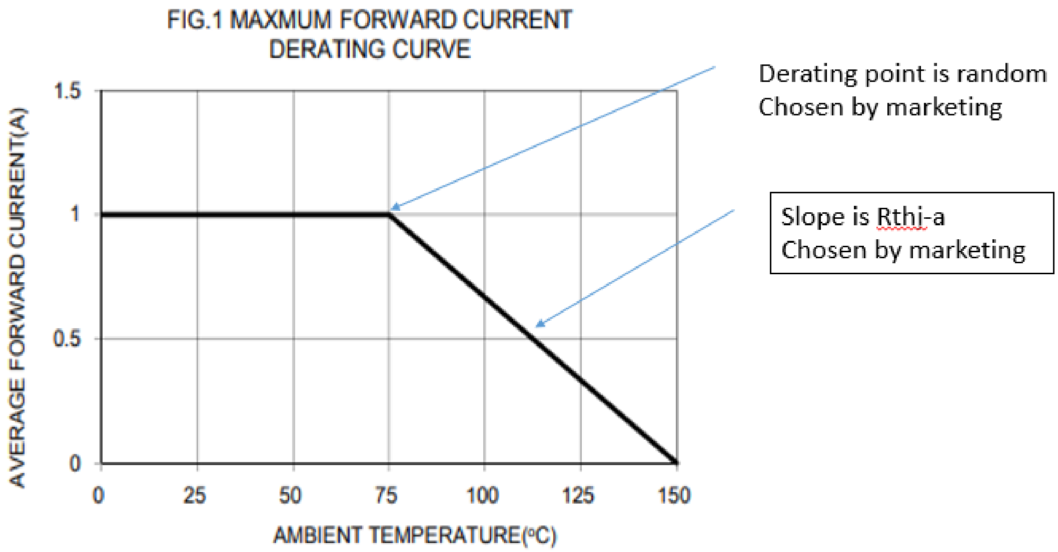

Fig. 1. Current derating curve is determined by marketing. (Courtesy of Taiwan Semiconductor)

But designers should also be careful when the derating graphs mention the T_c on the x-axis, not the T_a (especially for SMD parts). In most designs the thermal resistance consists of two parts: thermal resistance junction-to-case/lead and the thermal resistance case/lead-to-ambient. Unless the products are heatsinked, the latter part of the thermal resistance is the major contributor (75% plus). Derating using T_c then becomes meaningless. The concept of the infinite heatsink is purely theoretical—it has no practical application. Semiconductor suppliers can only control the junction to case (or tab or heat spreader.)

So, using a current rating as a main parameter when cross referencing rectifiers can result in many surprises. The statement that a rectifier is 3 A or 5 A can be meaningless. It is better to compare the V_f specifications and test conditions between two rectifiers (Fig. 2). In some cases, the testing currents do not match, and two different suppliers may also have two different Cpk targets. It is best to use the typical V_f curve, which plots V_f versus current in the datasheets. This curve cannot be manipulated and if measured correctly allows you to compare apples to apples (i.e., die sizes). You can compare this on the device datasheet or ask the supplier for the production distribution of V_f.

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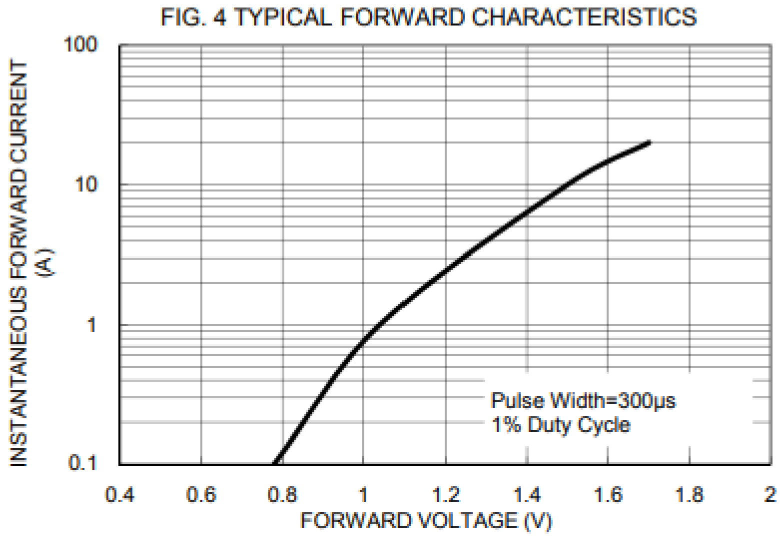

Fig. 2. The forward voltage (V_f) versus current curve cannot be manipulated by a company's marketing department. (Courtesy of Taiwan Semiconductor)

Leakage Current (I_r)

In many datasheets leakage current specifications are set at 1 µA to 5 µA for standard rectifiers. However, these specifications can be 30 to 50 years old, and there have been many technology improvements over the years. The normal distribution of the leakage current stops at a few hundred nanoamps, depending on the die size. Sometimes the T_j rating of 150°C or 175°C can be best verified by comparing the typical I_r curves vs voltage at different temperatures (Fig. 3).

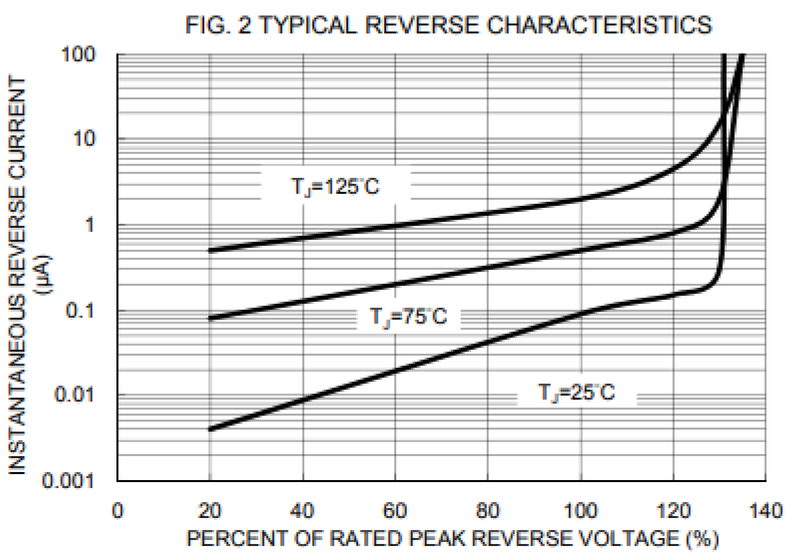

Fig. 3. Leakage current graphs for the S1 rectifier. (Courtesy of Taiwan Semiconductor)

An improved T_j should be supported by lower leakage data at high temperatures.

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When cross referencing standard rectifiers, the most important surprises may come from the different test programs used by various manufacturers. Reliable rectifiers need PAT testing, aligning the test specification on I_r with the normal distribution, not the datasheet value. If PAT testing is not applied, field failures may increase (Fig. 4). Ask your supplier if they use PAT testing.

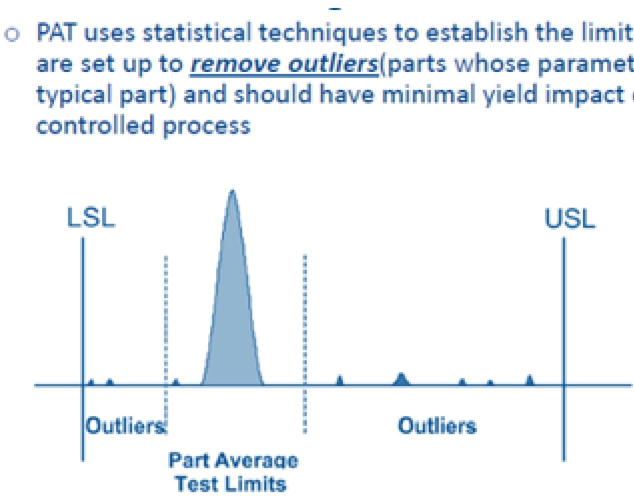

Fig. 4. PAT testing eliminates field failures. (Courtesy of Taiwan Semiconductor)

Avalanche Rating

Although it should be considered positive when a supplier gives an avalanche rating as it can be a sign of robustness, the rating should be studied carefully. The test time may differ significantly from the avalanche pulse in the designer's circuit. Many datasheets also give nonrepetitive avalanche ratings, whereas many real designs have repetitive spikes, which can dissipate a lot of power. Ask for test conditions, size of inductor used and the details on the avalanche rating testing—it's often not apples to apples.

In the case of a conservative design that is well derated with proper margin, it should be easier to cross reference standard rectifiers and change suppliers. If the design is marginal, extensive testing needs to be performed. Examples of a conservative design would be one limiting the PCB temperature to 90°C or 95°C, a derating of at least 20% on the breakdown voltage and a peak surge current below the 10-/8.3-ms value in the datasheet.

Fast Recovery And Fast Efficient Rectifiers

The definition of T_{rr} and its associated test condition may puzzle a lot of new designers. The typical test circuit used by the manufacturer (see Fig. 5) has no bearing on device usage in the real world. It is based on mass production test equipment, which was built more than 40 years ago and has not changed significantly since then. This makes it difficult to compare fast recovery and fast efficient rectifiers from two suppliers in an actual circuit.

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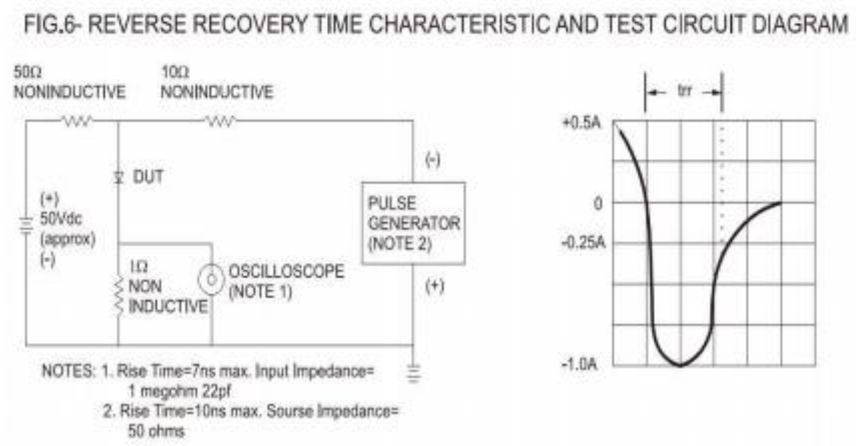

Fig. 5. T_{rr} test performed on a standard automatic test machine. (Courtesy of Taiwan Semiconductor

So, recovery behavior should always be tested in the real application circuit to make sure that the components are equivalent. The datasheet can give guidance, yet nothing is as good as in-circuit application testing to compare two devices. It's often useful to use a thermal imaging camera to perform A-B comparisons in the actual application circuit as well.

In applications switching at 40 kHz or less and using ZCS topologies, changing suppliers may be easy because recovery time is not so critical in these circumstances.

However, in circuits with hard switching, the T_{rr} parameter is a critical one and the technology differences between suppliers can become apparent. The peak reverse current I_{rrm} adds to the stress of the switching transistor, the Q_{rr} further determines switching losses and softness may be different (Fig. 6).

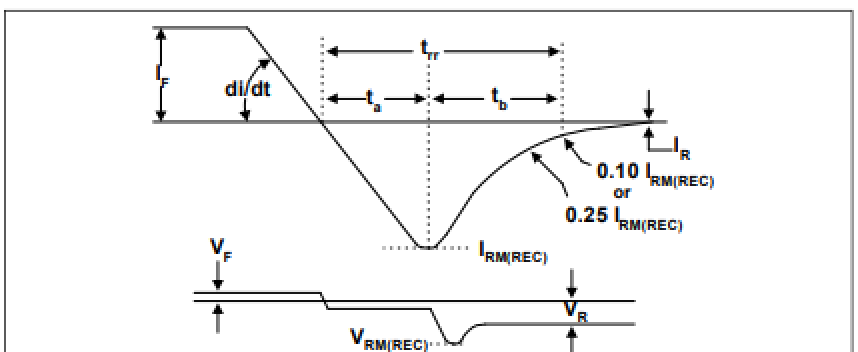

Fig. 6. T_{rr} losses in the case of a hard-switching power circuit. (Diagram courtesy of Microsemi.)

Different suppliers have different definitions of T_{rr}. They can be linked to a certain value of the maximum I_{rrm} or can be defined by extrapolating the recovery slope of the diode to zero (Fig. 7).

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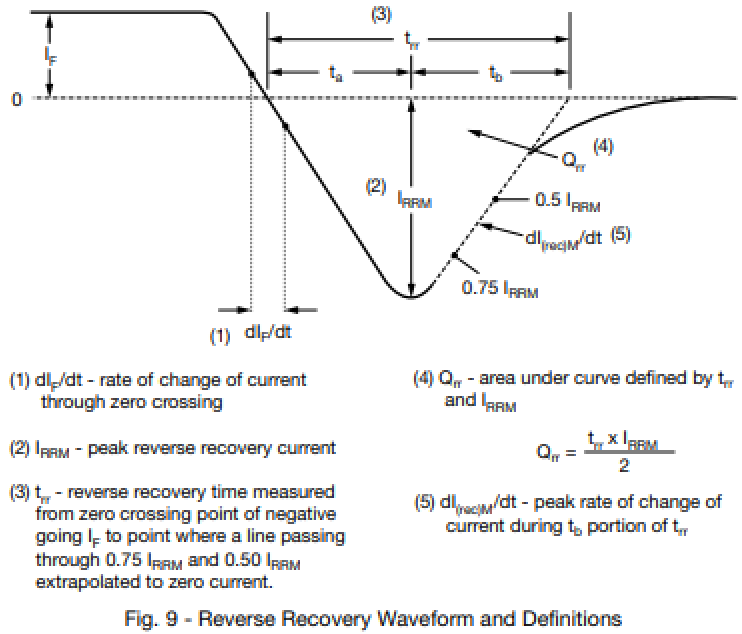

Fig. 7. T_{rr} as defined originally by International Rectifier (These devices were acquired by Vishay).

A meaningful comparison of two datasheets is only possible if the same forward current I_f and di/dt has been used to turn off the diode. Different values for these two parameters will lead to completely different results and data.

Different fast recovery rectifiers will also produce different EMI. The best indicator for EMI is the softness definition of the rectifier in the datasheet. A generally acceptable definition for softness would be a T_b/T_s ratio bigger than 1 (Fig. 8).

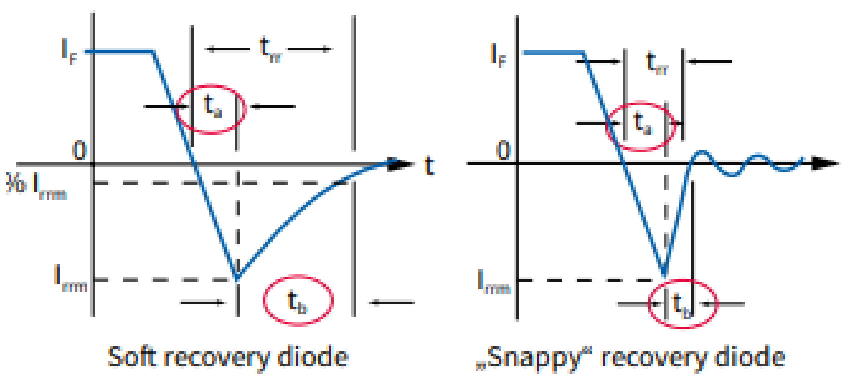

Fig. 8. Definition of a soft diode as per Infineon.

In the case of hard-switching fast efficient rectifiers (FERs), second sourcing is only possible after extensive testing. We need to also mention that Q_{rr}, I_{rrm} and T_b/T_a are temperature dependent and have a positive temperature coefficient. As such testing is also needed under worst-case temperatures.

You don't want to go through EMC certification again so careful testing including probing the area for EMC is a good idea when doing A and B comparisons in circuit. Lower-voltage FER rectifiers can be produced in several

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different ways. A 200-V output rectifier may be produced used EPI wafers or not. This may result in a lower V_f and a better T_{rr}. There is, however, a cost penalty.

There is no magic solution for FER diodes. In general, to reduce the T_{rr} and switching losses the supplier will need to add more platinum or other lifetime-killing materials. These tend to increase the V_f. So, when second sourcing or designing with FER diodes you will need to take this trade-off into account.

Bridge Rectifiers

Bridge rectifiers follow the same basic rules as standard rectifiers. In most cases there is only one wafer source and actual voltage rating and the forward-conduction electrical characteristics are the same for 100-V to 1000-V parts.

Different suppliers may have models with different construction and thermal resistance. So the temperature profiles should be checked with an infrared camera in the actual circuit. As an example, a recent product change notice (PCN) modification from Taiwan Semiconductor (TSC) optimized the heat distribution inside the bridge rectifiers, avoiding hot spots and improving reliability (Fig. 9).

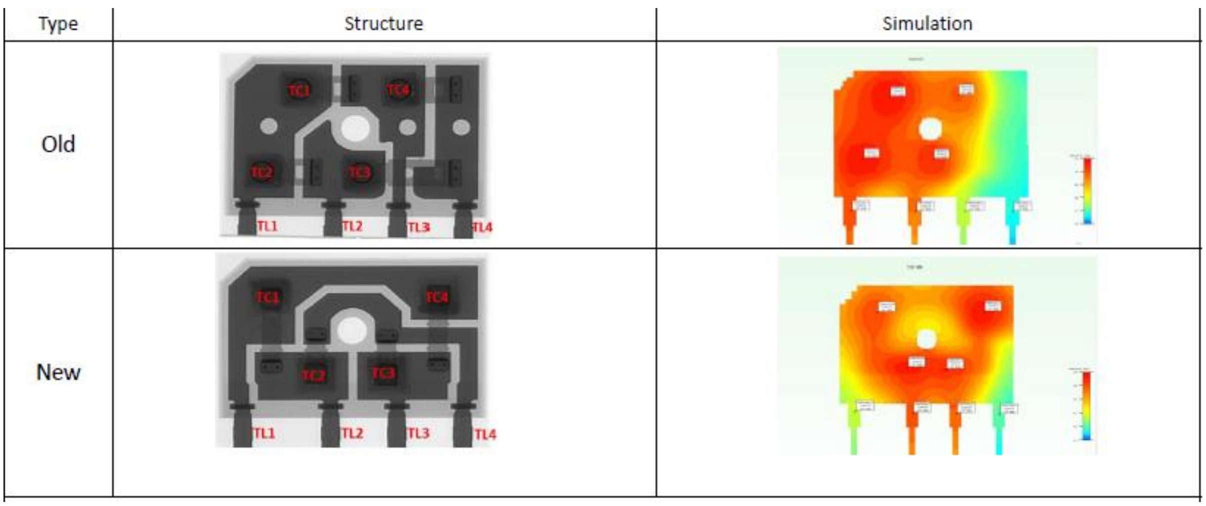

Fig. 9. A change in the package design used by Taiwan Semiconductor's bridge rectifiers, improved heat distribution, reducing hot spots.

In comparison with standard rectifiers, manufacturers take more liberties when selecting the die size for bridge rectifiers in order to reduce costs. So, make sure to always compare I_{fsm}, to ensure that you're finding a device with die of comparable size, more is better after all. The use of soft start in the application may change priorities when cross referencing a part, but the I_{fsm} rating gives the best initial indication of the die size used, as well as the typical V_f curves.

Producing a bridge rectifier tends to be a very manual process of packaging die in the package so differences in quality between suppliers is possible. The molding compound used has a big impact on humidity-related life testing such as the 85/85 long-term life test. If your product is used in a humid environment, you may want to discuss this with the supplier.

Only molded bridge rectifiers can be qualified as per AEC Q101. Potted bridges will not pass qualification testing so again, looking for AEC Q101 qualification is a good indication that the part will be highly reliable in the end application.

Schottky Diodes

When second sourcing Schottky diodes, the main difference versus standard rectifiers is that the leakage current losses can no longer be ignored when figuring power dissipation and need to be compared in detail and

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during testing. In the case of Schottky diodes, the P_d in the $T_j = T_a + P_d{*}R_{thj\text{-}a}$ equation consists of $P_d = V_f{*}i_f + I_r{*}V_{br}$. The leakage current losses depend on the voltage applied, the temperature, the barrier material used and the die size. In the case where an 80-V reverse voltage is applied, a 5-mA leakage current can cause significant losses. Of course the lower leakage current, the better.

The definition of T_j max for a Schottky diode is linked to the barrier material used to manufacture the product. Usually they are grouped in 150°C or 175°C rated products. The T_j max is the first and best indicator of the leakage current you can expect. When second sourcing a Schottky diode, make the Tj max comparisons after comparing the breakdown voltage and the V_f spec.

Many different barrier materials exist in the industry. As an example, some of these variations result from manufacturers varying the amount of silicide used. The Schottkys produced with these different barrier materials are then grouped by marketing convention into 150°C/175°C rated products. Each barrier material has unique V_f and I_r values for a given die size. Designers should not assume that different suppliers always use the same barrier material, and actual testing of devices in the intended circuit is necessary.

Like standard rectifiers, the current rating of a Schottky diode can be influenced by marketing. As the Schottky diodes are mainly used in pulsed environments with a certain duty cycle, the typical V_f curves are the better ones to compare.

Reverse losses can be important and as the voltage increases, the chance of thermal runaway increases. The maximum values of I_r in the datasheets are only an indication. Compare the I_r curves at higher temperatures. Making I_r curves for hundreds of datasheets at high temperatures can be a tedious job. As a result, there may be datasheet errors. So, compare the leakage currents in your circuit at your maximum temperature.

When a vendor specifies $dP_{tot}/dT_j < 1/Rt_{hj\text{-}a}$ for the definition of T_j, this indicates that the T_j of the Schottky is dependent on the test board. How does this work?

In recent years, most new Schottky products released have a unique die source per part number. This was not the case previously. In the past there was a so-called "prime bin," and products that did not meet the original specification were downgraded.

As an example, 40 V was sold as 30 V, 60 V as 50 V and 100 V as 90 V. The V_f rating of a Schottky diode is very dependent on the breakdown voltage so if a product has the same V_f specification but a different voltage, then the higher voltage is the prime bin. However, PAT testing by the manufacturer should eliminate reliability concerns about the lower voltages.

Schottky diodes have a major influence on the efficiency of your circuit so it should always be measured. Another reason for testing is that the EMI performance can be different and again—recertification for EMC can be very expensive as will be shipping a noncompliant product when all you did was change a diode.

The discussion so far has focused on Schottkys manufactured in a planar process. The trench Schottky makes cross referencing more complicated. They have a better V_f for a given die size or a lower I_r for a given V_f (versus a planar diode). However, their capacitance is usually higher which may increase losses, yet it will probably reduce EMI.

TVS Diodes

Among all the diodes and rectifiers being discussed here, these devices are the easiest to cross reference, especially when used against ESD, EFT, lighting pulses and standards-based transient events, i.e. IEC 61000-x-x. TVS diodes are 100% tested in the factory for pulse behavior, so you may not need to repeat the measurement of transient thermal impedance.

However, these diodes should be tested in snubber circuits, when used as higher-power Zeners or when applied in load dump applications. In these cases, TVS diodes are being used outside of their normal function and differences between suppliers may affect performance in these applications. Also, test devices on fast data

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lines, as differences in die size can show up in the capacitance. The higher the capacitance the slower the data allowed to pass.

Derating curves may vary if the parts are rated at 150°C or 175°C. How can the supplier guarantee the T_j? Most pulses are a one-off random event, and T_j can be exceeded (the part survives or does not survive). So T_j rating becomes less important.

Small-Signal Products

Small-signal diodes are usually straightforward to second source or replace. But there are some caveats.

Zeners can have a manipulated maximum power rating by mounting them on substrates with a much lower thermal resistance (such as ceramic substrates) or rating them into an infinite heat sink.

When there are pulses, the internal construction (such as the die attach method) becomes important and two different suppliers may not perform the same. Check the datasheet specifications carefully between suppliers and ask for data. In addition, if your supplier of all these types of devices cannot provide proof of AEC-Q automotive qualification data and processes, and does not possess automotive AEC-Q capabilities, it's probably not a great idea to consider them as a supplier.

References

"Secrets Of The Datasheet: What Rectifier Specs Really Mean" by Jos van Loo and Kevin Parmenter, How2Power Today, September 2019.

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For further reading on designing with rectifiers, see the How2Power Design Guide, and locate the Component category and select "Diodes and Rectifiers."

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