WHITE PAPER

Second Sourcing Rectifiers

How to compare components and data sheets

Author: Jos van Loo, Taiwan Semiconductor Europe GmbH

April 2020

www.taiwansemi.com

Introduction

Rectifiers are critical components for any manufacturer of power management systems. Although they are usually low in a Pareto analysis of field failures, they are some of the hottest components on the PCB, determine efficiency and EMI, and are exposed to many temperature cycles and high voltages.

Billions of rectifiers are produced every year. Because there are not that many technological advances, designers are quite happy to continue recycling old designs with rectifiers and manufacturers they trust. Never change a winning team is a good slogan for rectifier design.

Sometimes for cost or supply chain reasons a change becomes necessary. This usually starts with a Google search and by comparing datasheets. This article will highlight some of the issues designers may face that are not apparent from just comparing datasheets

Testing is necessary in many cases. By better understanding the manufacturing processes, datasheets and technology, the testing can be more focussed and mass production failures can be avoided. Test programs and statistics should also be taken into account

We will start with some general concerns when cross referencing standards rectifiers. Afterwards we will go into more details when looking specifically at Bridge Rectifiers, Fast Recovery and Fast Efficient Rectifiers, Schottky Diodes, TVS diodes, small signal products and zeners.

1. Standard Rectifiers

With standard rectifiers we mean products like the S1 in an SMA package or the 1N4007 in a DO41 package. Please understand that these products are 55 years and 30 years old respectively. They are mostly used as 50/60Hz AC/DC Rectifiers or as polarity protection.

First always compare the absolute maximum ratings on the two datasheets. There are really only 2 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. The maximum junction temperature will be discussed at a later stage.

The breakdown voltage is 100% tested in production. Designers can take this parameter for granted. Cross reference problems may come from not taking into account the distributions of the V_{rrm}. Most standard rectifiers have many different partnames going typically from 100V to 1000V, but they may only have one die source (or 2). These wafer sources may have a large spread in distribution of the breakdown voltage. Different suppliers may have different test conventions, guard bands and distributions on breakdown voltages. This can lead to surprises. If you are building prototypes or test a few samples in the lab, you are testing only a small sample in a large population. If your design is marginal to the datasheet specification, and you may not notice any problems until you switch supplier.

Having only one wafer source means the electrical characteristics in forward direction will be the same for all voltages. This information can be helpful in case of supply chain problems.

The I_{fsm} surge current 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 1.5ms. To save costs, different suppliers may reduce their die size. The manufacturing process may produce different amounts of solder voids – which also impacts the surge current. So if your design is marginal on surge, you may want to do some detailed testing when cross referencing (surge to failure)

Different suppliers may also have different test conventions on delta V_f to eliminate worst case solder voids. A delta V_f test measures the V_f before and after a short current pulse, which heats up the die. The V_f of a rectifier has a negative T_c. The shift in V_f gives an indication of the thermal resistance and an indication of the solder voids.

The maximum junction temperature T_j of a rectifier can be interpreted and used in 3 different ways: to determine the current rating, set reliability testing and determine long term reliability using the Arrhenius equation.

Marketing can determine the maximum T_j in the datasheet. In the case of AECQ qualified devices, testing should be done 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 by the supplier in the datasheets and it may be beneficial to understand how the supplier determines the datasheet maximum T_j when cross referencing parts. In the case of Schottky diodes there is a bigger variety in processes and technologies (barrier materials) resulting in various T_j definitions. Standard rectifiers are manufactured using so called GPP processes (Glass Passivated Pellet). There are differences in quality between these processes. These differences can usually be observed by comparing leakage current distributions.

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, Ta the ambient temperature, P_d the power dissipation and R_{thj-a}, the thermal resistance junction to ambient. Usually one can ignore leakage current and switching losses: in that case $P_d = I_f * V_f$. The current rating of a rectifier follows this equation and it can be easily observed that marketing people 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. We took the derating curve of the 1N4007 as an example.

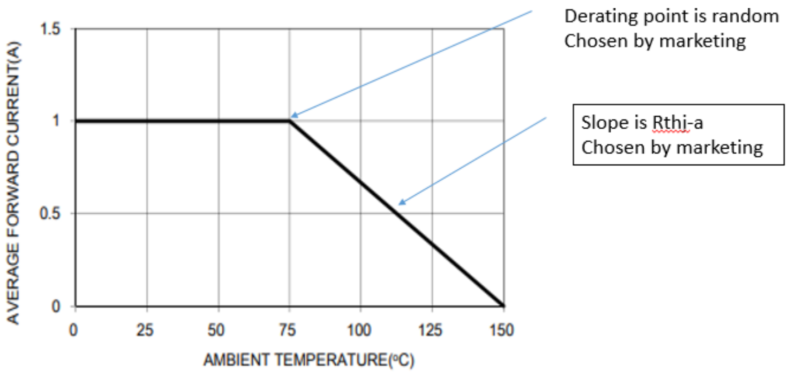


Figure 1: Derating-Curve of the Rectifier diode 1N4007

Marketing determines the R_{thj-a} in this curve and the point 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 Tc on the x-axis and the R_{thj-l} is a fixed value in the datasheet. But designers should also be careful when the derating graphs mention the Tc on the x-axis, not the Ta (especially for SMD parts). In most designs the thermal resistance consists of 2 parts: thermal resistance junction to case / lead and the thermal resistance case / lead to ambient. Unless the products are heatsinked (or very good convection cooling), the latter part of the thermal resistance is the major contributor (75% plus). Derating using Tc then becomes meaningless. The concept of the infinite heatsink is purely theoretical – it has no practical application.

So using current rating as a main parameter when cross referencing can result in a lot of surprises. The statement that a rectifier is 3A or 5A can be meaningless. It is better to compare the V_f specifications and test conditions between 2 rectifiers. In some cases the testing currents do not match and 2 different suppliers may also have 2 different Cpk targets. It is best to use the typical V_f curve - plotting V_f versus current in the datasheets. This curve cannot be manipulated and if measured correctly allows you to compare apples to apples (die sizes).

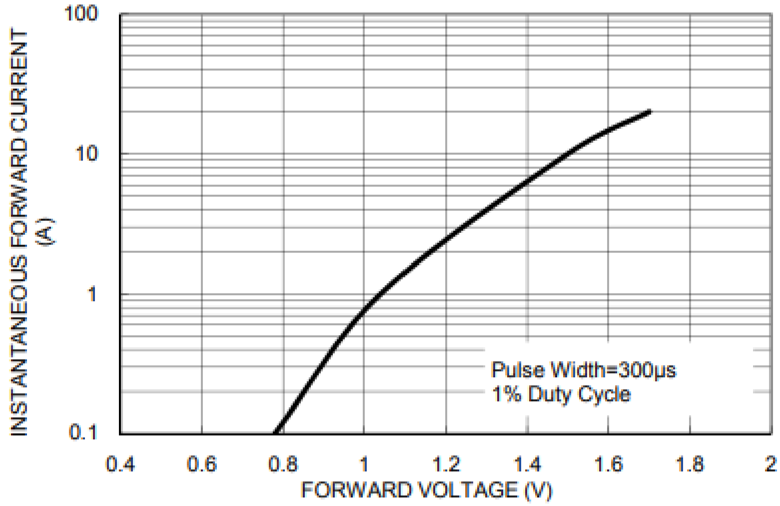


Figure 2: Typical Vf-curve

Leakage Current (I_r): Leakage current specifications are set at 1uA to 5uA for standard rectifiers in many datasheets. These specifications can be 30-50 years old, and there have been many technology improvements. The normal distribution of the leakage current stops at around 100nA, depending on the die size. Sometimes the discussion on a T_j rating of 150 or 175C can be best verified by comparing the Typical I_r curves vs voltage at different temperatures.

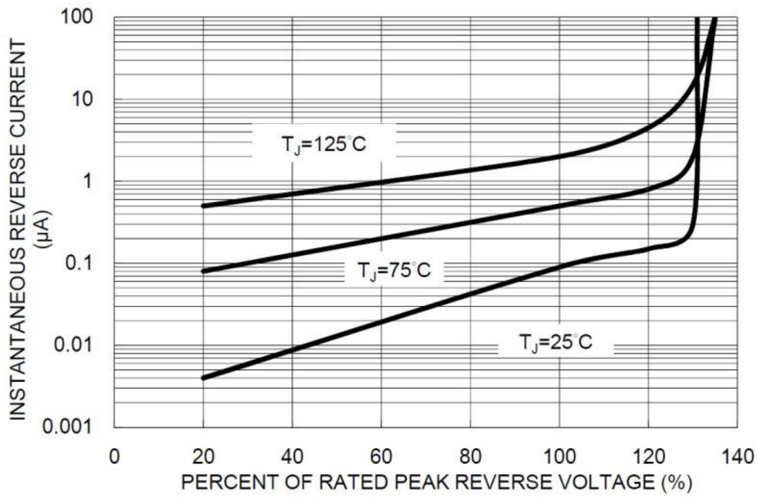


Figure 3: Typical leakage current graph for component S1

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

The most important surprises when cross referencing 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. Especially downgrading – retesting rectifiers that do not meet 1000V at a much lower price and selling them eg as 100V with a higher leakage than the normal distribution – is a recipe for failure in the field.

PAT uses statistical techniques to determine the limits of these test results. These test limits are used to remove outliers and should have minimal effect on the yield of correctly processed parts. Parts are called outliers when their parameters are statistically different from the typical part.

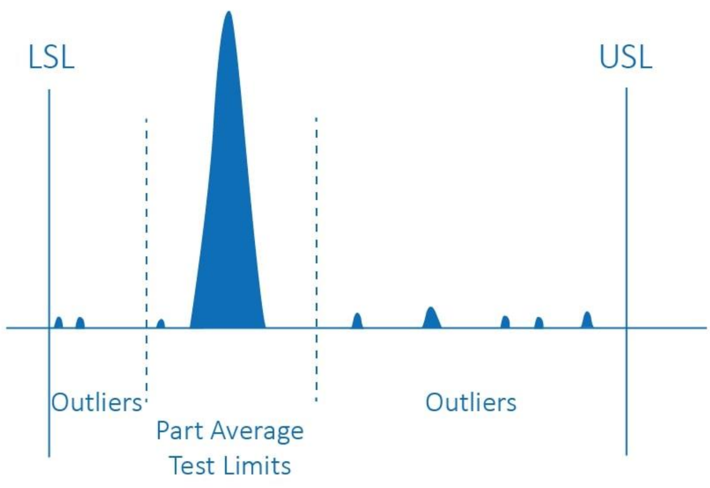


Figure. 4: PAT testing eliminates field failures

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 non-repetitive avalanche ratings, whereas many real designs have repetitive spikes – which can dissipate a lot of power.

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

2. Fast Recovery / Fast Efficient Rectifiers (FER)

The definition and test condition of T_{rr} may puzzle a lot of young designers. The typical test circuit used has no bearing with the real world. It is based upon mass production test equipment built more than 40 years and has not changed significantly. This makes it difficult to compare 2 suppliers in the actual circuit using just a datasheet.

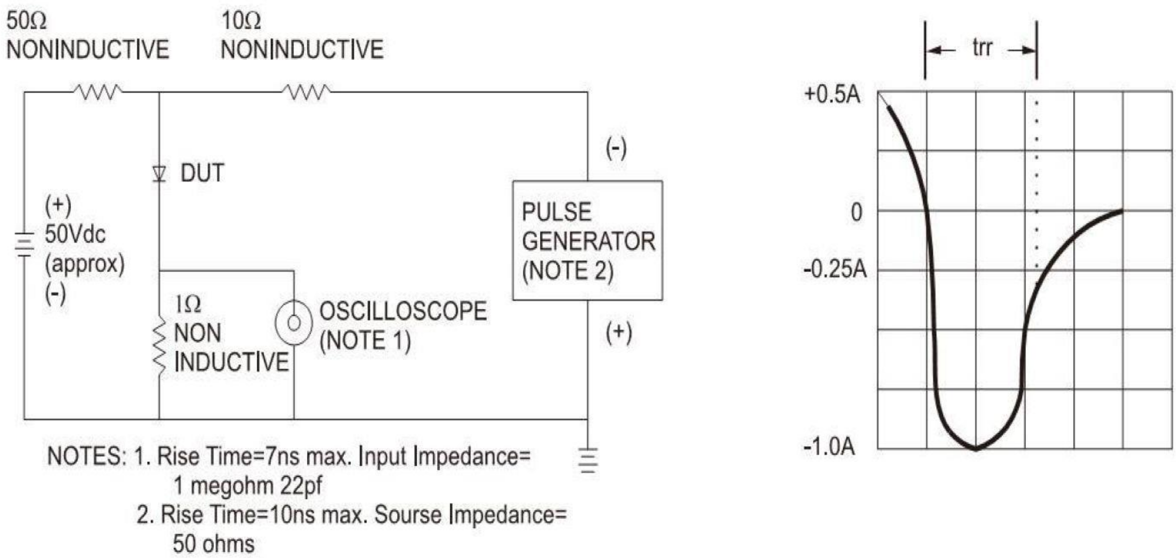


Figure 5: Test specifikation t_{rr} from the 80s is still used

So recovery behaviour should always be tested in the real circuit to make sure that the components are equivalent.

In applications switching at 40kHz or less and ZCS (Zero Current Switching) topologies, switching suppliers may be easy.

However in circuits with hard switching, the T_{rr} parameter is not the most important 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 (e.g. in a PFC boost converter topology).

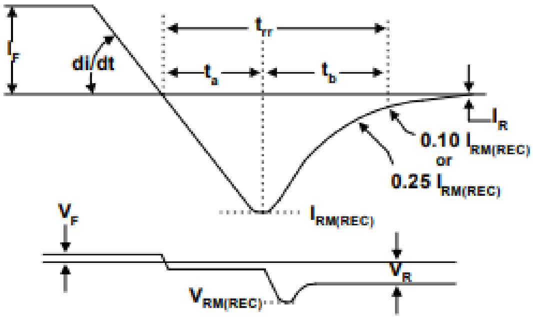
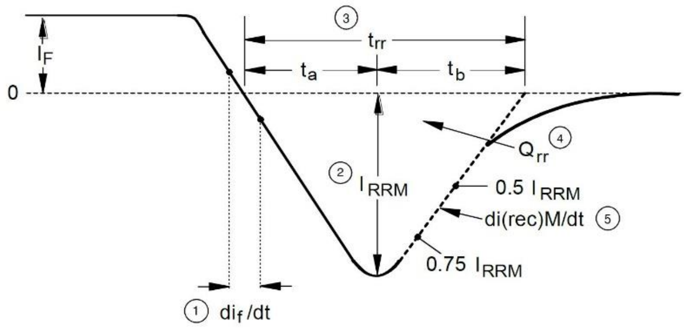


Figure 6: t_{rr}-losses in case of hard switching (microsemi)

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



(1) dI_F/dt – rate of change of current through zero crossing
(2) I_{RRM} peak reverse recovery current
(3) t_{rr} – reverse recovery time measured from zero crossing point of negative going I_F to point where a line passing through 0.75 I_{RRM} and 0.5 I_{RRM} extrapolated to zero current.
(4) Q_{rr} – area under the curve defined by t_{rr} and I_{RRM}
$Q_{rr} = \frac{trr\ x\ IRRM}{2}$
(5) $dI_{(rec)M}/dt$ – peak rate of change of current during t_b portion of t_{rr}

Figure 7: t_{rr} Definition as per IR (Source: Infineon/Vishay)

A meaningful comparison of 2 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 2 parameters will lead to different results and data.

Different fast recovery rectifiers will also produce different EMI in the circuit. The best indicator for EMI is the softness definition of the rectifier in the datasheet. A generally acceptable definition for softness would a Tb/Ta ratio bigger than 1.

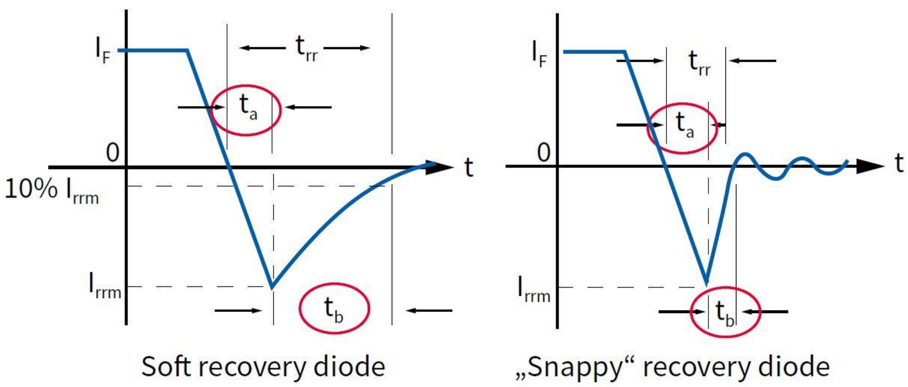


Figure 8: Definition of a Soft-Diode (Source: Infineon)

In the case of hard switching Fast Efficient Rectifiers, second sourcing is only possible after extensive testing. We need to also mention that Q_{rr},I_{rrm} and Tb/Ta are temperature dependent and have a positive temperature coefficient. As such testing is also needed under worst case temperatures.

Lower Voltage FER rectifiers can be produced in several different ways. A 200V output rectifier may be produced using Epitaxial wafers or non-EPI wafers. 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 life time 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. Every supplier may have a unique recipe.

3. Bridge Rectifiers

Bridge rectifiers follow the same basic rules as standard rectifiers. In most cases there is only one wafer source / voltage – and the electrical characteristics in forward directions are the same for 100V to 1000V parts

Different suppliers may have different construction models / leadframes and thermal resistance so the temperature profiles should be checked with an IR camera. As an example a recent PCN from TSC optimized the heat distribution inside the bridge rectifiers – avoiding hot spots and improving reliability.

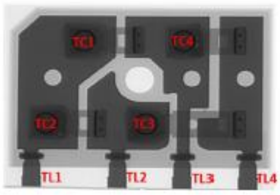
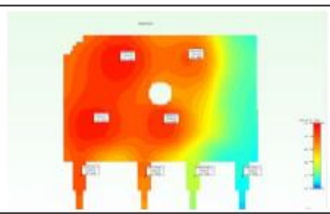
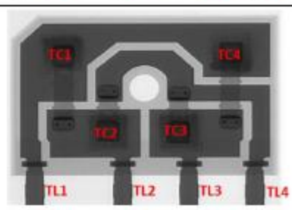
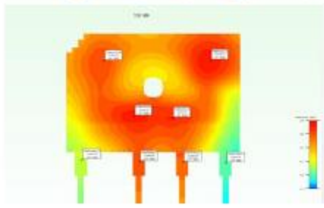
Type	Structure	Simulation
Old		
New		

Figure 9: Avoidance of hot spots through improved lead frame design

More liberty is taken on the die size when manufacturing bridge rectifiers to reduce costs. Make sure to always compare I_{fsm}. Soft Start may change priorities when cross referencing a part, but the Ifsm 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 still a manual process so differences in quality between suppliers is possible. The moulding compound used has a big impact on humidity related life testing like the 85/85 long term life test (85C and 85% Relative Humidity). If your product is used in an environment with a high humidity you may want to discuss this with the supplier

Only moulded bridge rectifiers can be qualified as per AEC Q101. Potted bridges will not pass these tests.

4. Schottky Diodes

The main difference when second sourcing Schottky diodes is that the leakage current losses can no longer be ignored and need to be compared in detail and during testing. The Pd in the $T_j=Ta+Pd*R_{thj-a}$ equation in the case of Schottky diodes consists $Pd=V_f*i_f + I_r*V_{br}$. The leakage current losses depend on the voltage applied, the temperature, the barrier material used and the die size. In the case an 80V reverse voltage is applied, a 5mA leakage current can cause significant losses.

The definition of T_{jmax} of a Schottky diode is linked to the barrier material used to manufacture the product. Usually they are grouped in 150C or 175C 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, after comparing the Breakdown Voltage and the V_f spec, the next step is to compare the maximum T_j. Many different barrier materials exist in the industry eg by varying the amount of Silicide used. These are then grouped by marketing convention into 150/175C rated products. Each barrier material has a unique V_f/I_r value for a given die size. Designers should not assume however that different suppliers always use the same barrier material for a given $T_{j\,max}$, and actual testing in the circuit is necessary.

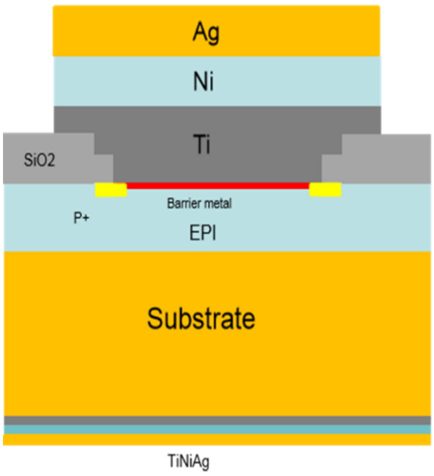


Figure 10: Demonstrates the barrier materials – planar Schottky device structure

Similar to 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 chances of thermal runaway also increase. The I_r maximum values in the datasheets are only an indication. Compare the I_r curves at higher temperatures. Making I_r curves for 100s of datasheets at high temperatures can be a tedious job. There might be datasheet errors. Compare the leakage currents in your circuit at your maximum temperature.

$dPtot/dTj < 1/R_{thj-a}$ for the definition of T_{jmax} shows that the T_{jmax} of a Schottky is dependent on the test board . In case of a Schottky diode, a higher T_{jmax} does not necessarily mean a more reliable product or better quality. In normal commercial / industrial applications, efficiency is a key factor and the V_f of a T_j 150C rated product is better than a T_j 175C rated product at the same die size. Only in circuits with a very high Ta (automotive) and /or very high voltage, a higher T_j is needed. The formula shows what the thermal runaway point is for each diode / application combination. It will never be the same for 2 different products, so testing is needed.

In recent years, most new Schottky products released have a unique die source per partname. This was not the case in the past. In the past there was a so called prime bin, and products that did not meet the original specification were downgraded. As an example 40V was sold as 30V, 60V as 50V and 100V as 90V. 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. PAT testing should eliminate reliability concern about the lower voltages. This information may help you when faced with a supply chain problem.

A Schottky diode has a major influence on the efficiency of your circuit so it should always be measured. The EMI performance will be different and obviously needs to be retested.

Trench Schottky makes cross referencing more complicated. They have a better better V_f for a given die size or a lower I_r for a given V_f (versus a planar diode). Their capacitance is usually higher which may increase losses but also reduce EMI. Maybe they have a different temperature coefficient. Mixing Planar and Trench Schottky diodes makes cross referencing more complicated.

5. TVS Diodes

Transient Voltage Suppressors are the easiest products to cross reference, especially when used against ESD, EFT and Lighting pulses which are normed. They are 100% tested in the factory using the pulse which is specified in the datasheet. When you calculated which TVS you need by studying the norms – you can easily replace it with the product of another vendor. The biggest nuisance is that different manufacturers use different part number system, based upon either working voltage or breakdown voltage. The only difference is a different test program. Even if second sourcing is simple, norms such as the CE sign require retesting if the TVS is not on the original B.O.M

There are a few things which may produce different results. Two suppliers may meet the same norm but use a different die size or slightly different technologies. This can be visible in the actual clamping voltage in the circuit.

You should also consider that IEC61000-4-5 – the norm that deals with lightning – is only a norm and lightning strikes do what they want and may exceed that norm. If your design is marginal and the product is used outside and exposed to the elements of nature, different die sizes may explain the difference in field failures between 2 suppliers.

When protecting against single pulses like IEC61000-4 the transient thermal impedance is the key factor to determine the performance. When used as a snubber or a higher power Zener – there is steady state power dissipation and the power dissipation (determined by the die size) and the thermal resistance becomes critical. In these applications TVS products always need to be tested in the actual circuit to measure temperature differences.

On fast data transmission lines, differences in die size can show up in the capacitance

Derating curves may vary if the parts are rated at 150C /175C. The difference between 2 different temperature rated devices should show up in the I_r curves. In a single pulse event, the $T_{j\,max}$ can be exceeded. In the case of steady state power dissipation, traditional derating curves should be observed.

6. Small Signal Diodes and Zeners

Small signal diodes are usually straightforward to second source or replace and can be safely left to search engines and automated programs.

Zeners can have a manipulated maximum power rating by mounting them on substrates with a much lower thermal resistance. For example when you read: "device mounted on a ceramic PCB of 7.6mm x 9.4mm x 0.87mm with pad areas of 25mm2 " ask yourself the question : does this really make sense for an SOD123 device? (BZT52 datasheet). Unfortunately there are no easy ways to verify or check power dissipation claims when comparing the datasheet.

When there are short pulses, the internal construction of the small signal devices becomes important (like die attach method) and 2 different suppliers may not perform the same. They may have a significantly different transient thermal impedance. Sometimes small signal products are used in an auxiliary power supply and there is a capacitor behind the device. Or a Zener is put at the gate of a MOSFET. Here different manufacturing methods can become visible to the user and can cause field failures

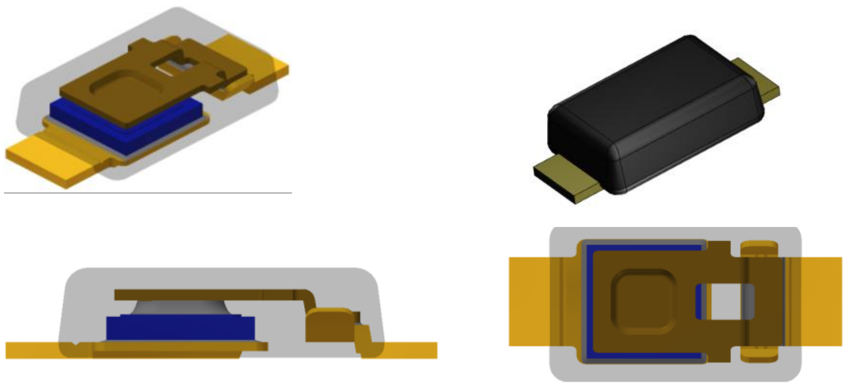


Figure 11: Drawing of a Zener diode where the die is soldered vs a Zener with a poor die attach

Conclusion

Rectifiers are usually not very high on the priority list of designers. Once designed in on a PCB and qualified they are rarely changed to other suppliers. If problems happen in the supply chain or some greater cost saving are found, attempts will be made to second source them.

Care should be taken when second sourcing products, especially in designs that push the rectifiers to the limit.

About the author:

Jos van Loo is a technical expert for Power Semiconductors for more than 30 years. In his role as Technical Support Engineer at Taiwan Semiconductor Europe GmbH, Jos consults customers on Rectifiers, MOSFETs and Power Management ICs.

About Taiwan Semiconductor:

Taiwan Semiconductor, a global manufacturer of discrete semiconductor devices and analog ICs with approximately 1,800 employees, was founded in Taipei in 1979. We started as a specialist in diodes and bridge rectifiers, now also offering a broad product portfolio of MOSFETs, LED drivers and voltage regulators. Today, our focus is centered on market-established technologies and packages.

Worldwide companies, in such industries as automotive, consumer, industrial and lighting, use our products for power management and overvoltage protection applications. Customers appreciate our on-site support and our attention to individual customer requirements. Whether at product or delivery levels, we offer fast and flexible solutions.

Global and Asian Headquarters	European Headquarters	American Headquarters
Taiwan Semiconductor Co., Ltd. 11 Fl., No. 205, Sec. 3, Beishin Rd., Xindian Dist., New Taipei City, 231 Taiwan R.O.C.	Taiwan Semiconductor Europe GmbH Georg-Wimmer-Ring 8b 85604 Zorneding Germany	TSC America Inc. 3040 Saturn Street, suite 200 Brea, CA 92821 USA
Phone: +886 2 8913 15 88 E-Mail: marketing@mail.ts.com.tw	Phone: +49 8106 9963-660 E-Mail: munich@tsceu.com	Phone: +1 657 258 0800 E-Mail: sales@tscus.com