ISSUE: September 2019

Secrets Of The Datasheet: What Rectifier Specs Really Mean

by Jos van Loo, Taiwan Semiconductor Europe, Zorneding, Germany and Kevin Parmenter, Taiwan Semiconductor America, Chandler, Ariz.

Rectifiers are considered some of the easiest semiconductor components to design with. Their datasheets are not very complex. Nevertheless, in a lot of high-volume designs they can be highly stressed: they operate at very high junction temperatures and voltages. To minimize field returns and achieve zero defects, designers need a good understanding of rectifier manufacturing processes, test programs and statistics.

Despite their simplicity, rectifier datasheets may puzzle modern designers. Some rectifier products and datasheets are 30 to 50 years old and in general the industry continues to follow fairly outmoded conventions when specifying new parts. Rectifier datasheets in the past were designed to optimize yield and minimize scrap—they did not have a zero defects strategy in mind and the difference between optimizing component yields and striving for zero-defects is significant.

In this article, we will discuss the key specifications that designers, especially power supply designers, must consider when selecting rectifiers, and explain how semiconductor manufacturers test and then specify these parameters on their datasheets. This in turn leads to advice on how designers should interpret or apply this data.

We'll discuss absolute maximum ratings such as surge current and breakdown voltage, and related parameters such as I^2t data and delta V_f. We'll also look at maximum junction temperature, and the various datasheet specs you'll use to calculate junction temperature in your application including the different contributors to thermal resistance and the forward current derating curve.

Some guidance will also be provided on cross referencing rectifiers from different suppliers and how to evaluate device reliability. Other parameters such as leakage current and Cpk values will also be discussed, along with the importance of part average testing. The focus throughout is on standard silicon rectifiers and bridge rectifiers. Datasheet considerations for Schottky diodes will be addressed in a future article.

Absolute Maximum Ratings

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. These failures have distinct failure modes which are recognizable in scanning electron microscope (SEM) images obtained during failure analysis. The failures can be easily reproduced.

The breakdown voltage is 100% tested in production—in fact, it's tested several times to guarantee zero ppm. So designers can take this parameter for granted. On the other hand, design problems may arise from not taking into account the distributions of the V_{rrm}. Most standard rectifiers have many different part numbers going typically from 100 V to 1000 V, but they may only have one die source (or two) and this may account for some of the spreads in distribution.

A design where the V_{rrm} is exceeded may survive in the lab and on small prototypes runs, but will seldom lead to zero failures once in mass production. Rectifiers in general should not be avalanched as they are not designed for this, unless their datasheet explicitly states so.

Exceeding the V_{rrm} is not recommended, as the avalanche current runs on the edge of the device in the passivation, not in the bulk of the die. 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.

© 2019 How2Power. All rights reserved.

The I_{fsm} surge current is not tested in mass production, but is guaranteed by design. Most surge currents in ac-dc conversion are less than 1.5 ms. The transient thermal impedance is the key parameter that determines the performance. Under 1.5 ms, the surge capability of the rectifier is determined by the die size and the die attach method, which is mainly the quality of the solder joints and the capability of the manufacturing process to minimize solder voids.

The I_{fsm} surge is usually specified in the datasheet for a pulse of 8.3 ms or a 10-ms sine wave and a resistive load—this resembles a 50/60-Hz linear power supply. This is obviously from a different day and age as today's power supplies are mainly switched-mode power supplies (SMPSs), so the rectifiers see a capacitive load. As such the typical inrush current is much shorter than 10 ms.

Some designers are tempted to use the I^2t data in the datasheets, but this can be misleading. The V_f is not constant for higher currents, the waveforms are different and you may work in a different transient thermal impedance area. So I^2t can only give you rough approximations. Therefore, you will need to test and validate your design.

Most rectifier suppliers include a delta V_f test in their final test program. This tests the V_f of a product before and after a short current pulse. The V_f of a rectifier has a negative temperature coefficient and as a result the shift in V_f gives an idea of the thermal resistance of the device and will eliminate the products with the worst solder joints. To get to zero defects though you will need to discuss the manufacturing processes and surge current derating with the rectifier supplier.

Junction Temperature

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

Rectifiers are temperature-driven devices. The most important equation for a rectifier is

$$T_j = T_a + P_d * R_{thj\text{-}a}$$

where T_j is the junction temperature, T_a is the ambient temperature, P_d is the power dissipation and $R_{thj\text{-}a}$ is 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 $R_{thj\text{-}a}$ (sometimes to unrealistically low values) to make the datasheet more attractive. We took the derating curve of the 1N4007 as an example (Fig. 1).

© 2019 How2Power. All rights reserved.

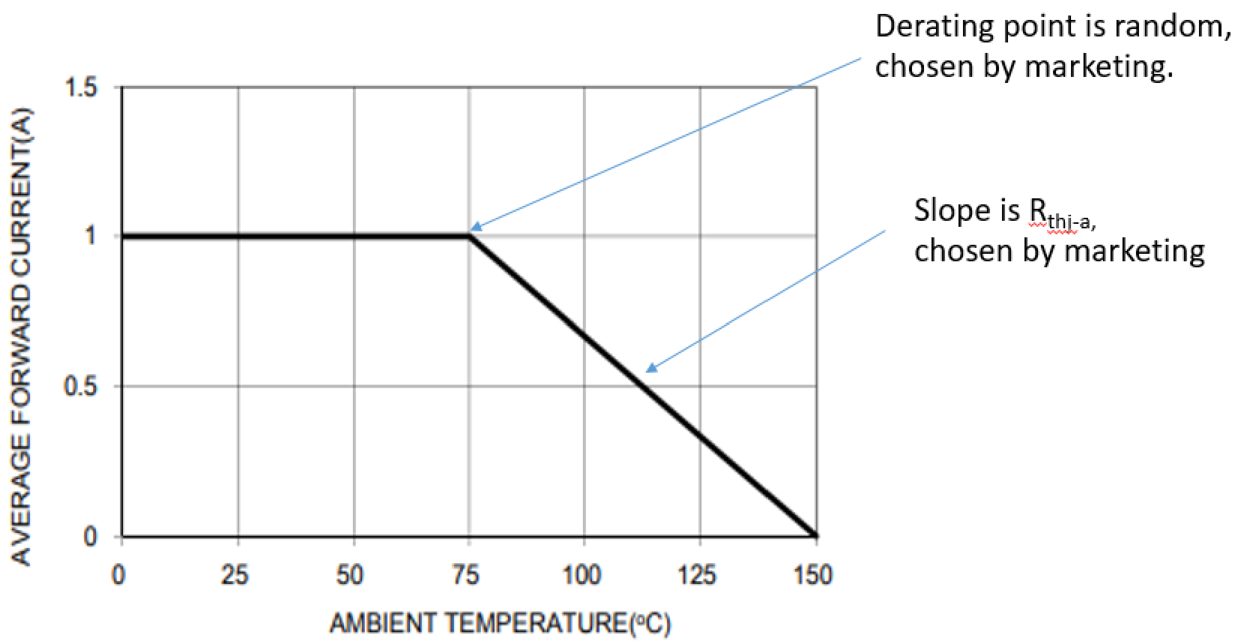

Fig. 1. Maximum forward current derating curve for the 1N4007 general-purpose silicon rectifier.

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 problem can be avoided by using case temperature T_c on the x-axis and the R_{thj-l}, which is a fixed value in the datasheet.

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) to the thermal resistance. Derating using T_c then becomes meaningless. The concept of the infinite heatsink is purely theoretical—it has no practical application.

When cross referencing rectifiers, different suppliers may use different conditions and as a result, current ratings in datasheets can be misleading. The statement that a rectifier is 2 A or 5 A can be meaningless. It is better to compare the V_f specifications and test conditions between two rectifiers. Most suppliers give a 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).

The maximum junction temperature also determines the conditions for reliability testing. Please note that rectifier vendors are free to choose how they define the maximum junction temperature and how they perform reliability testing. But if a part is AEC Q101 qualified, these testing conditions are clearly defined. High-temperature reverse-bias (HTRB) testing is especially critical to determine the reliability of the front-end process. AEC Q101-qualified parts should be tested to the rated T_j and dc/V_{RRM} voltage in the datasheet. If a part is not AEC Q101 qualified the designer may want to inquire how the HTRB testing is performed.

It is important to understand that even though the maximum junction temperature is defined in the datasheet, a lower temperature in the application will always result in fewer field failures. To understand this, it is best to study the acceleration factors in the Arrhenius equation. In case you are an automotive designer working in a 12-V environment, Coffin Manson and temperature cycling may be your main tool to evaluate long-term reliability and field failures. In case of non-automotive applications such as those involving ac-dc and dc-dc conversion however, Arrhenius should be used.

© 2019 How2Power. All rights reserved.

Manufacturers usually give FIT data at 55°C with a certain confidence level like 60% or 90%. FIT stands for failures in time—the number of device failures in one billion device hours. The acceleration factor AF then gives the designer an idea what the FIT rate will be in his or her design by determining the T_j and by multiplying the FIT rate at 55°C with the AF for the measured T_j. The table below lists the acceleration factors calculated with a 0.7-eV activation energy, which is standard for silicon rectifiers.

T_j (°C)	AF
55	1
100	19
110	34
120	58
130	97
140	158
149	240
150	251
151	263

A lot of companies have a rule to minimize the lead temperature on the PCB to a worst case of around 90°C. This usually results in a T_j of 100°C to 110°C for rectifiers. This is considered a good design practice. We also included the AFs for 149°C and 151°C to highlight that for a rectifier with a maximum T_j of 150°C the difference in failure rate between 149°C and 151°C is not that big—both designs have a high failure rate in case of ac-dc conversion.

Other Parameters

Leakage current (I_r) specifications are set at 1 µA or 5 µA for standard rectifiers in many datasheets. These specifications can be 30 to 50 years old, and there have been many technology improvements over the years. Today, the normal distribution of the leakage current stops at a few hundred nanoamps, depending on the die size. So the 5-µA specifications or even 1-µA test specifications are meaningless.

These same datasheets typically specify Cpk (process capability index) values of 20 and more. These Cpk numbers do not mean that the parts are very low ppm but indicate an error in the datasheets. As a matter of fact, rectifiers with a leakage current between the normal distribution and the datasheet limits of 1 to 5 µA are the ones that are most likely to cause field failures. They have either mechanical damage, passivation problems or other defects. Rather than relying on the datasheet values, a designer that aims to get close to zero defects should ask if the products are part average tested (PAT) (Fig. 2).

© 2019 How2Power. All rights reserved.

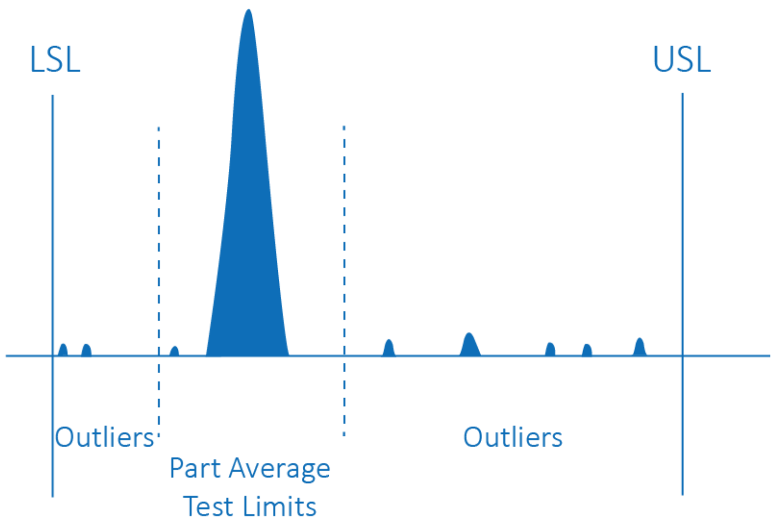

Fig. 2. Part average testing is intended to weed out the outliers.

PAT Testing overrides datasheet values and links the test specification to the normal distribution (6 sigma testing methodology). It makes sure parts with poor reliability are screened out. Rectifiers that should have a breakdown voltage of 1000 V but fail this specification are sometimes sold by some vendors as, for example, 100-V products, as they still have a lower breakdown voltage that can pass a 100-V test. But the initial test failure indicates that there is a defect somewhere and these parts will have reduced reliability.

Conclusion

Billions of rectifiers are manufactured every year. In their applications, they experience a lot of stress including high voltages as well as high temperatures. When temperatures on a PCB are measured, in many cases rectifiers are some of the hottest components. Potentially, this puts rectifiers at a higher risk of failure than other components.

However, by following some basic rules and understanding not just the datasheets but also the manufacturing process and test programs for rectifiers, field failures can be avoided. Consequently, rectifiers should be very low in the Pareto analysis of field returns.

About The Authors

Jos van Loo is a technical expert on power semiconductors with more than 30 years' experience. In his role as technical support engineer at Taiwan Semiconductor Europe, Jos consults with customers on rectifiers, MOSFETs and power management ICs.

Kevin Parmenter is an IEEE Senior Member and has over 20 years of experience in the electronics and semiconductor industry. Kevin is currently director of Field Applications Engineering North America for Taiwan Semiconductor. Previously he was vice president of

© 2019 How2Power. All rights reserved.

applications engineering in the U.S.A. for Excelsys, an Advanced Energy company; director of Advanced Technical Marketing for Digital Power Products at Exar; and led global product applications engineering and new product definition for Freescale Semiconductors AMPD - Analog, Mixed Signal and Power Division. Prior to that, Kevin worked for Fairchild Semiconductor in the Americas as senior director of field applications engineering and held various technical and management positions with increasing responsibility at ON Semiconductor and in the Motorola Semiconductor Products Sector. He holds a BSEE and BS in Business Administration.

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

© 2019 How2Power. All rights reserved.