

WHITE PAPER

Thermal Runaway on Schottky-Diodes

Understand Schottky Technology to improve your design

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Introduction

Recent developments in the market result in the fact that Schottky diodes are used more and more in applications where there is a combination of high ambient temperatures and higher voltages. Typical examples would be longer and longer LED strings in lighting applications and automotive applications now also working in 48V environments. On top of that, Trench Schottky technology pushes Schottky voltages up to 200V or even 300V.

This means it is time to revisit thermal runaway on Schottky Diodes. By better understanding how the maximum T_j of a Schottky diode is defined and why thermal runaway happens, design engineers will be able to build more efficient and more reliable products.

Maximum Junction Temperature

The maximum junction temperature T_j of a Schottky rectifier can be interpreted and used in four different ways:

- to determine the current rating
- sets reliability testing
- is determined by thermal runaway
- calculate long term reliability

What is unique about a Schottky diode is that the maximum junction temperature is also dependent on the PCB layout and the application and the working condition. The root cause for this is thermal runaway.

1. Marketing Conventions

The definition of $T_{j\max}$ 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 e.g. by varying the amount of silicide used. In theory they could be called 145C, 155C or 170C products. These are then grouped by marketing convention into 150/175C rated products. Each barrier material has a unique V_f/I_f 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 to compare two diodes.

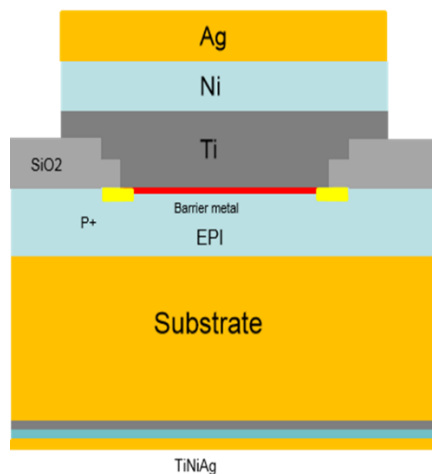


Figure 1: Demonstrates the barrier materials – planar Schottky device structure

In general, in a planar device the V_f depends on the height of the barrier material, the die size and the resistivity of the EPI (which is linked to the breakdown voltage).

2. Thermal Runaway

The formula $dP_{tot}/dT_j < 1/R_{thj-a}$ for the definition of T_{jmax} shows that the T_{jmax} of a Schottky is dependent on the test board or application. 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 for the same die size. Only in circuits with a very high T_a (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 two different products, so testing is needed.

One should also distinguish between static and dynamic thermal runaway. Dynamic thermal runaway happens when a Schottky diode is switched from the on to the off state. When the reverse power losses become dominant thermal runaway can happen. The V_f has a negative temperature coefficient that keeps the system stable with increased currents and temperatures. The leakage current I_r has a positive temperature coefficient resulting in potential positive feedback. If a device is switched from on to off at a higher temperature and the reverse losses are higher than the forward losses the junction temperature may drift upward resulting in thermal runaway.

This may happen in fast switching applications like power supplies or LED drivers or even in a DC operation like in a photovoltaic junction box. So designers using a 150C T_j rated barrier material and seeing I_r currents go into the several mA and blocking voltages of 80V or plus should seriously consider going to a lower leakage higher temperature barrier material (usually with a V_f penalty).

A typical example is the IEC62979 norm for PV junction boxes researching thermal runaway on Schottky diodes.

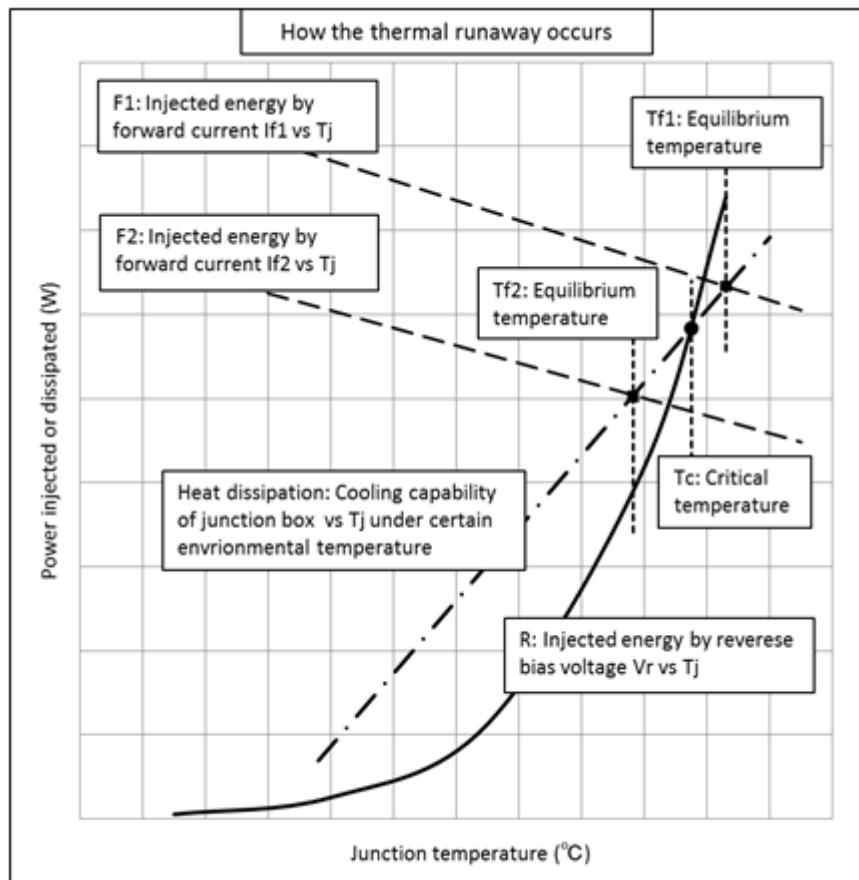


Figure 2: Thermal Runaway-Graphs IEC62979

This curve can easily be generalized. A certain forward loss F1 or F2 occurs in a diode, depending on the forward current through the diode. This line intersects with the thermal resistance curve to determine the junction temperature. The forward losses of the diode decrease linearly due to the negative temperature coefficient. Plotted against these curves are the exponentially growing reverse losses R. The intersection points will determine whether thermal runaway happens or not. If the reverse losses are higher at a given T_j than the forward losses there is instability.

Static thermal runaway happens when the device is purely reverse biased, like in an HTRB test (High Temperature Reverse Bias). The ambient temperature is increased until the maximum T_j is reached taking into account reverse losses. $T_j = T_a + P_d \cdot R_{thj-a}$. At one stage thermal runaway will happen. When evaluating an HTRB board, the T_a temperature needs to be adjusted to reach the correct maximum T_j in the datasheet based upon the thermal resistance.



Figure 3: Typical pictures of HTRB test boards

From the perspective of the designer this is purely theoretical. In practical circuits a Schottky diode would never be used this way. In the case of static thermal runaway, the situation implies a very high ambient temperature. In the case of dynamic thermal runaway, the root cause is very high power dissipation and blocking voltage.

3. Reliability

The purpose of the HTRB test is to detect manufacturing defects – like contamination, mechanical damage etc. - not to measure thermal runaway. An incorrect barrier height is a serious defect, usually detected via an HTRB test. These manufacturing defects also result in thermal runaway.

For rectifiers and TVS, designers rightly assume that a T_j of 175°C is better than a T_j of 150°C and that the higher the $T_{j\max}$ the better the reliability. This argument does not necessarily apply in the same way for a Schottky diode – the difference in T_j may be just a difference in the thermal runaway point of a barrier material.

Schottky rectifiers are quite sensitive to moisture. So when it comes to reliability testing, moisture stress test are quite important. In a lot of applications, Schottky diodes are some of the hottest components on the PCB.

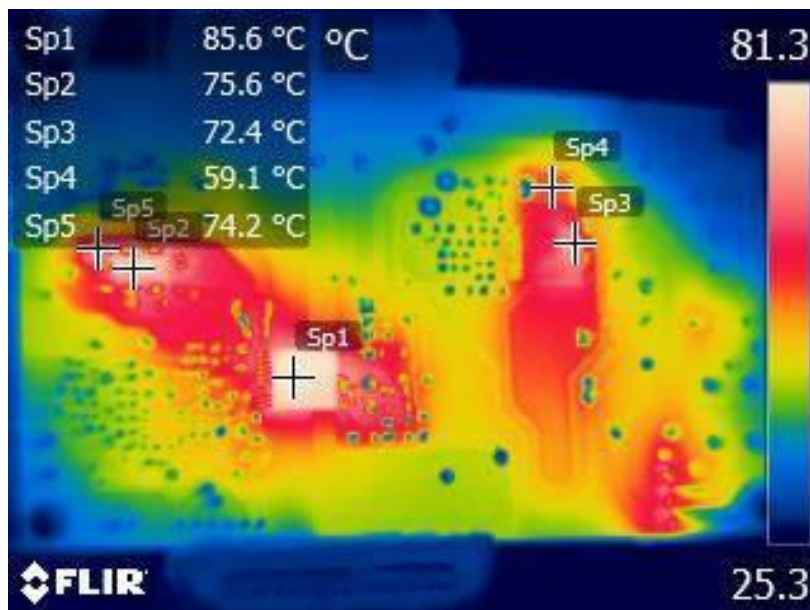


Figure 4: A picture of a PCB with an IR camera showing the Schottky diode as one of the hottest components in the PCB (Sp2 – source from DER 750 from Power Integrations a 42V/42W Led driver at 90VAC input – at low line input rectifiers and input transistors also dissipate a lot of power – at 270VAC the Schottky diode is one of the hotter parts) IR camera measurements are the easiest way to judge / compare efficiency and critical to evaluate reliability)

That implies that there are a lot of temperature / power cycles with a very high ΔT_j . So Coffin Manson calculations are also very important to determine reliability. These two factors are key for long term reliability.

From this discussion, it becomes clear that it is in the designer's interest to have a low ΔT_j in his design. This is mainly achieved via a good thermal resistance and choosing a barrier material with a lower barrier height or a lower V_f . The good thermal resistance will be discussed further in the current rating / package design section. Here the new packages with exposed pads help the designer.

The discussion shows the conflicting reliability directions for every Schottky designer.

From a static thermal runaway perspective, some packages are worse than others. The SMC package is one of the worst when it comes to static thermal runaway. It can handle very big die – with as a result large leakage currents and reverse losses. It combines this with a larger R_{thj-l} thermal resistance inherent in the long leads within the package, producing a larger ΔT_j . If this is combined with the recommended soldering pad layouts (which can be quite small) you get some off the worst conditions for static thermal runaway.

A lot of Schottky diodes are available with a T_j rating of 125C. If the cause of the T_j rating is static thermal runaway during an HTRB test due to a low barrier height, then the designer should take this into account. If the application runs at a lower ambient temperature and there is no risk of thermal runaway, good and reliable designs can be achieved with Schottky diodes rated at 125C.

4. Second Sourcing

Similar to standard rectifiers, the current rating of a Schottky diode can be influenced by marketing.

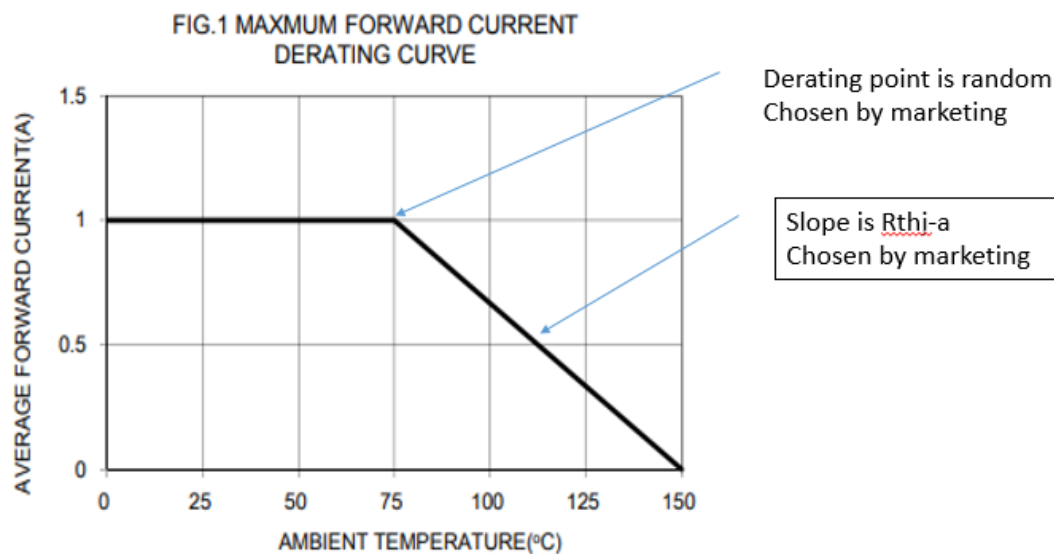


Figure 5: Derating curve of a Schottky diode

Marketing determines the R_{thj-a} in this curve and the point at which the derating starts. The same diode 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. This is done in most SMD parts. But designers should also be careful when the derating graphs mention the T_c on the x-axis, not the T_a . 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 (or very good convection cooling), 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.

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. With a Schottky diode, the typical V_f curves are also dependent on the barrier material used and the technology (Trench or Planar) so they do not necessarily allow you to compare apples to apples (die sizes). Compare the V_f at the highest pulsed repetitive current in your circuit and average temperature to get the best indication on how switching diodes might influence your efficiency.

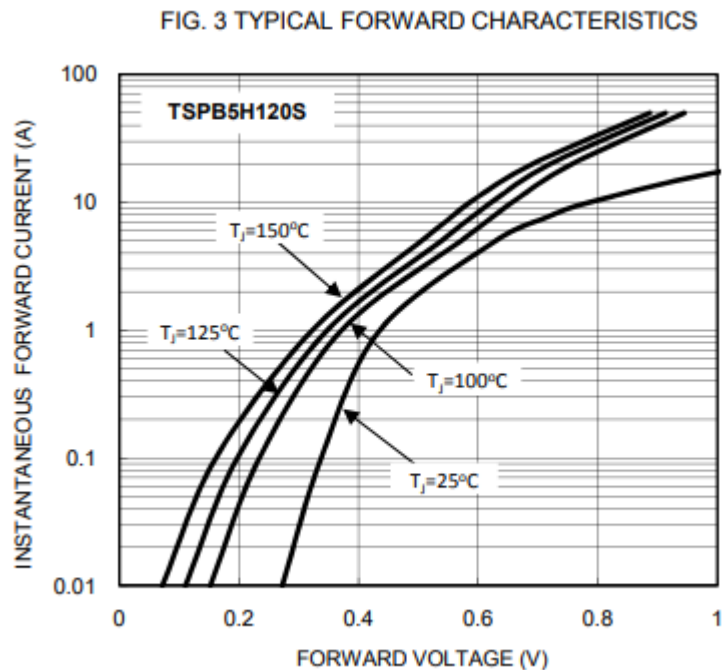


Figure. 6: V_f curves of the TSPB5H120S, a 120V Schottky in a SMPC 4.0 package

One can also get an immediate feeling of the T_c of the V_f of the part used and can compare curves at 100C or 125C with other products

So using current rating alone to second source can lead to practical problems.

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 P_d in the $T_j = T_a + P_d \cdot R_{thj-a}$ equation in the case of Schottky diodes consists $P_d = V_f \cdot I_f + I_r \cdot V_{br}$. 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.

Reverse losses can be important, and as the voltage increases the chances of thermal runaway also increase. 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. Understand that there may be outliers and that five samples in the lab could be insufficient. Design with enough margin. The I_r maximum values in the datasheets are an indication but may be impractical for your design.

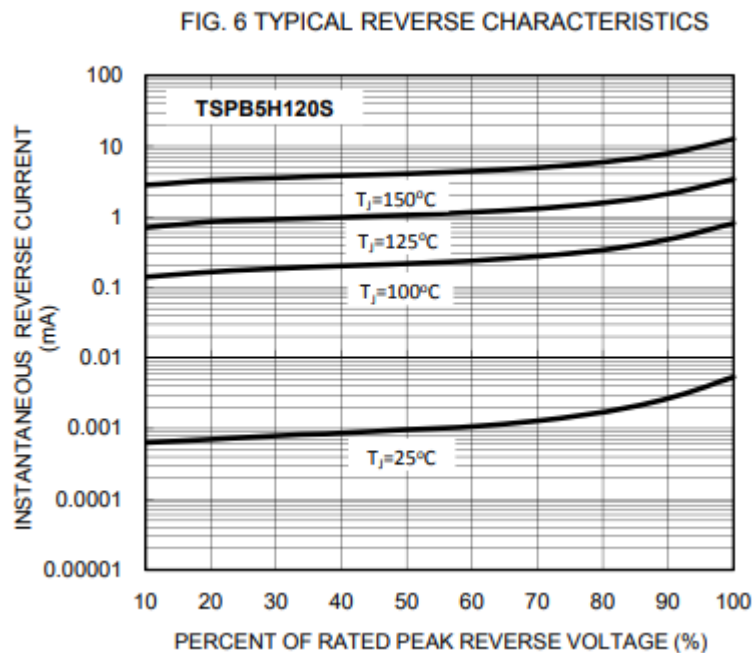


Figure 7: Leakage current of the TSPB5H120S, a 120V Schottky in a SMPC 4.0 package

By contemplating reverse losses designers should be encouraged to have a conservative design, especially when the Schottky diode is not heatsinked. An example of a conservative design would be to limit the temperature on the PCB to 90C or 95C. A 20% derating on voltage is also a good idea.

The T_j can sometimes also be used to make life time calculations using FIT data and the Arrhenius equation. If the main losses are in forward direction, then it needs to be noted that a design with a T_j of 149C is not that much better than a design with a T_j of 151C for a 150C rated product. The FIT data maybe just a little bit lower but neither design will offer zero defects. It puts again the concept of maximum T_j in perspective.

In recent years, most new Schottky products released have a unique die source per part name. 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. A comparison of the capacitance curves are a good start.

5. Planar und Trench Technology

Trench Schottky is a very different technology from Planar Schottky. 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). Their capacitance is usually higher which may increase losses but also reduce EMI. They have a different temperature coefficient. Mixing Planar and Trench Schottky diodes makes cross referencing more complicated.

The advantages of Trench Schottky become clearer at higher voltages. They result in V_f specifications at 120V which planar products cannot meet.

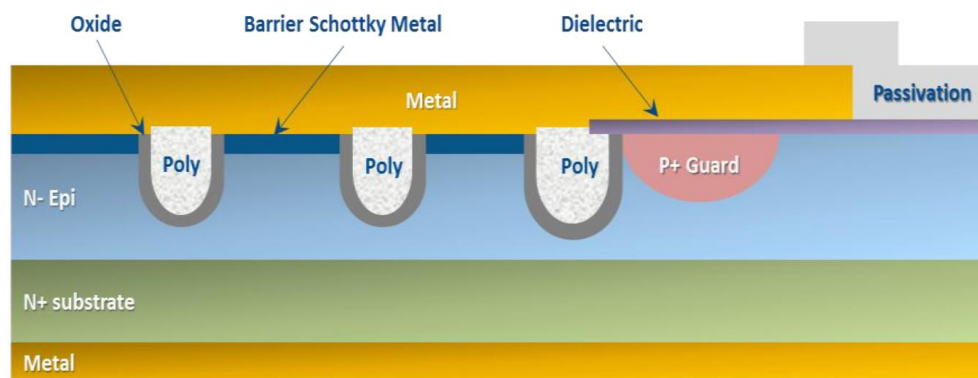


Figure 8: Trench-Schottky structure

Including T_{rr} in the datasheet for Trench devices may be more of a gimmick by some suppliers than a real important parameter for a Schottky diode, realistic for the design.

6. Packaging

Packages with exposed pads help Schottky technology the most. When downsizing packages one needs to distinguish between applications where transient thermal impedance (surges) are the most critical or application where power dissipation is more critical. Usually TVS diodes and standard rectifiers used in AC/DC conversion at lower power are driven by transient thermal impedance demands. The existing die can be put in a smaller package while still keeping the surge performance. This is different with Schottky diodes. In most applications there is significant power dissipation and the thermal resistance is critical. As the thermal resistance is mainly determined by the size of the solder pads and the PCB used (number of layers, thermal vias etc.) the relevance of smaller packages is more limited, although the reduced height can be of interest.

The exception are the new packages with exposed pads. Their reduced R_{thj-l} gives a meaningful contribution in the reduction of the junction temperature when keeping the PCB temperature limited to 90 or 95°C.

This can be best visualized by looking at the construction of the package:

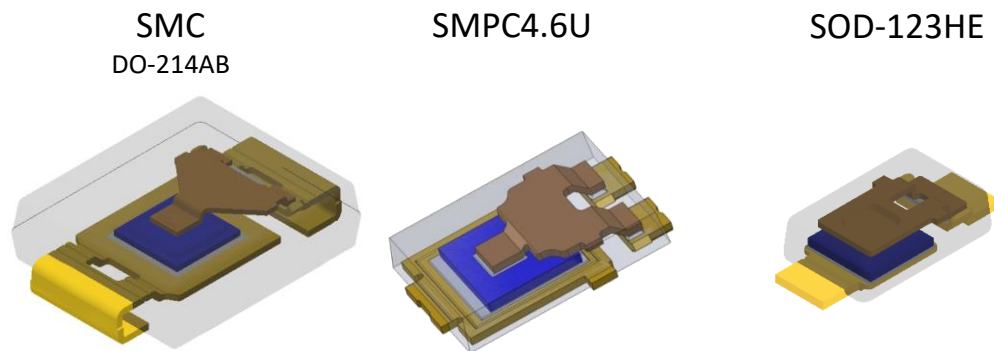


Figure 9: Drawing of typical Schottky packages

Every mm of lead length adds to the thermal resistance R_{thj-l} . So if you look at the SMC package as an example the distance, the heat has to travel to the PCB is quite long. Packages such as the SOD123HE and SMPC4.6U are ideally suited to Schottky technology.

Conclusion

Every designer should evaluate whether thermal runaway is a potential in his design or not. If it isn't Schottky diodes rated at a lower T_j of 150°C may produce not only a more efficient but also a more reliable design. When thermal runaway can potentially happen, a careful analysis is necessary of the diode in the application. It cannot be assumed that two different diodes will behave in a similar way. Special care needs to be taken when second sourcing Schottky rectifiers in this case.

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 1,600 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.

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