

# Application Note No. 065

Schottky Diodes for Clipping, Clamping and  
Transient Suppression Applications

Small Signal Discretes



Never stop thinking

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<b>Page</b>	<b>Subjects (major changes since last revision)</b>
All	Document layout change

# 1 Schottky Diodes for Clipping, Clamping and Transient Suppression Applications



SOT23



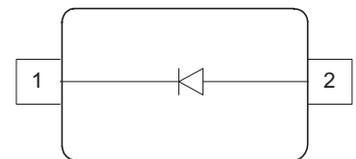
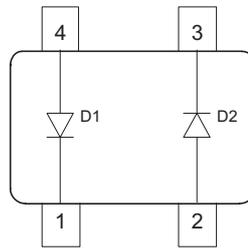
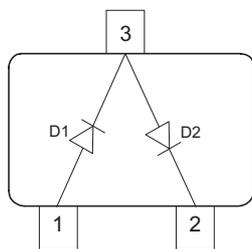
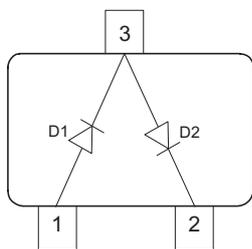
SOT323



SOT343



SCD80



## Features

- Ultra-low series resistance for higher current handling
- Low Capacitance
- Fast Switching (picosecond)
- Available in Single, Dual and Series-Pair configurations
- Industry-Standard Packaging: SOT23, SOT323, SOT343 and SCD80

## Applications

- Computer Peripherals
- Microprocessor-based designs
- RF designs
- Other systems requiring high-speed switching, voltage clipping, clamping, and protection from noise spikes, ringing and other transients

### 1.1 Description

Infineon Technologies offers a complete line of Schottky diodes, including several types which are optimal for circuit protection and waveshape preservation. Manufactured in a 6-inch wafer process, available in single, dual and series-pair configurations, and housed in industry-standard SMT packages, Infineon's line of Schottky diodes provides a high performance, cost-effective solution for today's circuit designs requiring protection from undesired, potentially damaging transients. [Table 1](#) and [Table 2](#) give an overview of the devices being discussed in this particular applications note, along with a cross-reference to Avago Technologies Schottky diodes, where applicable. Additional detail and applications information begins on [Page 6](#). Information on the **Schottky Diode Sample Kit** available from Infineon Technologies is found on [Page 13](#).

**Table 1 Schottky Diode Overview, Part 1**

Infineon Part	Configuration	Package	Package Marking	Maximum Forward Voltage $V_F$	Minimum Breakdown Voltage $V_{BR}$ <sup>1)</sup>
BAS70-04	Series pair	SOT23	74s	410 mV @ 1 mA 1000 mV @ 15 mA	70
BAS70-04W	Series pair	SOT323	74s	410 mV @ 1 mA 1000 mV @ 15 mA	70
BAS40-04	Series pair	SOT23	44s	380 mV @ 1 mA 500 mV @ 10 mA	40
BAS40-04W	Series pair	SOT323	44s	380 mV @ 1 mA 500 mV @ 10 mA	40
BAT62-02W	Single diode	SCD80	2	1000 mV @ 2 mA	40
BAS125-04W	Series pair	SOT323	14s	400 mV @ 1 mA	25 <sup>2)</sup>
BAT17-04	Series pair	SOT23	54s	350 mV @ 0.1 mA 600 mV @ 10 mA	4
BAT17-04W	Series pair	SOT-223	54s	350 mV @ 0.1 mA 600 mV @ 10 mA	4
BAT64-04	Series pair	SOT323	64s	350 mV @ 1 mA 750 mV @ 100 mA	25 <sup>3)</sup>
BAT64-04W	Series pair	SOT323	64s	350 mV @ 1 mA 750 mV @ 100 mA	30 <sup>4)</sup>
BAT68-04W	Series pair	SOT323	84s	340 mV @ 1 mA 500 mV @ 10 mA	8 <sup>5)</sup>
BAT62-07W	Dual, unconnected	SOT343	62s	1000 mV @ 2 mA	40

- 1)  $I_{(BR)} = 10 \mu A$
- 2)  $I_R = 0.15 \mu A$
- 3)  $I_R = 2 \mu A$
- 4)  $I_R = 0.002 \mu A$
- 5)  $I_{(BR)} = 100 \mu A$

**Table 2 Schottky Diode Overview, Part 2**

Infineon Part	Typical Capacitance $C_T$ (pF)	Typical Differential Forward Resistance $R_S$ ( $\Omega$ ) <sup>1)</sup>	Maximum Effective Carrier Lifetime $\tau$ (ps)	Agilent Technologies Nearest Equivalent
BAS70-04	1.6	30	100	HSMS-2802
BAS70-04W	1.5	34	100	HSMS-280C
BAS40-04	4	10	100	HBAT-5402
BAS40-04W	3	10	10	HBAT-540C
BAT62-02W	0.44	225 k <sup>2)</sup>	–	–
BAS125-04W	1.1	16 <sup>3)</sup>	–	HSMS-281C
BAT17-04	0.55	8 <sup>3)</sup>	–	HSMS-2822
BAT17-04W	0.55	8 <sup>3)</sup>	–	HSMS-282C
BAT64-04	4	–	–	HSMS-2702
BAT64-04W	4	–	–	HSMS-270C
BAT68-04W	1	10 <sup>3)</sup>	–	HSMS-282C
BAT62-07W	0.45	225 k <sup>2)</sup>	–	–

1)  $I_F = 10$  mA,  $f = 10$  kHz

2)  $I_F = 25$  mA

3)  $I_F = 5$  mA,  $f = 10$  kHz

## 1.2 General Description

A concern in many electronic systems is the presence of impulses of noise or “voltage spikes” on data or signal lines. These undesired transient signals can originate from within or outside of a given system, and if severe enough, can cause permanent damage to system components such as microprocessors. Long transmission lines connecting different parts of a system are particularly susceptible to noise pickup and are often the major culprits in noise and spike problems.

**Clipping and Clamping** is the deliberate limiting of a voltage at a circuit node or supply bus. Generally, in the context of using Schottky diodes for such purposes, **clipping** is the limiting of a circuit node voltage by using the forward threshold voltage of a diode. **Clamping** is the limiting of node voltage in two directions via use of an anti-parallel pair of clipping diodes. In other words, clipping limits node voltage below a certain threshold; clamping limits node voltage within a certain “window” set by an anti-parallel diode pair. The absolute limiting voltage level(s) can be adjusted by biasing the diode(s) with an offset voltage via use of pull-up or pull-down circuits. Please refer to [Figure 1](#). Note that if the input signal voltage rises above the supply voltage due to “noise spikes”, the upper diode will turn on, dumping current into the  $V_S$  node, limiting the voltage at Node “A” to 1 diode drop above the supply voltage. Similarly, if a negative-going transient on the data stream dips more than 1 diode drop below ground, the lower diode will begin to conduct, limiting Node “A” voltage to one diode drop below ground. In summary, the “window” of voltages allowed at Node A is limited to a maximum of  $V_S + V_D$ , and a minimum of  $-V_D$  (one diode drop below ground). This assumes that the diodes behave as perfect switches. In reality, non-ideal diode properties, including the current-handling capability of the diode used, play a major role in how well such clipping and clamping circuits function in actual practice. This will be discussed in a later section. **Note that the Schottky diodes offered in the Series-Pair configuration, in SOT-23 or SOT-323 outlines, offer a single-package solution for clamping circuits such as the circuit shown in [Figure 1](#).** (Please refer to [Table 1](#) and [Table 2](#) for a quick overview of diode types and configurations discussed in this applications note).

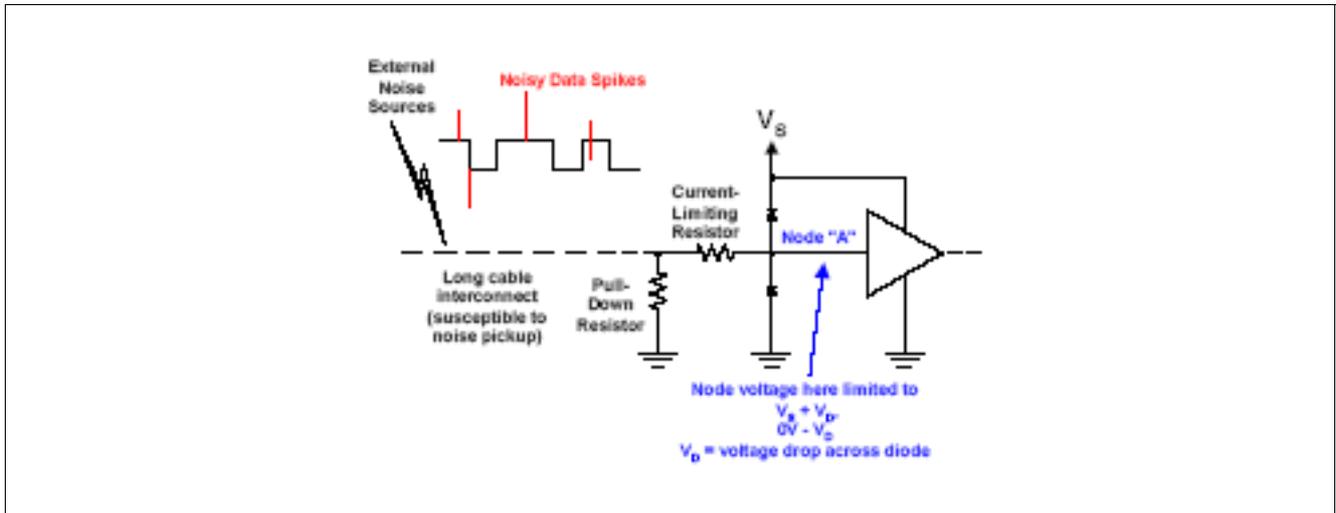


Figure 1 Diagram of a Clamping Circuit using two Schottky Diodes

### 1.3 Desirable Characteristics of Clipping / Clamping Diodes, or “Why Use Schottky Diodes?”

In looking at the circuit shown in [Figure 1](#), one can envision several desired properties for the diodes used:

1. Low forward voltage
2. Fast switching
3. High current-handling capability

A **low forward voltage** at all current levels ensures that the maximum / minimum voltage seen by the system or component being protected by the clipping or clamping circuit is only slightly above or slightly below the reference voltages used. For example, in the particular case shown in [Figure 1](#), the clamping levels are set at a maximum by the use of the supply voltage  $V_S$  as one reference, and at a minimum by using ground as the other reference.

**Fast switching** of the diode between ON and OFF states guarantees the clipping / clamping circuit can react quickly enough to catch noise spikes with fast rise times.

**High current-handling capability:** the ability of a diode to limit or “clip” the noisy voltage spikes is dependent on the diode’s ability to sink the current pulses associated with the noise spikes. A key diode parameter in current-handling capability is the diode’s series resistance. Low series-resistance diodes are preferred for clipping and clamping applications since such types can more easily pass high currents while maintaining a low forward voltage  $V_F$ . In addition, lower diode series resistance gives rise to less device self-heating under high-current conditions.

Properly designed and fabricated Schottky diodes will satisfy all three requirements - low forward voltage ( $V_F$ ), fast switching times and high current-handling ability. Infineon’s line of Schottky Diodes includes devices suitable for RF applications such as mixers and detectors, as well as others more suitable for clipping and clamping. The focus of this applications note is on those devices most useful for clipping and clamping applications.

### 1.4 Schottky Diode Basics

A Schottky diode is formed by making a metal-semiconductor contact between a metal and an “n” or “p” doped semiconductor material. For the case of a diode formed by a metal & n-doped semiconductor, at the junction of these two dissimilar materials, free electrons flow across the junction from the semiconductor to the metal. This flow of charge-carriers creates a junction potential. The difference in energy between the metal and the semiconductor materials is referred to as a Schottky barrier.

P-doped Schottky diodes are good for applications requiring very low turn-on voltage, like those found in zero-bias RF detectors. But these P-doped types also exhibit a low breakdown voltage and high series resistance.

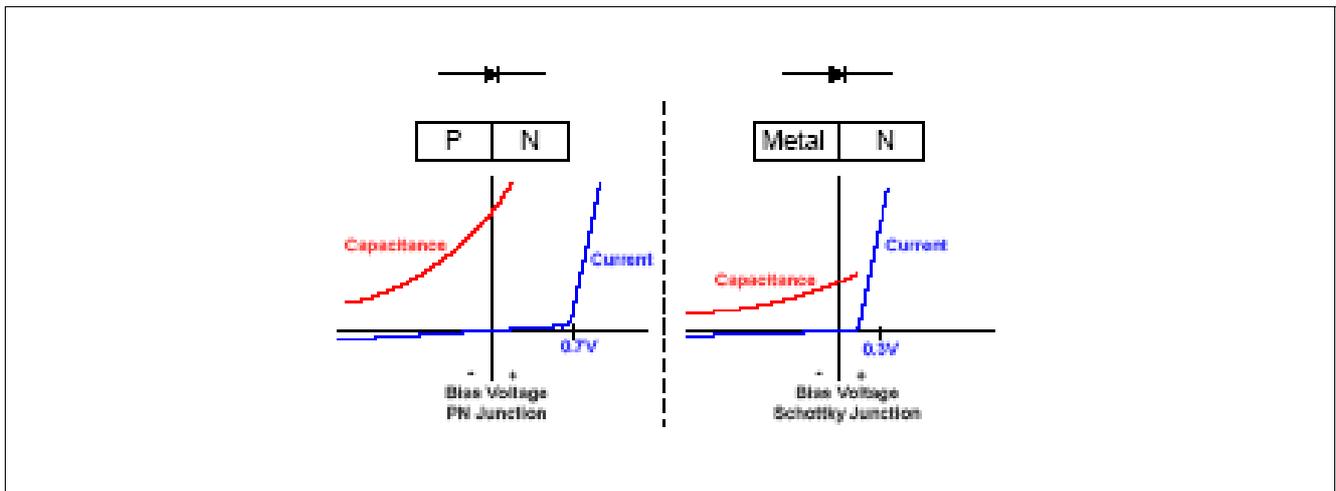
Therefore, in general, n-doped Schottky diodes are preferred for clipping and clamping circuits which see high reverse voltages and high current spikes.

Under increasing forward bias conditions - positive voltage connected to the metal, and negative voltage connected to the semiconductor in an n-doped Schottky diode - the number of electrons with sufficient energy to cross the Schottky barrier into the metal rises rapidly. Once the forward bias exceeds the junction potential of the diode, the forward current ( $I_F$ ) will increase rapidly as the applied forward bias ( $V_F$ ) increases.

When in reverse bias, the potential barrier for electron flow becomes large. As a result, there is a diminishing chance that an electron will have sufficient energy to cross the junction. The reverse leakage current for the diode when reverse-biased will be in the range of nanoamps to microamps, depending on diode construction, the applied reverse bias, and junction temperature. If the reverse bias is increased beyond a certain point, referred to as the reverse breakdown voltage,  $V_{(BR)}$  - the reverse leakage or reverse saturation current will depart abruptly from its nominal value and quickly increase as the diode enters the breakdown region.

In a standard diode formed by the contact of P and N semiconductor materials, current flow is carried by both electrons and “holes”. By contrast, current in a Schottky diode is carried solely by electrons. Because no “hole” charge-storage effects are present, Schottky diodes have carrier lifetimes under 100 picoseconds, and extremely fast switching times. As a result, Schottky diodes make good choices for rectifiers at millimeter wave frequencies, e.g. 30 GHz and higher.

The forward voltage drop or junction potential of a Schottky diode (0.3 V) is also far less than that of a standard PN diode (0.7 V). **Figure 2** provides a graphical, generic comparison of Schottky and PN diodes.

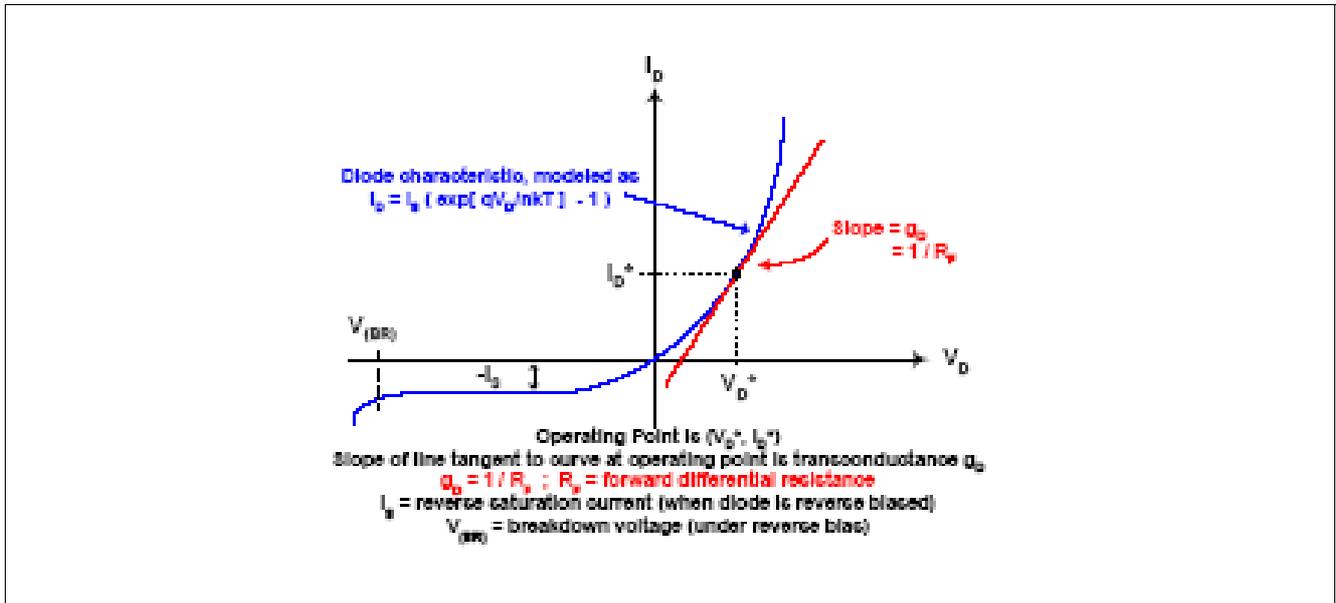


**Figure 2 Comparison of  $I$ - $V$  and  $C$ - $V$  Curves for a PN Diode (left) and a Schottky Diode (right)**

By controlling the dimensions and doping of the semiconductor, and by proper selection of metal used for the metal-semiconductor contact, the primary traits of the diode can be optimized for the specific target application. These key diode parameters are:

1. Junction capacitance  $C_T$
2. Parasitic series resistance  $R_S$
3. Differential forward resistance  $R_F$
4. Breakdown voltage  $V_{(BR)}$
5. Forward voltage  $V_F$

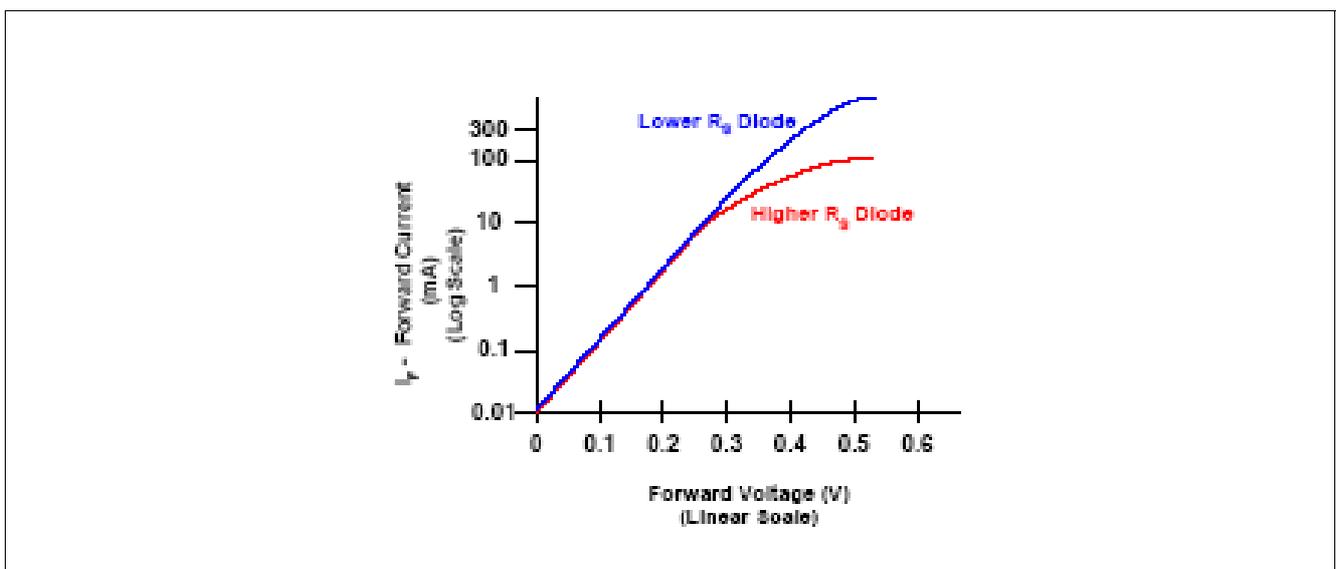
The junction capacitance  $C_T$  accounts for the charge-storage effects in the diode's junction, and for Infineon Schottky diodes,  $C_T$  is typically specified at a reverse bias voltage of 1 V.  $R_S$  is the result of non-ideal ohmic losses in contacts to the active junction region, and is usually modeled as a parasitic resistance in series with an “ideal” diode.  $R_F$ , the forward differential resistance, is the inverse of the slope or gradient of the diode's  $I$ - $V$  curve **at the given operating point**. Please refer to **Figure 3**.



**Figure 3 Graphical Representation of Forward Differential Resistance  $R_F$ , when diode  $I-V$  curve is modeled as an exponential function.  $R_F$  is the reciprocal of the slope of the line tangent to the curve at a given operating point**

The breakdown voltage  $V_{(BR)}$  is defined as the reverse bias voltage where diode reverse current begins to increase rapidly beyond the nominal value of  $-I_S$  (reverse saturation current).

A comparison of Current - Forward Voltage curves for two different Schottky diodes is shown in **Figure 4**. The main idea here is, the diode with the lower series resistance  $R_S$  gives a much lower forward voltage at high currents. High transient currents are likely when the diode has to sink a large current pulse associated with a big noise spike. Therefore, the lower  $R_S$  diode has a higher current-handling capability. The price paid for this lower forward resistance  $R_S$  is a higher junction capacitance, and thus, slower switching speed. The higher capacitance found in low  $R_S$  diodes is partly due to the higher doping levels used in the semiconductor material - the higher dopant concentration giving a lower parasitic resistance.



**Figure 4 High and Low Series Resistance Schottky Diodes. Forward Voltage ( $V_F$ ) vs. Forward Current ( $I_F$ ). Note Low  $R_S$  diode maintains a given  $V_F$  at higher currents - a desirable trait for Clipping / Clamping diodes**

### 1.5 Current Handling Issues

A clipping / clamping diode must handle high currents in order to shunt away “spikes” and transients from the circuitry to be protected. Current-handling is primarily a thermal issue, and is determined by:

1. Diode chip characteristics
2. Package characteristics
3. How the packaged device is mounted (e.g. “heat sinking” effect of mounting method and PCB or carrier material)

Consider **Figure 5**, where the forward voltage of two different Schottky diodes versus forward current is compared. The first curve is for a standard Schottky diode of the type that might be used in high-frequency radio circuits, say, as a mixer. This device has a relatively high series resistance  $R_S$ . The second curve is for a Schottky diode with similar traits, except for having a lower series resistance  $R_S$ . For the standard diode, the higher value of series resistance causes the voltage across the diode to rise more quickly as current increases, dissipating power in the diode. This power dissipation heats the diode junction, causing the series resistance to increase further, giving a thermal runaway condition. For the diode with the lower series resistance, the heating doesn’t happen, and the voltage across the diode stays at lower levels even at high current levels.

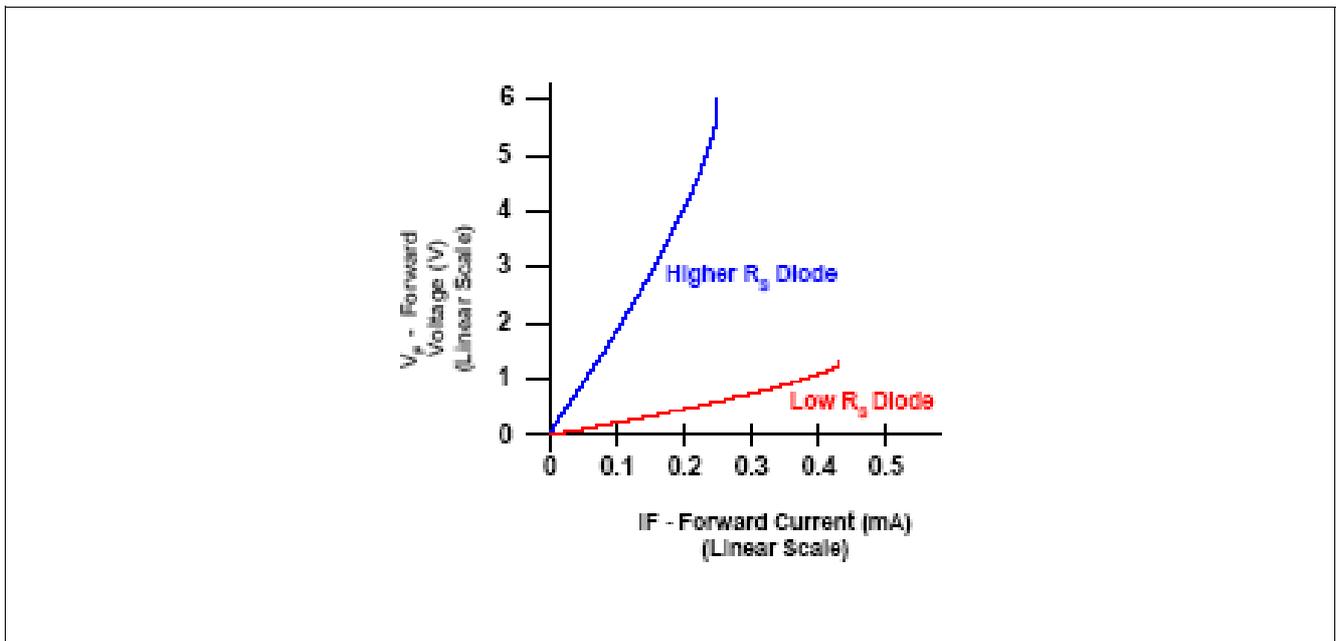


Figure 5 Forward Voltage vs. Forward Current for a Low and High  $R_S$  Diode

Solving for the actual junction temperature of a clipping / clamping diode in actual practice can involve some messy mathematics. Essentially one must solve the equation for the forward  $V$ - $I$  curve [Equation \(1\)](#), simultaneously with [Equation \(3\)](#). Also, it is important to note that, for very short duration current spikes - e.g. less than 1 microsecond - the diode junction does not have time to reach a thermal steadystate condition. Additional information can be found in references [\[2\]](#) and [\[3\]](#).

$$I_F = I_S \left( e^{qV_D / nkT} - 1 \right) \quad (1)$$

With  $V_D$  = diode forward voltage =  $V_F - I_F R_S$

$$I_S = \left( A^* T^2 e^{-q\phi_B} \right) / kT = I_0 e^{-q\phi_B} / kT \quad (2)$$

With  $I_0$  = reverse saturation current @ 25 °C =  $A^* T^2$

$$T_J = V_F I_F R_{thJA} + T_A \quad (3)$$

Where

- $I_F$ : diode forward current
- $I_S$ : diode reverse saturation current
- $n$ : ideality factor (e.g. “fudge factor”)
- $q$ : electronic charge,  $1.6 \times 10^{-19}$  C
- $V_F$ : diode forward voltage
- $R_S$ : diode series resistance
- $k$ : Boltzmann’s constant =  $1.38 \times 10^{-23}$  J/K
- $T_J$ : diode junction temperature, in Kelvin
- $T_A$ : ambient temperature (e.g. heat sink temperature)
- $A^*$ : “effective Richardson constant”  $\approx 250 \text{ A} \times \text{cm}^{-2} \times \text{K}^{-1}$
- $\phi_B$ : Schottky barrier voltage (approx. 0.3 V)
- $R_{thJA}$ : thermal resistance from diode junction to heat sink, in degrees Kelvin per Watt or degrees C per Watt (K/W, °C/W)

The key contributors in diode power dissipation in clipping / clamping applications are  $R_S$  (the series resistance of the diode during high-current conditions) and  $R_{thJA}$ , the thermal resistance from diode junction to ambient air temperature. It should be noted that:

$$R_{thJA} = R_{thJT} + R_{thTS} + R_{thSA} \quad (4)$$

$$R_{thJS} = R_{thJT} + R_{thTS} \quad (5)$$

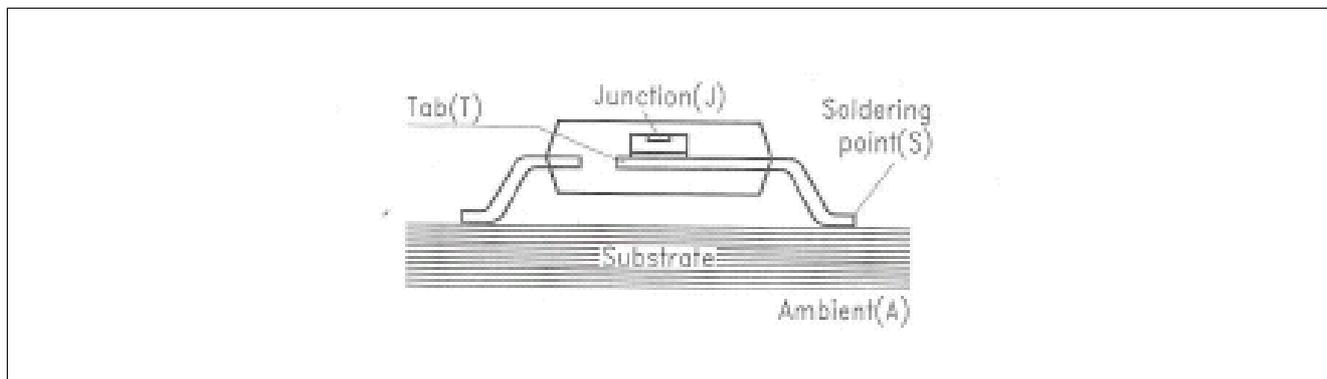
Where

- $R_{thJA}$ : thermal resistance between junction and ambient (total thermal resistance)
- $R_{thJS}$ : thermal resistance between junction and soldering point
- $R_{thJT}$ : thermal resistance between junction and chip base (chip thermal resistance)
- $R_{thTS}$ : thermal resistance between chip base and soldering point (package/alloy layer)
- $R_{thSA}$ : thermal resistance between soldering point and ambient (substrate thermal resistance) - e.g. quality of “heat sink”

$R_{thJS}$ , the thermal resistance between the junction and the soldering point, contains all the thermal resistances that are unique to a particular diode die + package combination, and omits substrate contributions to overall thermal resistance. For this reason,  $R_{thJS}$  is often the best metric to use when comparing different devices for thermal characteristics, allowing for an “apples-to-apples” comparison between two different parts, without regard for the type of circuit board substrate being used.

It is worth pointing out that, for a given diode die in different packaging, the same diode die placed in a slightly different package will often yield “much better thermals”. In comparing the BAT64-04 and BAT64-04W series-pair

Schottky diodes (same die, different packaging) one may note that while the SOT23 package is larger and may have more cross-sectional area in its metal leads for heat conduction, the shorter distance for heat to travel in the smaller SOT323 package yields a lower thermal resistance between junction and soldering point. Please refer to **Figure 6** and **Table 3**. Note the significant thermal advantage given by the smaller SOT323 package. For additional detail, the interested reader is referred to reference [2].



**Figure 6**  $R_{thJA}$  is the Overall Thermal Resistance between Diode Junction and Ambient Air Temperature

$R_{thJA}$  is a composite figure including several individual thermal resistances as shown in the text. Often the best metric to use is  $R_{thJS}$ , the thermal resistance from device junction to soldering point. Using  $R_{thJS}$  effectively removes the uncertainty of different substrate types when benchmarking different devices for thermal characteristics.

**Table 3** Comparison of BAT64-04 and BAT64-04W Thermal Characteristics

Part	Package	$R_{thJS}$ (K/W)
BAT64-04	SOT23	355
BAT64-04W	SOT323	155

*Note: Advantage of smaller package.*

## 2 Conclusions

Infineon Technologies offers a broad line of Schottky diodes in industry-standard packaging, including devices suitable for switching, clipping / clamping, high and low-level RF detecting, RF mixing and guard-ring applications. This applications note focuses primarily on clipping / clamping Schottky diodes. Available from Infineon Technologies is a Schottky Diode Sample Kit containing diodes suitable for clipping and clamping use. For further information on the Schottky diode line, please consult references [1] and [2].

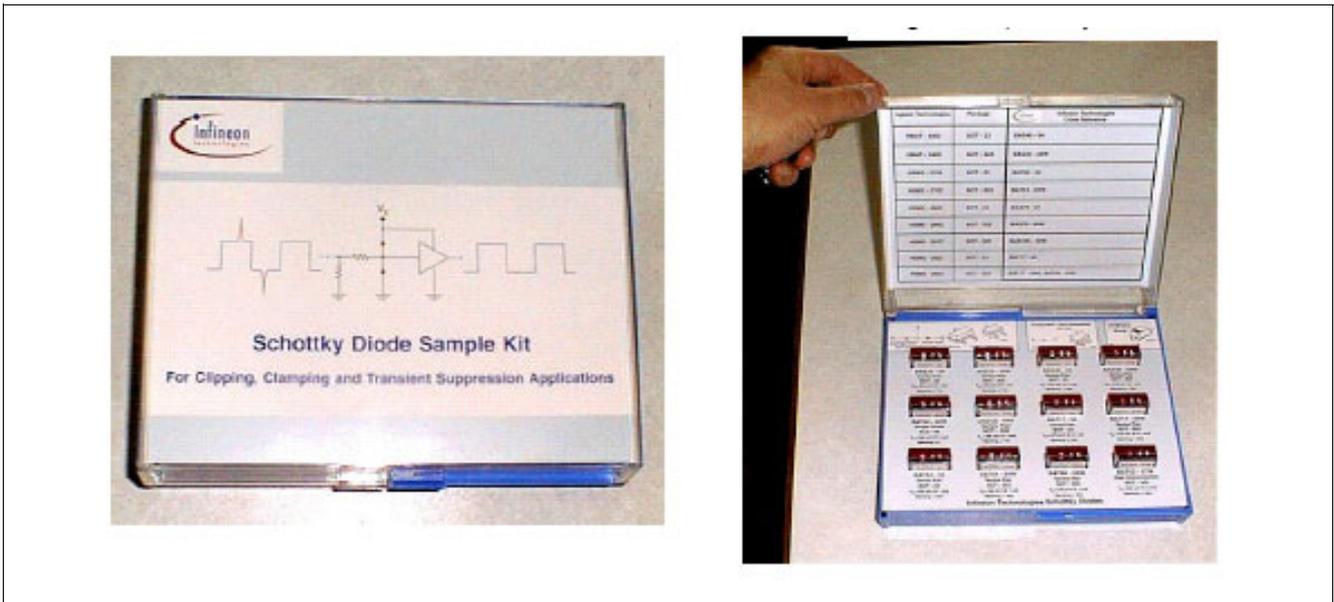
SPICE models for the diodes described in this applications note may be downloaded from <http://www.infineon.com>.

### References

- [1] Infineon Technologies, "Small Chips for Big Visions - Schottky Diodes". Brochure, ordering number B132-H7456-GI-X-7600. (This brochure contains general information and selection guides for both Audio Frequency (AF) and Radio Frequency (RF) Schottky diodes).
- [2] Infineon Technologies, "Discrete and RF Semiconductors", Data Book, Parts 1 and 2, September 2000. Ordering Number B132- H7021-G3-X-7400. (Volume 1 of Data book has thermal resistance information on pages 73 - 78, in addition to data sheets and selection guides.)
- [3] Semiconductor Device Modeling with SPICE. Second Edition. Giuseppe Massobrio and Paolo Antognetti, McGraw-Hill, 1993, ISBN 0-07-002469-3 (A discussion of Schottky diode modeling begins on page 26).

**Sample Kit**

A “Schottky Diode Sample Kit For Clipping, Clamping and Transient Suppression Applications” is available from Infineon Technologies. The sample kit contains a minimum of 10 pieces of each of the diodes listed in the leftmost column of **Table 1** of this application note. Two images of the kit are shown below. The kit is inserted into a protective cardboard sleeve for shipping. In addition to the samples, the kit contains a copy of this applications note, as well as a FAX form used for ordering sample refills. To obtain a sample kit, please contact your local Infineon Technologies Sales Office or Authorized Infineon Sales Representative.



**Figure 7** Image of Kit, Lid Closed and Open