

Calculation of reverse losses in a power diode

Introduction

This application note explains how to calculate reverse losses in a power diode by taking into account the impact of the junction temperature (T_j) as well as the reverse voltage V_R on the leakage current.

The ideal current and voltage waveforms of an ultrafast diode in a power supply system during a switching cycle are illustrated *in Figure 1*.





The reverse losses in a diode are the result of a reverse bias applied on the diode. They are due to the leakage current (I_R) . This parameter (I_R) increases exponentially with the junction temperature. Most of time, the reverse losses are negligible for bipolar and silicon carbide diodes. For silicon Schottky structured diodes, these losses should be accurately estimated as they are the main origin of the thermal runaway risk phenomenon (*See AN1542*).

Contents

1	Diode reverse characteristics					
	1.1 Junction temperature and reverse voltage dependence	3				
	1.2 Diode reverse characteristics modeling: $I_R(V_R,T_j)$, "c" thermal coefficient .	4				
2	Reverse losses: Basic equations	5				
3	An application example					
4	Revision history	9				



1 Diode reverse characteristics

1.1 Junction temperature and reverse voltage dependence

The leakage current is an intrinsic parameter of the diode. In each ST Schottky and SiC diode datasheet, a curve of the leakage current (typical value) versus the reverse voltage and the junction temperature is provided (*Figure 2*).

Most of the time, the reverse losses are calculated using maximum values in order to consider the worst operating conditions for the diode in the application. The ratio between typical and maximum values can be obtained using the values given in the section "Static electrical characteristic" of the datasheet. (*Figure 3*)







Symbol	Parameter	Test conditions		Min.	Тур.	Max.	Unit
I _R	Reverse leakage current	$T_j = 25 \ ^{\circ}C$	V = 70 V		5		μA
		T _j = 125 °C	$v_{\rm R} = 70$ v		5		mA
		T _j = 25 °C	V = 100 V		10	40	μA
		T _i = 125 °C	$v_{\rm R} = 100 v$		10	40	mA



1.2 Diode reverse characteristics modeling: I_R(V_R,T_j), "c" thermal coefficient

The parameter (I_R) increases by an exponential law with the junction temperature. Knowing a reference point $I_R(V_R, Tj_{Ref})$ and the value of the thermal coefficient "c", one can easily calculate the leakage current at a given temperature T_i using the following formula:

Equation 1

$$I_{R}(V_{R},T_{j})=I_{R}(V_{R},T_{jRef}) \cdot e^{C(T_{j}-T_{jRef})}$$

Where V_R is the reverse "plateau" voltage applied across the diode.

The "c" thermal coefficient represents the leakage current dependence with the junction temperature. Each diode has its own coefficient that can be calculated using two points as follows:

Equation 2

$$c = \frac{1}{T_{jRef2} - T_{jRef1}} \cdot ln \left(\frac{l_R (V_R, T_{jRef2})}{l_R (V_R, T_{jRef1})} \right)$$

In each ST Datasheet, Tj_{Ref1} & T_{jRef2} are respectively 25°C and 125°C.

The "c" coefficient is independent of the reverse voltage V_R applied across the diode.

2 Reverse losses: Basic equations

Reverse losses expression is the average dissipated power in the diode during the reverse biasing phase:

Equation 3

$$\mathsf{P}_{\mathsf{REV}}(\mathsf{T}_j) = \frac{1}{\mathsf{T}_{\mathsf{sw}}} \int_{0}^{\mathsf{T}_{\mathsf{sw}}} \mathsf{V}_{\mathsf{R}}(\mathsf{t}) \cdot \mathsf{I}_{\mathsf{R}}(\mathsf{V}_{\mathsf{R}}, \mathsf{T}_j) \cdot \mathsf{d}\mathsf{t}$$

In case of a typical square waveform as illustrated on *Figure 1*, the reverse losses are equal to:

Equation 4

 $\mathsf{P}_{\mathsf{REV}}(\mathsf{T}_{j}) \!=\! (1 \! \cdot \! d) \! \cdot \! \mathsf{V}_{\mathsf{R}} \cdot \! \mathsf{I}_{\mathsf{R}}(\mathsf{V}_{\mathsf{R}},\! \mathsf{T}_{j})$

Substitution of Equation 1 into Equation 4 yields

Equation 5

 $\mathsf{P}_{\mathsf{REV}}(\mathsf{T}_{j}) {=} (1 {\text{-}} d) \cdot \mathsf{V}_{\mathsf{R}} {\text{-}} \mathsf{I}_{\mathsf{R}}(\mathsf{V}_{\mathsf{R}}, \mathsf{T}_{j\mathsf{Ref}}) \cdot e^{c(\mathsf{T}_{j} {\text{-}} \mathsf{T}_{j\mathsf{Ref}})}$

In some literature, it is possible to find the following expression:

Equation 6

 $P_{REV}(T_j) = P_{ref} \cdot e^{c \cdot (T_j - T_j_{Ref})}$

With:

Equation 7

 $P_{ref} = (1 - d) \cdot V_R \cdot I_R(V_R, T_{jRef})$



3 An application example

Let us consider the example of a 45 W notebook adapter, using a flyback converter (*Figure 4*) working in continuous mode. The input voltage V_{in} is 375 V and the output voltage V_{out} is 14.5 V. The rectifier diode is a ST power Schottky STPS20M100S (20 A, 100 V). *Figure 5* shows the ideal waveforms of the diode. The duty-cycle of the transistor is: $\delta = 0.2$ and the transformer ratio is: m = 0.148.

Let us calculate the maximum reverse losses in the diode for this application.

Figure 4. Flyback converter



Figure 5. Ideal current and voltage waveforms of the diode in the flyback converter



Doc ID 022588 Rev 1

Step 1: Reverse voltage applied across the diode

When the transistor on the primary side of the transformer is on, the rectification diode is blocked with a reverse voltage equal to:

Equation 8

 $V_{R}^{i} = m \cdot V_{in}^{i} + Vout = 0.148 \cdot 375 + 14.5 = 70V$

Step 2: I_R(V_R,T_{iRef}) and thermal coefficient "c":

The second step is to read the reference point value using the *Figure 2* given in each datasheet for the corresponding V_R. The reference temperature (T_{jRef}) considered is at a junction temperature of 125 °C.

In this example:

 $I_{R(typ)}(V_R = 70 \text{ V}, T_{iRef} = 125 \text{ °C}) = 5 \text{ mA} (typical value)$

In order to consider the worst case for the power losses, we use the maximum values for the leakage current using the ratio given by the *Figure 3*.

Equation 9

Ratio =
$$\frac{I_{R (max)}(100V, 125^{\circ}C)}{I_{R (typ)}(100V, 125^{\circ}C)} = \frac{40}{10} = 4$$

 $I_{R(max)}(V_{R} = 70 \text{ V}, \text{ } \text{T}_{jRef} = 125 \text{ }^{\circ}\text{C}) = 5 \text{ } \text{x} \text{ } 4 = 20 \text{ } \text{mA}$

Using *Equation 2* and *Figure 2*, the coefficient "c" can be calculated:

Equation 10

$$c = \frac{1}{T_{jRef2} - T_{jRef1}} \cdot \ln(\frac{I_{R}(V_{R}, T_{jRef2})}{I_{R}(V_{R}, T_{jRef1})}) = \frac{1}{125 - 25} \cdot \ln(\frac{5 \cdot 10^{-3}}{5 \cdot 10^{-6}}) = 0.069^{\circ}C^{-1}$$

Step 3: Reverse losses expression:

From *Equation 5*, the maximum reverse losses expression is then:

Equation 11

 $P_{\text{REV}(\text{max})}(T_{j}) = (1-d) \cdot V_{\text{R}} \cdot I_{\text{R}}(V_{\text{R}}, T_{j \text{ Ref}}) \cdot e^{c(T_{j} - T_{j \text{Ref}})}$

 $P_{\text{REV}(\text{max})}(T_j) = (1 - 0.2) \cdot 70 \cdot 20 \cdot 10^{-3} \cdot E^{0.069(T_j - 125)}$

with T_{iRef} = 125 °C

 $P_{\text{REV(max)}}(T_j) = 1.12 \cdot e^{0.069(T_j - 125)}$

Finally, one can plot the evolution of reverse losses in the diode versus the junction temperature (*Figure 6*).





Figure 6. Maximum reverse losses versus the junction temperature



For ST Bipolar diodes, the doping being platinum, the leakage current is very low resulting in negligible reverse losses.

For Schottky diode, there is a trade-off between the forward voltage drop and the reverse leakage current. In order to improve the efficiency of a Switch Mode Power Supply, a Schottky diode with a low forward voltage to the detriment of higher leakage current would be preferred.

In this case, the heat sink size will be larger in order to keep the junction temperature of the diode low enough and avoid a thermal runaway phenomenon. (Refer to the AN1542).



4 Revision history

Table 1. Document revision history

Date	Revision	Changes
26-Apr-2012	1	Initial release.



Please Read Carefully:

Information in this document is provided solely in connection with ST products. STMicroelectronics NV and its subsidiaries ("ST") reserve the right to make changes, corrections, modifications or improvements, to this document, and the products and services described herein at any time, without notice.

All ST products are sold pursuant to ST's terms and conditions of sale.

Purchasers are solely responsible for the choice, selection and use of the ST products and services described herein, and ST assumes no liability whatsoever relating to the choice, selection or use of the ST products and services described herein.

No license, express or implied, by estoppel or otherwise, to any intellectual property rights is granted under this document. If any part of this document refers to any third party products or services it shall not be deemed a license grant by ST for the use of such third party products or services, or any intellectual property contained therein or considered as a warranty covering the use in any manner whatsoever of such third party products or services or any intellectual property contained therein.

UNLESS OTHERWISE SET FORTH IN ST'S TERMS AND CONDITIONS OF SALE ST DISCLAIMS ANY EXPRESS OR IMPLIED WARRANTY WITH RESPECT TO THE USE AND/OR SALE OF ST PRODUCTS INCLUDING WITHOUT LIMITATION IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE (AND THEIR EQUIVALENTS UNDER THE LAWS OF ANY JURISDICTION), OR INFRINGEMENT OF ANY PATENT, COPYRIGHT OR OTHER INTELLECTUAL PROPERTY RIGHT.

UNLESS EXPRESSLY APPROVED IN WRITING BY TWO AUTHORIZED ST REPRESENTATIVES, ST PRODUCTS ARE NOT RECOMMENDED, AUTHORIZED OR WARRANTED FOR USE IN MILITARY, AIR CRAFT, SPACE, LIFE SAVING, OR LIFE SUSTAINING APPLICATIONS, NOR IN PRODUCTS OR SYSTEMS WHERE FAILURE OR MALFUNCTION MAY RESULT IN PERSONAL INJURY, DEATH, OR SEVERE PROPERTY OR ENVIRONMENTAL DAMAGE. ST PRODUCTS WHICH ARE NOT SPECIFIED AS "AUTOMOTIVE GRADE" MAY ONLY BE USED IN AUTOMOTIVE APPLICATIONS AT USER'S OWN RISK.

Resale of ST products with provisions different from the statements and/or technical features set forth in this document shall immediately void any warranty granted by ST for the ST product or service described herein and shall not create or extend in any manner whatsoever, any liability of ST.

ST and the ST logo are trademarks or registered trademarks of ST in various countries.

Information in this document supersedes and replaces all information previously supplied.

The ST logo is a registered trademark of STMicroelectronics. All other names are the property of their respective owners.

© 2012 STMicroelectronics - All rights reserved

STMicroelectronics group of companies

Australia - Belgium - Brazil - Canada - China - Czech Republic - Finland - France - Germany - Hong Kong - India - Israel - Italy - Japan -Malaysia - Malta - Morocco - Philippines - Singapore - Spain - Sweden - Switzerland - United Kingdom - United States of America

www.st.com

Doc ID 022588 Rev 1

