AN2025
APPLICATION NOTE

Converter Improvement Using Schottky Rectifier Avalanche Specification

STMicroelectronics gives in product datasheets useful information for all their Schottky Rectifier families to define their working limit in the avalanche area. A simple method to determine if a Schottky diode can work in the avalanche area in a given Switch Mode Power Supply (SMPS) is described in this document. Then an accurate method will be defined in order to estimate the maximum average avalanche power losses. Finally, a concrete example will be illustrated to show how the choice of a Schottky diode can be optimized in order to improve the efficiency of the converter.

I. Introduction

The design of SMPS is subjected to heavy constraints in order to improve the trade-off between the cost and the power density. One way to respond to these aggressive specifications is to drive components closer to their intrinsic limits. The use of Schottky diodes in the avalanche area is a good example of this evolution.

II. Description of the specification tool

STMicroelectronics guarantees for each Schottky diode a reference avalanche power capability corresponding to a rectangular current pulse: P_{ARM}(1µs, 25°C) (given at t_p=1µs and T_j = 25°C) - See figure 1.

Derating curves shown in figure 2 and figure 3 give the admissible avalanche power for each Schottky diode versus the operating junction temperature (T_j) and the pulse duration (t_p).
P_{ARM}(1µs,25°C) for each part number as well as derating curves are given in the respective data sheet.
The designer must ensure that the guaranteed avalanche power P_{ARM} (t_p,T_j) is greater than the avalanche power in the application $P_{AVALANCHE}$:

$$\mathbf{P_{AVALANCHE}\ (application) < P_{ARM}\ (t_p\ ,\ T_j)}$$

Figure 1: P_{ARM} (1µs, 25°C) (Maximum repetitive avalanche power)

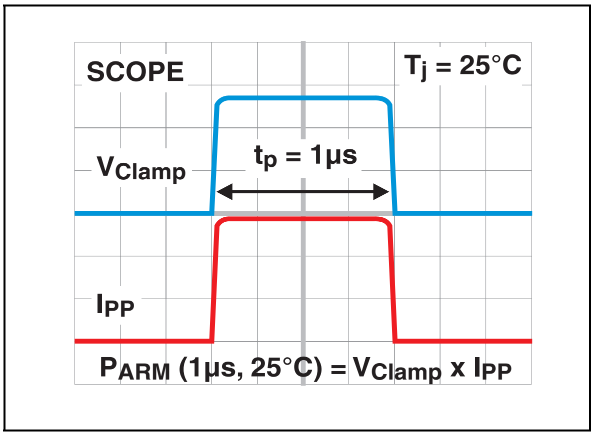


Figure 2: $\dfrac{P_{ARM}(t_p, T_j)}{P_{ARM}(t_p, 25^oC)}$ *versus* T_j

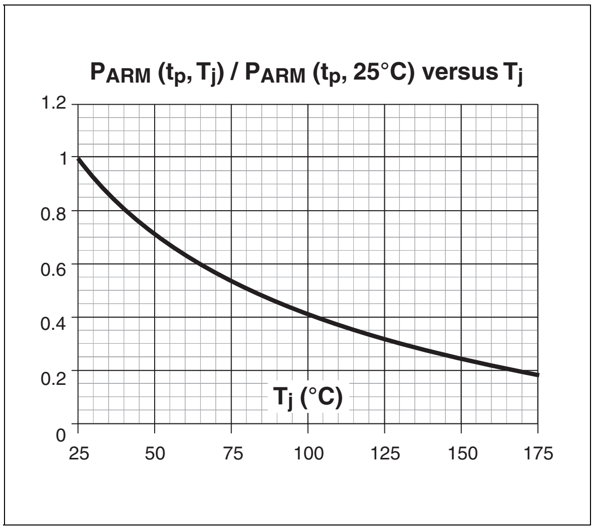
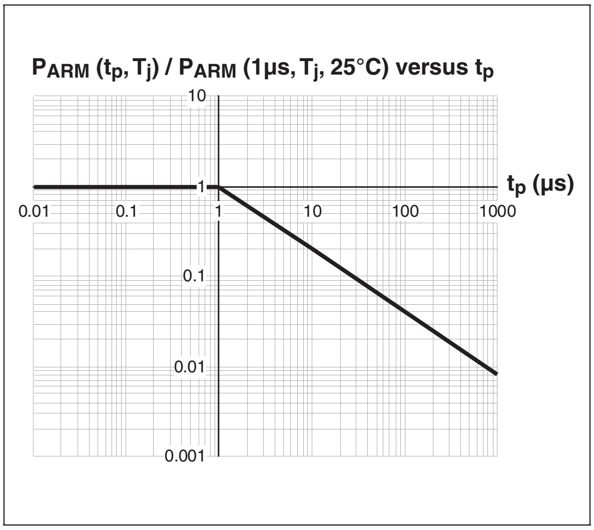


Figure 3: $\dfrac{P_{ARM}(t_p, T_j)}{P_{ARM}(1\mu s, T_j)}$ *versus* T_p



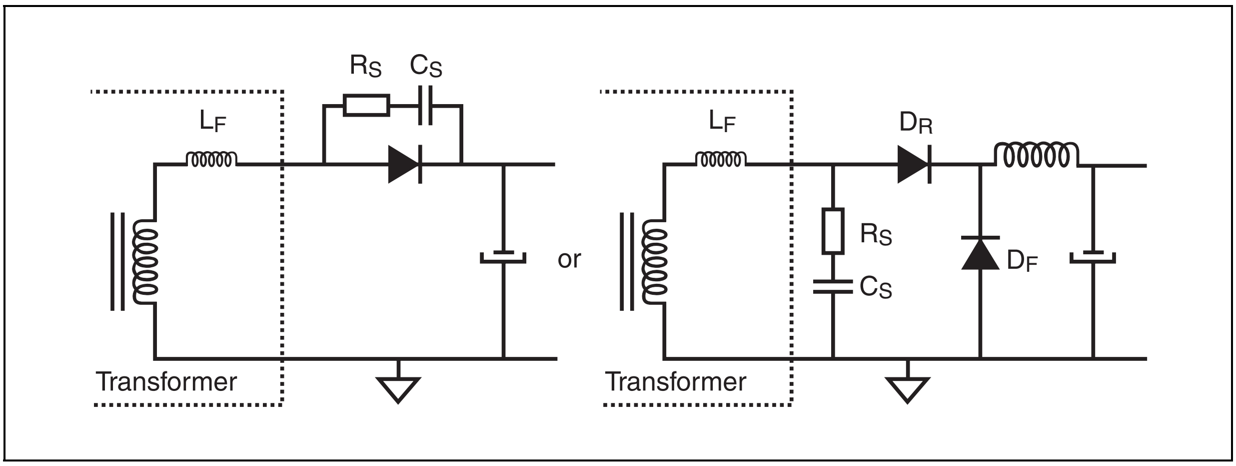
III. Simple method to estimate the maximum avalanche peak power

III.1. Setting the Problem

Most of the time, it is difficult to accurately determinate the avalanche power through the diode in the hardware circuit.
This is mainly due to measuring problems such as delay time between current and voltage probe, the very low pulse duration and the snubber circuit impact. Generally, in SMPS applications, the maximum avalanche peak power occurs for a diode having the lowest clamping voltage. Practically, this diode is very difficult to find.

These are the reasons why STMicroelectronics proposes a simple method to estimate the maximum avalanche peak power P_{PEAK_AV}. In most of SMPS applications, this method will be pessimistic ($P_{PEAK\_AV} > P_{AVALANCHE}$) but sufficient to determine whether or not a given Schottky diode will sustain the applied avalanche energy. This method only covers Schottky diodes used in rectification function for SMPS (see figure 4), where the pulse duration of the avalanche current t_p is less than 1µs.

Figure 4: Typical secondary rectification topologies



III.2. Switching-off analysis (simple method)

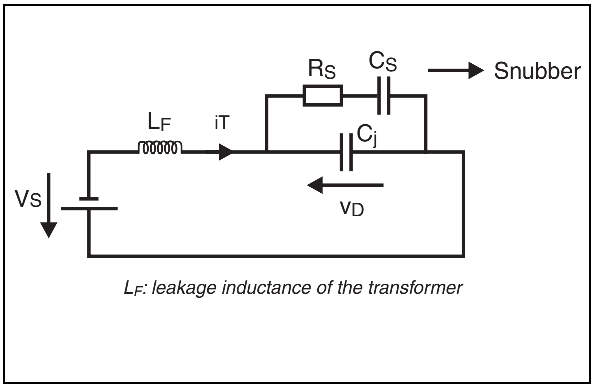
III.2.1. Introduction

The figure 5 shows the equivalent circuit that can be used to simulate a secondary rectification function when the diode turns off : L_F represents the leakage inductance of the transformer. The diode is modelized by the capacitance Cj, R_S and C_S are the snubber components.

The figure 6 shows the corresponding current and voltage waveforms taking into account the delay time between current and voltage probes. When the total current (current in the diode + current in the snubber) is at maximum (I_{PEAK}), the voltage across the leakage inductance is zero ($dI_T/dt = 0$). Consequently the voltage across the diode is equal to V_S.

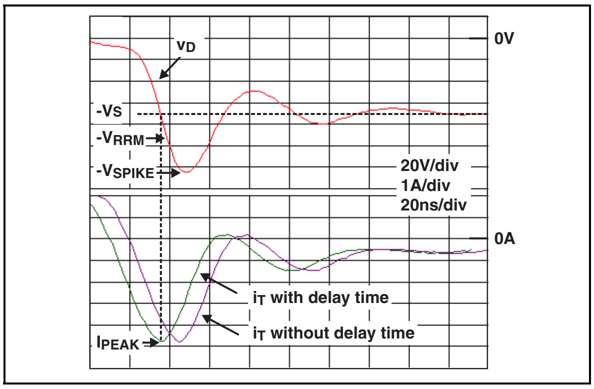
$$\mathbf{i_T = I_{PEAK} \Leftrightarrow v_D = -V_S}$$

Figure 5: Basic equivalent circuit



L_F: leakage inductance of the transformer

Figure 6: Total current (i_T) and voltage (V_D) when the diode turns off



III.2.2. Switch-off behavior when the diode works in the avalanche area

The figure 7 shows the switch-off behavior when the diode works in the avalanche area.
This characteristic is made up of 2 distinct phases.

Phase 1: $t \in [t_0, t_1]$

At $t = t_0$: $i_T = I_0$
$v_D = 0$

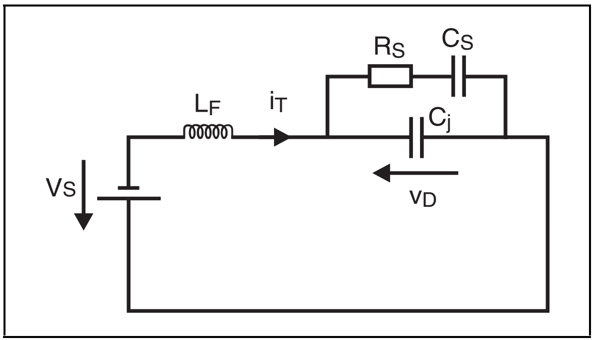
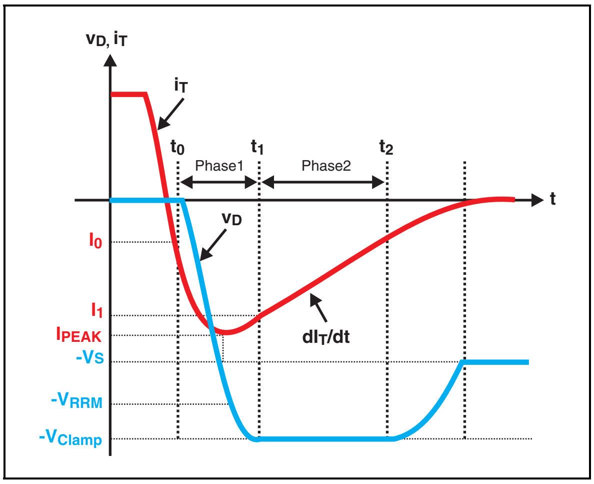


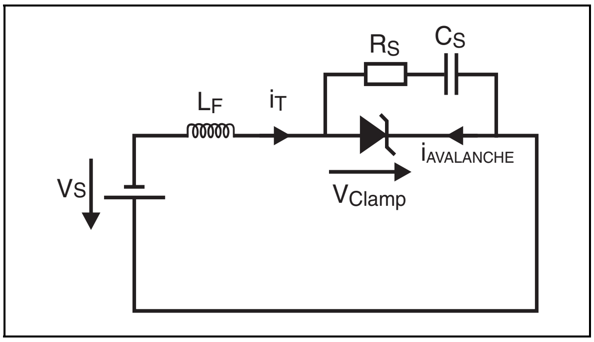
Figure 7: Switch-off behavior when the diode works in the avalanche area



The first phase corresponds to the charging of the junction capacitance of the diode, Cj.
The voltage across the diode V_D decreases until it reaches the clamping voltage of the diode $-V_{Clamp}$ (see figure 7). As was explained above, when the total current is equal to I_{PEAK}, V_D is equal to $-V_S$.
Once the current has reached I_{PEAK}, it then increases to reach the value I_1 corresponding to $V_D = -V_{Clamp}$ (see figure 7).

Phase 2: $t \in [t_1, t_2]$

At $t = t_1$: $i_T = I_1$
$v_D = V_{Clamp}$



During this phase, the diode works in the avalanche region. Consequently, the voltage across the diode is equivalent to a voltage generator equal to V_{Clamp}.
The total current increases linearly with a slope equal to:

$$\frac{di_T}{dt} = \frac{V_{Clamp} Vs}{L_F}$$ (see figure 7)

After t_2, the voltage across the diode increases towards $-V_S$ (see figure 7).

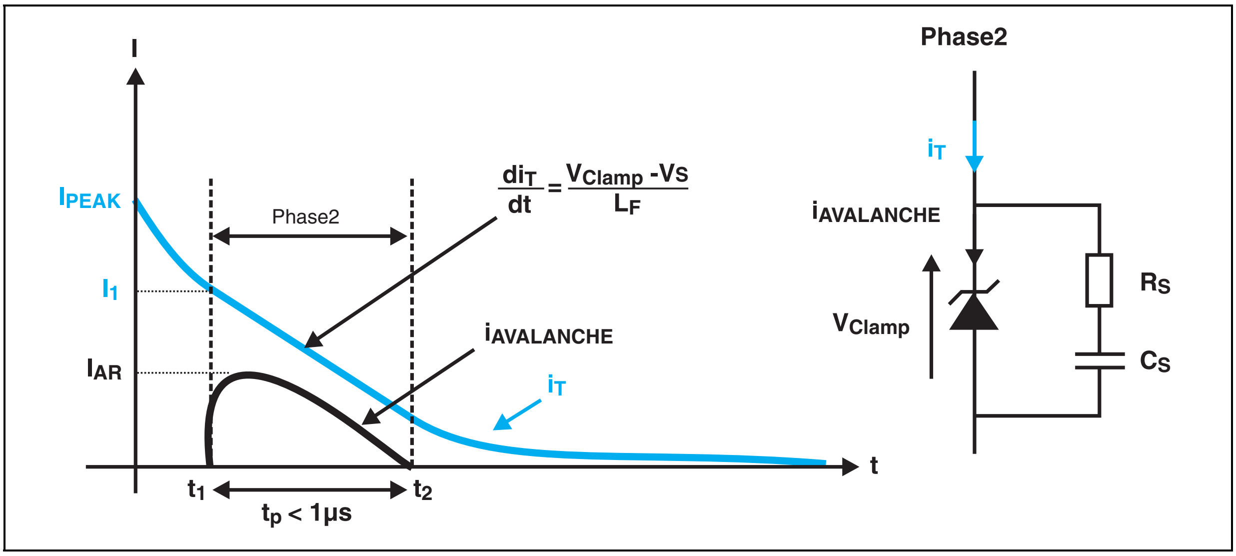
These considerations show that:

$$I_1 < I_{PEAK}$$

III.2.3. Estimation of the maximum avalanche peak power: P_{PEAK_AV}

The figure 8 shows in blue color the total current I_T (diode + snubber) and in black line the real avalanche current waveforms during the switching-off of the diode.

Figure 8: Total current and avalanche current waveforms when the diode works in the avalanche area



The real peak current in avalanche (I_{AR}) is less than I_1 and I_1 is less than I_{PEAK}. We first approximate an avalanche current value by taking I_{PEAK} for all further calculations.
Moreover, STMicroelectronics guarantees that the maximum clamping voltage of Schottky diodes is always less than $2\times V_{RRM}$ (V_{RRM}: Maximum repetitive reverse voltage).
Consequently from these 2 conditions, a conservative estimation of the maximum avalanche peak power can be done:

$$P_{AVALANCHE} = I_{AR} \cdot V_{Clamp} < P_{PEAK\_AV} = I_{PEAK} \cdot (2\times V_{RRM})$$

Finally, to determine if a given Schottky diode can work in the avalanche area in a given SMPS, the following condition must be respected:

$$\mathbf{2.I_{PEAK} \cdot V_{RRM} < P_{ARM}(1\mu s, T_j)}$$

III.3. Methodology

Here below are the three steps to follow in order to define P_{PEAK_AV} and to then compare it with $P_{ARM}(1\mu s, T_j)$.

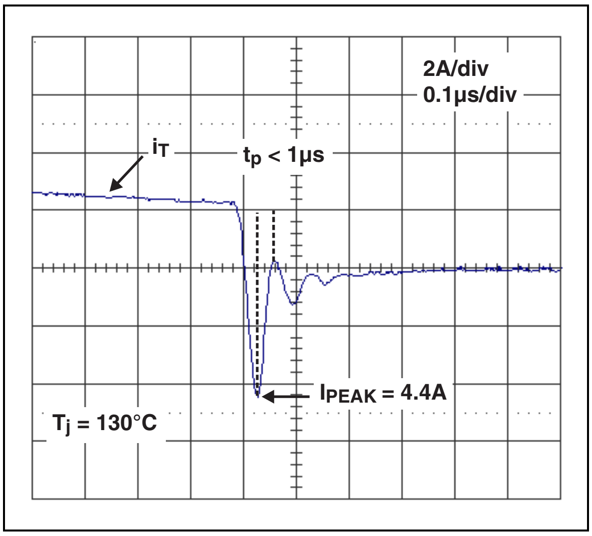
- **Step1:** Total current measurement i_T (with snubber)
  $\Rightarrow I_{PEAK}$
- **Step2:** Maximum avalanche peak power estimation
  $\Rightarrow P_{PEAK\_AV} = 2.I_{PEAK} \cdot V_{RRM}$
- **Step3:** Check that:
  $\Rightarrow P_{PEAK\_AV} < P_{ARM}(1\mu s, T_j)$ using the specification tool (see § II)
  [As tp < 1µs $\Rightarrow P_{ARM}(t_p, T_j) = cst = P_{ARM}(1\mu s, T_j)$]

Example:
In this example, a 16A-100V Schottky diode (STPS16H100CT) working in the avalanche area is considered.

- **Step1:**

The figure 9 shows the total current through both the snubber circuit and the STPS16H100CT.

Figure 9: Total current i_T (diode + snubber)



- **Step2:**

P_{PEAK_AV} is given by:
$\Rightarrow P_{PEAK\_AV} = 4.4 \text{ x } (2 \text{ x } 100)$
$\Rightarrow \mathbf{P_{PEAK\_AV} = 880W}$

- **Step3:**

The data sheet of the STPS16H100CT gives:
$P_{ARM}(1\mu s, 25°C)_{(STPS16H100CT)} = 8700W$

With the derating curve figure 2, we get:
$\mathbf{P_{ARM}(1\mu s, 130°C)_{(STPS16H100CT)} = 3045W}$

As P_{PEAK_AV} is lower than $P_{ARM}(1\mu s, T_j)$, the STPS16H100CT can be used safely in this application.

IV. Estimation of the average avalanche power losses

The accurate method given below allows the maximum average avalanche power to be determined, and it can be used to optimize the choice of the diode in order to improve the converter's efficiency. The equivalent circuit during the time the diode works in the avalanche is simulated. From this simulation, the real avalanche current as well as the pulse duration can be found from which an estimation of the maximum avalanche energy can be made. The simulation is performed using the Pspice software. The 2 steps that comprise this method are explained using an adaptor for Notebook as a concrete example (see figure 10).

First step: Measurement

This first step consist of measuring 3 waveforms:

⇒ the total current i_T (taking into account the delay time in order to have I_{PEAK} at $V_D = -V_S$)
⇒ the voltage across the diode V_D
⇒ the voltage across the snubber capacitor V_{CS}

Figure 11 shows typical waveforms corresponding to the example.

Figure 10: 70W Adaptor for Notebook, using a STPS16H100CT in the avalanche

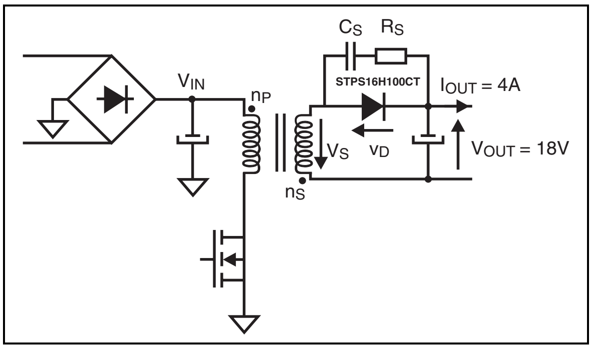
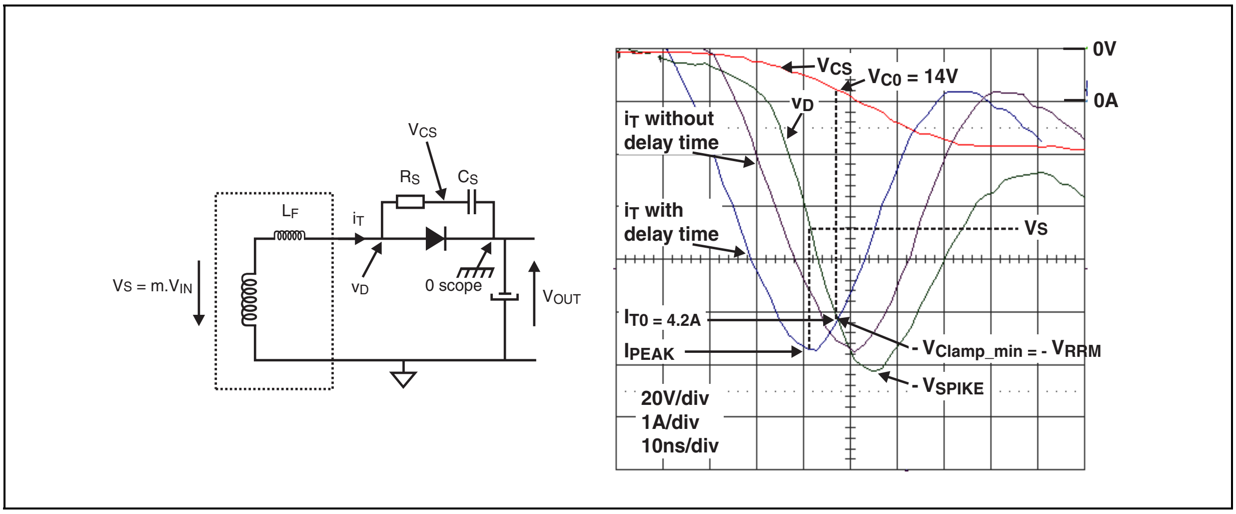


Figure 11: Waveforms when the diode turns off



The maximum avalanche energy in the diode corresponds to a diode with a minimum clamping voltage V_{Clamp_min}. As this value is not given in the data sheet, one can consider that the minimum clamping voltage will be equal to V_{RRM}. The figure 11 gives the initial conditions when the voltage across the diode is equal to V_{Clamp_min}, that is to say V_{RRM}.

At $v_D = V_{RRM}$: $i_T = i_{TO} = 4.2A$
$V_{CS} = V_{CO} = 14V$

Second step: Pspice simulation

Knowing the initial conditions i_{TO} and V_{CO}, the equivalent circuit can be simulated (see figure 12). The figure 13 shows the simulation results. The result of this simulation is:

$$E_{AVALANCHE\_max} = \int_0^{t_p} V_{RRM} \cdot i_{AVALANCHE} \cdot dt$$

$E_{AVALANCHE\_max} = 2.5\mu J$

Therefore:
$P_{AVALANCHE(AVERAGE)max} = E_{AVALANCHE\_max}$ x Fc (with Fc = 100kHz)

$\mathbf{P_{AVALANCHE(AVERAGE)max} = 250mW}$

This accurate method can be used to estimate the maximum real avalanche peak power in the case where the estimation with the simple method (cf §III) is too pessimist.

Figure 12: Pspice equivalent circuit with initial conditions I_{TO} and V_{CO}

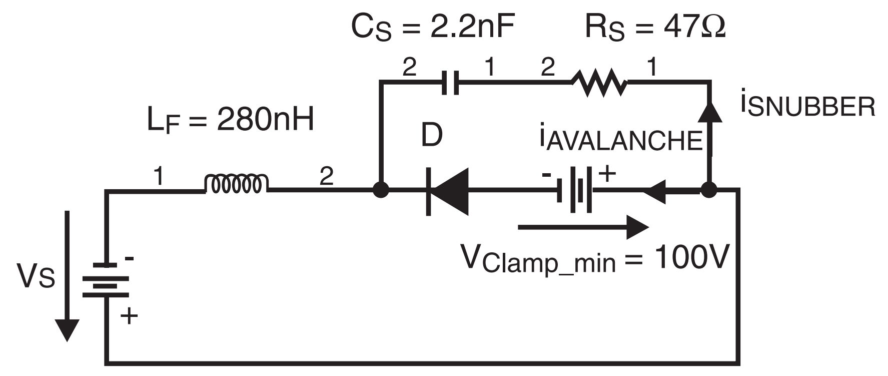
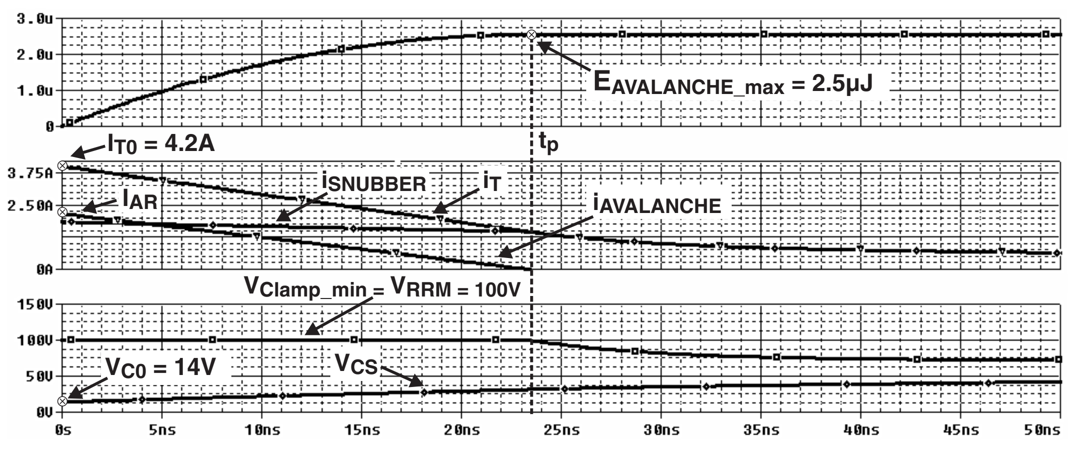


Figure 13: Simulation results



V. Rectification Schottky diode optimization using avalanche specification

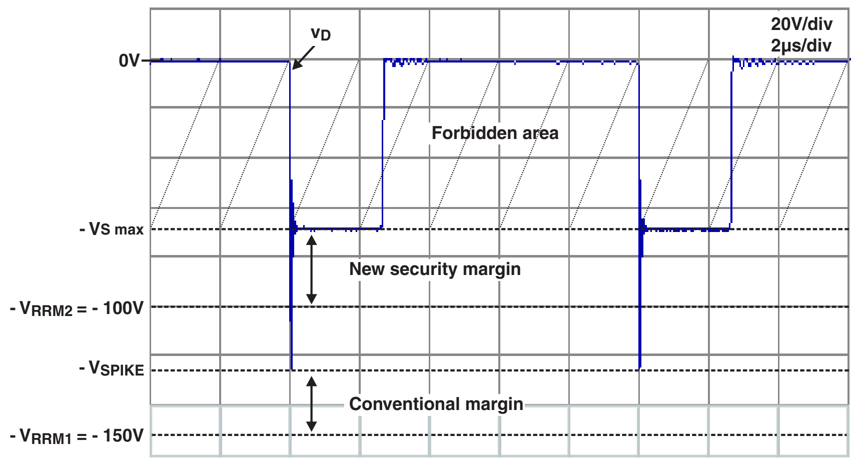
V.1. Changing security margin criteria

The figure 14 shows a typical voltage waveform across a rectification diode. Usually, designers take a conventional security margin between the V_{RRM} and the spike voltage (see figure 14). With the avalanche specification of Schottky diodes, this security margin is not required anymore because the diode can work in avalanche during the turn-off. On the other hand, the new security margin which is an essential condition to assure the correct working of the power supply is the margin between the maximum voltage $V_S$max and the new V_{RRM} (V_{RRM2}, see figure 14).
In the example illustrated here below, a 150V Schottky diode is replaced by a 100V Schottky diode.
$V_S$max needs to be defined by the designer in the worst case conditions (Vin_{max}, transient phase...).
Consequently, the following condition is necessary for V_{RRM}:

$$V_S max + margin < k \times V_{RRM}$$

k is a cold start coefficient that is equal to 0.95 in the case where the diode is exposed to very low temperature (-40°C or -20°C) (for $T_j > 0°C$, k = 1).

Figure 14: Voltage across the diode



V.2. Snubber size optimization

The snubber design is defined by the 3 following constraints:
1. Power losses in the snubber resistance R_S
2. EMC compatibility
3. $V_{SPIKE} < V_{RRM}$

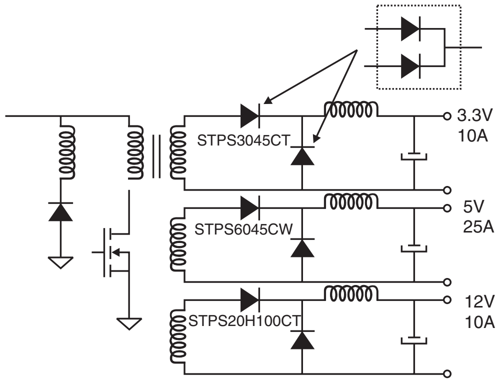
With the avalanche specification, the third constraint ($V_{SPIKE} < V_{RRM}$) is not relevant anymore.
Consequently in a few cases, it is possible to reduce the snubber size.

V.3. Schottky diode optimization

Using the Schottky avalanche specification, two methods of optimization can be considered:
- Power losses saving (same "price")
- Cost saving (same power losses)

In order to show how it is possible to optimize the converter using Schottky diodes in avalanche, a concrete example of a Switched Mode Power Supply for computer is illustrated (see figure 15).

Figure 15: SMPS for PC



The two method of optimization of conventional parts numbers are given in the table below:

V_{OUT}	Part Number		
	Current solution	**Power losses saving sol.**	**Cost saving solution**
3.3 V	STPS3045CT	STPS3030CT	STPS2030CT
5 V	STPS6045CW	STPS6030CW	STPS3030CT
12 V	STPS20H100CT	STPS20L60CT	STPS10L60CT

In this example, avalanche losses and switching-off losses are negligible in comparison with the forward losses. The following table gives the forward losses saving for each output.

Output	Part Number	Pfwd (W)
V_{OUT} = 3.3 V I_{OUT} = 10 A	STPS3045CT	4.35
	STPS3030CT	3.12
V_{OUT} = 5 V I_{OUT} = 25 A	STPS6045CW	12
	STPS6030CW	9.1
V_{OUT} = 12 V I_{OUT} = 10 A	STPS20H100CT	5.85
	STPS20L60CT	4.66

In this example, the total efficiency improvement on the 3 outputs is equal to 1.9%.

VI. Conclusion

This paper presents the specification tool allowing the admissible avalanche power of Schottky diodes to be calculated. With this tool and the simple method to estimate the maximum avalanche peak power, one can easily determine if a given Schottky diode can work in the avalanche area. In SMPS, the efficiency drop is mainly determined by the rectification diode stage.
In most of cases and according to the converter topology, the use of Schottky diodes in the avalanche area will allow the converter's efficiency to be improved. Alternatively it can enable the cost to be optimized by reducing the current rating of the rectification diode.

References:

[1] AN1453: NEW FAMILY OF 150V POWER SCHOTTKY (by F.Gautier)
[2] AN587: TRANSISTOR PROTECTION BY TRANSIL(by B.Rivet)
[3] ANALYSIS AND OPTIMISATION OF HIGH FREQUENCY POWER RECTIFICATION (by J.M.Peter)

Table 1: Revision History

Date	Revision	Description of Changes
Oct-2004	1	First issue

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