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: $P_{ARM(1\mu s, \, 25^\circ C)}$ (given at $t_p=1\mu s$ and $T_j = 25^\circ C$) - 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 ($t_p$). $P_{ARM(1\mu s, 25^\circ C)}$ 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 $P_{AVALANCHE}$:

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

Figure 1: $P_{ARM \,(1\mu s, \, 25^\circ C)}$ (Maximum repetitive avalanche power)
III. Simple method to estimate the maximum avalanche peak power

III.1. Setting the Problem

Most of the time, it is difficult to accurately determine 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 modeled by the capacitance $C_j$, $R_S$ 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 $V_S$.

$$I_T = I_{PEAK} \iff v_D = -V_S$$

**Figure 5: Basic equivalent circuit**

**Figure 6: Total current ($I_T$) and voltage ($V_D$) when the diode turns off**

![Figure 5: Basic equivalent circuit](image1)

**Figure 7: 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**

![Figure 7: Switch-off behavior when the diode works in the avalanche area](image2)
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 $t = t_1$: $i_T = I_1$

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:

$$\frac{di_T}{dt} = \frac{V_{Clamp}V_s}{L_F}$$  \hspace{0.5cm} (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:

\[
P_{AVALENCH} = I_{AR}.V_{Clamp} < P_{PEAK\_AV} = I_{PEAK}.(2 \times V_{RRM})
\]

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

\[
2.I_{PEAK}.V_{RRM} < P_{ARM(1\mu s,T_j)}
\]

### 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
  \( \Rightarrow P_{PEAK\_AV} = 2.I_{PEAK}.V_{RRM} \)

- **Step3**: Check that:
  \( \Rightarrow P_{PEAK\_AV} < P_{ARM(1\mu s,T_j)} \) using the specification tool (see § II)
  
  \[\text{As } t_p < 1\mu s \Rightarrow P_{ARM(t_p,T_j)} = \text{cst} = P_{ARM(1\mu s,T_j)}\]

**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.

- **Step2**:
  \( P_{PEAK\_AV} \) is given by:
  \( \Rightarrow P_{PEAK\_AV} = 4.4 \times (2 \times 100) \)
  \( \Rightarrow P_{PEAK\_AV} = 880W \)

- **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:
  \( P_{ARM(1\mu s,130°C)(STPS16H100CT)} = 3045W \)

  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 \( i_{\text{PEAK}} \) 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.

The maximum avalanche energy in the diode corresponds to a diode with a minimum clamping voltage \( V_{\text{Clamp, min}} \). 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 \( V_{\text{Clamp, min}} \), that is to say \( V_{RRM} \).

At \( V_D = V_{RRM} \):
\[
\begin{align*}
i_T &= i_{TO} = 4.2A \\
V_{CS} &= V_{CO} = 14V
\end{align*}
\]
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:

$$E_{AVALANCHE_{\text{max}}} = \int_0^t V_{RRM} \cdot i_{AVALANCHE} \cdot dt$$

$E_{AVALANCHE_{\text{max}}} = 2.5\mu J$

Therefore:

$$P_{AVALANCHE(\text{AVERAGE})_{\text{max}}} = E_{AVALANCHE_{\text{max}}} \times F_c \text{ (with } F_c = 100kHz)$$

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

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 pessimistic.

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

![Pspice equivalent circuit with initial conditions $i_{TO}$ and $V_{CO}$](image)

Figure 13: Simulation results

![Simulation results](image)
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 $V_{S\text{max}}$ 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. $V_{S\text{max}}$ needs to be defined by the designer in the worst case conditions ($V_{in\text{max}}$, transient phase...). Consequently, the following condition is necessary for $V_{RRM}$:

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

$k$ 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).
The two method of optimization of conventional parts numbers are given in the table below:

<table>
<thead>
<tr>
<th>Output Voltage</th>
<th>Current Solution</th>
<th>Power Losses Saving Solution</th>
<th>Cost Saving Solution</th>
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<tr>
<td>3.3 V</td>
<td>STPS3045CT</td>
<td>STPS3030CT</td>
<td>STPS2030CT</td>
</tr>
<tr>
<td>5 V</td>
<td>STPS6045CW</td>
<td>STPS6030CW</td>
<td>STPS3030CT</td>
</tr>
<tr>
<td>12 V</td>
<td>STPS20H100CT</td>
<td>STPS20L60CT</td>
<td>STPS10L60CT</td>
</tr>
</tbody>
</table>

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.

<table>
<thead>
<tr>
<th>Output Voltage</th>
<th>Part Number</th>
<th>P(_{\text{fwd}}) (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>V(_{\text{OUT}}) = 3.3 V</td>
<td>STPS3045CT</td>
<td>4.35</td>
</tr>
<tr>
<td>I(_{\text{OUT}}) = 10 A</td>
<td>STPS3030CT</td>
<td>3.12</td>
</tr>
<tr>
<td>V(_{\text{OUT}}) = 5 V</td>
<td>STPS6045CW</td>
<td>12</td>
</tr>
<tr>
<td>I(_{\text{OUT}}) = 25 A</td>
<td>STPS6030CW</td>
<td>9.1</td>
</tr>
<tr>
<td>V(_{\text{OUT}}) = 12 V</td>
<td>STPS20H100CT</td>
<td>5.85</td>
</tr>
<tr>
<td>I(_{\text{OUT}}) = 10 A</td>
<td>STPS20L60CT</td>
<td>4.66</td>
</tr>
</tbody>
</table>

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

<table>
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<tr>
<th>Date</th>
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