



## AN601 APPLICATION NOTE

### NEW HIGH VOLTAGE ULTRA-FAST DIODES: THE TURBOSWITCH™ A and B SERIES

#### INTRODUCTION

In today's power converter, the commutation speed of the transistor and the operating frequencies are higher and higher.

Fast diodes used for freewheel, snubber, and rectifier functions become one of the main causes of the power losses. In the range of 600V-1200V, ST has developed a new family of ultrafast diodes.

Taking into account these new constraints which are different from one application to another, ST proposes two series: TURBOSWITCH "A" and TURBOSWITCH "B".

The specific characteristics of these two series offer to the designer a double choice, allowing him to use the best diode in this application.

The choice of the optimum diode for a given application depends on the estimation of the power losses generated by the diode. This note explains how to calculate the different losses with information given in the datasheet and shows the difference between TURBOSWITCH "A" and TURBOSWITCH "B" and their respective advantages.

#### LOSSES CALCULATION

##### Conduction losses

Conduction losses are estimated with the classical formula:

$$P_{CON} = V_{to} I_{F(AV)} + r_d I_{F(RMS)}^2$$

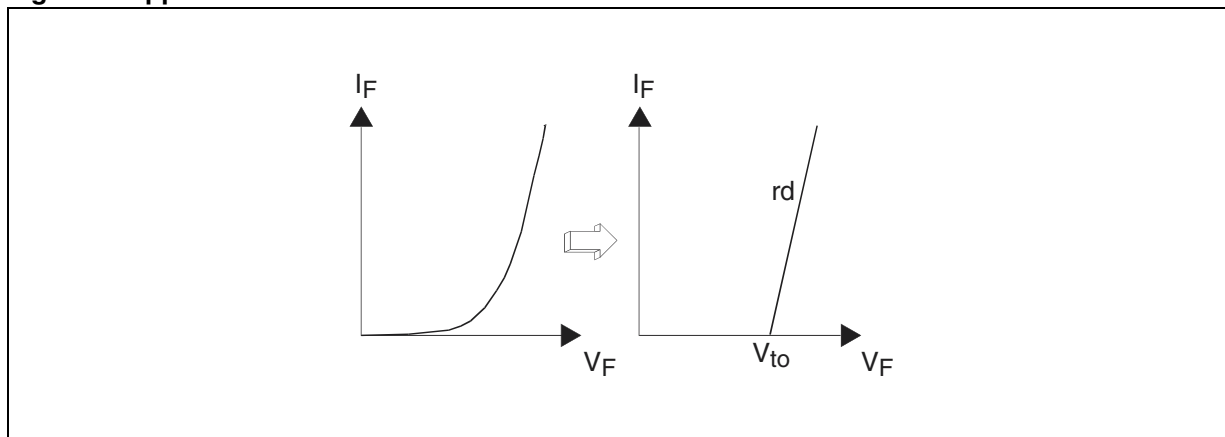
$V_{to}$ : Threshold voltage (see Figure 1);

$r_d$ : Dynamical resistance (see Figure 1);

$I_{F(AV)}$ : Average current;

$I_{F(RMS)}$ : RMS current.

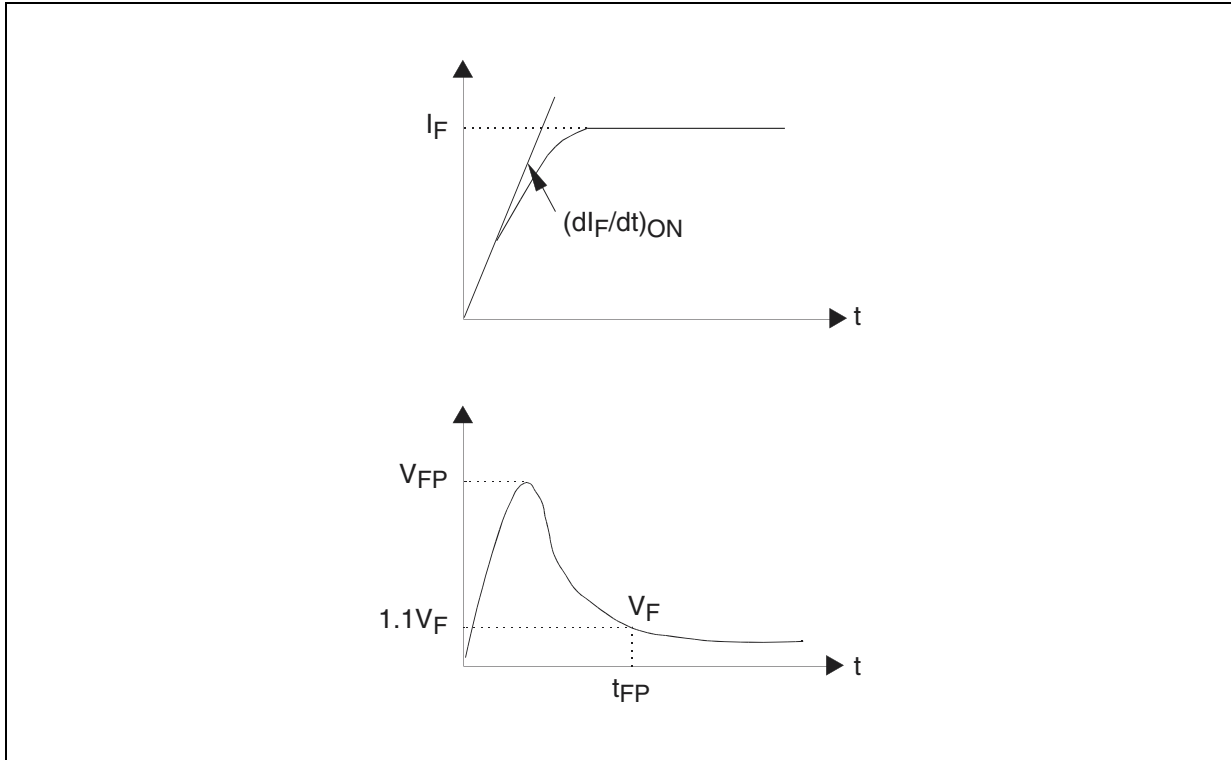
**Figure 1. Approximation of the forward characteristic**



### Turn-ON losses

When the diode turns ON, the voltage across the diode increases to  $V_{FP}$  (Peak forward voltage) before it decreases to  $1.1V_F$  at the time  $t_{FR}$  (Forward recovery time) (see Figure 2).

**Figure 2. Turn-ON waveforms**



Turn-ON losses can be approximated by the following formula:

$$P_{ON} = 0.4 (V_{FP} - V_F) \times t_{FR} \times I_F \times f$$

Where  $f$  is the operating frequency:

$V_{FP}$  and  $t_{FR}$  depend on  $(dI_F/dt)_{ON}$  and  $I_F$ . Curves in the datasheet giving  $V_{FP}$  and  $t_{FR}$  versus  $(dI_F/dt)_{ON}$  allow the estimation of  $P_{ON}$  for each application.

Example:

$$I_F = 8A$$

$$(dI_F/dt)_{ON} = 64A/\mu s$$

$$f = 100kHz$$

With an STTA806D (TURBOSWITCH A, 8A / 600V / TO220AC) in these conditions:

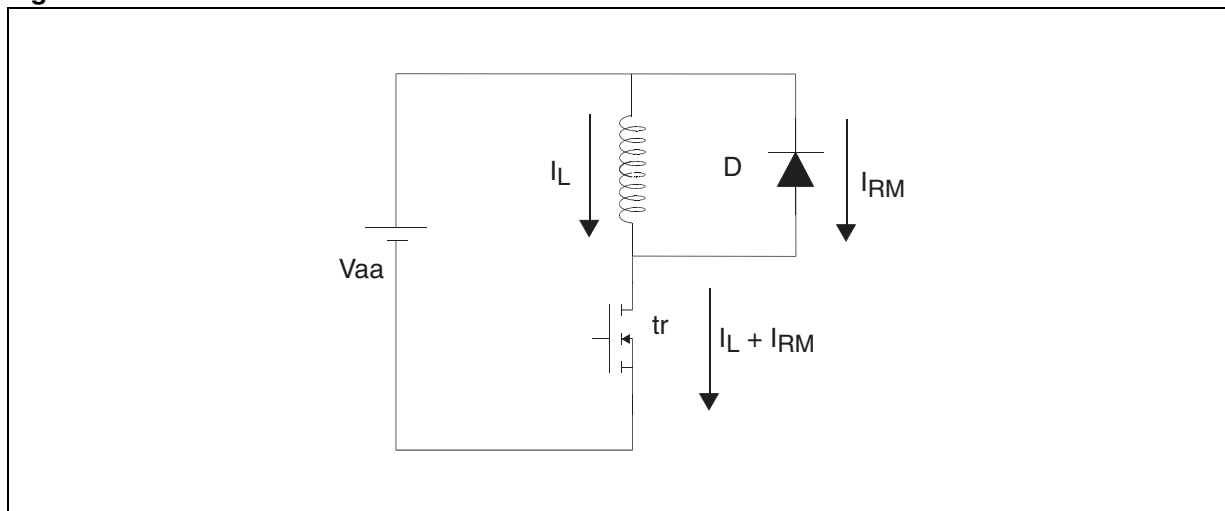
$$V_{FP(max)} = 10V$$

$$t_{FR(max)} = 500ns$$

$$P_{ON} = 1.4W$$

### Turn-OFF losses

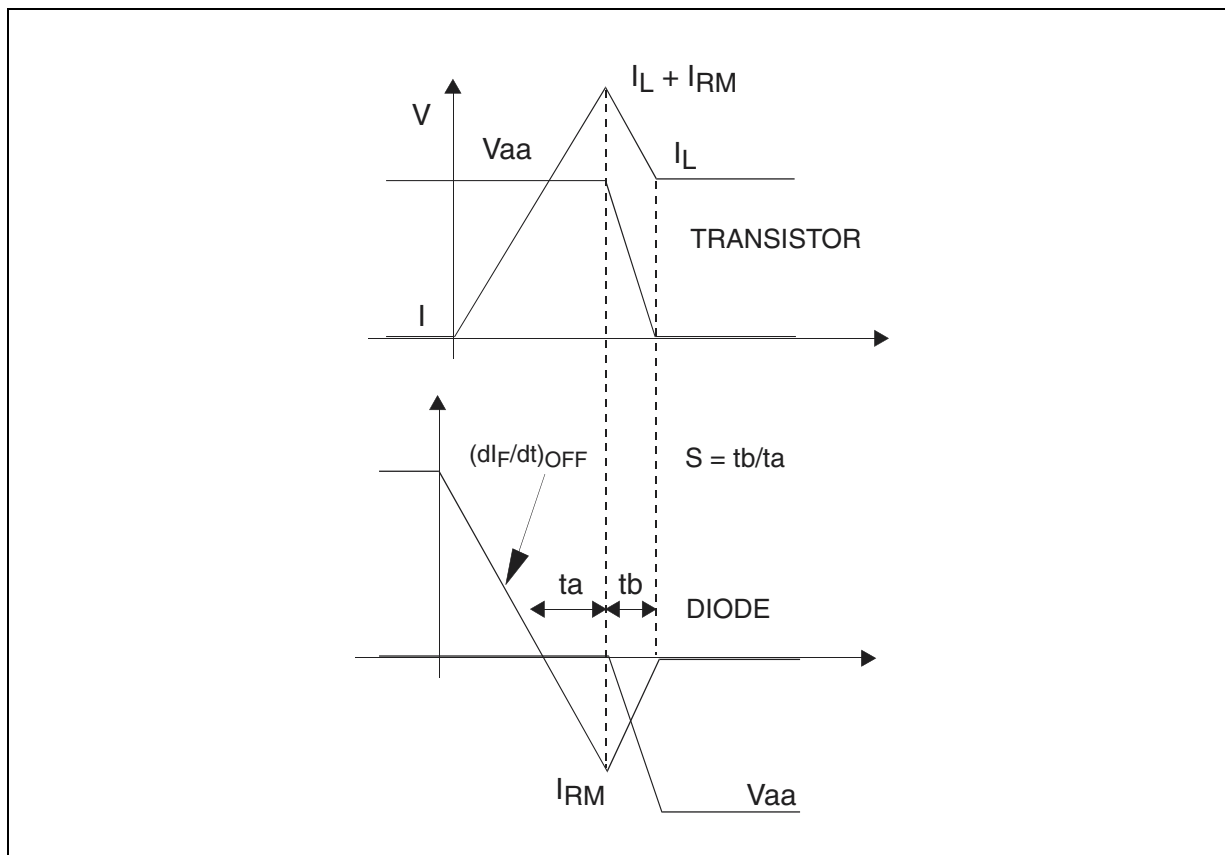
Turn-OFF losses are studied in the case of a freewheel function where the switch is a MOS transistor (see Figure 3).

**Figure 3. Basic circuit with freewheel diode**

Note:  $I_L$  = Load current.

$I_{RM}$  = Maximum reverse recovery current of the freewheel diode D.

The typical waveform of the current and the voltage when the transistor switches ON and the diode switches OFF is shown in Figure 4 in the case where the stray inductance is low ( $< 50\text{nH}$ ).

**Figure 4. Fig.4: Current and voltage waveforms of a freewheel diode at turn-OFF and the associated transistor at turn-ON**

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The turn-OFF losses in the diode can be calculated by:

$$P_{OFF} = \frac{V_{aa} \cdot I_{RM}^2 \cdot S \cdot f}{6(dI_F/dt)_{OFF}}$$

### Transistor losses due to the diode

When the diode switches OFF, the recovery current flows in the transistor which induces turn-ON losses in the transistor. The turn-ON losses in the transistor due to the diode can be estimated by:

$$P_{ON(tr)} = \frac{V_{aa} \cdot I_{RM}^2 \cdot (3 + 2S) \cdot f}{6(dI_F/dt)_{OFF}} + \frac{V_{aa} \cdot I_{RM} \cdot I_L \cdot (S + 2) \cdot f}{2(dI_F/dt)_{OFF}}$$

Turn-ON losses in the transistor are generally much higher than turn-OFF losses in the diode.

These two formulas include  $I_{RM}$  and  $S$  parameters which characterize the turn-ON behaviour. These parameters depend on the  $(dI_F/dt)_{OFF}$ .

In the datasheet, curves giving  $I_{RM}$  and  $S$  versus  $(dI_F/dt)_{OFF}$  allow to calculate these losses for a given application.

Example:

$$V_{aa} = 400V$$

$$f = 30kHz$$

$$I_L = 12A$$

$$(dI_F/dt)_{OFF} = -500A/\mu s$$

$$T_j = 125^\circ C$$

with a STTA12060 (TURBOSWITCH "A", 12A / 600V / TO220AC) we find:

$$P_{OFF} = 0.43W$$

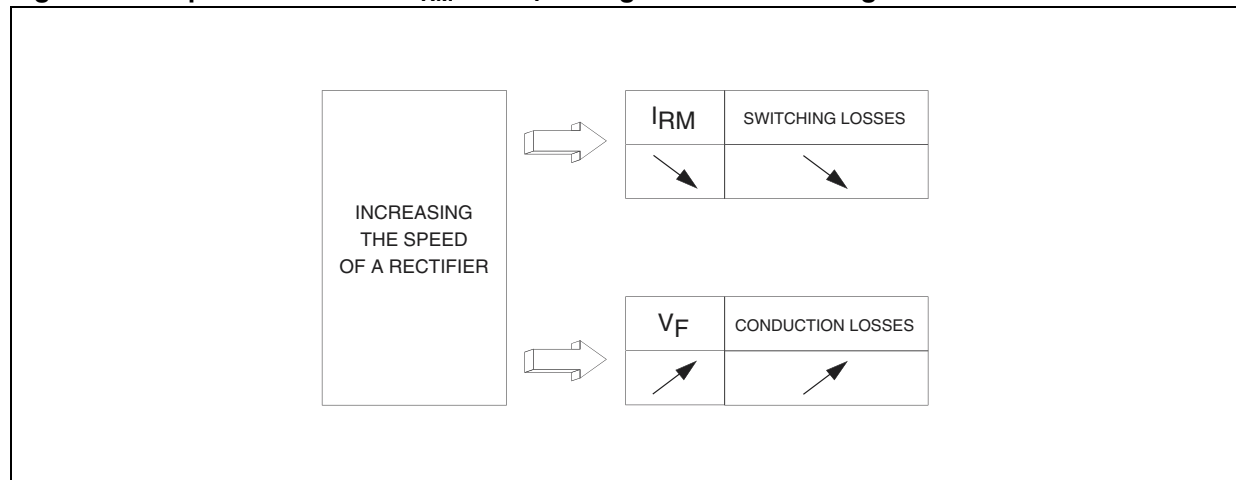
$$P_{ON(tr)} = 9.5W$$

## COMPARISON BETWEEN TURBOSWITCH "A" AND TURBOSWITCH "B"

### Difference between characteristics

The design of a fast rectifier is known to be the result of a trade-off for a given reverse voltage, and the compromise can be explained in the Figure 5.

Figure 5. Compromise between  $I_{RM}$  and  $V_F$  for a given reverse voltage



For the diode of the family "A", the compromise  $V_F - I_{RM}$  has been chosen to reduce the total losses in both the diode and the companion transistor in a freewheel configuration.

On the other hand, the compromise of the family "B" has been chosen to minimize the conduction losses.

Table 1 summarizes the main characteristics of a STTA806D (TURBOSWITCH"A", 8A / 600V / TO220AC) and a STTB806D (TURBOSWITCH"B", 8A / 600V / TO220AC).

**Table 1. Main characteristics of a STTA806D and a STTB806D**

Type	$(di_F/dt)_{OFF} = 500A/\mu s;$ $I_F = 8A; T_j = 125^\circ C$		$I_F = 8A$ $T_j = 125^\circ C$	$(di_F/dt)_{ON} = 64A/\mu s;$ $T_j = 25^\circ C$	
	$I_{RM}$	S	$V_F$	$V_{FP}$	$t_{FR}$
	Typ	Typ	Max	Max	Max
STTA806D	14A	0.45	1.5V	10V	500ns
STTB806D	28A	0.79	1.3V	8V	500ns

Data in this table show that conduction losses and switch-ON losses will be lower in a TURBOSWITCH "B" while switch-OFF losses will be lower in a TURBOSWITCH "A".

The oscillogram in Figure 6 shows the current in a STTA806D and in a STTB806D when the diodes switch-OFF in the following conditions:

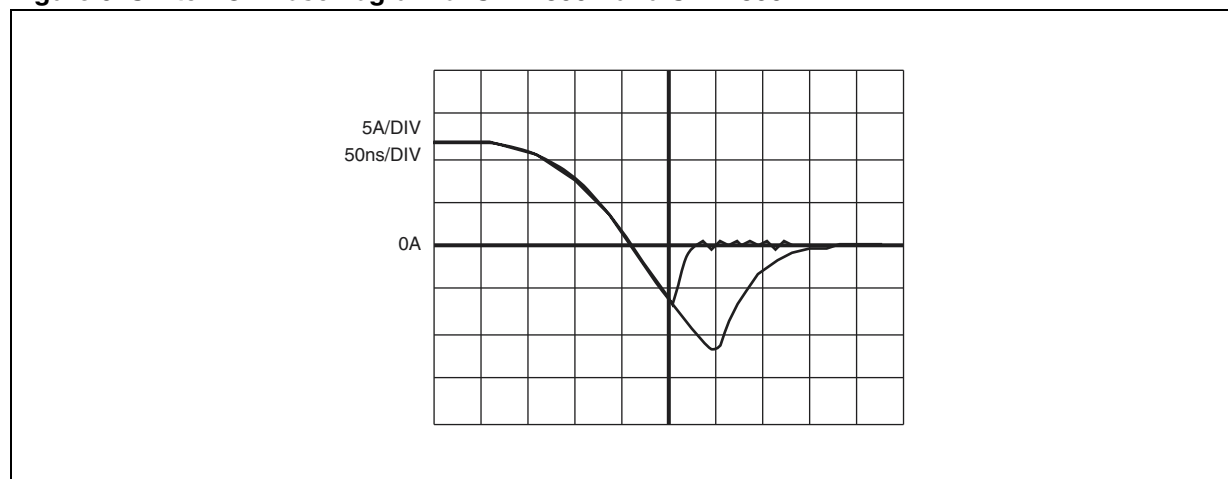
$$V_R = 350V$$

$$(di_F/dt)_{OFF} = -300 A/\mu s$$

$$T_j = 100^\circ C$$

$$I_F = 12A$$

**Figure 6. Switch-OFF oscillogram of STTA806D and STTB806D**



This oscillogram shows that the  $I_{RM}$  value is approximately two times lower with a STTA1206D, and that STTB1206D is a very soft diode.

### Application examples

**Example 1:** In this example, a comparison of the loss differences is done in a freewheel application where the current in the diode is rectangular. The main parameters are:

Peak current

$$I_M = 12A$$

$$V_{aa} = 400V$$

$$\text{Duty cycle: } \delta = 0.6$$

$$(dI_F/dt)_{ON} = 200A/\mu s$$

$$(dI_F/dt)_{OFF} = 500A/\mu s$$

$$T_j = 125^\circ C$$

$$f = 30kHz$$

In these conditions the reverse recovery characteristics of the diodes are given in Table 2:

The losses of the table Table 3 are calculated by

**Table 2. Reverse recovery characteristics of STTA1206D and STTB1206D with the conditions of the example 1**

Type	$I_{RM}$	S
STTA1206D	16A	0.42
STTB1206D	30A	0.90

using relations given in part 2.

In this type of application, the TURBOSWITCH "A"

**Table 3. Comparison between STTB1206D and STTA1206D in a freewheel diode function**

Type	Conduction losses	Switch ON losses	Switch OFF losses	Transistor losses	Total losses
STTA1206D	9W	0.1W	0.43W	9.5W	19W
STTB1206D	7.8W	0.07W	3.2W	29.8W	40.9W

is obviously the better choice.

**Example 2:** In this example, the diode is used as a rectifier diode with the following conditions:

$$I_F = 12A$$

$$(dI_F/dt)_{ON} = (dI_F/dt)_{OFF} = 100A/\mu s$$

$$V_{aa} = 350V$$

$$T_j = 125^\circ C$$

$$\delta = 0.8$$

$$f = 20kHz$$

The estimated losses are summarized in the Table 4.

In this application, we have to take into account the leakage inductance and the fact that a very soft diode is required to limit the overvoltage. The total losses are 10% lower with the STTB1206D, therefore the TURBOSWITCH "B" is the best choice.

**Table 4. Comparison between STTA1206D and STTB1206D in a rectifier function**

TYPE	Conduction losses	Switch ON losses	Switch OFF losses	Total losses
STTA1206D	14.4W	negligible	0.2W	14.6W
STTB1206D	12.4W	negligible	1W	13.4W

**CONCLUSION**

This note shows how to calculate the different losses due to the diodes in basic power switching circuits. These calculations can be done by using the parameters given in the datasheet of the TURBOSWITCH "A" and the TURBOSWITCH "B".

In most of cases, it is easy to choose between the "A" type and the "B" type.

The "A" type is very efficient in freewheel diode applications with high frequencies ( $f > 10\text{kHz}$ ).

The "B" type is better when conduction losses are predominant like in the case of the power factor corrector circuit in discontinuous mode (low  $(di_F/dt)_{OFF}$ ), or for applications where very high soft recovery behaviour is required (commutation with series inductances, for example).

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### REVISION HISTORY

**Table 5. Revision History**

<b>Date</b>	<b>Revision</b>	<b>Description of Changes</b>
January-1993	1	First Issue
16-Apr-2004	2	Stylesheet update. No content change.



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