SGS-THOMSON MICROELECTRONICS

APPLICATION NOTE

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

B. Rivet

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, SGS THOMSON has developed a new family of ultrafast diodes.

Taking into account these new constraints which are different from one application to another, SGS-THOMSON 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.

I. INTRODUCTION

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.

II. LOSSES CALCULATION

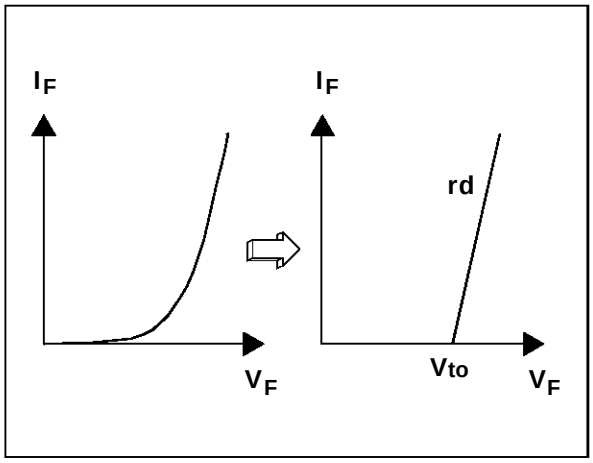
II.1 Conduction losses

Conduction losses are estimated with the classical formula :

$$Pcon = V_{to}\, I_{F(AV)} + rd\, I^2_{F(RMS)}$$

Vto	: Threshold voltage (Fig.1)
rd	: Dynamical resistance (Fig.1)
$I_{F(AV)}$	: Average current
$I_{F(RMS)}$	: RMS current

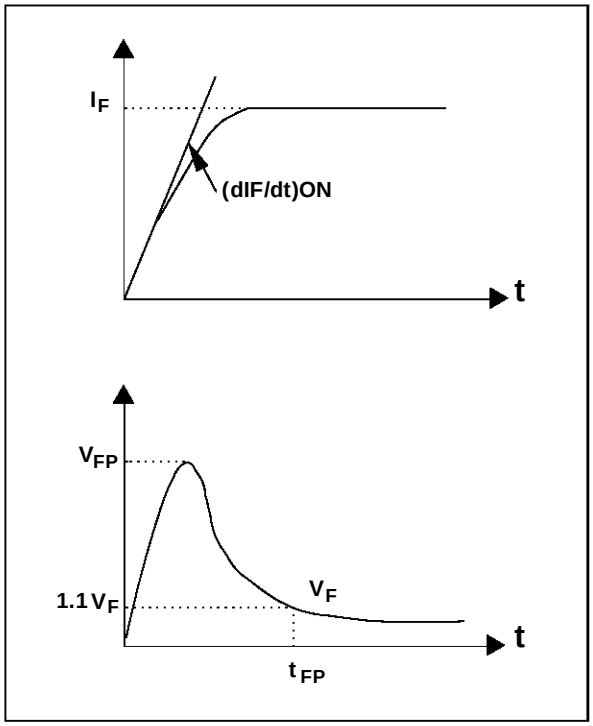
Fig.1 : Approximation of the forward characteristic



II.2. Turn on losses

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

Fig.2 : Turn ON waveforms



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Turn ON losses can be approximated by the following formula :

$$Pon = 0.4\ (V_{FP} - V_F)\ x\ t_{FR}\ x\ I_F\ x\ f$$

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 Pon for each application.

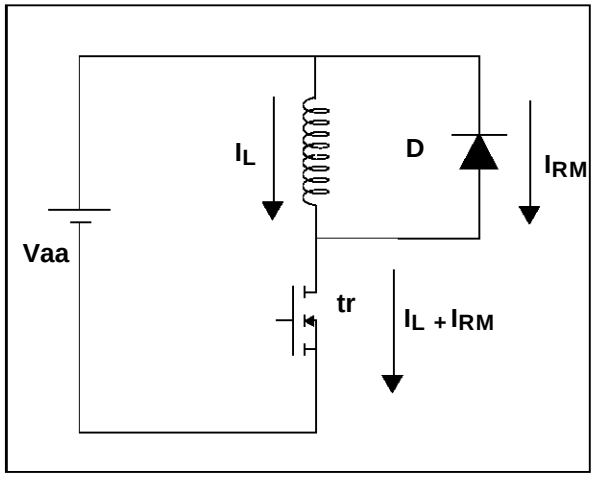
Example :

I_F = 8A
$(dI_F/dt)ON$ = 64A/µs
f = 100 kHz
With an STTA806D
(TURBOSWITCH A, 8 A / 600 V / TO220AC)
in these conditions
$V_{FP}(max)$ = 10V
$t_{FR}(max)$ = 500ns
Pon = 1.4 W

II.3. Turn-on losses

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

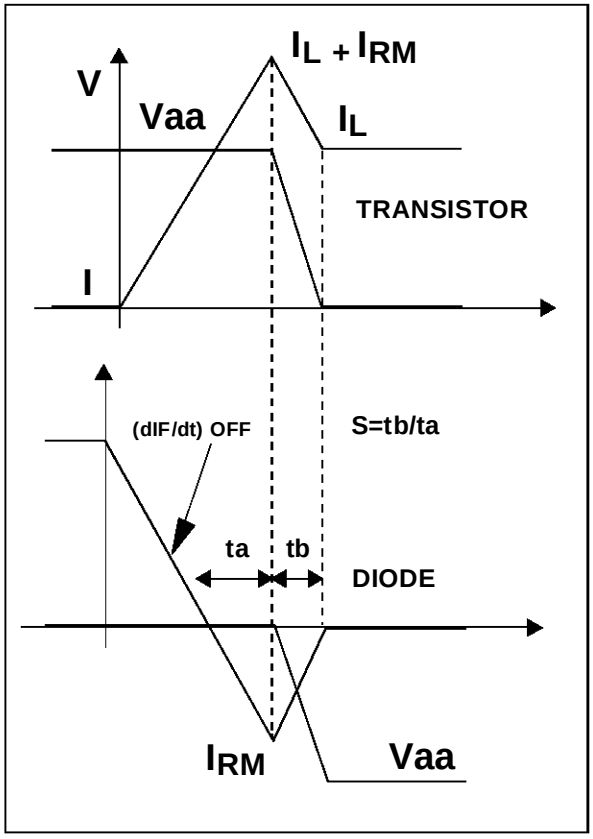
Fig.3 : Basic circuit with freewheel diode



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 Fig.4 in the case where the stray inductance is low (< 50 nH).

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



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

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

II.4. 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 :

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

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 :

Vaa	= 400V
f	= 30 kHz
IL	= 12 A
$(dI_F/dt)OFF$	= -500A/µs
Tj	= 125°C

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

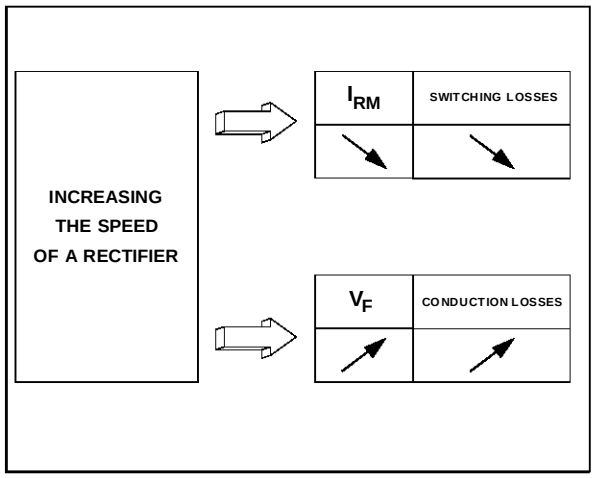
Poff	= 0.43 W
Pon(tr)	= 9.5 W

III. COMPARISON BETWEEN TURBOSWITCH "A" AND TURBOSWITCH "B"

III.1. 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 fig.5.

Fig.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 in Fig.6 summarizes the main characteristics of a STTA806D
(TURBOSWITCH"A", 8 A / 600V / TO220AC)
and a STTB806D
(TURBOWSITCH"B", 8 A / 600V / TO220AC)

Fig.6 : Main characteristics of a STTA806D and a STTB806D

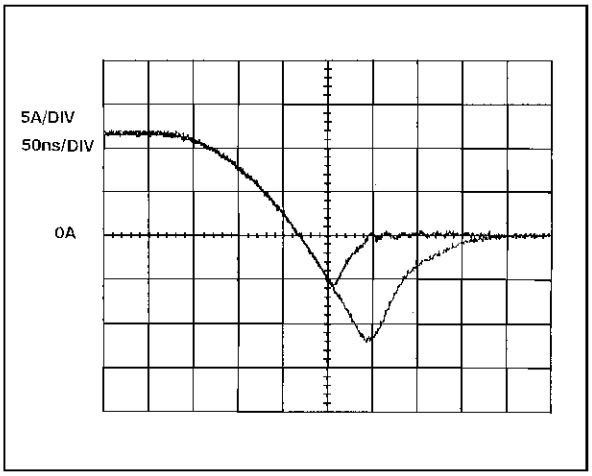
TYPE	$(dI_F/dt)OFF$ = 500 A/µs I_F = 8A Tj = 125°C		I_F = 8A Tj = 125°C	$(dI_F/dt)ON$ = 64 A/µs Tj = 25°C	
	I_{RM}	S	V_F	V_{FP}	t_{FR}
	typ	typ	max	max	max
STTA806D	14 A	0.45	1.5 V	10 V	500 ns
STTB806D	28 A	0.79	1.3 V	8 V	500 ns

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 TURBOSWICH "A".

The oscillogram in Fig.7 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/µs
Tj	= 100°C
I_F	= 12 A

Fig.7 : Switch-OFF oscillogram of STTA806D and STTB806D



This oscillogram shows that the IRM value is approximately two times lower with a STTA1206D, and that STTB1206D is a very soft diode.

III.2. 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	= 12 A
Vaa	= 400 V

Duty cycle: $\delta = 0.6$
$(\delta I_F/dt)ON$= 200 A/µs
$(dI_F/dt)OFF$= 500 A/µs
Tj = 125°C
f = 30 kHz

In these conditions the reverse recovery characteristics of the diodes are given in fig.7 :

The losses of the table fig.8 are calculated by

Fig.7 : Reverse recovery characteristics of STTA1206D and STTB1206D with the conditions of the example 1

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

using relations given in part 2.

In this type of application, the TURBOSWITCH "A"

Fig.8 : Comparison between STTB1206D and STTA1206D in a freewheel diode function

TYPE	Con-duction losses	Switch ON losses	Switch OFF losses	Tran-sistor losses	Total losses
STTA1206D	9 W	0.1 W	0.43 W	9.5 W	19 W
STTB1206D	7.8 W	0.07 W	3.2 W	29.8 W	40.9 W

is obviously the better choice.

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

I_F = 12 A
$(dI_F/dt)ON = (dI_F/dt)OFF$ = 100 A/µs
Vaa = 350 V
Tj = 125°C
δ= 0.8
f = 20 kHz

The estimated losses are summarized in the table fig.9

Fig.9 : Comparison between STTA1206D an STTB1206D in a rectifier function

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

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.

IV. 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 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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