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AN11310

FlatPower Schottky rectifier in low power adapter

Rev. 2 — 8 April 2013

Application note

Document information

Info	Content
Keywords	Low Power Adapter (LPA), charger, secondary side Schottky rectifier, SPICE simulation, thermal simulation, Printed-Circuit Board (PCB) heat sink layout
Abstract	This document gives an overview of the performance of secondary side Schottky rectifier in LPA with 5 W to 7.5 W output power. Forward power losses and junction temperatures of the rectifier PMEG4050ETP are calculated by SPICE and thermal simulations. PCB heat sink sizes and layout recommendations are discussed to control the junction temperature of the rectifier.

Revision history

Rev	Date	Description
2	20130408	Added Table 3 “Schottky rectifiers in SOD128 for LPA: highlights”
1	20130115	Initial version

Contact information

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1. Introduction

LPA in the range from 5 W to 7.5 W, as for example used for battery charging of mobile phones, typically choose Switched Mode Power Supply (SMPS) in a single switch flyback topology. Schottky rectifiers are a popular solution as secondary side rectifiers in these designs, as they offer significantly lower forward losses compared to PN-rectifier, increasing power efficiency.

This application note discusses the performance of a 40 V Schottky rectifier in NXP Semiconductors FlatPower SOD128 package, with focus on most important parameter for device selection and power losses generated under operation at full load. Power losses are calculated by SPICE simulations using simplified waveforms and junction temperatures by thermal simulations for different sizes of solder pads, i.e. additional heat sinks, on single layer PCB.

2. Flyback converter

2.1 Basic topology of a flyback converter

A flyback converter consists of an input, a power and an output stage. The input stage is connected to AC mains and its purpose is to convert the AC to a smoothed, unregulated DC voltage. The basic function blocks of the input stage are a bridge rectifier, followed by a smoothing capacitor. The capacitor smooths the rectified voltage and acts as an energy storage device.

The unregulated DC is then passed to the power stage, in which power is converted. The power stage is controlled by a switch and contains a transformer. Energy stored in the transformer is controlled by the switching frequency and duty cycle of the switch. When the switch is closed, the primary side of the transformer is connected to the input voltage, current rises and energy is stored. The voltage in the secondary winding is negative and the Schottky rectifier is reverse-biased. No current is flowing through it and energy to the output is delivered from the output capacitor.

When the switch is opened, the current in the primary side drops, the voltage at the secondary winding reverses and the rectifier becomes forward biased, allowing current flow, or energy transfer, to the output and the output capacitor. As a consequence of current flowing through the rectifier, forward losses are generated and temperature rises in the device.

Figure 1 shows a basic application schematic.

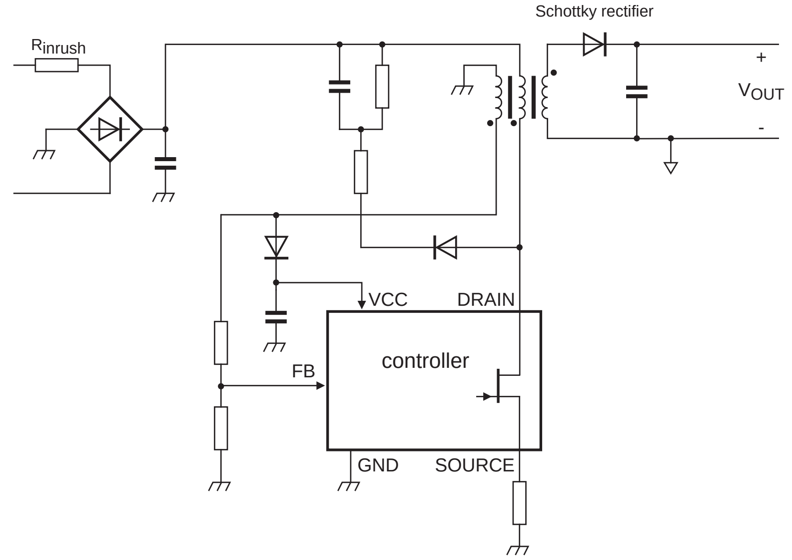


Fig 1. Basic application schematic of a flyback converter

2.2 Current waveform and associated forward losses of a Schottky rectifier in a low power flyback converter

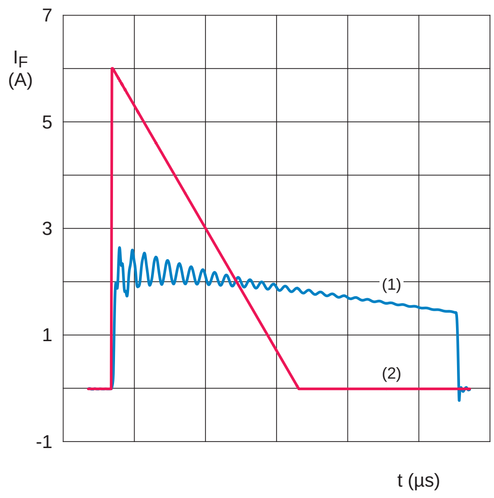
The current through the Schottky rectifier in a flyback converter is either continuous or discontinuous. Continuous current never reaches zero while for discontinuous mode the current drops down to zero and stays there for some time. The waveform has a more or less triangular shape.

Figure 2 shows a simplified waveform in comparison to a more realistic one for discontinuous mode. For a 7.5 W adapter with 1.5 A output current, peak currents up to 6 A can occur, with switching frequencies typically in a range from 50 kHz to 150 kHz.

The more realistic waveform shows the ringing, associated to the leakage inductance of the coils. In addition to the ringing, in steady state also peak current and duty cycle differ from the simplified waveform. They do not only depend on the average output current but also on size of the coils and additional circuitry, like a snubber across the rectifier.

The simplified waveform however is a good approach to investigate the effect of losses associated to the forward voltage at high currents, by simple SPICE simulations. The average losses in the rectifier will be in a similar range for both waveforms, if the average current is the same and the rectifier is able to handle peak currents without a deviation in the $V_F = f(I_F)$ characteristic. At currents > $I_{F(MAX)}$ ohmic losses in the EPItaxial layer (EPI) of the semiconductor can play a dominant role for an increase of forward voltage.

A simplified waveform with high peak current therefore is a good test to simulate full load conditions and the ability of the device to handle high currents. In addition, a simulation model for the magnetics and the driving scheme on the primary side has to be very elaborate to reflect all current and voltage-related matters in an isolated flyback. This effort was not spent for the investigations in the following chapters.



(1) I_F waveform with ringing

$I_{F(AV)}$ = 1.47 A, P_{AV} = 579 mW

(2) I_F simplified waveform

$I_{F(AV)}$ = 1.48 A, P_{AV} = 594 mW

Fig 2. Simplified and realistic current waveform through the secondary side rectifier, discontinuous mode

3. Important parameters for selection of a Schottky rectifier

3.1 I_F - maximum forward current

Forward current limits in Schottky rectifier data sheets are often specified as

- $I_{F(AV)}$: average forward current. The parameter is based on a pulsed, rectangular waveform with a duty cycle of typically 0.5.
- I_F: forward current limit for DC conditions.

$I_{F(AV)}$ is a useful parameter, as the current through the Schottky in a low power flyback SMPS is a pulsed, triangular current. Peak currents of the triangular waveform occur at less time than for a rectangular waveform, so in principle higher peak values are allowed for triangular waveforms.

For further information how to calculate peak values of pulsed waveforms or convert average values of different shaped waveforms please see Ref. 2 “Application Note AN10808 Thermal consideration of NXP FlatPower MEGA Schottky barrier rectifier - Selection criteria” on www.nxp.com.

For a design focusing on low losses, it is beneficial to choose a rectifier with $I_{F(AV)}$ limits that are at least three times greater than the average output current of the application.

3.2 V_F - forward voltage

With respect to on-state power losses and the efficiency of the adapter, V_F is the most important parameter. The lower the V_F, the lower the power loss and the better the power efficiency.

As the temperature goes up, the forward voltage V_F decreases and the losses are reduced, by the way increasing the efficiency of the LPA.

3.3 V_R - reverse voltage

The reverse voltage limit specifies the maximum allowable reverse voltage, at which a certain reverse current is not exceeded. Beyond this limit, safe operation cannot be guaranteed.

When selecting a rectifier with higher reverse voltage limits, the forward voltage V_F typically increases due to the higher Schottky barrier used. To gain efficiency, a diode with the lowest possible breakdown voltage is beneficial. In an LPA with 5 V output voltage, up to 35 V arise across the Schottky when the diode is in a blocking state. This voltage is related to the winding ratio of the transformer and will differ from design to design.

- V_R requirements for an isolated flyback are often calculated by:
  $V_{peak} / turnsratio + V_{OUT} + V_F$
- For an adapter connected to 230 V mains (+ 10 %) and a turns ratio of for example 15, peak reverse voltage calculates to:
  $253V \times 1,414 / 15 + 5V + 0,5V = 29,35V$

To add a safety margin, a minimum of $V_R \geq 40$ V is recommended for a 5 V adapter.

3.4 I_R - leakage current

Leakage current can have a negative effect on two important design features of modern low power adapter: overall efficiency and standby power losses.

Usually, the leakage current through the Schottky rectifier when in blocking state does not significantly effect the efficiency of a flyback transformer under operation, as the energy (minus ohmic losses) is reused every switching cycle and ohmic losses are rather small. In addition, the average blocking voltage across the rectifier is much lower than peak voltages so that overall losses typically do not lead to thermal runaway. Peak leakage current occurs at the peak reverse voltage of typically 30 V - 35 V and a device junction temperature of 85 °C.

For standby power considerations, the data sheet gives information about the leakage at 5 V and 25 °C ambient temperature. The value must be small enough, so that standby power loss requirements of the design are fulfilled.

3.5 C_d - diode capacitance

Diode capacitance is associated with the Schottky barrier and depends on reverse voltage conditions. Lower capacitance improves ElectroMagnetic Interference (EMI) behavior.

3.6 t_{rr} - reverse recovery time

To measure t_{rr}, the rectifier is forward biased and forward current is limited to a value I_X. Next, the rectifier is reverse biased while reverse current is limited to the same value I_X and the time needed for the current to decrease to 20 % of I_X is measured. This time is called t_{rr}.

Small values of t_{rr} result in less reverse current flow when the Schottky rectifier is reversed biased, improving EMI.

3.7 P_{tot} - maximum allowed power dissipation

The package of a semiconductor influences its maximum power dissipation capabilities, the required PCB space and height of the application.

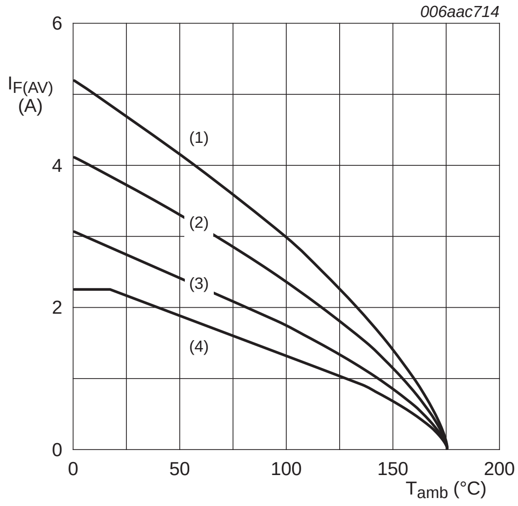
The maximum allowed power dissipation P_{tot} of the secondary side rectifier in an LPA mainly depends on $V_F \times I_F$, i.e. the generated forward losses. The dissipated power generates heat. The package of the rectifier and PCB layout conduct this heat to ambience, mainly to the PCB, via conduction through the leads and heat sinks.

4. Schottky rectifier in FlatPower SOD128 package for 5.0 W - 7.5 W LPA

NXP Semiconductors MEGA Schottky rectifiers in FlatPower SOD128 package are rugged, low V_F devices and the high-power density package with solid copper clips on the silicon die supports small and power efficient designs.

PMEG4050ETP is a 40 V, 5 A $I_{F(AV)}$ rectifier ideal for 7.5 W non-synchronous flyback adapter with up to 1.5 A average output current. To improve efficiency and power losses, a diode with higher $I_{F(AV)}$ limits than the average output of the adapter is beneficial. A device rated to 5 A $I_{F(AV)}$ has significant lower V_F at 6 A peak than a device rated to, for example 3 A average, reducing forward power losses.

Figure 3 indicates the maximum $I_{F(AV)}$ when the device is operated at different ambient temperatures, while mounted on a single layer PCB with 1 cm² mounting pad for the cathode. With a duty cycle of 50 % and an ambient temperature of 75 °C, PMEG4050ETP allows for $I_{F(AV)} > 1.5$ A.



FR4 PCB, mounting pad for cathode 1 cm^2

T_j = 175 °C

(1) $\delta = 1.0$

(2) $\delta = 0.9$

(3) $\delta = 0.8$

(4) $\delta = 0.5$

Fig 3. Average forward current as a function of ambient temperature; typical values

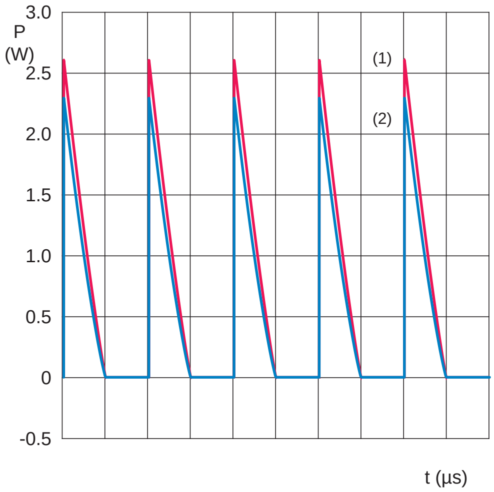
If higher breakdown voltage limits are required, PMEG6030ETP is a 60 V, 3 A $I_{F(AV)}$ rectifier and suited for 5 W non-synchronous adapter with 1 A average output current.

5. Power dissipation and thermal simulations

5.1 Simulation of average power dissipation of PMEG4050ETP in 7.5 W LPA

A SPICE simulation with a simplified waveform is useful to estimate the average power dissipation of a secondary side rectifier in an LPA. The waveforms shown in Figure 4 were generated by a SPICE simulation tool. A current source drives a 6 A peak, triangular current (1.5 A average) through the Schottky rectifier. The software calculates average power values.

With this setup, P_{tot} of PMEG4050ETP is around 600 mW at 25 °C junction temperature. As a SPICE model usually gives values at 25 °C junction temperature, the calculated P_{tot} will be too high compared to the conditions in a real application. Under operation, the Schottky rectifier will get hot and forward losses will decrease due to the lowered forward voltage V_F at high temperatures. To estimate the decrease in P_{tot}, a SPICE model for PMEG4050ETP at 85 °C junction temperature was extracted. The same simulation calculates a decrease of $P_{tot(AV)}$ of about 90 mW.



(1) T_j = 25 °C, $I_{F(AV)}$ = 1.5 A

P_{AV} = 594 mW

(2) T_j = 85 °C, $I_{F(AV)}$ = 1.5 A

P_{AV} = 501 mW

Fig 4. Simplified power dissipation of PMEG4050ETP in a 7.5 W flyback transformer at 25 °C and 85 °C

Table 1. SPICE models for PMEG4050ETP at 25 °C and 85 °C junction temperature

SPICE model for 25 °C junction temperature	SPICE model for 85 °C junction temperature
.SUBCKT PMEG4050ETP 1 2	.SUBCKT PMEG4050ETP_85°C 1 2
R1 1 2 1E+006	R1 1 2 1.5E+004
D1 1 2	D1 1 2
+ DIODE	+ DIODE
.MODEL DIODE D(IS = 3.589E-006 N = 1.017 BV = 48.4 IBV = 0.0003 RS = 0.009506 CJO = 1.209E-009 VJ = 0.3154 M = 0.4858 C = 0.5 TT = 0 EG = 0.69 XTI = 2)	.MODEL DIODE D(IS = 0.0004 N = 1.2 BV = 48.4 IBV = 0.0003 RS = 0.014 CJO = 1.209E-009 VJ = 0.3154 M = 0.4858 FC = 0.5 TT = 0 EG = 0.69 XTI = 2)
.ENDS	.ENDS

5.2 Thermal simulations of PMEG4050ETP on a single layer PCB

Thermal simulations were performed to investigate the rectifier junction temperature with different sizes of heat sinks. 500 mW P_{tot} was used for the simulations, according to the simulated power losses under full load at 85 °C.

The simulation setup is a single layer PCB in free air. To compare the influence of copper thickness of heat sinks and signal traces, 35 μm and 70 μm was used for the simulation. The SOD128 package model represents a heat source attached to the PCB.

PCB layout, 0.5 cm^2 heat sink at cathode and anode

3D picture of the Schottky rectifier on PCB

Thermal flow, cathode lead on the upper side

Fig 5. **Examples of PCB layout, model of the Schottky rectifier in SOD128 package and thermal flow**

The simulation calculates < 80 °C on a PCB with two times 0.5 cm^2 heat sinks of 70 μm in free air:

Table 2. **Thermal simulation results for PMEG4050ETP**

P power dissipation, T_{amb} = 25 °C	mW	500		500
copper thickness	μm	35		70
heat sink at cathode and anode	cm^2	1 + 0	0.5 + 0.5	0.5 + 0.5
T_j	°C	92.1	87.9	79.2
T_{lead} cathode	°C	88.6	85.7	77

The simulation with 1 cm^2 heat sink only at the cathode is shown in comparison to two times 0.5 cm^2 at anode and cathode to highlight the positive effect of distributed heat sinks. Typically there is not enough space for the heat sinks as used for the simulation. But surrounding components like capacitors, a transformer or a connector act as heat sinks, resulting in a similar performance.

It is however strongly recommended to verify the temperatures of the power semiconductors by measurements. The simulation here shall only indicate, that standard layouts sufficiently control the junction temperature of a Schottky rectifier in SOD128 package in a 7.5 W LPA.

6. Heat sink layout

In this chapter some aspects of heat sinks design and increased solder pads are discussed.

6.1 Heat sinks at one terminal comparing to heat sinks at both terminals of the rectifier (anode and cathode)

It is beneficial to use heat sinks at both terminals of the Schottky rectifier, i.e. two heat sinks with, for example 0.5 cm^2 each, are more efficient for cooling than one heat sink of 1 cm^2 at one terminal. The better the heat is distributed across the PCB, the more heat can be transferred into space via radiation and convection. As the SOD128 package uses solid copper clips from the top side of the die to the anode pin, heat conduction to both sides of the package is supported. The cathode is soldered on the leadframe and has an even slightly lower thermal resistance to the outside world. Figure 5 gives an overview of the inside structure of the Schottky rectifier in SOD128.

As a rule of thumb the junction temperature will decrease by 5 % to 10 % when two heat sinks are used, with an equal total covered area.

Drawback of an increased copper area at the anode is also an increased parasitic capacitance on the PCB at the anode terminal, that can influence EMI. Using Schottky diodes with small diode capacitance C_d and small t_{rr} improves EMI ruggedness. Compared to other devices in SMB or flat SMB, SOD128 rectifier uses rather small dies, with small capacitance and t_{rr} values.

6.2 Heat sinks on the bottom layer, thermal vias

If heat sinks are placed on the opposite site of the PCB, thermal vias must be used to conduct the heat through it and the heat sinks at top and bottom should be shifted to different areas of the PCB. As mentioned above, it is crucial to distribute the heat across the PCB and placing a one-to-one copy of the heat sink directly underneath the top layer does not result in significant additional cooling capabilities.

7. Conclusion

Medium power Schottky rectifiers in FlatPower SOD128 package are ideal for the usage as a secondary side rectifier in 5 W - 7.5 W LPAs.

PMEG4050ETP and PMEG6030ETP are rated to 5 A and 3 A $I_{F(AV)}$ with respective 7 A and 4.3 A DC ratings. With their low V_F and the small but powerful SOD128 package, these devices help to increase efficiency and ruggedness of LPA designs, while operation at high peak currents is supported.

By using additional heat sinks on the PCB, the maximum junction temperature under full load can be controlled.

Table 3. Schottky rectifiers in SOD128 for LPA: highlights

Type number	Reverse voltage $V_{R(max)}$	Average forward voltage $I_{F(AV)(max)}$	Forward voltage V_F		Reverse current I_R
			T_{amb} = 25 °C; I_F = 1 A	T_{amb} = 25 °C, I_F = 3 A	T_{amb} = 25 °C; V_R = 5 V
PMEG4050ETP	40 V	5 A	340 mV	390 mV	8 μA
PMEG6030ETP	60 V	3 A	380 mV	460 mV	4 μA
PMEG6030EVP	60 V	3 A	355 mV	420 mV	7 μA
PMEG6045ETP	60 V	4.5 A	355 mV	420 mV	7 μA

8. References

[1] Application Note AN11060 TEA172X 5 W to 11 W Power Supply/USB charger

[2] Application Note AN10808 Thermal consideration of NXP FlatPower MEGA Schottky barrier rectifier - Selection criteria

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Date of release: 8 April 2013
Document identifier: AN11310