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Performance of Schottky rectifier in CFP15 package in low power adapter

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Document information

Info	Content
Keywords	Low Power Adapter (LPA), flyback adapter, charger, secondary side Schottky rectifier, thermal runaway, PMEG45U10EPD, TEA1720B3T
Abstract	This document gives an overview of the 10 A/45 V rated MEGA Schottky rectifier PMEG45U10EPD in CFP15 (SOT1289) package on the secondary side of low voltage flyback adapters. This document introduces device parameters that influence efficiency, device temperatures and safety demands of a typical charger for smart phones and tablets. Using this parameter, power losses of the Schottky rectifier, junction temperature rise and the problem of thermal runaway are evaluated. To verify the performance of the Schottky rectifier in an typical application, an efficiency measurement is shown.

Revision history

Rev	Date	Description
1.0	20140616	Initial version

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1. Introduction

Chargers for smart phones and tablet PCs are designed for an increased output power, as fast charging cycles make a real difference to users nowadays. Typical power rating is up to 10.5 W and mainly Switched Mode Power Supply (SMPS) flyback topology is used. Schottky rectifiers are popular as secondary side rectifiers in these designs, as they are cost efficient solutions and offer significantly lower forward losses compared to PN-diodes, increasing power efficiency.

Chargers also need to be compact and circuit elements in small packages are preferred. One issue with slim designs is the high junction temperature of the secondary side rectifiers under full load conditions. As the designs also need to be low cost, one tends to choose non-synchronous flyback topologies with single or paralleled Schottkys as second side rectifiers in a Surface-Mounted Device (SMD) package with low thermal resistance.

The following chapters give an overview of the performance of NXP Semiconductors 10 A/45 V rated PMEG45U10EPD MEGA Schottky barrier rectifier in a 10.5 W, 5 V adapter design. Typical Schottky barrier rectifier data sheet parameter and limits such as the maximum reverse voltage V_R or the forward voltage V_F are discussed to ease the choice of a specific device.

Since designers are concerned about the junction temperature rise of Schottky in a low power adapter, power losses of the rectifier are calculated under full load condition.The estimate provides steady state junction temperature on a typical Printed-Circuit Board (PCB) layout, as well as limits for the effect of thermal runaway.

In addition, an efficiency measurement according to the latest efficiency standard for external power supplies from the U.S. Department of Energy (DOE) is shown.

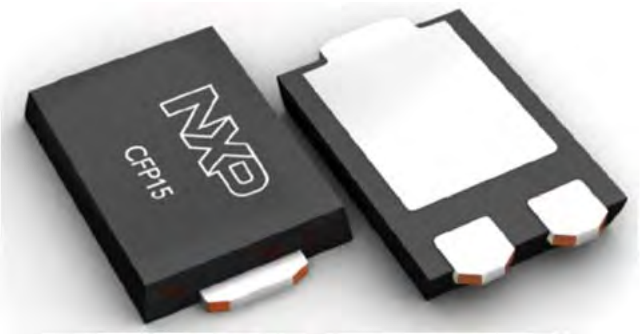
2. Overview of PMEG45U10EPD MEGA Schottky barrier rectifier

The 10 A / 45 V rated PMEG45U10EPD MEGA Schottky barrier rectifier from NXP Semiconductors has been developed to satisfy the needs of new smartphone and tablet chargers. Extremely low forward voltage drop helps to reach high efficiency levels of the chargers, as well as increased output power ratings needed for fast charging cycles.

- Forward voltage V_F < 420 mV for a current of 10 A at T_j = 85 °C junction temperature enable high efficiency levels.
- High peak current capabilities and a guaranteed breakdown voltage V_{BR} > 45 V to meet safety demands of battery chargers with output voltage V_O = 5 V.
- Low thermal resistance CFP15 (SOT1289) package optimizes heat transfer into the ambient environment, supporting compact and thin designs.

The device is housed in NXP Semiconductors CFP15 (SOT1289) package, which is an ideal choice for designs where low thermal resistance on a small footprint is required. It offers a benchmark flat design with 0.8 mm height and its tin plated front side leads enable not only visual solder inspection but support reflow and wave solder processes.

Table 1. Features and benefits of NXP Semiconductors CFP15 (SOT1289) package

Power (MEGA) Schottky barrier rectifier • higher power density compared to DPAK, SMB/C packages • reduced height and less occupied PCB area		3-leaded SMD package • tin-plated front side of leads enables visual solder inspection • exposed heat sink • benchmark flat design: typ. height 0.8 mm • halogen-free plastic material • pin compatibel to Diodes Inc PowerDI 5, Vishay TO-277A (SMPC)

3. Performance in a 10 W flyback converter

Figure 1 shows the basic application schematic of a flyback converter in a non-synchronous topology with a single, secondary side Schottky rectifier.

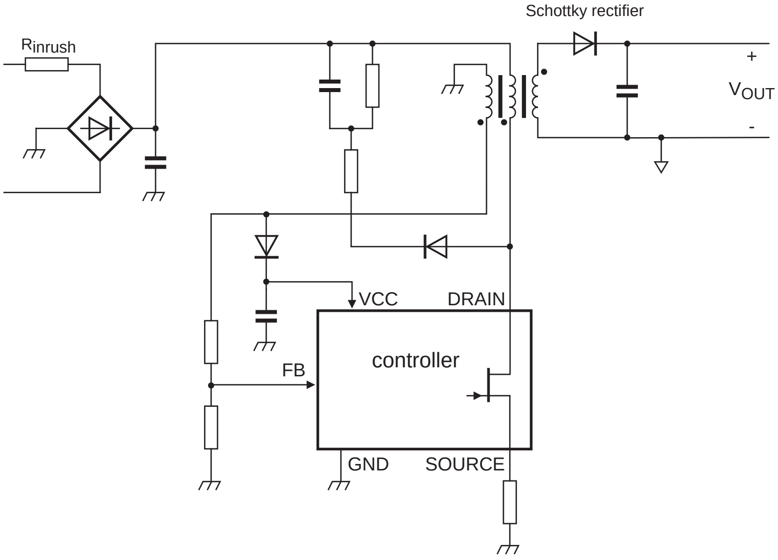


Fig 1. Basic application schematic of a flyback converter

When making the choice for the secondary side Schottky rectifier, designers have to take care that overall efficiency targets of the application are met and the rectifier meets safety demands regarding breakdown voltages or maximum junction temperature limits.

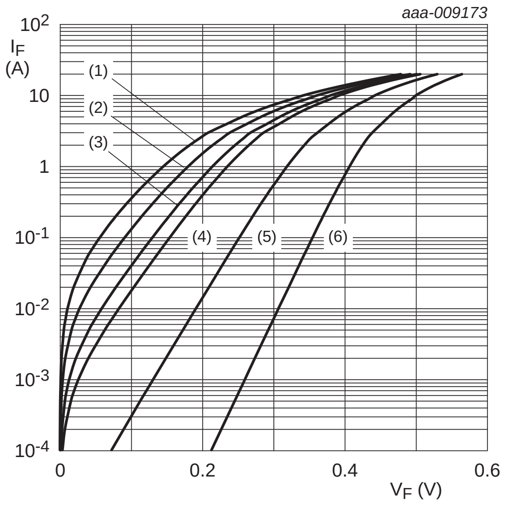
The parameters that influence adapter efficiency, device temperatures and safety demands in a typical application will be discussed in the next chapters, and used to calculate power losses and thermal runaway limits.

4. Forward voltage V_F requirements and forward pulse power losses

The forward voltage V_F of the Schottky rectifier is the main contributor to its power losses in a low power adapter and influences overall efficiency.

When a flyback adapter is active, the junction temperatures of the Schottky rectifier will rise due to power losses. With rising junction temperatures, the forward voltage of the Schottky will decrease, lowering the losses and improving efficiency. To compare the performance of different Schottky rectifiers for a flyback, it is recommended to look at the V_F characteristic at 85 °C junction temperature.

PMEG45U10EPD is a extremely low V_F MEGA Schottky barrier rectifier, especially at elevated temperatures. Figure 2 highlights the decrease of forward voltage drop at higher temperatures:



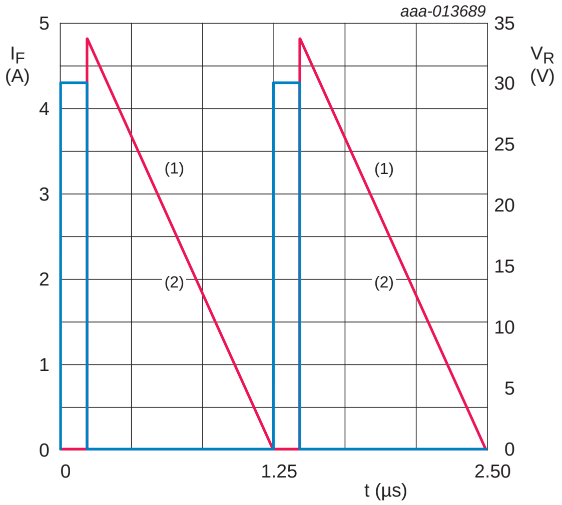
(1) T_j = 150 °C
(2) T_j = 125 °C
(3) T_j = 100 °C
(4) T_j = 85 °C
(5) T_j = 25 °C
(6) T_j = –40 °C

Fig 2. Forward current as a function of forward voltage; typical values

To calculate the power losses of a forward current pulse through a single Schottky rectifier, let's assume a simplified triangular current for a 10.5 W (2.1 A/5 V) flyback adapter with the following operation conditions:

- discontinuous mode (rectifier current drops down to 0 A)
- switching frequency of 80 kHz
- forward duty cycle of 0.875 (on-time)
- triangular forward current shape through the Schottky rectifier
- 30 V reverse voltage
- 85°C to 125°C junction temperature

Figure 3 shows simplified forward current (red curve) and reverse voltage (blue curve) waveforms used to evaluate power losses of a single forward pulse at different temperatures.



(1) Forward current I_F; red curve

(2) Reverse voltage V_R; blue curve

Fig 3. PMEG45U10EPD simplified waveforms in flyback adapter with 2.1 A/5 V output

With a duty cycle δ = 0.875, the peak value for a triangular current waveform in a 2.1 A/5 V flyback adapter is 4.8 A:

$$I_{F(peak)} = I_{F(AV)} \times 2/\delta = \dot{2},1A \times 2/0,875 = 4,5A$$

The forward pulse power losses for a triangular current waveform at different junction temperatures are shown in the Table 1 according to:

power loss of single forward pulse =($I_{F(peak)} \times V_F@I_{F(peak)}$) / 2

Table 2. PMEG45U10EPD forward pulse power at different junction temperatures

T_j; °C	$V_{F(typ)}@I_{F(peak)}$; V	$I_{F(peak)}$; A	Single forward pulse power; W
85	0.325	4.8	0.77
100	0.3	4.8	0.72
125	0.275	4.8	0.66

The simplified current waveform of Figure 3 and the formula above for the forward pulse power loss assume a characteristic of a linear device, for example a resistor. For a linear device, a doubling of forward current would result in a doubling of forward voltage. But a Schottky rectifier is a nonlinear device. When the current rises to higher values, the nonlinear dependence of forward voltage on forward current becomes visible. It causes an over proportional increase of the forward power losses.

The formula above takes the V_F value at $I_{F(peak)}$ to calculate the power losses. In reality, the total power loss of the forward pulse will be a bit lower due to the non-linear characteristic.

The results clearly show, that the forward power loss of the Schottky rectifier is reduced when the junction temperature rises.

5. Maximum requirements of reverse voltage V_R

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

The reverse voltage across the Schottky rectifier in an isolated flyback is related to the winding ratio of the transformer and therefore design dependent. In an typical LPA with 5 V output voltage, around 30 V can arise across the Schottky when the diode is in blocking state.

V_R requirements for an isolated flyback are often calculated by:

$$(V_{R(peak)} / \text{winding ratio}) + V_O + V_F$$

For an adapter connected to 240 V mains (+ 10%) and a typical winding ratio of 15, reverse pulse voltage calculates to:

$$\text{reverse pulse voltage} = 264\ \text{V} \times 1.414 / 15 + 5\ \text{V} = 30.32\ \text{V}$$

To add a safety margin, a minimum of 40 V – 45 V V_R is recommended for a 5 V flyback adapter design with transformer winding ratios of 10 to 15.

6. Reverse current I_R and reverse pulse power losses

The reverse current through the Schottky when in blocking state does not significantly effect the overall efficiency of a flyback adapter, as the energy (excluding small ohmic losses) is stored in the secondary winding of the transformer and reused during the next switching cycle.

But reverse currents influence another important design feature - the junction temperature and with it the thermal runaway limits of the Schottky rectifier.

When the rectifier is in blocking state, the reverse current results in power losses and therefore add to the junction temperature rise. A typical requirement for modern smart phone and tablet charger is a maximum junction temperature of $T_j < 100$ °C at ambient temperature $T_{amb} = 25$ °C.

In addition, one has to take care of the thermal runaway effect. To check, if PMEG45U10EPD runs safe, in the next chapter the power losses of a single reverse current pulse through the Schottky rectifier are estimated for a 10.5 W (2.1 A, 5 V) flyback adapter with 80 kHz switching frequency. A typical condition is a reverse duty cycle of 0.125 and a reverse voltage V_R of 30 V; see Figure 3.

Reverse pulse power is then simply calculated by $V_R \times I_R$. Table 3 shows the results for different temperatures and with typical and maximum I_R values of PMEG45U10EPD. Note, that the maximum I_R limits as shown in data sheets are what suppliers guarantee and these values are hardly found in production. But they will be used to evaluate the worst case scenario.

Table 3. PMEG45U10EPD reverse pulse power at different junction temperatures

T_j; °C	I_R @V_R = 30 V; mA		Single reverse pulse power; W
	typ	max	
85	3	-	0.09
	-	9	0.27
100	12	-	0.36
	-	21	0.63
125	38		1.14
		70	2.1

7. Thermal runaway

When the junction temperature of a Schottky increases, the leakage current increases as well. This effect can result in a commonly known problem called thermal runaway. Increasing temperature causes further increase in temperature until at some point the part is destroyed.

Application can be considered safe, if the rise of power divided by the rise in temperature is smaller than the reciprocal of the thermal resistance from the device junction to the ambient environment $R_{th(j\text{-}a)}$: $\frac{\Delta P}{\Delta T} < \frac{1}{R_{th(j-a)}}$

By using the results from Table 2 and 3, the total power loss P_{tot} of the application can be estimated:

> P_{tot} = (forward pulse power × forward duty cycle) + (reverse pulse power × reverse duty cycle)

To the check the thermal runaway, junction temperature values of 100 °C and 125 °C, at $V_{F(typ)}$ and $I_{R(max)}$, were used, to take the worst case conditions into account. The higher the junction temperature, the higher the leakage currents.

For T_j = 100 °C: $P_{tot} = (0,72W \times \dot{0},875) + (0,63W \times \dot{0},125) = \dot{0},63 + \dot{0},08 = 0,71W$

For T_j = 125 °C: $P_{tot} = (0,66W \times \dot{0},875) + (2,1W \times \dot{0},125) = \dot{0},58 + \dot{0},265 = 0,84W$

The PMEG45U10EPD data sheet specifies $R_{th(j\text{-}a)max}$ = 165 K/W on a single layer standard footprint PCB.

Thermal runaway safety check ($R_{th(j\text{-}a)max}$ = 165 K/W, single layer standard footprint):

$$\Delta P / \Delta T = (0,84W - 0,\dot{7}1W)/(125°C - 100°C) = \dot{0},63 + \dot{0},08 = 0,71W$$

$$1/R_{th(j-a)} = 1/165K/W = 0,0061W/K$$

$$0,0054 < 0,0061 = safe$$

Under the worst case conditions above (maximum I_R, limit at 125°C, maximum $R_{th(j\text{-}a)}$, thermal runaway will not occur with PMEG45U10EPD.

The typical $R_{th(j\text{-}a)}$ found for modern low power adapter is rather in the range of 90 to100 K/W, and not 165 K/W, given for a standardized test PCB in the PMEG45U10EPD data sheet.

With e.g. 100 K/W, the junction temperature on a PCB in free air and under full load calculates to: $T_j = T_{amb} + P_{tot} \times R_{th(j-a)} = 25°C + 0,71W \times 100K/W = 96°C$

8. Efficiency measurement in a 10 W adapter design

The Energy Policy and Conservation Act (EPCA) from the U.S. Department of Energy (DOE) prescribes energy conservation standards for various consumer products, including battery chargers and External Power Supplies (EPSs).

If adopted for power adapters, these standards would apply for products listed in Table 4

Table 4. Energy conservation standards for direct operation and external power supplies (compliance starting February 10, 2016)

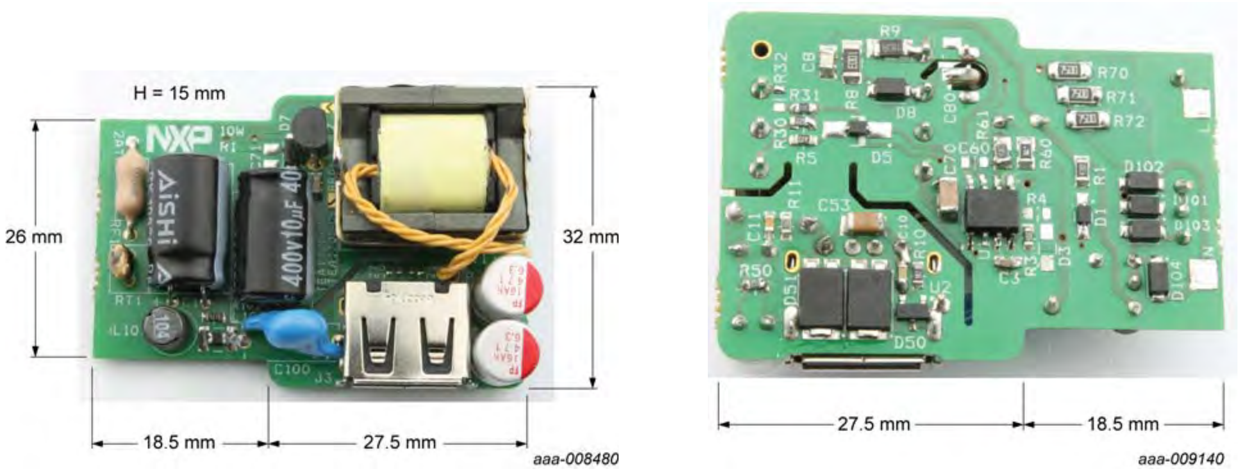
AC-to-DC, low-voltage external power supply		
Nameplate output power P_{out}; W	**Minimum overage efficiency in active mode; as a decimal**	**Maximum power in no-load mode; W**
0 to ≤ 1	≥ 0.517 × P_{out} + 0.087	≤ 0.10
> 1 to ≤ 49	≥ 0.0834 × ln (P_{out}) – 0.0014 × P_{out} + 0.609	≤ 0.10
> 1 to ≤ 250	≥ 0.870	≤ 0.21
> 250	0.875	≤ 0.50

For a 10.5 W (5 V / 2.1 A) battery charger, the minimum average efficiency in active mode calculates to:
≥ 0.0834 × ln(P_{out}) – 0.0014 × P_{out} + 0.609 =
= 0.0834 × ln(10.5) – 0.0014 × 10.5 + 0.609 = 0.7904; i.e. an efficiency of > 79%.

Efficiency measurements were performed in a 10 W NXP Semiconductors flyback power adapter, using TEA1720B3T Switched Mode Power Supply (SMPS) controller IC with two PMEG45U10EPD in parallel configuration as secondary side rectifiers.

TEA1720B3T is a small and low cost SMPS controller IC for low-power applications (up to 12.5 W) and operates directly from the rectified universal mains input.

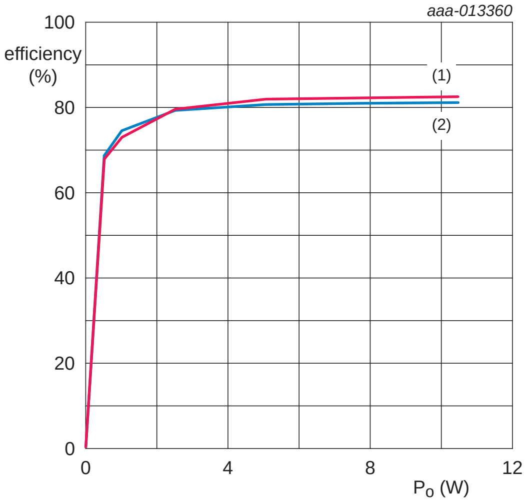
For more information regarding TEA1720B3T adapter application, refer to Ref. ”User manual UM10724”, which describes a 10 W Constant Voltage/Constant Current (CV/CC) universal input power supply for tablet adapters or chargers.



a. Top view

b. Bottom view

Fig 4. TEA1720B3T 10 W demo board; top and bottom view



(1) 230 V AC; red curve

(2) 115 V AC; blue curve

Fig 5. Efficiency results of a 10 W flyback power adapter with PMEG45U10EPD

With this design, efficiency levels > 80% are reached, measured at the adapter output. According to DOE, the average efficiency should be taken from the efficiencies from 25%, 50%, 75%, and 100% load. At V_{rms} = 230.9 V, the average efficiency of the design above is 79.8%, i.e. greater than the target of 79%.

9. Conclusions

The 10 A/45 V rated Schottky barrier rectifier in CFP15 (SOT1289) package PMEG45U10EPD is an ideal choice for smart phone and tablet charger up to 12.5 W output power in non-synchronous flyback topology.

Extremely low V_F at higher junction temperatures helps to reach efficiency levels of > 80% in a typical charger, meeting latest DOE standard requirements. The slim CFP15 package offers low thermal resistance and high power density to support small designs, while the Schottky case temperature will stay < 100 °C and thermal runaway is well under control.

10. References

[1] **User manual UM10724** — TEA1720B3T and TEA1705 10 W EVD15 demo board

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