POWERpuzzler

Understanding the Effects of Diodes

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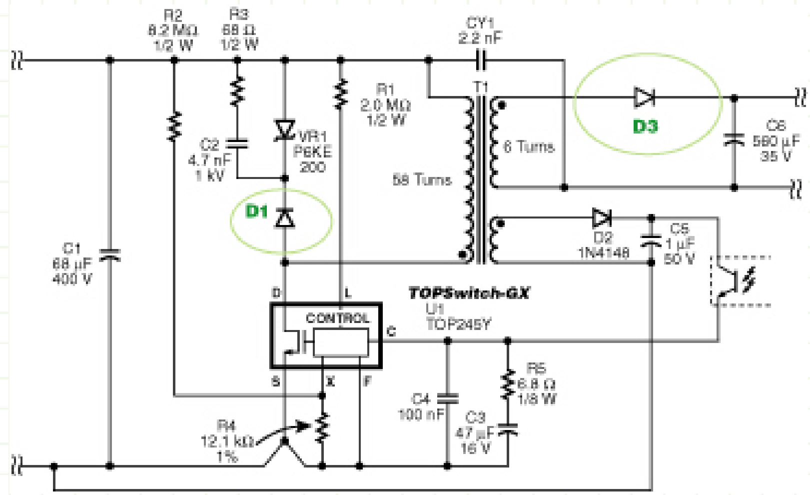
The schematic below shows a Flyback power supply built with a *TOPSwitch*® *-GX* power conversion IC. The following questions concern the selection of the output diode (D3) and the clamp diode (D1).

Question 1: beginner

Which diode or diodes from the following list are suitable for use as D3 and why?

a. 80 V, 5 A, Schottky (e.g. SB580)
b. 600 V, 3 A, Ultrafast (e.g. UF5406)
c. 50 V, 3 A, Rectifier (e.g. 1N5400)
d. 100 V, 8 A, Ultrafast (e.g. BYV29-100)
e. 45 V, 7.5 A, Schottky (e.g. MBR745)
f. 1000 V, 2.5 A, Fast (e.g. FR257)

Click to see the Answer



Input: 90-375 VDC
Output: 12 V, 2.5 A

Answer: a and d

Diode	Diode Parameters	Suitability of Diode Parameters		
		Peak Reverse Voltage (V_{RRM})	Average Forward Current (I_{AVE})	Reverse Recovery Time (t_{rr})
(a) SB580	80 V, 5 A	X	X*	X
(b) UF5406	600 V, 3 A, 75 ns	X	-	-
(c) 1N5400	50 V, 3 A, 2000 ns	-	-	-
(d) BYV29-100	100 V, 8 A, 25 ns	X	X	X
(e) MBR745	45 V, 7.5 A	-	X	X
(f) FR257	1000 V, 2.5 A, 500 ns	X	-	-

* With bench verification of temperature rise

Why?:

In selecting the output rectifier three key parameters should be considered; voltage rating, current rating and reverse recovery time.

Considering each of these in turn we can see which of the diodes is suitable.

Maximum repetitive reverse voltage (V_{RRM})

Ideally the diode selected should have a V_{RRM} rating 1.25 · V_R, where V_R is the reverse voltage seen by the diode. The 1.25 de-rating factor provides margin to take account of leakage inductance generated voltage spikes, and AC line transients that increase the DC bulk voltage temporarily plus reducing the device stress improves reliability.

Normally where people get into trouble is determining the value of V_R. You ' d be forgiven for thinking that the reverse voltage seen by the diode is just the output voltage, here 12 V so anything above a 15 V diode would be fine. However the anode of D3 is connected to a Flyback transformer. This means that when the MOSFET inside U1 turns on, under maximum input line of 375 VDC (265 · VAC x √ 2) is seen across the primary. This voltage is transformed by the primary to secondary turns ratio and due to the phase of the windings drives the anode of the output diode negative. In this design the value of V_R is given by:

$$V_R = V_O + (V_{MAX}) \cdot (N_S/N_P)$$

这个公式是很重要的，在MOSFET导通的瞬间，
初级有一个电势会耦合到次级， 和输出滤波电容器两端
电压成串联叠加 D3
两端。

$= 12 + 375 \cdot 6/58$

$= 50.7\ V$

Applying the 1.25 V de-rating this gives a minimum diode rating of 63 V. The closest standard diode rating would be an 80 V Schottky or a 100 V PN diode.

Therefore all the diodes have an acceptable V RRM rating except (c) and (e).

这句话的意思是1N54系列： 从厂商提供的降额曲线来看3A的管子在引线周围温度为100摄氏度时实际上最多只能通过1.5A的平均电流。

Forward Current Rating (I_{AVE})

Diodes manufacturers generally specify the current rating as the average current through the diode or for a Flyback power supply the load current. In this design the specified output current is 2.5 A so a diode with a current rating above 2.5 A is acceptable right? Yes and no.

- The diode manufacturers provide de-rating curves so for example at a lead temperature of 100 ° C a 3 A PN diode is actually a 1.5 A diode!
- Diode type. The choice between PN and Schottky and the actual voltage rating changes a diode ' s forward voltage. The lower the forward voltage drop, the lower the dissipation is for a given forward current.
- Overload fault conditions. All power supplies have some degree of overload capability. Due to tolerances a typical supply will be able to deliver significantly more than the specified output power, especially at high line. Therefore if an overload condition can exist then the diode should be sized to operate without overheating and failing. Products from Power Integrations significantly help here as the key parameters associated with power delivery (frequency and current limit) are very tightly specified, reducing the overload power. In addition line voltage power limiting is easy to add to reduce overload power. In this example the addition of R2 reduced the primary current limit as the line voltage increases and provides a very flat overload power characteristic with line voltage as shown below.

As a general rule of thumb select the current rating such that $I_{AVE} = 3 \times I_O$ irrespective if the diode is a PN or a Schottky type (although a Schottky diode will have lower dissipation check the maximum operating temperature – some are 25-50 ° C lower than a PN diode). Finally measure the diode temperature under maximum overload power, highest ambient to check it is within either internal or manufacturers design limits.

Looking at the diodes in the list to determine if they are acceptable or not:

Diode	Rated I_{AVE}	Acceptable?	Notes
(a) SB580	5 A	Yes - based on bench verification	I_{AVE} is only $2 \times I_O$ it ' s a Schottky diode has a maximum temperature specification of 150 C and used in a supply with power limiting (R2 and R4 in schematic) so it ' s likely this diode would be acceptable.
(b) UF5406	3 A	No	I_{AVE} is only 1 or $1.2 \times I_O$ - diodes would overheat
(c) 1N5400	3 A	No	
(f) FR257	2.5 A	No	

(d) BYV29-100	8 A	Yes	I_{AVE} is $\geq 3 \times I_O$ and in a TO220 package. When attached to a suitable heatsink this diode is a good choice.

So diodes (a), (d) and (e) have an acceptable current rating but if you ruled out (a) that would also be ok.

Reverse recovery time (t_{rr})

An ideal diode would instantly block reverse current flow when a reverse bias is applied. In practice a Schottky approaches zero recovery time however for a PN diode it takes a finite time for charge stored in the diode to be swept away before it can block. The amount of charge is proportional to the current flowing through the diode.

This is significant as even a Flyback converter operating in discontinuous conduction mode will actually operate in continuous conduction mode at start-up meaning the output diode has to reverse recover with a significant forward current flowing. In this design the converter operates in continuous conduction mode some the diode has to recover with forward current on every switching cycle.

To prevent large reverse currents from flowing through the diode when the MOSFET in U1 turns on, applying a reverse voltage, the diode should have a reverse recovery time less than switching time. This means a recovery time of 50 ns or better.

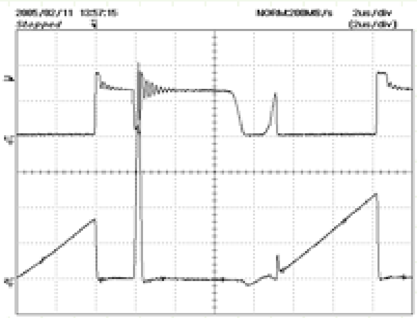
Longer duration than this causes large primary side current spikes at the turn on event and high diode dissipation – for example the 1N5400 became hot enough to melt the solder holding into the PCB while taking the measurements for question 2.

Diode	t_{rr}	Acceptable?	Notes
(a) SB580	0	Yes	
(b) UF5406	75 ns	No	
(c) 1N5400	-	No	Not specified but >>2000 ns
(f) FR257	500 ns	No	
(d) BYV29-100	25 ns	Yes	
(e) MBR745	0	Yes	

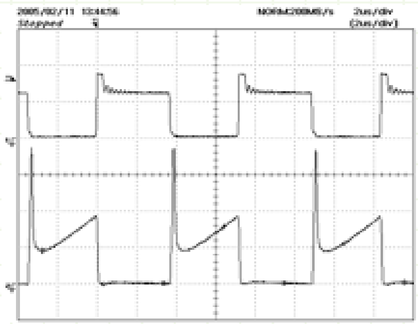
So diodes (a), (d) and (e) have an acceptable reverse recovery time.

Question 2: advanced

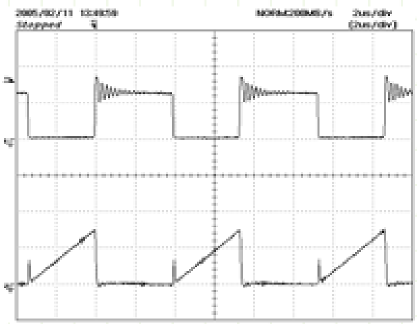
Below is a series of oscillograms showing the drain voltage (V_{DS}) and current (I_D) of U1, measured with the different diodes listed in question 1*. Can you match the resultant waveforms to the diode(s) that generated them?



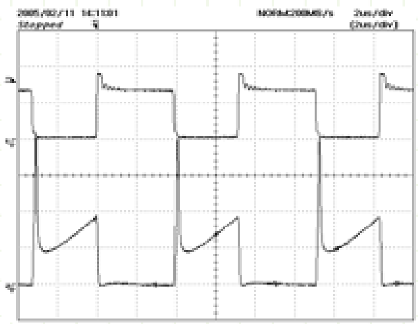
Waveform 1: ________



Waveform 2: ________



Waveform 3: ________



Waveform 4: ________

*Test Conditions: 1.5 A load @ 115 V AC; Upper Trace V_{DS}=100 V/div; Lower Trace I_D=0.4 A/div, 2 µs/div

Click to see the Answer

Answer:

Waveform	Associated Diode
1	(C) 1N5400
2	(B) UF5406s
3	(A) SB580, (D) BYV29-100 and (E) MBR745
4	(F) FR257

对第一个波形，那电流尖峰的时间是ontime的开始，因为过了current limit，220ns后被turn off而已

Why?: As discussed for question 1, as the reverse recovery time of the diode increases so does the magnitude of the reverse current. This current is transformed according to the turns ratio of the transformer and results in a large drain current spike when the *TOPSwitch* turn on. Accordingly the slowest diode, the 1N5400 causes the largest spike – large enough to trigger the internal *TOPSwitch* current limit at the end of the 220 ns leading edge blanking time. 第一个波形

This waveform also shows the effect of the diode forward current on reverse recovery time. The next switching cycle occurs normally with almost no current spike, as there is no current flowing in the diode when it is reverse biased. As no energy was stored in the transformer due to the early termination of the switching cycle all the energy in the transformer is transferred to the load and the diode current falls to zero. 第 3 个波形

Next is sequence is the FR257, and the UF5406 both which have unacceptably high reverse currents. With a turns ratio of 58:6 the FR257 allowed a reverse current of 15.4 A (1.6 x 58/6) to flow during reverse recovery. This explains why this and all the slow diodes would have been destroyed had the test been longer than a few seconds. 第 2 和第 4 个波形

The 25 ns reverse recovery of the BYV29-100 diode produces identical results to the Schottky – the spike now seen is purely due to parasitic capacitance, largely the capacitance of the primary winding. 用反向恢复时间只有25ns的BYV和肖特基结果是一样的，这有一点电流尖刺纯粹是初级绕组的分布电容引起的。

Question 3: expert

Selecting diodes with different recovery times for the clamp diode D1 has an interesting effect. The table shows the measured input power and resultant efficiency for the different diode tested. Can you explain the changes in efficiency and why the rectifier diode must be glass-passivated?

Diode	P_{IN} (W)	P_{OUT} (W)	η (%)
UF4005	36.18	30.23	83.6
1N4937	36.07	30.23	83.8
1N4007GP*	35.92	30.23	84.2
*Glass Passivated			

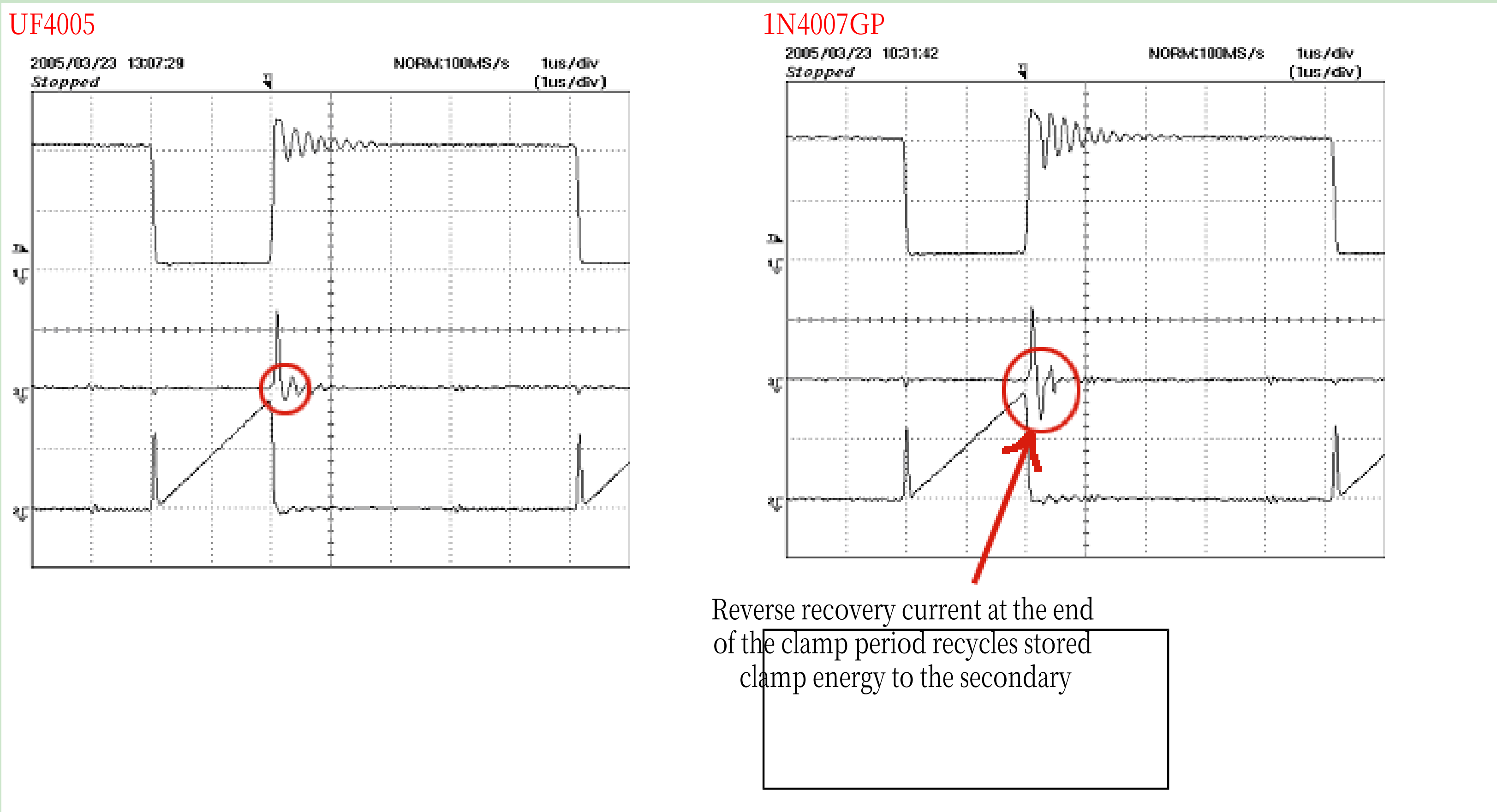
Click to see the Answer

Answer: Diode reverse currents effectively recover some of the leakage inductance energy stored in the capacitance of the clamp. The longer the recovery time, the more energy is recovered.

Why?: The two oscillograms below show the drain voltage (upper, 200 V/div), drain current (lower, 0.4 A/div) and the current through the clamp diode, D1, for both a UF4005 and 1N4007GP (middle, 0.4 A/div).

The slower recovery time of the 1N4007GP causes a reverse current to flow back through the primary winding at the end of the clamping period. This partially discharges the leakage energy stored in clamp capacitor, C2, and transfers some of the energy stored to the secondary, thus improving efficiency.

It might appear that the ideal diode would be very slow to maximize this effect. However, to prevent excess diode dissipation, to limit drain ringing for EMI reasons, and to prevent the drain ringing below the source at low line, the diode must have a specified recovery time. A small value series resistor is also required to limit ringing. In this case R3 acts as the damping resistor. This resistor can also be placed directly in series with D1. The 1N4007GP is a glass passivated version of the 1N4007, with a reverse recovery time specified at 2 us. The 1N4007 does not have a specified recovery time and must not be used.



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