Application Report
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Choosing Standard Recovery Diode or Ultra-Fast Diode in Snubber

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ABSTRACT

While using a Snubber circuit is very common for flyback design, suppressing the stress of MOSFET is not the only design consideration for snubber. The Snubber circuit will also impact the efficiency, standby power, and EMI performance. This paper reviews the working principle of snubber and illustrates the diode selection for RCD/R2CD and TVS Snubber.

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1 Snubber Circuit in Flyback

Flyback topology is widely used in low-power applications because of its simple structure, low component count, and low cost. However, after the MOSFET turns off, there is high voltage stress on the drain-source of MOSFET. To protect the MOSFET, a Snubber circuit is needed to suppress the stress.

Figure 1 is a typical Flyback circuit without a primary snubber circuit. When MOSFET Q1 is turned on, the current going through the primary of transformer will increase linearly. The primary current will be equal to $\frac{Vin \times Ton}{Lp}$ when the MOSFET is turned off, where Vin is the input voltage, Ton is the on time of MOSFET, Lp is the sum of magnetic inductance Lm and Leakage inductance Lk. When MOSFET is turned off, Ip will continue to charge into Cp + Coss, where Cp is the primary winding capacitance in the transformer and Coss is the drain to source capacitance of the MOSFET, until the voltage on the secondary-side of the transformer reaches to Vo + Vf, where Vo is the output voltage, Vf is the sum of forward voltage of rectifier

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and the voltage drop on the resistance of secondary. At this moment, the energy stored in the Lm will begin to transfer to secondary. However the energy stored in Lk will resonate with Cp+Coss at a fixed frequency $\frac{1}{2\pi\sqrt{Lk(Cp + Coss)}}$. If there is no snubber circuit, the voltage stress will be very high. Its peak value could reach to $\left(Ip\sqrt{\frac{Lk}{Cp + Coss}} + Vin + \frac{(Vout + Vf)}{N}\right)$. This very high spike could cause bad EMI or even destroy the MOSFET. It would be worst at maximum Ip and Vin.

To suppress the spike, the usual way is to use an RCD snubber like in Figure 2.

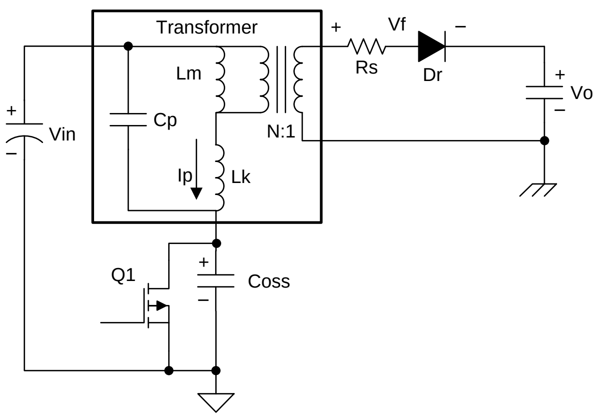

Figure 1. Flyback Circuit Model Without Snubber

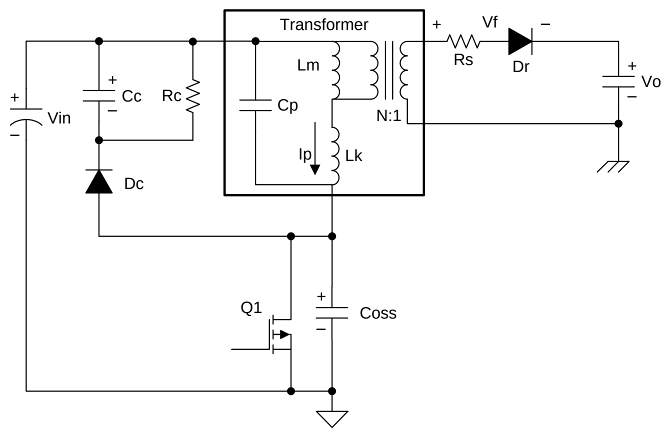

Figure 2. Flyback Circuit With RCD Snubber

2 RCD and R2CD Snubber

For the low-power flyback applications, more and more engineers like to use the standard recovery diode instead an ultra-fast diode in the Snubber circuit. They often have another damping resistor series with the clamp diode to damp oscillations due to parasitic resonance. The effect of the standard diode's reverse recovery profile is difficult to calculate quantitatively because its model is not clear in the spec. However using standard recovery diodes has benefits for efficiency and EMI performance.

The energy stored in the clamp capacitor will be discharged by the resistor in parallel with it. After an ultra-fast recovery diode stops conducting current, there is still a resonance between Lk, Cp, and Coss. This is a damped resonance as in Figure 3, for some of the energy is dissipated in the resistance of the circuit and some of it is transferred to the secondary [1].

But if the snubber is implemented with the standard recovery diode, it has a relatively long trr – usually from 0.5 µs to several µs. The trr is usually longer with higher voltage rating. Because the standard recovery diode will conduct negative current, the energy stored in the clamp capacitor can also participate in the resonance with Lk, Cp, and Coss. From Figure 4, we can see the voltage across the clamp capacitor decreases quickly, caused by the slow reverse recovery of the standard diode. In this case, most of energy takes part in the resonance and some of it will be transferred to the secondary causing less power loss than that of resistance discharge with ultra-fast diode. The efficiency could be better with standard diode than with an ultra-fast diode.

When using a standard recovery diode as the clamp diode, the value of resistor paralleled with the clamp capacitor could be much higher than with an ultra-fast diode. Another side, the choice of the resistor value should ensure that the voltage across the clamp capacitor is always higher than N(Vo + Vf), or else it will dissipate some energy from the transformer.

The ringing of using standard diode is better than using ultra-fast because with an ultra-fast diode, the ringing has higher amplitude and higher frequency. So the EMI performance should be better with the standard recovery diode.

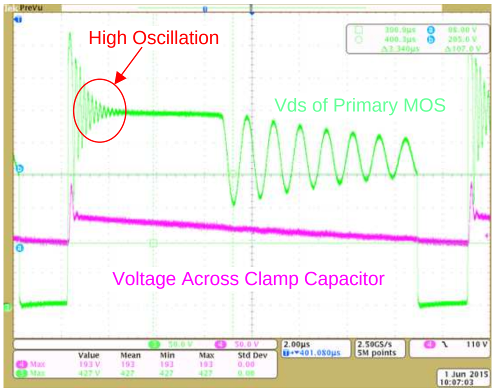

Figure 3. Vds and Voltage Across the Cc Using US1M-E3

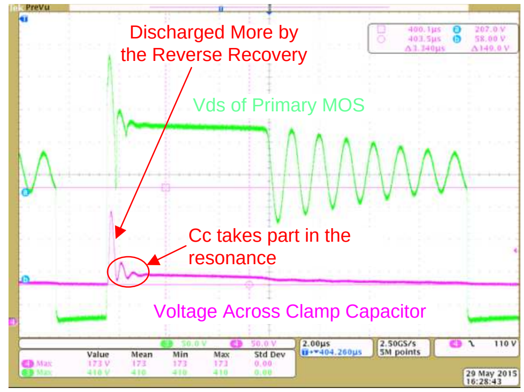

Figure 4. Vds and Voltage Across the Cc Using 1N4007

As previously explained, when using a standard diode, Cc, Lk, Coss, and Cp all participate in the resonance. A second resistor Rd can be added to damp the ringing as in Figure 5. The structure is called R2CD snubber. The choice of Rd value is to damp the Lk-Cc resonance with a Q that is between 1.7 and 2.2[1].

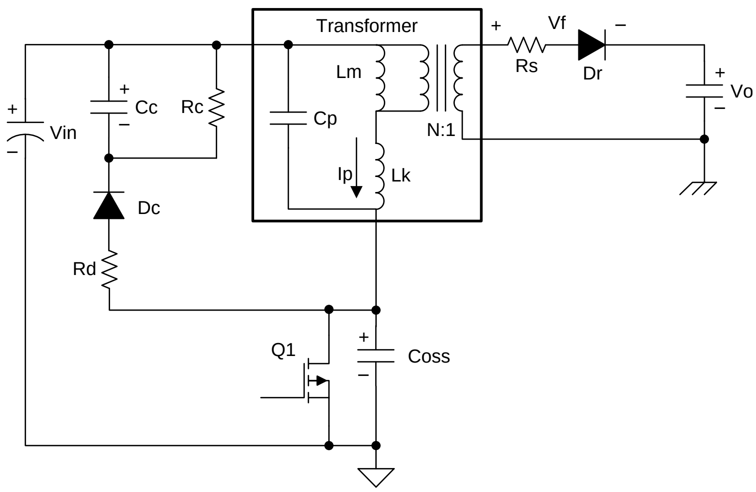

Figure 5. R2CD Snubber

3 TVS Snubber

Figure 6 illustrates the UCC28740EVM-525 using a TVS snubber.

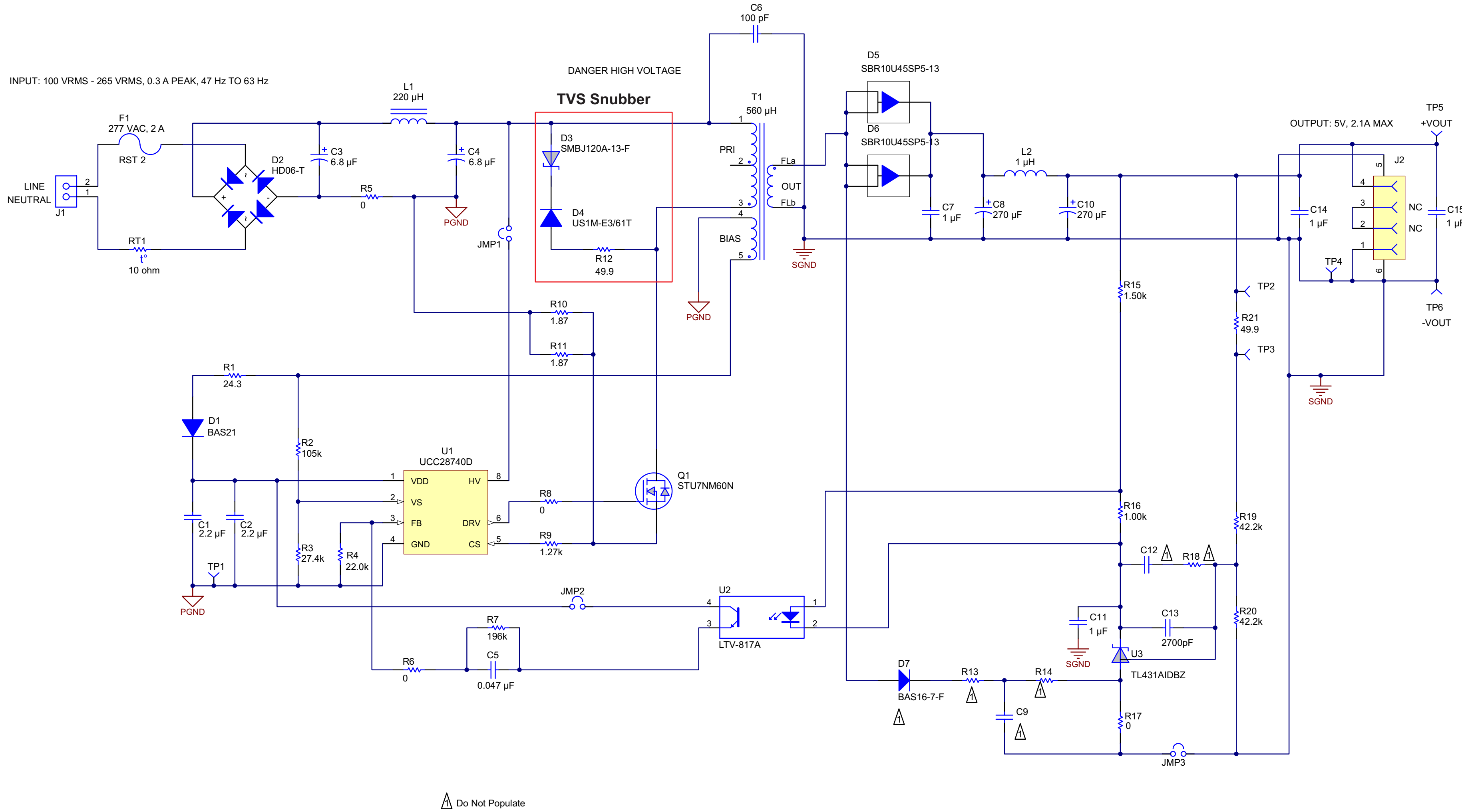

Figure 6. UCC28740EVM-525 Using TVS Snubber

In some applications, it is advantageous or even necessary to use a TVS snubber instead of an R2CD snubber. To get the TVS snubber, we change the clamp capacitor in R2CD snubber to TVS and remove the parallel resistor, as in Figure 6. The TVS snubber has a higher cost than R2CD. However, there is a growing need for the ultra-low standby power in the market, and a TVS snubber has an advantage for this application. It could help achieve higher efficiency in zero load and light load, for it will not dissipate power before the voltage at its cathode reaches Vin + V_{RWM}.

In addition to that, the choice of clamp diode is very important. The improper choice could cause an efficiency drop and improper Vds waveforms. We use UCC28740EVM-525 for the test as in Figure 6; the comparison is tested between Standard recovery diode 1N4007 and ultra-fast diode US1M-ES. UCC28740 is TI's new valley-switching controller to get high overall efficiency. The test condition is to apply 230-V DC on the bulk capacitor. If we look at the Vds waveforms in Figure 7 and Figure 8, we can see the difference between the two kinds of diodes. Using 1N4007 has a flat Vds before MOSFET is turned on.

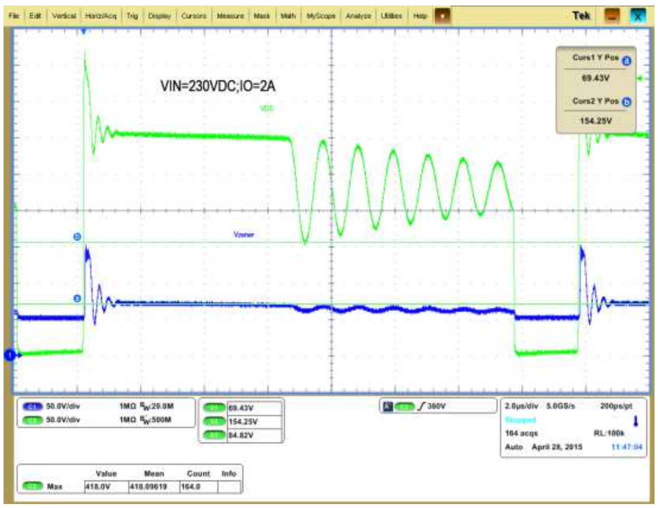

Figure 7. Vds and Voltage Across TVS Using US1M-ES

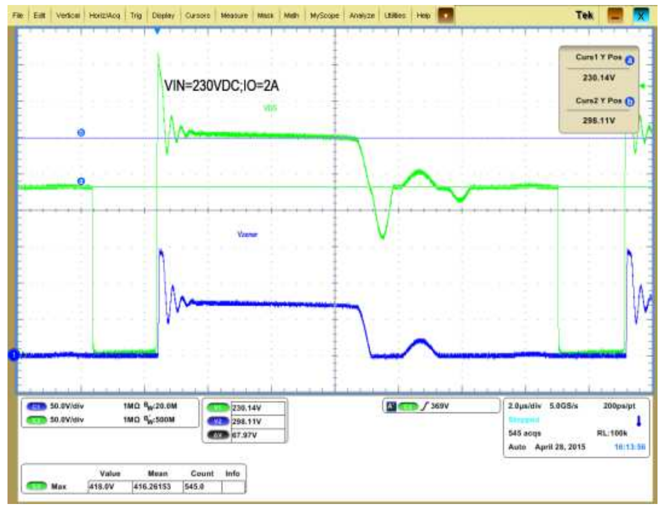

Figure 8. Vds and Voltage Across TVS Using 1N4007

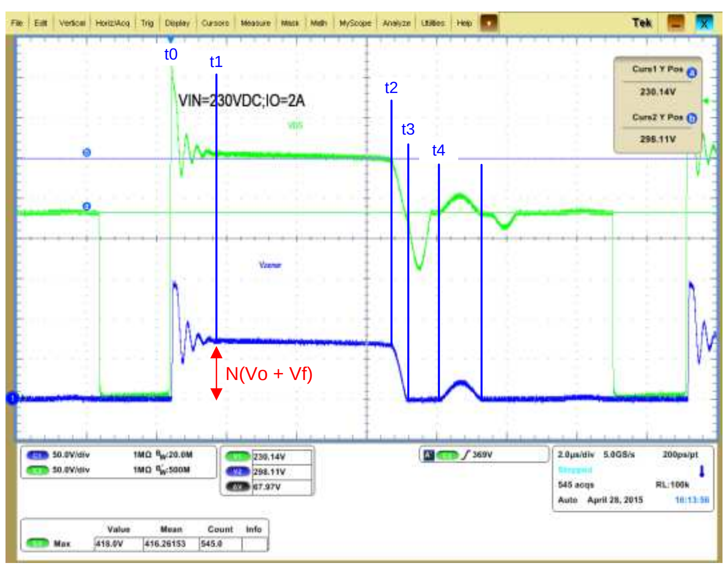

Figure 9. Waveforms Using 1N4007(CH1: Vds; CH3: Voltage Across TVS)

3.1 Process of the Quick Decaying Resonant

To understand the reason why using 1N4007 loses the “valley”, we could zoom in the waveform in Figure 9.

t0, MOSFET is turned off; the total drain capacitance is charged by I_{LK}. I_{LK} is the current in the primary leakage inductance.

t0–t1, The parasitic capacitor of the TVS resonates with Cp, Coss, and Lk, and its voltage goes down to N(Vo + Vf) because of the longer trr of 1N4007.

t2, the current in secondary diode goes to zero. The parasitic capacitor of TVS, Cp, Coss, Lk, and Lp starts to resonate.

t2–t3, because of the very low energy stored in TVS before t2 (the Cj of SMAJ120A is bout 30 pf at VR, according to its datasheet), and long trr of 1N4007. The voltage across TVS is resonated to zero.

t3–t4, still in the resonance. When the capacitor of TVS is discharged to zero, the TVS is in forward conduction by its diode characteristic. So Vin takes part into the resonance, and makes the resonance decay quickly.

After t4, the resonance vanishes in a few cycles, and the voltage on Vds stays flat at Vin. For ICs which have valley switching characteristics, it loses the benefits of valley switching.

An efficiency test was done on the EVM board with these two kinds of diodes. We can see the efficiency is lower with 1N4007 in Figure 10. The efficiency was tested with 230-V DC input.

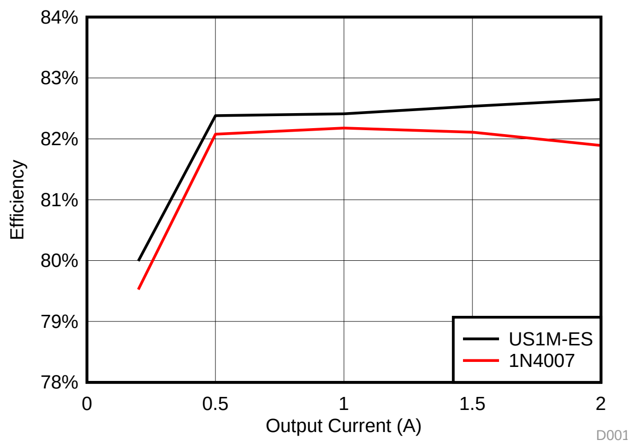

Figure 10. Efficiency Comparison of UCC28740EVM Using US1M and 1N4007

The working frequency of UCC28740EVM is about 70 kHz at full load. We calculate the delta efficiency from operating differences. As in Figure 7 and Figure 8 showed, the Vds voltage before MOSFET turn-on is different. For 1N4007, it is 230 V, For US1M-ES it is 200 V. The MOSFET used is STMicroelectronics®' STU7NM60N, from its datasheet the output capacitance stored energy are 0.55 µJ and 0.7 µJ. So we calculated the delta switching loss at MOSFET turn on to be about (0.7–0.55) µJ × 70 kHz = 10.5 mW. (This loss will be higher at higher input voltages.)

Another power loss difference is in the energy stored in the resonant circuit after the secondary current goes to zero. This energy with 1N4007 is all dissipated in the circuit, but with US1M-ES, it is only partly dissipated since the resonant oscillation still exists before the turn-on of primary switch. With 1N4007, the peak current on Rd measured is about 40 mA in the resonance which also goes through the primary inductance.

Other power loss differences include the energy sinked from Vin by the snubber when the TVS is forward-conducting due to the reverse recovery current of the 1N4007.

4 Conclusion

The following conclusions are made based on the information provided in this application report:

1. In low power offline flyback application, using standard recovery diode in the RCD/R2CD snubber can help get higher efficiency and better EMI than using an ultra-fast diode.
2. A resistor in-series with the clamp diode is suggested to suppress the ringing in R2CD snubber circuit.
3. A TVS snubber is fit for those applications which need very low standby power. But in these cases, the clamp diode should use the ultra-fast diode to avoid significant efficiency drop.

5 References

1. Liu Shunlin, Cao Xiaosheng and Ma Yibo, *Design and Analysis on Feedback Energy Loss of RCD Clamping Flyback Converters*, Proceedings of the CSEE, 2010-33
2. UCC28600 Datasheet (SLUS646J)

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