AN-6203

Applying SG6203 to Control a Synchronous Rectifier of a Flyback Power Supply

Abstract

This application note describes a detailed design strategy for a high-efficiency compact flyback converter. Design considerations and mathematical equations are presented. A 12V, 120W evaluation board is built to evaluate the performance improvement by the SG6203.

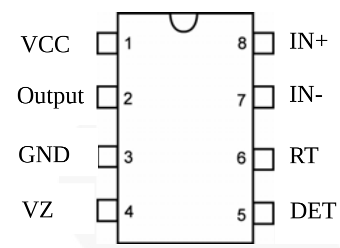

Figure 1. SG6203 Pin Configuration

Description

Generally, the conduction loss of the output diode is the dominant loss component in low output voltage power supplies. This loss can be reduced by using a low on resistance MOSFET. Improved efficiency can be obtained and a smaller heat sink can be used.

The SG6203 is designed to control and drive the synchronous rectifier for the flyback converter. The synchronous signal of the primary switch is obtained by a single diode connected between the transformer secondary winding and the SG6203. Using the SG6203, no additional transformer winding is required and the circuit complexity can be minimized.

In heavy load conditions, the flyback converter is usually designed to operate in continuous conduction mode (CCM) to have higher efficiency. To prevent the so called “shoot through” or “cross conduction” problem in synchronous rectifier applications, one external resistor and an internal automatic tracking circuit is used to program a suitable dead time for the primary switch and the synchronous rectifier.

On the other hand, the converter enters discontinuous conduction mode (DCM) in light load conditions. To improve light load efficiency, the synchronous rectifier is turned off when the stored energy in the transformer is fully released to the output. This feature can prevent reverse energy flow and green-mode PWM IC in the primary side can be used. To detect the secondary current flow and determine the driving signal for the synchronous rectifier, a current shunt or RC network for the output capacitor can be used. An RC network is recommended for better efficiency.

Detailed operation and application information are presented in the following section. A 12V, 120W evaluation board using the SG6203 is built and the performance is measured on this unit to show its improvement on the efficiency.

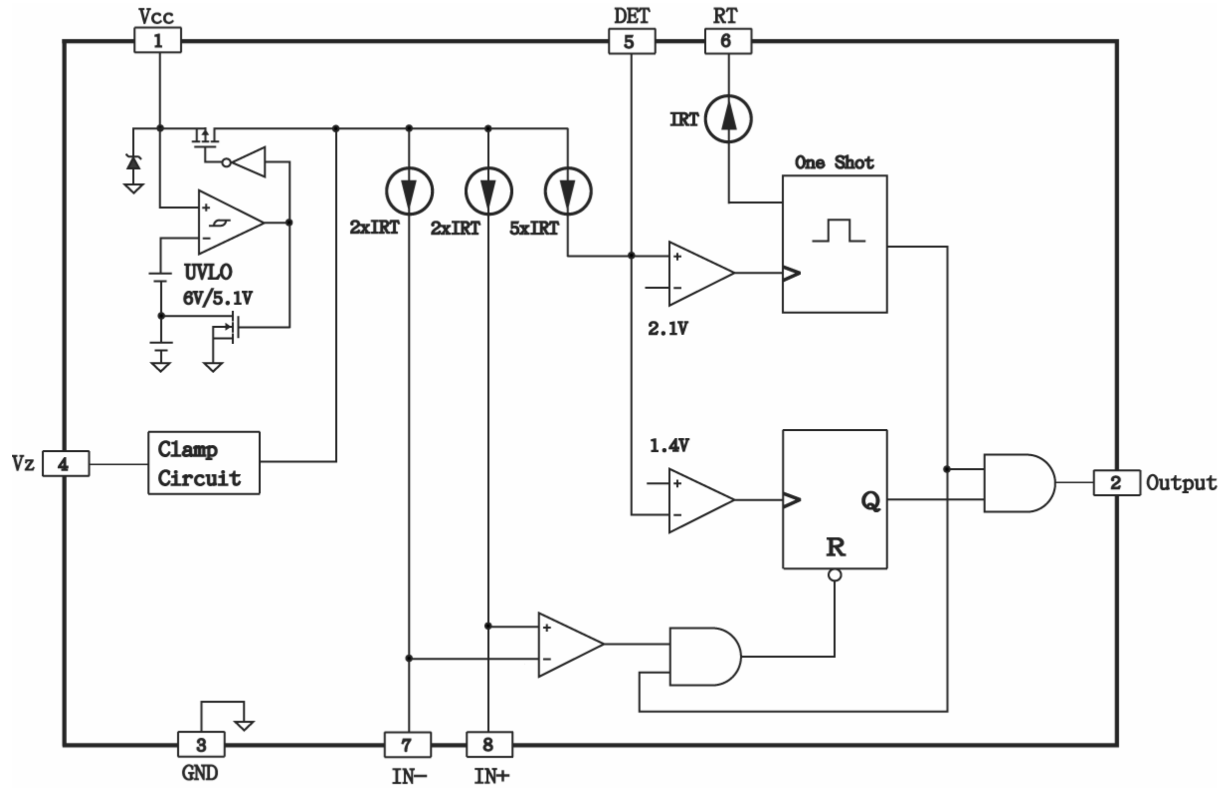

Figure 2. Block Diagram

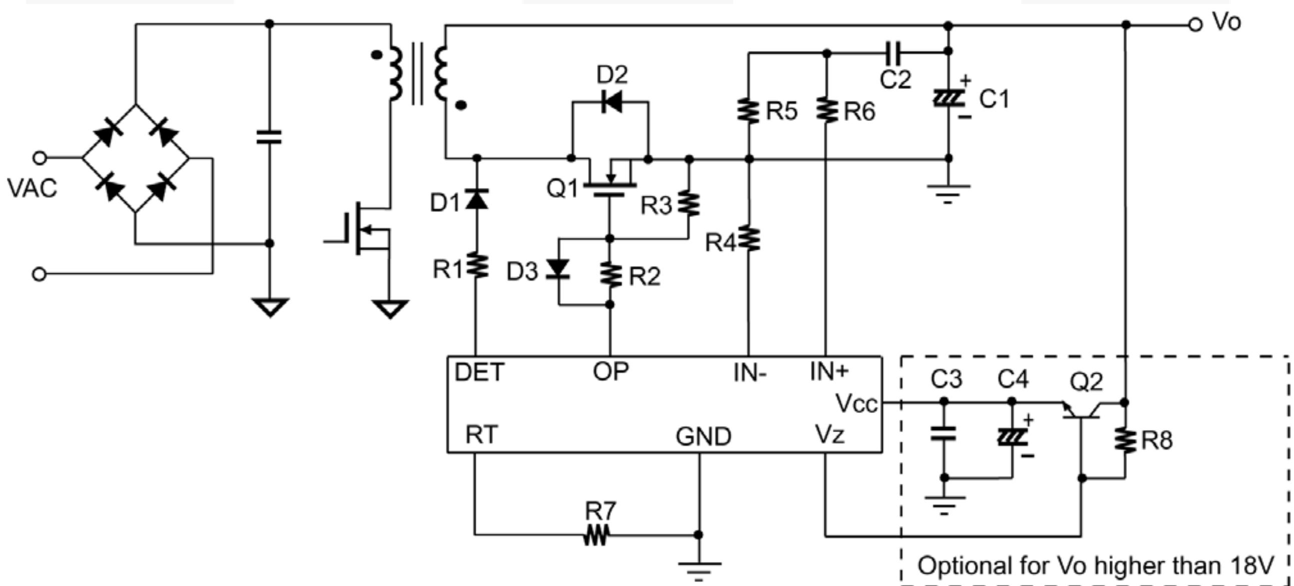

Figure 3. Circuit Configure to Obtain the Primary Switch Synchronous Signal

Synchronization

To achieve proper control of the synchronous rectifier in the secondary side, the switching timing signal of the primary switch should be obtained from the transformer secondary winding. As shown in Figure 3, a detecting diode connected from the DET pin to the transformer secondary winding is used to detect the on/off information of the primary switch. Once the primary switch turns on, the voltage on the cathode of the DET diode is high enough to push the DET diode to reversed state. The high level on the DET pin initializes an internal one-shot signal to mark the beginning of a new switching cycle.

While the primary switch turns off, the voltage on the primary switch starts to increase. Meanwhile, the secondary winding voltage begins to reverse accordingly. Once the voltage on the secondary winding is large enough to forward conduct the rectifier diode, D2, the energy stored in the transformer starts to release to the secondary side. At that time, the DET diode turns to forward-biased and the LOW level is on the DET pin. Once the DET pin reduces to LOW and the one-shot signal keeps HIGH status, the SG6203 output stage becomes HIGH to drive the external synchronous rectifier.

The high duration of the internal one-shot signal is programmed by an external resistor between the RT and GND pins. An internal automatic tracking mechanism automatically extends the original one-shot signal to a maximum of 180% to have a suitable dead time between the primary switch and the secondary synchronous rectifier in continuous conduction mode (CCM). This results in better efficiency improvement than a fixed dead time mechanism. The duration of this one-shot signal can be expressed as:

$$t = \frac{15 \times RT(K\Omega)}{24}(\mu s) \qquad (1)$$

If the resistor is too small, the synchronous rectifier may be turned off while the secondary rectifier diode is still conducting, decreasing efficiency. If the RT resistor is too large, there is no dead time. The output of the SG6203 shuts off immediately once the voltage on DET pin goes HIGH before the one-shot signal reduces to LOW. The target value for the RT resistor is to set the original one-shot signal to around 75%, compared to the primary PWM period.

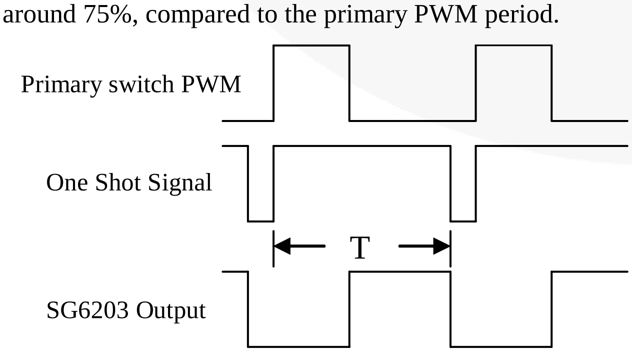

Figure 4. Timing of the One-shot Signal

Continuous Conduction Mode (CCM)

When the flyback converter operates under CCM, the secondary rectifier diode does not turn off until the primary switch is turned on. Therefore, an anti-shoot-through mechanism is needed to prevent the cross conduction of the primary switch and the secondary synchronous rectifier. To achieve this, an internal automatic tracking circuit maintains a suitable dead time under CCM conditions.

Discontinuous Conduction Mode (DCM)

When operated under DCM, the energy stored in the transformer during the on time of the primary switch is completely released during the subsequent off time. Therefore, the secondary current reduces to zero before the primary switch is turned on. To prevent the discharge of the output capacitor through the conducting synchronous rectifier, the synchronous rectifier must be terminated once the secondary current reaches zero or shortly thereafter. Accordingly, a zero current crossing detector is needed when the converter is operated under DCM. To achieve this, two different configurations can be used: a current sensing resistor method and an output capacitor ESR method.

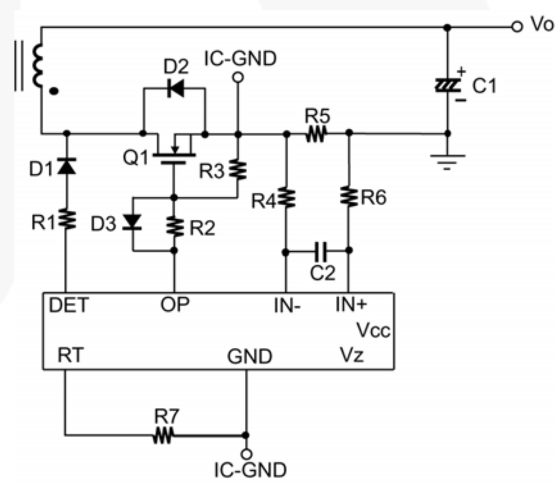

Figure 5. Current Sensing Resistor Method

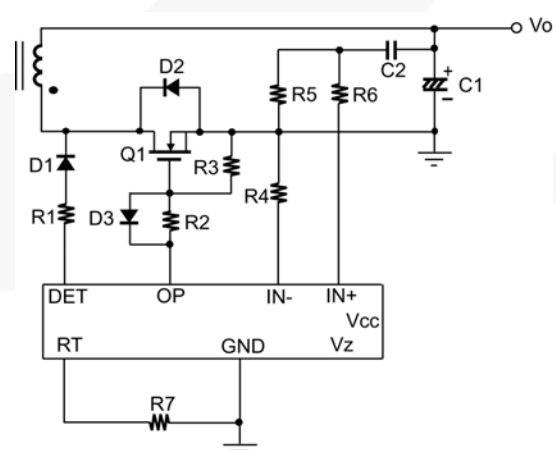

Figure 6. Output Capacitor ESR Method

As shown in Figure 5, a current sensing resistor, R5, is used to sense the secondary winding current. This sensing resistor must be placed within the current rectifier loop (ns→C1→D2), but not after C1. This is different from the usual secondary over-current protection application, which puts a current sensing resistor after C1 and a DC value that represents the output loading is obtained. Here, the need is for the discharging current waveform to obtain the zero current crossing timing signal. Once zero current crossing occurs, the voltage on IN+ is lower than that on IN- and the driving signal for the synchronous rectifier is turned off to prevent the excessive energy circulating between the primary and secondary.

The internal current I_{IN+} and I_{IN-} from IN+ and IN-, respectively, results in a DC value on these two pins. Adjusted external resistors connected outside IN+ and IN- can modulate the turn-off current level of the synchronous rectifier. To prevent switching noise interfering with the comparator operation, an external capacitor with 2.2nF to 4.7nF is recommended between the IN+ and IN- pins.

Figure 6 shows another current sensing method. This method uses a high pass RC (R5 and C2) network to capture the discharging current waveform of the secondary winding across the R5 resistor. The resistors (R4 & R6), connected to IN+ and IN-, are used to adjust the DC level on these two pins, then adjust the turn-off timing.

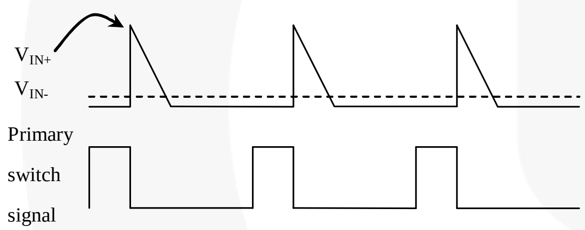

Figure 7. IN+/- and Primary Switch Signal

Because the synchronization signal of the primary switch is through the transformer secondary winding, false trigger conditions may occur in light loads. To prevent this, a series resistor (R1: 2~3kΩ) in the DET diode and a capacitor (C5: 22~47pF) connecting DET to GND, are recommended.

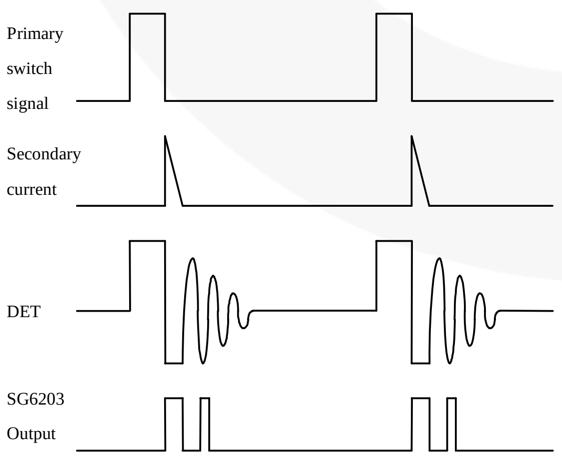

Figure 8. False Synchronization Caused by Ringing on the Transformer Winding

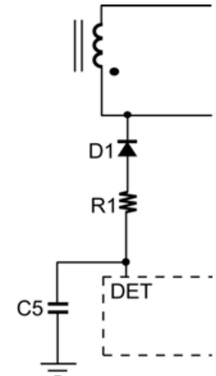

Figure 9. Add RC filter to prevent false trigger

Built-in 18V Zener Diode

An 18V Zener diode is built in to the SG6203. When the converter output voltage is higher than 18V, a linear regulator formed by a BJT and the internal Zener can be used to limit the voltage supplied to the SG6203, then clamp the driving voltage for the synchronous rectifier to a safe level. If the converter output voltage is lower than 18V, the SG6203 can be directly powered by the output voltage. The operating voltage of the SG6203 can be from 6 to 20V.

Voltage Stress on Synchronous Rectifier

When the output diode is replaced by a low on resistance MOSFET, the conduction loss is reduced. However, another side effect of the turn-off spike on the synchronous rectifier should be considered. The added synchronous MOSFET introduces a stray capacitor (C_{DS} of MOSFET), which leads to a larger turn-off spike. This condition becomes even serious when the converter is operated under CCM. To overcome this side effect, re-design the transformer to reduce the turn-off voltage stress on the secondary side.

The phenomenon of extra voltage spike introduced by synchronous MOSFET can be duplicated on the original power board (without synchronous rectifier). Add a synchronous MOSFET in parallel with the original output diode (drain connected to cathode of diode, source connected to anode of diode, and gate connected to source), and observe the turn-off voltage spike between the output diode. The voltage spike increases after the synchronous MOSFET is added.

Evaluation Board Description

A 12V, 120W evaluation board with full range input voltage (90~264V_{AC}) and PFC function is available to analyze the performance improvement contributed by the synchronous rectifier. The SG6902 combo controller is used to control the primary switches (PFC & PWM). The measured performance on this evaluation board is shown as below:

Table 1. Performance Comparison Between Diode Rectifier and MOSFET Synchronous Rectifier

I_O (A)	Efficiency (%)			
	90V_{AC}		264V_{AC}	
	20A Schottky	MOS (15mΩ R_{DS}) + 1A Schottky	20A Schottky	MOS (15mΩ R_{DS}) + 1A Schottky
1	81.8	80.2	81.8	79.1
2	83.2	85.4	82.4	81.5
3	82.6	85.0	83.6	85.8
4	81.7	83.5	83.1	85.7
5	82.0	84.3	82.9	85.3
6	81.8	84.1	83.5	85.4
7	81.4	83.7	83.3	85.4
8	80.8	83.0	83.1	84.7
9	80.2	82.1	83.1	84.8
10	79.5	81.3	82.7	84.3

The efficiency improvement is around 1.7~3% in heavy load conditions. The improvement is highly dependent on the synchronous MOSFET rectifier chosen to replace the diode rectifier. The lower the R_{DS-ON} the chosen synchronous MOSFET has, the larger the improvement achieved.

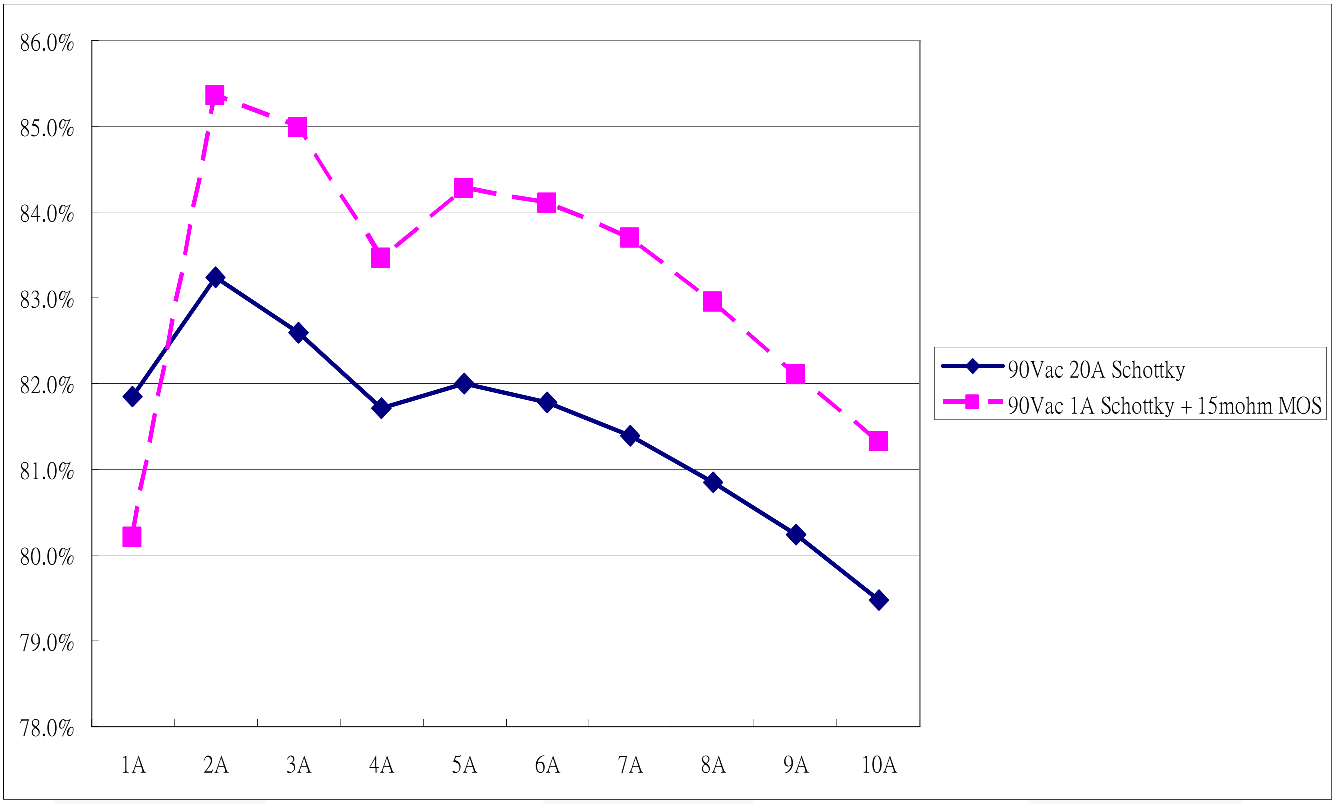

Figure 10. Performance Comparison Between Diode Rectifier and MOSFET Synchronous Rectifier at $90V_{AC}$

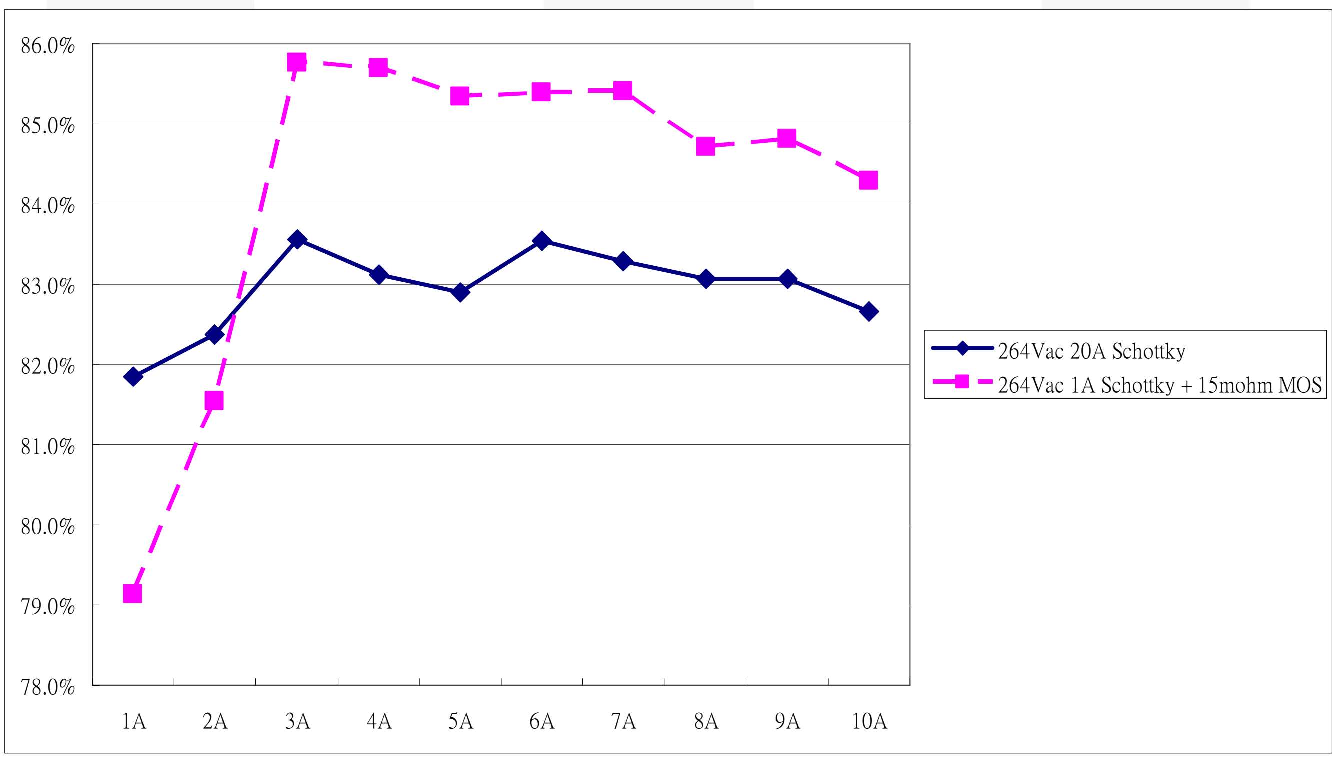

Figure 11. Performance Comparison Between Diode Rectifier and MOSFET Synchronous Rectifier at $264V_{AC}$

Table 2. Eval Board Bill of Materials (BOM)

Ref Des	Part Number	Description
C2		1µF
C5		22pF
D1	FR102	100V/1A
D2	SB1100	100V/1A
D3	1N4148	100V/0.2A
Q1	PSMN015-110P	110V/75A; 15mΩ
R1		2.2KΩ
R2		22Ω
R3		47KΩ
R4		1.8KΩ
R5		2KΩ
R6		0
R7		16.2kΩ

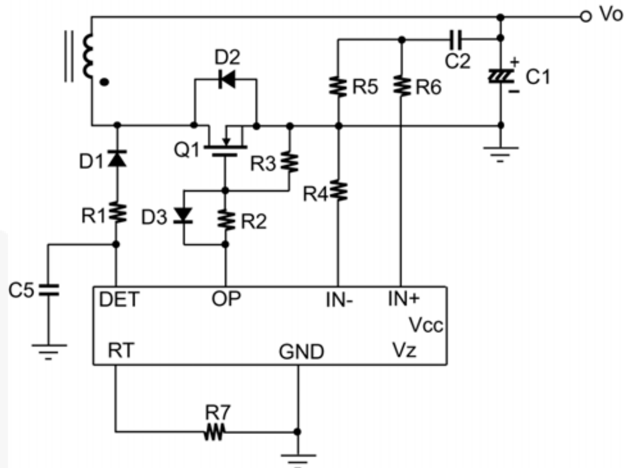

Figure 12. Evaluation Board Schematic

Lab Notes

- Before rework or solder/de-solder on the power supply, it is suggested to **discharge the primary capacitors by an external bleeding resistor** to avoid the PWM IC being destroyed by external high voltage during solder/de-solder.
- This device is sensitive to ESD discharge. To improve production yield, the production line should be ESD protected according to ANSI ESD S1.1, ESD S1.4, ESD S7.1, ESD STM 12.1, and EOS/ESD S6.1.

Related Datasheets

SG6203 — Synchronous Rectifier Controller for Flyback Converter

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