DN91
Synchronous rectification improves set top box power supply efficiency

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Introduction

This design note describes the implementation of synchronous rectification on multiple-output flyback converters. It is focused on the low side rectification approach as shown in Figure 1 to facilitate a common drive for synchronous MOSFETs on low voltage 3.3 and 5V outputs. The note concludes with practical measurement on a 27W four-output set top box power supply to demonstrate that a 3% efficiency improvement over a Schottky solution can be achieved with the aid of the ZXGD3101 synchronous MOSFET controller.

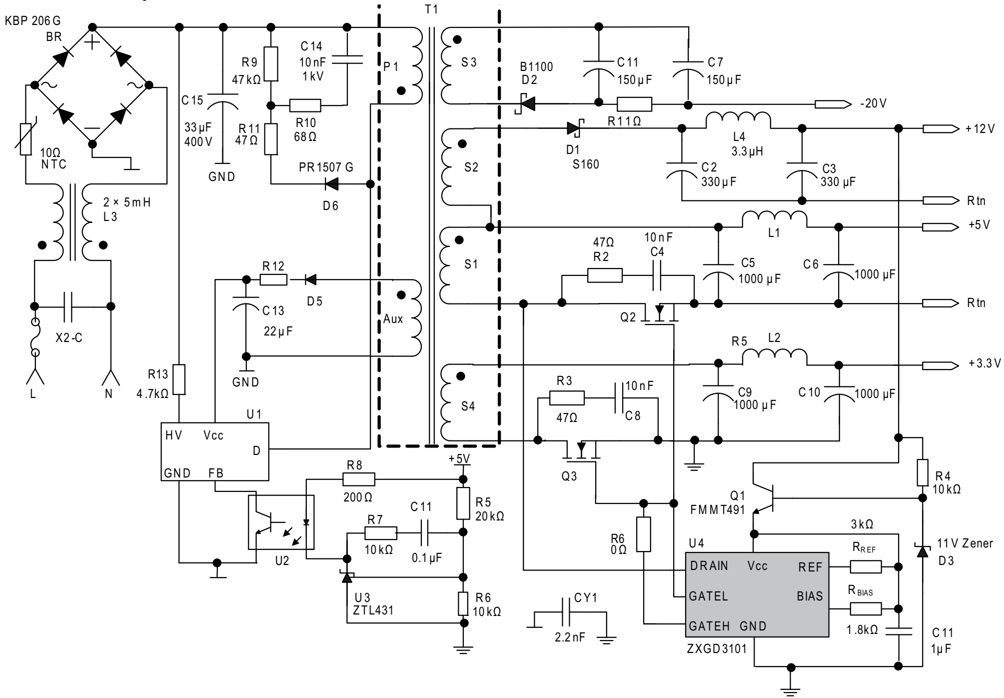


Figure 1 - Flyback converter with synchronous rectification on 5V and 3.3V output

General description

Figure 2 shows a typical set top box power supply. It is a cost effective design with minimum component count. The circuit is designed to operate in Discontinuous Conduction Mode ('DCM') because there are lower switching losses. Furthermore, the flyback transformer size can be reduced owing to the lower average energy storage whilst its smaller magnetizing inductance also yields a better transient line/load response.

The primary stage is built around a monolithic high voltage current mode control IC, U1 running at a fixed frequency of 50kHz. The secondaries of the transformer are rectified and filtered by D1, C2, D2, C5, D3, C7, D4 and C9 to produce four outputs - +5V, +3.3V,+12V and -20V, where the +5V main output channel is closed loop regulated through the optocoupler U2. LC post filters on each output remove switching noise and minimize ripple level.

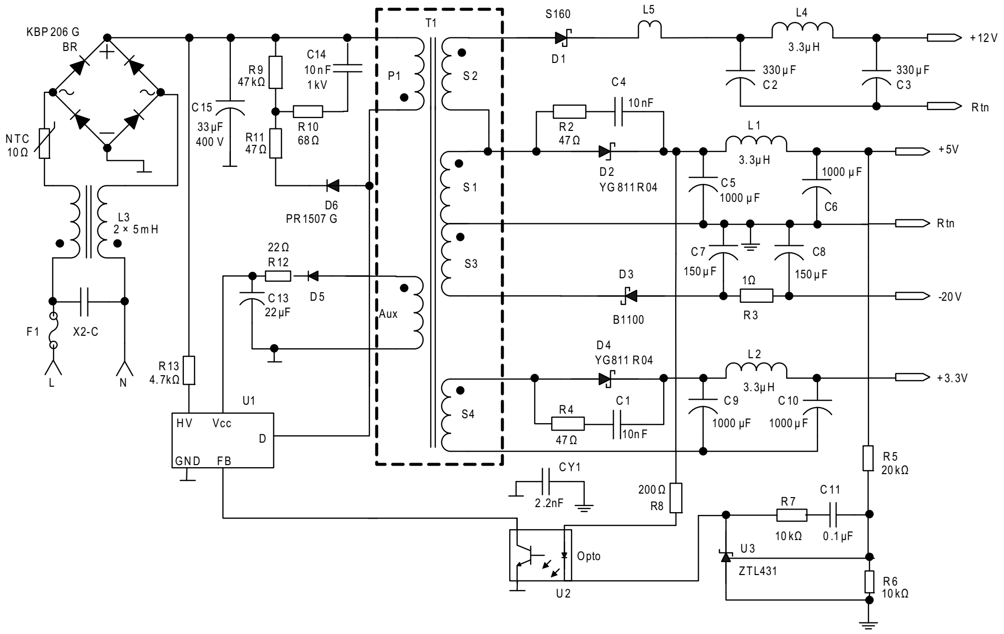


Figure 2 - Typical set top box power supply

For set top box power supplies, it is common to stack secondary windings with the same polarity and share a common source. This gives better voltage regulation between the outputs. In Figure 2, the winding for the 5V output will provide the return to ground whilst forming part of the winding for the 12V output. This also helps to keep the total number of secondary winding turns to a minimum. The wire size for the 5V winding needs to be chosen to accommodate its own maximum load current plus the output current of the 12V output stacked on top of it.

The example set top box power supply was specified for a nominal input voltage of 230Vac and load profile as shown in table 1.

Table 1 - Set top box power supply load profile

Nominal voltage	Nominal load current	Maximum load current	Minimum load current	Function
5V	2.5A	3.25A	1.25A	Tuner/Demodulator
3.3V	2A	2.5A	1A	Audio & Video CODEC, Video DAC, Memory, TVI TDMS
12V	500mA	500mA	125mA	Video and Audio Amp
-20V	60mA	60mA	20mA	
Power	26.3W	31.7W	11.05W	

Critically, much of the power supply heat generation and inefficiency is caused by Schottky diodes, D2 and D4 on the 5V and 3.3V high current outputs. Replacing the diodes with more efficient MOSFETs is recognized as a clear means of dramatically improving power supply efficiency, thereby removing the need for bulky heat sinks and reducing the size and weight of the end product. This design note therefore examines the implementation of synchronous rectification on these outputs.

More recently single output flyback has also been suggested for set top boxes. This approach derives the low voltage 3.3V and 5V outputs from the main 12V flyback output through synchronous or asynchronous buck post regulators. Although this simplifies the transformer design and eliminates cross regulation issues, it incurs a higher BOM cost, component count and possibly lower efficiency due to additional power loss in the post regulators. For information on synchronous rectification on single output flyback refer to AN54.

Secondary side synchronous rectification approach

High-side synchronous rectification is not considered here as a common drive circuit controlling a MOSFETs on each of the 5V and 3.3V outputs is not possible. For high side, a separate controller on each output is required. The overall solution BOM component count and cost will be prohibitive for a low power set top box.

Figure 1 shows a design where two MOSFETs are driven by a single ZXGD3101 Synchronous MOSFET controller. Low side rectification positions Q2 and Q3 on the ground return of the 5V and 3.3V outputs respectively. This enables the MOSFETs to be driven by a common controller because Q2 and Q3 share a common source point. The controller will derive its supply from the 12V output via an emitter-follower transistor Q1. R_{REF} and R_{BIAS} are chosen to be 3kΩ and 1.8kΩ to set the controller turn-off threshold value to -20mV.

Either Q2 or Q3 can be the ‘Control’ MOSFET, whose Drain terminal signal needs be fed back to the ‘Drain’ pin of the ZXGD3101. In the design shown in Figure 1, Q2 is selected to be the ‘Control’ FET because the 5V output has a higher load current; therefore the Q2’s peak current will be higher than that of Q3. The controller monitors Q2’s Drain voltage for body diode conduction and then turns on the MOSFET. The same gate voltage also drives Q3 on the 3.3V output, though the gate voltage level is entirely independent of its current status.

The ‘Control’ MOSFET should ideally be the MOSFET that carries the highest current so that the controller produces a sufficient gate voltage to minimize conduction loss. The gate voltage output from the controller is proportional to Q2’s Drain voltage during MOSFET on time. Furthermore, Q2 will also carry the current that flows through D1 on the 12V output as well as suppling the 5V output due to the stacked winding design. This puts additional current stress on the MOSFET.

The sink and source current from the controller is used to drive both synchronous MOSFETs. The switching time of Q2 and Q3 depends on their respective gate charge value. The controller turns these MOSFETs off without reverse current flow in DCM. More care has to be taken using the proposed configuration in a Continuous Conduction Mode (‘CCM’) converter to ensure that the secondary side switches are turned off safely without imposing huge current stress on the primary switch. This is because the increased likelihood of shoot through current occurring when switching off the large current in a CCM converter as the available sink current is now shared by Q2 and Q3.

Evaluation of results

Laboratory evaluation was conducted on a 27W set top box power supply to assess the performance benefits of synchronous rectification. Set top box power supplies are typically minimally designed and usually have efficiency around 75% with diode rectification which results in hot internal component operation.

Although different types of MOSFETs could be selected for Q2 and Q3 based on their breakdown voltage and Drain current requirement, a common part is used in this design because the 5V and 3.3V output have fairly similar load current. Based on the current level through Q2, a 16mΩ, 79A, 82nC MOSFET was selected so that voltage-drop across the Drain-Source pins is within 50 to 100mV at the peak MOSFET current.

Figure 3 compares the performance of synchronous rectification against a YG81S04R Schottky Barrier diode at 230Vac input voltage. The results demonstrate that a set top box power supply can be designed with efficiencies approaching 80% utilizing low on-resistance MOSFETs with the ZXGD3101. Synchronous rectification is 1% more efficient than the Schottky diode at 25% loading and the efficiency improvement gradually increases until it yields 2.9% better efficiency at full load. For completeness, the power supply efficiency against supply voltage variation is shown in Figure 4. The efficiency of this solution could be further improved beyond 80% if a discrete high voltage transistor and PWM controller are used on the primary stage instead of the existing monolithic solution.

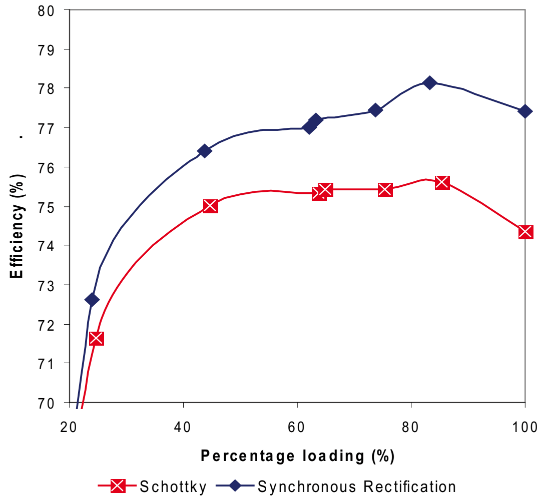


Figure 3 Efficiency vs. output loading, room temperature

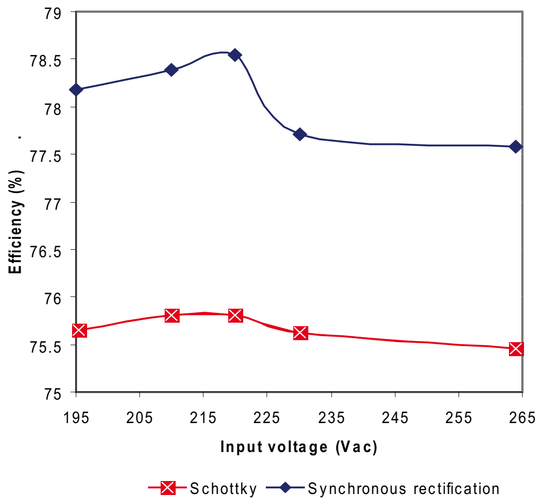
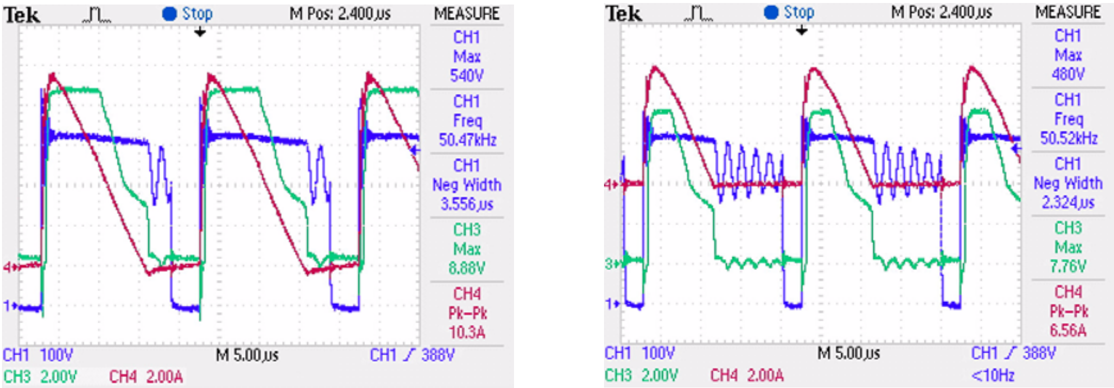


Figure 4 Set Top Box power supply efficiency vs. input voltage

Figure 5 shows the Gate voltage and Drain current waveforms of the ‘Control’ MOSFET at the maximum and minimum loading profile. In Figure 5(a), the Gate voltage reaches 8.5V to obtain a low MOSFET resistance at 100% loading. The Gate enhancement eases off gradually as the Drain current through the MOSFET decreases due to the ZXGD3101’s proportional gate drive scheme. The controller reduces the Gate voltage magnitude as the MOSFET current decreases. Although this produces a larger on-state resistance, the subsequent increase in conduction voltage drop ensures that the controller maintains the gate voltage above 2-3V as the current decreases linearly down to zero. The MOSFET is driven off near the zero current point to ensure that there is no reverse current flowing through Q2.



(a) Maximum output power 31.7W **(b) Minimum output power 11.05W**

Figure 5 ‘Control’ MOSFET current and voltage waveforms (CH1: Primary Drain voltage; CHx: Q2’s Gate voltage; CH4: Q2’s Drain current)

Set top box power supplies normally have tracking between critical loads where the minimum and maximum loads on the +5V and +3.3V output occurs at the same time. In products where there is no tracking between outputs, the 3.3V load current could be minimum loaded whilst the 5V output is fully loaded. In that instance, Q2 will conduct a current a few times higher than that in Q3. As the Drain voltage level across the ‘Control’ MOSFET dictates that both Q2 and Q3 are kept on when Q2 is still conducting substantial current, even though the current in Q3 has reached zero as shown in Figure 6.

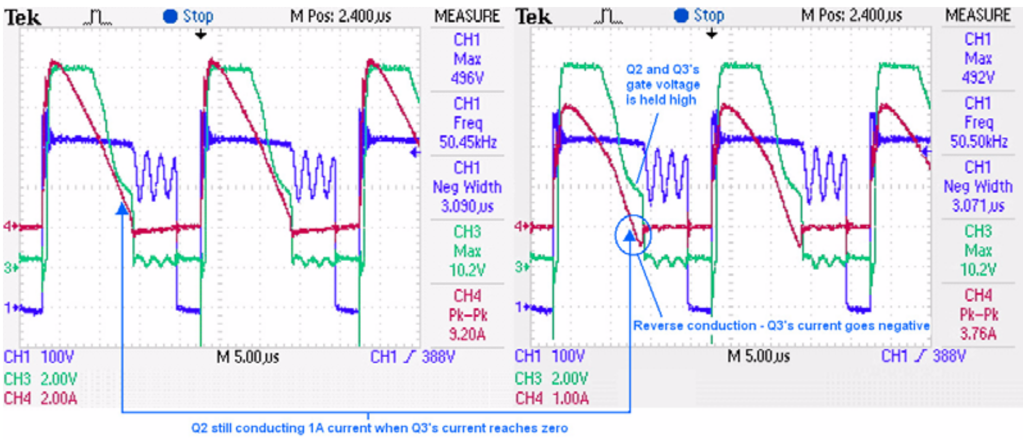


Figure 6 - Synchronous MOSFET current and voltage waveforms for uneven output loading (CH3: Gate voltage; CH4: Drain current)

Subsequently, a negative current flows through Q3 and discharges the output capacitor C9. This negative or reverse current flow under uneven loading is inhibited in normal Schottky rectification because the diode acts as a unidirectional switch. In the event of reverse current flow in one of the synchronous rectified outputs, the converter will need to replenish this lost output energy through a slight increment in Q3's peak current in the next switching cycle. This maintains the same average current that goes to the 3.3V load. Nevertheless the effect of higher peak Q3 current is compensated by the use of a low on-resistance MOSFET, so the efficiency improvement over a Schottky is preserved as shown in table 2.

Figure 7 below shows Q2 and Q3's voltage and current when the 3V output is more heavily loaded than the 5V output. Although the current on the 5V output is now 1.25A compared with 2A on the 3V output, the Gate voltage is still high enough to enhance the MOSFETs

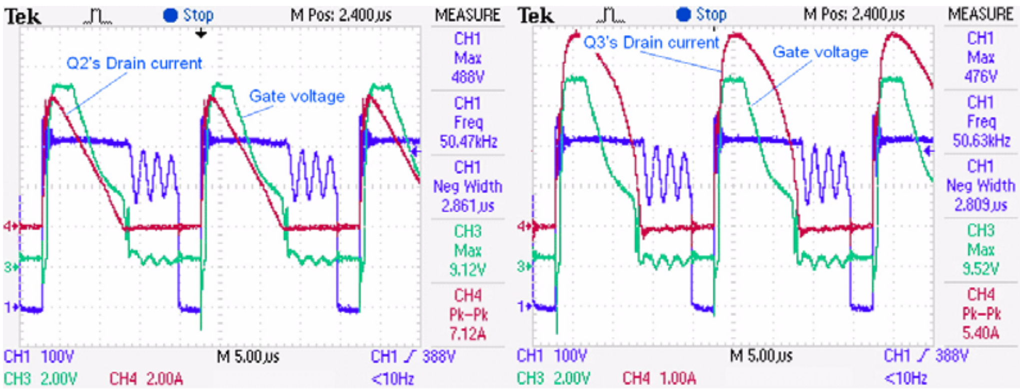


Figure 7 - Q2 and Q3's current and voltage for 5V, 1.25A; 3.3V, 2A loads

(CH3: Gate voltage; CH4: Drain current)

Table 2 shows the efficiency measurement as well as output voltage regulation taken at varying load profiles. Another important aspect to be considered is the effect of synchronous rectification on the power supply cross regulation performance. The regulation on the more critical 5V and 3.3V outputs are within ±3% under the considered conditions. Generally flyback converters have fairly poor regulation at lighter load, which could be improved with a few mW of dummy load resistor on the affected output.

Table 2 – Synchronous rectification's efficiency vs. loading profile

Loading profile	5V		3.3V		12V		-20V		Pout	Efficiency
	(V)	(A)	(V)	(A)	(V)	(A)	(V)	(mA	(W)	(%)
1	5.03	3.25	3.28	2.5	12.03	0.5	-19.30	60	31.7	77.4
2	5.05	2.5	3.32	2	12.03	0.5	-20.30	60	26.5	78.2
3	5.07	2.5	3.40	1	12.08	0.5	-20.52	60	23.4	77.4
4	5.11	1.25	3.18	2	12.14	0.5	-20.72	60	20.06	77.0
5	5.13	1.25	3.54	1	12.16	0.125	-21.6	20	11.9	73.9

Efficiency results in the previous section show that synchronous rectification can yield more than a 3% better efficiency than diodes in multiple output flyback converters suitable for set top boxes. This improvement is attributed to the significant conduction loss saving from the MOSFETs.

Another observation is that the synchronous rectified power supply will consume more power at low load. Its standby power consumption to produce 1W on output is approximately 1W higher than that of Schottky solution as shown in Figure 8. This increased low load power is due to the accumulation of losses associated with synchronous MOSFET's gate charge loss and power consumption of the ZXGD3101.

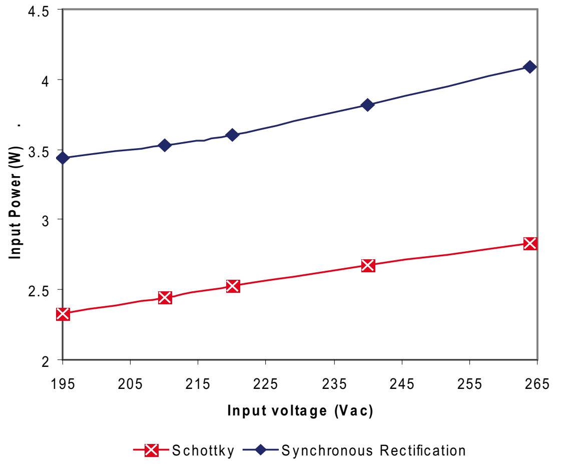


Figure 8 - Required input power to maintain 1W output

Conclusion

Low side synchronous rectification has been examined on a multiple output flyback converter suitable for use as a set top box power supply. The proposed configuration allows two synchronous MOSFETs to be driven by a common ZXGD3101 controller. The main control loop is closed around the 5V output of the set top box power supply and a stacked winding is employed to ensure a manageable transformer design as well as achieving a satisfactory cross regulation performance.

The experimental four output set top box power supply manages to achieve more than 78% efficiency when Schottky diodes on the low voltage outputs are replaced with low resistance MOSFETs. PC board could now be used to provide heat sinking, eliminating the need for an external heat sink, and also removing the cost of the heat sink and associated assembly costs.

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