"Greener" Rectifier Loses The Diodes, Adds Power MOSFETs, Efficiency

CHRISTIAN RAUSCH
TOPTICA PHOTONICS AG, GRAEFELFING, GERMANY
Christian.Rausch@toptica.com

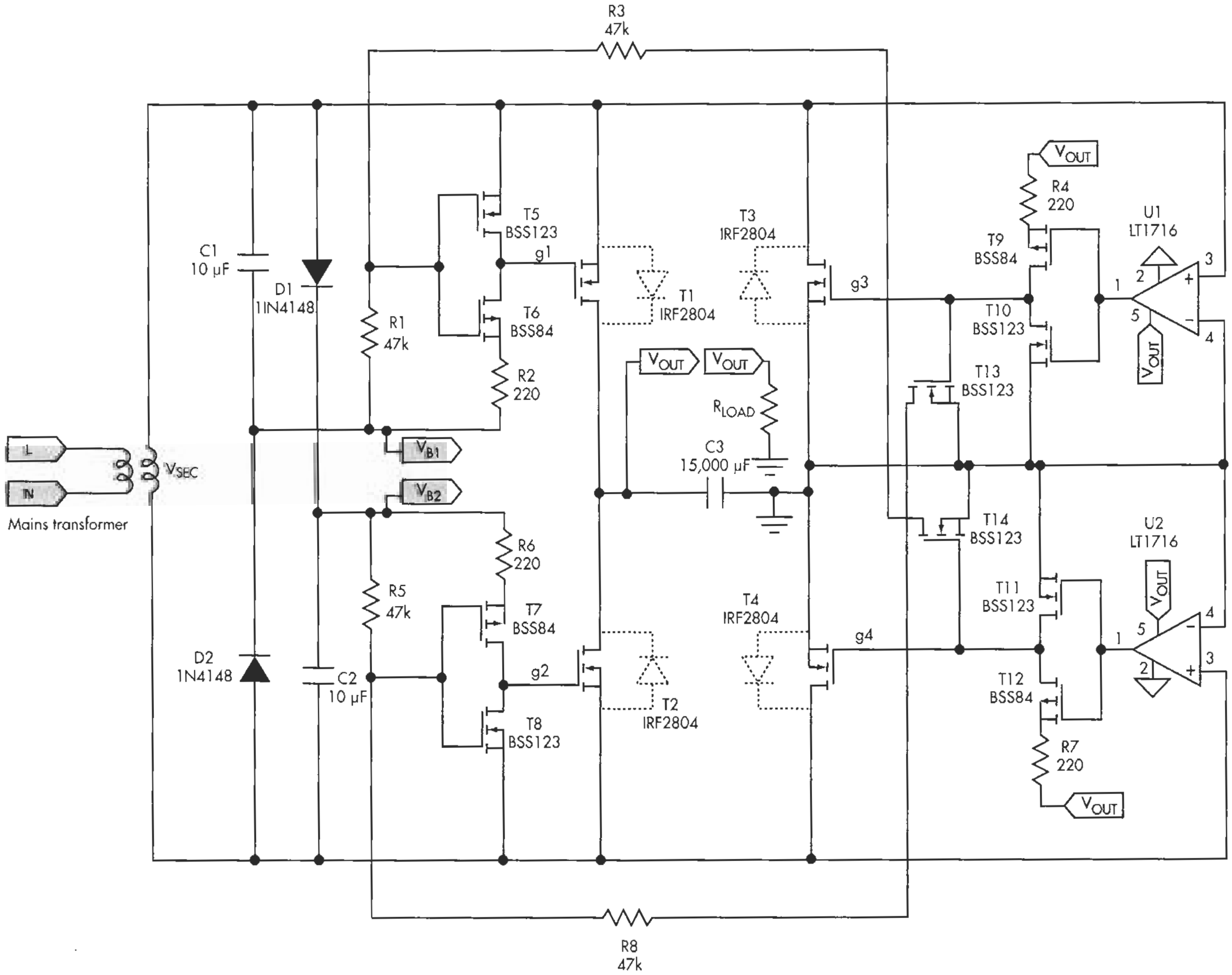
ED ONLINE 19871

A major cause of losses in a conventional power supply using a 50/60-Hz transformer is the bridge rectifier. This article shows how to build a "greener" rectifier, substantially reducing losses by eliminating the diodes in the bridge rectifier and substituting modern low-$R_{DS(ON)}$ power MOSFETs. The MOSFETs used are typically employed in high-frequency switch-mode power supplies. Aside from the power MOSFETs, the circuit uses only two comparators and a few inexpensive transistors, diodes, capacitors, and resistors.

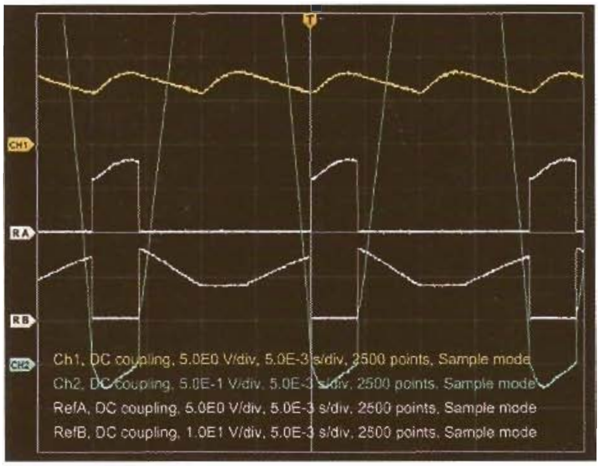
Four IRF2804 n-channel power MOSFETs, T1-T4, replace the bridge diodes *(Fig. 1)*. The remaining components are needed to steer the gates of the MOSFETs. The power MOSFETs' body diodes (shown by dashed lines) make up a diode bridge rectifier in the usual way.

During the first half cycle after power-up, this "parasitic" bridge rectifier charges load capacitor C3. When V_{OUT} becomes higher than 2.7 V, comparators U1 and U2 get into the act. In addition, driver stages T9-T12 on the right side, which are also powered by V_{OUT}, now have enough supply voltage to switch on the gates of the T3 and T4.

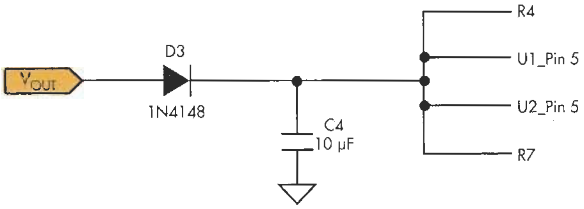
After the second half cycle, the two boost capacitors on the left side, C1 and C2, have charged to the peak value of the input



1. This rectifier circuit substitutes four power MOSFETs with built-in body diodes (dashed lines) for the four diodes of a conventional bridge rectifier.



2. With the power MOSFET T4 switched on, the drain-source voltage (Ch2) is very small because the transistor $R_{DS(ON)}$ is only 2 mΩ.



3. To increase the voltage on the gates of the right-side MOSFETs, the designer can add a diode and capacitor to supply the right side of the circuit.

voltage, and supply driver stages T5-T8 for the power MOSFETs T1 and T2. The voltages across C1 (V_{B1}) and C2 (V_{B2}) are always positive with respect to the source connections of T1 and T2, respectively.

Comparator U2's inputs are connected to T4's source and drain connections, so it also senses the voltage polarity of this transistor's body diode. Whenever the polarity across T4 becomes negative—that is, when a forward current could flow through T4's body diode—the power MOSFET is switched on via U2's output and the driver stage T11/T12. *(The gate voltage, V_G, is shown as R_A in Fig. 2.)* The drain-source voltage V_{DS} *(the blue trace, Ch. 2, in Fig. 2)* now becomes very small, since $V_{DS} = I_D \times R_{DS(ON)}$, and the transistor's $R_{DS(ON)}$ is only 2 mΩ.

Virtually all the current now flows from source to drain and almost no current is flowing through the body diode. Notice that V_{DS} remains negative, so the comparator can keep T4's gate high. At the same time, T1 is also switched on, with the help of T14 *(trace R_B in Fig. 2)* and driver stage T5/T6.

Later in the cycle, when the current through T1 and T4 drops to zero (that is, when the transformer output voltage dives below V_{OUT}), T4's V_{DS} also becomes zero, and the comparator cuts off both T4 and its left-side partner, T1. While T1 is conducting, boost capacitor C2 amasses charge that's needed one-half period later for dumping into T2's gate.

CHRISTIAN RAUSCH, designer of electronics for diode lasers and laser systems, holds a diploma in physics and a PhD from the Technische Universität München, Germany.

After that one-half period, similar things happen to the other power MOSFET pair. Comparator U1 senses T3's V_{DS} and switches on this transistor and its cousin T2 on the left side just at the moment before a current begins to flow through the respective body diodes.

The values of C1 and C2 must be high enough to ensure that the gate-source voltage at the end of the gate-charging process is high enough to switch on the respective power MOSFET completely. For a gate charge of $Q_G = 160$ nC (the data-sheet value for the IRF2804) and an allowed voltage drop of, say, $\Delta U_G = 100$ mV, the minimum capacitance would be $C_{MIN} = Q_G/\Delta U_G = 1.6$ µF. Therefore, 10 µF is high enough. Multilayer chip capacitors can be used, but beware of the voltage dependency of dielectrics like Y5V.

The two comparators are LT1716 low-power devices in small SOT-23 packages. They are particularly suitable for this application because they can cope with negative voltages on their inputs, even when running from a single supply. That's important because the drains of T3 and T4 become negative with respect to ground.

Another advantage of this comparator is its wide operating voltage range—from 2.7 V to 44 V. Unfortunately, the device's output drive is too low to drive T3 and T4 directly. That's why the need arises for driver stages T9-T12. They are small p- and n-channel MOSFETs that put a maximum voltage swing on the gates of the power MOSFETs.

With a 5-A load, the circuit worked with transformer voltages of 2.8 V rms to 14 V rms. The lower limit is determined by the gate threshold voltages of the MOSFETs, and the upper limit is determined by the maximum allowed gate voltages. If the circuit must run at higher transformer voltages, the supply voltages for the driver stages should be limited by resistors/Zeners or voltage regulators.

The circuit's efficiency is quite good. At a 10-A dc output (7 V rms ac input), none of the components require a heatsink. The power MOSFET case temperatures stay well below 50°C.

Due to a lack of equipment, I could not test the circuit at higher currents. But beyond 10 A, it may be worthwhile to connect two MOSFETs in parallel to reduce $R_{DS(ON)}$ even further. But pay attention to the resistances of the PCB traces, since they could be higher than the MOSFETs' $R_{DS(ON)}$!

The circuit was compared to a popular KBU8B silicon diode rectifier. At an input voltage of 5 V rms at 50 Hz and a constant load of 5 A dc, the KBU8B's output was 4.45 V dc, average, measured across C3 (15,000 µF). Under the same conditions, the "greener" rectifier produced an output of 5.9 V dc, average.

Another comparison that may be even more meaningful involves determining what rectifier input voltage is needed for a given dc output voltage. For this measurement, a transformer with several output windings (Ultron ULT2) was connected to the mains via a Variac. The desired output was 5 V dc, average. Measurements were done at two constant load currents: 5 A and 10 A.

For the KBU8B rectifier and a 5-A load, the transformer's 6-V output winding was used. The Variac had to be adjusted for a transformer output (secondary) voltage of V_{SEC} = 5.55 V rms, which had to be corrected slightly to 5.48 V when the rectifier got hot. The measured input power was 47 W. With a 10-A load, which is already beyond the specs of the KBU8B, the 8-V output winding had to be used. The Variac was adjusted to 5.97 V rms (5.87 V rms when hot). Under these conditions, the real input power of the Variac was 88 W.

Using the "greener" rectifier with a load current of 5 A, the Variac had to be tuned back to a transformer output voltage of V_{SEC} = 4.34 V rms (off the 6-V winding). The Variac's real input power was only 36 W. At 10 A, the 6-V winding could still be used, with the Variac tuned to 4.82 V rms. The real input power was 69 W. Thus, the power MOSFET rectifier circuit saved roughly 10 W at 5 A and 20 W at 10 A.

At high currents and low voltages, and especially when the output ripple voltage increases, the two power MOSFETs on the right get a little warmer than those on the left. The reason is because the driver stages on the left have their own filter capacitors (C1 and C2) that provide a smooth dc voltage, while the driver stages on the right are directly supplied from the high-ripple output voltage. Unfortunately, right at the moment when the gates of the right-side MOSFETs should be taken high, the available output voltage is rather low, since output capacitor C3 has discharged to its minimum value *(traces CH1 and R_A in Fig. 2)*.

The cure for this problem is simple. Add a diode and a capacitor to supply the right half of the circuit *(Fig. 3)*.

The whole circuit fits into roughly the same volume as a conventional bridge rectifier. Considering that there's usually no need for heatsinks, the circuit should pay off quickly. Also, in many cases, a smaller and cheaper transformer can be employed.

REFERENCES:

www.linear.com (search for "lt1716")
www.irf.com/product-info/datasheets/data/irf2804.pdf
www.vishay.com/docs/88658/kbu8.pdf