Resonant Controller-Power Switch Combination Enables Efficient Power Solution for LED Street Lighting

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LEDs provide high efficiency and long life compared to conventional lighting sources. Therefore, they are becoming a priority among lamp types in order to reduce energy consumption for internal or external lighting. This is also the case in street lightings where better efficiency and longer life are essential for less cost. A switching power supply designed to power up an LED lamp should also have high efficiency and robustness to assure maintenance free lifetime as long as the lamp. Resonant converters are one of the most popular power supply topologies here since their performance delivers increased power efficiency and reduces EMI compared to previous power supply topologies. Soft switching is an important feature of resonant converters. However, the use of the body diode in resonant converters sometimes leads to system failure. The stored charge in the body diode should be completely removed to avoid high current and voltage spikes including high dv/dt and di/dt in these topologies. Therefore, critical parameters of power MOSFETs such as Qrr, and reverse recovery dv/dt directly affect the dynamic performance of resonant converters. This article will explore a total solution for a switching power supply targeted to LED street lighting. The new resonant controller combined with new power switch enable a high efficiency solution for LED lighting power supplies without sacrificing the robustness and cost effectiveness of the converter.

Resonant Converters for High Efficiency

Several DC-DC power conversion topologies have been introduced to reduce switching losses, device stresses on the power MOSFETs and the radio frequency interference (RFI) while achieving high power density. Among them, resonant converters, which utilize the body diode of MOSFETs for zero voltage switching, are proven to be very effective for higher efficiency. An LLC resonant converter can achieve high efficiency at high input voltage and low voltage stress on the secondary rectifier since there is no inductor on secondary. In addition, an LLC resonant converter can guarantee zero voltage switching (ZVS) operation even at no load. The ZVS technique dramatically reduces the switching losses and significantly improves efficiency. The zero voltage switching also reduces the switching noise noticeably, which allows a small sized electromagnetic interference filter. Because of these unique characteristics, LLC resonant converters are becoming a popular topology for many applications including LED street lighting. Fairchild’s FAN7621S offers everything necessary to build a reliable and robust LLC resonant converter. It simplifies designs and improves productivity by including a high-side gate drive circuit, an accurate current controlled oscillator, frequency limit circuit, soft start, and built-in protection functions. Among the various protection functions are over voltage and over current protections (OVP/OCP), abnormal over

current protection (AOCP), and internal thermal shutdown (TSD). All protections are auto-restart because of the particular application requirement of LED street lighting. The high-side gate drive circuit has a common mode noise cancellation capability that guarantees stable operation with excellent noise immunity. Even with the latest resonant controller, the converter operating point moves into zero the current switching (ZCS) region under shorted output condition. Figure 1 shows how an operating point moves. During this condition, ZVS is lost and the MOSFET conducts extremely high current. The most severe drawback of ZCS operation is hard switching at turn-on that leads to MOSFET body diode reverse recovery stress. The body diode turns off at a very large dv/dt and therefore, at a very large di/dt, generates a high reverse-recovery current spike. These spikes can be over ten times higher than the magnitude of the steady-state current. This high current causes a considerable increase in losses and heats up the MOSFET. Then, the dv/dt capability of MOSFET is degraded due to temperature rise in the junction. In extreme cases, it may destroy the MOSFET and cause system failure.

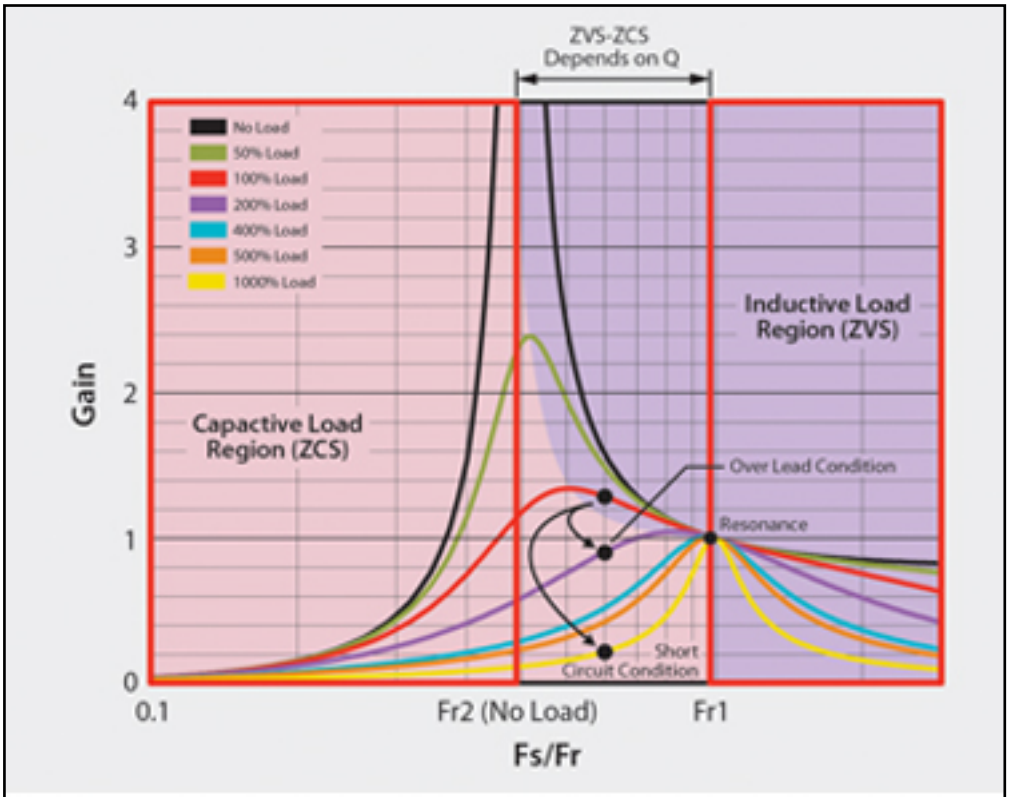

Figure 1. Operating points of LLC resonant converter according to load condition.

The Latest MOSFET Technology

The body diode of a MOSFET typically has very long reverse recovery time and large reverse recovery charge. In spite of its poor performance, the body diode has been used as a freewheeling diode because it can make a simple circuit without adding system cost in some applications such as resonant converters. As more and more applications use an intrinsic body diode as the critical component in the system, Fairchild designed a new highly optimized power MOSFET for resonant converters with deep analysis of MOSFET failure mechanisms. It has an improved body diode ruggedness and less stored energy in output capacitance. As shown in Table 1, the reverse recovery charge (Qrr) of the new UniFET II MOSFET family is dramatically

reduced by 50 and 88 percent compared to alternate solutions.

DUTs	Rds(on) Max (Ω)	BVDss (V)	ID (A)	Qg (nC)	Trr (ns)	Qrr (μC)
UniFET™ II MOSFET Family	0.85	500	8	18	160	1.2
Competitor A	0.85	500	7.2	32	238	2.5
Competitor B	0.70	500	8	45	1200	10

Critical specification comparison of DUTs.

The MOSFET's capacitance is nonlinear and depends on the drain-source voltage since its capacitance is essentially a junction capacitance. In soft switching applications, the MOSFET's output capacitance can be used as a resonant component. When the MOSFET is turned on, the current that extracted from the magnetizing energy stored in transformer flows to discharge the MOSFET output capacitance to allow ZVS condition. Therefore, if stored energy in the output capacitance of the MOSFET is small, less resonant energy is required to achieve soft switching without increasing the circulating energy. The UniFET II MOSFET family has approximately 35 percent reduced stored energy in output capacitance than same on-resistance competitor's devices at typical switching power supply bulk capacitor voltage. The benchmark of stored energy in output capacitance is shown in Figure 2.

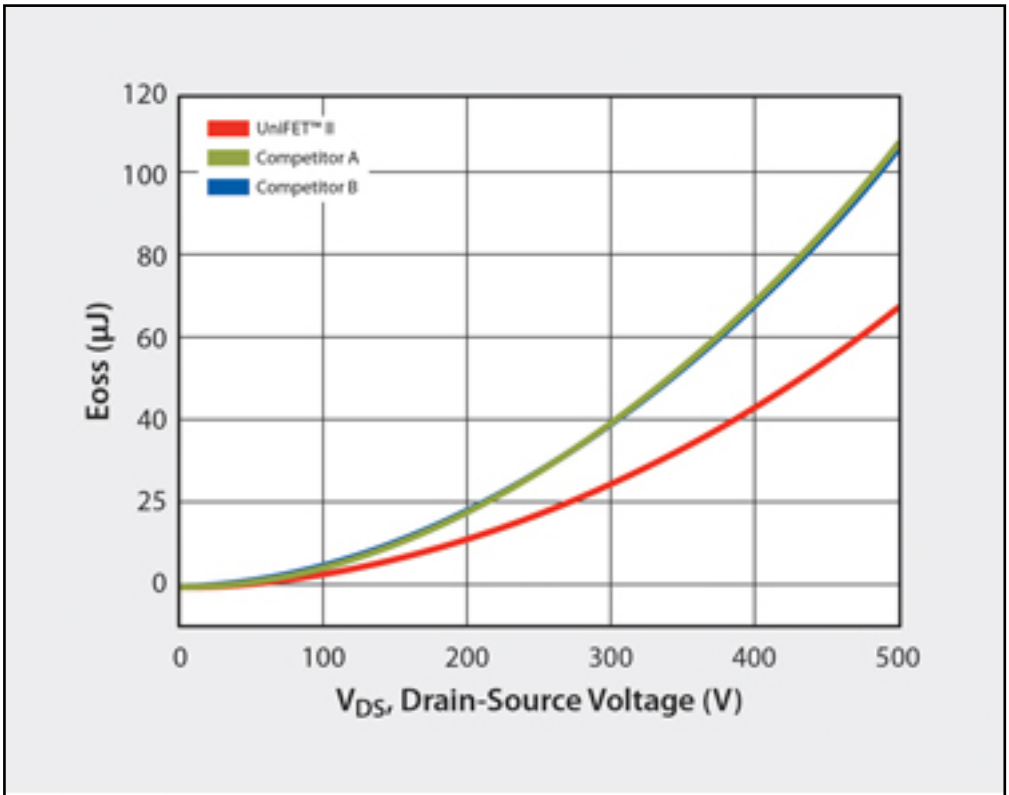

Figure 2. Stored energy in output capacitance.

Benefit to the Resonant Converter

The switching process of the diode from on state to reverse blocking state is called reverse recovery. During forward conducting of diode, charges are stored in the P-N junction of the diode. When reverse voltage is applied, stored charge should be removed to go back to blocking state. The removal of the stored charge occurs via

two phenomena: the flow of a large reverse current and recombination. A large reverse recovery current occurs in the diode during the process. In the MOSFET body diode case, some reverse recovery current flows right underneath the N+ source. Figure 3 shows MOSFET failing waveforms during body diode reverse recovery. With competitor A, failure happens right after the current level reaches peak reverse recovery current at 6.87 V/ns of dv/dt. It means the peak current triggered parasitic BJT. But the UniFET II MOSFET family survives up to even more higher dv/dt, 14.32 V/ns.

Figure 4 presents how the rugged body diode of the UniFET II MOSFET family benefits the reliability of the converter under shorted output. Operation mode is changed from ZVS to ZCS after output short. The current spike of the UniFET II MOSFET family is much lower due to smaller Qrr, and most importantly the device is not failed.

Figure 3. Voltage and current waveforms during reverse recovery of body diode

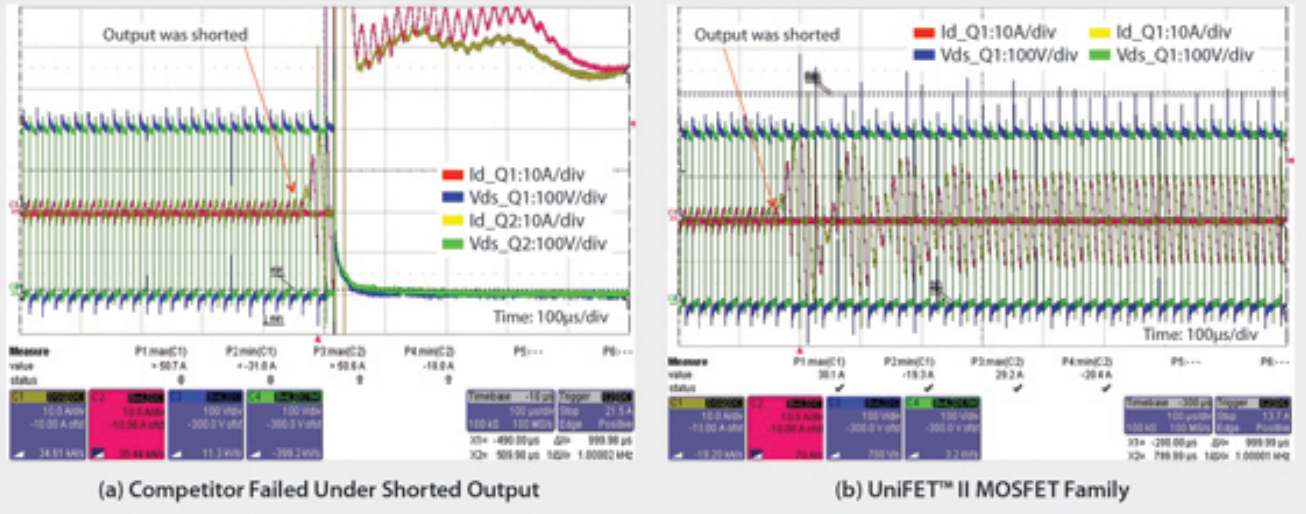

Figure 4. Operating waveforms under short circuit condition.

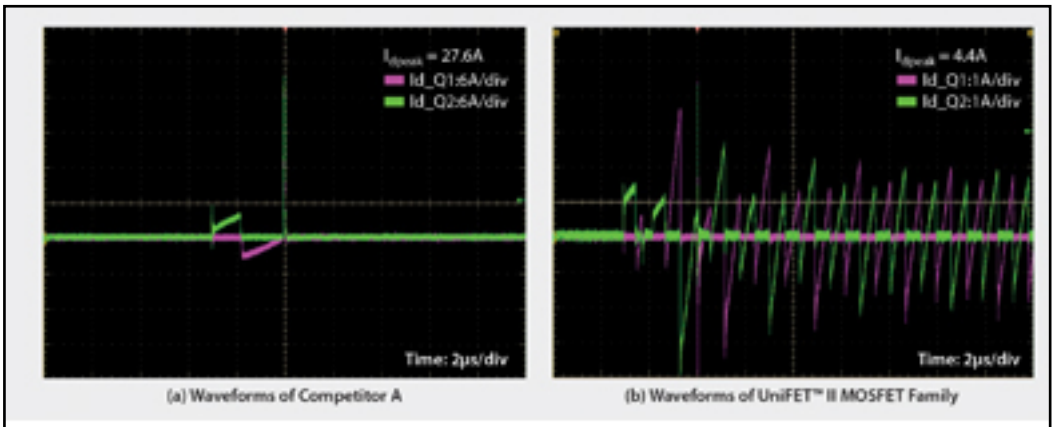

Figure 5. Waveforms at start-up state.

The other misbehavior of the converter can happen during start-up state. Figure 5 shows switch current waveforms at start-up. The high level of current spike, exceeding 27 A, is induced due to big peak reverse recovery current. It can trigger a protection function of the control IC. On the contrary, the UniFET II MOSFET family shows no high current spike.

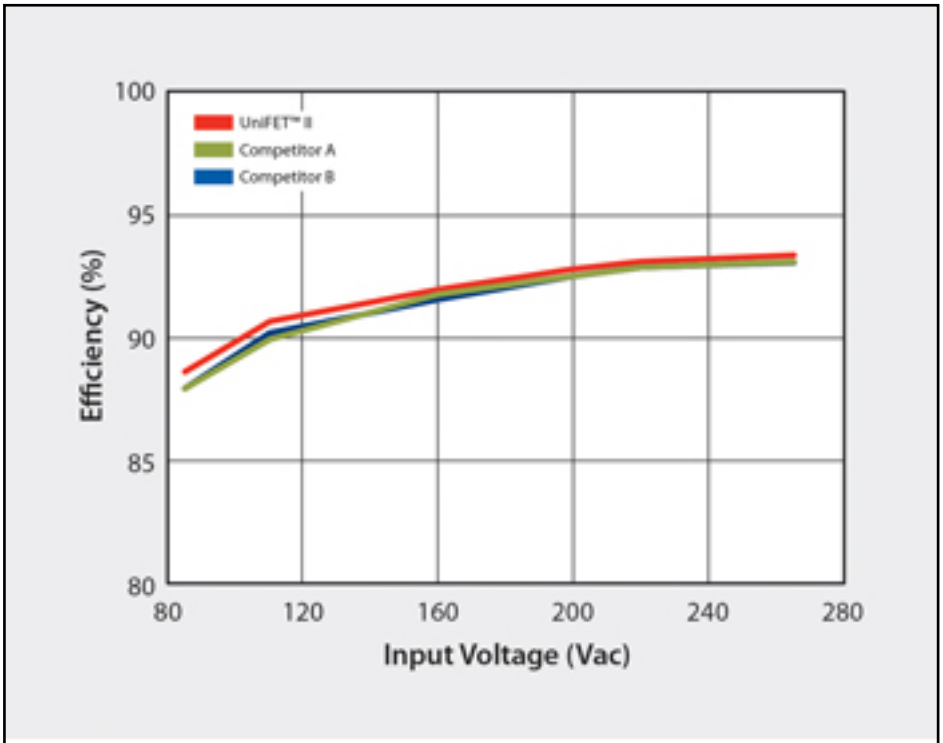

Figure 6. Efficiency comparisons on LLC resonant converter.

In order to compare the power conversion efficiency of the UniFET II MOSFET family and competitors, a 150-W LLC resonant half-bridge converter is designed. The summary of the efficiency measurements is shown in Figure 6. The system efficiency is higher than the competitor’s MOSFETs for the entire input voltage range. The major reason for the higher efficiency is the reduced switch-off loss and output capacitive loss because of lower Qg and Eoss.

Summary

The new power MOSFET family combines rugged intrinsic body diode performance with fast switching, aimed at achieving better reliability and efficiency in resonant converter applications. With reduced gate charge and stored energy in output capacitance, driving loss is decreased and switching efficiency is increased. The UniFET II MOSFET family provides designers better reliability and efficiency at minimum cost.

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