

# ON Semiconductor

## Is Now



To learn more about onsemi™, please visit our website at  
[www.onsemi.com](http://www.onsemi.com)

onsemi and onsemi® and other names, marks, and brands are registered and/or common law trademarks of Semiconductor Components Industries, LLC dba "onsemi" or its affiliates and/or subsidiaries in the United States and/or other countries. onsemi owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of onsemi product/patent coverage may be accessed at [www.onsemi.com/site/pdf/Patent-Marking.pdf](http://www.onsemi.com/site/pdf/Patent-Marking.pdf). onsemi reserves the right to make changes at any time to any products or information herein, without notice. The information herein is provided "as-is" and onsemi makes no warranty, representation or guarantee regarding the accuracy of the information, product features, availability, functionality, or suitability of its products for any particular purpose, nor does onsemi assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using onsemi products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by onsemi. "Typical" parameters which may be provided in onsemi data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. onsemi does not convey any license under any of its intellectual property rights nor the rights of others. onsemi products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use onsemi products for any such unintended or unauthorized application, Buyer shall indemnify and hold onsemi and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that onsemi was negligent regarding the design or manufacture of the part. onsemi is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner. Other names and brands may be claimed as the property of others.



Is Now Part of



**ON Semiconductor®**

To learn more about ON Semiconductor, please visit our website at  
[www.onsemi.com](http://www.onsemi.com)

---

ON Semiconductor and the ON Semiconductor logo are trademarks of Semiconductor Components Industries, LLC dba ON Semiconductor or its subsidiaries in the United States and/or other countries. ON Semiconductor owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of ON Semiconductor's product/patent coverage may be accessed at [www.onsemi.com/site/pdf/Patent-Marking.pdf](http://www.onsemi.com/site/pdf/Patent-Marking.pdf). ON Semiconductor reserves the right to make changes without further notice to any products herein. ON Semiconductor makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does ON Semiconductor assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using ON Semiconductor products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by ON Semiconductor. "Typical" parameters which may be provided in ON Semiconductor data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. ON Semiconductor does not convey any license under its patent rights nor the rights of others. ON Semiconductor products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use ON Semiconductor products for any such unintended or unauthorized application, Buyer shall indemnify and hold ON Semiconductor and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that ON Semiconductor was negligent regarding the design or manufacture of the part. ON Semiconductor is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner.



# AN-9725

## Robust Body Diode Characteristics of the Latest Power MOSFETs, UniFET™ II for Resonant Converters

### Introduction

Resonant converters are one of the most exciting power supply topologies. These converters are popular for many applications because the performance increases power efficiency, minimizes components count, and reduces Electromagnetic Interference (EMI) over older power supply topologies. Soft switching is the representative feature of resonant converters.<sup>[1][2]</sup> However, use of the body diode in resonant converters sometimes leads to system failures. 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  $C_{oss(er)}$ ,  $Q_{rr}$ , and reverse-recovery dv/dt; directly affect dynamic performance of resonant converters. A new power MOSFET, called UniFET™ II, is optimized for resonant converters. It provides better reliability and higher efficiency in resonant converters.

### Resonant Converters Reliability

Several topologies of DC-DC converters for server and telecom power supplies have been introduced to reduce switching losses, device stresses on the power MOSFETs, and Radio Frequency Interference (RFI) while achieving high power density. Resonant converters that utilize the body diode of MOSFETs for Zero-Voltage Switching (ZVS) are very suitable for these applications. Specifically, the phase-shifted ZVS full-bridge converters have been widely accepted for high-end power supplies since they allow all switches to operate at ZVS by effective  $C_{oss}$  of power MOSFETs and leakage inductance of transformer without an additional auxiliary switch. However, ZVS range is very narrow and the freewheeling current consumes high circulating energy. In the late 1990s, power MOSFET failures were reported in the phase-shifted ZVS full-bridge topology. One cause of failure is slow reverse recovery of the body diode by low reverse voltage. The other failure is due to the  $C_{dv/dt}$  shoot-through at no-load or light-load conditions.<sup>[3][4]</sup> This kind of failure does not occur in LLC resonant converters because LLC resonant converters can guarantee ZVS operation, even at no load.

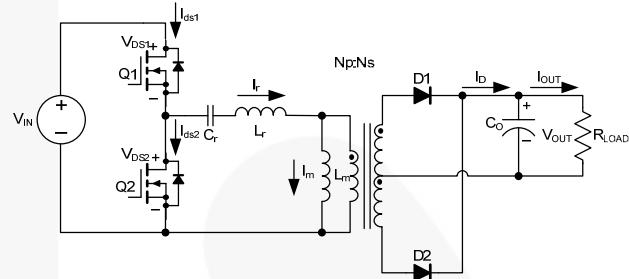


Figure 1. LLC Resonant Converter

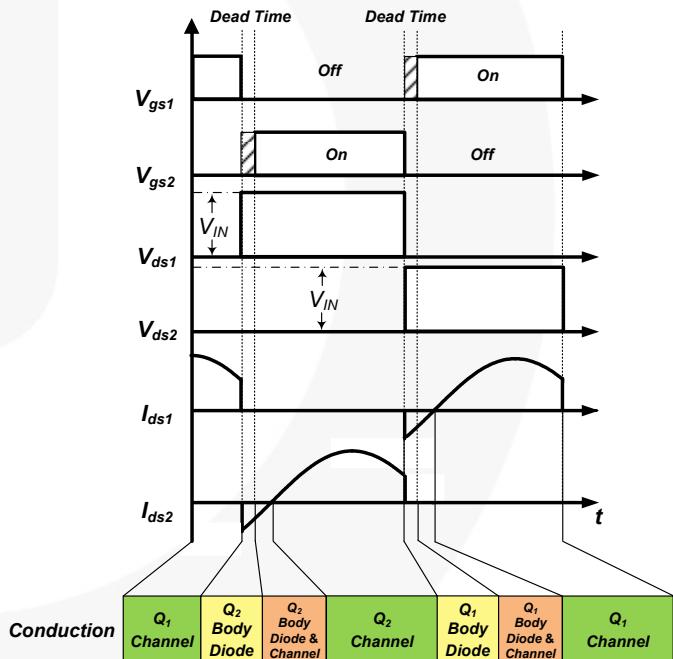


Figure 2. Zero Voltage Switching in Resonant Converter

LLC resonant converters can achieve high efficiency at high input voltage with low voltage stress on the secondary rectifier since there is no inductor on the secondary. Due to of these unique characteristics, LLC resonant converters are becoming a popular topology for many applications, especially server and telecom power supplies and low-profile flat-panel display TV power supplies. A block diagram of an LLC resonant converter is shown in Figure 1. Figure 2 shows typical waveforms of its zero voltage switching. Conduction periods of Q1 and Q2 should not overlap to guarantee proper operation of the converter. A dead time must be introduced to prevent simultaneous conduction of the MOSFETs. As shown in Figure 3, during this delay time, current flows through the body diode of the each MOSFET to guarantee ZVS operation. ZVS is achieved with magnetizing current, which is not related to load current, so ZVS can be realized even with zero load. The voltage across the MOSFET is the forward-voltage of the body diode, which can be negligible. When the other MOSFET turns on, the body diode naturally turns off, resulting in no reverse-recovery losses. Therefore, a fast-recovery MOSFET is not necessary in normal ZVS operation. However, MOSFET failures in LLC resonant converters are associated with shoot-through current due to the poor reverse-recovery characteristics of the body diode at startup. Figure 3 shows the first five switching waveforms of the power MOSFET at startup. Just before startup of the converter, resonant capacitance and output capacitance are completely discharged. These empty capacitances cause further conduction of the body diode of the low-side MOSFET during startup, compared to normal operation conditions. As a result, the reverse-recovery current that flows through body diode of the low-side MOSFET is much higher and is enough to create shoot-through problems when the high-side MOSFET is turned on.<sup>[5]</sup>

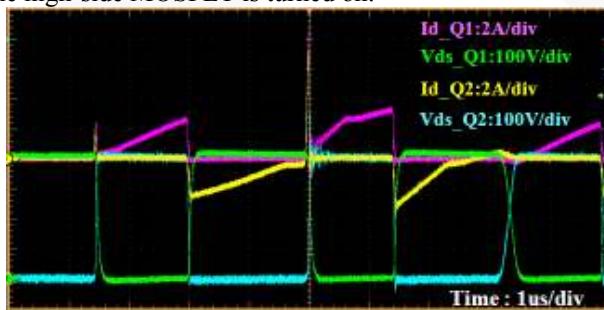


Figure 3. Waveforms of Power MOSFETs at Startup

Another field failure was revealed at specific conditions, such as overload or short-circuit condition in the LLC resonant converter.<sup>[6]</sup> Even though the voltage and current of power MOSFETs are within safe operating range, some unexpected failures associated with shoot-through current, reverse recovery  $dv/dt$ , and breakdown  $dv/dt$  occur in conditions such as overload and output-short circuit. Figure 4 shows how an operating point moves during overload and short-circuit condition. As shown in Figure 4, DC gain characteristics of an LLC resonant converter is classified into three regions according to different operating frequency and load condition. The right-side (blue box) of resonant

frequency,  $Fr_1$ , is the ZVS region. The left-side (red box) is minimum second resonant frequency,  $Fr_2$ , at no load, which is ZCS region. The region between  $Fr_1$  and  $Fr_2$  can be either ZVS or ZCS region, according to load condition. The converter operates with ZVS in normal operation, but the operating point moves to the ZCS region under overload or short-circuit condition and the characteristics of a series resonant converter become dominant. During overload or short-circuit condition, the switch current is increased and ZVS is lost.  $L_m$  is fully shorted by a reflected load,  $R_{LOAD}$ , at overload condition. This condition usually results in ZCS operation. The most severe drawback of ZCS operation (below resonance) is that hard switching at turn-on leads to the diode reverse-recovery stress. Furthermore, switching loss increases at turn-on and noise or EMI is generated. The 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 switch current. This high current causes considerable increase in losses and heats up the MOSFET. Then an increase in junction temperature degrades  $dv/dt$  capability of MOSFET. In extreme cases, it may destroy the MOSFET and cause system failure. In specific applications, load conditions are suddenly changed from no load to overload and more rugged operating is required for system reliability.<sup>[7][8]</sup>

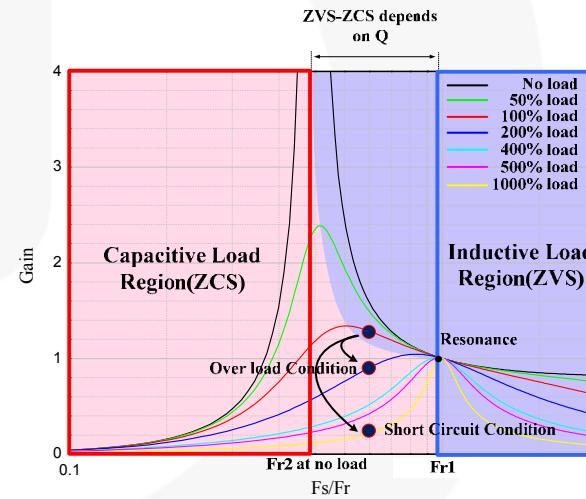


Figure 4. Operating Points of LLC Resonant Converter According to Load Condition

The worst case is a short-circuit condition. During short circuit, the MOSFET conducts extremely high (theoretically unlimited) current and frequency is reduced. When short circuit occurs,  $L_m$  is shunted in resonance. The LLC resonant converter can be simplified as a series resonant tank by  $C_r$  and  $L_r$  because  $C_r$  resonates with only  $L_r$ . Operation mode during short circuit is almost the same as in overload condition, but short-circuit condition is worse because reverse-recovery current, which flows through the body diode of the switch, is much higher. Figure 5 shows the switching waveforms of the power MOSFETs at short-circuit condition. Waveforms during short-circuit are similar to those during overload condition, but the higher current

level during short-circuit condition can lead to increased junction temperature of MOSFET and increased likelihood of failure.

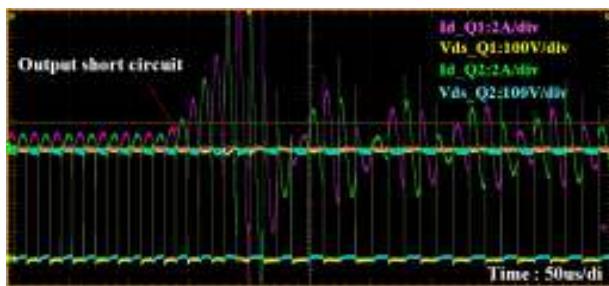


Figure 5. Waveforms of Power MOSFETs at Short-Circuit Condition

## MOSFET Failure Mechanism

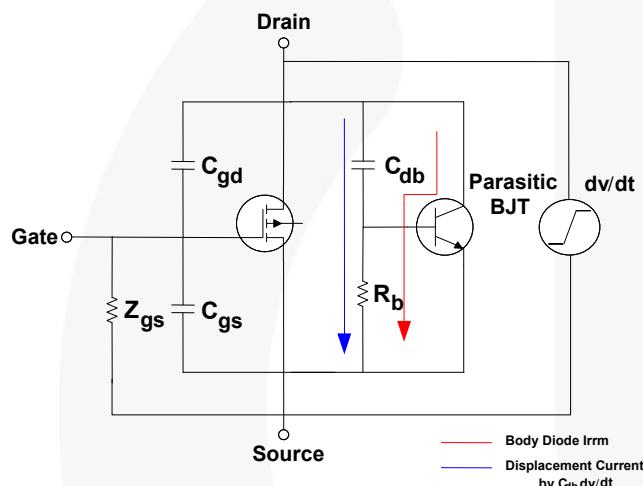


Figure 6. MOSFET Equivalent Circuit

As shown in Figure 6, there is a small resistance described as  $R_b$ . Basically, base and emitter of parasitic Bipolar Junction Transistor (BJT) are shorted together by source metal. Therefore, the parasitic BJT should not be activated. In practice, however, the small resistance works as base resistance. When large current flows through  $R_b$ , a voltage across  $R_b$  that acts as base-emitter forward bias becomes high enough to trigger the parasitic BJT. Once the parasitic BJT turns on, a hot spot is formed and more current crowds into it due to negative temperature coefficient of the BJT. Finally, the device fails.

Another failure mode is breakdown  $dv/dt$ . It is a combination of breakdown and static  $dv/dt$ : the device undergoes avalanche current and displacement current at same time. In the case of extremely fast transition, drain-source voltage may exceed maximum rating of a device during the body diode reverse-recovery process. If the MOSFET enters breakdown mode due to high-voltage spikes, commutating current flows through P-N junction. It is exactly the same mechanism as avalanche breakdown. In addition to this process, high  $dv/dt$  affects the failure point of the device. More displacement current is built up with

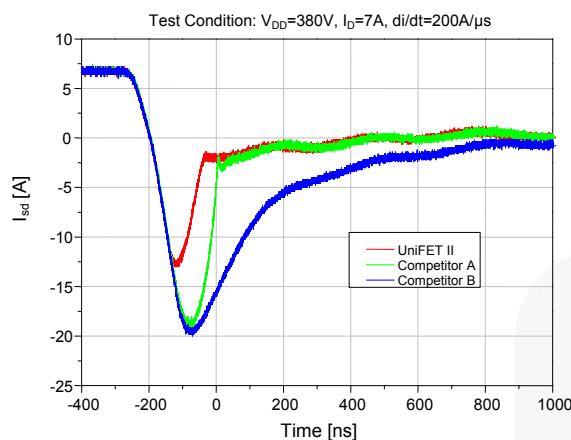
greater  $dv/dt$ . The displacement current is added to avalanche current and the device becomes more vulnerable to failure. Basically, the root cause of failure is parasitic BJT turn-on due to high current and temperature. However, the primary cause is body diode reverse recovery or breakdown. In practice, these two failure modes occur randomly and sometimes in combination.

## UniFET™ II MOSFET Technology



Figure 7. UniFET™ II MOSFET Technology Overview

The body diode of power MOSFETs has a very long reverse-recovery time and large reverse-recovery charge. In spite of its poor performance, the body diode has been utilized as a freewheeling diode because it simplifies the circuit without adding system cost in applications such as resonant converters. As more and more applications use an intrinsic body diode as the critical component in the system, body diode characteristics have been developed. Fast-recovery MOSFET is good choice for reliability on resonant converters, but there are drawbacks. More lifetime control results in further increase of MOSFET on resistance. This adds conduction loss and is critical to the resonant converter. Another negative effect is the increase of drain-source leakage current. Manufacturing cost increases due to additional process for life-time control. For better body diode performance, Fairchild designed a highly optimized power MOSFET, called UniFET™ II MOSFET, for resonant converters with deep analysis of MOSFET failure mechanisms. It has improved body diode ruggedness and output stored energy in  $C_{oss}$ , while minimizing negative effects. Its peak reverse-recovery current has been reduced to the level that does not cause device failure without increasing on-resistance. It can withstand more than double the current stress during breakdown  $dv/dt$  mode. As shown in Figure 8, the reverse-recovery charge of UniFET™ II MOSFET is reduced by 50%; 88% when compared to competitor parts.

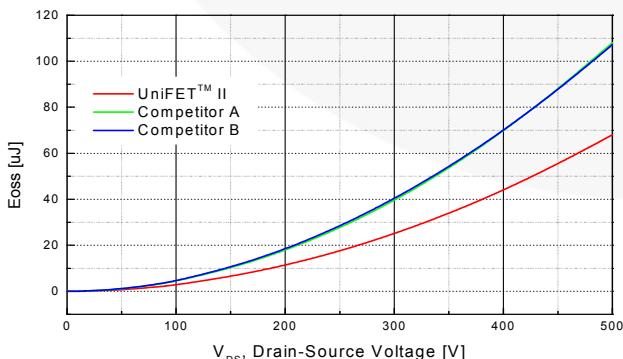


**Figure 8. Measured Body Diode Reverse-Recovery Waveforms Showing UniFET™ II Low  $Q_{rr}$ ,  $t_{rr}$ , and  $I_{rrm}$  Relative to Competitor Devices**

**Table 1. Critical Specification Comparison of DUTs**

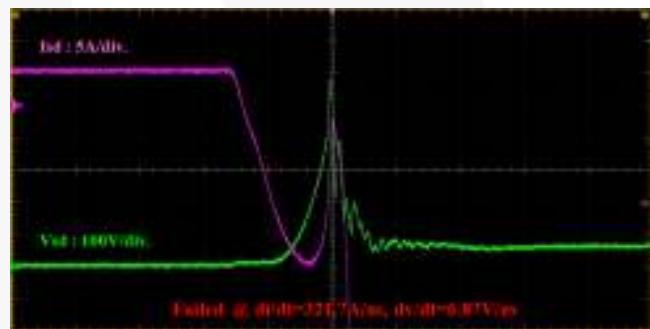
DUTs	$R_{DS(on)}$ Max.	$BVD_{SS}$	$I_D$	$Q_g$	$T_{rr}$	$Q_{rr}$
UniFET™ II	0.85	500V	8.0A	18nC	160ns	1.2 $\mu$ C
Competitor A	0.85	500V	7.2A	32nC	238ns	2.5 $\mu$ C
Competitor B	0.80	500V	8.0A	45nC	1200ns	10.0 $\mu$ C

MOSFET capacitance is nonlinear and depends on the drain-source voltage since its capacitance is essentially a junction capacitance. In soft-switching applications, MOSFET output capacitance can be used as a resonant component. When the MOSFET is turned on, the current extracted from the magnetizing energy stored in the transformer flows to discharge the MOSFET output capacitance to allow ZVS condition. Therefore, if the stored energy in output capacitance of MOSFET is small, less resonant energy required to achieve soft switching without increasing the circulating energy. The UniFET™ II MOSFET has approximately 35% less stored energy in output capacitance than the same on-resistance of competitor devices for typical switching power supply bulk capacitor voltage. The benchmark of stored energy in output capacitance is shown in Figure 9.

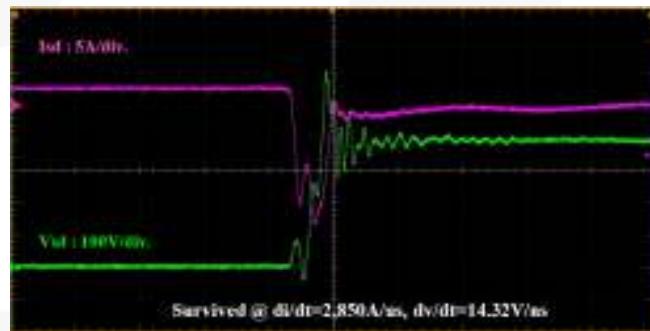


**Figure 9. Stored Energy in Output Capacitance**

The switching process of the diode from on state to reverse blocking state is called reverse recovery. First, the body diode is forward-conducted for a while. During this period, charges are stored in the P-N junction of the diode. When reverse-voltage is applied across the diode, 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. This reverse-recovery current flows through the body diode of MOSFET because the channel is already closed. Some of reverse-recovery current flows right underneath the N<sup>+</sup> source. Figure 10 shows MOSFET failing waveforms during body diode reverse recovery. With competitor A, failure occurs right after the current level reaches  $I_{rrm}$ , peak reverse recovery current at 6.87V/ns. This indicates the peak current triggered parasitic BJT. As shown in Figure 11, the UniFET™ II did not fail at even higher  $dv/dt$  (14.32V/ns) and  $di/dt$  (2,850A/us) conditions.



**Figure 10. Competitor A MOSFET Failing Waveforms During Body Diode Reverse Recovery**



**Figure 11. UniFET™ II MOSFET Withstanding Waveforms During Body Diode Reverse Recovery**

## Application Benefits

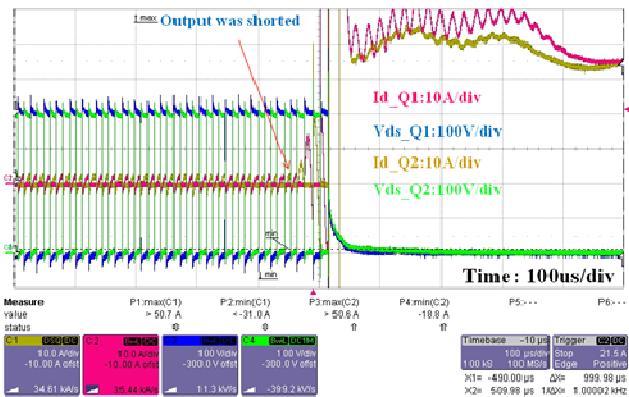


Figure 12. Waveforms of Competitor A Under Short-Circuit Condition

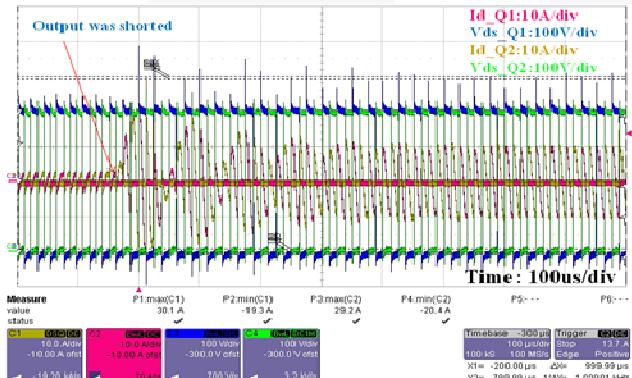


Figure 13. Waveforms of UniFET™ II Under Short-Circuit Condition

Figure 12 and Figure 13 present waveforms comparing reverse-recovery characteristics at short circuit between the competitive device and the UniFET™ II MOSFET. Operation mode is changed from ZVS to ZCS after the output short. A peak drain-source voltage of the competitor exceeded rated voltage (500V) and the current spike is several tens of ampere current due to large  $Q_{rr}$ . The MOSFET to be switched on carries reverse-recovery current of the other MOSFET. The current spike of UniFET™ II MOSFET is relatively lower due to much smaller  $Q_{rr}$  on ZCS operation during output short and the device did not fail.

The other failure case occurs during startup. Figure 14 and Figure 15 present key waveforms comparing reverse-recovery characteristics at startup between the competitor MOSFET and UniFET™ II MOSFET. With the competitor MOSFET, a high level of shoot-through current, exceeding 27.6A, is induced due to higher  $I_{rm}$  of body diode. It triggered a protection function of control IC. A low peak current spike occurred in the UniFET™ II MOSFET. These negative behaviors of the MOSFET may result in device

failure as mentioned; reverse recovery dv/dt and breakdown dv/dt. The UniFET™ II MOSFET can effectively minimize shoot-through current, peak drain-source voltage, and reverse recovery dv/dt; which are potential causes of failure at startup, overload, and short-circuit conditions.

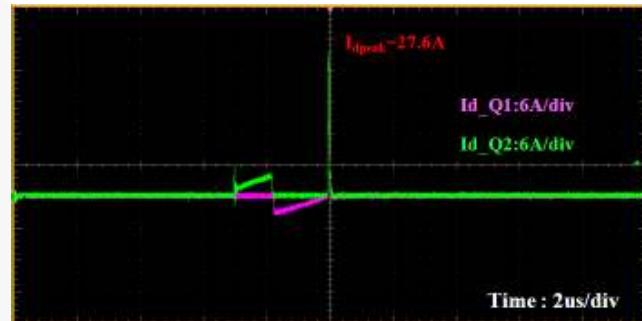


Figure 14. Waveform of Competitor A During Startup

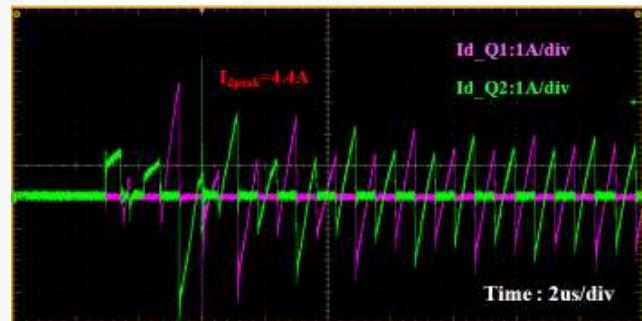


Figure 15. Waveform of UniFET™ II During Startup

To compare the efficiency of a UniFET™ II MOSFET and competitors, a 240W LLC resonant half-bridge converter was designed with input voltage of 110-220V<sub>AC</sub> and output voltage and current set to 12V and 20A, respectively. Synchronous rectification was used for the secondary side. The summary of the efficiency measurements is shown in Figure 16. Efficiency increases about 0.5% compared to competitor MOSFETs at heavy load condition. The major reason for higher efficiency is the reduced switch-off loss and output capacitive loss because of lower  $Q_g$  and  $E_{oss}$ . UniFET™ II MOSFETs have a robust Electrostatic Discharge (ESD) capability of 2kV Human Body Model (HBM). This strong ESD capability is instrumental in protecting the application from adverse electrostatic events.

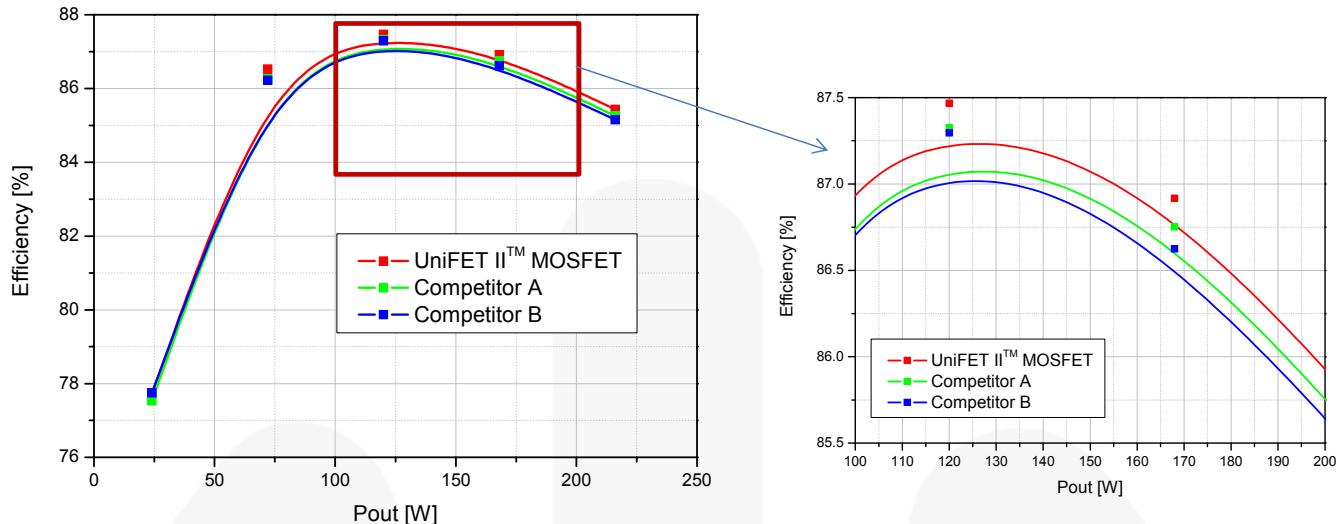


Figure 16. Efficiency Comparisons on LLC Resonant Converter

## Conclusion

Fairchild's new power MOSFETs family, UniFET™ II, combines a faster and more rugged intrinsic body diode performance with fast switching, aimed at achieving better reliability and efficiency in applications including resonant converters. With reduced gate charge and stored energy in output capacitance, switching efficiency is increased and

driving and output capacitive losses are decreased. Performance of UniFET™ II MOSFET allows designers to significantly increase system reliability, particularly for resonant converters.

**Table 2. 500V, 600V UniFET™ II Lineup**

Part Number <sup>(1)</sup>	BV <sub>DSS</sub>	R <sub>DS(ON),max</sub> [Ω] at V <sub>GS</sub> = 10V	Q <sub>g,typ</sub> [nC] at V <sub>GS</sub> = 10V	I <sub>D</sub> [A]	Package
FDPF3N50NZ	500	2.50	8	3.0	TO-220F
FDD3N50NZ	500	2.50	8	2.5	TO-252 (DPAK)
FDP5N50NZ	500	1.50	9	4.5	TO-220
FDPF5N50NZ	500	1.50	9	4.5	TO-220F
FDD5N50NZ	500	1.50	9	4.0	TO-252 (DPAK)
FDPF5N50NZF	500	1.75	9	4.2	TO-220F
FDD5N50NZF	500	1.75	9	3.7	TO-252 (DPAK)
FDPF5N50NZU	500	2.00	9	4.0	TO-220F
FDP8N50NZ	500	0.85	14	8.0	TO-220
FDPF8N50NZ	500	0.85	14	8.0	TO-220F
FDD8N50NZ	500	0.85	14	6.5	TO-252 (DPAK)
FDPF8N50NZF	500	1.00	14	7.0	TO-220F
FDPF8N50NZU	500	1.20	14	6.5	TO-220F
FDP12N50NZ	500	0.52	25	11.5	TO-220
FDPF12N50NZ	500	0.52	25	11.5	TO-220F
FDP22N50N	500	0.21	49	22.0	TO-220
FDPF5N60NZ	600	2.00	11	4.5	TO-220F
FDD5N60NZ	600	2.00	11	4.0	TO-252 (DPAK)
FDP7N60NZ	600	1.25	13	6.5	TO-220
FDPF7N60NZ	600	1.25	13	6.5	TO-220F
FDD7N60NZ	600	1.25	13	5.5	TO-252 (DPAK)
FDU7N60NZ	600	1.25	13	5.5	TO-251 (IPAK)
FDD7N60NZU	600	1.70	13	4.6	TO-252 (DPAK)
FDP10N60NZ	600	0.75	27	10.0	TO-220
FDPF10N60NZ	600	0.75	27	10.0	TO-220F
FDP12N60NZ	600	0.65	30	12.0	TO-220
FDPF12N60NZ	600	0.65	30	12.0	TO-220F
FDPF17N60N	600	0.34	48	17.0	TO-220F

**Note:**

1. Part suffix: N = UniFET™ II, Z = internal ESD diode.

## References

- [1] *N. Mohan, T. M. Undeland and W. P. Robbins, "Power Electronics, Converters, Applications, and Design," John Wiley & Son, Inc., New York 1995, 2nd Edition.*
- [2] *R. Farrington, M. M. Jovanovic, and F. C. Lee, "Analysis of Reactive Power in Resonant Converters," Proc. IEEE PESC '92, 1992.*
- [3] *Hubert Aigner. Et al., "Improving the Full-Bridge Phase-shift ZVT Converter for Failure-Free Operation Under Extreme Conditions in Welding and Similar Applications," IEEE Proceedings of Industrial Application Society Annual Meeting. St. Luis, 1998.*
- [4] *Sampat Shekhawat, Mark Rinehimer, Bob Brokway, "FCS Fast Body Diode MOSFET for Phase-Shifted ZVS Full Bridge DC/DC Converter," Fairchild Application Note AN-7536.*
- [5] *Wonsuk Choi and Sungmo Young, "Improving System Reliability Using FRFET® in LLC Resonant Converters," PESC 2008, June 2008.*
- [6] *Wonsuk Choi, Sungmo Young, Dongwook Kim, "Analysis of MOSFET Failure Modes in LLC Resonant Converter," INTELEC 2009, October 2009.*
- [7] *Hangseok Choi, "Analysis and Design of LLC Resonant Converter with Integrated Transformer," APEC 2007, Feb. 2007.*
- [8] *Bo Yang, F. C. Lee, and Concannon, "Over-Current Protection Methods for LLC Resonant Converter," APEC 2003, Feb. 2003.*

## Author

*Won-suk Choi and Sungmo Young, Application Engineering*

*HV PCIA PSS Team / Fairchild Semiconductor*

*Phone +82-32-680-1839*

*Fax +82-32-680-1823*

*Email wonsuk.choi@fairchildsemi.com*

### DISCLAIMER

FAIRCHILD SEMICONDUCTOR RESERVES THE RIGHT TO MAKE CHANGES WITHOUT FURTHER NOTICE TO ANY PRODUCTS HEREIN TO IMPROVE RELIABILITY, FUNCTION, OR DESIGN. FAIRCHILD DOES NOT ASSUME ANY LIABILITY ARISING OUT OF THE APPLICATION OR USE OF ANY PRODUCT OR CIRCUIT DESCRIBED HEREIN; NEITHER DOES IT CONVEY ANY LICENSE UNDER ITS PATENT RIGHTS, NOR THE RIGHTS OF OTHERS.

### LIFE SUPPORT POLICY

FAIRCHILD'S PRODUCTS ARE NOT AUTHORIZED FOR USE AS CRITICAL COMPONENTS IN LIFE SUPPORT DEVICES OR SYSTEMS WITHOUT THE EXPRESS WRITTEN APPROVAL OF THE PRESIDENT OF FAIRCHILD SEMICONDUCTOR CORPORATION.

As used herein:

- 1. Life support devices or systems are devices or systems which, (a) are intended for surgical implant into the body, or (b) support or sustain life, or (c) whose failure to perform when properly used in accordance with instructions for use provided in the labeling, can be reasonably expected to result in significant injury to the user.
- 2. A critical component is any component of a life support device or system whose failure to perform can be reasonably expected to cause the failure of the life support device or system, or to affect its safety or effectiveness.

ON Semiconductor and  are trademarks of Semiconductor Components Industries, LLC dba ON Semiconductor or its subsidiaries in the United States and/or other countries. ON Semiconductor owns the rights to a number of patents, trademarks, copyrights, trade secrets, and other intellectual property. A listing of ON Semiconductor's product/patent coverage may be accessed at [www.onsemi.com/site/pdf/Patent-Marking.pdf](http://www.onsemi.com/site/pdf/Patent-Marking.pdf). ON Semiconductor reserves the right to make changes without further notice to any products herein. ON Semiconductor makes no warranty, representation or guarantee regarding the suitability of its products for any particular purpose, nor does ON Semiconductor assume any liability arising out of the application or use of any product or circuit, and specifically disclaims any and all liability, including without limitation special, consequential or incidental damages. Buyer is responsible for its products and applications using ON Semiconductor products, including compliance with all laws, regulations and safety requirements or standards, regardless of any support or applications information provided by ON Semiconductor. "Typical" parameters which may be provided in ON Semiconductor data sheets and/or specifications can and do vary in different applications and actual performance may vary over time. All operating parameters, including "Typicals" must be validated for each customer application by customer's technical experts. ON Semiconductor does not convey any license under its patent rights nor the rights of others. ON Semiconductor products are not designed, intended, or authorized for use as a critical component in life support systems or any FDA Class 3 medical devices or medical devices with a same or similar classification in a foreign jurisdiction or any devices intended for implantation in the human body. Should Buyer purchase or use ON Semiconductor products for any such unintended or unauthorized application, Buyer shall indemnify and hold ON Semiconductor and its officers, employees, subsidiaries, affiliates, and distributors harmless against all claims, costs, damages, and expenses, and reasonable attorney fees arising out of, directly or indirectly, any claim of personal injury or death associated with such unintended or unauthorized use, even if such claim alleges that ON Semiconductor was negligent regarding the design or manufacture of the part. ON Semiconductor is an Equal Opportunity/Affirmative Action Employer. This literature is subject to all applicable copyright laws and is not for resale in any manner.

## PUBLICATION ORDERING INFORMATION

### LITERATURE FULFILLMENT:

Literature Distribution Center for ON Semiconductor  
19521 E. 32nd Pkwy, Aurora, Colorado 80011 USA  
**Phone:** 303-675-2175 or 800-344-3860 Toll Free USA/Canada  
**Fax:** 303-675-2176 or 800-344-3867 Toll Free USA/Canada  
**Email:** [orderlit@onsemi.com](mailto:orderlit@onsemi.com)

**N. American Technical Support:** 800-282-9855 Toll Free  
USA/Canada

**Europe, Middle East and Africa Technical Support:**  
Phone: 421 33 790 2910  
**Japan Customer Focus Center**  
Phone: 81-3-5817-1050

**ON Semiconductor Website:** [www.onsemi.com](http://www.onsemi.com)

**Order Literature:** <http://www.onsemi.com/orderlit>

For additional information, please contact your local  
Sales Representative