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New PowerTrench® MOSFET with Shielded Gate Technology Increases System Efficiency and Power Density in Synchronous Rectification Applications

Abstract

Synchronous rectification in a high-performance converter design is essential for low-voltage and high-current applications because significant efficiency and power density improvements can be achieved by replacing Schottky rectification with synchronous rectification MOSFETs. Many critical parameters for synchronous rectification MOSFETs and even parasitic components in devices and printed circuit board directly affect the system efficiency of synchronous rectification. Optimization of the MOSFETs plays an important role in improving efficiency. The PowerTrench® MOSFET with shielded-gate technology can dramatically reduce both on-resistance and gate charge, which are usually in conflict. With soft-body diode characteristics, the new power MOSFETs reduce voltage spikes that cause additional losses in the snubber circuits. For better system efficiency and power density, the characteristics of new PowerTrench® MOSFETs are introduced and compared to other power MOSFETs available in the market. The benefits of these MOSFETs are shown in synchronous rectifier of target application.

Introduction

As our economy moves from paper-based to digital information management; data centers for data processing, storage, and networking play an important role in many industries. However, data centers are becoming increasingly expensive to power and cool. Higher system efficiency and power density in modern data and telecommunication power systems are the core focus since making a small high-efficiency power system means saving space and energy bills. From a topology point of view, synchronous rectification that converts the AC voltage from the transformer back to DC becomes an essential building block for the secondary side of the switched-mode power supply (SMPS) in many applications. This solution offers improved efficiency for these conversion stages with both lower conduction loss and switching losses.[1]-[3] For this reason, synchronous rectification is very popular in low-voltage and high-current applications, such as server power supplies or telecom rectifiers. As shown in Figure 1, it replaces Schottky rectifiers, allowing lower voltage drop. From a device point of view, the power MOSFET transistor has enjoyed significant evolution in the last decade, which enabled new topologies and high power density in power supplies. The key requirements for synchronous rectification MOSFETs are:

- Low R_{SP}
- Low dynamic parasitic capacitances. This also reduces the gate drive power since synchronous rectification circuit is generally operated at high frequency.
- Low Q_{RR} and C_{OSS} reduces reverse current. This becomes a problem when this topology is operated at high switching frequency. At high switching frequency, this current acts as high leakage current.
- Low t_{RR}, Q_{RR}, and less snappy body diode is needed to avoid momentary shoot-through and reduce loss. Snappy diode may require a snubber across each MOSFET.
- Low Q_{gd}/Q_{gs} ratio prevents dynamic turn-on.

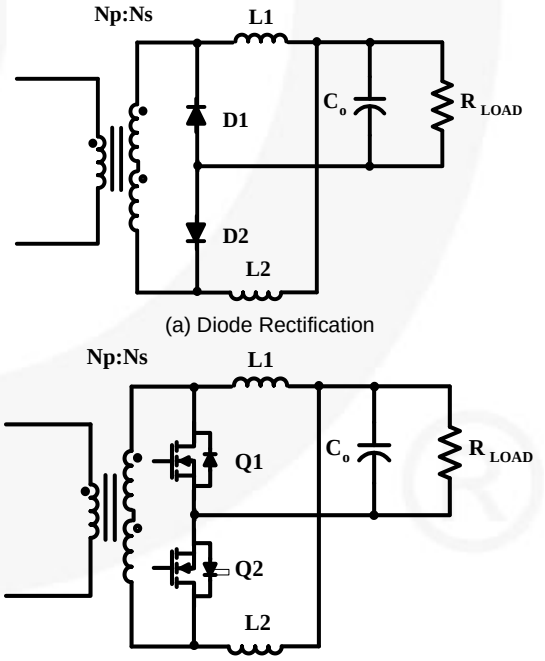

Figure 1. Diode Rectification and Synchronous Rectification

The low- and medium-voltage MOSFETs developed rapidly to accomplish significant performance improvements with trench gate technology after the introduction of planar technology in early 1970s. The trench gate MOSFETs are now the preferred power devices for medium- to low-voltage power applications. These MOSFETs implement a gate structure embedded into a trench region carefully etched into the device structure. The specific on-resistance improves about 30% with this new technology, thanks to the ability to increase channel density and eliminate the JFET resistance component. Power losses in synchronous rectification can be lowered when the product of MOSFET on resistance and drain current is less than the diode forward-voltage drop. However, low on-resistance is not the only requirement for the power switches in terms of synchronous rectification. They should have small gate charge to reduce driving losses. Soft-body diode reverse-recovery characteristics can reduce snubber losses by damping the peak level of voltage spikes. There are also switching losses due to the output charge, Q_{OSS}, and reverse-recovery charge, Q_{rr}. Therefore, critical parameters for low- and medium-voltage MOSFETs; such as $R_{DS(ON)}$, Q_G, Q_{OSS}, Q_{rr}, and reverse-recovery characteristics; directly affect to system efficiency of synchronous rectification. Fairchild designed a new highly optimized power MOSFET, called PowerTrench® MOSFET, with shielded gate technology for synchronous rectification with deep analysis of power losses in synchronous rectification of server power supplies or telecom rectifiers.

Medium Voltage MOSFETs Technologies

The $R_{DS(ON)} \times Q_G$, Figure Of Merit (FOM) is generally considered the single most-important indicator of MOSFET performance in switching mode power supplies. Therefore, several new technologies have been developed to improve the $R_{DS(ON)} \times Q_G$ FOM. While MOSFET technologies and cell structure have dramatically changed through the years, the vertical cell structure of a MOSFET can be classified into three structure types: planar, trench, or lateral. Among the three structures, trench-gated MOSFETs have become the mainstream for high-performance discrete power MOSFETs with $BV_{DSS} < 200$ V.

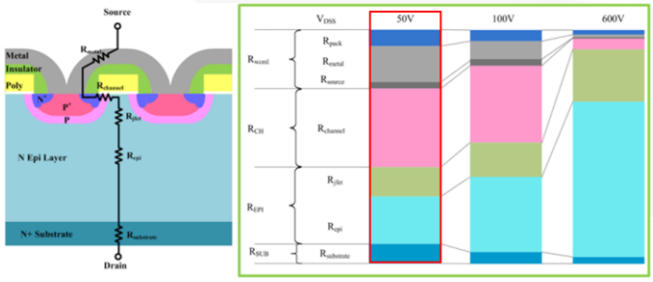

Figure 2. Relative Contribution to $R_{DS(ON)}$ with Different Voltage Ratings

They are chosen primarily for their particularly low specific on resistance and capability for excellent $R_{DS(ON)} \times Q_G$ FOM across the BV_{DSS} spectrum. The trench gate structure can dramatically reduce the channel resistance ($R_{channel}$) and JFET resistance (R_{JFET}) that are the major contributors to on-resistance of low-voltage MOSFETs ($BV_{DSS} < 200$ V), as shown in Figure 2. With compelling advantage of the trench structure in the ability to reduce $R_{DS(ON)}$ by providing the shortest possible current path (vertical) from drain to source, it is possible to increase cell density without any JFET pinch-off effect. The percentage of resistance associated with each region varies dramatically, depending on design and BV_{DSS}. While $R_{DS(ON)}$ is indispensable to the low conduction losses, consideration must be made for enhanced FOM, where trade-offs in trench depths and widths exist to optimize the structure.

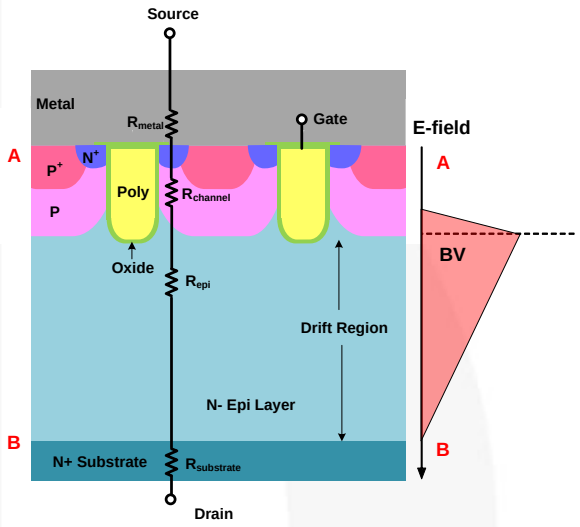

Figure 3. Conventional Trench Gate MOSFET

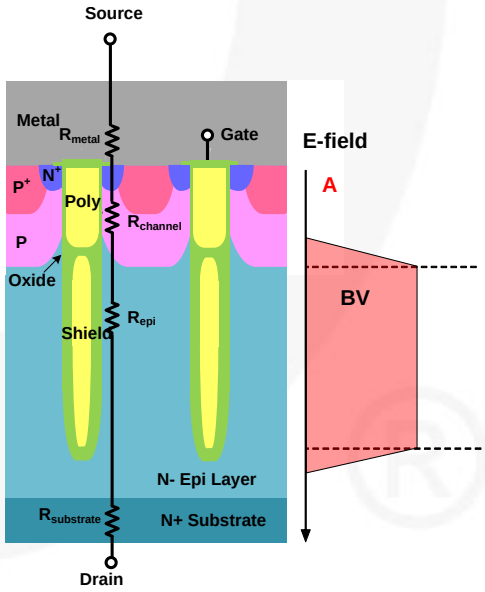

Figure 4. The latest trench MOSFET with shielded gate technology

Variations to the standard trench cell are often designed with the intention of preserving low resistance, while enhancing the FOM. The conventional trench gate structure of Figure 3 enables lower on resistance by increasing the

channel width-to-length ratio. The other concept originally developed for high-voltage devices, but now being used for low-voltage devices as well; is the use of charge balance or super-junction device structures. With the use of the charge balance approach, two-dimensional charge coupling in the drift region can be obtained. The latest middle-voltage power MOSFETs from Fairchild employ this shielded-gate structure, where the shield electrode is connected to the source, as shown in Figure 4. The shield electrode, along with the thicker oxide between electrode and drift region, provides charge balance for drift region. This enables higher doping in the drift region, resulting in reduced drift resistance. The specific resistance of these new medium-voltage power MOSFETs has been significantly improved over the previous generation, while improving on the already superior switching characteristic. Apart from $R_{DS(ON)}$ and Q_G, body diode reverse recovery, internal gate resistance, and the output charge of the MOSFET (Q_{OSS}) are now becoming more relevant in synchronous rectification. The importance of these loss components rises at higher switching frequencies and higher output currents. Fairchild's new medium-voltage MOSFETs are being optimized to minimize the diode reverse recovery as well as the output capacitance. The latest PowerTrench® MOSFET, FDP045N10A, employs shielded-gate structure that provides charge balance. By utilizing this advanced technology, the FOM ($Q_G \times R_{DS(ON)}$)) is 66% and 38% lower than the previous generation and competitor MOSFETs, as shown in Figure 5.

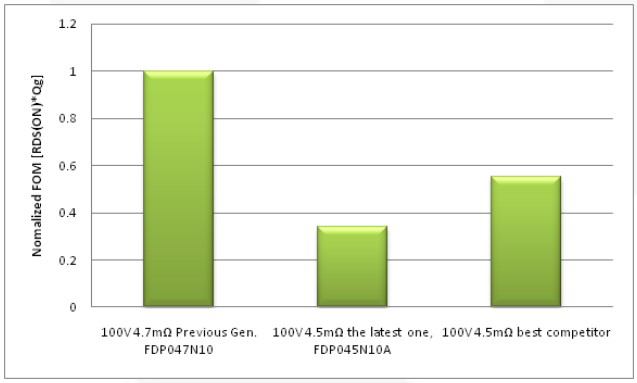

Figure 5. Normalized Figure of Merit (FOM) [$R_{DS(ON)}$*Q_G]

Power Losses in Synchronous Rectification

Conduction Loss

Power losses in secondary rectification are very critical, especially in low-voltage and high-current applications, as shown in Figure 6. Therefore, secondary-side synchronous rectification is an excellent solution to improve system efficiency. As shown in Figure 7, the conduction loss of diode rectifier contributes significantly to the overall power loss in a power supply. The rectifier conduction loss is proportion to the product of its forward-voltage drop, V_F, and the forward current, I_F. Synchronous rectification presents a resistive V-I characteristic. The forward-voltage drop of synchronous rectification can be lower than that of a diode rectifier and, consequently, dramatically reduces the rectifier conduction loss. Conduction loss can be obtained through below equation:

$$P_{Con} = I^2_{RMS} \bullet R_{DS(ON)} \quad (1)$$

For high-voltage MOSFETs, the resistance of packages has not been a concern. $R_{DS(ON)}$ can be achieved at 1~2 mΩ in a TO-220 standard package, depending on the voltage rating, by using modern medium voltage MOSFETs technology. Unlike high-voltage MOSFETs, the package itself contributes a significant portion of the total resistance for medium-voltage MOSFETs due to wire bonding, lead, and source metal. For example, up to around 33% of the $R_{DS(ON)}$ is accounted for by the package resistance in a 75 V/2.3 Ω MOSFET, as shown in Figure 8. SO-8 packages were popular before upgraded power package Power56. Total on resistance of medium-voltage MOSFET can be dramatically reduced by using an SMD package, such as Power56. It can also reduce package inductance that causes undesirable voltage spikes. It enables use of lower $R_{DS(ON)}$ MOSFETs by replacing lower voltage rating MOSFETs.

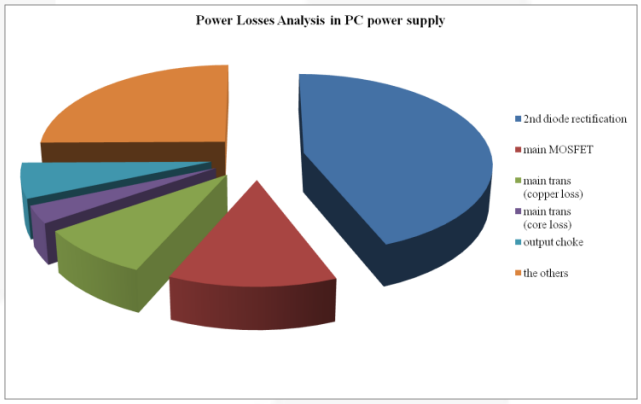

Figure 6. Power Losses Analysis in ATX Power Supply

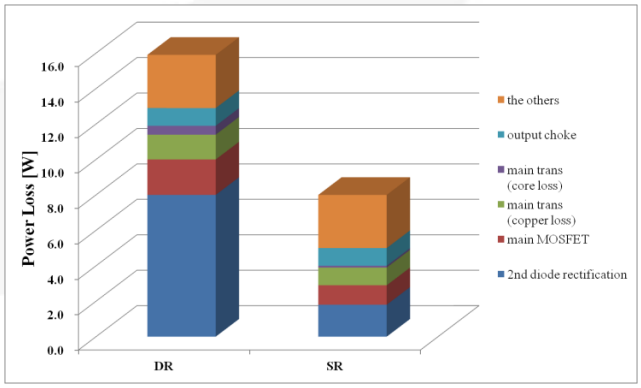

Figure 7. Power Losses Comparison between Diode Rectification and Synchronous Rectification

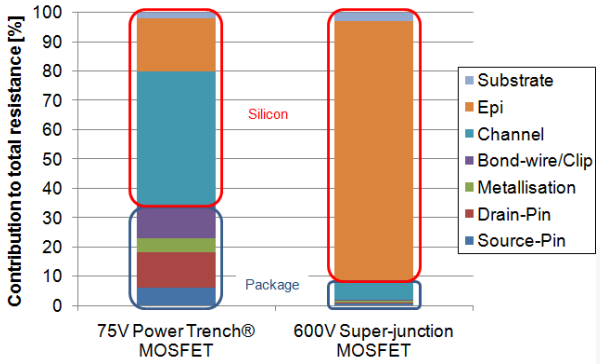

Figure 8. Relative Contribution to $R_{DS(ON)}$ with 75 V MOSFET and 600 V MOSFET

Gate Driving Loss

Major power losses in power switches are conduction and switching losses. There are also capacitive losses caused by output capacitance; off-state losses due to leakage current; and reverse recovery losses. Driving losses at the gate driver are related to Q_G. These losses are often neglected in high-voltage, high-power applications even though the capacitive losses can be more than 50% of total power losses in applications of several Watts. It is important to note that a faulty device with excessive leakage can lead to thermal runaway failure, especially at hot ambient temperatures, but this is a rare occurrence. In low-voltage applications, the driving losses can consume a large portion of the total power losses as low-voltage switches have very low conduction losses compared to high-voltage switches. During light-load conditions, conduction losses are minimal and the driving losses are even more important. As new efficiency guidelines, such as Climate Savers Computing Initiative, are introduced; the driving losses become critical for light-load efficiency.[4] The driving losses can be obtained through Equation (2):

$$P_{drive} = Q_g \cdot V_{gs} \cdot f_s \quad (2)$$

The switching frequency and gate drive voltage are design parameters and the gate charge value is specified in datasheets. In synchronous rectification, one difference from a diode rectifier is that the MOSFET is bidirectional device.

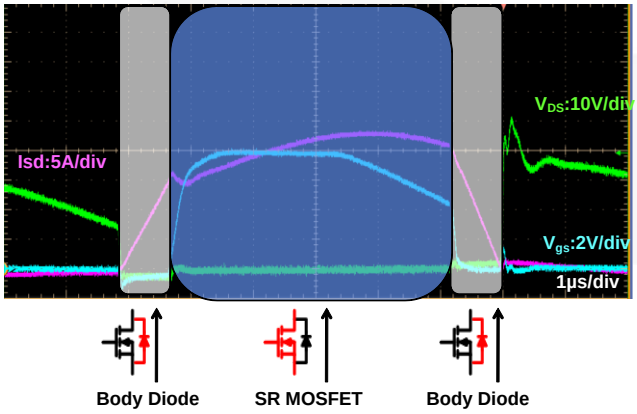

Figure 9. Power MOSFET in Synchronous Rectification

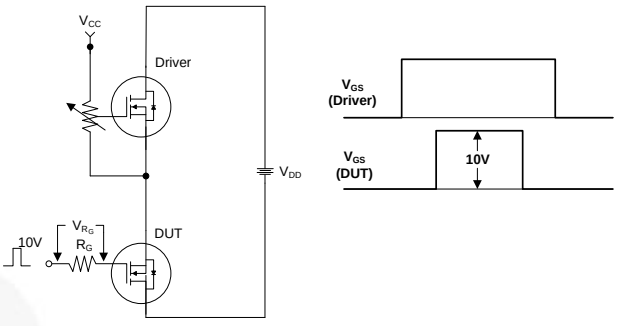

Figure 10. Q_{SYNC} Measurement

Generally, current flows through MOSFET channel from source to drain during conduction time and flows through body diode during dead time, as shown in Figure 9. Since there is body diode turn-on prior to gate turn-on in synchronous rectification, zero-voltage switching (ZVS) is possible for the synchronous switch. Since the MOSFET does soft switching at switch turn-on and turn-off transients, dV_{ds}/dt is zero. Therefore, capacitive current from C_{GD} is also zero. Because of the sequence, the gate charge value in Equation 2 should be selected carefully. As there is no voltage across the synchronous switch during turn-on transient, the "Miller effect" does not occur.[5] Therefore, a resulting gate charge becomes approximately the value of the gate-drain portion of gate charge, Q_{GD} subtracted from total gate charge, Q_G. This is a reasonable estimate for the driving losses; but, in practice, gate charge value in a synchronous switch varies from Q_G-Q_{GD} estimation because there is a negative bias between drain and source in synchronous rectification. However, a positive bias is being used to measure Q_G and Q_{GD} in the datasheets. Also, the curve of the Q_{SYNC} below the V_{th} is similar to the slope above the V_{th} because the drain-source voltage is zero in both regions during ZVS in synchronous rectification. A gate charge for synchronous rectification, Q_{SYNC} can be measured using simple circuitry, as shown in Figure 10. Appropriate driving signals for DUT and driver with a known value of resistor, Q_{SYNC} becomes as Equation 3:

$$Qsync = \frac{1}{R_G} \cdot \int V_{R_G}(t)\ dt \quad (3)$$

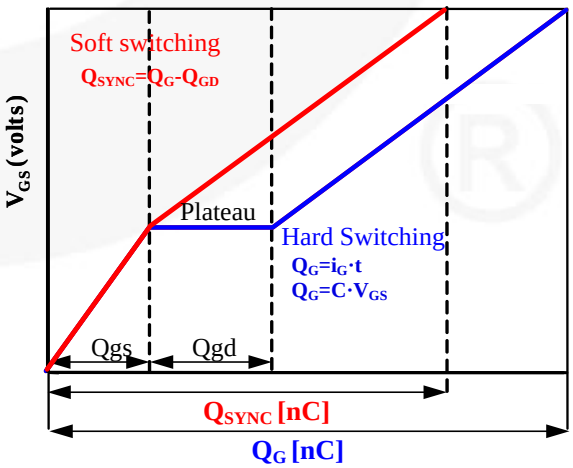

Figure 11. Definition of Q_{SYNC}

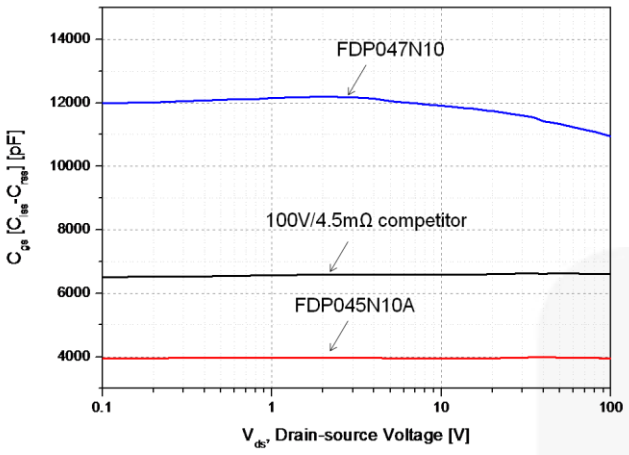

Figure 12. Gate-Source Capacitances Comparisons

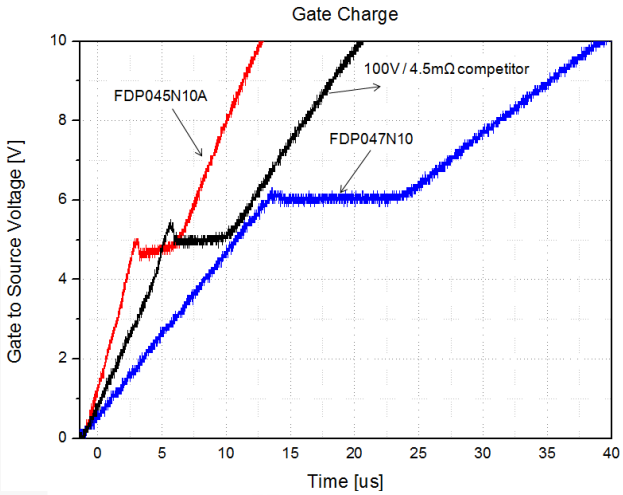

Figure 13. Gate Charge Comparisons

This gives more accurate estimation of the gate driving power losses. A device with smaller Q_{SYNC} shows better performance in synchronous rectification. As shown in Figure 11, there is no plateau region on gate-source voltage of power MOSFFET for synchronous rectification. In synchronous rectification, C_{GS}(C_{ISS}-C_{rss}) is a more critical factor to reduce Q_{SYNC}. As shown in Figure 12 and Figure 13, C_{GS} and Q_G of the FDP045N10A is greatly reduced compared to FDP047N10 and a 100 V / 4.5 mΩ competitor. As shown in Table 1, Q_{SYNC} of the FDP045N10A is reduced by 64% and 34%, compared to the FDP047N10 and the same 100 V / 4.5 mΩ competitor. Figure 14 shows a calculated loss ratio between driving loss and conduction loss in a 24 V synchronous rectification stage with gate driving voltage of 10 V and switching frequency of 100 kHz. When there are two synchronous switches, the gate driving losses of the FDP047N10 is three times higher than the conduction losses at 10% load condition. This graph indicates that the FDP045N10A dramatically reduces driving loss at light-load condition due to small Q_{SYNC}.

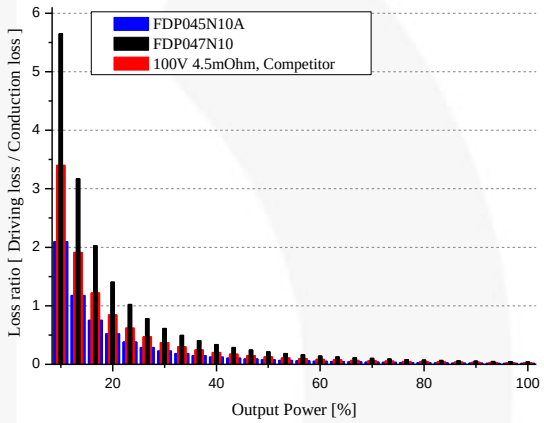

Figure 14. Comparisons of Loss Ratio [Driving Loss / Conduction Loss] According to Output Load

Table 1. Critical Specification Comparison of DUTs

DUTs	Q_{SYNC} (nC)	Q_G (nC)	Q_{GS} (nC)	Q_{GD} (nC)	Q_{rr} (nC)	I_{rrm} (A)	Softness
100 V / 4.5 mΩ, Latest Shielded-Gate Trench MOSFET FDP045N10A	49.5	63.0	18.9	13.5	295.5	12.1	0.45
100 V / 4.7 mΩ, Conventional Trench Gate MOSFET FDP047N10	137.7	182.7	67.5	45.0	290.1	12.9	0.31
100 V/4.5 mΩ Competitor	75.2	95.9	20.7	20.3	379.7	12.8	0.40

Body Diode Losses

During the dead time, body diode conduction occurs. Body diode conduction leads to substantial power loss because of the high voltage drop across the P-N junction compared to the voltage drop caused by the MOSFET channel. This MOSFET loss due to body diode conduction during dead time has a degrading effect on overall efficiency, especially at low voltages and high frequencies. Therefore, the body diode conduction losses can be minimized through proper dead-time management. Gate drivers tend to have effective minimum dead-time. The lower threshold voltage, V_{th}, of the power MOSFET leads to a shorter delay and switching times to allow for much tighter dead-time control, beneficial in reducing body diode conduction loss in synchronous rectification. A lower threshold voltage helps in turning on the MOSFET by reducing the rise time, which can be obtained through below equation:

$$t_r = R_G \cdot C_{iss} / (V_{GS} - V_{th}) \quad (4)$$

Table 2 shows key parameter comparisons between FDP150N10 and FDP150N10A. As shown, the threshold voltage of FDP150N10A is 1.16 V lower than FDP150N10. As shown in Figure 15, the FDP150N10A with a lower threshold voltage MOSFET shows a shorter dead time, up to 40 ns, and less forward current peak that flows through body diode, up to 3.7 A, compared to the FDP150N10.

Table 2. Comparisons of Key Parameters

DUTs	$R_{DS(ON)}$ [mΩ]	V_{TH} [V]	Q_{sync}[nC]	ESR [Ω]
Conventional Trench Gate MOSFET, FDP150N10	11.3	3.57	32.51	1.25
Latest Shielded-Gate Trench MOSFET, FDP150N10A	11.6	2.41	11.87	1.13

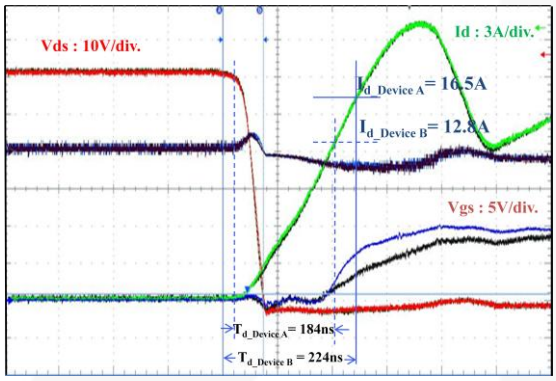

Figure 15. Comparisons of Dead Time According to Threshold Voltage of Power MOSFETs in 90 W Synchronous Rectification

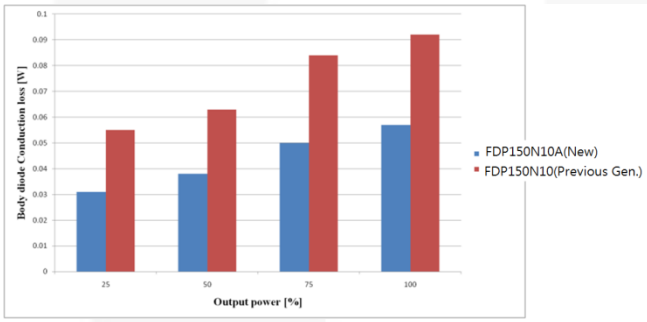

Figure 16. Comparisons of Body Diode Conduction Loss in 90 W Synchronous Rectification

With FDP150N10A, body diode conduction loss has been reduced by 38%~44% compared to FDP150N10, according to output power level shown in Figure 16. Body diode conduction loss can be calculated by Equation (5):

$$P_D = V_F \cdot I_{OUT} \cdot (t_{BD(rise)})\, f_s \quad (5)$$

At MOSFET turn-off transient, the Q_{rr} has to be removed and C_{oss} must be charged up to the transformer voltage of the secondary side. The reverse-recovery charge, Q_{rr}, also produces power losses in the system while turning off the switch. Power losses by the body diode characteristics can be obtained through Equation (6):

$$P_{Qrr} = Q_{rr} \cdot V_{ds} \cdot f_s \quad (6)$$

The diode reverse recovery time (t_{rr}) and reverse recovery (Q_{rr}) specified on datasheets are generally used by loss calculations as straight-forward switching losses. A word of caution on using datasheet Q_{rr} values for loss calculations: the reverse-recovery current of a body diode is a function of many parameters such as forward current, I_F; conduction time; reverse-recovery current slew rate, di_F/dt; DC bus voltage; and junction temperature, T_J. An increase in any of these conditions generally results in increased Q_{rr}. Datasheet conditions are usually much different from typical converter operating conditions. Since switching converters attempt to switch the power MOSFET as fast as possible; edge rates, such as di_F/dt, can be up to ten times faster than the datasheet conditions. However, conduction time of the body diode in actual applications is much shorter. In conclusion, power loss due to Q_{rr} is not easy to quantify and often the best way to evaluate is measuring system efficiency. The stored charge in output capacitance, Q_{oss}, also affects to the capacitive losses. This portion of loss is proportional to the switching frequency and V_{DS}. Therefore, power losses by C_{oss} can be obtained through Equation 7:

$$P_{coss} = 0.5 \cdot Q_{oss} \cdot V_{ds} \cdot f_s \quad (7)$$

Voltage Spikes Losses

General guidelines to minimize the undesirable voltage spikes include short and thick board patterns and minimized current loops. However, it is not easy to apply all of them due to size and cost limitations. Sometimes designers need to consider mechanical structures, like heat sinks and fans, and sometimes are forced to use single-sided printed circuit board due to cost constraints. For a practical alternative, snubbers can be used to manage voltage spikes within the maximum drain-source voltage ratings. Additional power losses are inevitable in this case. In addition, the power losses due to the snubbers are not negligible at light load. Besides the circuit board parameters, device characteristics also affect to the voltage spike level. In synchronous rectification, a major device-related parameter is a softness of the body diode during reverse recovery. Basically, reverse-recovery characteristics of diodes are determined by device design. There are several control inputs that affect to the reverse recovery, but when the conditions are fixed, a diode always shows the same behavior. Therefore, device-level evaluation results are very effective to assess what will occur in the system. Figure 17 shows the reverse-recovery waveforms of two different devices with very similar ratings. In the reverse-recovery current waveform, a time

from zero crossing to peak reverse current is called t_a. t_b is defined as a time from the peak to return to zero. From the t_a and t_b, softness factor is defined as t_b/t_a. A soft device has softness >1 and a device is called "snappy" when its softness is <1. As shown in Figure 17, a snappy diode shows larger peak voltage during reverse recovery. When all situations are equal, snappy diodes always have higher voltage spikes that cause additional losses in the snubber circuits. At light-load conditions, this can be more important than having 1 mΩ less $R_{DS(on)}$. Figure 18 shows the parasitic capacitances and resistances and its equivalent circuit of the shielded gate trench technology. Intrinsic shield resistance and two capacitances, R_{shield}, $C_{Drain-Shield}$, and $C_{Gate-Shield}$, inserted with dashed lines in the equivalent circuit, act as virtual snubbers. Furthermore, low reverse-recovery charge and the soft reverse-recovery body diode of new PowerTrench® MOSFET reduces the undesirable voltage spikes or oscillation in synchronous rectification, eliminating the snubber circuit or replacing a higher voltage rating MOSFET, which enhances efficiency and reduces the design bill of materials. Figure 19 - Figure 21 show measured peak drain-source voltage levels due to body diode characteristics comparing Fairchild's FDP045N10A, FDP047N10, and a 100 V / 4.5 mΩ competitor at I_D=50 A, V_{DD}=50 V, and di/dt of 400 A/µs.

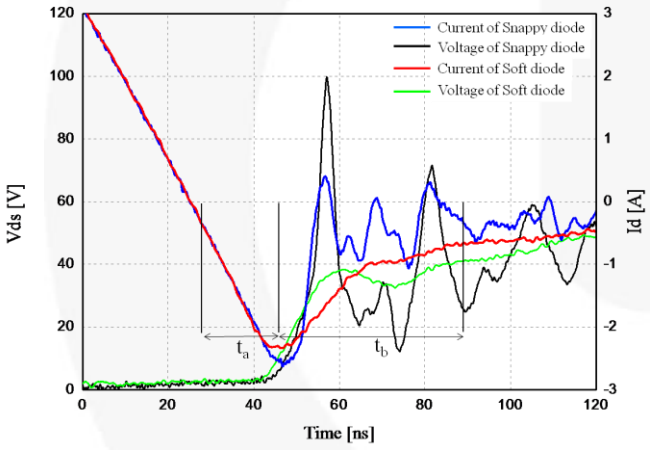

Figure 17. Reverse Recovery Waveforms According to Softness

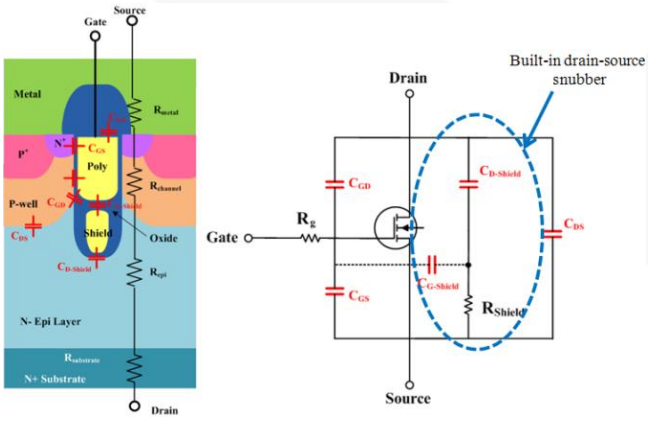

Figure 18. Parasitic Capacitances and Resistances (Left) and its Equivalent Circuit (Right) of the Shielded Gate Trench Technology

The peak drain-source voltage of the FDP045N10A during body diode reverse recovery is lower by 20.8 V and by 6.5 V than that of FDP045N10 and by 100 V / 4.5 mΩ compared to the closest competitor.

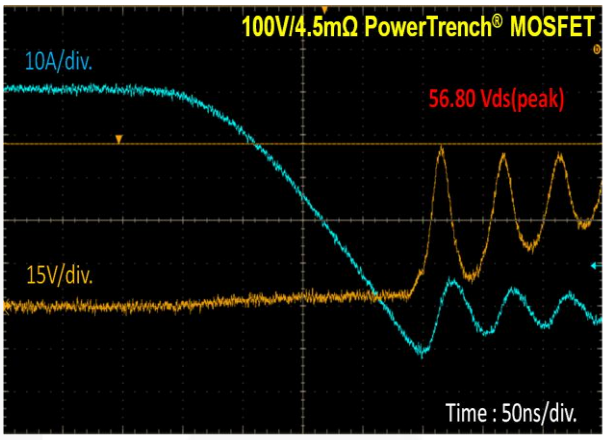

Figure 19. 100 V / 4.5 mΩ, Shielded-Gate Trench MOSFET, FDP045N10A

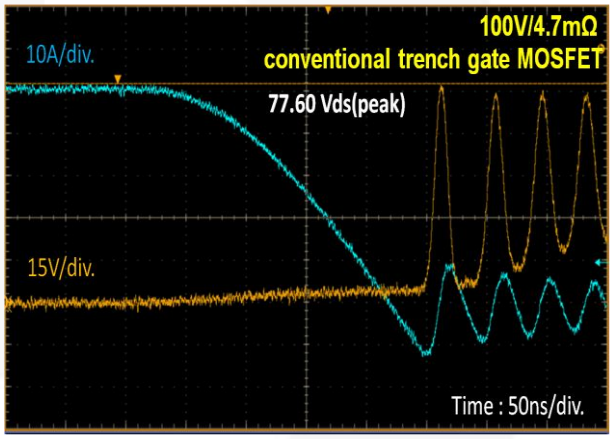

Figure 20. 100 V / 4.7 mΩ, Conventional Trench Gate MOSFET

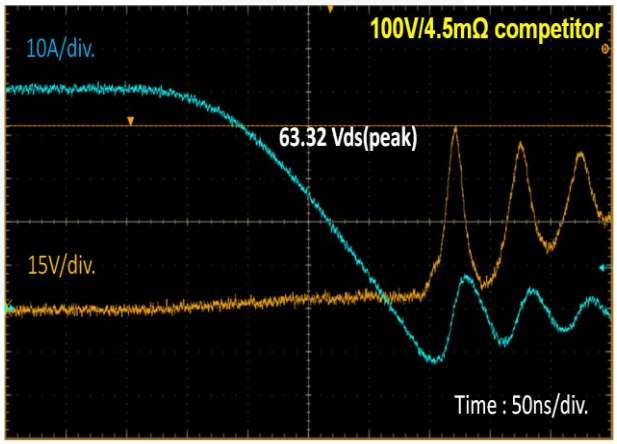

Figure 21. 100 V / 4.5 mΩ Competitor Voltage Spikes Comparisons Under Reverse-Recovery Behavior

Parasitic Inductance Effects

Parasitic inductance can strongly influence MOSFET switching characteristics, usually causing increased switching losses and deviations from expected performance. Parasitic inductance arising from both component packaging and circuit layout is the reality of any circuit.[6][7] Figure 22 shows a simplified schematic for a power MOSFET with all parasitic components. Low $R_{DS(on)}$ and low inductance packages are a must for low- and medium- voltage MOSFETs to achieve best switching performance and reduced conduction losses for highest efficiency. The length of the lead takes quite a bit of the source inductance of the package. Industry standard through-hole type TO-220 package has 7 nH of typical lead inductance, but typical lead inductance of PQFN56 SMD package is only 1 nH. Other important parasitic components are layout parasitic inductance and capacitance. In circuit board layout, 1 cm of trace pitch has an inductance of 6-10 nH. These parasitic inductances directly affect to body diode reverse-recovery characteristics and peak voltage spikes. The body diode recovery charge on a datasheet is generally the sum of C_{OSS} displacement current, the recovered minority carrier current, and the reactive currents arising from common-source inductance of the test circuit, as shown Figure 23.

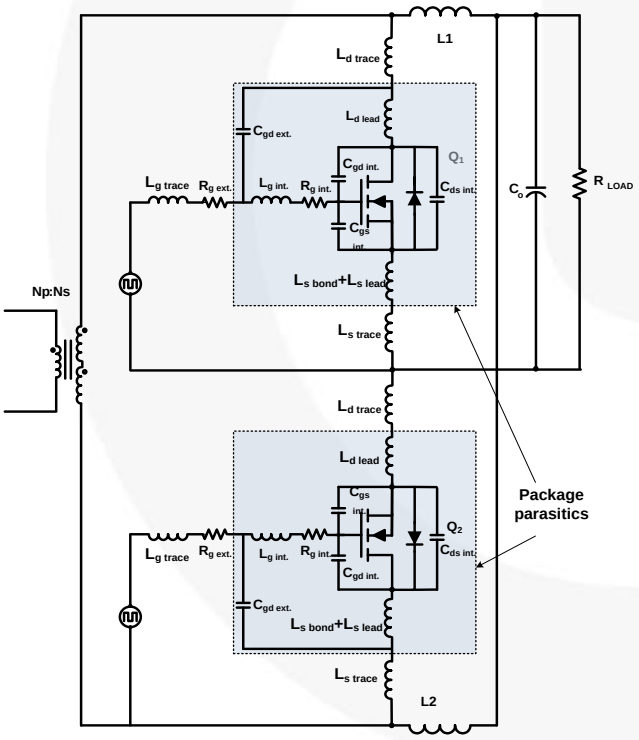

Figure 22. Power MOSFET with Internal and External Parasitic Components in Synchronous Rectification

The addition of common-source inductance effectively reduces system efficiency by increasing Q_{rr} and inducing a voltage across the MOSFET. Figure 24 shows the simulation and Figure 25 the experimental waveforms of body diode reverse recovery with the same MOSFET in TO-220 and Power56 packages. It is clear that higher inductance can cause larger Q_{rr} and higher peak voltage. Body diode performance of the same device in TO-220 and Power56 package is also evaluated.

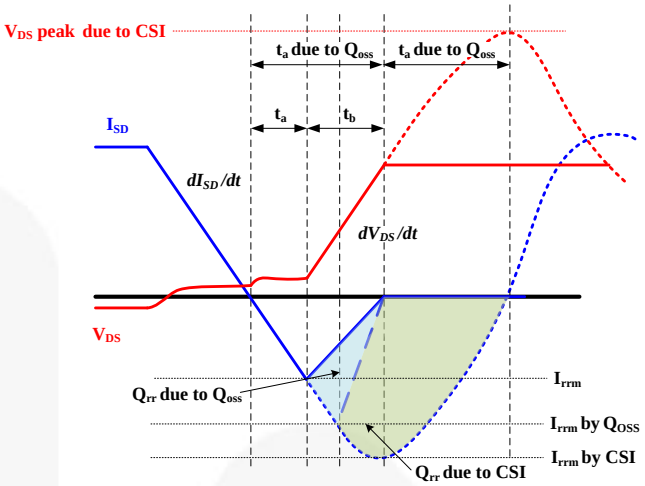

Figure 23. Body Diode Reverse Recovery Waveforms Considering Common Source Inductance (CSI)

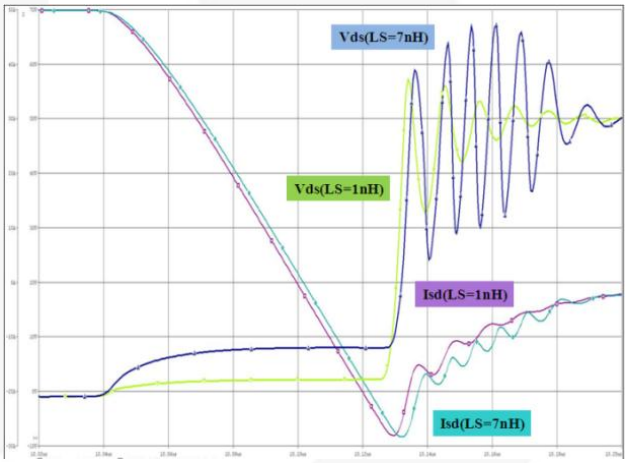

Figure 24. Body Diode Reverse Recovery Waveforms Comparisons According to Source Inductance (Simulation Result)

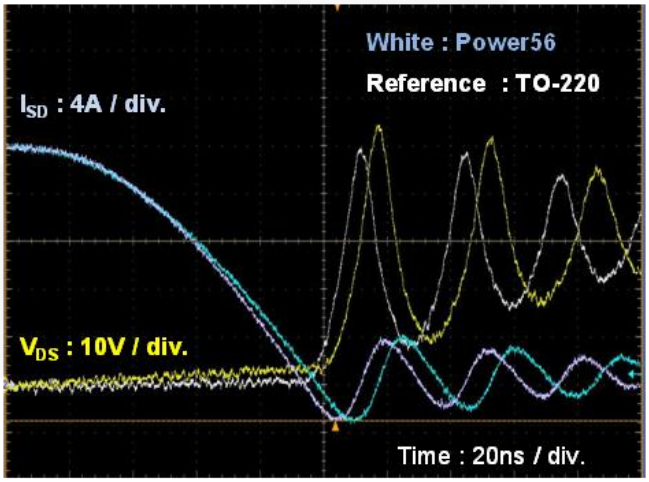

Figure 25. Body Diode Reverse Recovery Waveforms Comparisons According to Source Inductance (Experimental Result)

Table 3, shows a reverse-recovery performance comparison with the same silicon in both Power56 and TO-220 packages. As shown in Table 3, $R_{DS(ON)}$ is reduced 0.9 mΩ, Q_{rr} is reduced 12%, and the peak voltage is reduced from 49.6 V to 54.45 V by using Power56 package instead of TO-220 package. Minimizing common-source inductance is critical to system efficiency.

Figure 26 shows the system efficiency comparison for the three devices from Table 1 in a 500 W phase-shifted full-bridge converter with synchronous rectification. The total system efficiency with the FDP045N10A, the latest shielded-gate trench MOSFET, is 84.59% at light-load condition and 88.99% at full-load condition. It is 0.3% higher than that of FDP047N10, a conventional trench gate MOSFET, and 0.2% higher than that the 100 V / 4.5 mΩ competitor, due to lower driving loss and output capacitive loss at 10% load condition. From the efficiency results shown in Figure 26, it is clear that the FDP045N10A, with the latest shielded-gate trench MOSFET, shows significant loss reduction under full- and light-load conditions because of its optimum design. MOSFET parameters have the most impact on the efficiency of synchronous rectification.

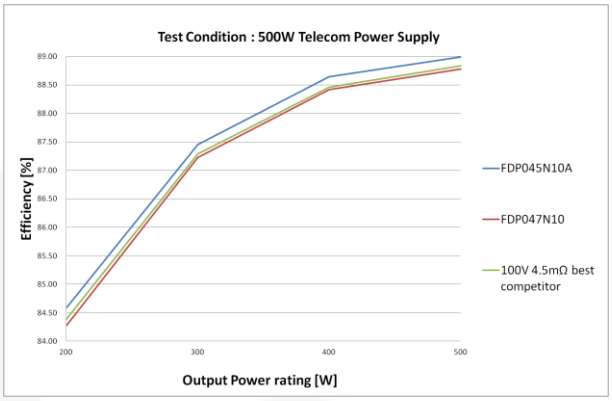

Figure 26. Efficiency comparisons in 500 W Synchronous Rectification

Table 3. Body Diode Performance Comparisons by Package

DUTs (Same Silicon Device)	V_{ds}(peak) [V]	I_{rrm} [A]	Q_{rr} [nC]	t_{rr} [ns]	di/dt [A/µs]
60 V / 7.4 mΩ in Power56	49.60	3.04	36.21	16.96	407
60 V / 8.5 mΩ in TO-220	54.45	3.20	41.23	18.84	368

Conclusion

More than just low $R_{DS(on)}$ must be considered to create highly efficient power switches for synchronous rectification. As light-load efficiency is getting important, the gate driving losses and the snubber losses become serious factors. Consequently, low Q_{SYNC} and soft body diode are critical characteristics for better synchronous rectification efficiencies. However, the $R_{DS(on)}$ is still a key parameter of the application. Fairchild's latest shielded gate PowerTrench® MOSFET, which combines a smaller Q_{SYNC} and soft reverse-recovery intrinsic body diode performance with fast switching, can substantially improve the efficiency of synchronous rectification.

Table 4. PowerTrench® MOSFETs Available

Part Number	BV_{DSS}	$R_{DS(ON)\ Max}$ at V_{GS} = 10 V	$Q_{g\ Typ.}$ at V_{GS} = 5 V	I_D (A), T_C = 25°C (Silicon Limited)	Q_{rr} Typ. at di_F/dt=100 A/µs	Package
FDMS015N04B	40 V	1.5 mΩ	87 nC	100 A	90 nC	Power56
FDP020N06B	60 V	2.0 mΩ	206 nC	313 A	194 nC	TO-220
FDMS030N06B	60 V	3.0 mΩ	75 nC	100 A	85 nC	Power56
FDP023N08B	75 V	2.350 mΩ	150 nC	242 A	114 nC	TO-220
FDP027N08B	80 V	2.70 mΩ	137 nC	223 A	112 nC	TO-220
FDB024N08BL7	80 V	2.40 mΩ	137 nC	229 A	112 nC	D^2PAK7L
FDP032N08B	80 V	3.3 mΩ	111 nC	211 A	102 nC	TO-220
FDMS037N08B	80 V	3.7 mΩ	76.8 nC	100 A	84 nC	Power56
FDMS039N08B	80V	3.9 mΩ	77 nC	100 A	80 nC	Power56
FDP039N08B	80 V	3.9 mΩ	102 nC	142 A	87.9 nC	TO-220
FDP053N08B	80 V	5.3 mΩ	65.4 nC	120 A	62.5 nC	TO-220
FDB035N10A	100 V	3.5 mΩ	89 nC	214 A	129 nC	D^2PAK
FDP036N10A	100 V	3.6 mΩ	89 nC	214 A	129 nC	TO-220
FDP045N10A	100 V	4.5 mΩ	57 nC	164 A	120 nC	TO-220
FDPF045N10A	100V	4.5 mΩ	57 nC	67 A	120 nC	TO-220F
FDI045N10A	100 V	4.5 mΩ	57 nC	164 A	120 nC	I^2PAK
FDP085N10A	100 V	8.5 mΩ	31 nC	96 A	80 nC	TO-220
FDPF085N10A	100 V	8.5 mΩ	31 nC	40 A	80 nC	TO-220F
FDP150N10A	100 V	15 mΩ	16.2 nC	50 A	55 nC	TO-220
FDH055N15A	150 V	5.5 mΩ	92 nC	167 A	342 nC	TO-247
FDP075N15A	150 V	7.5 mΩ	77 nC	130 A	264 nC	TO-220
FDB075N15A	150 V	7.5 mΩ	77 nC	130 A	264 nC	D^2PAK
FDP083N15A	150 V	8.3 mΩ	64.5 nC	105 A	268 nC	TO-220
FDB082N15A	150 V	8.3 mΩ	64.5nC	105 A	268 nC	D^2PAK
FDB110N15A	150 V	11 mΩ	47 nC	92 A	255 nC	D^2PAK
FDPF190N15A	150 V	19 mΩ	30 nC	27.4 A	180 nC	TO-220F
FDB390N15A	150 V	39 mΩ	14.3 nC	27 A	131 nC	D^2PAK
FDPF390N15A	150 V	39 mΩ	14.3 nC	15 A	131 nC	TO-220F
FDD390N15A	150 V	39 mΩ	14.3 nC	26 A	131 nC	DPAK
FDPF770N15A	150 V	77 mΩ	8.6 nC	10 A	124 nC	TO-220F

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