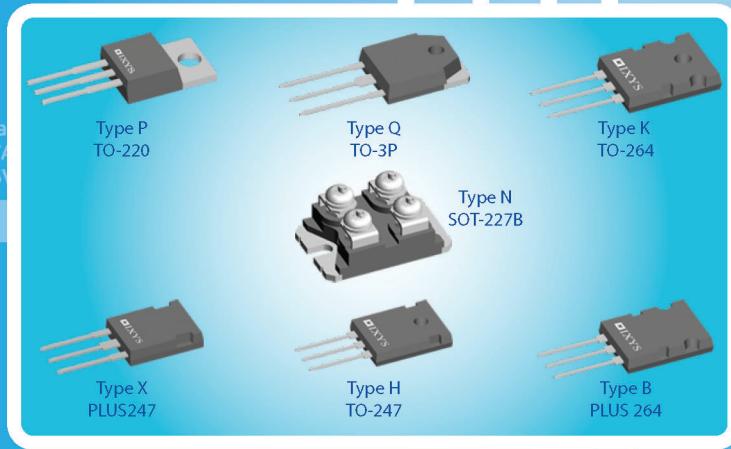


POLAR3™ POWER MOSFETS

NEXT GENERATION OF ENERGY-EFFICIENT AND RELIABLE POWER-SWITCHING SOLUTIONS



Comparison between HiPerFET™ MOSFETs and Super Junction MOSFETs

With the introduction of P3-series HiPerFET™ power MOSFETs, IXYS sets a milestone in HiPerFET™ technology, provides one of the best solutions in power MOSFETs for medium to high frequency designs. These devices have an optimum combination of low on-resistance ($R_{DS(on)}$), low gate charge (Q_G), a fast intrinsic diode for low reverse-recovery (Q_{rr}) and improved turn-off dV/dt immunity. The enhanced dV/dt ratings offer significant safety margins for the stresses encountered in high-voltage switching applications.

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Additional features include low thermal resistances (R_{thJC}), high power dissipation (P_D), and high avalanche energy capabilities (E_{AS}). These outstanding electrical and thermal characteristics are essential for implementing improved power efficiency and reliability in today's demanding high-voltage conversion systems. Innovative designs and process technologies yield switching characteristics that can challenge the total switching performance (conduction + switching) of a comparable super junction (SJ) power MOSFET available in the market [1].

The objective of this article is to explore the switching characteristics and to present a comparison between P3-series HiPerFET™ power MOSFETs and super junction (SJ) power MOSFETs under the same operating conditions. We have selected three SJ-MOSFETs: IPW60R041C6, FCH76N60NF and STW88N65M5 and one P3-series MOSFET: IXFX80N60P3 with similar characteristics in order to have a correct comparison. Table 1 shows the principal characteristics of these devices.

Symbol	Super Junction (SJ) power MOSFETs			P3-series MOSFET	Unit
	IPW60R041C6	STW88N65M5	FCH76N60NF	IXFX80N60P3	
V_{DS}	600	650	600	600	V
I_D	77	84	73	80	A
I_{DM}	272	336	218	200	A
$R_{DS(on)}$ (max)	0.041	0.029	0.038	0.070	Ω
P_D	481	450	543	1300	W
Q_G	290	204	230	190	nC
T_{JM}	150	150	150	150	°C
I_A	13	15	24	40	A
E_{AS}	1954	2000	7381	2000	mJ
t_{rr}	950	660	200	250	nS

Table 1: Principal characteristics of SJ power MOSFETs and One P3-series MOSFET ($T_J = 25^\circ\text{C}$ unless otherwise specified)

Based on Table 1, IXFX80N60P3 has better values on Q_G , P_D , I_A and t_{rr} than that of SJ devices.

Gate Charge Evaluation

Figure 1 shows gate voltage vs. gate charge plots for IXFX80N60P3 (red), IPW60R041C6 (blue), STW88N65M5 (light blue) and FCH76N60F (green) under the same operating conditions.

IXFX80N60P (Red line) shows much better gate charge characteristics than that of SJ devices. The advantages of using IXFX80N60P3 can be easily understood from its gate charge curve.

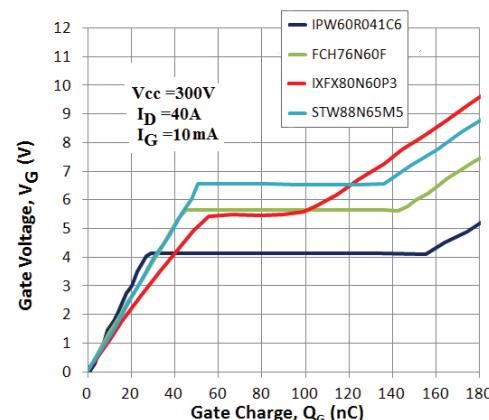


Figure 1: Gate voltage vs. Gate charge plots for IXFX80N60P3 (red), IPW60R041C6 (blue), STW88N65M5 (light blue) and FCH76N60F (green).

High frequency switching applications such as switch mode power supplies (SMPS) and uninterruptible power supplies (UPS) will greatly benefit from the low total gate charge (Q_G) and gate-to-drain charge (Q_{GD}) observed for IXFX80N60P. Low Q_G and Q_{GD} characteristic allows designers the ability to boost power conversion efficiency through the use of high-speed switching and to promote the use of smaller passive components, thus freeing up additional PCB real-estate and reducing the cost of bulky passive components. In addition, the low total gate charge (Q_G) reduces the amount of gate drive power requirement (Gate Drive Power = $Q_G \times V_{GS} \times f_{SW}$) needed for the Power MOSFET to fully conduct. Since these devices require less gate drive power, simple economical gate drive solutions can be implemented, further reducing cost and complexity [2].

Body Diode Reverse Recovery Evaluation

Figure 2 shows an inductive switching circuit that IXYS uses for MOSFET's body diode reverse recovery evaluation. The gate and source of the D.U.T. (Q1) are shorted to test the body diode.

Q2 acts as a control device which is subjected to a double pulse. The current ramps in Q2 and freewheels through the D.U.T. body diode when Q2 turns off. When Q2 is turned on again by the second pulse, the D.U.T. body diode must recover before Q2 voltage can drop. During diode reverse recovery, its reverse current goes to Q2 along with the load current. The reverse recovery dI/dt can cause large voltage overshoots (Ldi/dt) due to circuit and package lead's stray inductance. Figure 3 demonstrates the test waveforms at 75°C operation. The larger the reverse current and the longer recovery time translate into more reverse recovery losses.

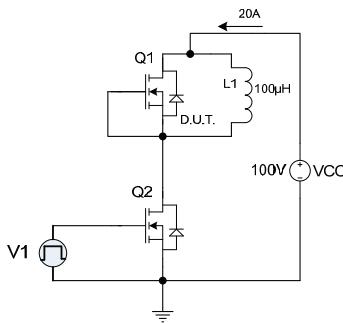


Figure 2: Body diode reverse recovery test setup for MOSFET. The test conditions are $V_{CC}=100V$, $I_D=20A$, $V_{GS}=10V$ and $L=100\mu H$ and $di/dt=200A/ns$.

Table 2 summarizes the reverse recovery test parameters for each device at 75°C operation. IXFX80N60P has the second fastest recovery time and the lowest peak reverse current. Severe voltage spikes are generated by FCH76N60NF (>320V), STW88N65M5 (>350V), FCH76N60NF (>140V) and comparatively very small by IXFX80N60P. In comparing with IPW60R041C6, we can see that the reverse recovery time of IXFX80N60P is 37% of IPW60R041C6. The peak reverse current is cut down to 30% and the reverse recovery energy is reduced by 80% of IPW60R041C6. Lower Err leads to lower switching loss. This is often the largest single component of switching loss in a switching converter [4].

Part Number	trr (ns)	Irrm (A)	Reverse-recovery energy, Err (Joules)
IXFX80N60P	200	24	2.18e-04
IPW60R041C6	540	80	8.72e-04
FCH76N60NF	165	30	1.65e-04
STW88N65M5	330	52	2.74e-04

Table 2: Diode Reverse Recovery parameters at 75°C operation.

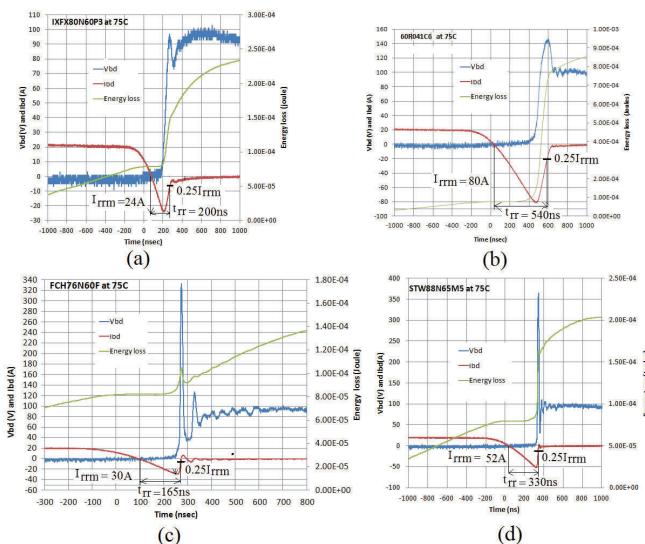


Figure 3: Body diode reverse recovery waveforms at 75°C operation: (a) IXFX80N60P, (b) IPW60R041C6, (c) FCH76N60F and (d) STW88N65M5.

Because of superior intrinsic diode characteristics, P3-series MOSFETs can eliminate the need for discrete anti-parallel high voltage diodes used in conventional designs, thereby reducing part count, simplifying PCB layouts, reducing overall losses and improving power density

Turn-off and Turn-on Switching

Turn-on and turn-off switching comparisons with SJ power MOSFETs have been carried out in order to give evidence to the performance of P3-series power MOSFET. Figure 4 shows a half-bridge inductive load switching circuit for this test. The gate and source of the top transistor (Q1) are shorted. The bottom transistor (Q2) with a gate resistor (RG1) is used as the D.U.T. for evaluating turn-on and turn-off performance under the same operating conditions: $V_{CC}=300V$, $I_D=20A$, $V_{GS}=15V$, $L=100\mu H$ and $R_{G1}=20\Omega$.

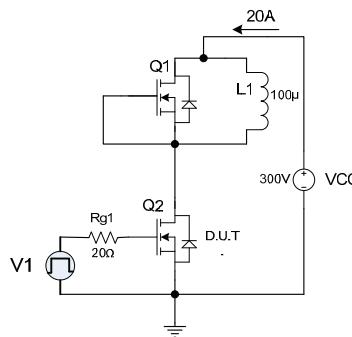


Figure 4: Test circuit for turn-on and turn-off characteristics of power MOSFET.

Turn off Characteristics

The turn-off waveforms are shown in Figure 5 for 75 oC operation. The quantities measured are the energy losses (E_{off}), the fall time of the drain current (t_{fi}), the rise time of the drain voltage (t_{rv}) and the current slope (di/dt), which are presented in Table 3.

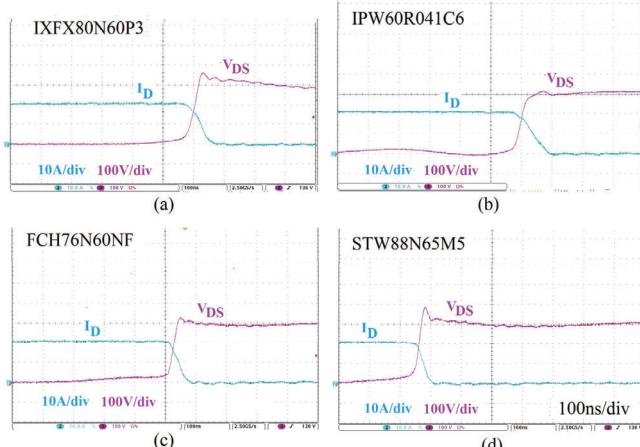


Figure 5: Turn-off waveforms at 75 oC operation: (a) IXFX80N60P3 (b) IPW60R041C6, (c) FCH76N60F and (b) STW88N65M5.

Devices	E_{off} (μJ)	t_{fi} (ns)	t_{rv} (ns)	di/dt [A/ns]
IXFX80N60P3	322	51	24	0.260
IPW60R041C6	449	87	46	0.284
FCH76N60NF	350	68	28	0.210
STW88N65M5	420	58	27	0.177

Table 3: Extracted turn-off switching parameters at 75 oC operation

According to parameters in table 3, under the same operating conditions, E_{off} of IXFX80N60P is better than that of all SJ devices. Fall and rise times (t_{fi} and t_{rv}) of IXFX80N60P are better than all SJ devices. Therefore, IXYS P3-series MOSFET IXFX80N60P behaves

better than most of SJ devices in terms of turn-off energy losses, fall and rise times. These results are reflected in the computation of di/dt as well [4].

Turn on Characteristics

The turn-on waveforms are shown in Figure 6 for 75 °C operation. The quantities measured are the turn-on energy losses (E_{on}), the rise time of the drain current (t_{ri}), the fall time of the drain voltage (t_{fv}) and the current slope (di/dt), which are presented in Table 4.

Devices	Peak Current (A)	E_{on} (mJ)	t_{ri} (ns)	t_{fv} (ns)	di/dt [A/ns]	t_{fr} (ns)	I_{RRM} (A)
IXFX80N60P3	80	1.14	30	146	0.260	174	60
IPW60R041C6	89	1.39	32	149	0.284	212	68
FCH76N60NF	79	1.43	32	158	0.210	155	59
STW88N65M5	108	2.45	43	215	0.177	228	87

Table 4: Extracted turn-on switching parameters

According to parameters in table 4, under the same operating conditions, E_{on} of IXFX80N60P is better than that of all SJ devices. Rise and fall times (t_{ri} and t_{fv}) of IXFX80N60P are much better than all SJ devices. Therefore, IXYS P3-series MOSFET IXFX80N60P behaves better than most of SJ devices in terms of turn-off energy losses and the switching speed. These results are reflected in the computation of di/dt as well [4].

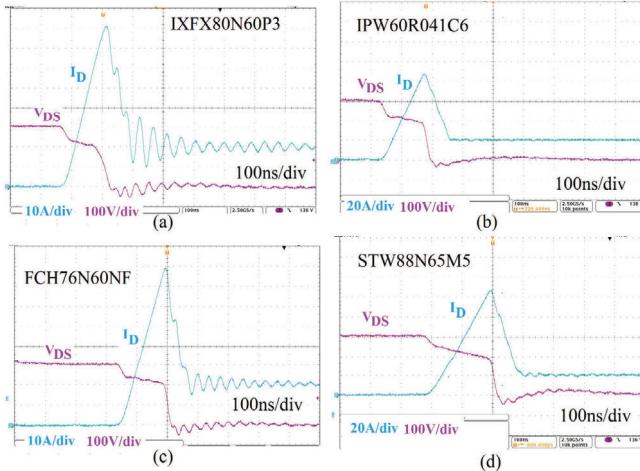


Figure 6: Turn-on waveforms at 75 °C operation: (a) IXFX80N60P3 (b) IPW60R041C6, (c) FCH76N60F and (d) STW88N65M5.

Intrinsic body diode plays an important in the turn-on behavior of the device. The peak current during turn-on is strongly depended on both the di/dt of the drain current and the intrinsic characteristics of the diode. The peak current values are 80A for IXFX80N60P, 89A for IPW60R041C6, 79A for FCH76N60NF and 108A for STW88N65M5.

A Case Study

100 kHz switching with 50% duty cycle

Table 5 summaries the reverse-recovery energy, inductive turn-on and turn-off energy and the conduction energy losses for both MOSFET and body diode under 75 °C operation. All energies are in

Part number	Diode reverse-recovery energy loss	Inductive switch energy loss			Conduction energy loss at 50% duty cycle	Total Energy Loss/Cycle (J)
		E_{off} (J)	E_{on} (J)			
IPW60R041C6	8.72E-04	4.49E-04	1.39E-03	2.90E-03	1.10E-04	2.90E-03
FCH76N60NF	1.65E-04	3.50E-04	1.43E-03	2.11E-03	8.60E-05	2.11E-03
IXFX80N60P3	2.18E-04	3.22E-04	1.14E-03	1.91E-03	1.60E-04	1.91E-03
STW88N65M5	2.74E-04	4.20E-04	2.45E-03	3.29E-03	6.00E-05	3.29E-03

Table 5: Reverse-recovery energy, switching and conduction switching losses in joules at 75 °C operation.

joules. The conduction energy are computed using datasheet parameters (V_f and $R_{DS(on)}$) at specific temperature, assumed device current $I_D=20A$ and duty cycle-50%.

The efficiency of a power converter mainly depends on the power losses on the switching devices. The total power losses can be divided into the following two major items: switching power losses and conduction power losses:

$$P_{total} = P_{sw} + P_{con} = (P_{off} + P_{on}) + P_{con}$$

Table 6 presents the total power losses (P_{total}), total switching power losses (P_{sw}) and total conduction power losses (P_{con}) for 75 °C operation. IXFX80N60P rows are marked with dark blue in table 6. IXFX80N60P3 has total power losses of 191 watts whereas IPW60R041C has 289 watts, FCH76N60NF has 210 watts and STW88N65M5 has 329 watts.

Part Number	Switching Power Loss, P_{sw} (W)			Conduction Power Loss, P_{con} (W)			Total Power Loss, P_{total} (W)
	Diode Loss (W)	MOSFET Loss (W)	Total Switching Loss (W)	Diode loss (W)	MOSFET Loss (W)	Total Cond. Loss (W)	
IPW60R041C6	87.2	183.9	271.1	7.5	11.0	18.5	289.6
FCH76N60NF	16.5	178.0	194.5	7.5	8.6	16.1	210.6
IXFX80N60P3	21.8	146.2	168.0	7.0	16.0	23.0	191.0
STW88N65M5	27.4	287.0	314.4	9.0	6.0	15.0	329.4

Table 6: Total energy loss (in joules), total switching power loss (P_{sw}), total conduction power loss (P_{con}) and total power loss (P_{total}) for different MOSFETs at 75 °C operation.

In this article a full analysis of advantages and disadvantages of a P3-series MOSFET relative to comparable SJ power MOSFETs has been presented. The switching characterization shows the better performances of the P3-series MOSFETs in comparison with SJ MOSFETs available in the market now.

Applications such as motor drives, lamp ballasts, laser drivers, DC-DC converters, battery chargers, solar inverters and robotic control will greatly benefit from the superior performance, energy savings, rugged design, and cost effectiveness of these P3-Series Power MOSFETs.

Power MOSFET's principal limitation in high voltage devices is the on-state resistance ($R_{DS(on)}$) which reduces the current carrying capability. Because of high on-resistance, power MOSFETs experience high power losses, which increase at increasing temperatures. In order to overcome the on-resistance power loss, P3-series power MOSFETs can deliver the better overall (conduction + switching) performance than the existing MOSFETs available in the market [3].

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