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800 V SuperFET® II MOSFET Cuts Switching Loss for High System Efficiency with Reliability

Abstract

Fairchild's 800 V SuperFET® II MOSFET family using the latest super junction technology provides extremely low conduction, switching loss and reliability; thanks to the lowest $R_{DS(ON)}$, stored energy in output capacitance (E_{OSS}) and best-in-class robust body diode performance for lighting, PC power, adapter, audio power, solar inverter, industrial 3-phase topologies and auxiliary power supplies. Utilizing an advanced charge balance technology, Fairchild Semiconductor helps designers to achieve excellent system efficiency and thermal characteristics with the 800 V SuperFET® II MOSFET family. Coupled with its best-in-class reliability makes it ideal for a variety of applications, while its broad range of package options give designers tremendous flexibility, particularly with size constrained designs.

Introduction

With lighting devices consuming around 19% of the world's total electrical power, many countries are phasing out the sale of inefficient incandescent lamps as part of their energy conservation efforts. According to industry reports, over 8000 billion incandescent lamps were sold in 2012, which amounts to about 45% of total lighting sales. The United States, China, Russia, and Brazil started banning sales of incandescent light bulbs up to 60 W in 2014, putting the conversion of residential indoor lighting from incandescent to LED well on track. Meanwhile, advancements in LED technology and improvements in production costs will most certainly accelerate the growth of the LED lighting market. Table 1 highlights the higher efficiency and longer lifetime benefits of LED lighting over incandescent lamps.

Table 1. Efficiency and Lifetime Comparison

Important Facts	Incandescent Lamp	LED Lighting
Efficiency	6~16 lm/W	80~160 lm/W
Average Lifetime	1,200 hours	50,000 hours

The development of LED lighting power supply system focuses on higher efficiency, dimming control and lower cost. Furthermore, smart-phones are rapidly developing to support multiple functions and features. It combines the functionality of a pocket-sized communication device with PC-like capabilities. As this happens, it requires more chips and more processing cycles, which mean higher power levels. Because of these additional functions, smart-phones require much higher power than before. The conventional linear battery charger no longer adequately meets charge requirements due to its high-power dissipation. Therefore, the key design challenge for battery charger of portable devices such as smart-phones or tablet PCs is high power density and high efficiency to meet energy regulation shown in Table 2 [1].

Table 2. Energy-Efficiency Criteria for AC-AC and AC-DC External Power Supplies in Active Mode: Low Voltage Models

Nameplate Output Power (P_{no})	Minimum Average Efficiency in Active Mode
0 to ≤ 1 W	$\geq 0.497 * P_{no} + 0.071$
> 1 to ≤ 49 W	$\geq [0.075 * \text{Ln}(P_{no})] + 0.569$
> 49 W	≥ 0.860

Flyback converters are very popular for low power applications such as LED lighting, battery charger or adaptor because of its simplicity and low cost [2]. In order to increase system efficiency, switching losses on the primary-side have to be reduced. Low stored energy in output capacitance; E_{OSS} and low $R_{DS(ON)}$ of the MOSFET are critical factor for flyback converters to maximize system efficiency. New 800 V, SuperFET® II MOSFET which is optimized for primary switch, enables lower switching losses and case temperature without sacrificing EMI performance due to its optimized design.

800 V SuperFET® II MOSFET Technology

800 V MOSFETs are widely used in many applications such as lighting, chargers, adaptors, solar inverters and industrial 3-phase topologies. However, there are silicon limits for a significant reduction in the on-resistance with the conventional planar MOSFET. In high voltage MOSFET technologies, the most remarkable achievement for on-resistance reduction is a super-junction technology. It has deep p-type pillar-like structure in the body in contrast to well-like structure of conventional planar technology. The effect of the pillars is to confine the electric field in the lightly doped epi region. Thanks to this p-type pillar this super-junction technology broke silicon limit in terms of on-resistance and achieved only one sixth specific on-resistance per unit area compared to planar processes at 800 V breakdown voltage as shown in Figure 1. With Fairchild's advanced super-junction technology, the 800 V SuperFET II series feature the industry's best $R_{DS(on)}$ and excellent figure of merit for increased power density and efficiency in applications.

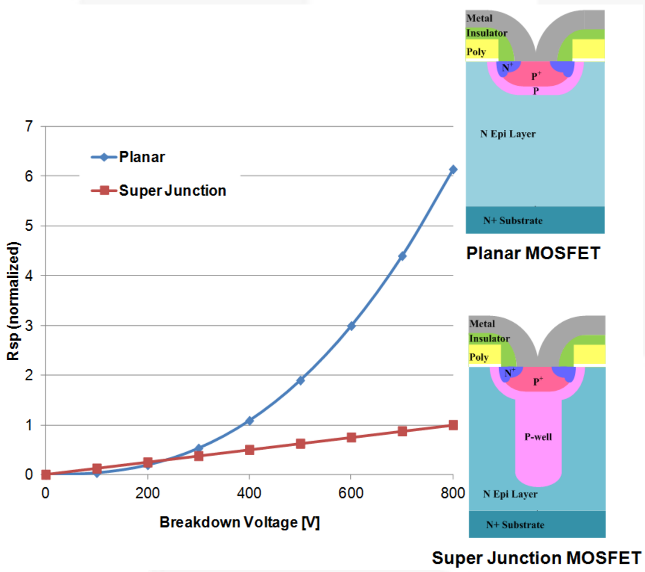


Figure 1. Specific $R_{DS(ON)}$ comparison between conventional and Super-junction MOSFETs

The 800 V SuperFET® II series provide industrial lowest $R_{DS(on)}$ for each packages, the lowest $R_{DS(ON)}$, max. of 800 V SuperFET® II MOSFET is 60 mΩ(max.), 220 mΩ(max.) and 850 mΩ(max.) respectively for in the standard TO-247, TO-220 and TO-251(IPAK) packages. It is well suited for space-constrained applications that need high power density by replacing with smaller packages or reducing paralleling device counts.

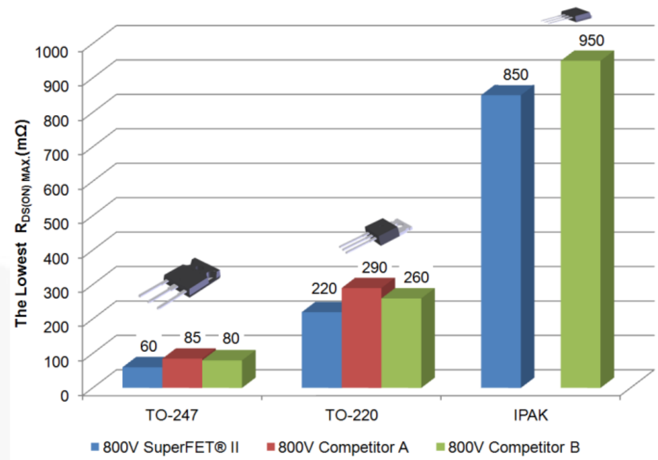
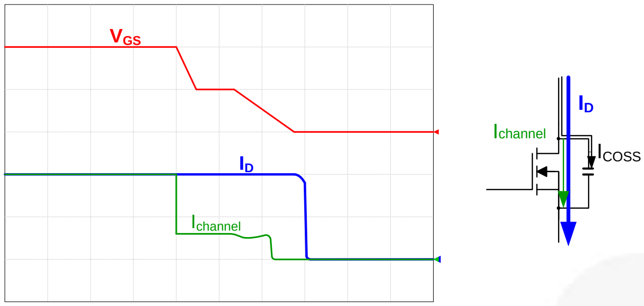
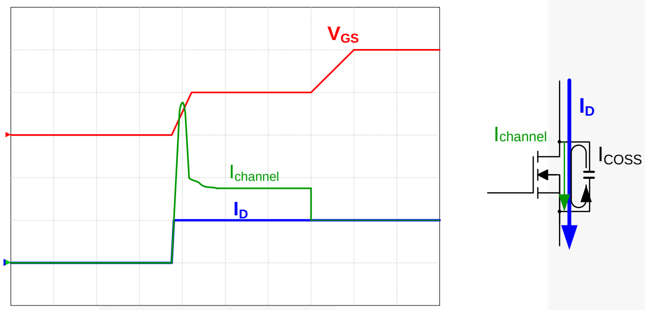


Figure 2. Comparison of the Lowest $R_{DS(ON)}$ vs. Competitor's 800 V SJ MOSFETs

The $R_{DS(ON)} \times Q_G$ Figure Of Merit (FOM) is generally considered as the single most important indicator of MOSFET technology. Several new device technologies have been developed lately to improve the $R_{DS(ON)} \times Q_G$ FOM. Since a MOSFET is a unipolar device, parasitic capacitances are the only limiting factors during switching transient. Lower parasitic capacitance is required for lower switching losses. As the charge balance principle reduces the chip size for same $R_{DS(ON)}$ as compared to standard MOSFET technology, 800 V SuperFET® II MOSFET have much less capacitance. One way to find out how the output capacitance corresponds to switching losses is by evaluating an effective value of output capacitance. The stored energy in the output capacitance of a MOSFET can be calculated by integrating the product of the output capacitance and drain-source voltage with respect to the drain-source voltage from zero to the drain-source voltage just before the turn-on transient. Figure 3 (a) clearly shows that the channel current ($I_{channel}$) is significantly lower than the drain current (I_D) during turn-off because drain current is diverted from the MOSFET channel to charge the output capacitor. At turn-on transient, The MOSFET channel conducts a current significantly higher than drain current (I_D) because of the additional current coming from the discharging of the output capacitor. The energy stored in the output capacitance of the power MOSFET during turn-off is internally dissipated through the MOSFET channel in the form of joule heating during turn-on. This stored energy is dissipated through the channel of the MOSFET on every turn-on of the switching cycle. Therefore, the stored energy in output capacitance, E_{oss} of the MOSFET, is very critical in hard-switching applications, such as flyback/forward converters or Power Factor Correction (PFC), especially at light loads and high switching frequency, because it is fixed and independent of load. For low power flyback converters, lower $R_{DS(ON)} \times E_{oss}$, Figure-Of-Merit (FOM) is the most important for primary-side MOSFETs.



(a) Decreased MOSFET Channel Current during Turn-off due to C_{OSS} Charging



(b) Increased MOSFET Channel Current during Turn-on due to C_{OSS} Discharging

Figure 3. MOSFET Channel Current and Drain Current Waveform during (a) Turn-off and (b) Turn-on

As shown in Figure 4, the 800 V SuperFET® II MOSFET has respectively 18% and 38% less stored energy in output capacitance at 400 V, compared to 800 V competitors. Therefore the 800 V SuperFET® II MOSFETs provide higher switching efficiency in hard switching applications by smaller Eoss

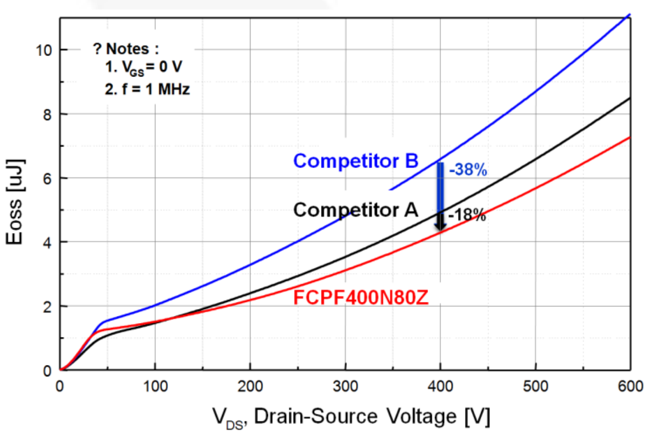
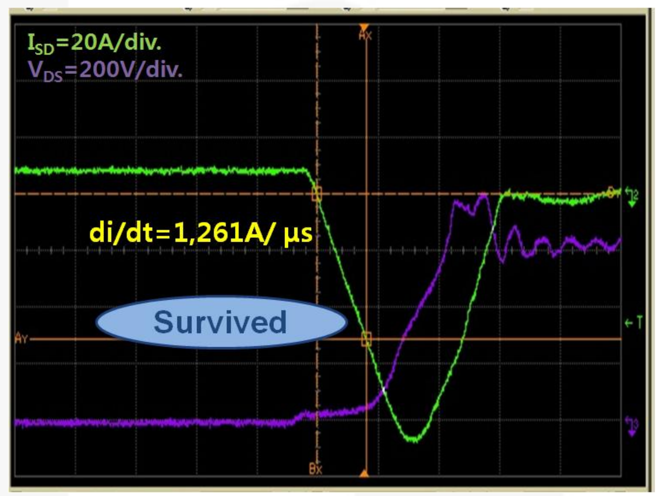
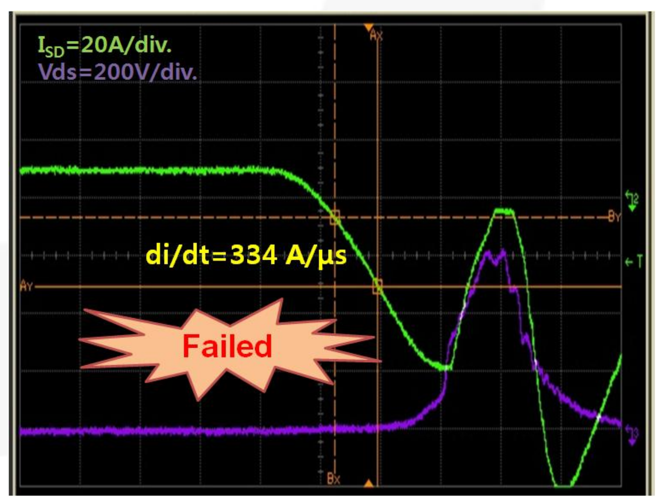


Figure 4. Comparisons of Stored Energy in Output Capacitance, E_{OSS}

Figure 5 shows body diode ruggedness comparison under V_{DD}=600 V, I_{SD}=11 A. Figure 5 (b) and (c) show competitor's MOSFET failing waveforms during body diode reverse recovery. With competitor A and B, failure occurs right after the current level reaches I_{rrm}, peak reverse recovery current at 334 A/µ and 375 A/µs respectively. This indicates the peak current triggered parasitic BJT. As shown in Figure 5 (a), the 800 V SuperFET® II MOSFET did not fail at even higher di/dt (1,261 A/µs) conditions. Robust body diode characteristics are related to the reliability issues in LLC resonant converters. Rugged intrinsic body diode performance of 800 V SuperFET® II series can provide better reliability in applications including resonant converters.



(a) 800 V SuperFET® II MOSFET Withstanding Waveforms During Body Diode Reverse Recovery



(b) Competitor A MOSFET Failing Waveforms During Body Diode Reverse Recovery

(c) Competitor A MOSFET Failing Waveforms during Body Diode Reverse Recovery

Figure 5. Body Diode Ruggedness Comparison under V_{DD}=600 V, I_{SD}=11 A

Application Evaluation Results

Power Loss Analysis in Flyback Converters

Figure 6 shows typical flyback converter. Due to the high RMS and peak currents, the MOSFET and output rectifier diode in the flyback have high switching and conduction losses, which results in its relatively low efficiency. Through power loss analysis on 45 W Flyback converters in Figure 7, critical power loss factors in primary-side MOSFET are switching losses during switch transient especially, when a high drain to source voltage, $V_{DS,}$ apply to the MOSFET.

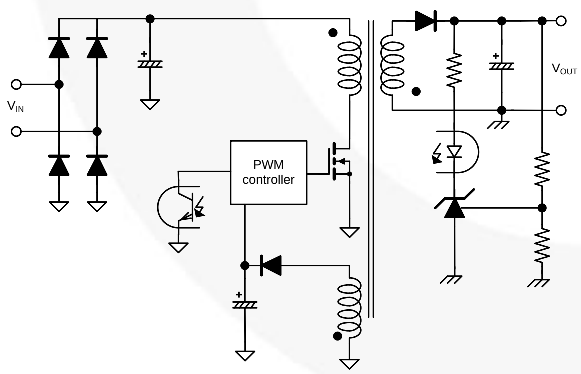


Figure 6. Typical Flyback Converter Circuit

The most popular approach for increased power density is increasing the switching frequency, which reduces the size of passive components. The most heat dissipations are created by transformer, primary power MOSFET and secondary diode in flyback converters. Especially, power loss is critical for power MOSFETs since the power MOSFETs dissipate much more power than any other devices. It is not only an issue of efficiency, but also of thermal management and long term reliability. Power dissipation in the MOSFETs is highly dependent on on-resistances, gate charge and current and voltage rise and fall times, as well as the switching frequency and operating temperature. Losses in the power MOSFETs consist of switching loss, conduction loss and gate driving loss. Figure 7 shows the power loss analysis of the MOSFETs in flyback converter for laptop adaptor application under V_{IN}=230 V_{AC} and P_{OUT}=45 W condition. As shown in Figure 7, the switching losses are the most critical. As the MOSFET switches on and off, it's intrinsic parasitic capacitance stores and then dissipates energy during each switching transition. The losses are proportional to the switching frequency. As the physical die size of the MOSFET increases, its capacitance also increases; so, increasing MOSFET die size also increases switching losses. Therefore, in order to increase both system efficiency and power density, switching loss on the primary-side MOSFET have to be reduced.

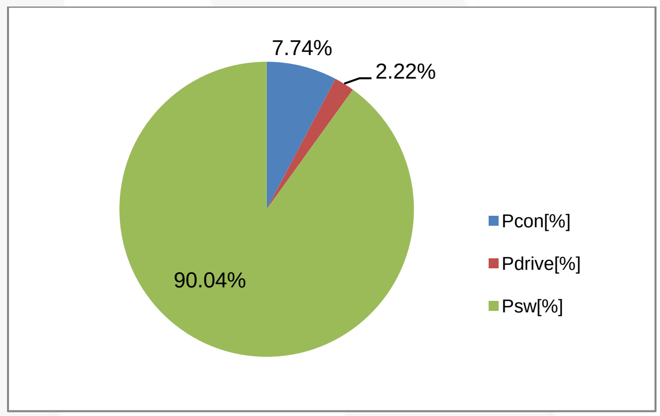


Figure 7. MOSFET's Power Loss Analysis under 45 W Flyback Converter

High-Efficiency and Low-Temperature Solution

The 45 W flyback converter is designed to evaluate the efficiency of a 800 V SuperFET® II MOSFET. Input voltage of the rectifier is 230 V_{AC}, and output voltage and current are set to 15 V and 3 A, respectively. Power losses, efficiency and case temperature of 800 V, 400 mΩ SuperFET® II MOSFET is compared with competitor's 800 V super-junction MOSFETs which has same voltage rating in TO-220 full package as shown in Table 3, which shows the key parameter comparison of Fairchild's 800 V 400 mΩ SuperFET® II MOSFET, FCPF400N80Z and competitors. Reduced Stored energy in output capacitance (E_{OSS}) is one of the advantages of 800 V SuperFET® II series. The 800 V SuperFET® II MOSFET has respectively 27% and 34% less FOM [$R_{DS(ON)}$ × E_{OSS} at 400V_{DS}] than 800V competitors. Also 800 V, 400 mΩ SuperFET® II MOSFET provide better reliability thanks to robust body diode and ESD capability by integrated Zener diode.

Table 3. Key Parameter Comparison of 800 V SuperFET® II MOSFET and Competitors

DUTs	BV_{DSS}	$R_{DS(ON)}$ Max	E_{OSS} at 400 V_{DS}	Zener Protection	FOM [$R_{DS(ON)}$ Max× E_{OSS} at 400V_{DS}]	Peak Diode Recovery dv/dt
800 V SuperFET® II MOSFET, FCPF400N80Z	800 V	400 mΩ	4.0 μJ	Yes	1.6 Ω·μJ	20.0 V/ns
800 V Competitor A	800 V	450 mΩ	4.9 μJ	No	2.2 Ω·μJ	4.0 V/ns
800 V Competitor B	800 V	375 mΩ	6.5 μJ	Yes	2.4 Ω·μJ	4.5 V/ns

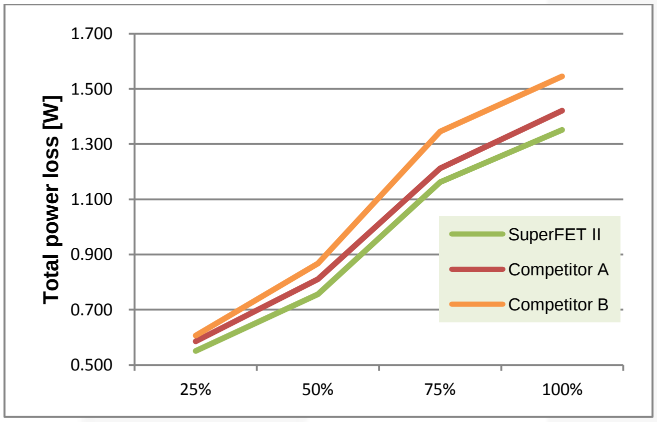


Figure 8. Power Loss in 45 W laptop adaptor

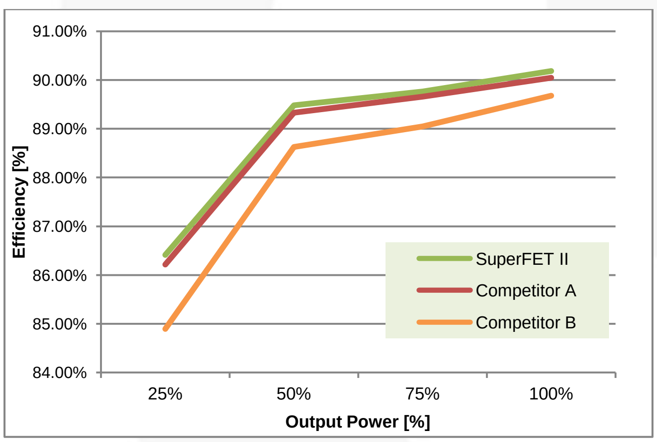


Figure 9. Efficiency vs. Output Power in 45 W Laptop Adaptor

As shown in Figure 8, power loss of FCPF400N80Z is 5% and 13% less compared to competitors SJ MOSFETs at full load condition due to its low switching losses. The summary of the efficiency measurements is shown Figure 9.

Efficiency increases about 0.15% and 0.9% at light load and 0.19% and 1.52% at heavy load respectively compared to competitor A and B SJ MOSFETs. The major reason for higher efficiency of FCPF400N80Z is the reduced switching losses because of its lower Eoss. Figure 10 shows the relative temperature performance comparison of 800 V SuperFET® II MOSFET and 800 V competitor's SJ MOSFETs in 45 W laptop adaptors. The temperature difference between 800 V SuperFET® II MOSFET and competitor SJ MOSFETs is 4.8°C and 7.1°C, respectively, which shows the outstanding thermal performance of 800 V SuperFET® II MOSFET at full load condition.

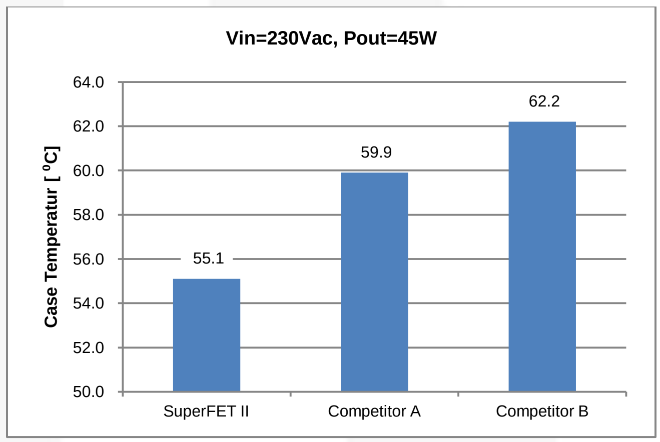
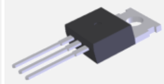
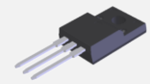
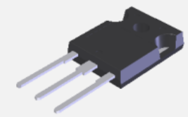


Figure 10. Case Temperature Comparison in 45 W Laptop Adaptor

Conclusion

800 V SuperFET® II MOSFET is Fairchild's high performance MOSFET family offering 800 V breakdown voltage. This new family of 800 V SuperFET® II MOSFET enables to make more efficient, compact, cooler and more robust applications for switching application designers because of its remarkable performance.

Table 4. 800 V SuperFET® II MOSFET Lineup

PKG	DPAK	IPAK	D2PAK	TO-220	TO-220F	TO-247
$R_{DS(ON)}$ / Q_g						
60 mΩ / 270 nC						FCH060N80_F155
85 mΩ / 196 nC						FCH085N80_F155
220 mΩ / 78 nC				FCP220N80	FCPF220N80	
290 mΩ / 58 nC			FCB290N80	FCP290N80	FCPF290N80	
400 mΩ / 43 nC				FCP400N80Z	FCPF400N80Z FCPF400N80ZL1	
650 mΩ / 27 nC				FCP650N80Z	FCPF650N80Z	
850 mΩ / 22 nC	FCD850N80Z	FCU850N80Z		FCP850N80Z	FCPF850N80Z	
1300 mΩ / 16.2 nC	FCD1300N80Z				FCPF1300N80Z	
2250 mΩ / 11 nC	FCD2250N80Z	FCU2250N80Z			FCPF2250N80Z	
3400 mΩ / 7.4 nC	FCD3400N80Z	FCU3400N80Z				
4300 mΩ / 6.8 nC		FCU4300N80Z			FCPF4300N80Z	

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