ISSUE: December 2019

SiC FETs Lower On-Resistance To Less Than 10 mΩ

UnitedSiC has introduced four SiC FETs with $R_{DS(ON)}$ levels as low as 7 mΩ, delivering unprecedented levels of performance and efficiency for use in high-power applications such as electric vehicle (EV) inverters, high-powered dc-dc converters, high-current battery chargers and solid-state circuit breakers. Of the four new UF3SC SiC FET cascode devices, one is rated at 650 V with an $R_{DS(ON)}$ of 7 mΩ (the UF3SC065007K4S), and three are rated at 1200 V with an $R_{DS(ON)}$ of 9 mΩ (the UF3SC120009K4S) and 16 mΩ (the UF3SC120016K3S and UF3SC120016K4S). All are available in the versatile TO-247 package (Table 1).

According to the company, these devices represent the industry's first SiC FETs with $R_{DS(ON)}$ below 10 mΩ. Fig. 1 below offers some comparisons of these new UF3SC SiC FETs with data sheet specs for comparable SiC MOSFETs currently on the market. Moreover, because the UF3SC SiC FETs devices behave well when paralleled, these conventionally packaged devices can be combined to scale up to current levels that would previously have required use of SiC MOSFET or silicon IGBT modules.

These new SiC FETs combine the company's high-performance (hard switching) third-generation SiC JFET and a cascode-optimized Si MOSFET. This circuit configuration creates a fast, efficient device in a familiar package that can be driven with the same gate voltages as silicon IGBTs and MOSFETS and SiC MOSFETs. In addition, to optimize the devices for high-temperature operation, silver sintering is employed in the assembly of the TO-247 package to achieve low thermal-resistance mounting.

"What is really significant here is that we have achieved the industry's lowest $R_{DS(ON)}$ for any device in this class," explained Anup Bhalla, VP of Engineering, UnitedSiC. "But in addition to that, the standard drive characteristics and versatile packaging mean these SiC FETs can be used as drop-in replacements for less efficient parts in a wide variety of applications, with little or no additional design effort."

According to Chris Dries, president and CEO of United Silicon Carbide, these new devices were produced in the same third-generation SiC JFET process that was released in 2018. However, over time the yield obtained using this process has been improved, allowing for an increase in die size. This in turn made possible the very low values of on-resistance achieved by these new devices. In other words, these new SiC FETs have larger die than their predecessors.

The UF3SC065007K4S has a maximum operating voltage of 650 V, a drain current of up to 120 A, and an $R_{DS(ON)}$ of 6.7 mΩ. The UF3SC120009K4S has a maximum operating voltage of 1200 V, drain current of up to 120 A, and an $R_{DS(ON)}$ of 8.6 mΩ. Both come in a four-lead Kelvin package, enabling cleaner drive characteristics.

For lower-power designs, UnitedSiC offers two parts with maximum operating voltages of 1200 V, drain currents of up to 77 A, and an $R_{DS(ON)}$ of 16 mΩ. The UF3SC120016K3S has a three-lead package, while the UF3SC120016K4S has a four-lead package.

The low $R_{DS(ON)}$ characteristic of these devices make it possible to achieve efficiencies of more than 99% in inverter designs. The excellent reverse-recovery performance helps in this regard, along with their low conduction drop in the freewheeling mode.

Using these new devices, inverter designers will be able to extract more power from their existing designs without reinventing their basic circuit architecture, by switching at the same speed but handling higher currents without excessive resistive heating. Alternatively, the low switching losses allow designers to operate the inverter at higher frequencies in order to produce a cleaner output current waveform. This improves the efficiency of the motors it drives by reducing their core losses. If the inverter is designed to have a filtered output, higher frequency operation will also enable smaller filters.

The parts also work well in parallel to handle very high currents. Careful loss calculations show that the combined switching and conduction losses of a 200-kW, 8-kHz inverter built using six UF3SC120009K4S SiC FETs in parallel will be about one third those of a similar inverter built using state-of-the-art IGBT/diode modules, according to the vendor.

On the other hand, the switching frequency of the SiC FETs can be doubled while still reducing power stage losses by more than a third versus the IGBT-based design. Table 2 tabulates the power losses of the SiC FET-based inverter designs versus the IGBT-based inverter.

Another application example illustrating the benefits of these SiC FETs is a 60-kVA photovoltaic inverter with an 800-V dc link. The loss performance of this inverter was evaluated by the company at three frequencies (12.5, 25 and 50 kHz) with the UF3SC SiC FETs applied in three topologies—a two-level voltage source inverter, a conventional neutral point clamped (NPC) inverter and a T-type NPC inverter.

The ultra-low conduction losses enabled by the low $R_{DS(ON)}$ figures of the UF3SC series SiC FETs mean the devices can also be used as solid-state circuit breakers and battery disconnect switches in EVs. The devices can turn off very high currents very quickly, and when used as a circuit breaker have a self-limiting characteristic that controls the peak current that flows. This characteristic can also be used to limit inrush currents flowing into inverters and motors.

In another application, the UF3SC series SiC FETs can form the basis for more efficient high-current battery chargers. For lower battery-voltage systems, the UF3SC65007K4S offers much greater efficiencies in charging circuits than IGBT-based systems. If SiC FETs are used to build a synchronous rectifier to replace the secondary-side diodes, this also dramatically cuts losses and so reduces the cooling burden on the charger.

For example, at a 100-A operating current with a 50% duty cycle, a JBS diode will have conduction losses of nearly 100 W, but the UF3SC065007K4S working as a synchronous rectifier will have conduction losses of just 45 W (Fig. 3).

In quantities of 1000+, unit pricing ranges from $35.77 for the UF3SC0120016K3S to $59.98 for the UF3SC120009K4S. Samples are available now, with production volumes expected in Q2 of 2020. For more information, see the company website.

Table 1. Key specifications for the four new members of United SiC's third-generation family of SiC FETs.

Device	Package	$V_{DS(MAX)}$ (V)	I_D(100C) (A)	R_{THJC}(max) (C/W)	$R_{DS(ON)}$(25C) mohm	$R_{DS(ON)}$(125C) mohm	$R_{DS(ON)}$(175C) mohm	$C_{OSS(ER)}$ 800V pF	E_{ON} mJ	E_{OFF} mJ	Switching Conditions
UF3SC120009K4S	TO247-4L	1200	120	0.19	8.6	13.3	18.2	395	3.5	0.7	100A, 800V HB 150C
UF3SC120016K4S	TO247-4L	1200	77	0.29	16	24.8	33	243	2.82	0.15	80A, 800V HB 150C
UF3SC120016K3S	TO247-3L	1200	77	0.29	16	24.8	33	243	3.35	0.67	80A, 800V* HB 150C
UF3SC065007K4S	TO247-4L	650	120	0.19	6.7	8.7	11	856	1.08	0.1	80A, 400V HB 150C

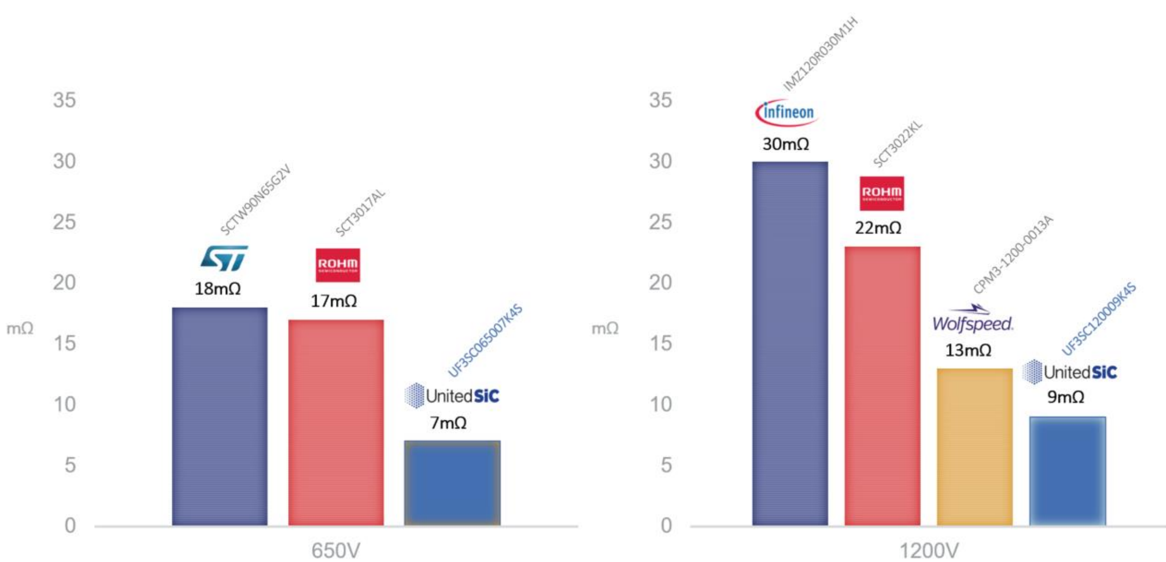

Fig. 1. When compared with similarly rated SiC MOSFETs, the new UF3SC SiC FET cascode devices achieve significantly lower on-resistance. These comparisons by UnitedSiC are based on data sheet specifications published by the competitors.

Table 2. Comparing the power losses of a 200-kW 8-kHz switching IGBT-based inverter versus designs using United SiC's UF3SC SiC FETs. Note that SIC FET performance is shown for cases where four SiC FETs are used per switch as well as for one case where six SiC FETs are used per switch.

Voltage Class	Device Type	Chips/Switch	Bus Voltage	Frequency	Loss Type	Power Output					
						50KW	100KW	150KW	200KW	250KW	300KW
1200	IGBT+Diode	100A X4 each	800V	8kHz	Pconduction (W)	193	440	742	1097		
					Pswitching (W)	823	1191	1559	1927		
					Ptotal (W)	1016	1631	2301	3024		
					Semi Efficiency	97.97%	98.37%	98.47%	98.49%		
1200	SiC FET	UF3SC120009K4S X 4	800V	8kHz	Pconduction (W)	67	270	608	1080		
					Pswitching (W)	185	218	261	313		
					Ptotal (W)	252	488	869	1393		
					Semi Efficiency	99.50%	99.51%	99.42%	99.30%		
1200	SiC FET	UF3SC120009K4S X 6	800V	8kHz	Pconduction (W)	45	180	405	720	1127	1621
					Pswitching (W)	265	293	327	368	415	469
					Ptotal (W)	310	473	732	1088	1542	2090
					Semi Efficiency	99.38%	99.53%	99.51%	99.46%	99.23%	98.96%
1200	SiC FET	UF3SC120009K4S X 4	800V	16kHz	Pconduction (W)	67	270	608	1080		
					Pswitching (W)	370	436	521	625		
					Ptotal (W)	437	706	1129	1705		
					Semi Efficiency	99.13%	99.29%	99.25%	99.15%		

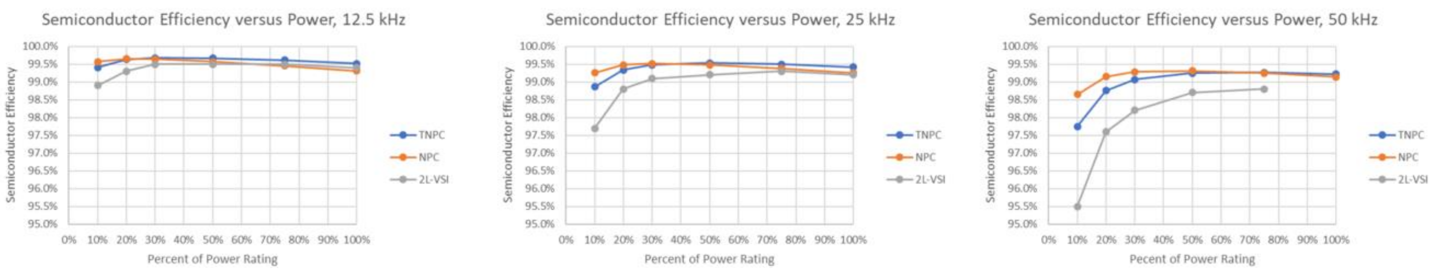

Fig. 2. Loss evaluation for a 60-kVA solar inverter with an 800-V dc link at three operating frequencies for a 2-level, an NPC and a TNPC inverter topology obtained using the packaged UF3SC SiC FETs. According to UnitedSiC, until now achieving this level of performance required use of IGBT or SiC modules. The move from modules to packaged FETs represents a cost savings.

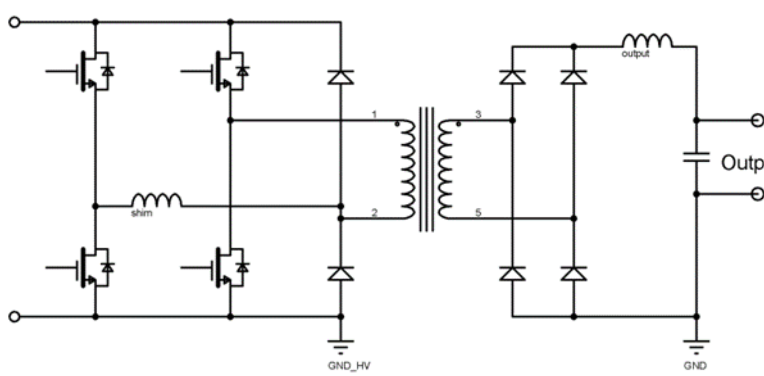

Fig. 3. In a low-voltage, high-current battery charger, replacing the diode rectifiers on the secondary with synchronous rectifiers using UF3SC SiC FETs can cut conduction losses in half.

