SMPD™ : An Advanced Isolated Packaging to Fully Exploit the Advantages of SiC MOSFETs

In the standard discrete packages of power semiconductors, application specific topology needs are not taken into consideration. On the other hand, power modules, typically incorporating a full topology but feature complex package handling requirement. The advanced isolated packages from Littelfuse such as SMPD fill the gap between modules and discretes, offering the performance of power module with the flexibility of discrete devices.

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ISOPLUS - SMPD™ and its Advantages

SMPD stands for **S**urface **M**ount **P**ower **D**evice, the advanced top side cooled, isolated package pioneered by IXYS, now part of Littelfuse, back in 2012. As displayed in Figure 1, having the size of a two Euro coin, the SMPD offers several key advantages:

- Integrated Direct Copper Bonded (DCB) isolation provides best in class reliability under power and temperature cycling.
- IXYS proprietary DCB with 2.5 kV minimum isolation voltage.
- The optimized use of DCB space in component increases power density and simplifies thermal management.
- Allows fully automated pick & place and standard reflow soldering for the ease of manufacturing.

The SMPD is a revolutionary package which simplifies the way design engineers address their power semiconductor system integration and assembly. They are available in standard topologies such as buck, boost, phase-leg, or even customized combinations. They are available in a variety of technologies such as Si/SiC MOSFET, IGBT, Diode, Thyristor, Triac, or customized combinations with different voltage classes from 40V to 3000V.

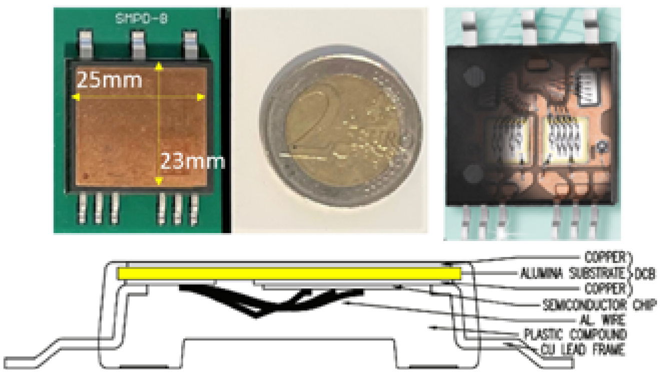


Figure 1: ISOPLUS SMPD™ internal construction and size

Performance advantages of SiC based SMPD compared to standard discrete

Dynamic measurements were carried out between the silicon carbide (SiC) MOSFET based SMPD and standard discrete packages to quantify the advantages Littelfuse SMPD can offer. The measurement principle is based on standard double pulse test setup as depicted in Figure 2 and the dynamic characterization platform from Littelfuse was used to conduct tests. The devices have been compared in terms of MOSFET switching parameters such as switching time T_{sw} and switching energy E_{sw} as well as the diode switching parameters such as reverse recovery time t_{rr}, maximum reverse current I_{rm}, and reverse recovery energy E_{rr}.

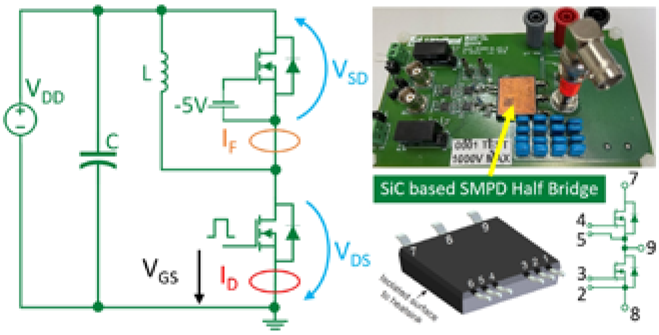


Figure 2: Double pulse test set up and dynamic characterization platform

As displayed in Figure 3, a 1200V SiC SMPD device was compared with standard discrete packaged devices having similar on-state resistance $R_{DS(ON)}$ and similar technology in terms of gate-to-source operating voltage (V_{GS}).

	SMPD™	TO-263-7L	TO-247-4L	TO-247-3L
Configuration	Phase leg	Single with kelvin source	Single with kelvin source	Single
SiC Dice	Die A	Die B	Die C	Die A
$V_{(BR)DSS}$ [V]	1200	1200	1200	1200
$R_{DS(ON)25}$ [mΩ]	80	80	80	80
I_{D25} [A]	25.5	30	36	39
$V_{GS,OP}$ [V]	-5 to +20	-5 to +20	-5 to +20	-5 to +20

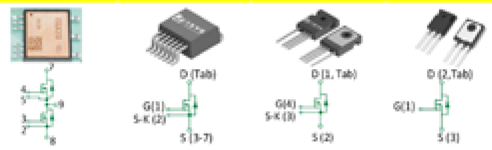


Figure 3: Devices compared featuring SiC MOSFETs

The measurement waveforms of gate voltage, drain current and body diode reverse recovery current are given in Figure 4. The gate voltage comparison reveals, that the SMPD with kelvin source not only speeds up charging of gate but also due to its low package inductance, it eliminates the gate oscillations at same operating conditions. The drain current comparison during turn-on reveals, that the TO-247-4L and TO-263-7L devices have about 25% higher peak current despite having similar channel resistance $R_{DS(ON)}$ and similar technology MOSFET dice. Consequently, these devices may experience more stress to the body diode due to higher values of maximum reverse recovery current I_{rm}. From the body diode's reverse current comparison, it can be observed, that despite having the same dice in SMPD and TO-247-3L packages, the SMPD offers shorter reverse recovery time with higher di/dt which in turn reduces the losses of body diode and increases overall system level efficiency.

The dynamic parameters are quantified and compared in terms of percentage comparison as can be seen in Figure 5. It is evident from measurements that by far, the SMPD offers significant reduction in all dynamic parameters as compared to standard discrete packages. It is observed that despite having the same dice in SMPD and TO-247-3L package, the SMPD offers significant performance improvements in the application. Assuming an application with 80 kHz switching frequency and 800 V drain-to-source voltage, the SMPD offers 21% switching loss reduction for medium load condition and 18% reduction for 80% load condition. The SMPD loss

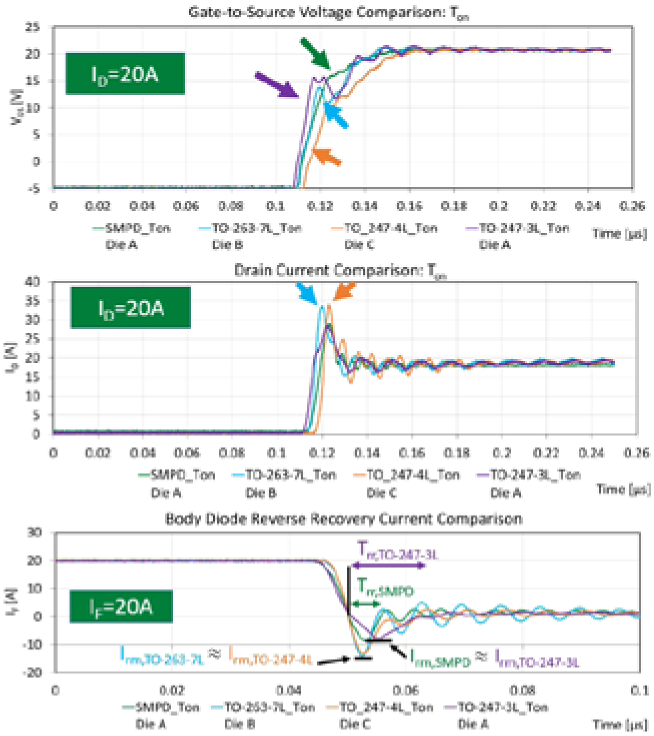


Figure 4: Waveform comparison between SMPD and standard TO-packages

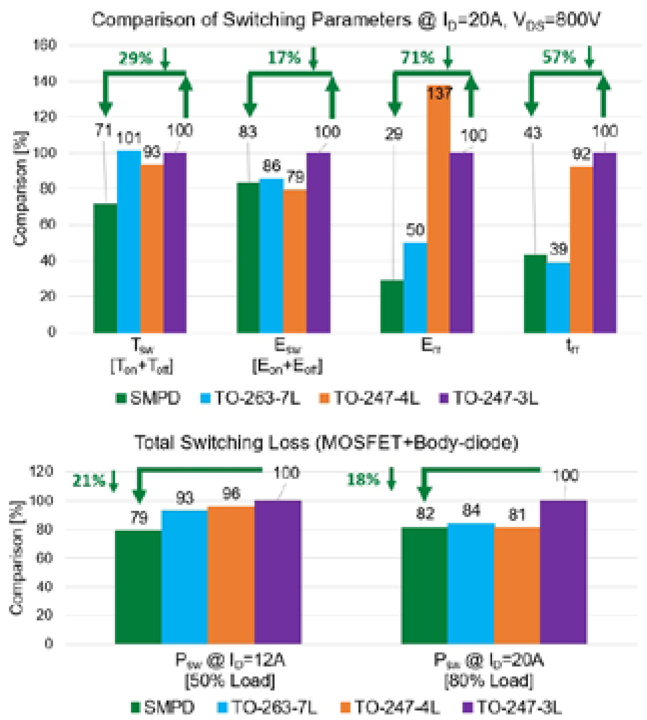


Figure 5: Comparison of relevant parameters between SMPD and standard discretes

reduction is more pronounced at medium load compared to all other discrete devices. The performance of TO-263-7L device is on par with SMPD for heavy load condition but the usage of this device usually needs an Insulated Metal Substrate (IMS) PCB which restricts the number of PCB layers, adds complexity in PCB design and includes nearly 50% higher cost compared to a standard PCB. The SMPD, offering kelvin source connections and minimized package-level stray-inductance, optimizes performance, efficiency, power density, and ease of manufacturing with standard PCB. Reflow soldering capability along with simplified thermal design add to the list of benefits.

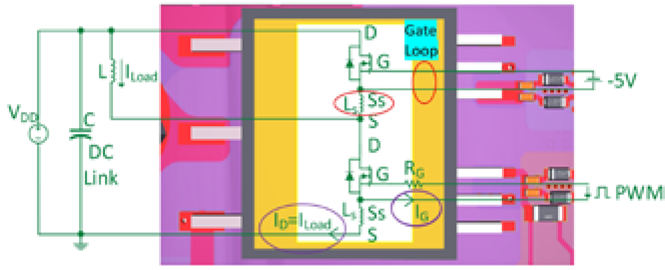


Figure 6: SMPD mounted on PCB with standard load circuit

Applicational advantage when using SiC MOSFETs in SMPD

The depiction of SMPD device mounted on PCB with standard load circuit is visualized in Figure 6.

The SMPD offers multiple advantages in application:

- The Gate drive path is separated from load circuit thanks to kelvin source. No negative feedback of load current into gate loop which improves EMI and reduces the risk of parasitic turn-on.
- Most of the stray inductance L_S is excluded from gate loop, enabling faster switching, reduced losses, improved efficiency and reduced gate oscillations.
- Minimized mutual parasitic inductance and coupling capacitance of the package.
- Minimized losses which improves efficiency. It also keeps the junction temperature T_{vj} low which simplifies thermal design.
- DCB based, fully isolated package with reduced mounting and cooling efforts [1]

By using SMPD in the application, designers can achieve shorter power loops along with reducing the number of necessary components. The shorter power loop minimizes stray inductance which helps to mitigate gate ringing and drain voltage overshoot. The power loop optimization by using SMPD compared to standard TO-packages is depicted in Figure 7.

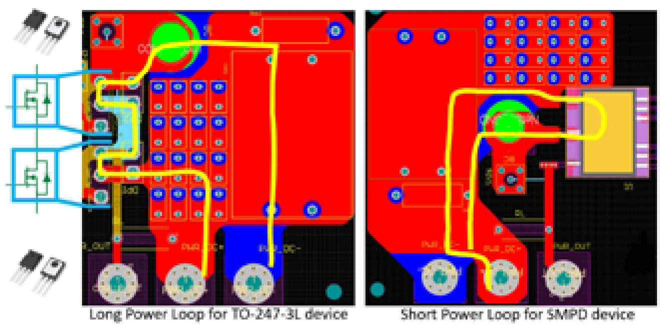
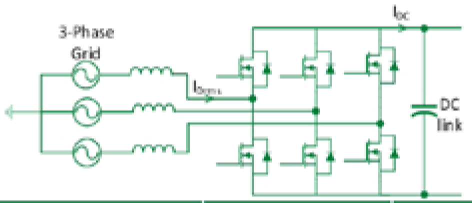


Figure 7: Shorter power loop with SMPD compared to standard discrete devices



	SiC SMPD 25mΩ		SiC TO-247-3L SiC TO-247-4L 25mΩ	
Total number of device	3	+	12	✗
No. of isolation pad	No need	+	12	✗
Mounting efforts	Simplified	+	12 screws 12 washers	✗
R_{thJH} per device [K/W]	0.85	+	1.33	✗
P_{DJH} per device [W]	176 ↑36%	+	113	✗
Total Semiconductor Area on PCB [mm²]	2453 ↓57%	+	5651	✗

For 3L/4L device: Assumed Silpad R_{thch} = 1K/W acc. to Sil-Pad® 2000 datasheet

Figure 8: The 22kW AFE design example using SMPD

Power stage building block using SMPD in SiC MOSFET based application

The Littelfuse SMPDs are available in standard power electronic building blocks. The 22kW active front end (AFE) converter can be visualized in Figure 8 using SMPD assuming 380V AC input, 750V DC output, 55 kHz switching frequency and 65°C heat-sink temperature. By using SMPD in AFE converter, the designers can achieve 36% higher power capability with less components. The SMPD based design occupies 57% less PCB area compared to TO-247-3L/TO-247-4L based design having the same dice.

Summary

By comparing the Littelfuse SMPD performance to the standard discrete packages, advantages of SMPD are evident. The usage of SMPD in application reduces mounting efforts, enables space saving, provides DCB based isolation, increases power density and efficiency along with simplified thermal design compared to the standard discrete packages. The SMPD package furthermore allows integration of sensing elements like for example NTC thermistors to enable temperature monitoring of semiconductor or a shunt resistor to measure device current. The Littelfuse SMPD product portfolio can be checked at Littelfuse web page [2].

References

[1] Application Note: 'Mounting and Cooling Solutions for SMPD Packages'; www.littelfuse.com.
[2] Littelfuse SMPD product offering; https://www.littelfuse.com/products/power-semiconductors.aspx

www.littelfuse.com