AN-CM2307

POWERMASTER SEMICONDUCTOR

Masters of Power Solution

TO-247-4L Kelvin Source Package for Maximizing Switching Performance

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1. Introduction

Silicon Carbide (SiC) MOSFETs have become more and more attractive thanks to its higher breakdown voltage, higher operating temperature, higher thermal conductivity and lower conduction and switching losses compared to Silicon IGBTs or MOSFETs. SiC MOSFETs offer significant system advantages such as higher power density, efficiency and less cooling effort due to its much lower power losses. In order to meet the high power density design requirement in switching mode power supplies, high efficiency and high frequency should be considered at same time. However, the source inductance in a TO-247-3L package has a major influence on both switching losses and noise. The kelvin source configuration package, TO-247-4L, can greatly reduce both switching losses and gate oscillations of SiC and SJ MOSFETs for high efficiency and high switching frequency applications. This application note describes how to maximize switching performance of SiC MOSFET by using TO-247-4L kelvin source package in figure 1.

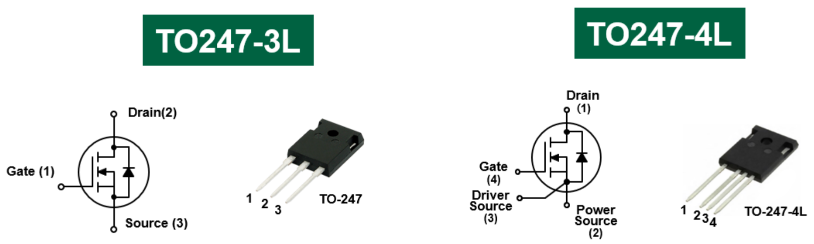
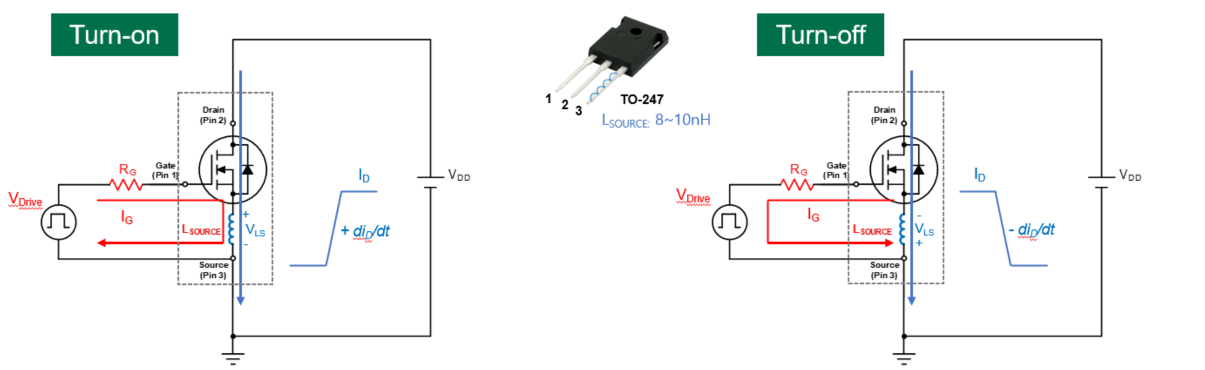


Figure 1. TO-247-3L Package and TO-247-4L Package with Kelvin Source Configuration (Driver Source)

2. Kelvin Source Package Introduction

2.1. Influence of Source Inductance on Switching Behavior

The faster switching of SiC MOSFETs enable higher power density and higher system efficiency. However, performance of SiC MOSFET cannot be always maximized due to limitation of the traditional through hole packages such as TO-247-3L because parasitic components in the packages and PCB boards are involving switching characteristics more as the switching speed is getting faster. This creates unwanted side effects, like high voltage spikes or poor EMI performance or parasitic turn-on in bridge topologies.



$V_{GS}=V_{Drive(ON)} - R_G \cdot I_G - \boxed{L_{SOURCE} \cdot di_D/dt}$ $V_{GS}=V_{Drive(OFF)} - R_G \cdot I_G + \boxed{L_{SOURCE} \cdot di_D/dt}$

Figure 2. Source Inductance influence of TO-247-3L Package at Switching Turn-On & Turn-Off Transient

As shown in figure 2, parasitic inductances of the source lead are part of the gate-drive loop when main current is switched through the common source inductance. During MOSFET turn-on transient, source inductance (L_{SOURCE}) generates the inductive voltage drop ($L_{SOURCE}*di_D/dt$) by positive drain current slop ($+di_D/dt$). It results lower effective gate voltage which slows down the turn-on transient time and increases turn-on switching losses of SiC MOSFET. During turn-off transient, inductive voltage drop ($L_{SOURCE}*-di_D/dt$) across the common source inductance is caused by negative drain current slop ($-di_D/dt$). This voltage drop leads to increase ground voltage level and negative gate voltage. Finally, larger common source inductances (8~10nH) of TO-247-3L cause the higher turn-on switching losses and turn-off gate oscillation in SiC MOSFET.

2.2. Benefits of TO-247-4L Kelvin Source Package

As shown in figure 3, TO-247-4L package has additional “Drive Source” lead that is directly connected to gate loop and separated from power source loop. Pin-out of TO-247-4L package is different from conventional TO-247-3L to ensure the creepage distance from high voltage drain lead.

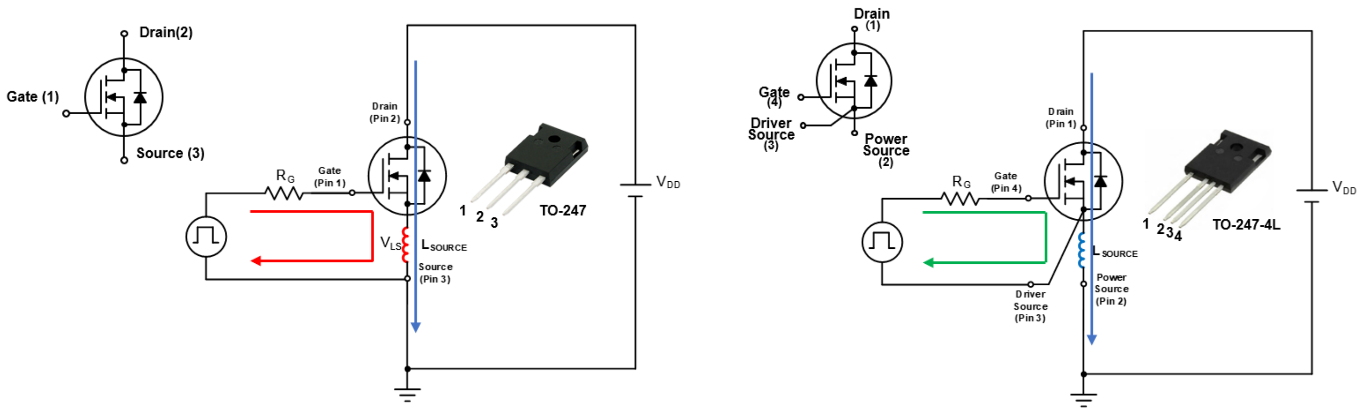


Figure 3. Gate Driving Circuit : TO-247-3L (left) vs. TO-247-4L (right)

As shown in figure 4, Thanks to additional drive source lead of the kelvin source TO-247-4L package, negative effect by induced voltage drop can be eliminated and switching losses can dramatically reduce especially at turn-on transient and reduce gate oscillation at turn-off transient.

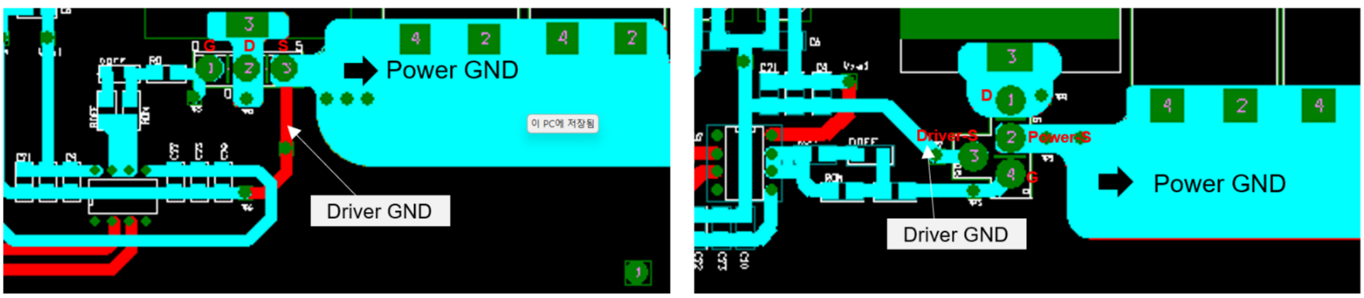


Figure 4. PCB Layout of Gate Driving Circuit : TO-247-3L (left) vs. TO-247-4L (right)

3. Switching Performance Comparison : TO-247-3L vs TO-247-4L Kelvin Source Package

To compare the switching performance between TO-247-3L and TO-247-4L packages with 1200V/80 mΩ *e*SiC MOSFET (PCW120N80M1 and PCZ120N80M1), a double pulse switching circuit was designed as shown in figure 5. This board is optimized to minimize parasitic inductance for each package. The switching performance measured at V_{DD}=1200V, V_{GS}= -3V/+18V, R_G=2Ω and 1200V/10A SiC diode (PCH120S10D1) is used as a high side freewheeling diode.

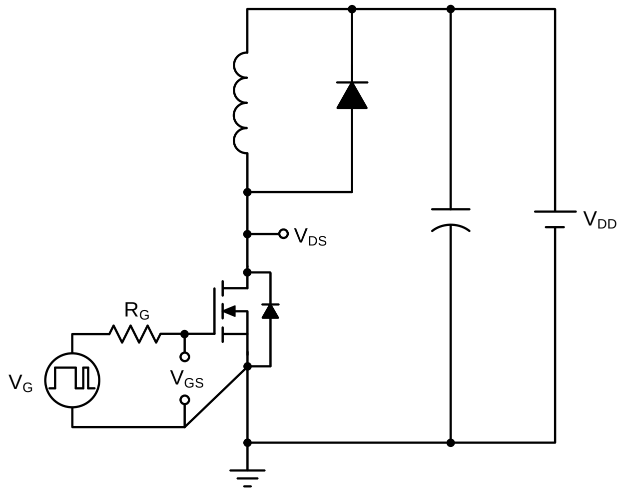


Figure 5. Double Pulse Switching Test Board

Figure 6 shows switching losses comparison between TO-247-3L and TO-247-4L packages. As shown in the switching loss analysis, TO-247-4L package greatly reduced turn-on loss (E_{ON}) by 71% and turn-off loss (E_{OFF}) by 28% compared to one of TO-247-3L at I_D=25A thanks to its separated drive source and power source lead.

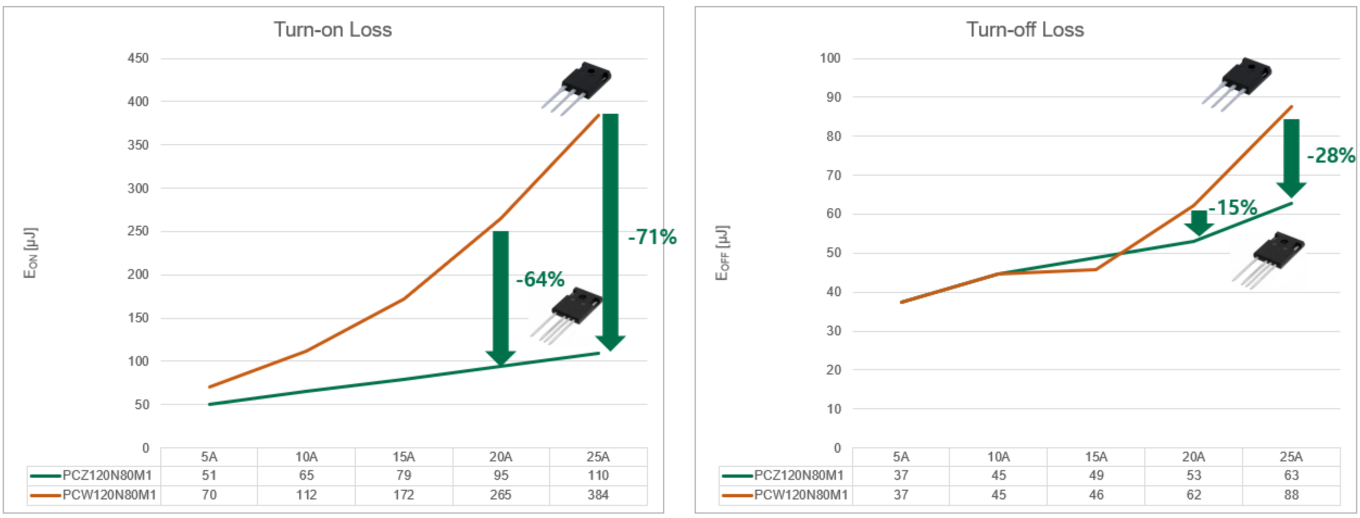


Figure 6. Switching Loss Comparison (E_{ON} & E_{OFF}): TO-247-3L vs TO-247-4L Kelvin Source Package under V_{DD}=1200V, V_{GS}=-3V/+18V, R_G=2Ω, FWD : PCH120S10D1(1200V/10A SiC Diode) and I_D=5~25A

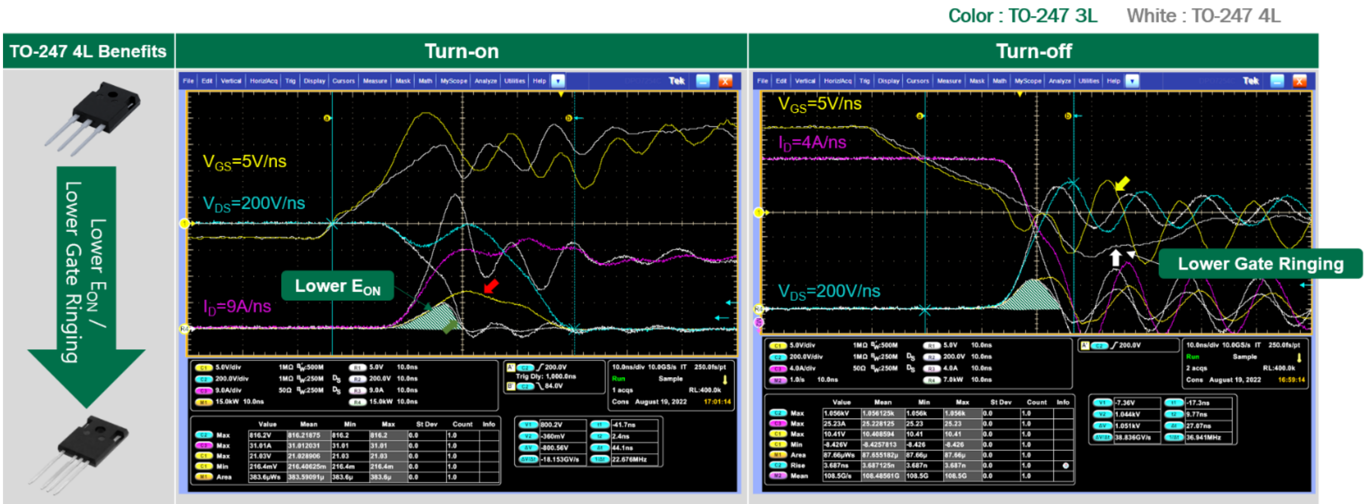


Figure 7. Switching Waveforms Comparison at Turn-On (left) and Turn-Off (right) transient : TO-247-3L vs TO-247-4L Kelvin Source Package under V_{DD}=1200V, V_{GS}=-3V/+18V, R_G=2Ω, FWD : PCH120S10D1(1200V/10A SiC Diode) and I_D=5~25A

Figure 7 shows switching waveforms comparison of TO-247-3L(color) and TO-247-4L(white) during turn-on and turn-off transients in double pulse switching test board. The cross-over area of the drain-source voltage and drain current is switching loss in figure 7. At turn-on transient, TO-247-3L package shows turn-on delay by reduced internal gate-source voltage from the positive induced voltage across source inductance. However, TO-247-4L package enable shorter turn-on transient and lower E_{ON} by avoiding induced voltage across power source in gate driving loop thanks to additional driver source of TO-247-4L. E_{ON} of PCZ120N80M1 in TO-247-4L is 71% (110µJ) less than one (E_{ON}:384 µJ) of PCW120N80M1 in TO-247-3L. At turn-off transient, TO-247-3L package shows higher gate ringing and it leads to turn-off delay and higher turn-off loss. Gate ringing is highly reduced thanks to its separated power and drive source of TO-247-4L package. Consequently, TO-247-4L package enable to reduce turn-off delay and lower turn-off switching loss. E_{OFF} of PCZ120N80M1 in TO-247-4L is 28% (63µJ) less than one (E_{OFF}:88µJ) of PCW120N80M1 in TO-247-3L.

4. Simulation of Power Loss Analysis in Boost Converter of 5kW Solar inverter

Power losses of SiC MOSFETs in TO-247 3L (PCW120N80M1) and TO-247 4L (PCZ120N80M1) packages are analyzed in 5kW boost converter for solar inverter. Input voltage is 400V_{DC} and output voltage set to 630V_{DC}. Switching frequency is 40kHz. Figure 8 is summary of the power loss distribution of 1200V / 80mΩ *e*SiC MOSFET M1 in TO-247 3L and TO-247 4L packages in boost converter of 5kW solar inverter under full load condition. As show in figure 8, Turn-on loss of PCZ120N80M1 (TO-247-4L) is 42% less than that of PCW120N80M1(TO-247-3L). Total power loss of PCZ120N80M1 is about 18% lower than that of PCW120N80M1 thanks to kelvin source configuration of TO-247-4L package. Kelvin source package can greatly reduce turn-on switching loss especially in hard switching topologies.

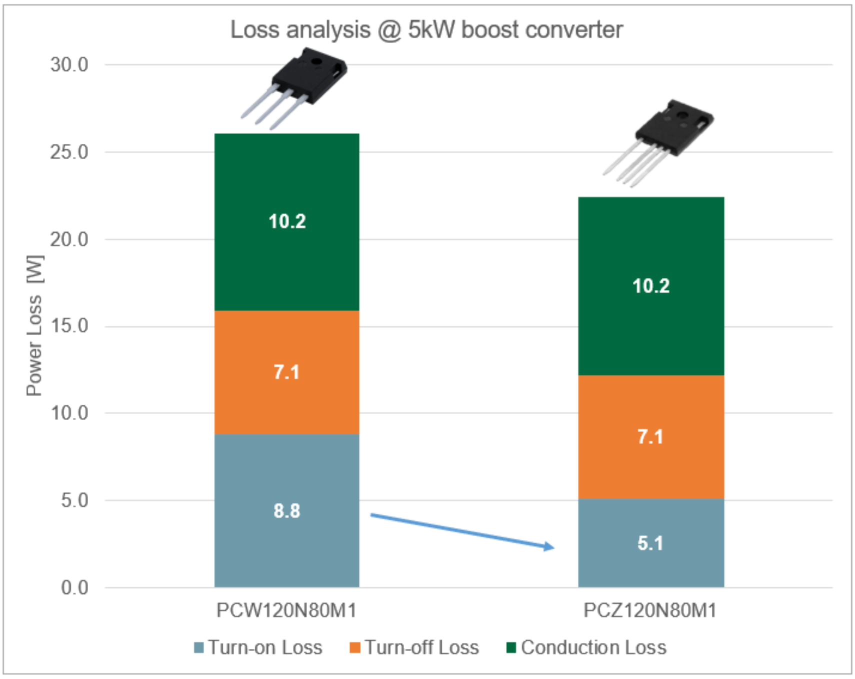


Figure 8. Power Loss Analysis under Full Load in Boost Converter of 5kW Solar Inverter

5. Drive Circuit Recommendation for TO-247-4L Package

To avoid this effect of common source inductance, the source inductance should not include in the gate driving loop. The TO-247-4L kelvin source package, which provide additional driving source lead, is the best choice to eliminate common source inductance effect on switching performance of SiC and SJ MOSFETs. Figure 9 shows the drive circuit recommendation of boost PFC for TO-247-4L package. Gate driving loop is completely separated from the power ground by induced voltage drop by high di/dt and source inductance. Finally, negative effect by common source inductance can be completely solved.

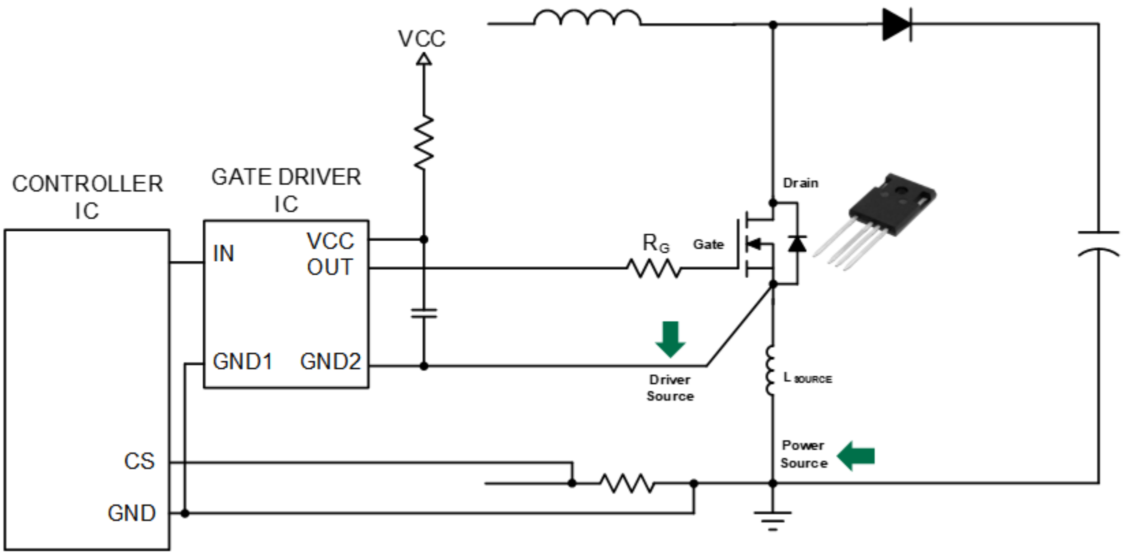


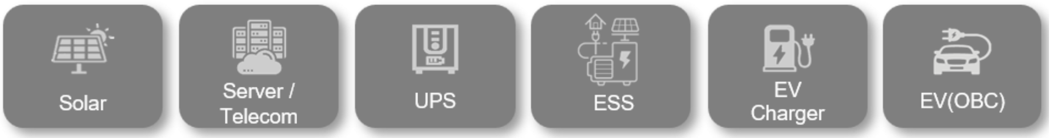
Figure 9. Drive circuit of Boost PFC for TO-247-4L Kelvin Source Package

6. Conclusion

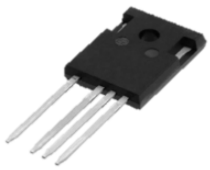
In many applications, the switching losses are significantly increased by the negative feedback caused by the parasitic inductance in the source lead of the power switch. TO-247-4L kelvin source configuration package that provides additional drive source leads solves this problem by removing induced voltage drops across the source inductance. It is very simple way to significantly improve higher system efficiency by lower switching losses. Power Master Semiconductor provides kelvin source packages (TO-247-4L and D2PAK-7L) product portfolio for *e*SiC MOSFET family.

7. TO-247 4L Package Product Portfolio

Table 1. TO-247 4L Package Product Portfolio



650V *e*SiC MOSFET	1200V *e*SiC MOSFET	600V *e*MOS E7
*PCZ65N18M1(-A)	PCZ120N21M1(-A)	PMZ60N028E7(-A)
*PCZ65N27M1(-A)	*PCZ120N30M1(-A)	
PCZ65N48M1(-A)	PCZ120N40M1(-A)	
*PCZ65N72M1(-A)	*PCZ120N60M1(-A)	
*PCZ65N107M1(-A)	PCZ120N80M1(-A)	



* Coming Soon (-A : Automotive Grade)

For more product information, please visit https://www.powermastersemi.com

8. Document Revision History

Major changes since the last version

Date	Description of change
15-June-2023	First Release

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