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DIOFET™ boosts PoL efficiency, reduces heat versus standard MOSFET

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Introduction

This application note describes the benefits of using the DMS3014SSS in the low-side MOSFET position of synchronous buck point-of-load (PoL) converters. The DMS3014SSS utilizes Diodes Incorporated's proprietary DIOFET™ technology that monolithically integrates a power MOSFET and a anti-parallel Schottky diode into a single die. DIOFET technology reduces both $R_{DS(ON)}$ and anti-parallel diode V_{SD} induced losses, ultimately improving the efficiency of PoL converters. The electrical and thermal performance benefits of the DMS3014SSS are illustrated through comparison with a comparable standard MOSFET in a popular synchronous buck converter.

Low-side MOSFET considerations for synchronous Buck converter

Microprocessor based computing, telecom and industrial systems have become increasingly sophisticated and ever more powerful. This places stringent demands on the power density and dissipation of the PoL converters. The synchronous buck converter is the most popular topology for PoL converters due to its low conduction loss and high switching frequency enabling miniaturization of magnetic component.

The primary building blocks of a synchronous buck converter are, shown in Figure 1: the high-side control MOSFETs (Q1 and Q3); low-side synchronous MOSFETs (Q2 and Q4); output inductors (L1 and L2) and PWM controller. The PWM controller was chosen because it can supply sufficient current to drive the MOSFETs at high frequency. It also provides simple, single feedback loop, voltage mode control with fast transient response. In this example, the PWM IC is a dual-output step down controller that operates from an input range of 3V to 28V.

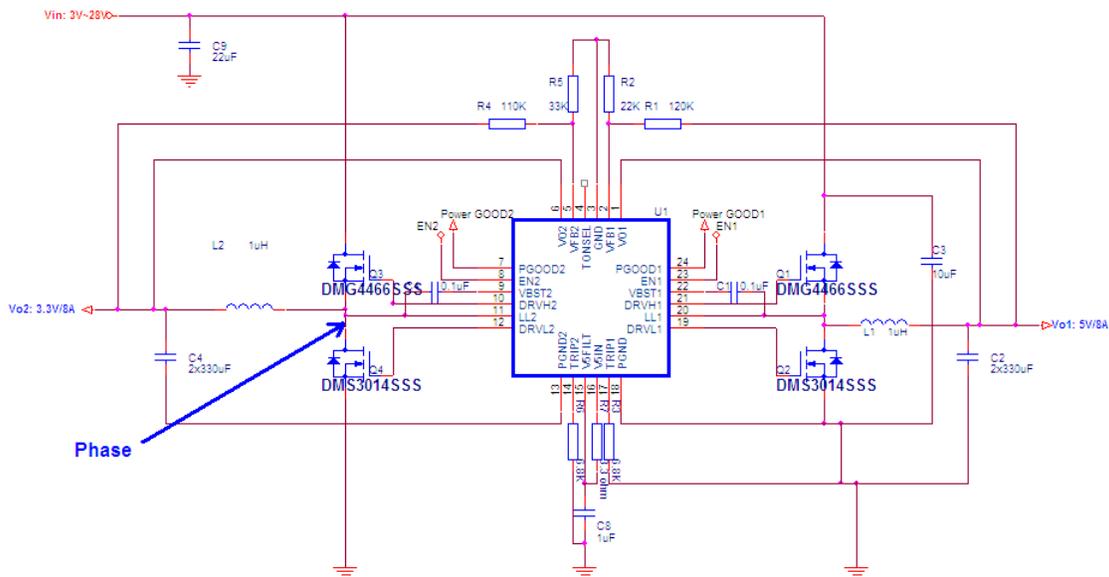


Figure 1. Dual-channel POL converter using DMS3014SSS and DMG4466SSS

The majority of the power losses in a PoL converter are due to losses in the external MOSFETs. These are:

- Conduction losses in the low-side synchronous MOSFETs (Q2 and Q4)
- Switching losses in the high-side MOSFETs (Q1 and Q3)
- Body diode conduction in Q2 and Q4
- Reverse-recovery charge losses due to Q2 and Q4 body diode

The efficiency of a PoL converter can be improved if these losses can be reduced. As the duty cycle of the PWM IC is low then the conduction cycle of the synchronous MOSFET can be as high as 73%. Therefore the biggest improvement in PoL performance can be achieved by selecting a synchronous MOSFET with low $R_{DS(ON)}$, to minimize these conduction losses.

Furthermore, conduction losses can be further reduced by ensuring that the forward voltage drop of the low-side MOSFET's anti-parallel diode is as low as possible. The anti-parallel diodes, which are normally the body diodes of Q2 and Q4, conduct during the PWM controller's dead time. It is for this reason that external Schottky diodes are often used in parallel with the low-side MOSFET since its V_{SD} is much lower than the intrinsic body diode of the MOSFET.

Schottky diodes also provides softer reverse recovery characteristic, lowering the turn ON losses of Q1 and Q3 at high frequency. However, the disadvantage of such implementation is that the external diode adds capacitance to the circuit, increasing the MOSFET turn OFF switching loss. Extra care is also needed to minimize layout's parasitic inductance; otherwise the effectiveness of the Schottky will be reduced—if not negated.

DMS3014SSS improves POL's efficiency and reliability

The DMS3014SSS is a monolithically integrated MOSFET and Schottky that addresses these circuit requirements. It features a low $R_{DS(ON)}$, to minimize conduction losses, and the typical V_{SD} of the integrated Schottky diode is 48% lower than that of a standard Trench MOSFET (see comparison in table 1) further reducing conduction losses. Furthermore, the lower Q_{RR} and softer reverse recovery characteristics of the integrated Schottky diode reduce switching losses.

The monolithically integrated DMS3014SSS removes the need for an additional anti-parallel Schottky diode, simplifying circuit design.

Table 1 compares details the main electrical parameters of the DMS3014SSS with a standard MOSFET – Diodes part number DMN4800LSS.

Parameter	SYMBOL	Test Condition	DMS3014SSS			DMN4800LSS			UNIT
Drain-Source Voltage	V_{DSS}		30			30			V
Gate Threshold Voltage	$V_{GS(th)}$	$V_{GS}=V_{DS}$, $I_D=250\mu A$	1		2.2	0.8	1.2	1.6	V
On- Resistance	$R_{DS(ON)}$	$V_{GS}=10V$ (DMS3014SSS) $V_{GS}=10V$ (DMN4800LSS)		10	14		11	14	m Ω
		$V_{GS}=4.5V$ (DMS3014SSS) $V_{GS}=4.5V$ (DMN4800LSS)		11	15.4		14	20	
Gate Resistance	R_G	$V_{DS}=0V$, $V_{GS}=0V$, $F=1.0MHz$		1.3			1.37		Ω
Gate-Source Charge	Q_{gs}	$V_{GS}=10V$, $V_{DS}=15V$ $V_{GS}=5V$, $V_{DS}=15V$		5.00			1.70		nC
Gate-Drain Charge	Q_{gd}			2.90			2.40		
Diode Forward Voltage	V_{SD}	$V_{GS}=0V$, $I_S=1A$		0.37	0.50		0.72	0.94	V

Table 1 Electrical characteristic of MOSFETs for low-side synchronous switch

Performance evaluation

The performance of DMS3014SSS was evaluated against that of the DMN4800LSS in a two output buck converter as shown in figure 1. The low gate charge, fast switching DMG4496SSS was selected as the high side switch (Q1 and Q3) and the DMS3014SSS and DMN4800LSS were in turn evaluated in the synchronous position (Q2 and Q4). The efficiency of the 3.3V and 5V output voltages were measured whilst the converters output load was then varied from 0.8A to 8A in 1A steps. These measurements were taken under two input voltage conditions: at 19V's, to simulate the input voltage of a notebook PC from the AC Adaptor and then at 9V to simulate the output voltage from a notebook PC battery pack. The results of these efficiency measurements are shown in Figures 2 and 3.

Figures 2a and 3a highlight that the PoL converter is 0.5 to 1% more efficient at output currents of >4A when the DMS3014SSS is used as the synchronous MOSFET. Similarly, an increase in efficiency is observed when the PoL converter operates from a 9V battery.

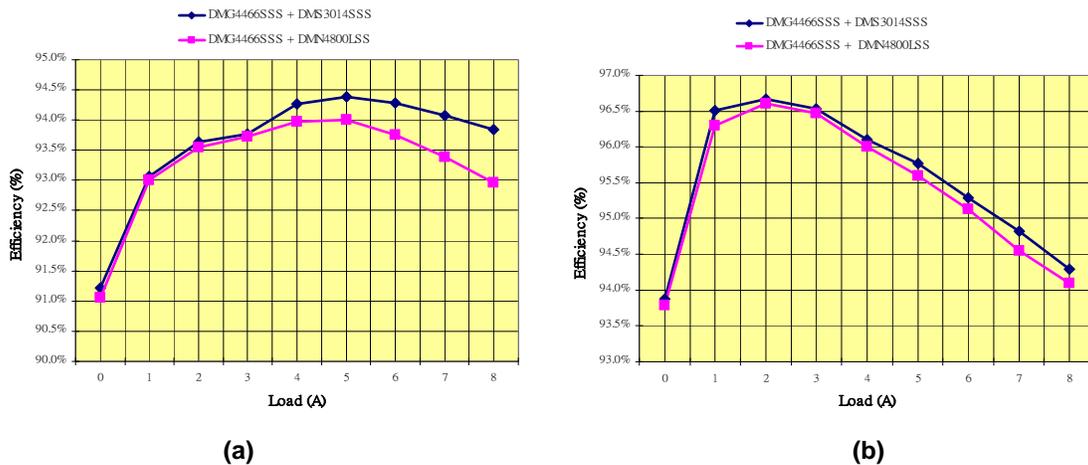


Figure 2. 5V output POL converter efficiency at (a) $V_{in} = 19V$ and (b) $V_{in} = 9V$

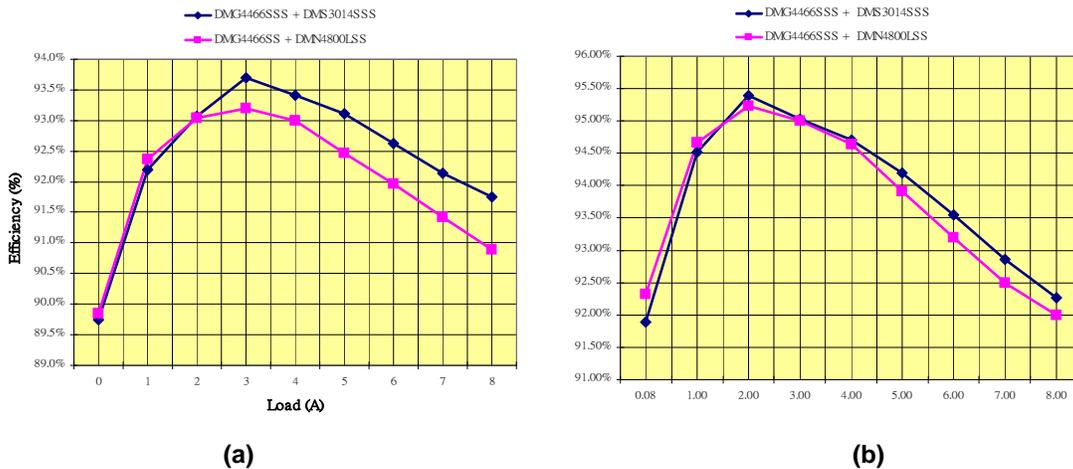


Figure 3. 3.3V output POL converter efficiency at (a) $V_{in} = 19V$ and (b) $V_{in} = 9V$

Another important circuit consideration is the limitation of shoot-through or cross conduction current in the circuit. At high switching frequencies there is a risk that a temporary shoot-through or cross conduction could happen. This occurs during the switch-on interval of the high-side MOSFET as a very high dV/dt on the phase node (see Figure 1) that induces a gate voltage on the synchronous MOSFETs (Q2 and Q4). If the synchronous MOSFET sees an induced voltage greater than the gate

threshold $V_{GS(th)}$, then it could be turned ON whilst the high-side switch is ON. This causes excessive power dissipation in both MOSFETs, and could ultimately lead to device failure.

Shoot through can be minimized by selecting a synchronous MOSFET that has a low gate capacitance ratio (Q_{gd}/Q_{gs}). The DMS3014SSS has a gate capacitance ratio of 0.58 which is much lower than that of the standard trench MOSFET, as shown in comparison table 1. Figure 4 illustrates that no shoot-through was observed when the DMS3014SSS was used as the synchronous MOSFET even when the phase node is subjected to a rate of change of 600V/ns.

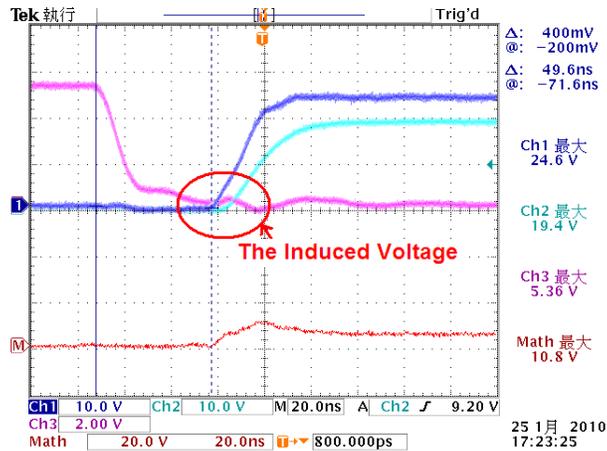


Figure 4 Operating waveforms at the turn-on transition of the high-side switch (Pink: Low-side MOSFET's V_{GS} ; Blue: High-side MOSFET's V_{GS} ; Cyan: Phase voltage)

Furthermore, a thermal camera was used to measure the temperature of the high side and synchronous MOSFETs under during these efficiency evaluations. As can be seen in Figure 5 the DMS3014SSS operates at a temperature that is 10% lower than that of the DMN4800LSS.

This lower operating temperature reduces conduction loss in the surrounding components and increases reliability, every 10°C reduction in the junction temperature of the MOSFET will double the lifetime reliability of the PoL converter.

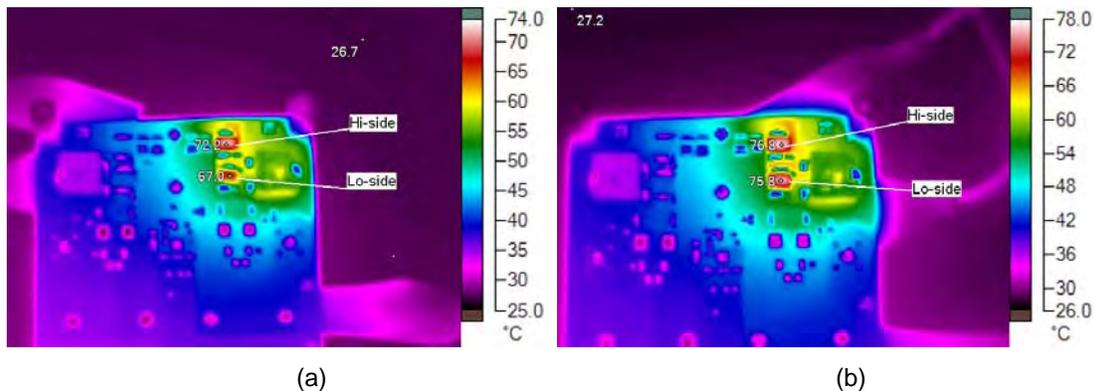


Figure 5. 5V output, 19V input POL converter thermal measurements for (a) DMS3014SSS and (b) DMN4800LSS

Conclusion

It has been demonstrated that the efficiency of the PoL converter can be increased by up to 1 % when the DMS3014SSS is used to replace a comparable standard trench MOSFET. Furthermore, the DMS3014SS provides this increase in performance whilst operating at a lower temperature, reducing conduction losses in the surrounding components and doubling the reliability of the PoL converter.

Furthermore, the DMS3014SSS operates at a higher efficiency enabling the PoL converter to have a higher current handling capability or operate with a lower device junction temperature.

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