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Small Signal OptiMOS™ 606 MOSFET in Low Power DC/DC converters

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Table of contents

1 Introduction

Infineon's new 60V class Small Signal OptiMOS™ 606 family will be available in TSOP-6, SOT-89 and SC59 packages.

The low Q_g and low $R_{DS\ (on)}$ makes the OptiMOS™ 606 suitable for low power DC/DC converters and cell balancing in Battery Energy Control Modules (BECM). Also the logic level gate enables it to be easily interfaced directly with MCUs / Digital circuits.

As all products are qualified to AEC Q101, they are ideally suitable for automotive and high quality demanding applications.

This application note illustrates the benefits of BSL606SN (TSOP-6 package) in low power DC/DC applications. The main features of BSL606SN are shown in the table below.

Parameter	Symbol	Conditions	Value			Unit
Continuous drain current	I_D	T_A = 25 °C	4.5			A
Drain-source breakdown voltage	$V_{(BR)DSS}$	V_{GS} =0 V, I_D = 250 µA	60	-	-	V
Gate threshold voltage	$V_{GS(th)}$	V_{DS} = 0 V, I_D = 15 µA	1.3	1.8	2.3	
Drain-source on-state resistance	$R_{DS(on)}$	V_{GS} =4.5 V, I_D = 3.6A		69	95	mΩ
Gate to source charge	Q_{gs}	V_{DD} = 48 V, I_D = 4.5 A, V_{GS} = 0 to 5 V		1.9	2.5	nC
Gate to drain charge	Q_{gd}			1.0	1.5	
Gate charge total	Q_g			4.1	6.1	

Table 1: BSL606SN Main Features

2 Application Example

A good example of a low power DC/DC converter is an LED power supply. In Automotive, LED lighting is now common. A typical automotive lighting application is the Daytime Running Light (DRL) function such as the one shown in the picture below.

Figure 1: DRL function example

2.1 Application Boundary conditions

An example of the application boundary conditions for a DRL function is given below.

- The sum of the LED forward voltage (DC/DC converter output voltage V_{OUT}) is approximately 25 V.
- The supply input voltage V_{IN} is specified in the range of 8 V to 16 V. The nominal value is 12 V.
- The LED current or the output current of the DC/DC converter I_{OUT} should be 400 mA.
- Boost configuration is used with a switching frequency of around 400 kHz operated in continuous conduction mode.

2.2 Application circuit configuration

The figure below illustrates the Boost configuration of a DRL application.

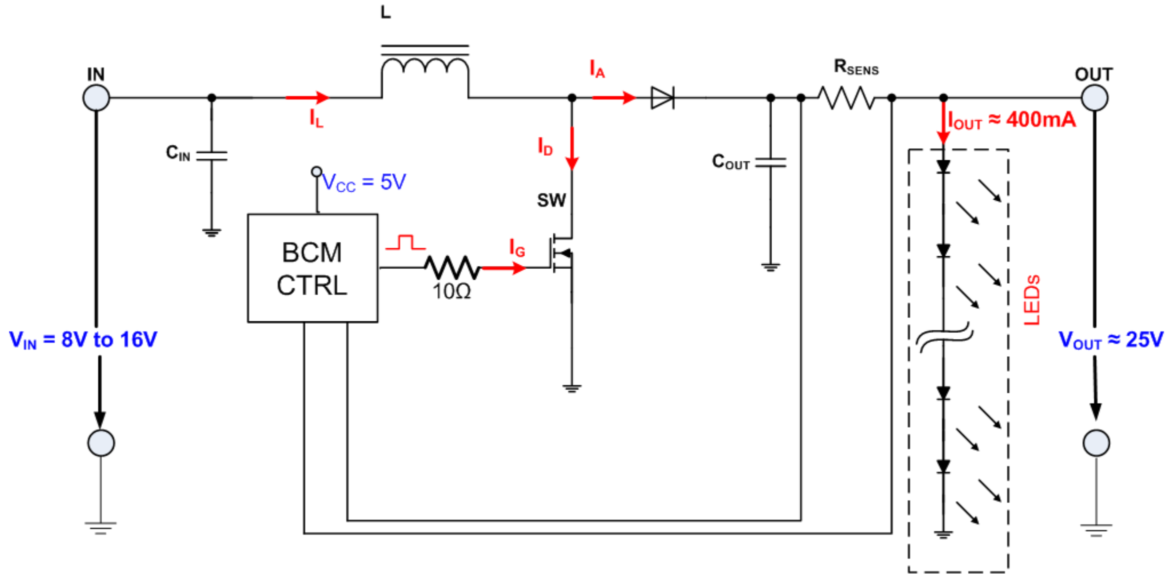

Figure 2: Boost circuit configuration

A summary of the application boundary conditions, which should be the basis for the calculation of the losses in the application, are presented in the table below

Symbol	Value	Unit	Name
V_{IN}	12	V	Nominal input Voltage
V_{OUT}	25	V	LED forward voltage
I_{OUT}	0.4	A	LED Current
F_s	400	kHz	Switching Frequency
ΔV_{OUT}	100	mV	Max. ripple voltage on V_{OUT}
$\Delta I_L\%$	20	%	Pk-Pk inductor Ripple current.

Table 2: Application Boundary conditions

3 Review of Losses in a DC/DC Converter

The efficiency of a DC/DC converter is a measure of the ratio of the output power supplied to the load with respect to the input power. The input power is equal to the load power plus the converter losses. A DC/DC converter has its losses in its control circuit and magnetics, out of which switching losses are the greatest contributor. These losses are briefly discussed in the following sub-sections.

3.1 MOSFET Switching Losses

Switching losses occur due to the positive product of current through the MOSFET and voltage across it during switching transition. The switching losses occur twice for every switching period during turn-on and turn-off. The figure below illustrates current and voltage during turn-on.

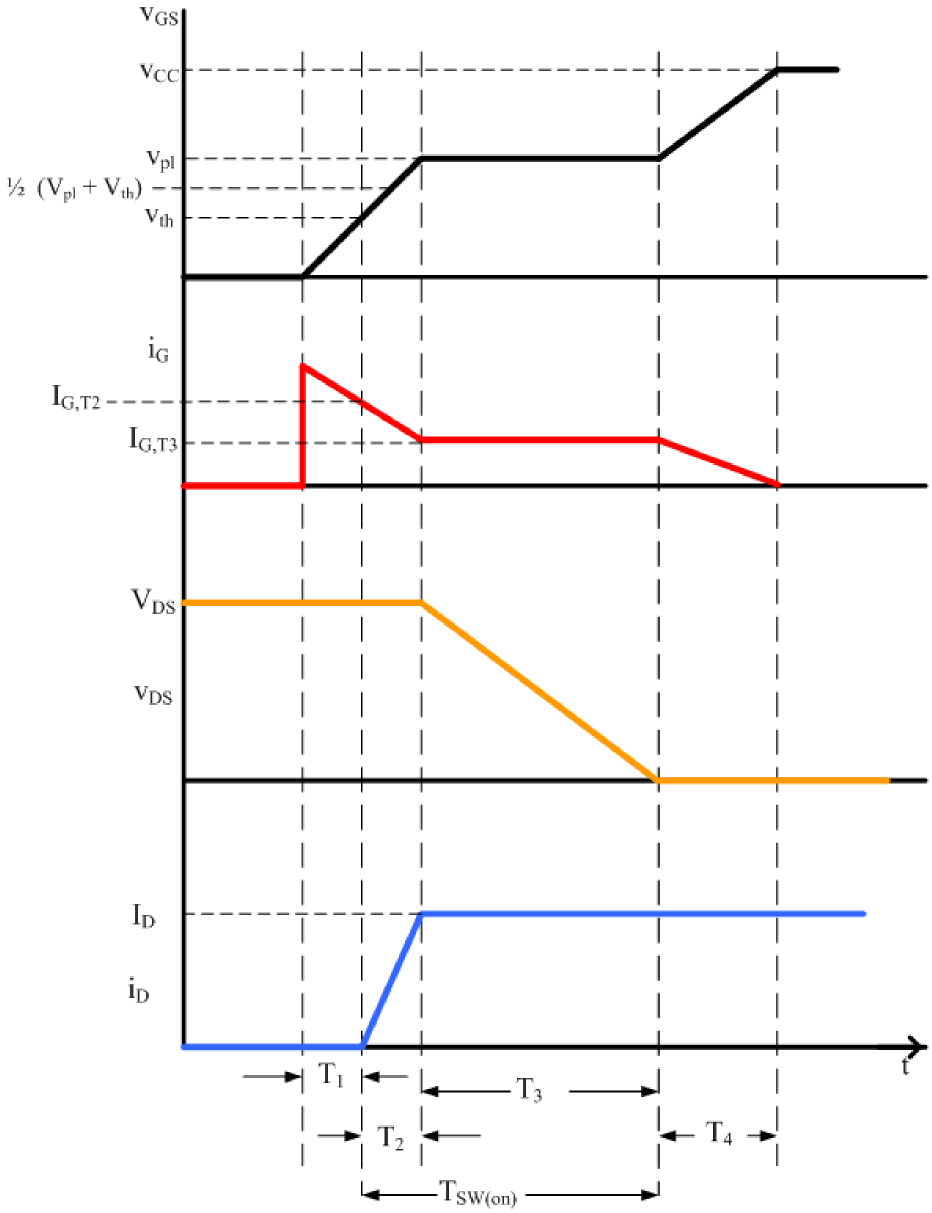

Figure 3: MOSFET turn on waveforms

Using linear approximations of the waveforms, the power loss components for the respective intervals can be estimated. The estimated power components in intervals T_2 and T_3 are given by:

$$P_2 = T_2 \cdot V_{DS} \cdot \frac{I_D}{2} \cdot F_s \tag{1}$$

$$P_3 = T_3 \cdot \frac{V_{DS}}{2} \cdot I_D \cdot F_s \tag{2}$$

The total turn-on switching losses are the sum of the two components and are given by:

$$P_{on} = P_2 + P_3 = \frac{1}{2} \cdot (T_2 + T_3) \cdot V_{DS} \cdot I_D \cdot F_s = \frac{1}{2} \cdot T_{SW(on)} \cdot V_{DS} \cdot I_D \cdot F_s \tag{3}$$

Where $T_{SW\ (on)}$ is the turn-on time for the MOSFET it depends upon the gate drive voltage.
The average gate drive currents during T_2 and T_3, $I_{G,\ T2}$ and $I_{G,\ T3}$ are given by:

$$I_{G,T2} = \frac{V_{cc} - 0.5(V_{pl} + V_{th})}{Rtot} \tag{4}$$

$$I_{G,T3} = \frac{V_{cc} - V_{pl}}{Rtot} \tag{5}$$

V_{cc} = gate driver power supply. R_{tot} = total gate resistance.
Assuming that $I_{g,\ T2}$ charges the input capacitors of the MOSFET from V_{th} to V_{pl} and $I_{g,T3}$ is the discharge current of the gate to drain capacitor while the drain voltage changes from V_{DS} to 0 then the approximate T_2 and T_3 are given by:

$$T_2 = C_{iss} \cdot \frac{(V_{pl} - V_{th})}{I_{G,T2}} \tag{6}$$

$$T_3 = C_{rss} \cdot \frac{V_{DS}}{I_{G,T3}} \tag{7}$$

The turn-on time, $T_{SW\ (on)}$ is the sum of T_2 and T_3 and is given by:

$$T_{SW(on)} = T_2 + T_3 = \frac{C_{iss} \cdot (V_{pl} - V_{th})}{I_{G,T2}} + \frac{C_{rss} \cdot V_{DS}}{I_{G,T3}} \tag{8}$$

Similarly the turn-off switching losses can be estimated and are given by:

$$P_{off} = \frac{1}{2} \cdot T_{SW(off)} \cdot V_{DS} \cdot I_D \cdot F_s \tag{9}$$

Thus the total switching losses are the sum of turn-on losses and turn-off losses.

$$P_{sw} = P_{on} + P_{off} = \frac{1}{2} \cdot \left(T_{SW(on)} + T_{SW(off)}\right) \cdot V_{DS} \cdot I_D \cdot F_s \qquad \textbf{(10)}$$

Where, $T_{SW\,(off)}$ is the turn-off time for MOSFET.

3.2 MOSFET Gate Losses

Energy is required in order to charge and discharge the gate capacitances of the MOSFET for each switching period. This energy is usually dissipated through gate series resistance in the gate driver circuit. Thus the gate losses are given by:

$$P_g = Q_g \cdot V_{cc} \cdot F_s \qquad \textbf{(11)}$$

Q_G = total gate charge, V_{cc} = gate driver power supply voltage and F_s = switching frequency of the converter.

3.3 MOSFET Output Losses

The output losses are the energy losses when the MOSFET output drain to source capacitance is discharging during turn-on. Thus the output losses are given by:

$$P_{out} = \frac{1}{2} \cdot C_{DS} \cdot {V_{DS}}^2 \cdot F_s \qquad \textbf{(12)}$$

C_{DS} = MOSFET output Drain to Source capacitance.

3.4 MOSFET Conduction Losses

In the on-state, MOSFETs do not behave like an ideal switch with zero impedance, but instead they have a small resistance typically called $R_{DS\,(on)}$. Due to this resistance there will be power losses in the MOSFET and these are calculated by:

$$P_{cond} = R_{DS(on)} \cdot {I_{D,RMS}}^2 \qquad \textbf{(13)}$$

$I_{ds,\,RMS}$ = RMS value of the current through the MOSFET.

The RMS values can be calculated by the current waveform in the MOSFET. When the converter is operating in continuous conduction mode the MOSFET current wave form will be as shown in the figure below. In the figure, $I_{L,\,avg}$ is the average current in the inductor, T_s is the switching period, D is the duty ratio and ΔI_L is the ripple current in the inductor

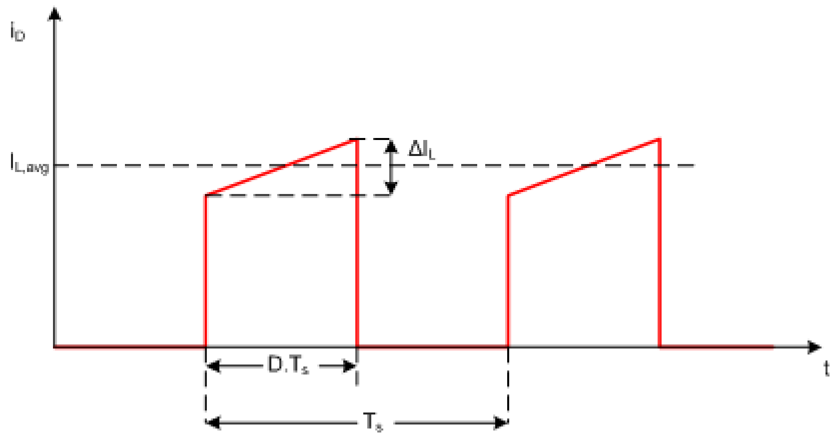

Figure 4: Current through MOSFET

When the MOSFET is turned on, the current within it is equal to the current in the inductor. Thus the RMS value of the MOSFET current is given by:

$$I_{D,RMS} = \sqrt{D.\left(I_{L,avg}{}^{2} + \frac{(\Delta I_L)^2}{12} \right)} \quad \textbf{(14)}$$

So the total MOSFET losses will be the sum of all losses

$$P_{MOSFET} = P_{sw} + P_g + P_{out} + P_{cond} \quad \textbf{(15)}$$

4 Calculation of MOSFET Losses in the Application

From the above section, BSL606SN losses can be estimated using the specified application values from Table 2.
Assuming the MOSFET is driven by a 5 V gate drive power supply with 10 Ohms of total gate resistance and the input voltage is 8 V the following is the case.

The switching losses of BSL606SN are:

$$P_{sw} = \frac{1}{2} \cdot \left(T_{SW(on)} + T_{SW(off)} \right) \cdot V_{DS} \cdot I_D \cdot F_s$$

$$P_{sw} = \frac{1}{2} \cdot \left(4.5 \times 10^{-9} s + 0.15 \times 10^{-9} s \right) \times 25V \times 0.4A \times 400 \times 10^3 Hz = 0.009W \quad \textbf{(16)}$$

$T_{SW\,(on)}$ and $T_{SW\,(off)}$ are calculated as discussed in section 3.1.

The gate losses of BSL606SN are:

$$P_g = Q_g \cdot V_{cc} \cdot F_s$$

$$P_g = 3.8\times10^{-9}C \times 5V \times 400\times10^{3}Hz = 0.008W \quad \textbf{(17)}$$

The output losses of BSL606SN are:

$$P_{out} = \tfrac{1}{2}\cdot C_{DS}\cdot V_{DS}^{\;2}\cdot F_s = \tfrac{1}{2}\cdot\left(C_{oss} - C_{rss}\right)\cdot V_{DS}^{\;2}\cdot F_s$$

$$P_{out} = \frac{1}{2}\times\left(180\times10^{-12} - 11\times10^{-12}\right)\times(25V)^2\times400\times10^3Hz = \frac{1}{2}\times169\times10^{-12}F\times(25V)^2\times400\times10^3Hz = 0.02W \quad \textbf{(18)}$$

The conduction losses of BSL606SN are:

$$P_{cond} = R_{DS(on)}\cdot I_{DS,RMS}^{\;\;2}$$

$$I_{DS,RMS} = \sqrt{D\left(I_{L,avg}^{\;\;2} + \frac{\Delta I_L^{\;2}}{12}\right)} = \sqrt{0.68\times\left((1.25A)^2 + \frac{(0.24A)^2}{12}\right)} \approx 1.03A$$

For the boost converter the duty ratio $D \approx \frac{(V_{OUT} - V_{IN})}{V_{OUT}}$ and the average current through the inductor is equal to the average input current for the converter and is given by $I_{IN,avg} = I_{L,avg} = \frac{I_{OUT}}{(1-D)}$ and the inductor ripple current ΔI_L is given in table 2.

$$P_{cond} = 0.066\Omega\times(1.03A)^2 = 0.07W \quad \textbf{(19)}$$

Thus the total losses of BSL606SN are summarized in the table below

		BSL606SN	
Conduction Losses	P_{cond}	70	**mW**
Switching Losses	P_{sw}	09	**mW**
Gate Losses	P_g	08	**mW**
Output Losses	P_{out}	20	**mW**
Total MOSFET losses	P_{MOSFET}	108	**mW**

Table 3: BSL606SN losses in application

5 Comparison and Summary

BSL606SN losses are compared with an automotive qualified competitor part of the same voltage class. The figure below illustrates the different losses in the respective device.

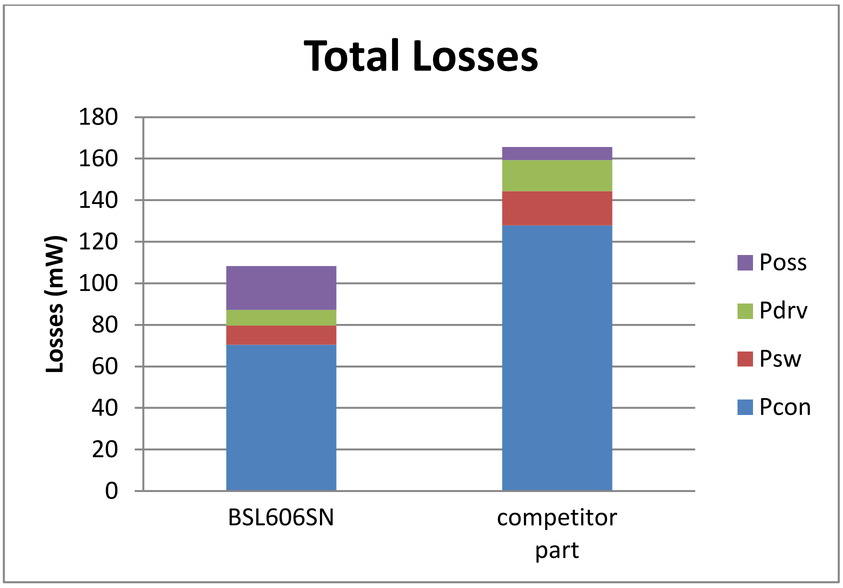

Figure 5: Loss comparison

The chart shows that there are significantly less losses in the converter when BSL606SN is used in comparison to that of the competitor part.

The benefits of using BSL606SN in low power DC/DC converters can be summarised as follows:

- The gate losses are comparitively very small in BSL606SN. This means that the gate requires little current even at logic level to turn it on. This makes it easy to interface to MCUs/ digital circuits.
- The switching losses are very small with BSL606SN. This gives the flexibility of increasing the switching frequency which in turn increases the transient performance. With the increase in switching frequency the inductance can be decreased which in turn decreases the total converter size and cost.