Freescale Semiconductor
Application Note

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Evaluation of Power Dissipation for the eXtreme Switch Devices

(MC10XS3412, MC35XS3400, MC10XS3435 and MC15XS3400)

1 Introduction

This application note relates to the power dissipation capability of 3rd generation quad devices:

- Quad 35mΩ: 35XS3400
- Quad 15mΩ: 15XS3400
- Dual 10mΩ - Dual 12mΩ: 10XS3412
- Dual 10mΩ - Dual 35mΩ: 10XS3435

This application note presents the theoretical computations of power dissipation including conduction and switching losses for resistive and inductive loads. It allows obtaining a rapid evaluation of the thermal losses occurring in a particular design.

Contents

2 Scope

This family of devices is designed for low-voltage automotive lighting applications. Its four low $R_{DS(ON)}$ MOSFETs can control four separate 55W / 28W bulbs, and/or Xenon modules, and/or LEDs, and/or other type of loads.

Programming, control, and diagnostics are accomplished using a 16-bit SPI interface. Its output with selectable slew-rate allows to satisfy electromagnetic compatibility (EMC) requirements. Additionally, each output can be controlled internal PWM modulated clock signal, instead of an external clock.

This family of devices can drive currents in Amperes range, continuously or in PWM mode up to 1.0 kHz. At these current levels the power dissipation becomes a critical parameter. It is the purpose of this application note to give analytical expressions for switching- and conduction losses. This will allow the potential user to make a rapid evaluation of power dissipation of his/her particular design, and can therefore help when dimensioning the cooling system.

Figure 1 gives a typical application diagram using this type of quad high-sides device.

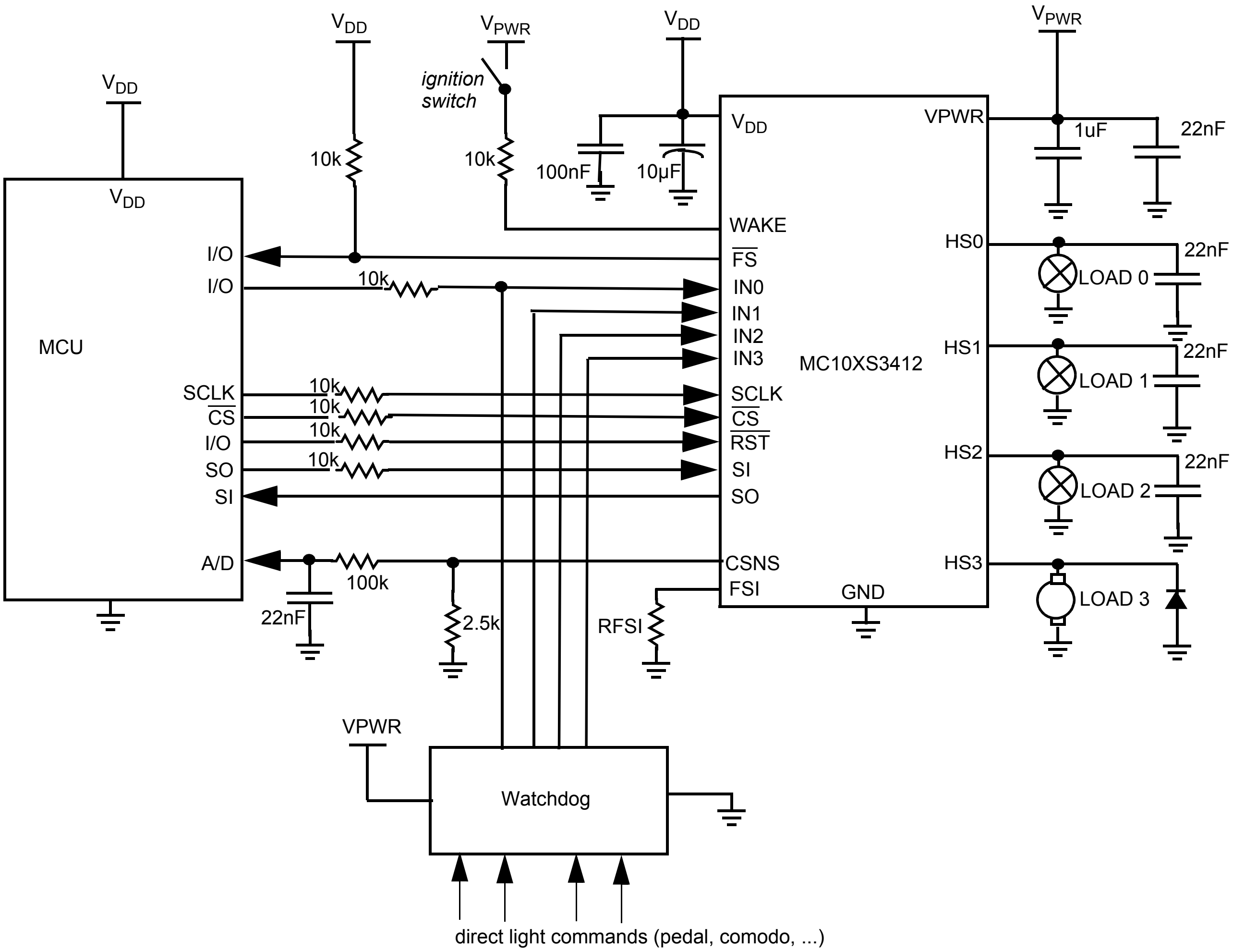


Figure 1. Typical Application Diagram

The losses occurring in each output, P_{DISS}, consists of conduction losses (P_{ON}) and switching losses (P_{SW}):

$$P_{DISS} = P_{ON} + P_{SW}$$

- Conduction losses P_{ON} occur when the device is fully ON.
- Switching losses P_{SW} occur during ON/OFF switching processes. The evaluation of switching losses is not as simple as that of the conduction losses and must take into account several factors such as output switching waveform, load type, battery voltage, …

Figure 2 shows a typical switching process for a resistive load with output voltage and current waveforms (Vout, Iout), along with dissipated power (Pdiss). Power losses are divided in 3 parts: ON switching losses (P_{SW_RISE}), conduction losses (P_{ON}) and OFF switching losses

(P_{SW_FALL}). In this particular example, we can be noted that the switching losses are higher than the conduction losses.

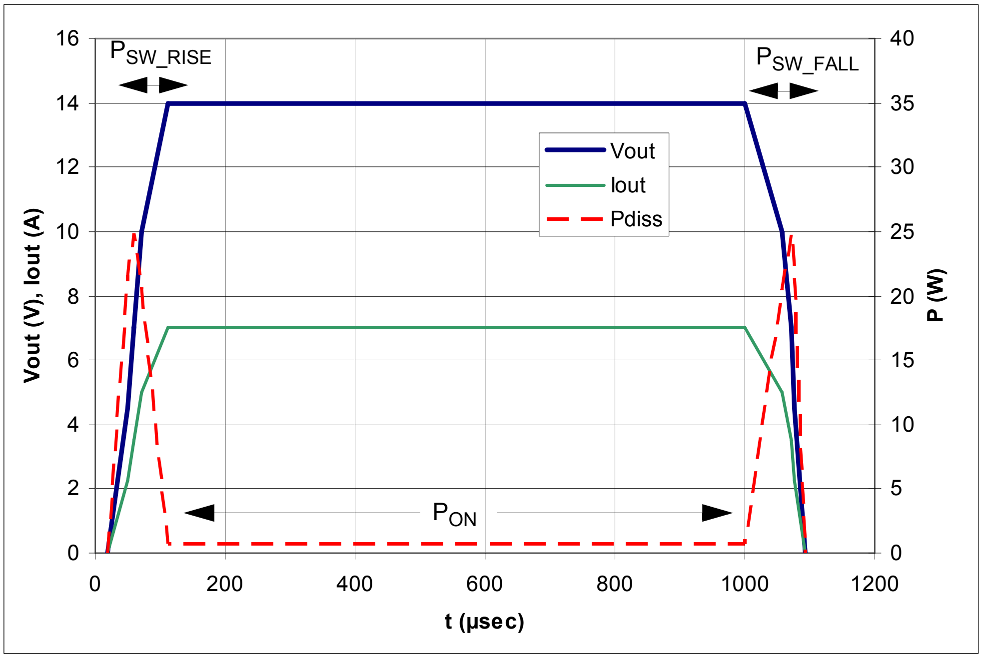


Figure 2. Power Dissipation Waveforms (Resistive load case for V_{PWR}=14V)

The total power dissipation of the device is the sum of power dissipated in each output switch (HS[0:3]):

$$P_{DISS} = P_{DISS(HS0)} + P_{DISS(HS1)} + P_{DISS(HS2)} + P_{DISS(HS3)}$$

3 Conduction Losses

For a given output current level (I_{OUT}), the conduction losses per output switch are:

$$P_{ON} = (V_{PWR} - V_{OUT}) \, . \, I_{OUT} = R_{DS(ON)}(T_J) \, . \, I_{OUT}^2$$

The value of $R_{DS(ON)}(T_j)$ depends on the junction temperature. Over the temperature range 25°C to 150°C, the temperature coefficient of $R_{DS(ON)}$ is about 1.7.

$$R_{DS(ON)}(T_J) = R_{DS(ON)}(25°C) \, . \, [\, 1 + 0.7.(T_J - 25) / 125 \,]$$

$$\text{with } T_J = T_A + P_{DISS} \, . \, R_{THJA}$$

R_{THJA} corresponds to the thermal resistance from junction to ambient.

In switching mode, it is necessary to take into account ON time. The conduction losses can then be approximated as:

$$P_{ON} = \alpha \, . \, R_{DS(ON)}(T_J) \, . \, I_{OUT}^2$$

α is PWM duty-cycle

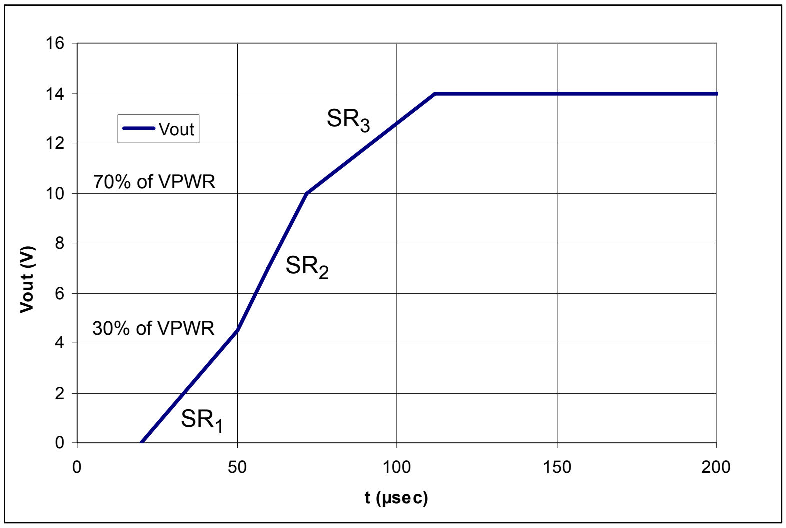
4 Switching Losses

The switching losses appear during ON and OFF switching.

$$P_{SW} = P_{SW\_RISE} + P_{SW\_FALL}$$

The output voltage slew-rate is the critical parameter for switching losses. The choice of the slew-rate will generally result from a compromise between low switching losses (fast switching) and acceptable EMC performance (slow switching). The AN3569 describes measured conducted emission levels as a function of selected output slew-sate.

A typical output switching waveform is presented in Figure 3. The switching process is not linear. The output switching behavior can be model by three different slopes depending on the value of output voltage.



SR_1 from 0% to 30% of VPWR

SR_2 from 30% to 70% of VPWR

SR_3 from 70% to 100% of VPWR

Figure 3. Output ON Switching Model using 3 Pieces of Slopes

4.1 Resistive Load

In case of purely resistive load (R_{LOAD}), both switching losses depend on the switching frequency (f_{PWM}):

- ON switching losses:

$$P_{SW\_RISE1} = f_{PWM} . \{ (0.3^2 . V_{PWR}^3) / (6R_{LOAD} . SR_{1\_RISE}) \}. (3 - 2.(0.3)\}$$

$$P_{SW\_RISE2} = f_{PWM} . \{ 0.4 . V_{PWR}^3) / (6R_{LOAD} . SR_{2\_RISE}) \}. (6(0.3). (0.7) + 0.4^2\}$$

$$P_{SW\_RISE3} = f_{PWM} . \{ 0.3^2 . V_{PWR}^3) / (6R_{LOAD} . SR_{3\_RISE}) \}. (3 - 2.(0.3)\}$$

- OFF switching losses:

$$P_{SW\_FALL1} = f_{PWM} . \{ (0.3^2 . V_{PWR}^3) / (6R_{LOAD} . SR_{1\_RISE}) \}. (2.(0.3) - 3\}$$

$$P_{SW\_FALL2} = f_{PWM} . \{ 0.4 . V_{PWR}^3) / (6R_{LOAD} . SR_{2\_RISE}) \}. (-6(0.3). (0.7) - 0.4^2\}$$

$$P_{SW\_FALL3} = f_{PWM} . \{ 0.3^2 . V_{PWR}^3) / (6R_{LOAD} . SR_{3\_RISE}) \}. (2.(0.3) - 3\}$$

4.2 Inductive Load

In case of an inductive load (inductor L_{LOAD} in series with parasitic resistor R_{LOAD} associated to freewheeling diode), the load current can be considered as constant ($I_{OUT} = \alpha. V_{PWR}/R_{LOAD}$) if the time constant of the load is higher than the switching period ($L_{LOAD}/R_{LOAD} >> 1/f_{PWM}$).

- ON switching losses:

$$P_{SW\_RISE1} = f_{PWM} . \{ 0.3V_{PWR}/SR_{1\_RISE} . (V_{PWR} + 0.7V_{PWR})/2 \} . I_{OUT}$$

$$P_{SW\_RISE2} = f_{PWM} . \{ 0.4V_{PWR}/SR_{2\_RISE} . (0.3V_{PWR} + 0.7V_{PWR})/2 \} . I_{OUT}$$

$$P_{SW\_RISE3} = f_{PWM} . \{ 0.3V_{PWR}/SR_{3\_RISE} . (0.3V_{PWR})/2 \} . I_{OUT}$$

- OFF switching losses:

$P_{SW\_FALL1} = f_{PWM} \,.\, \{ -0.3V_{PWR}/SR_{1\_FALL} \,.\, (V_{PWR} + 0.7V_{PWR})/2 \} \,.\, I_{OUT}$

$P_{SW\_FALL2} = f_{PWM} \,.\, \{ -0.4V_{PWR}/SR_{2\_FALL} \,.\, (0.3V_{PWR} + 0.7V_{PWR})/2 \} \,.\, I_{OUT}$

$P_{SW\_FALL3} = f_{PWM} \,.\, \{ -0.3V_{PWR}/SR_{3\_FALL} \,.\, (0.3V_{PWR})/2 \} \,.\, I_{OUT}$

5 Key Parameters per Device

Table 1 presents the values of output slew-rate parameters over the $R_{DS(ON)}$ range.

Table 1. Output Switching Parameters for 10V < V_{PWR} < 16V

Slew rate Value	Piece wise Linear Output Slope	10mΩ, 12mΩ and 15mΩ Outputs	35mΩ Output
low	SR_{1_RISE} (V/µs)	0.08	0.06
	SR_{2_RISE} (V/µs)	0.14	0.13
	SR_{3_RISE} (V/µs)	0.06	0.06
	SR_{1_FALL} (V/µs)	-0.13	-0.17
	SR_{2_FALL} (V/µs)	-0.13	-0.16
	SR_{3_FALL} (V/µs)	-0.05	-0.07
medium (by default)	SR_{1_RISE} (V/µs)	0.19	0.22
	SR_{2_RISE} (V/µs)	0.30	0.25
	SR_{3_RISE} (V/µs)	0.10	0.11
	SR_{1_FALL} (V/µs)	-0.32	-0.25
	SR_{2_FALL} (V/µs)	-0.30	-0.27
	SR_{3_FALL} (V/µs)	-0.13	-0.11
high	SR_{1_RISE} (V/µs)	0.45	0.37
	SR_{2_RISE} (V/µs)	0.69	0.69
	SR_{3_RISE} (V/µs)	0.20	0.17
	SR_{1_FALL} (V/µs)	-0.56	-0.56
	SR_{2_FALL} (V/µs)	-0.55	-0.45
	SR_{3_FALL} (V/µs)	-0.25	-0.20

6 Revision History

REVISION	DATE	DESCRIPTION OF CHANGES
1.0	8/2008	• Initial Release
2.0	6/2009	• Corrected Inductive Load formula on page 6.

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