1) The circuit of Fig. 1 is used to measure the current flowing in the power MOS M_0. M_0, M_1 M_2 and M_3 are all part of the same multi-cell DMOS transistor, where M_0 includes 3500 cells, M_1 includes 7 cells, M_2 and M_3 include 14 cells each (r_{dson_M0}=100 mΩ). The load is a solenoid valve (V_S = 24V, L = 1mH, R =1.5Ω).

a) Determine the ratio I_M/I_L.

The load current is limited to the nominal value of 10 A by a "peak current-mode" controller operating at f_{SW} = 200 kHz. The MOS switch is mounted on a heat sink ($R_{\theta JC}$ = 3.12 °C/W, $R_{\theta CA}$=5°C/W T_A = 40 °C).

b) Calculate the duty-cycle and the current ripple in the load.

c) Calculate the average junction temperature.

d) Due to a fault, the MOS switch sticks to the ON position. The current protection circuit (I_{MAX}=12A) switches off the MOS after a delay of 30 ms. By using the thermal impedance curves shown in Fig. 4, calculate the maximum junction temperature at the end of the delay time.

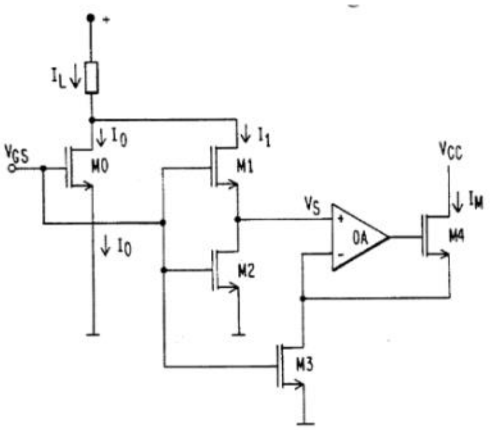


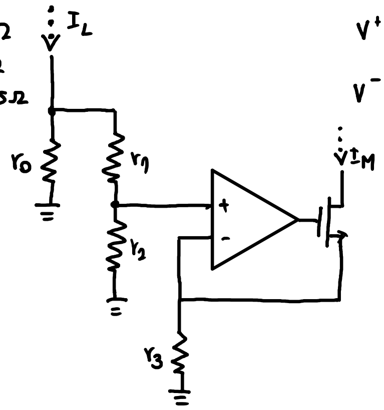
Fig. 1

a)

$r_0 = 0.1\,\Omega$

$r_1 = 50\,\Omega$

$r_2 = r_3 = 25\,\Omega$



$$V^+ = r_2 \cdot I_1 = r_2 \cdot \frac{r_0}{r_0 + r_1 + r_2} \cdot I_L$$

$$V^- = r_3 \cdot I_M$$

$$r_3 \cdot I_M = r_2 \cdot \frac{r_0}{r_0 + r_1 + r_2} \cdot I_L$$

$$\frac{I_M}{I_L} = \frac{r_2}{r_3} \cdot \frac{r_0}{r_0 + r_1 + r_2} \doteq 1.33 \times 10^{-3}$$

b) $I_{L\,Max} = 10\,A$

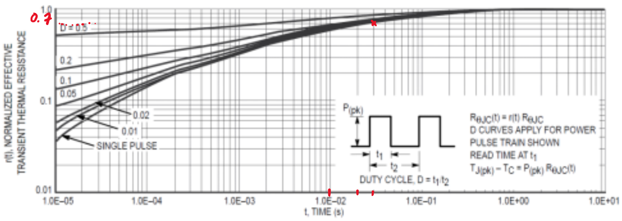
$$(V_S - (R + r_0) I_L) D + R I_L (1-D) = 0 \Rightarrow D = \frac{R I_L}{V_S - r_0 I_L} = 0.652$$

$$\Delta i = \frac{R I_L \cdot (1-D)}{L f_S} = 26\,mA$$

c) $P_{MOS} = r_0 I_L^2 D = 6.52\,W$

$$T_j = T_A + P_{MOS} (R_{\theta jc} + R_{\theta CA}) = 93^\circ C$$

d)



Step response $\tau = \frac{L}{R + r_{on}} = 0.625\,s$ $\quad t \gg \tau$ use $i(\infty) = \frac{V_S}{R + r_{on}} = 15\,A$

$t = 30\,ms$

$$\Delta P = |P_{MOS} - P_{Max}| \cong 16\,W \Rightarrow \Delta T_j = \Delta P \cdot R_{thjc} \cdot r(t_1, D) \cong 35^\circ C$$

$$T_{j\,max} = T_{j0} + \Delta T_j = 93 + 35 = 128^\circ C$$

2) A solenoid valve (L=0.3 mH; R=1 Ω) is driven by a low-side switch ($r_{dsonmax}$ = 0.25 Ω) operating at a fixed frequency of 100 kHz (Fig. 2). The valve is activated by applying the current profile represented in Fig. 3. A "peak current mode" controller is used to limit the load current to the desired value.

a) Calculate the duty cycle of the switch in the time intervals T1 and T2 (V_S=12V, V_D=1V).
b) Calculate the average power dissipated by the power MOS in the time intervals T1 and T2.
Using the curves in Fig. 4:
c) calculate the junction temperature at the end of the time interval T1 ($R_{\theta JC}$ = 3.12 °C/W; T_C = 80 °C);
d) calculate the junction temperature at the end of the time interval T2.

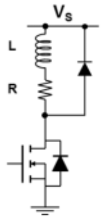


Fig. 2

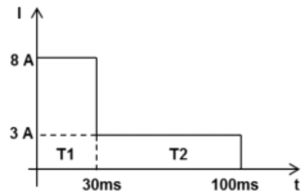


Fig. 3

a) Volt-Second balance L:

$$(V_S - I_L(R + r_{on}))D - (I_L R + V_D)(1-D) = 0 \qquad D_{T1} = 0.818$$

$$(V_S - I_L(R + r_{on}) + I_L R + V_D)D = I_L R + V_D \Leftrightarrow D = \frac{I_L R + V_D}{V_S - I_L r_{on} + V_D} \qquad D_{T2} = 0.327$$

b) $P_{T1} = I_L^2 r_O D_{T1} = 13.1 W$

$P_{T2} = I_L^2 r_O D_{T2} = 0.736 W$

c) $T_j = T_c + P_{T1} R_{Thjc} \cdot r(30 ms) = 108°C$

d) $(T_j(100ms) - T_c) = \Delta T_{jc} = [P_1 \overbrace{r(100ms)}^{0.9} - P_1 \overset{0.8}{r(70 ms)} + P_2 \overset{0.8}{r(70 ms)}] R_{th} = 5.9°C$

$T_j = 80 + 5.9°C \approx 86°C$