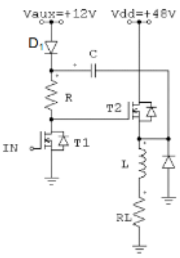
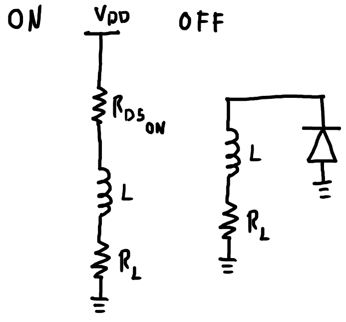
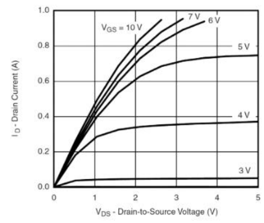
1) The high-side switch shown in Figure 1 is used to drive an inductive load. The load current is set to a value of 5A by a controller operating at a fixed frequency of 100 kHz (R = 100 Ω, R_L = 2 Ω, L = 1 mH, $r_{dsonmax}$ = 0.25 Ω, V_{IN}=0→5V. The output characteristics of T1 are shown in Fig. 2).
a) Calculate the duty cycle of the power MOSFET and the peak-to-peak ripple in the load current.



a) Volt second balance => $0 = [V_{DD} - (R_{DS_{on}} + R_L) I_L] D - R_L I_L (1-D) \Leftrightarrow$

$$\Leftrightarrow D = \frac{R_L I_L}{V_{DD} - R_{DS_{on}} I_L} = 21.4\%$$





$$V_L = L\frac{di}{dt} \Rightarrow \frac{di}{dt} = \frac{V_L}{L}$$

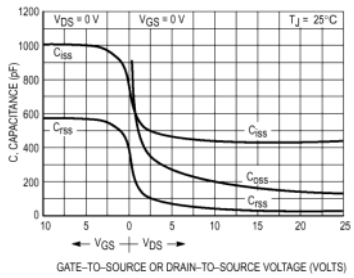
$$\Delta i_L = \frac{[V_{DD} - (R_{DS_{on}} + R_L) I_L] D}{L f_{sw}} = \frac{R_L I_L (1-D)}{L f_{sw}} = 78.6\,mA$$

b) Select the bootstrap capacitor C_B such that the maximum voltage drop, ΔV_{CB} is 500 mV (D1 has a leakage current of 2 μA and a Q_{RR} of 1 nC).

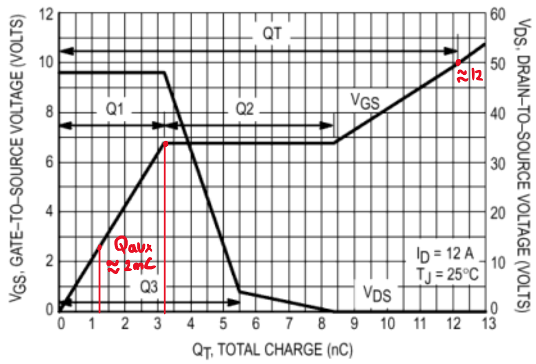
b) $\Delta V_{CB} = 500\,mV$ $\qquad \Delta Q_{CB} = C_B \cdot \Delta V_{CB}$

$D_1 \Rightarrow \begin{cases} I_{leak} = 2\,\mu A \\ Q_{RR} = 1\,mC \end{cases}$ $\qquad C_B \geq \frac{Q_G + Q_{RR} + I_{leak} \cdot 1/f_{sw}}{\Delta V_{CB}} \Leftrightarrow C \geq 26\,mF!$

$Q_G = C_{iss} \cdot V_{GS_{Max}} = 1000\,pF \cdot 12\,V = 12\,mC$ ⇐



c) Using the curves in Figures 3 and 4, calculate the average switching loss in the power MOS transistor (V_{TH}=2.5V).



Turn on: T_1 OFF [Lets assume $V_{D1} = 1V$]

$V_{GSP} = 6.8V$ $\quad V_B = V_{aux} - V_D = 11V$ $\quad Q_2 = 5.2\,mC$

$t_{don} = 40\,ms$ $\quad t_r = 124\,ms$ $\quad t_{Th} = 11\,ms$

− t_{don}: $V = V_\infty + (V_0 - V_\infty) e^{-t/\tau}$

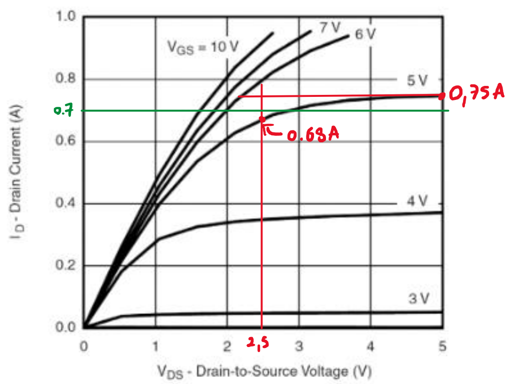
$V = V_B(1 - e^{-t/\tau})$ $\quad \tau = RC_{iss}$ $\quad C_{iss} = 420\,pF$

$$-\ln\left(1 - \frac{V_{GSP}}{V_B}\right) \cdot RC_{iss} = t_{don} \Leftrightarrow t_{don} = RC_{iss} \ln\left(\frac{V_B}{V_B - V_{GSP}}\right) = 40\,ms$$

− t_r: $t_r = \frac{Q_2}{I_{Driver}} = \frac{Q_2 R}{V_B - V_{GSP}} = 124\,ms$ $\qquad$ − t_{Th}: $t_{Th} = RC_{iss} \ln\left(\frac{V_B}{V_B - V_{Th}}\right) = 11\,ms$ ← Relevant

$I_{Driver} = \frac{V_B - V_{GSP}}{R}$

Turn off: $V_{Th} = 2.5 \Rightarrow V_{DS_{Min1}} = V_{Th} = 2.5V$



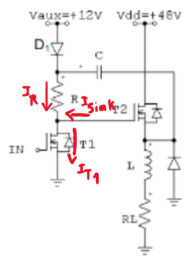
Plateau: t_f

$I_{T_1} = 750\,mA$

$I_R = \frac{V_B - V_{GSP}}{R} = 43\,mA$

$I_{sink} = I_{T_1} - I_R = 707\,mA$

$t_f = \frac{Q_2}{I_{sink}} = 7.4\,ms$



Discharge: t_{dis}

$I_{T_1min} = 680\,mA$

$I_{RMax} = \frac{V_B - V_{Th}}{R} = 85\,mA$

$I_{sinkmin} = 595\,mA$

Assume $I_{sinkmin}$ for all t ⇒ overestimate!

$t_{dis} = \frac{Q_{aux}}{I_{sinkmin}} = 3.4\,ms$

$t_f = 7.4\,ms$ $\quad t_{dom} = 40\,ms$

$t_{dis} = 3.4\,ms$ $\quad t_r = 124\,ms$

$t_{th} = 11\,ms$

$$E_{ON} = \frac{V_{DD} \cdot I_L}{2}(t_{dom} + t_r - t_{th})$$

$$E_{OFF} = \frac{V_{DD} \cdot I_L}{2}(t_{dis} + t_f)$$

$$> P = \frac{V_{DD} \cdot I_L}{2} \cdot (t_{dom} + t_r - t_{th} + t_{dis} + t_f) \cdot f_{sw} = 1.96\,W \approx 2W$$

d) Calculate the average power dissipation in the resistor R.

If ON $\Rightarrow I_R = \frac{V_{aux} - V_{D1}}{R}$ $\qquad P = (V_{aux} - V_{D1})^2 / R \,(1 - D) = 950\,mW$

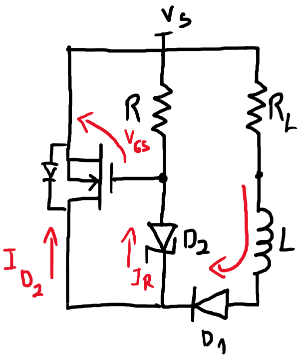
If OFF $\Rightarrow I_R = 0$

Assuming ideal transients since $t_s \gg t_{on,off}$

2) The inductive load of Fig.5 is driven by a MOSFET M1. V_S = 15 V, V_Z = 47 V, L = 6 mH, R_L = 3 Ω, R = 100 Ω, $r_{DSonM1} << R_L$.
After the load current has reached the steady state value, the MOSFET M1 is switched off.
a) Calculate the current flowing through the DMOS M2, whose output characteristics are shown in Fig. 6, after M1 is switched off.

a) At steady state $I_L(0) = 5A$

At turn-off



$I_{D_2} \approx 5A$

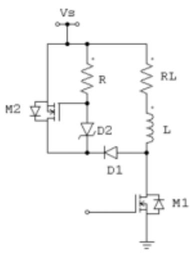


Fig. 5

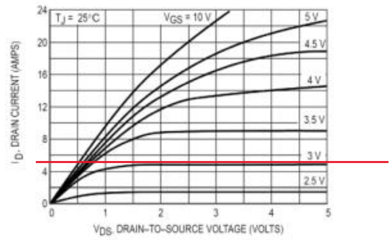
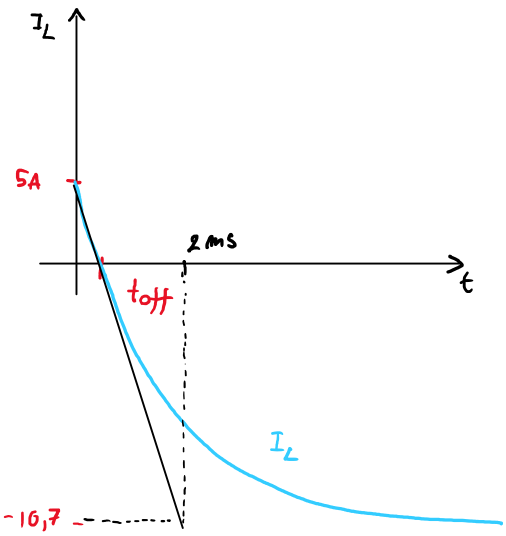


Fig. 6

b) Calculate the current flowing through the zener diode D2 after M1 is switched off.

$V_{GS2} = 3V \qquad V_R = 3V \Rightarrow I_R = I_Z = \frac{V_R}{R} = 30\,mA$

c) Draw a plot of the inductor current as a function of time. $\tau = \frac{L}{R} = 2\,ms$



$i_L(0) = 5A$

$i_L(\infty) = -\frac{V_{GS} + V_Z}{R_L} = -16.7A$

$$I_L(t) = K_1 + K_2 e^{-t/\tau}$$

$I_L(0) = K_1 + K_2$

$I_L(\infty) = K_1$

$K_1 = i_L(\infty) = -16.7\,A$

$K_2 = i_L(0) - K_1 = 21.7\,A$

$I_L(t) = -16.7 + 21.7\,e^{-t/\tau}$

$\hookrightarrow t_{off} = t|_{i_L(t)=0} \Rightarrow \ln\left(\frac{21.7}{16.7}\right)\tau = t = 0.524\,ms$

d) Calculate the energy dissipated in the MOSFET M2 during the turn-off transient.

with ideal D_1

$V_{DS} = V_{GS} + V_Z = 50V$

$E = 50 \cdot \int i_L dt \simeq 50 \cdot \frac{t_{off} \cdot I_L(0)}{2} = 65\,mJ$