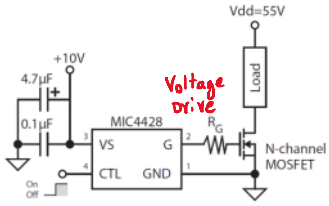
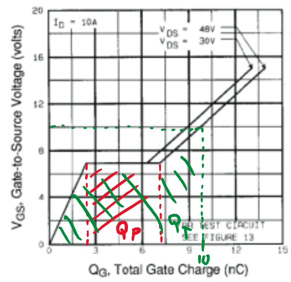
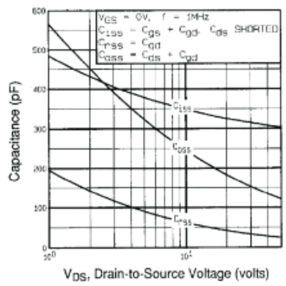
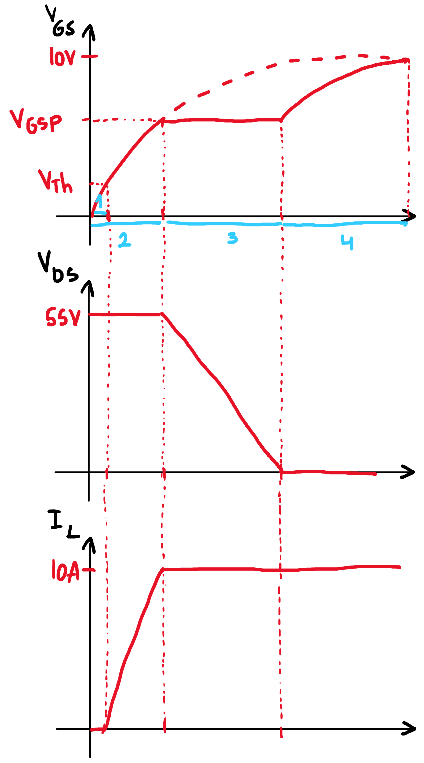
1) A low-side DMOS switch is used to drive a 10 A inductive load. The power MOSFET is driven by a MIC4428 biased at 10 V (Fig. 1). The MIC4428 driver has an output resistance, R_{out} of 6 Ω.
Using the curves shown in Figures 2 and 3:
a) calculate t_{dON}, t_{rise}, t_{dOFF}, t_{fall} (R_G = 33 Ω);
b) calculate the average switching loss in the power MOSFET transistor (f_{sw}=100 kHz);
c) calculate the driver loss.







a) Turn-ON



$t_1 = t_{Th}$ = Time to reach threshold voltage

$t_2 = t_{dom}$

$t_3 = t_r$

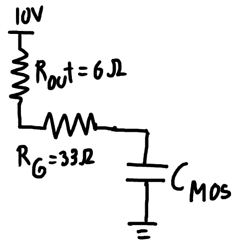
t_4 = Excess charge Time

IMP:

$V_c = V_\infty + (V_0 - V_\infty) e^{-t/\tau}$

$Q = I \cdot t$

For t_{dom} equivalent circuit



$C_M = C_{iss}|_{V_{DS}=55\,V} = 300\,pF$

$V_{GSP} = 7\,V$

$R_T = R_G + R_{out} = 39\,\Omega$

$Q = I \cdot t$

$Q_p \rightarrow$ Gate charge in plateu ~5 nC

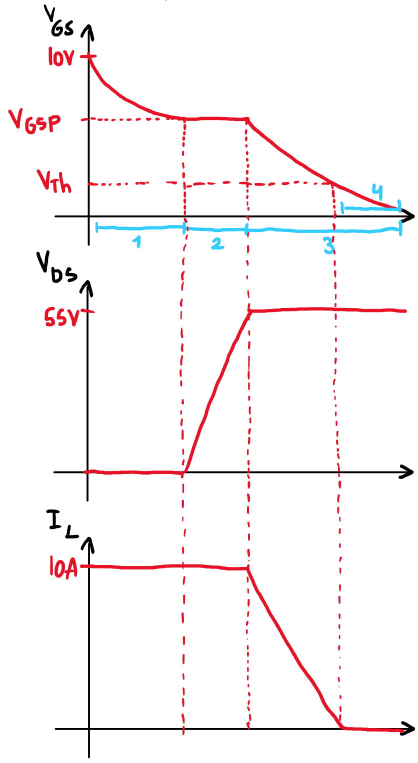
$Q_p = I_G \cdot t_r \Leftrightarrow t_r = \frac{Q_p}{I_G} = \frac{Q_p \cdot R_T}{V_{DD} - V_{GSP}} = 65\,ms$

$V_{C_{Mos}} = V_\infty + (V_0 - V_\infty) e^{-t/\tau}$

$V_{GSP} = V_{DD} - V_{DD} e^{-t/C_M \cdot R_T} \Leftrightarrow$

$\Leftrightarrow t = C_M \cdot R_T \ln\left(\frac{V_{DD}}{V_{DD} - V_{GSP}}\right) = 14\,ms$

Turn-off



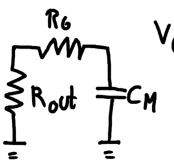
$t_1 = t_{doff}$

$t_2 = t_f$

$t_3 = t_d$ = Discharge Time

$t_4 = t_{Th}$ = Threshold Time

For t_{doff} equivalent circuit



$V_{GSP} = V_{DD} e^{t/\tau}$

$t_{doff} = C_M R_T \ln\left(\frac{V_{DD}}{V_{GSP}}\right) = 10\,ms$

$C_M = C_{iss}|_{V_{DS}=0\,V} =$

$C_{iss}|_{V_{DS}=0V} = \frac{\Delta Q}{\Delta V} = \frac{3\,nC}{4} =$
$= 750\,pF$

can be estimated using the gate charge

$V_{GSP} = 7\,V$

$R_T = R_G + R_{out} = 39\,\Omega$

$Q = I \cdot t$

$t_f = Q_p \cdot I_G = Q_p \cdot \frac{R_T}{V_{GSP}} = 28\,ms$

$t_{dom} = 14\,ms$ $t_{doff} = 10\,ms$

$t_r = 65\,ms$ $t_f = 28\,ms$

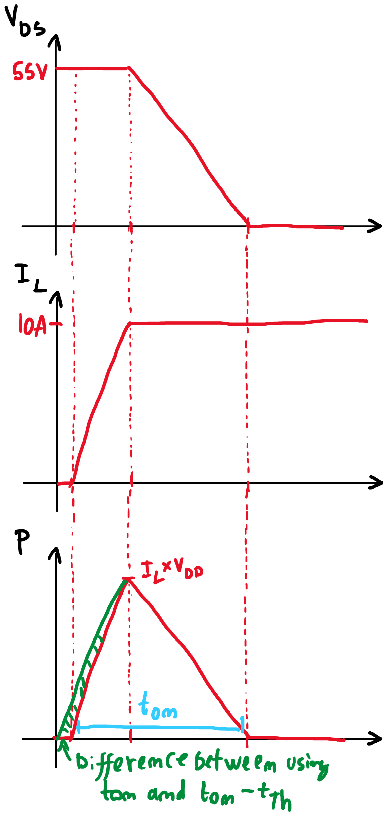
other relevant times $V_{th} = 4V$

$t_{Thom} = t = C_M \cdot R_T \ln\left(\frac{V_{DD}}{V_{DD} - V_{Th}}\right) = 6\,ms$

$C_M = C_{iss}|_{V_{DS}=55\,V} = 300\,pF$

$t_{dis} = t_d - t_{Thoff} = C_M \cdot R_T \ln\left(\frac{V_{GSP}}{V_{Th}}\right) = 6.5\,ms$

b) Turn-on



ON

with $t_{on} = t_{don} + t_r = 82\,ns$

$E_{ON} = t_{on} \cdot I_L \cdot V_{DD} \cdot \frac{1}{2} = 22.6\,\mu J$

With $t_{on} = t_{don} + t_r - t_{Th} = 73\,ns$

$E_{ON} = 20.1\,\mu J$

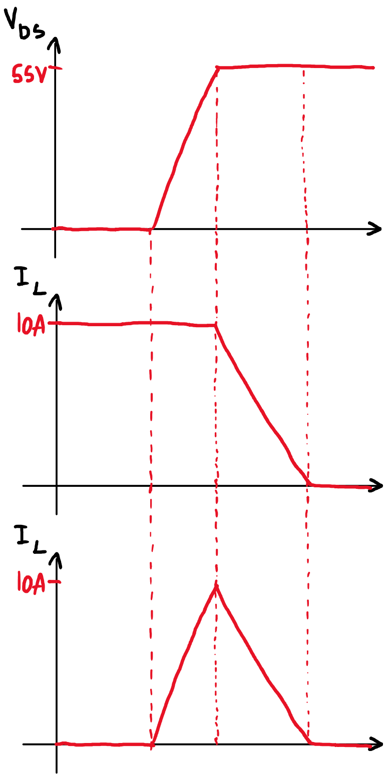
OFF

$t_{off} = t_{dis} + t_f = 34.5\,ns$

$E_{OFF} = t_{off} \cdot I_L \cdot V_{DD} \cdot \frac{1}{2} = 9.5\,\mu J$

$P_T = (E_{ON} + E_{OFF}) \cdot f_s = 29.6\,mW$ //

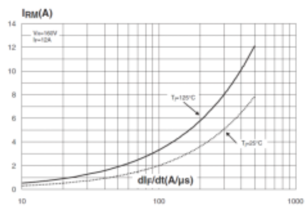
Turn-off



c) Driver loss $P_{DRV} = Q_T \cdot V_S \cdot f_s = 10\,mW$

$V_S = V_{G\,Max}$ $Q_T \Rightarrow$ All the gate charge

2) The circuit shown in Figure 4 is used to drive a 10 A inductive load (V_i = 5 V, V_{BEon} = 0.8V, V_Z = 5.6 V, R_1 = 130 Ω, R_2 = 240 Ω, f_{SW}=10 kHz). The current gain of Q_2 is 150.
a) Using the curves shown in Figures 2 and 3 calculate t_{dON}, t_{rise} t_{dOFF}, t_{fall}.
b) Calculate the turn-on power loss assuming V_{TH} = 4V and ideal freewheeling diode.
c) The freewheeling diode (STTH1202) has an abrupt recovery with $t_{rr} = t_a$ (t_b ~ 0).
Using the curves in Fig. 5, calculate the additional power loss in the MOSFET due to the diode reverse recovery.



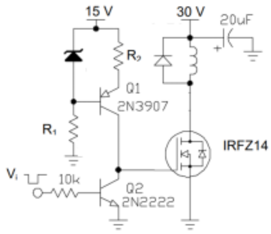
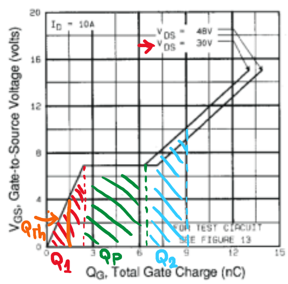
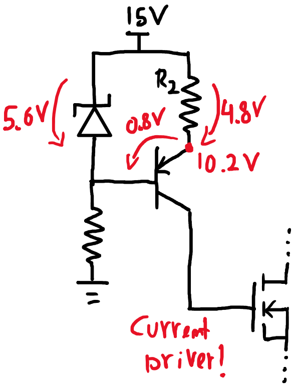


Fig. 4



a) ON

Equivalent ON Circuit   With $V_{CE_{Sat}} = 200mV \rightarrow V_{GS\,Max} \simeq 10V$!



$I_E = \frac{V_{R_2}}{R_2} \approx I_C = 20\,mA$! Constant current

$Q = I \cdot t \Rightarrow t_{don} = \frac{Q_1}{I_G} = \frac{2.3\,nC}{20\,mA} = 115\,ns$

$t_r = \frac{Q_P}{I_G} = \frac{4\,nC}{20\,mA} = 200\,ns$

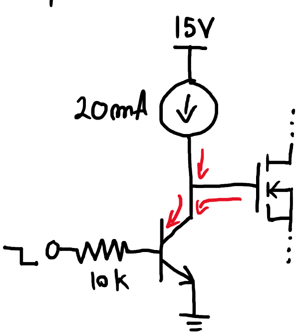
b) Turn-on

$P = (t_{don} + t_r) \cdot I_L \cdot V_{DD} \cdot \frac{1}{2} \cdot f_s = 0.47\,W$

$P = (t_{don} + t_r - t_{Th}) \cdot \frac{I_L V_{DD}}{2} f_s = 0.36\,W$ ← More Correct

$t_{th} = \frac{Q_{Th}}{I_{Gon}} = \frac{1.5\,nC}{20\,mA} = 75\,ns$

Equivalent OFF Circuit



$I_B = \frac{5 - 0.8}{10k} A = 0.42\,mA$

$I_C = \beta I_B = 63\,mA$

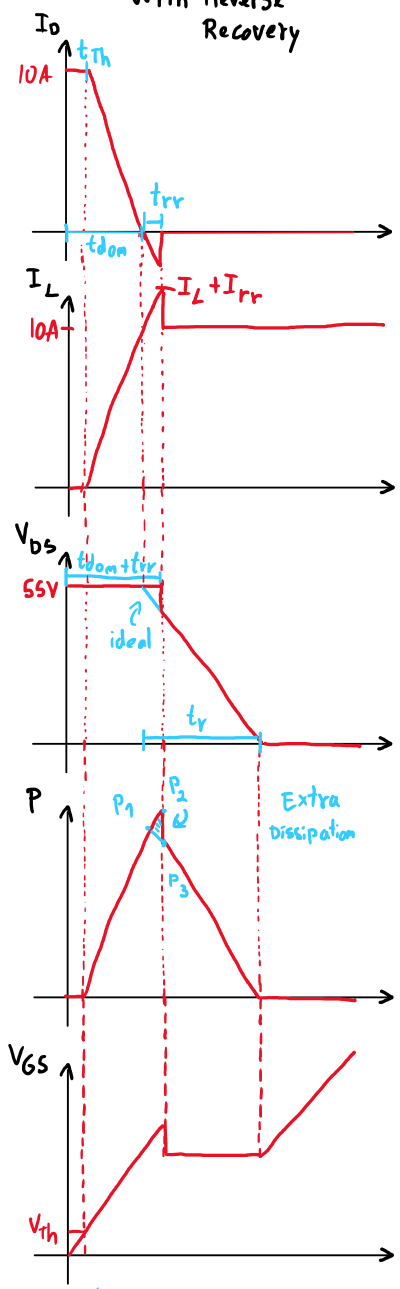
$I_G = I_C - I_{Source} = 43\,mA$

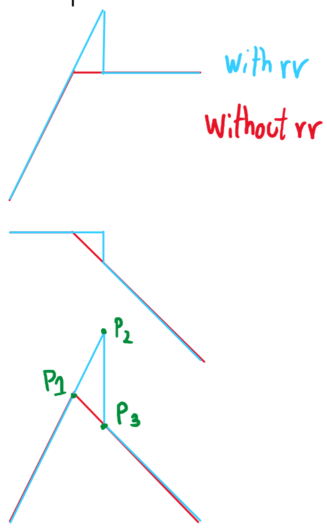
$Q = I \cdot t \Rightarrow t_{doff} = \frac{Q_2}{I_G} = \frac{2.7\,nC}{43\,mA} = 63\,ns$

$t_f = \frac{Q_P}{I_G} = 93\,ns$

c)

With Reverse Recovery





$P_1 = V_{DD} \cdot I_L = 300W$

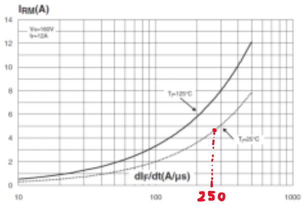
$P_2 = V_{DD} \cdot (I_L + I_{RR}) = 442.5W$

$P_3 = P_1 - \frac{dP}{dt} \cdot t_{RR} = 271.5W$

$\frac{dP}{dt} = \frac{P_1}{t_r} = 1.5 \, W/ms$

$E_{Dis} = \frac{(P_2 - P_3) \times t_{rr}}{2} = 1.6 \, \mu J$

$P_{Dis} = E_{Dis} \times f_s = 16 \, mW$ //



$\Rightarrow I_{RR} = 4.75A$

$\frac{dI_F}{dt} = \frac{I_L}{t_{dom}} = \frac{10}{40m} = 250 \, A/\mu s$

$t_{RR} = \frac{I_{RR}}{dI_F/dt} = 19ms \Rightarrow Q_{RR} = 45mC$

Less accurate alternative

$P = Q_{RR} \cdot V_{DD} \cdot f_{SW} = 13.5 \, mW$