1) The DC-DC converter shown in Fig. 1 operates in CCM with $V_O = 5$ V, $V_{IN} = 25 - 40$V, $f_{SW} = 100$ kHz, $P_O = 15$ W, $n_2/n_1 = 0.5$. Transistors Q1 and Q2 are driven by the same gate signal.
a) Derive an expression for the DC voltage conversion ratio V_O/V_{IN}.
b) Calculate the minimum inductance value that ensures CCM operation.
c) Calculate the maximum duty-cycle value for which the transformer core is completely demagnetized at the end of the switching cycle.
d) Calculate the maximum voltage drop across switches Q1 and Q2.
e) Calculate the output voltage ripple (C= 470 µF; ESR= 50 mΩ, L=3L_{min}).

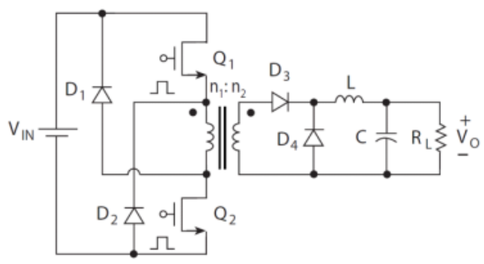
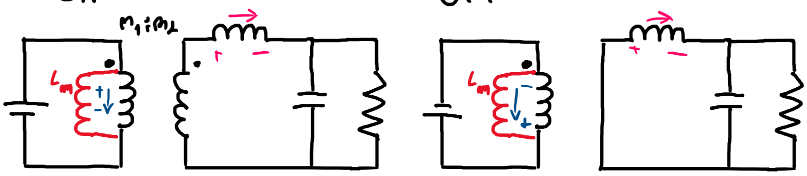


Fig. 1

1) a) ON OFF



$V_L = (V_{IN}\frac{n_2}{n_1} - V_O)$ $\qquad$ $V_L = -V_O$

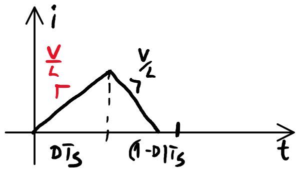
$(V_{IN}\frac{n_2}{n_1} - V_O)D - V_O(1-D) = 0 \Leftrightarrow V_{IN}\frac{n_2}{n_1}D - V_O D - V_O + V_O D = 0 \Leftrightarrow \frac{V_O}{V_{IN}} = \frac{n_2}{n_1}D$

b) $V = L\frac{di}{dt} \Leftrightarrow \Delta i = \frac{V\Delta t}{L} \Leftrightarrow \Delta i = \frac{V_O(1-D)t_s}{L}$ $\qquad \langle I_L \rangle = I_O$

Lowest D => Highest V_{IN} $D = 0.25$

$\langle I_L \rangle \geq \frac{\Delta i}{2} \Leftrightarrow I_O \geq \frac{V_O(1-D)t_s}{2L} \Leftrightarrow L \geq \frac{R_O(1-D)t_s}{2} \Rightarrow L \geq 6.25\,\mu H$

c)



$V = L\frac{di}{dt}$ $\qquad$ $D_{Max} = 0.5$

$\frac{V}{L}\cdot DT_S = di_{rise} < \frac{V}{L}\cdot(1-D)T_S = di_{fall}$

$D < \frac{1}{2}$

d) $V_{Q_1 Max} = V_{Q_2 Max} = V_{IN}$

When $V_{L_m} = 0$!

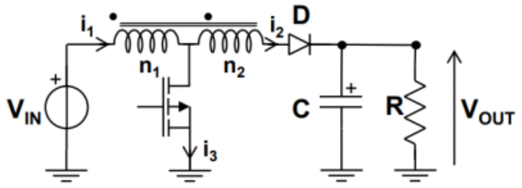
e) $C = 470\,\mu F$ $\qquad \Delta V_O = \Delta V_C + \Delta V_{ESR}$ $\qquad \Delta V_{ESR} = \Delta I_O \cdot ESR = 100mV$

$ESR = 50m\Omega$ $\qquad \Delta I = \frac{V_O(1-D)t_s}{L} = 2A$ $\qquad \Delta V_C = \frac{\Delta Q}{C} = \frac{\Delta I_O \cdot t_s}{8C} \simeq 5.32mV$ $\qquad \Rightarrow \Delta V_O = 105.32mV$

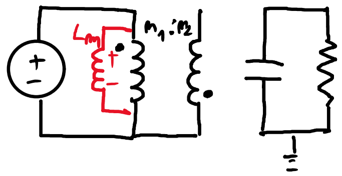
$L = 3L_{min} = 18.75\,\mu H$

Worst cas D min

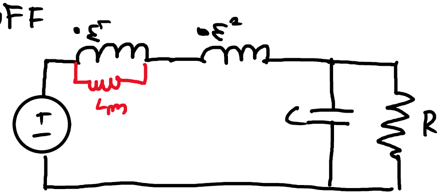
2) The DC/DC converter shown in Fig 2 operates in CCM.
a) Draw a plot of the DC voltage transfer function V_O/V_{IN} as a function of the duty cycle D and the turn ratio n_2/n_1.
Given: V_{IN} = 1.5 V, V_O = 24 V, P_O = 6 W; f_{SW} = 500kHz:
b) Select the turn ratio n_2/n_1 such that D=50%.
c) Calculate the minimum magnetizing inductance value for CCM operation.
d) Draw a plot of i_1, i_2 and i_3 as a function of time (assume L_m>>L_{mmin}).
e) Select the filter capacitor C such that the peak-to-peak output voltage ripple is less than 2% of the ouput nominal voltage (assume L_m>>L_{mmin}).



a) ON



OFF

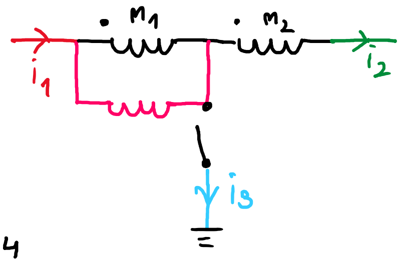


$V_{Lm} = V_i$

$V_{Lm} = V_i - V_{Lm}\frac{n_2}{n_1} - V_o \qquad V_{Lm} = \frac{V_i - V_o}{1+\frac{n_2}{n_1}}$

$$V_i D + \frac{V_i - V_o}{1+\frac{n_2}{n_1}}(1-D) = 0 \iff \frac{V_i D\left(1+\frac{n_2}{n_1}\right)}{(1-D)} + V_i = V_o \iff \frac{V_o}{V_{IN}} = \frac{(1-D) + D\left(1+\frac{n_2}{n_1}\right)}{(1-D)} =$$

$$= \frac{1 + D\frac{n_2}{n_1}}{1-D}$$



b) $V_{IN} = 1.5V \quad V_o = 24V \quad P_o = 6W \quad f_S = 500kHz$

$$\frac{24}{1.5} = 16 = \frac{1 + 0.5\frac{n_2}{n_1}}{0.5} \iff (8-1)2 = \frac{n_2}{n_1} \iff \frac{n_2}{n_1} = 14$$

c) $\Delta i = \frac{V_{IN} D T_S}{L}$

$I_{Lm} > \frac{\Delta i}{2} \iff L > \frac{V_{IN} D T_S}{I_{LM} \cdot 2} \Rightarrow L_{min} = 100nH$

$I_2 = I_D = I_o = \frac{P_o}{V_o} = 0.25A$

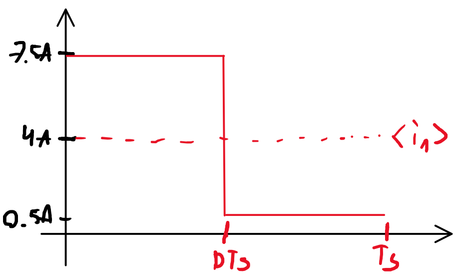
$I_3 = I_1 - I_2 \Rightarrow I_{Lm} = \frac{I_1 - I_2}{D} = 7.5A$

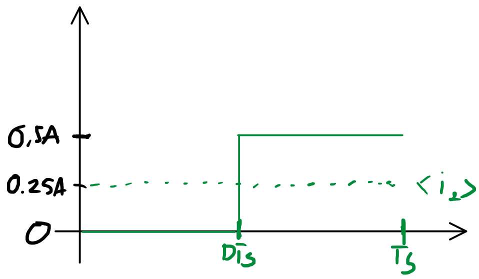
$I_{Lm} D = I_3$

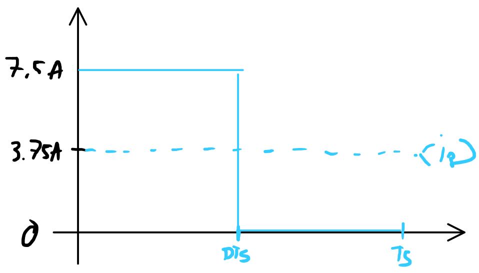
e) $i = C\frac{\Delta V}{\Delta t} \qquad \frac{i(1-D)T_S}{C} = \Delta V$

$\frac{0.25(1-0.5)}{500 \cdot 10^3 \cdot 0.02 \cdot 24} = C = 520nF$

d)







$\langle i_1 \rangle = \langle I_N \rangle = 4A$

$i_{1ON} = I_{Lm} = D\langle i_3 \rangle = 7.5A$

$i_{1off} = 2\left(4 - \frac{7.5}{2}\right) = 0.5A$

$\langle i_2 \rangle = \langle I_o \rangle = 0.25A$

$i_{2ON} = 0$

$i_{2off} = 2 \cdot 0.25A = 0.5A$

$\langle i_3 \rangle = \frac{I_{Lm}}{2} = 3.75A$

$i_{3ON} = I_{Lm} = 7.5A$

$i_{3off} = 0 = 0A$