1) The DC/DC converter shown in Fig. 1 operates in CCM. The control signals applied to switches S1 and S2 are shown in Fig 2. $V_O = 5$ V, $P_O = 100$ W; $V_{INmin} = 280$V, $V_{INmax} = 340$V $f_{sw} = 250$ kHz.
a) Derive the DC voltage transfer function V_O/V_{IN} as a function of D.
b) Calculate the turn ratio n such that $D_{max} \le 40\%$.
c) Draw a plot of i_{D1}, i_{D2}, i_L and i_{Lm} as a function of time (ignore the current ripple in L).
d) Calculate the minimum inductance value L to ensure CCM operation.
e) The output filter capacitor has the following specifications: C = 220 µF; ESR= 35 mΩ. Select L such that the output voltage ripple is less than 1% of the nominal value.
f) Select L_m such that the maximum magnetizing current is less than 10% of the current through the ideal transformer primary.

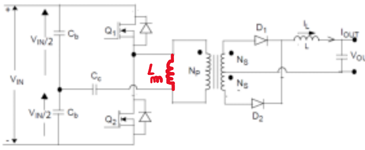
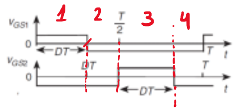
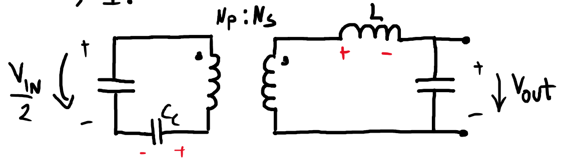


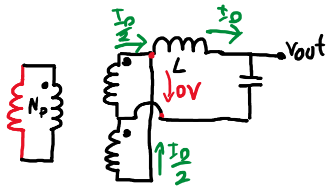
Fig. 1



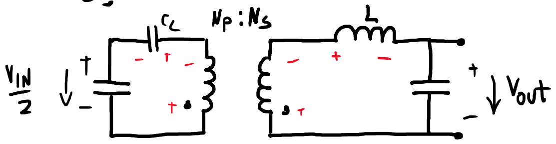
a) 1:



2/4:



3:



L:

$$\left[\frac{N_s}{N_p}\left(\frac{V_{IN}}{2}-V_c\right)-V_{out}\right]D+\left[\frac{N_s}{N_p}\left(\frac{V_{IN}}{2}-V_c\right)-V_{out}\right]D-2V_{out}\left(\frac{1}{2}-D\right)=0$$

$$\left[\frac{N_s}{N_p}\left(\frac{V_{IN}}{2}-V_c\right)-V_{out}\right]D-V_{out}\left(\frac{1}{2}-D\right)=0$$

L_m: $\left(\frac{V_{IN}}{2}-V_{C_c}\right)D+\left(-\frac{V_{IN}}{2}-V_{C_c}\right)D=0 \Rightarrow V_{C_c}=0$

$$\left[\frac{N_s}{N_p}\frac{V_{IN}}{2}-V_{out}\right]D-V_{out}\left(\frac{1}{2}-D\right)=0 \Leftrightarrow \frac{V_o}{V_{IN}}=D\frac{N_s}{N_p}$$

b) $D_{max}\le 0.4$

$\frac{V_o}{V_{IN}}\frac{N_s}{N_p}\le 0.4$ worst case $V_{IN_{Min}}=280$

$\frac{N_s}{N_p}\le 0.4\frac{V_{IN}}{V_o} \Leftrightarrow \frac{N_s}{N_p}\le 22.4 \Rightarrow m=\frac{N_s}{N_p}=22$

d) $\langle I_L\rangle \ge \frac{\Delta I_L}{2}$ $\quad\langle I_L\rangle = I_o$ $\quad\Delta I_L=\frac{V_o\left(\frac{1}{2}-D\right)}{L\cdot f_s}$

$I_o \ge \frac{V_o\left(\frac{1}{2}-D\right)}{2L\cdot f_s} \Leftrightarrow L\ge\frac{R_o\left(\frac{1}{2}-D\right)}{2f_s}$ $\quad R_o=0.25\,\Omega$ $\quad f_s=250\,kHz$

$L\ge 88.24\,mH$ $\quad D_{min}=\frac{V_o}{V_{IN\,M}}m=0.32$

e) $\Delta V_o=\Delta ESR+\Delta V_C$

$\Delta ESR = ESR\cdot\Delta I_o$

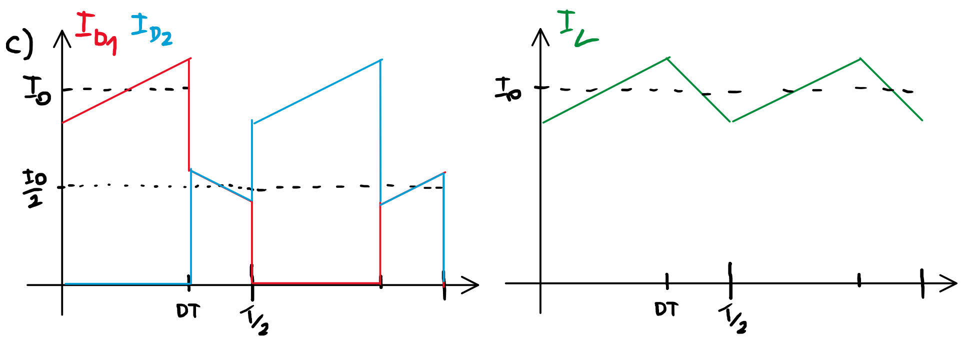
$\Delta V_C=\frac{T_s}{4}\cdot\frac{1}{2}\cdot\frac{I_o}{2}\cdot\frac{1}{C}=\frac{T_s\Delta I_o}{16C}$

$\Rightarrow \Delta V_o\le\left(ESR+\frac{T_s}{16C}\right)\Delta I_o \Leftrightarrow \Delta I_o\ge\frac{0.01V_o}{ESR+\frac{T_s}{16C}}$

$\Delta I_o\ge 1.38A$

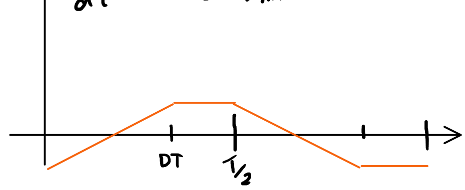
$L\ge\frac{V_o\left(\frac{1}{2}-D\right)}{\Delta I_o f_s}\Leftrightarrow L\ge 2.6\,\mu H$

c)



$\frac{di_{Lm}}{dt}=\frac{V_{in}}{2L_m}$ $\quad 0<t<DT$

$\frac{di_{Lm}}{dt}=-\frac{V_{in}}{2}\frac{1}{L_m}$ $\quad\frac{T}{2}<t<\left(\frac{1}{2}+D\right)T$



f) $\frac{V_{im}}{2L_m}\cdot\frac{DT_s}{2}=I_{Lm_{Max}}$ $\quad\frac{I_P}{I_S}=m$ $\quad\frac{V_o}{V_{IN}}=Dm \Leftrightarrow \frac{V_o}{m}=V_{IN}D$

$\frac{V_{im}}{2L_m}\cdot\frac{DT_s}{2}=0.1\,m\,I_o \Leftrightarrow \frac{10V_o}{4m^2I_o}\le L_m \Leftrightarrow L_m\ge 1.29\,mH$

2) The DC-DC converter shown in Fig. 2 works at a switching frequency f_{SW}=250 kHz.
a) Draw a plot of the DC voltage transfer function V_O/V_{IN} as a function of the duty cycle D, asuming that the inductors L and L_m work in CCM.
Given the following specifications: V_{IN} = 5V, V_O = 24V, P_O = 6W.
b) Select the turn ratio n_2/n_1 such that D=40%.
c) Select L such that the peak-to-peak current ripple is less than 25% of the average current.
d) Select L_m such that the inductor operates at the boudary CCM-DCM at D=40%.
e) Select the capacitor C_1 such that the voltage ripple (peak-to-peak) is less than 10% of the nominal voltage V_{C1}.
f) Calculate the peak-to-peak output voltage ripple (C= 470 μF, ESR= 20mΩ).

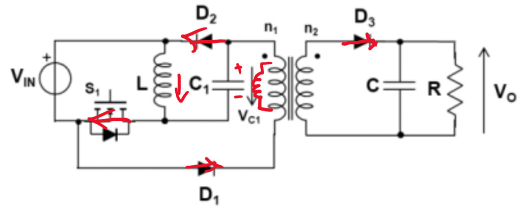
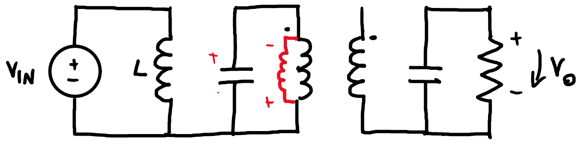
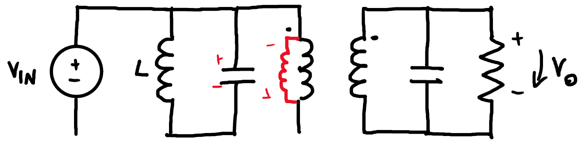


Fig. 2

ON



OFF



a) $L:\ V_{IN} D + V_{C1}(1-D) = 0$

$L_m:\ -V_{C1} D - V_O \frac{m_1}{m_2}(1-D) = 0$

$V_{C1} = -V_O \frac{m_1}{m_2}(1-D)/D \Rightarrow \frac{V_O}{V_{IN}} = \frac{D^2}{(1-D)^2} \frac{m_2}{m_1}$

b) $D = 0.4$
$V_O = 24\,V$
$V_{IN} = 5\,V$

$\frac{24}{5} \cdot \frac{(0.6)^2}{(0.4)^2} = \frac{m_2}{m_1} = 10.8$

$m = 11!$

c) $\Delta I_L \leq 0.25 \cdot \bar{I}_L \qquad \Delta I_L = \frac{V_{IN} D}{f_s L}$

$\frac{V_{IN} D}{f_s L} \leq \frac{I_{IN}}{4D} \qquad \bar{I}_L = \frac{I_{IN}}{D}$

$\frac{4 \cdot V_{IN} \cdot D^2}{f_s I_{IN}} \leq L \iff L \geq 10.67\,\mu H$

d) $D = 0.4$

$\bar{I}_{Lm} = \frac{\Delta I_{Lm}}{2} \qquad L \cdot 2\bar{I}_{Lm} = V_O \frac{(1-D)}{m f_s} \Rightarrow L = 592.6\,mH$

$\Delta I_{Lm} = V_O \frac{(1-D)}{m} \cdot \frac{1}{f_s L}$

$\bar{I}_{Lm} = \frac{1}{1-D} I_O \frac{m_2}{m_1} = 4.5\,A$

e) $V_{IN} D + V_{C1}(1-D) = 0 \Rightarrow V_{C1} = -\frac{V_{IN} D}{1-D} = -3.33\,V$

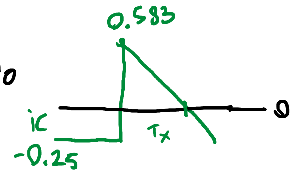
$i = C\frac{\Delta V}{\Delta t} \qquad I_{Lm} \leq C \frac{0.1 V_{C1}}{D T_s} \iff C \geq \frac{D I_{Lm}}{0.1 V_{C1} f_s} \iff C \geq 21.6\,\mu C$

why the triangle in 4t?
Ripple inductor?

f) $\Delta V_O = \Delta ESR + \Delta V_C$

$\Delta ESR = ESR \cdot \Delta I_O$

$i_C = i_{D3} - i_O$



$\frac{0.833}{(1-D)T_S} = \frac{0.5833}{T_x}$

$T_x = 1.68\,\mu s$

$\Delta Q = \Delta I \cdot t_x = \frac{0.583 \cdot t_x}{2} = 490\,mC$

$\Delta ESR = 20\,m\Omega \cdot 0.833\,A = 16.7\,mV$

$\Delta V_O = \frac{\Delta Q}{C} = 1.04\,mV$