1) The two-phase series capacitor buck converter shown in Fig. 1 operates in CCM at $f_{sw} = 1/T_s = 1MHz$. The switch driving waveforms are illustrated in Fig. 2.

a) Derive the DC voltage transfer function V_O/V_{IN} as a function of D (assume the converter is lossless and the inductance values are matched (i.e. $L_a = L_b$)).

Assuming $V_{IN} = 12V$, $V_O = 1.2V$, $P_O = 12W$:

b) calculate the average currents I_{La} and I_{Lb}.

c) Select the inductance values, L_a and L_b, such that the peak-to-peak current ripple is less than 20% of the average current.

d) Sketch a plot of the current flowing through C_1 as a function of time.

e) Select C_1 to ensure that the peak-to-peak voltage ripple is less than 0.3V.

f) Sketch a plot of the current flowing through L_a and L_b.

g) Calculate the peak-to-peak current ripple in C_O.

h) Calculate the peak-to-peak output voltage ripple ($C_O = 47\ \mu F$, $ESR = 5m\Omega$).

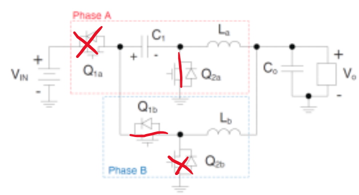


Fig. 1

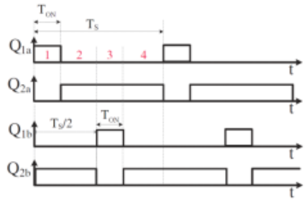
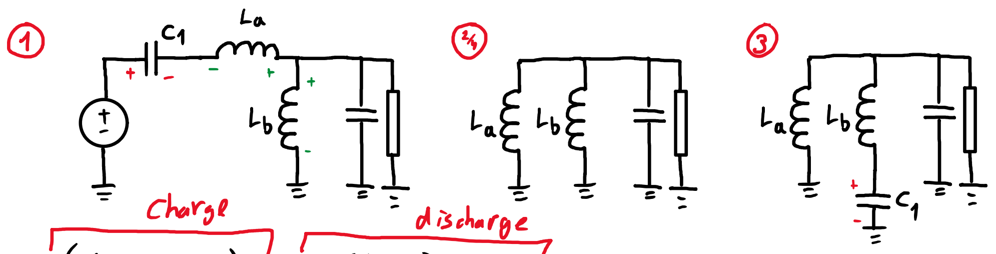


Fig. 2



a) $L_a \Rightarrow (V_o + V_{C_1} - V_i)D + V_o(1-2D) + V_o D = 0$

$L_b \Rightarrow V_o D + V_o(1-2D) + (V_o - V_{C_1})D = 0$

$V_{C1} = V_o/D$

$\rightarrow (V_o - V_i)D + V_o + V_o(1-2D) + V_o = 0 \Leftrightarrow \frac{V_o}{V_i} = \frac{D}{2}$

b) $V_i = 12V$ $2/4 \Rightarrow L_a = L_b \Rightarrow I_a = I_b$ and $I_a + I_b = I_o$

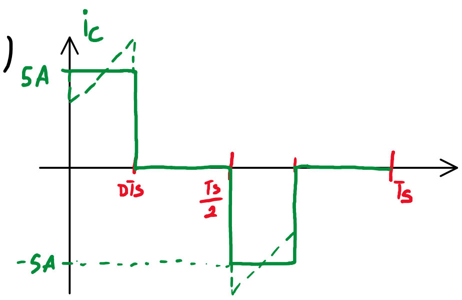
$V_o = 1.2V$ $I_a = I_b = \frac{I_o}{2} = 5A$

$P_o = 12W$

c) $L_a = L_b$ and $D = 0.2$

$\begin{cases} V = L_b \frac{\Delta i}{\Delta t} \\ \Delta i \leqslant 0.2 I_b \end{cases} \Rightarrow \frac{V_o D}{f_s L_b} \leqslant 0.2 I_b \Leftrightarrow L_b \geqslant \frac{V_o(1-D)}{0.2 I_b f_s} \Leftrightarrow L_b \geqslant 960\ mH$

d)

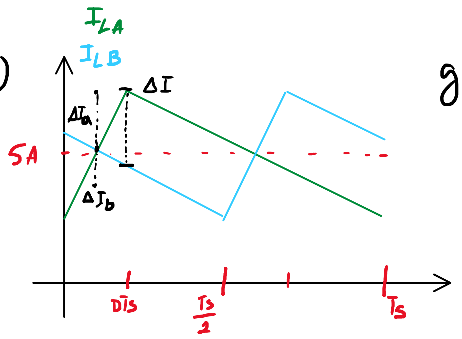


e) $i = C\frac{\Delta V}{\Delta t}$

$\Delta V \leqslant 0.3$

$C_1 \geqslant \frac{I\ D}{0.3 f_s} \Leftrightarrow C_1 \geqslant 3.33\ \mu F$

f)



g) ΔI? $\frac{di}{dt} = \frac{V}{L}$

$\frac{\Delta I}{2} = \Delta I_a - \Delta I_b =$

$= V_o \frac{(1-D)}{D L_a} \cdot \frac{D}{2} \cdot T_s - \frac{V_o}{L_b} \cdot \frac{D}{2} \cdot T_s =$

$\Delta I = \frac{V_o}{f_s} \cdot \frac{1-2D}{L} = 0.75A$

h) $\Delta V_o = \Delta V_C + \Delta ESR = 4.75\ mV$

$\Delta V_C = \frac{1}{2} \cdot \frac{T_s}{4} \cdot \frac{\Delta I}{2} \cdot \frac{1}{C} = \frac{\Delta I}{16 \cdot f_s \cdot C} \cong 1\ mV$

$\Delta ESR = \Delta I \cdot ESR = 3.75\ mV$

2) The DC/DC converter shown in Fig 3 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: $V_{IN} = 5$ V, $V_O = 48$ V, $P_O = 12$ W; $f_{SW} = 500$kHz:

b) Select the turn ratio N_2/N_1 such that D=50%.

c) Draw a plot of i_c, and i_d as a function of time.

d) Select L_{in} such that the peak-to-peak current ripple is less than 10% of the average current.

e) Calculate L_m such that the peak-to-peak current ripple is less than 20% of the average current.

f) Select C_1 such that the peak-to-peak voltage ripple is less than 2% of the average capacitor voltage.

g) Select the filter capacitor C_o such that the peak-to-peak voltage ripple is less than 0.1% of the ouput voltage.

h) Determine the inductance factor of the magnetic core such that N_1=5 turns.

The tapped inductor is wound on a ferrite core having an effective volume of 0.628 cm^3 and an effective area of 0.3 cm^2. The specific core loss can be approximated by the following expression, $P_{core} = C_m \cdot f^x \cdot B^y_{peak}$ [mW / cm^3], where $C_m=2\cdot10^{-5}$, x=1.8 and y=2.5 (f in Hz and B in T).

i) Calculate the core loss.

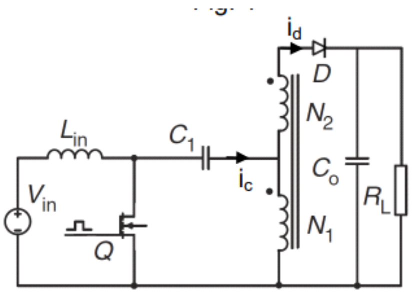
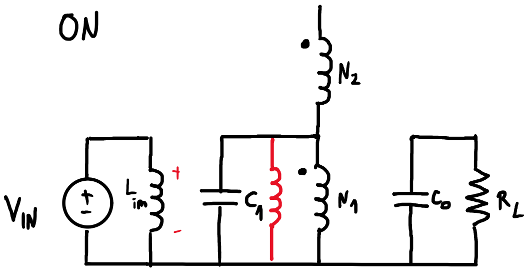
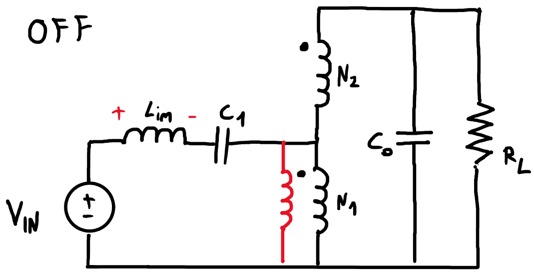


Fig. 3





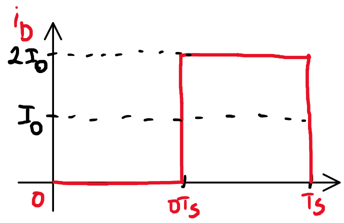
$$\bar{I}_{Lm} = I_o + I_o \frac{N_2}{N_1}$$

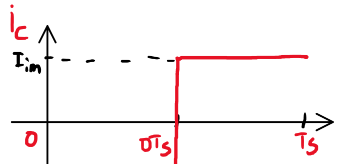
$$L_{im} \Rightarrow V_{im} D + \left(V_{im} - V_{C1} - \frac{V_o}{1 + \frac{N_2}{N_1}}\right)(1-D) = 0 \iff$$

$$L_m \Rightarrow -V_{C1} D + \frac{V_o}{1+\frac{N_2}{N_1}}(1-D) = 0 \Rightarrow \frac{V_O}{V_{IN}} = \frac{D}{1-D}\cdot\left(1+\frac{N_2}{N_1}\right)$$

b) $\frac{N_2}{N_1} = 8.6$

c)





$\bar{I}_D = I_o = 0{,}25A$ $\qquad I_{im} = 2.4A$

d) $V = L\frac{\Delta I}{\Delta t}$ $\qquad \Delta I \leq 0.1 \cdot \bar{I}$

$$\iff \frac{V_{im} D}{f_s L_{im}} \leq 0.1 \cdot I_{im} \iff L_{im} \geq \frac{V_{im} D}{0.1 \cdot I_{im} \cdot f_s} \iff L_{im} \geq 20.8\,\mu H$$

e) $\bar{I}_{Lm} = I_o + I_o\frac{N_2}{N_1}$

$$\frac{V_o(1-D)}{\left(1+\frac{N_2}{N_1}\right) f_s L_m} \leq 0.2 \cdot I_o\left(1+\frac{N_2}{N_1}\right) \iff L_m \geq \frac{V_o(1-D)}{0.2 \cdot I_o \cdot \left(1+\frac{N_2}{N_1}\right)^2 f_s} \iff L_m \geq 10.4\,\mu H$$

f) $I = C\frac{\Delta V}{\Delta t}$ $\qquad \Delta V \leq \frac{2}{100}\cdot V$

$V_{C1} = -V_{im}$

$$\frac{I_{im}(1-D)}{f_s \cdot C} \leq \frac{2}{100}\cdot V_{im} \iff C \geq \frac{I_{im}(1-D)}{\frac{2}{100}\cdot f_s \cdot V_{im}} \iff C_1 \geq 24\,\mu F$$

g) $$\frac{I_o \cdot D}{f_s \cdot C} \leq \frac{0.1}{100} V_o \iff C_o \geq \frac{I_o D}{\frac{0.1}{100} f_s V_o} \iff C_o \geq 5.2\,\mu F$$

h) $L_m = N_1^2 A_L$

$$A_L = \frac{L_m}{N_1^2} = 416\,mH$$

i) $L_m \Delta i = N_1 A_e \Delta B$

$$\Delta B = \frac{L_m \Delta i}{N_1 A_e} = 33.28\,mT$$

$$B_{Peak} = \frac{\Delta B}{2} = 16.64\,mT$$

$$P_{core} = P'_C \cdot V_e = C_m \cdot f^x \cdot B^y \cdot V_e = 8.13\,mW$$