1 Buck converter with input filter

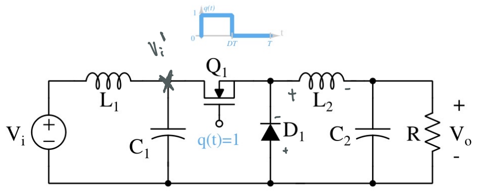


Figure 1.1: Buck Converter with input filter

We often need to include a filter at the input of a power converter to reduce the switching harmonics in the input current. Let's consider the converter of Figure 1.1. We assume the converter operates at a constant frequency, continuous conduction mode (CCM), and has reached periodic steady state. We assume the MOSFET (Q_1) has an on-resistance $R_{ds,ON}$ when ON, and the forward conduction characteristics of the diode D_1 can be modeled by a constant voltage V_D in series with a resistor R_D. For the inductors L_1 and L_2, assume they are large and have a winding resistance of R_{L1} and R_{L2}. You can ignore any other loss components. Also, assume that the capacitors C_1, C_2 are large in value.

- [ ] Derive the converter's DC averaged equivalent circuit model that incorporates the conduction loss in the semiconductors and the inductors.

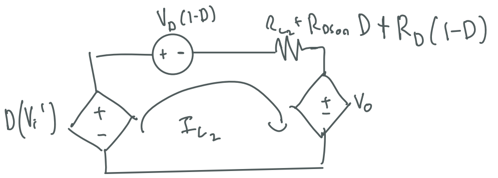
1. $V_{L_2}|_{q=1} = V_i' - R_{DS,on} I_{L_2} - I_{L_2} R_{L_2} - V_o$

$V_{L_2}|_{q=0} = -V_o - V_D - I_{L_2} R_{L_2}$

Periodic steady state

$0 = \langle V_{L_2} \rangle = (V_i' - R_{DS,on} I_{L_2} - I_{L_2} R_{L_2} - V_o) D + (1-D)(-V_o - V_D - I_{L_2} R_D - I_{L_2} R_{L_2})$

$0 = V_i' D - V_o + -I_{L_2} R_{L_2} - V_D(1-D) - R_{DS,on} I_{L_2} D - R_D(1-D) I_{L_2}$



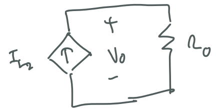
$i_{C_2}(t)|_{q(t)=1} = I_{L_2} - V_o/R$

$i_{C_2}(t)|_{q(t)=0} = I_{L_2} - V_o/R$

Periodic steady state

$\langle I_C \rangle = 0 = (I_{L_2} - V_o/R) D + (1-D)(-V_o/R)$

$I_{L_2} - \frac{V_o}{R} = 0$



V_o

$I_i =$

$\langle V_{L_1} \rangle =$

$V_{L_1}|_{q(t)=1} = V_i - V_i' - I_{L_1} R_{L_1}$

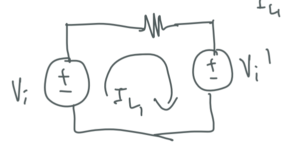
$V_{L_1}|_{q(t)=0} = V_i - V_{C_1} - I_{L_1} R_{L_1}$

$V_{C_1} \approx V_i'$

$\langle V_{L_1} \rangle = 0 = (V_i - V_i' - I_{L_1} R_{L_1}) D + (V_i - V_i' + I_{L_1} R_{L_1})(1-D)$

$V_i = V_i' + I_{L_1} R_1$

$I_{L_1} = I_i$

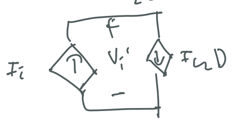


$i_{C_1}|_{q(t)=1} = I_i - I_{L_2}$

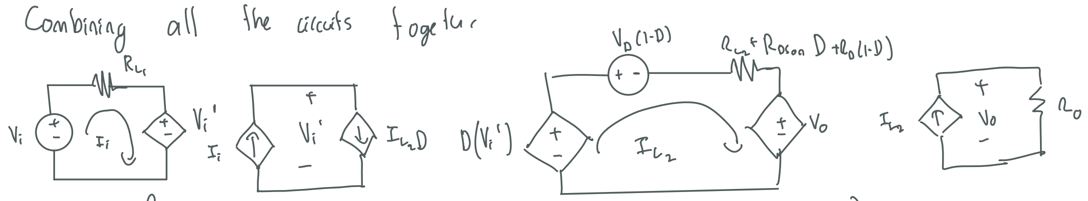
$i_C|_{q(t)=0} = I_i$

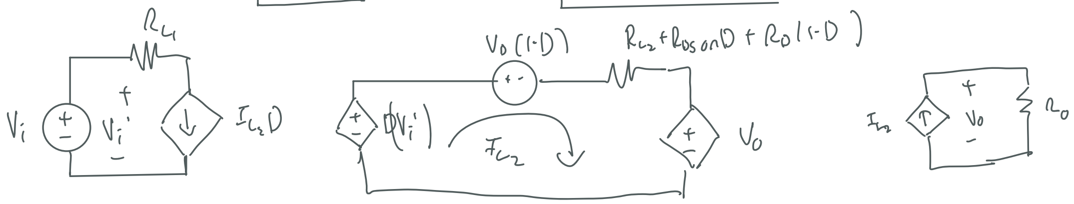
$\langle I_{C_1} \rangle = 0 = (I_i - I_{L_2}) D + (I_i)(1-D)$

$-I_{L_2} D + I_i = 0$

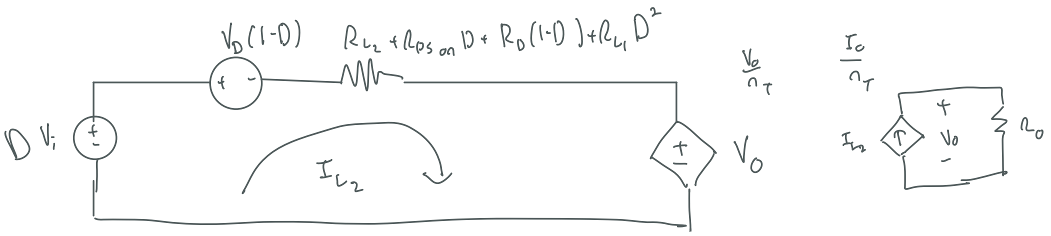


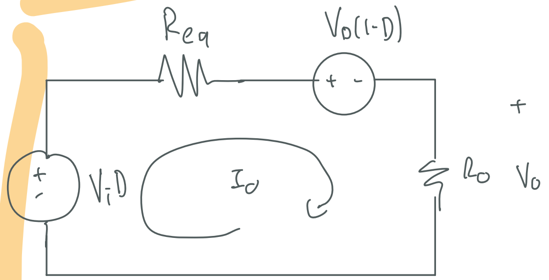
Combining all the circuits together





$n_T(I_s) = I_{L_2} D \qquad n_T = D$





$$R_{eq} = R_{L_2} + R_{DS\,on} D + R_D(1-D) + R_{L_1} D^2$$

☐ Find an expression for the conversion ratio of the converter $\frac{V_o}{V_i}$ as a function of the duty ratio and the other circuit parameters. *(You may leave the expression in explicit form)*

$$V_o = \left(V_i D - V_D(1-D)\right)\left(\frac{R_o}{R_o + R_{eq}}\right) \qquad \text{where } R_{eq} = R_{L_2} + R_{DS\,on} D + R_D(1-D) + R_{L_1} D^2$$

$$\frac{V_o}{V_i} = \left(D \left(\frac{1 - \frac{V_D(1-D)}{DV_{in}}}{1 + \frac{R_{eq}}{R_o}} \right) \right)$$

- [ ] Find an expression for the efficiency of the converter.

$I_i = I_{L_2} D$ $\quad \frac{I_I}{I_o} = D$

$$\eta = \frac{P_o}{P_i} = \frac{V_o}{V_i}\frac{I_o}{I_i} = \frac{1 - (V_o)(1-D)/DV_{in}}{(1 + R_{eq}/R_o)}$$

$\frac{1}{D}$

where $R_{eq} = \frac{R_{L_2}}{D^2} + \frac{R_{DS\,on}}{D} + \frac{R_D(1-D)}{D^2}$

2 Dc-dc converter

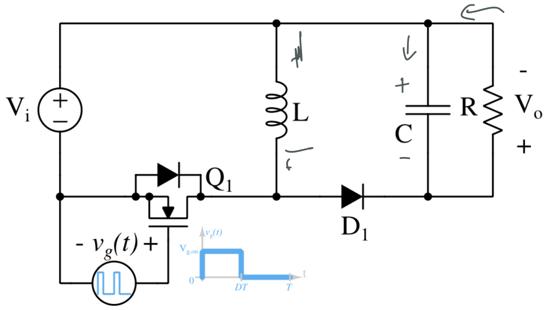


Figure 2.1: Dc-dc converter.

In this setup, we have $V_i = 6$ V, $V_o = 12$ V, $P_o = 30$ W, and $f_s = 145$ kHz.

- [ ] Assuming all components are ideal, find the value of the inductor to achieve an inductor ripple ratio $\%\mathcal{R}_L = 10\%$.

check signs

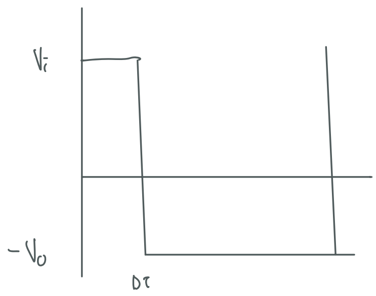
Inductor voltage

$V_{L_1}|_{q=1} = V_i$

$V_{L_1}|_{q=0} = -V_o$

$0 = V_i D - V_o(1-D)$

$\frac{V_i D}{(1-D)} = V_o$



$\Delta I = 2R_L I_L$

$i_c|_{q=1} = -\frac{V_o}{R}$

$I_c|_{q=0} = I_L + \frac{V_o}{R}$

$= \left(I_L + \frac{V_o}{R}\right)(1-D) + -\frac{V_o}{R}(D)$

$I_o = I_L(1-D)$

$I_L = I_o/1-D$

$V = L\frac{\Delta I}{\Delta T}$

$\frac{V_i DT}{L} = \Delta I$

V_i:

$\frac{V_i DT}{\Delta I} = L$

$\frac{V_i D}{f_s 2R_L I_L} = L$

$\frac{V_o(1-D)}{f_s 2R_L I_L} = L_{min}$

$\frac{V_o(1-D)^2}{f_s 2R_L I_o} = L_{min}$

$\frac{V_i(D)}{(1-D)} = V_o$

$V_i D = V_o(1-D)$

$6D = 12 - 12D$

$18D = 12$

$D = \frac{2}{3}$

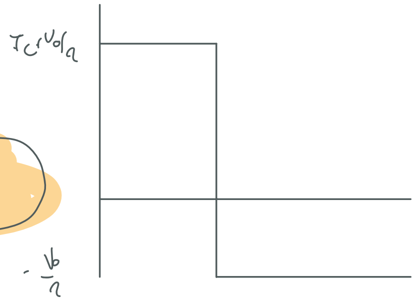
$I_o = P_o/V_o$

$I_o = 2.5A$

$\frac{12(1-\frac{2}{3})^2}{(145E3)(2)(0.1)(2.5)} = 0.0000184$

18.4 μH

- [ ] Find the capacitor value to achieve a capacitor ripple ratio of $\%\mathcal{R}_C = 6\%$



$$\frac{I_o}{C} DT = \Delta V_o$$

$$\frac{I_o D}{f \Delta V_o} = C = \frac{I_o D}{2 f_s R_C V_o} = \frac{\left(\frac{1}{3}\right)(2.5)}{2(145E3)(0.06)(12)} = 7.98\,\mu F$$

The MOSFET (Q) has an on-resistance $R_{ds,ON}$ when ON, and the forward characteristics of the diode can be modeled by a constant voltage V_D. Also, assume the inductor L has a winding resistance R_L. Other losses can be neglected. The converter operates in Periodic Steady State (PSS).

- [ ] Derive the converter's dc averaged equivalent circuit model that incorporates the conduction loss in the semiconductors and the inductor.

Inductor voltage

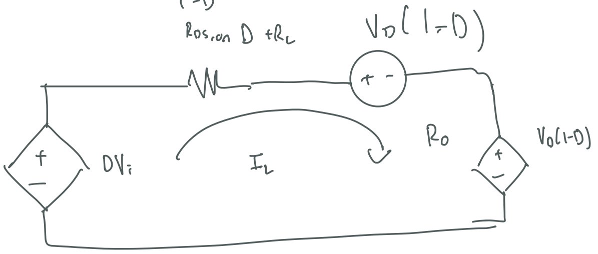
$$V_L\big|_{q(t)=1} = V_i - R_{DS,on} I_L - R_L I_L$$

$$V_L\big|_{q(t)=0} = -V_o - R_L(I_L) - V_D$$

$$0 = D(V_i - R_{DS,on} I_L - R_L I_L) + (1-D)(-V_o - R_L(I_L) - V_D)$$

$$0 = DV_i - R_{DS,on} I_L D - \cancel{R_L I_L D} + -V_o + DV_o - R_L I_L + \cancel{D R_L I_L} - V_D(1-D)$$

$$V_o = \frac{\quad}{1-D}$$

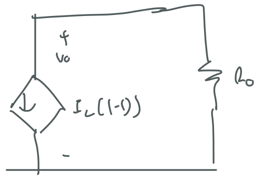


$$i_C\big|_{q=1} = +\frac{V_o}{R}$$

$$I_C\big|_{q=0} = I_L + \frac{V_o}{R}$$

$$0 = \left(I_L + \frac{V_o}{R}\right)(1-D) + \frac{+V_o}{R}(D)$$

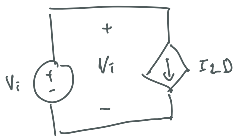
$$-I_o = I_L(1-D)$$



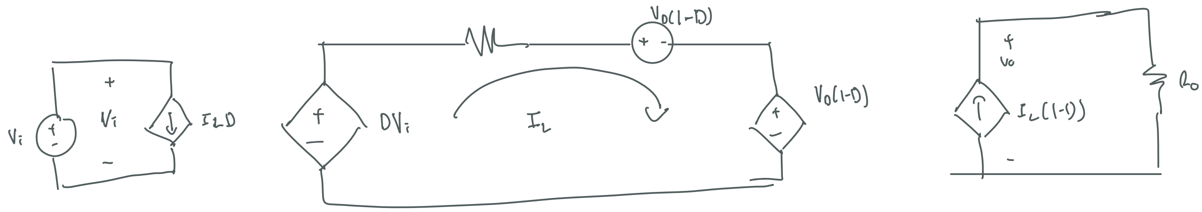
$$I_{i\,q(t)=1} = I_L$$

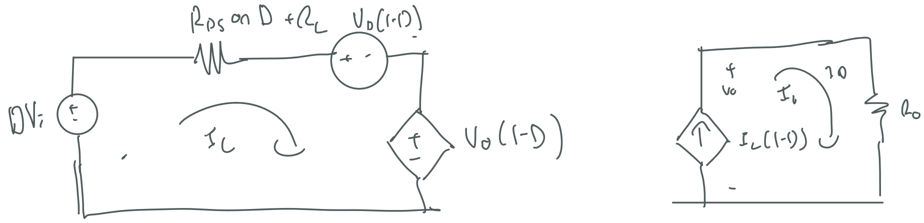
$$I_{i\,q(t)=0} = 0$$

$$I_L D = I_i$$

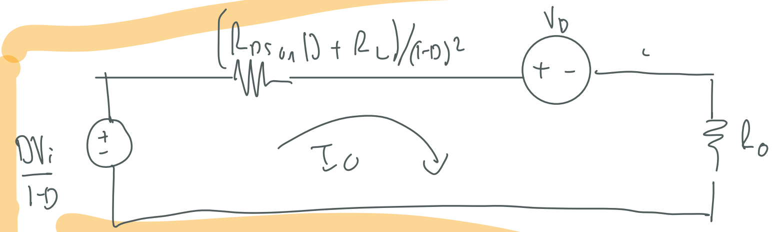


$R_{DS,on} D + R_L$





$n_T = \frac{1}{1-D}$



- [ ] Find an expression for the conversion ratio $\frac{V_o}{V_i}$ and the efficiency of the converter as a function of the duty ratio and the other circuit parameters.

$$V_o = \left(\frac{D V_i}{1-D} - V_D\right)\left(\frac{R_o}{R_o + (R_{DS\,on} D + R_L)/(1-D)^2}\right)$$

$$V_o = \left(\frac{D V_i}{1-D} - V_D\right)\frac{1}{1 + \frac{R_{DS\,on} D + R_L}{(1-D)^2 R_o}}$$

$$\frac{V_o}{V_i} = \frac{D\left(1 - \frac{(1-D)V_o}{D V_{in}}\right)}{\left[1 + \frac{R_{DS\,on} D + R_L}{(1-D)^2 R_o}\right](1-D)}$$

$$\frac{V_o}{V_i} = \frac{\left(1 - \frac{(1-D)V_o}{D V_{in}}\right) D}{\left[1 + \frac{R_{DS\,on} D + R_L}{(1-D)^2 R_o}\right](1-D)}$$

$I_i = I_o D$

$P_o = V_o I_o$

$P_i = V_i I_i = I_o D$

$$\frac{1-D}{D}\frac{V_o}{V_i} = \frac{\left(1 - \frac{(1-D)V_o}{D V_{in}}\right)}{\left[1 + \frac{R_{DS\,on} D + R_L}{(1-D)^2 R_o}\right]} = \eta$$

$I_i = I_L D$

$I_L(1-D) = I_o$

$\frac{I_o}{1-D} D = I_i$

$\frac{I_o}{I_i} = \frac{1-D}{D}$

- [ ] Now, assuming the forward drop of the diode is $V_D = 0.4V$ and the winding resistance of the inductor is $10m\Omega$.
  - [ ] What is the MOSFET's $R_{ds,ON}$ needed for the efficiency of the converter to reach 92%?
  - [ ] What is the converter's duty cycle under this condition?

$D = 0.685$ $V_o = 12$

$V_i = 6$

$$\frac{\left(1 - (1-D)V_D/(DV_{in})\right)}{\left(1 + \frac{R_{Dson}D + R_L}{(1-D)^2 R_o}\right)} = 0.92$$

$P_o = V_o^2/R$

$$\boxed{R_{DS,on} = 0.0227\Omega}$$

$30 = \frac{V_o^2}{R}$

$R = 4.8$

$$\frac{V_o}{V_i} = \frac{D\left(1 - \frac{(1-D)V_o}{DV_{in}}\right)}{\left(1 + \frac{R_{Dson}D + R_L}{(1-D)^2 R_o}\right)(1-D)} \qquad \frac{D}{V_i}$$

$$\frac{12}{6} = \frac{D - \frac{0.4(1-D)}{6}}{\left((1-D) + \frac{0.0263D + 0.01}{4.8(1-D)}\right)}$$

$$\frac{(1-D)V_o}{(D)V_i} = 0.92$$

$$\frac{1-D}{D} = 0.46$$

$$1-D = 0.46D$$

$$1 = 1.46D$$

$$\boxed{D = 0.685}$$

- [ ] Simulate the circuit of Fig. Figure 2.1 on LTspice with the inductor and capacitor values your found, including the losses in the inductor, MOSFET and diode in your simulation.
  - [ ] Save 5 complete periods of the following waveforms once the converter has reached periodic steady state: $i_L(t), i_{Q1}(t), i_{D1}(t), v_o(t)$
  - [ ] What are the inductor and capacitor ripple ratios in your simulation?
  - [ ] What's the simulated efficiency of the converter? Compare the simulated efficiency to the one obtained using the averaged circuit model.
  - [ ] Find the average power losses in all the devices. Compare (in %) the simulated values to the losses obtained using the average circuit model.

a. see pdf

b. Inductor current ripple

ΔI_L 1.46A

$I_{L_{avg}} = 7.902$

$R_L = \frac{\Delta I_L}{2 I_{L_{avg}}} = 9.24\%$

Capacitor voltage ripple

$\Delta V_c = 1.46V$

$\Delta V_{c_{avg}} = 11.963$

$R_c = \frac{\Delta V_c}{2 V_{c_{avg}}} = \frac{1.46}{2(11.954)} = \boxed{6.10\ \%}$

c. $P_{o_{avg}} = V_{o_{avg}} \cdot I_{o_{avg}}$

$I_o = 2.492$ $V_o = 11.963$ A

$I_i = 5.4123$ $V_i = 6$ A

$\frac{V_o \cdot I_o}{V_i \cdot I_i} = 0.918$

$\boxed{\eta = 91.8\%}$

The two efficiencies are very similar. However, they are not exactly aligned because the average circuit model can underestimate error because it does not account for the ripple. The ACM is a good estimation usually

d. MOSFET loss ACM

$P_{loss} = I_L^2 D R_{DS,on}$

$D = 0.685$
$I_o = 2.5$

$I_L(1-D) = I_o$

$I_L = 7.936$

$(7.936)^2 D (22.7E-3)$

ACM: $P_{loss\,mos} = 0.979\,W$

From sim $I_{rms} = 6.5473A$

Simulation $(I_{q,rms})^2 R_{DS} = 0.973\,W$

Inductor loss

$(I_L^2)(R_L) = P_{loss}$

$(7.936)^2 (10m\Omega) = 0.6298\,W$

Simulation $(I_{L\,rms})^2 R_L = 0.626$

$I_L = 7.9135$

MOS: $\frac{P_{Acm}}{P_{loss}} = 0.9939$

$\frac{P_{Acm}}{P_{loss}} = .994$

The loss should be more for simulations. The I_L calculated from ACM may be too high. Still same errors

- ☐ Search for the following commercial components on either Digikey or Mouser (include part number and datasheet). Check and familiarize yourself with the different packages:
  - ☐ N-MOSFET on Digikey or Mouser (in stock) with a 25V drain-source rating and with the $R_{ds,ON}$ you calculated assuming a 125°C case temperature. Ensure that the device can handle the power dissipation at 125°C.
  - ☐ Schottky Diode with a minimum 25 V maximum reverse voltage and the ability to carry 150% ~~of the average current you calculated at 125°C.~~

On google sheet

3 Indirect Boost-buck converter

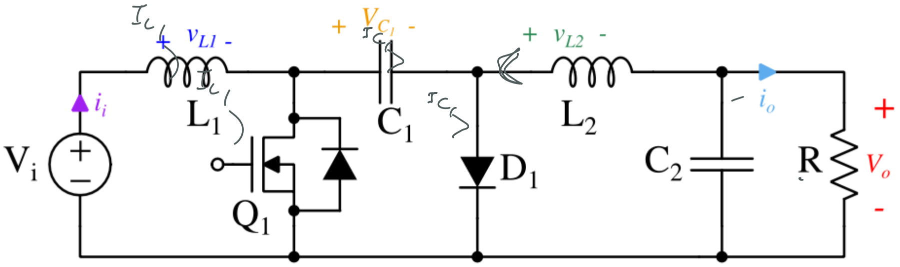


Figure 3.1: Indirect Boots-buck converter

Consider the converter of Figure 3.1. Assume that the MOSFET (Q_1) has an on-resistance $R_{ds,ON}$ when it is ON, and the forward characteristics of the diode (D_1) can be modeled by a constant voltage V_D. You can assume the inductors and capacitors in the circuit are ideal.

- ☐ Develop the dc averaged equivalent circuit model for the converter, taking into account the conduction loss in the semiconductors.
- ☐ Determine an expression for the conversion ratio $\frac{V_o}{V_i}$ and the efficiency of the converter as functions of the duty ratio and the other circuit parameters.
- ☐ What are the relationship between the operating parameters of your converter (V_i, R, D) and your component parameters ($L, C, R_{ds,ON}, V_D$) that you need to achieve high efficiency?

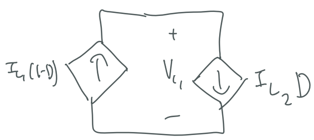
Assuming PSS

$I_{C_1}\big|_{q(t)=1} = -I_{L_2}$

$I_{C_1}\big|_{q(t)=0} = I_{L_1}$

$-I_{L_2}D + I_{L_1}(1-D) = 0$

$I_{L_1}(1-D) = I_{L_2}D$



$I_{C_2}\big|_{q(t)=1} = I_{L_2} - V_o/R$

$I_{C_2}\big|_{q(t)=0} = I_{L_2} - V_o/R$

$I_{C_2} = \left(I_{L_2} - V_o/R\right)D + \left(I_{L_2} - V_o/R\right)1\cdot D$

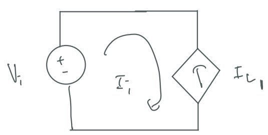
$I_{C_2} = 0 = I_{L_2} - V_o/R$

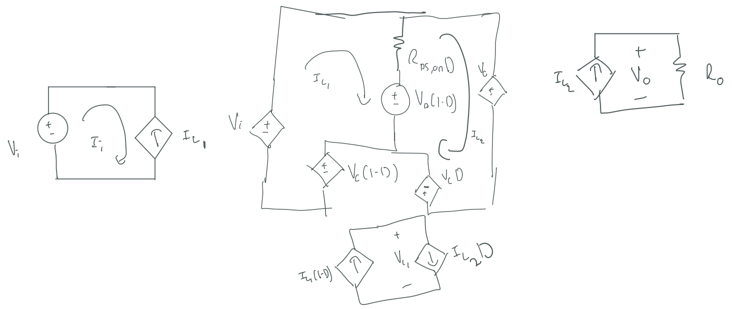
$V_o/R_o = I_{L_2}$

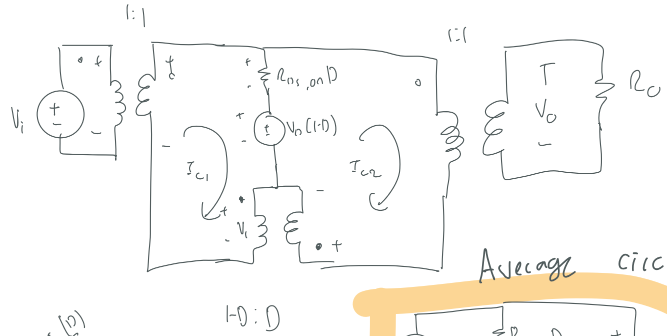
$I_i\big|_{q(t)=1} = I_{L_1}$

$I_i\big|_{q(t)=0} = I_{L_1}$

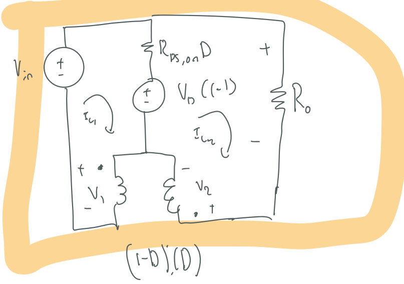
$I_{L_1}(D) + I_{L_1}(1-D) = \langle i_i(t) \rangle$

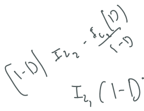






Average circuit model





$I_{L_1}(1-D) + I_{L_2}(D) = 0$

$I_{L_1}(1-D) = -I_{L_2} D$

$I_{L_1} = \frac{-I_{L_2} D}{1-D}$

$I_{L_1} - I_{L_2} = \frac{-I_{L_2}}{1-D}$ $\qquad I_{L_2} = \frac{V_o}{R}$

☐ Determine an expression for the conversion ratio $\frac{V_o}{V_i}$ and the efficiency of the converter as functions of the duty ratio and the other circuit parameters.

b.

$$V_i - R_{DS,on} D (I_{L_1} - I_{L_2}) - V_D(1-D) - V_1 = 0$$

$$-V_o - V_2 + V_D(1-D) + R_{DS,on} D (I_{L_1} - I_{L_2}) = 0$$

$$D V_1 = V_2(1-D)$$

$$D\left(V_i + R_{DS_{on}} D \frac{V_o}{R(1-D)} - V_D(1-D)\right) = (1-D)\left(-R_{DS_{on}} D \left(\frac{V_o}{(1-D)R}\right) + V_D(1-D) - V_o\right)$$

$$D V_i - V_D D' D - V_D D'^2 = -R_{DSon} D \frac{V_o}{R} - D' V_o - R_{DS_{on}} D^2 \frac{V_o}{R(1-D)}$$

$$D V_i \left[1 - \frac{V_D(1-D)}{V_i} - \frac{V_D(1-D)^2}{D V_i}\right] = -D' V_o \left(\frac{R_{DSon} D}{R D'} + 1 + \frac{R_{DSon} D^2}{R(1-D)^2}\right)$$

$$\underbrace{\frac{V_o(1-D)}{V_i}\left(1-\frac{1-D}{D}\right)} \qquad \underbrace{\frac{D}{D'}\frac{R_{DS\,on}}{R}\left(1+\frac{D}{1-D}\right)}$$

$$DV_i\left(1-\frac{V_o(1-D)}{DV_i}\right) = -D'V_o\left(\frac{R_{DS\,on}}{(D')^2R}+1\right)$$

$I_{L_1}(1-D) = I_{L_2}D$

$I_i(1-D) = I_oD$

$\frac{I_o}{I_i} = \frac{1-D}{D}$

$$\boxed{\frac{V_o}{V_i} = \frac{-D\left(1-\frac{V_o(1-D)}{DV_i}\right)}{(1-D)\left(1+\frac{R_{DS,on}}{D'^2R}\right)}}$$

$$\eta = \frac{V_oI_o}{V_iI_i} = \frac{V_o}{V_i}\frac{(1-D)}{D} = \boxed{\eta = \frac{\left(1-\frac{V_D(1-D)}{DV_i}\right)}{\left(1+\frac{R_{DS,on}}{(1-D)^2R}\right)}}$$

- [ ] What are the relationship between the operating parameters of your converter (V_i, R, D) and your component parameters $(L, C, R_{ds,ON}, V_D)$ that you need to achieve high efficiency?

$V_i >> V_D$

$R >> R_{DS\,on}$

L and C don't dictate efficiency

It would be better if D is larger because denominator is $R_{DS\,on} / (1-D)^2R$

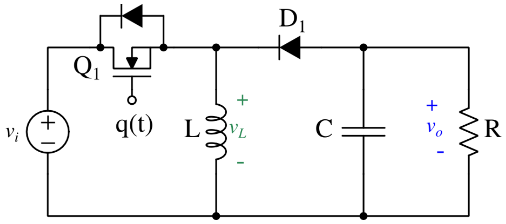


Figure 4.1: Buck-boost dc-dc converter.

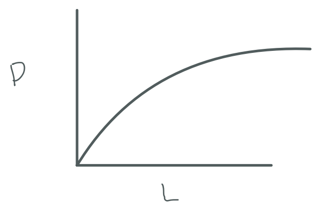
Please design a discontinuous conduction mode (DCM) buck-boost converter (Figure 4.1) with the following operating requirements:

Converter's operating requirements

Parameter	Value
V_i	150 V-200 V
V_o	-170 V
$\mathcal{R}_C$ (Capacitor Ripple Ratio)	0.5%
f_s	145 kHz
P_o	50 W-150 W

1. Find the inductor values L that minimize the peak inductor current
2. Find the maximum and minimum values of the duty cycle D
3. What's the maximum inductor current $i_{L,max}$
4. The output capacitor value C

$\frac{V_o}{V_i} = -D\sqrt{\frac{R_o T}{2L}}$ therefore as we ↑D, we decrease L. If we graphed it out, $\sqrt{L} \propto D$. We must minimize L/D because
$\Delta I_{L\,peak} = \frac{V_i}{L} DT$ so we know that $\frac{D}{L}$ must be as small as possible. Therefore, D must be as large as possible.



For output resistance, we know that

Output voltage is -170

Given that $P = V^2/R$

We know

$R_o = V^2/P$

$R_o = \boxed{192.67 - 578\,\Omega}$

$P_o = 150$ $P_o = 50W$

We also know that the maximum Duty cycle we can have is just below boundary conditions

BCM

$-170 = \frac{-D}{1-D}(150)$ — 150 V — $D < 0.53125$

$-170 + 170D = -150D$ — 200 V — $D < 0.459$

$D = 0.53125$

$-170 = \frac{-D}{1-D}(200)$

$D = 0.459$

We'll use the smaller R_o because it will give tighter design requirements. I'll use the $D < 0.53125$ because it will be able to create the $\frac{V_o}{V_i} = \frac{170}{200}$ conversion ratio at DCM. The other duty cycle will not be able to create the larger $\frac{170}{150}$ at DCM.

$$L < \frac{R_o D'^2}{2f_s}$$

$$L < \frac{192.67(1-.53125)^2}{2f_s} \Rightarrow L = 1.46 \cdot 10^{-4}\ H$$

Therefore to create the smallest inductance peak ripple, inductor value

$$\boxed{L = 1.46 \cdot 10^{-4}\ H}$$

1. Find the inductor values L that minimize the peak inductor current

2. Find the maximum and minimum values of the duty cycle D

Min use $R_o = 578$, $L = 1.46 \cdot 10^{-4}\ H$ @ 200 V_{input}

$$\frac{V_o}{V_i} = -D\sqrt{\frac{R_o T}{2L}}$$

$$\boxed{D_{min} = 0.2300}$$

Max use $R_o = 192.67$, $L = 1.46 \cdot 10^{-4}\ H$ @ 150 V_{in}

$$\frac{V_o}{V_i} = -D\sqrt{\frac{R_o T}{2L}}$$

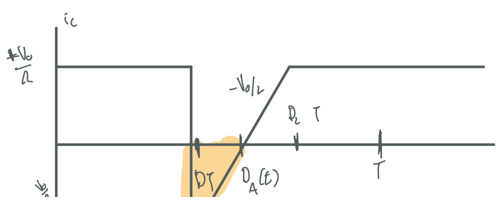
$$\boxed{D_{max} = 0.531}$$ (same as calc above)

3. What's the maximum inductor current $i_{L,max}$

$$i_{L_{max}} = \frac{V_i}{L} DT = \frac{150}{1.46E\text{-}4}(0.531)\left(\frac{1}{145E3}\right) = 3.76\ A$$

To find when i_L is max, look at conditions for max!)

4. The output capacitor value C



$$-3.76 - \frac{-170}{192.76} = -i_{L_{peak}} - \frac{V_o}{2} = -2.876$$

$$\int i\,dt = \int C\,dV$$

$$\Delta Q = C \Delta V$$

$$-2.878 + \frac{170}{146E-6}(D_A - D_2)T = 0$$

$$\frac{\Delta V}{2} = R$$

$$.005 \cdot 2 = \Delta V$$

$$D_A - D_2 = 0.358$$

Area of triangle

$$\frac{1}{145E3} \frac{1}{2}(0.358)(+2.878) = 0.5157$$

$$\frac{0.5157}{\Delta V} = 3.56E-4$$

$$\boxed{356\ \mu F}$$

$$\frac{I_o}{C} DT = \Delta V_o \qquad \frac{\Delta V_o}{C} = R$$

$$\frac{I_o D}{2f R} = C$$

Use small output resistance to get upper bound for capacitance

$$\frac{\frac{V_o}{R_o}(D)}{2fR} > C$$

$$\boxed{3.23\text{E-}4 \text{ F}}$$

will use $R_o = 192.67$

minimize $\frac{V_i}{L} DT$ so D/L has to be as small as possible

$$\langle V_{L_1} \rangle = 0 = \text{Given} \quad \frac{V_o}{V_i} = -(1-D)V_{c_1} - V_D(1-D) - \frac{V_o}{R_{DS,on}} \sqrt{\frac{2f}{R_o}}(I_{L_1} - I_{L_2}) \; D/\sqrt{L}$$

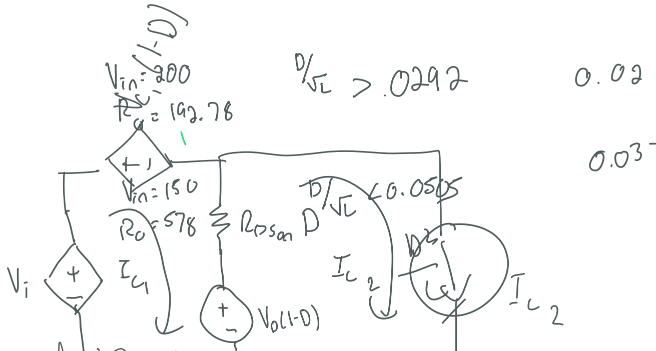
From above

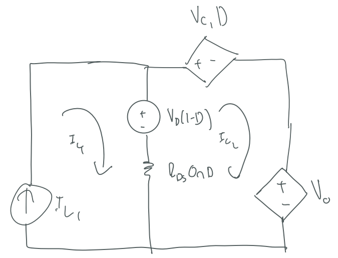
$$0 = V_i - (1-D)V_{c_1} - V_D(1-D) - R_{DS,on}(I_{L_1} - I_{L_2})D$$

$$-V_{c_1}D + R_{DS,on}(I_{L_1} - I_{L_2})D + -V_o + V_D(1-D) = 0 = V_{L_2}$$

$D/\sqrt{L} > .0292 \qquad 0.0219$

0.0377



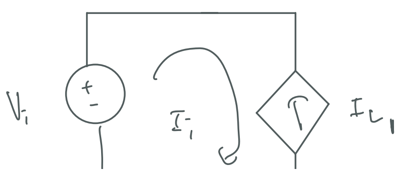


As LT, $D\downarrow$ for same V_o. Therefore to minimize the peak of current $\frac{V_i}{L} DT = \Delta i_{L,peak}$ we want D to be as small as possible

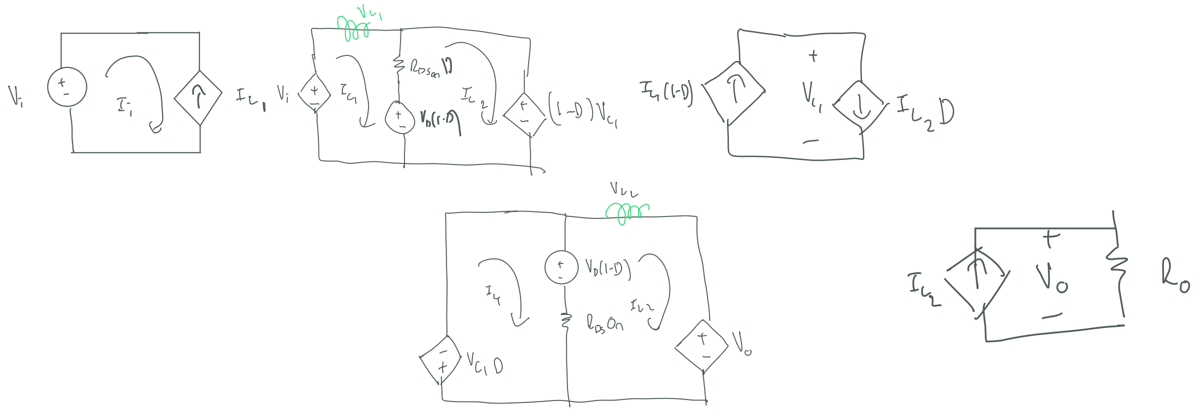
$I_i \big|_{q(t)=1}$ and $=$ I_{L_1} to be as large as possible

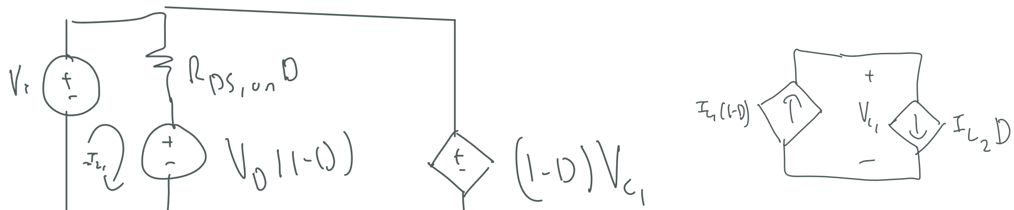
$$I_i \big|_{q(t)=0} = I_{L_1}$$

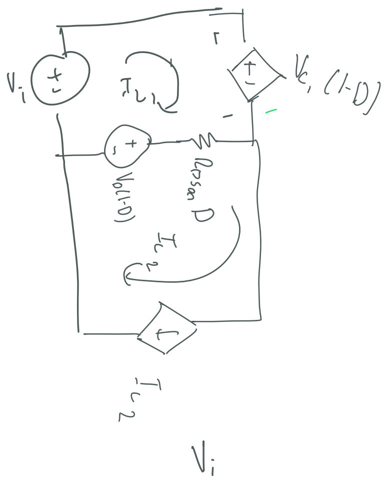
$$I_{L_1}(D) + I_{L_2}(1-D) = \langle i_i(t) \rangle$$

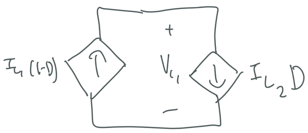


Average circuit model

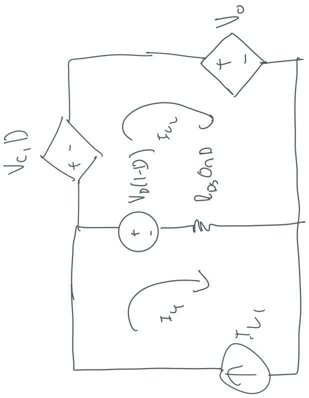




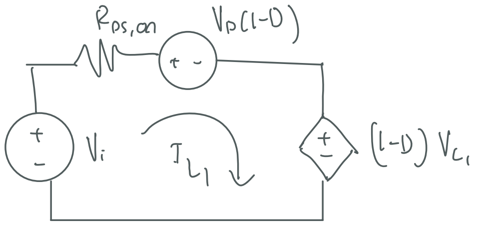


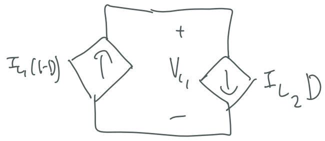


$\frac{aD}{(1-D)}$

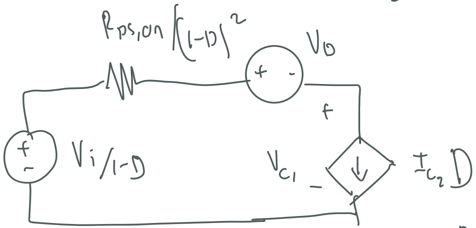


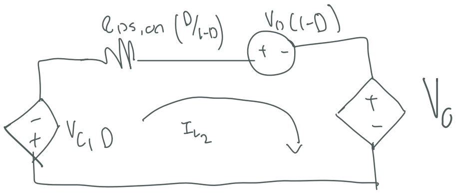
IDK!!



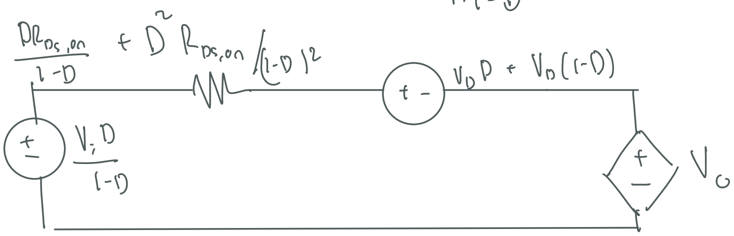


$n_T = \frac{1}{1-D}$

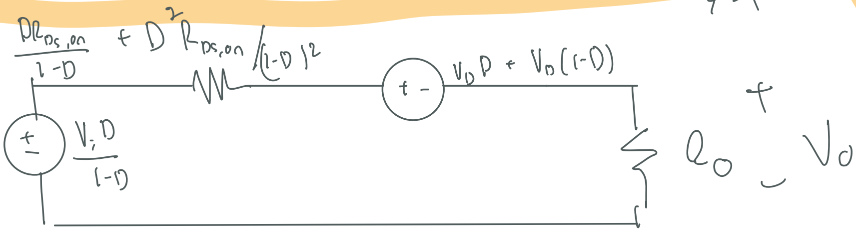




$n_T = D$



$n_T = 1$



☐ Determine an expression for the conversion ratio $\frac{V_o}{V_i}$ and the efficiency of the converter as functions of the duty ratio and the other circuit parameters.

$$V_o = \left(\frac{V_i D}{1-D} - V_D\right)\left(\frac{R_o}{\frac{D R_{DS,on}}{1-D} + \frac{D(R_{DS,on})}{(1-D)^2}}\right) \quad \div \quad R_o/R_o$$

$$\frac{V_o}{V_i} = \frac{\frac{D}{1-D}\left(1 - \frac{V_D(1-D)}{V_i D}\right)}{\left(\frac{1}{1-D}\right)\left(\frac{D R_{DS,on}}{R_o} + \frac{D^2 R_{DS\,on}}{R_o(1-D)}\right)}$$

$I_i = I_{L_1}$

$(1-D) I_{L_1} = D(I_{L_2})$

$I_i = \frac{D\, I_{L_2}}{1-D}$

$I_{L_2} = I_o$

$\frac{I_o D}{1-D} = I_i$

$$\frac{P_o}{P_i} = \frac{V_o I_o}{V_i I_i} = \left(\frac{1-D}{D}\right)\frac{V_o}{V_{in}}$$

$$\eta = \frac{\left(1 - \frac{V_D(1-D)}{V_i D}\right)}{\left(\frac{1}{1-D}\right)\left(\frac{D R_{DS,on}}{R_o} + \frac{D^2 R_{DS\,on}}{R_o(1-D)}\right)}$$

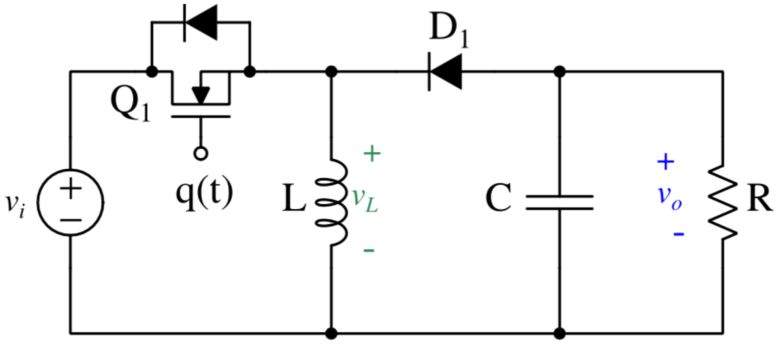
- [ ] What are the relationship between the operating parameters of your converter (V_i, R, D) and your component parameters $(L, C, R_{ds,ON}, V_D)$ that you need to achieve high efficiency?

$R_{DS,on}$ should be small compared to R_o for higer efficiency

V_i should be much greater than V_D for high efficiency

D should be smaller for higuer efficiency

L & C do not matter for efficieny.



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1. Find the inductor values L that minimize the peak inductor current
2. Find the maximum and minimum values of the duty cycle D
3. What's the maximum inductor current $i_{L,max}$
4. The output capacitor value C

The converter operates in if

$\frac{\Delta i}{2} > I_L$

$\frac{V_o}{2L(1-D)T} > I_L$

$-\frac{V_o T(1-D)}{2L} > \frac{-V_o}{(1-D)R}$

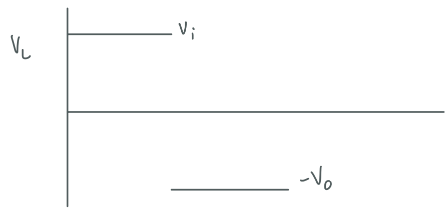
Output voltage is -170

Given that $P = V^2/R$

We know

$R_o = V^2/P$

$R_o = \boxed{192.67 - 578\,\Omega}$



$V_i / LDT = \Delta i$

$\frac{[V_o(1-D)]}{L} = \Delta i$

$$\frac{R_o T}{2L} = \frac{1}{K}$$

$$K = \frac{2L}{R_o T}$$

$\frac{D}{1-D}(V_{in}) = V_o$ if CCM

$D = 0.45945 \sim 0.53125$

therefore, to operate in DCM

$$\frac{2L}{R_o T} < (1-.5312)^2$$

$$\frac{2L}{R_o T} < 0.21977$$

$$L < \frac{0.21977(192.67)}{1453} 2$$

$L < 5.84E-4$