EE 322 Advanced Analog Electronics, Spring 2010
Homework #2 solution

HH 6.8

Theoretically, a linear regulator delivers on the output up to the same current as it draws on the input. The maximum delivered output power is therefore

$$P_{\text{out,max}} = V_{\text{out}} I_{\text{in}}.$$

The power drawn from the input is

$$P_{\text{in}} = V_{\text{in}} I_{\text{in}}.$$

The maximum theoretical efficiencey of a linear regulator is thus

$$\eta_{\text{max}} = \frac{P_{\text{out,max}}}{P_{\text{in}}} = \frac{V_{\text{out}}}{V_{\text{in}}}.$$

For a linear regulator which provides +5 V from a +12 V supply, the maximum theoretical efficiency is thus

$$\eta_{\text{max}} = \frac{5}{12} = 42\%$$

The rest of the energy is dissipated as heat in the regulator (more precisely the pass transistor).

HH 6.9

The high efficiency of a switching regulator means that the output power is almost equal to the input power, $P_{\text{in}} \approx P_{\text{out}}$, or

$$V_{\text{in}} I_{\text{in}} \approx V_{\text{out}} I_{\text{out}}$$

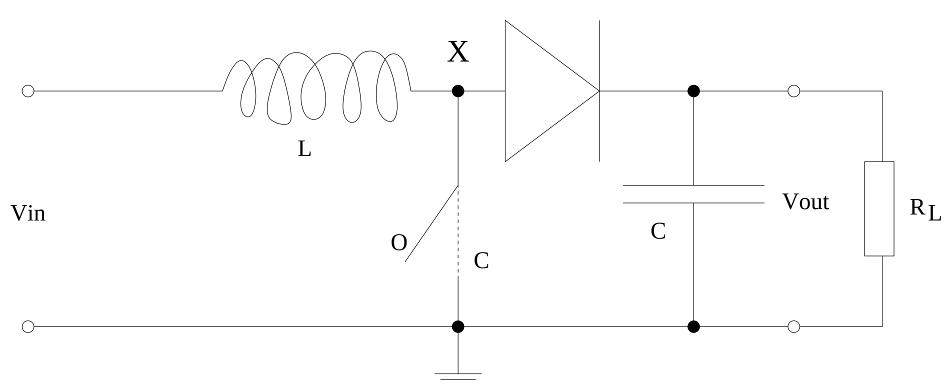
The ratio of currents is thus

$$\frac{I_{\text{out}}}{I_{\text{in}}} = \frac{V_{\text{in}}}{V_{\text{out}}}$$

For a step-down regulator $V_{\text{in}} > V_{\text{out}}$, the input current is therefore smaller than the output current.

For a linear regulator it is the output current which is almost equal to the input current, not the power.

HH 6.10

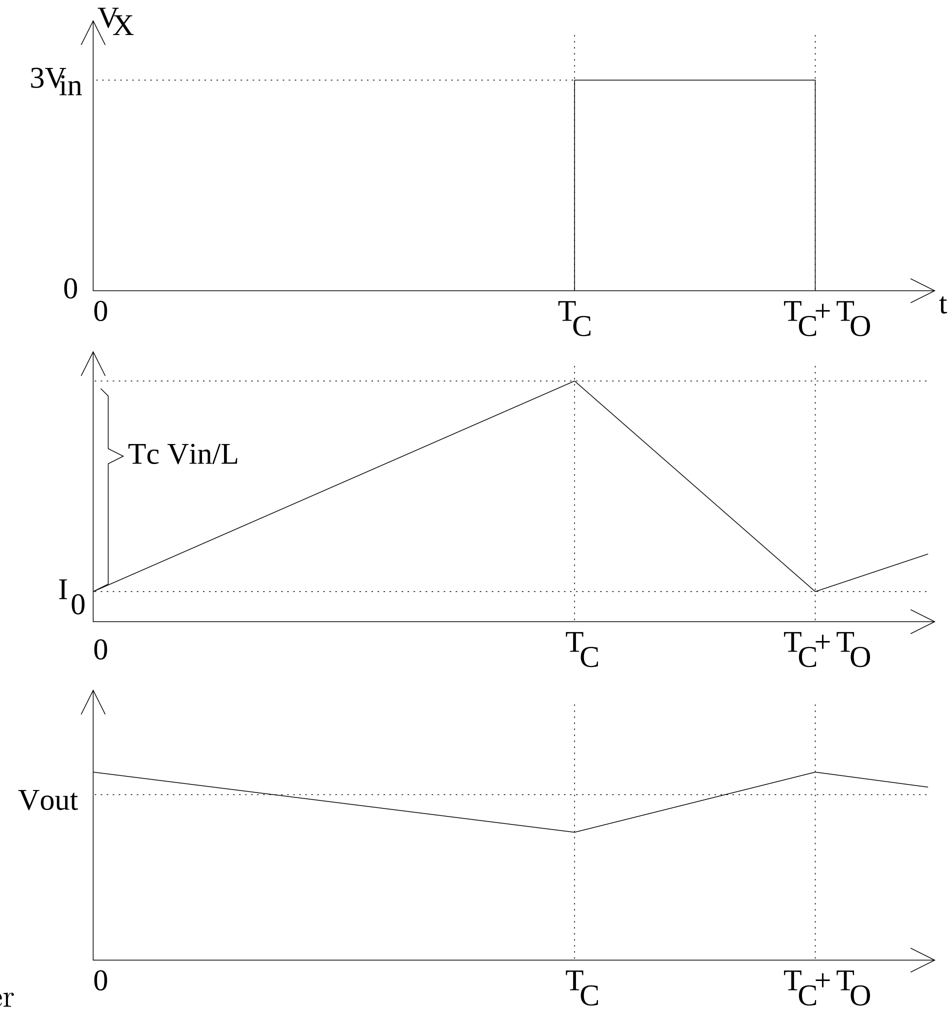


We are asked to plot voltage at point "X", inductor current, and output voltage as a function of time. We will do this for the steady state case in which the current through the inductor is the same at the end of the cycle as it is at the beginning of the cycle.

When the switch is closed the voltage at point "X" is zero, the voltage drop across the inductor is V_{in}, and its current increases as $\frac{dI_L}{dt} = V_{\text{in}}$. However there is no current flowing into the capacitor and thus the output voltage will decrease (or stay constant if there is no load on the circuit).

When the switch is open the voltage drop across the inductor is $V_{\text{in}} - V_{\text{out}}$, and the current is decreasing as $\frac{dI_L}{dt} = V_{\text{in}} - V_{\text{out}}$, assuming that $V_{\text{out}} > V_{\text{in}}$. Because we are doing this for the steady state, the output voltage is the same at the end of the cycle as it is at the beginning of the cycle.

I am going to solve this problem for the case $\frac{V_{\text{out}}}{V_{\text{in}}} = 3$. In that case the voltage drop across the inductor is V_{in} when the switch is closed and $V_{\text{in}} - V_{\text{out}} = -2V_{\text{in}}$ when the switch is open. The voltage at point "X" is ground when the switch is closed, and $3V_{\text{in}}$ when the switch is open. Because the voltage drop across the inductor is twice as large (and opposite sign) when the switch is open as when the switch is closed, the duration of the open period should be half as long as the duration of the closed period, in the steady state, $T_C = 2T_O$. That is illustrated in the top panel of the figure belo. Also, the current drops twice as fast during open period as it rises during closed periods. That is illustrated in the second panel of the figure below. Finally, the output voltage will rise slightly while the switch is open, and fall slightly while the switch is open. These variations will not be exactly linear. The drop will probably be exponential, and the rise will be quadratic. However, if the total voltage drop is small while the switch is closed, and the change in current through the inductor is small compared to its mean value, the variation in output voltage will be close to linear. This is illustrated in the third panel in the figure below.



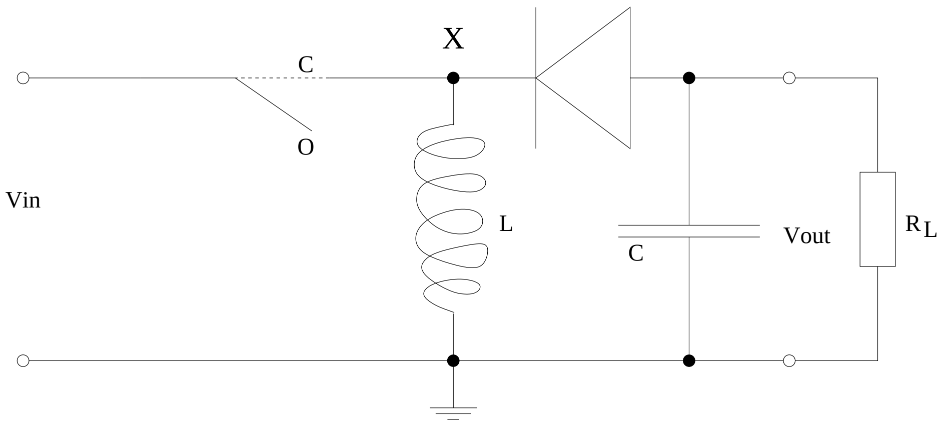
center

where $T_C = 2T_O$.

HH 6.11

The step-up converter cannot be used as a step-down converter because the inductor will only discharge when the output voltage is greater than the input voltage. During the open cycle the voltage drop across the inductor is $V_{\text{in}} - V_{\text{out}}$. If this is not negative, the inductor will keep charging and keep putting charge onto the capacitor until the capacitor voltage begins to exceed the inductor voltage. Only then will it begin to discharge during the open cycle. Even if the load draws a very large current the average inductor curent will simply increase until it is large enough that the inductor can supply the necessary current.

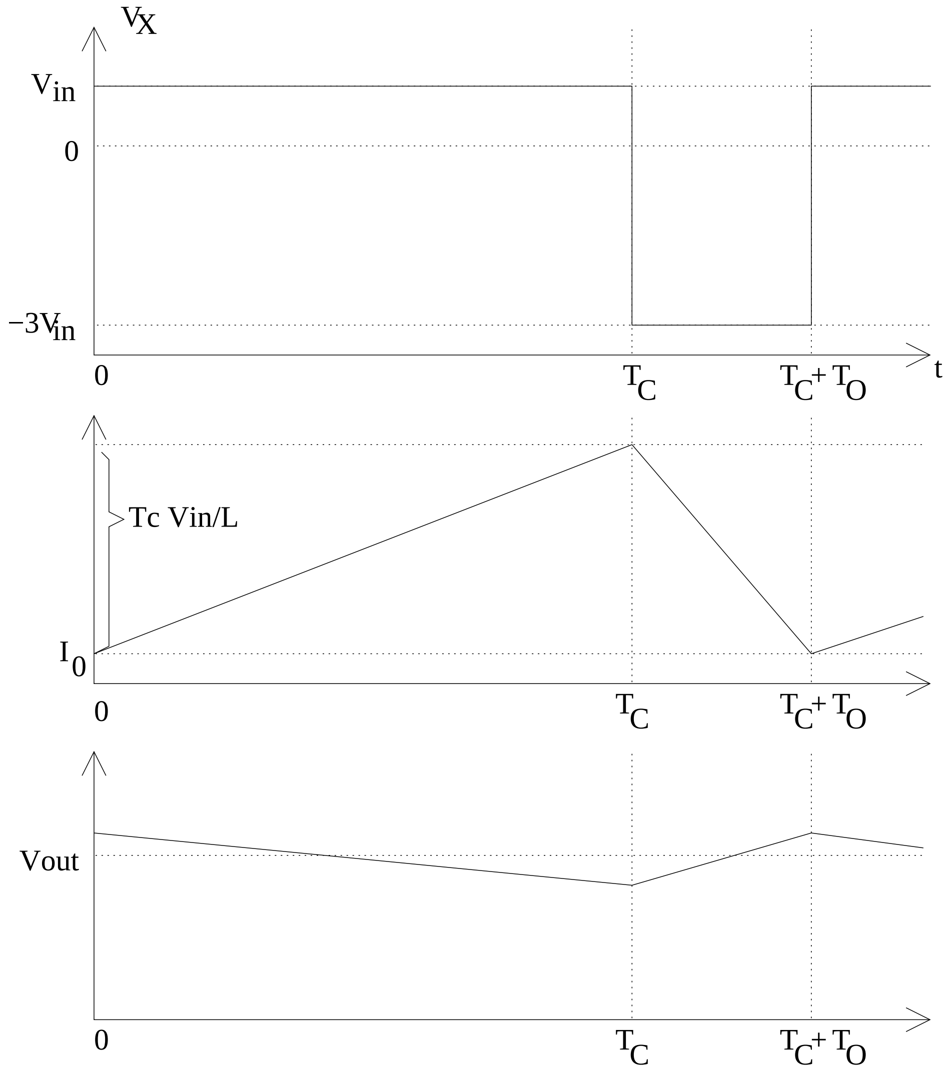
HH 6.12



This problem is similar to HH 6.10 except that we are analyzing the inverting switching regulator. When the switch is closed the voltage across the inductor is V_{in}. When the switch is open the voltage across the inductor is V_{out}. In order for the inductor to discharge when the switch is open, $V_{\text{out}} < 0$ in steady state. The charge and discharge speeds are determined by the voltages, and to be in steady state, the time the switch is open and closed must thus be related as

$$\frac{V_{\text{out}}}{V_{\text{in}}} = -\frac{T_C}{T_O}$$

I will assume that $V_{\text{out}} = -3V_{\text{in}}$. That means that the closed time is three times as long as the open time, and that the circuit spends three quarters of the time charging the inductor, and one quarter of the time discharging it. When the switch is closed the voltage at point "X" is V_{in}. When the switch is open the voltage at point "X" is $V_{\text{out}} = -3V_{\text{in}}$. This is illustrated in the first panel of the plot below. When the switch is closed the current through the inductor is building slowly. When the switch is open the current through the inductor is decreasing three times as quickly as it grew. This is illustrated in the second panel in the figure below. When the switch is closed the load will draw current from the capacitor, decreasing the voltage across the capacitor, and thus *raising* the potential V_{out}. While the switch is open the inductor will charge the capacitor, thus increasing the voltage across the capacitor, and *decreasing* the potential V_{out}. This is illustrated in the third panel in the figure below.



V_X
V_{in}
0
$-3V_{in}$
0
T_C
$T_C + T_O$
t
Tc Vin/L
I_0
0
T_C
$T_C + T_O$
Vout
0
T_C
$T_C + T_O$