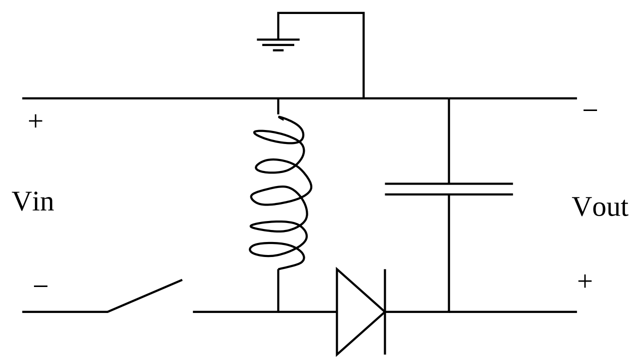
EE 322 Analog Electronics, Spring 2010
Exam 1 March 2, 2011
solution

Rules: This is a closed book test. You may use the help sheet handed out as well as a calculator. The exam will last 50 minutes. Each numbered question counts equally toward your grade.

Switching regulator



1. **Explain in words why this circuit acts like a switching regulator converting a negative input voltage to a positive output voltage. What happens during one cycle?**

   When the switch is closed the current flowing through the inductor from top to bottom increases linearly, charging the inductor. When the switch is opened the current keeps flowing, but now through the diode to the capacitor. When the switch is open the current through the inductor decreases linearly. If the output draws only little current the inductor current may reach zero in discontinuous mode and stay there until the switch is closed again.

2. **What should be the relationship between T_C and T_O to obtain an output of $+15\,\mathbf{V}$ for an input of $-5\,\mathbf{V}$.**

   Use

$$V = L\frac{dI}{dt}$$

   like this

$$T_C \frac{dI}{dt}_{\text{closed}} + T_O \frac{dI}{dt}_{\text{open}} = 0$$

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

and then

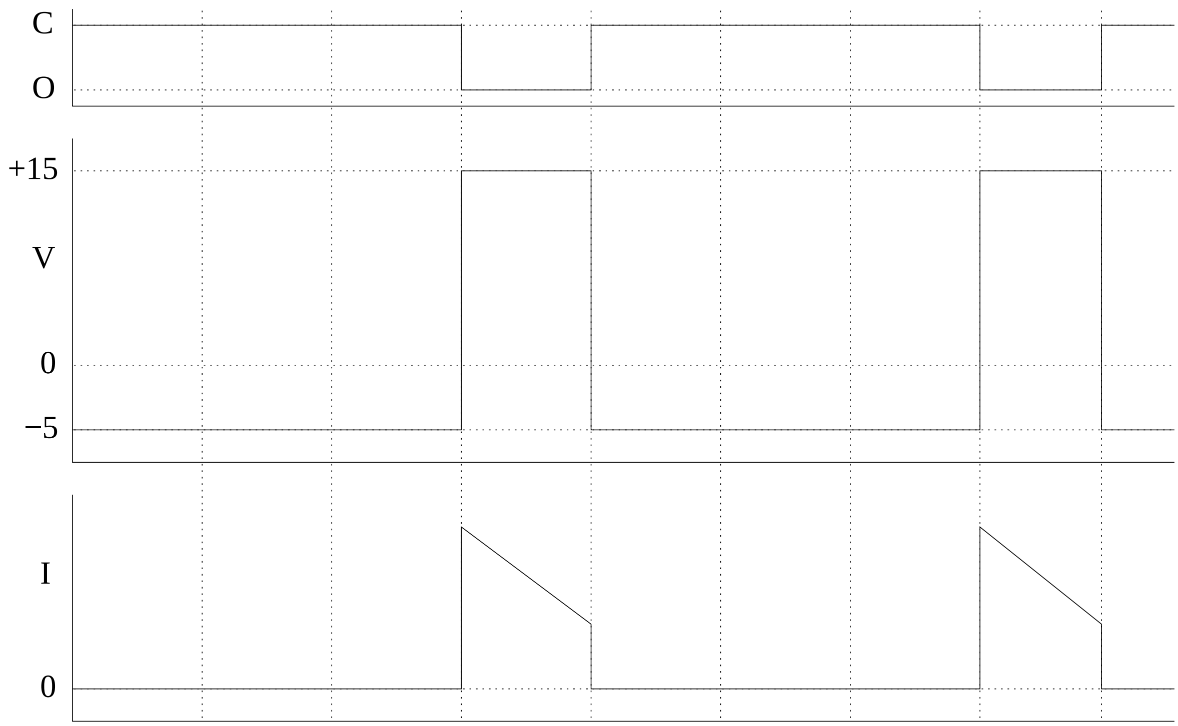
$$\frac{T_C}{T_O} = -\frac{V_{\text{out}}}{V_{\text{in}}}$$

Inserting values we get

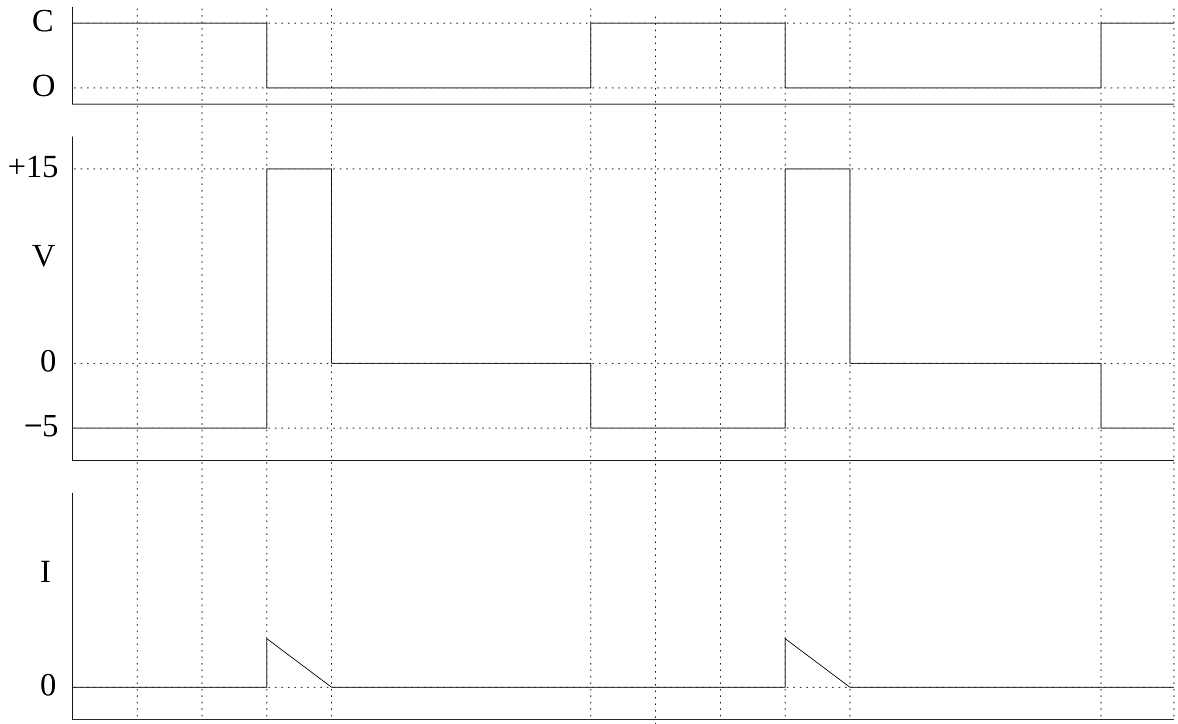
$$\frac{T_C}{T_O} = \frac{15}{5} = 3$$

$$T_C = 3T_O$$

3. **For the same voltage carefully plot and label the voltage at the node connecting the diode the inductor and the switch, as well as the current through the diode, for continuous mode operation for 2 periods.**

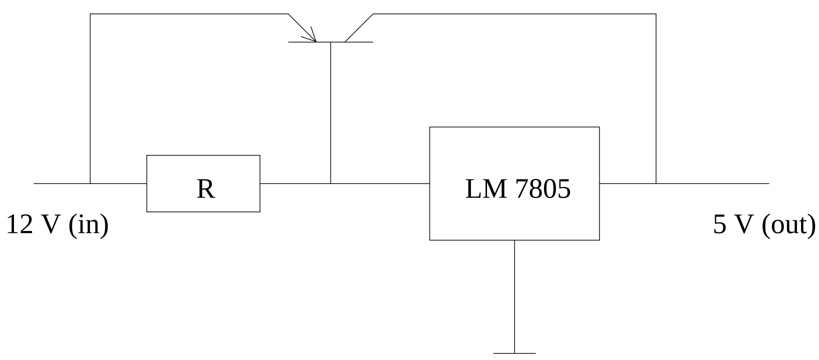


4. **Repeat for discontinuous mode operation.**



Linear regulator

5. **Draw a simple schematic symbol for a LM7805 (5 V linear regulator) labeling the three leads, and adding in a outboard pass transistor.**



6. **If the unregulated input averages $12\,\mathrm{V}$ and the maximum power dissipation in the LM7805 is $500\,\mathrm{mW}$, compute first the maximum current and next the resistor for turning on the outboard transistor.**

   We first find the maximum current through the LM 7805. It is

$$P_{\max} = (V_{\text{in}} - V_{\text{out}})\, I_{\max}$$

$$I_{\max} = \frac{P_{\max}}{V_{\text{in}} - V_{\text{out}}} = \frac{500}{12 - 5} = 71.4\,\mathrm{mA}$$

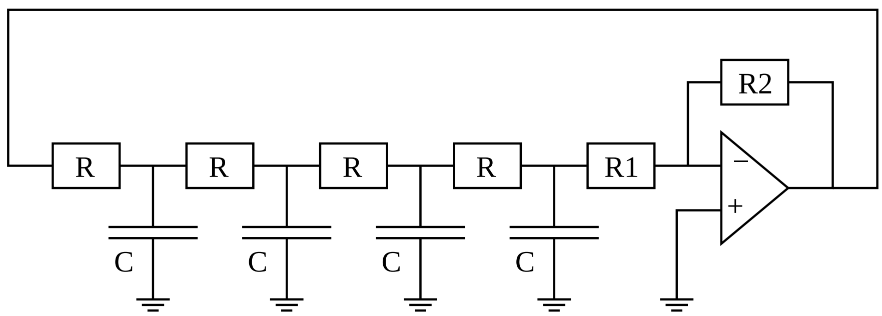
The outboard transistor turns on when the voltage across the resistor is V_{on}.

$$RI_{\text{max}} = V_{\text{on}}$$

$$R = \frac{V_{\text{on}}}{I_{\text{max}}}$$

If we pick $V_{\text{on}} = 0.5\,\text{V}$ we get $R = 7\,\Omega$. If we pick $V_{\text{on}} = 0.7\,\text{V}$ we get get $R = 9.8\,\Omega$.

Sinusoidal Oscillator



7. **Derive an expression for the oscillation frequency of this circuit. Note that there are four RC low-pass filters in series (we have worked with 3 in class). You may assume that the RC links are buffered, and thus do not draw current from each other.**

The inverting amplifier has phase $-180°$, which means that we need a phase of $-180°$ from the RC network. Since we can assume that each is buffered, the transfer function of the network is simply

$$T_{\text{network}} = T^4$$

where T is the transfer function for each RC link, simply a low-pass filter,

$$T = \frac{\frac{1}{j\omega C}}{R + \frac{1}{j\Omega C}} = \frac{1}{1 + j\omega CR}$$

Each RC link should contribute $-45°$ of phase shift. Thus we want

$$\tan^{-1} \omega CR = 45°$$

or

$$\omega = \frac{1}{CR}$$

8. **If $C = 0.1\,\mu$F, what resistor will produce a $10\,$kHz oscillation frequency?**

$$R = \frac{1}{\omega C} = \frac{1}{2\pi f C} = \frac{1}{2\pi 10^4 \times 0.1 \times 10^{-6}} = 159\,\Omega$$

9. **What should be the minimum gain of the inverting amplifier in the circuit in order to sustain oscillation? What feedback resistor value is that if the input resistor to the inverting stage is $1\,$kΩ?**

   The inverting amplifier must compensate for the gain amplitude loss in the RC links. Each RC link generates an amplitude loss of

$$|T| = \frac{1}{\sqrt{1^2 + (\omega RC)^2}} = \frac{1}{1^2 + 1^2} = \frac{1}{\sqrt{2}}$$

   The entire RC chain thus generates an amplitude gain loss of

$$\left|T^4\right| = \frac{1}{\left(\sqrt{2}\right)^4} = \frac{1}{4}$$

   The inverting stage then needs to have a gain amplitude of at least 4, preferably more. If the input resistor on the inverting amplifiers is $R_1 = 1\,\text{k}\Omega$ the feedback resistor needs to be $R_2 = 4\,\text{k}\Omega$