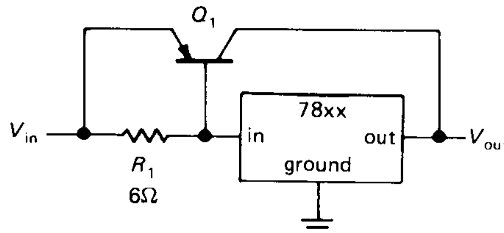
EE 322 Analog Electronics, Spring 2010
Exam 4 May 12, 2010
Solution

1. Linear regulator

The LM7805 is a linear regulator with a fixed output of 5 V and up to 1 A. Design a voltage regulator using the LM7805 and a external pass transistor, in which the pass capacitor turns on at a current of 0.7 A through the LM7805. The transistor turns on at $|V_{BE}| = 0.5$ V.

The circuit looks like this

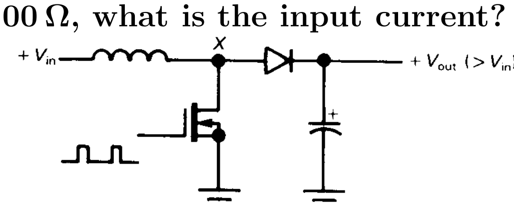


In this case we want the transistor to turn on when $V_{EB} = 0.5$ V, so $I_{\text{in}} R_1 = V_{EB}$, or

$$R_1 = \frac{V_{EB}}{I_{\text{in}}} = \frac{0.5}{0.7} = 0.71\,\Omega$$

2. Switching regulator

Draw a step-up switching voltage regulator. If the output voltage is 2.5 V, the input voltage is 1 V, and the voltage drop across the conducting diode is 0.7 V, sketch the voltage across the inductor. Be sure to get the switch duty cycle correct in continuous mode, and to take into account the diode voltage drop. If the load resistance is 100 Ω, what is the input current?

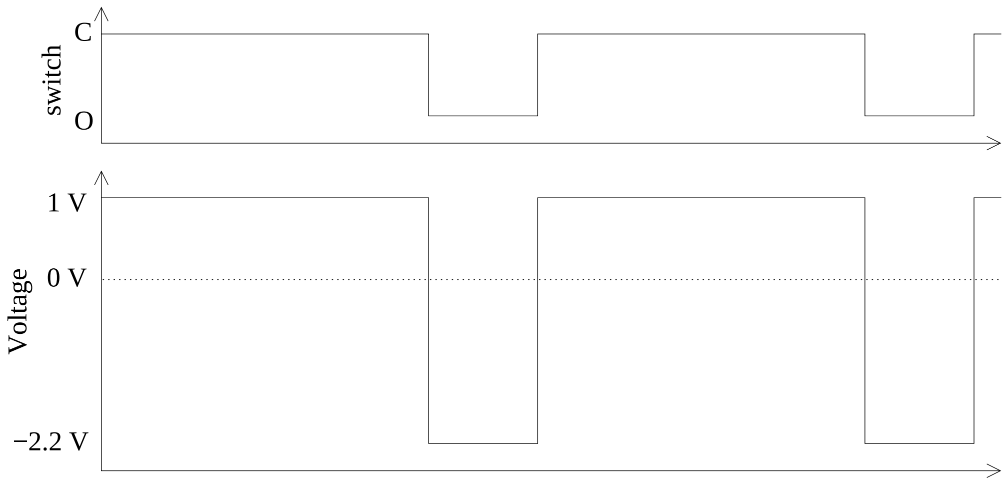


When the switch is closed the voltage across the inductor is $V_{LC} = V_{\text{in}} = 1$ V. When the switch is open the voltage across the inductor is $V_{LO} = -\left(V_{\text{out}} + V_D - V_{\text{in}}\right) = -\left(2.5 + 0.7 - 1\right) = -2.2$ V. The slopes are proportional to these voltages. Thus, during continuous mode we must have $T_C V_{LC} = T_O V_{LO}$, or

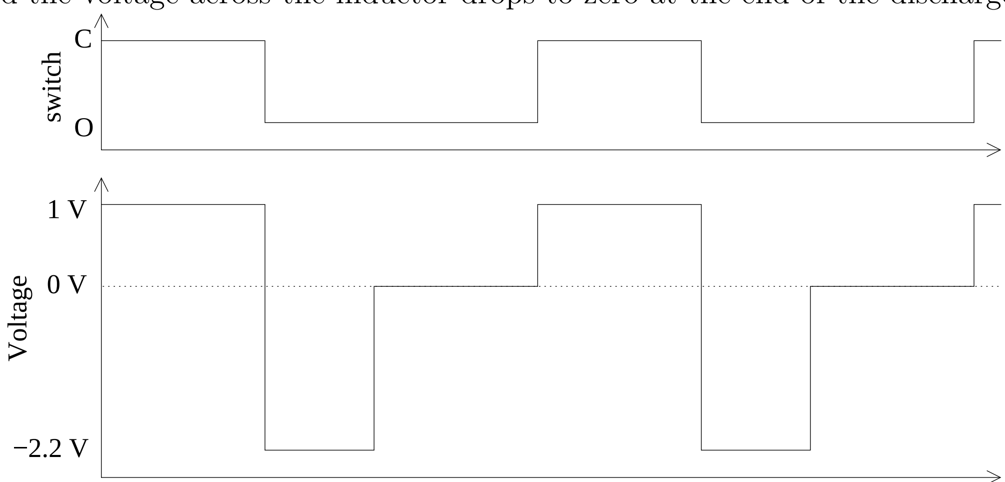
$$\frac{T_C}{T_O} = \frac{V_{LO}}{V_{LC}} = \frac{2.2}{1} = 2.2$$

The duty cycle of the switch is then

$$\text{duty} = \frac{T_C}{T_C + T_O} = \frac{T_C}{T_C\left(1 + \frac{1}{2.2}\right)} = 0.69$$



During discontinuous mode the closed-switch time is shorter, the time to discharge is the same, and the voltage across the inductor drops to zero at the end of the discharge period.



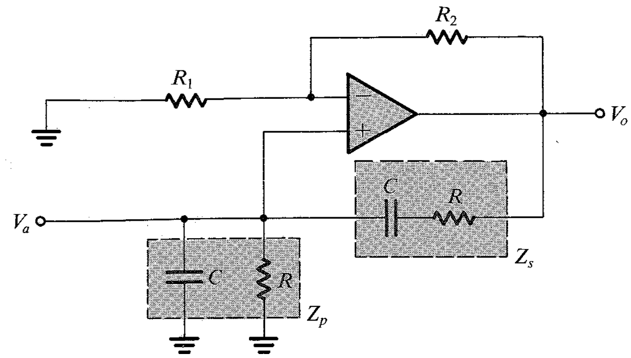
If the load resistance is is $R_L = 100\,\Omega$, the output current is $I_{\text{out}} = \frac{V_{\text{out}}}{R_L}$. The input current is related to the output current as the ratio of voltages, because there is no power loss in the switching regulator. $P_{\text{out}} = P_{\text{in}}$, $V_{\text{in}} I_{\text{in}} = V_{\text{out}} I_{\text{out}}$, or

$$I_{\text{in}} = I_{\text{out}} \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{V_{\text{out}}}{T_L} \frac{V_{\text{out}}}{V_{\text{in}}} = \frac{V_{\text{out}}^2}{R_L V_{\text{in}}} = \frac{3.2^2}{100 \times 1} = 102\,\text{mA}$$

3. Sinusoidal oscillator

Design a Wien-bridge oscillator which oscillates at 10 kHz, and is limited to an output signal of $\pm 2V_D$, where V_D is one diode voltage drop. Use mostly 10 kΩ resistors. Be sure to design for sustained oscillations in a real circuit.

Here is the Wien-bridge oscillator.



Attach four diodes to the output, two in series, and the two sets in parallel to ground. This will limit the output to two diode voltage drops. The frequency is selected with

$$f = \frac{1}{2\pi RC}$$

or, since $R = 10\,\mathrm{k}\Omega$

$$C = \frac{1}{2\pi f R} = \frac{1}{2\pi \times 10^4 \times 10^4} = 1.6\,\mathrm{nF}$$

Choose $R_1 = 10\,\mathrm{k}\Omega$. Then nominally, R_2 should be twice that. In order to be certain to sustain oscillations we make it a bit larger, so I choose $R_2 = 30\,\mathrm{k}\Omega$ instead of $20\,\mathrm{k}\Omega$.

4. Filter

Using a two-integrator-loop bi-quad circuit, design a 2nd order low-pass Butterworth filter with a pass-band edge of $f_p = 10\,\mathrm{kHz}$, and a 3-dB pass-band ripple, using 10 nF capacitors.

First, determined the ϵ parameter for the filter.

$$\epsilon = \sqrt{10^{A/10} - 1} = \sqrt{10^{3/10} - 1} = 1.0$$

That then means that the radius of the poles is

$$\omega_0 = 2\pi f_p = 63 \times 10^3\,\mathrm{s}^{-1}$$

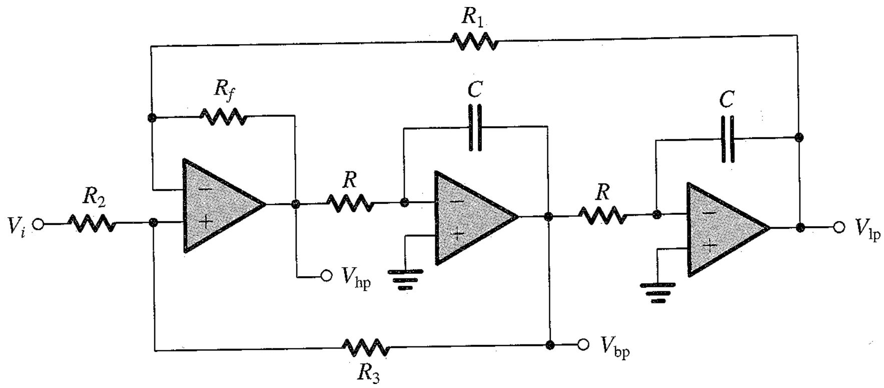
The real coordinate of the poles is

$$-\frac{\omega_0}{2Q} = -\omega_0 \cos(45^\circ)$$

or

$$Q = \frac{1}{2\cos(45^\circ)} = \frac{1}{\sqrt{2}}$$

We now have all the information we need to select components for a two-integrator-loop bi-quad filter like this one.



We have $\omega_0 = \frac{1}{RC}$, or

$$R = \frac{1}{\omega_0 C} = \frac{1}{63 \times 10^3 \times 10 \times 10^{-9}} = 1.6\,\mathrm{k}\Omega$$

Next, make $R_1 = R_f = 1\,\mathrm{k}\Omega$. Then make $R_2 = 1\,\mathrm{k}\Omega$. Then $\frac{R_3}{R_2} = 2Q - 1$, or

$$R_3 = R_2\,(2Q-1) = 1 \times 10^3 \left(\frac{2}{\sqrt{2}} - 1\right) = 414\,\Omega$$