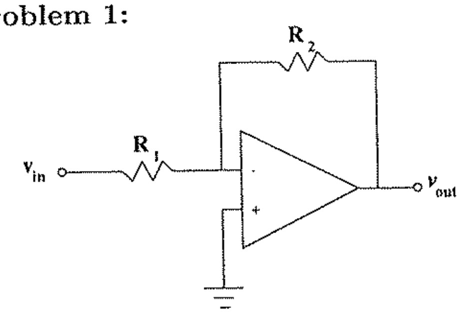
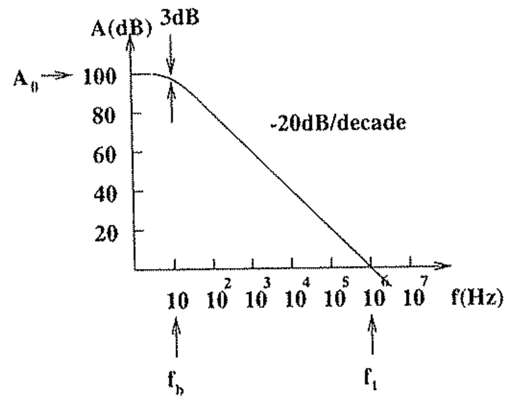
Due by lab time, Thurs. 2010-10-07

**Physics 364: Problems on Op. Amps.** **Prof. Kroll**

**Problem 1:**




(a)




(b)

Part (a) of the figure above shows the inverting amplifier configuration for an operational amplifier that we discussed in class and that you studied in lab. We are going to discuss three cases. In all three cases you should assume the inputs ("−" and "+") have infinite input impedance, that is, they draw no current.

**(a) Case 1:** The operational amplifier has infinite gain. What is the gain $v_{\text{out}}/v_{\text{in}}$ assuming that $v_- = v_+$ (*i.e.*, the op-amp adjusts the output so that the difference between the inputs is zero)? We did this case in class. You have the answer in your notes.

**(b) Case 2:** The operational amplifier has large but finite gain $A$ so that $v_{\text{out}} = A \cdot (v_+ - v_-)$. This gain is called the **open loop** gain. What is the gain $v_{\text{out}}/v_{\text{in}}$? We did this case in class. You have the answer in your notes. Show that in the limit of $A \to \infty$ your answer here reduces to your answer for Case 1.

**(c) Case 3:** The gain of the operational amplifier is a function of frequency as depicted in the curve in part (b) of the figure above. The vertical scale is in decibels, so $100 = 20 \log A_0$ implies $A_0 = 10^5$. The horizontal axis is the frequency $f$ in Hz. You will notice this looks like the Bode plot of a low-pass filter. You may be struck, however, that the large gain decreases rapidly with frequency starting at the very low frequency of $f_b = 10\,\text{Hz}$. This rapid decrease is designed into the amplifier to protect it from unstable operation at higher frequency. It is due to a capacitor in the op-amp (which was visible in the schematic of the 741 I showed you in class - see Sedra and Smith Figure 10.1). The op-amp is said to be **internally compensated**.

The form of $A(\omega)$ is

$$A(\omega) = \frac{A_0}{1 + j\omega/\omega_b},$$

where $\omega = 2\pi f$, $\omega_t = A_0\omega_b$, and $\omega_b = 2\pi f_b$ (see Figure (b)). Substitute this form into your result from Case 2 and show that in the approximation $A_0 \gg 1 + R_2/R_1$ the gain is

$$\frac{v_{\text{out}}}{v_{\text{in}}} = \frac{-R_2/R_1}{1 + \frac{j\omega}{\omega_t/(1+R_2/R_1)}},$$

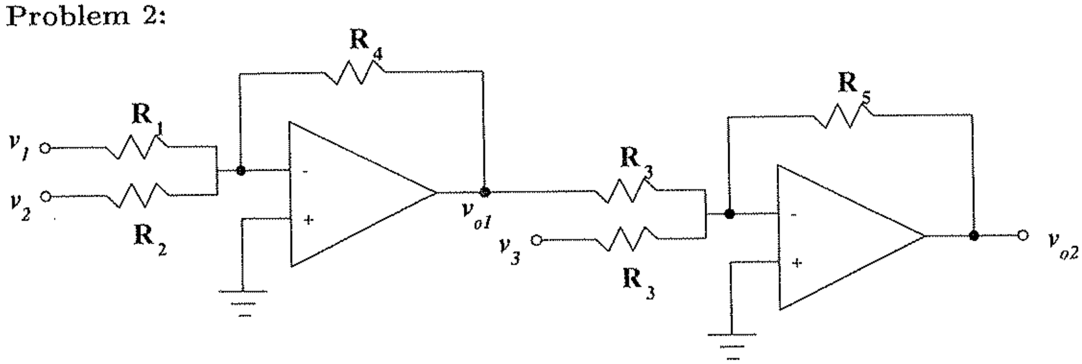
$f_t \equiv \omega_t / 2\pi$

The quantity $f_t$ is known as the **unity-gain bandwidth** and is usually specified on the data sheet of the op-amp.

**Op-amp laboratory analysis**: In the ~~op-amp~~ Week4 laboratory, you ~~measured~~ will measure the gain of an inverting amplifier configuration as a function of frequency. The open gain of your 741 op-amp follows the curve given in Figure (b), and the unity-gain bandwidth is typically $f_t = 10^6$ Hz. For your first configuration in which $R_1 = 1\,\text{k}\Omega$ and $R_2 = 10\,\text{k}\Omega$, what is the value of your 3 dB frequency (the frequency where the gain is reduced by $\sqrt{2}$)? ~~How does this result compare to your measurements? In other words, is it consistent with the value of frequency at which the gain started to fall from -10?~~ How does this 3 dB frequency change for the case that $R_1 = 1\,\text{k}\Omega$ and $R_2 = 50\,\text{k}\Omega$? ~~How does this result compare to your measurements?~~ (If you did not do the measurement for $R_1 = 1\,\text{k}\Omega$ and $R_2 = 50\,\text{k}\Omega$ just explain what you would expect to see.) Not done yet, so just explain what you expect.

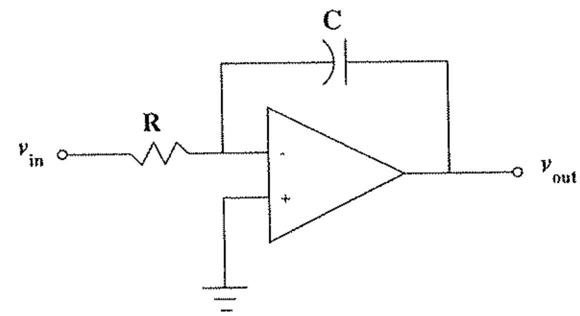
**Reference:** Sedra and Smith Section 2.7 and Figure 10.1.

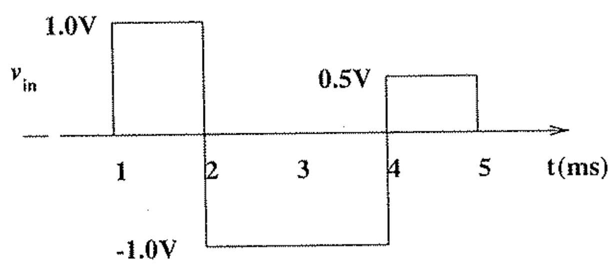
**Problem 2:**




Find the output voltage $v_{o2}$ in terms of the three inputs $v_1$, $v_2$, $v_3$. Assume the op-amps are ideal op-amps.

**Problem 3:**




Calculate and make a quantitative sketch of the output of the op-amp for the circuit shown above when the input $v_{in}$ varies with time as shown below the circuit diagram. Use $R = 1\,\mathrm{k}\Omega$ and $C = 1.0\,\mu\mathrm{F}$, and assume the initial charge on the capacitor is $Q_0 = 0$.

**Problem 4:**

Design a circuit with 3 input voltages $v_1$, $v_2$, and $v_3$ that provides the output

$$v_{out} = -(v_1 + 2v_2 + 3v_3).$$

Use resistor values that are $10\,\mathrm{k}\Omega$ or larger only.