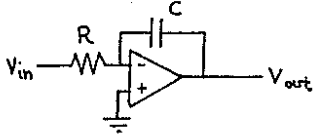
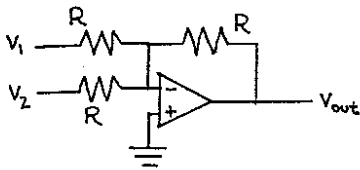


# Physics 623 — Problem Set 4

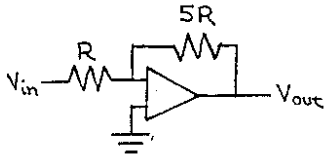
1. Calculate  $V_{OUT}$  for the following circuits:



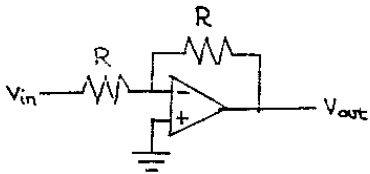
$$V_{out} = \underline{\hspace{2cm}}$$



$$V_{out} = \underline{\hspace{2cm}}$$



$$V_{out} = \underline{\hspace{2cm}}$$



$$V_{out} = \underline{\hspace{2cm}}$$

2. Use the circuits in problem 1 and a signal generator set to deliver 2 volts peak at frequency  $\omega_0$  to construct an analog computer where the voltage at point x satisfies the following equation:

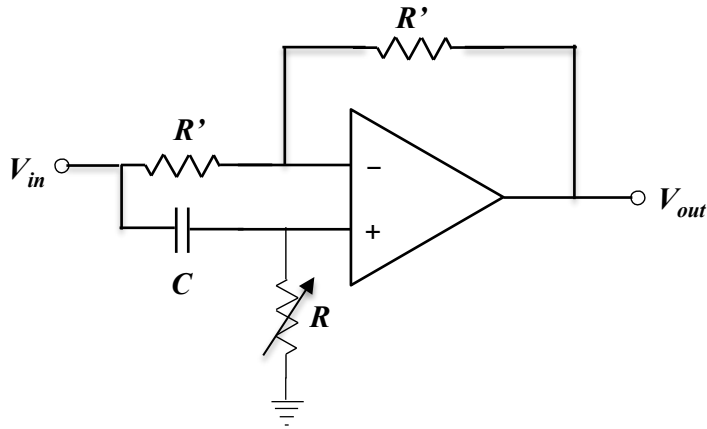
$$\frac{d^2x}{dt^2} = 5 \frac{dx}{dt} + x + 2 \sin(\omega_0 t)$$

Let  $RC = 1$ . Mark the point in your circuit where the voltage = x.

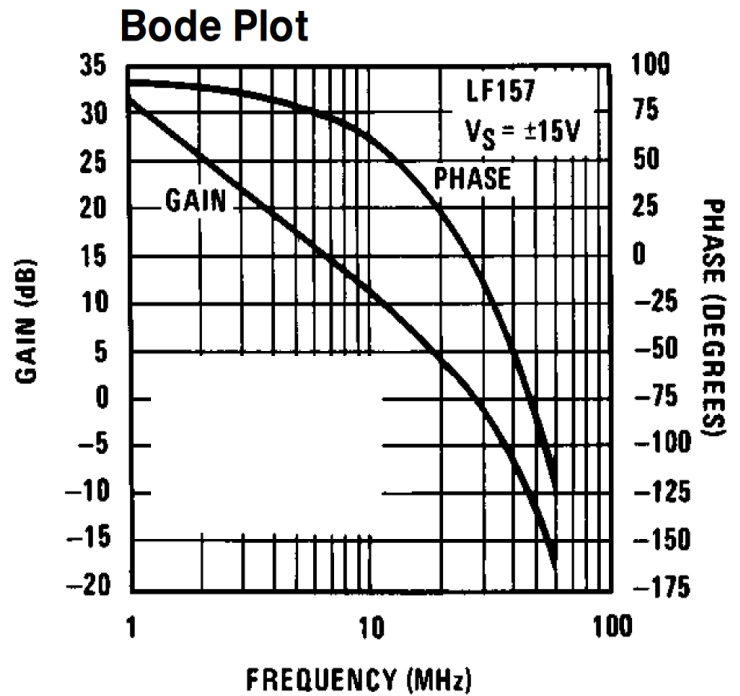
Hint: Start at a point where you define the voltage to be  $d^2x/dt^2$ . It is standard practice to start with the highest derivative present in the equation. This avoids the use of differentiator circuits, which have the practical problem of high gain for high frequency noise. Use the circuits from problem 1 to generate the right hand side of the equation from this starting point. Connect the resultant point back to your starting point to force the differential equation to be true.

4. Design a circuit where the output is the square root of  $V_{in}$ .

5. Calculate the magnitude and phase of  $V_{out}/V_{in}$  for the circuit shown below. Use  $1/i\omega C$  for the impedance of the capacitor and do the analysis using complex numbers until you have a final result for  $V_{out}/V_{in}$ . Then convert to magnitude and phase notation.  $R$  can be adjusted from zero to infinity. This circuit is called a “phase shifter”.



6. The open-loop gain curve for an LF157/357 op-amp is shown at the right. This is a detailed view of the high frequency end of the curve, and explicitly shows the phase as well as the magnitude of the gain. The reference for the phase is  $+180^\circ$  instead of the usual  $0^\circ$ , so you'll need to subtract  $180^\circ$  from phases read from the plot



a) What is the approximate gain-bandwidth product for this op-amp?

b) If you use it as a unity-gain buffer ( $B = -1$ ), what is the phase margin? Is this a useable amplifier circuit?

(Here's how to use this plot: First, use the Gain curve to find the critical frequency if  $B = -1$ . Then, go up from that point on x-axis until you intersect the Phase curve. Use the right-hand y-axis scale to identify what the phase is, and subtract  $180^\circ$  from the value you read due to the way this plot is constructed.

c) What is the minimum closed-loop gain ( $-1/B$ ) that will provide a reasonably safe  $45^\circ$  phase margin?

d) Suppose your circuit in part c) is a conventional non-inverting amplifier with a voltage divider on the output connecting a fraction  $B$  of the output back to the negative input. We usually assume this  $B$  is entirely real, but suppose there is a significant stray capacitance between the wiring to the negative input and ground. Explain the qualitative effect on your phase margin. If the bottom resistor in the divider is 10 K ohms (the gain then determines the top one) and the stray capacitance is 5 pF, at what frequency do you get an additional  $45^\circ$  phase shift? What will happen?