EECS 40, Fall 2007
Prof. Chang-Hasnain

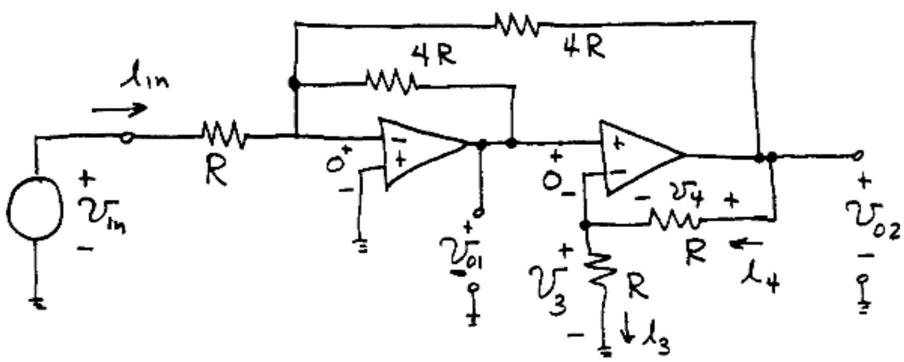
Homework #7

Due at 5 pm in 240 Cory on Thursday, 11/08/07
Total Points: 100

- Put (1) your name and (2) discussion section number on your homework.
- You need to put down all the derivation steps to obtain full credits of the problems. Numerical answers alone will at best receive low percentage partial credits.
- No late submission will be accepted except those with prior approval from Prof. Chang-Hasnain.
- Problems of this HW are from Hambley 4th Edition

Negative Feedback (35 points)

1. (Non-Inverting Amplifiers) P14.34 (10 points)



From the circuit we can write:

$$v_{o1} = v_3$$

$$i_4 = i_3 = \frac{v_{o1}}{R}$$

Thus we have

$$v_4 = v_3 = v_{o1}$$

$$v_{o2} = v_3 + v_4 = 2v_{o1}$$

$$i_{in} + \frac{v_{o1}}{4R} + \frac{v_{o2}}{4R} = 0$$

$$i_{in} = \frac{v_{in}}{R}$$

$$\frac{v_{in}}{R} + \frac{v_{o1}}{4R} + \frac{v_{o2}}{4R} = 0$$

$$A_1 = \frac{v_{o1}}{v_{in}} = -4/3$$

$$A_2 = \frac{v_{o2}}{v_{in}} = \frac{2v_{o1}}{v_{in}} = 2A_1 = -8/3$$

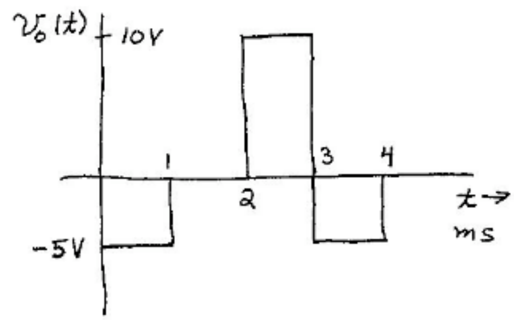
2. (Integrators and Differentiators) P14.75, and P14.80.

14.75 (5 points)

This is a differentiator circuit, and the output is given by:

$$v_o(t) = -RC\frac{dv_{in}(t)}{dt}$$
$$= -10^{-3}\frac{dv_{in}(t)}{dt}$$

A sketch of $v_o(t)$ versus is:



14.80 (5 points)

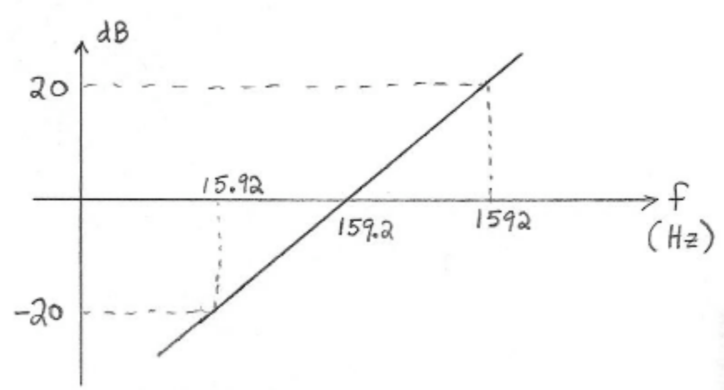
The gain is:

$$A(f) = -\frac{R}{\frac{1}{j\omega C}} = -j\omega RC = -j(f/159.2)$$

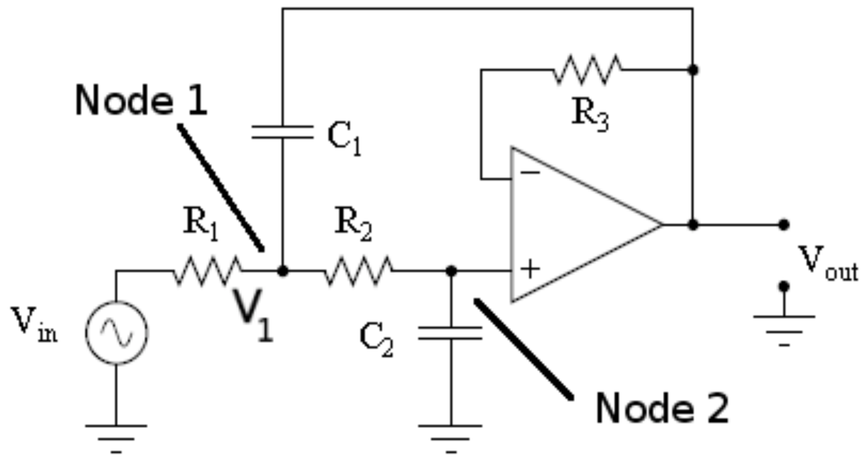
In decibels, the gain magnitude is

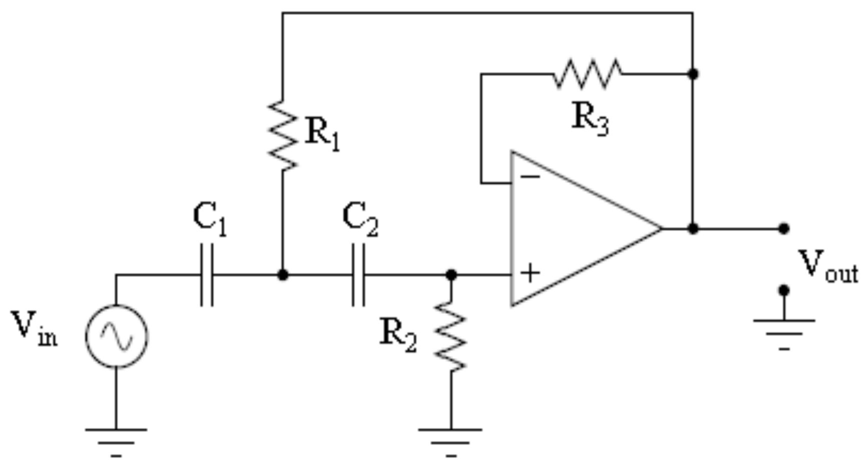
$$20\log|A(f)| = 20\log(f/159.2)$$

The sketch is:



3. (Active Filters) For each of these, answer whether it is lowpass or highpass, and explain the role or R3. (15 points)





(i) The voltage at the – terminal of the op amp is V_out.
(ii) Applying KCL at node 1 and 2 gives the following equations:

$$\frac{V_{in} \_ V_1}{R_1} - \frac{V_{out} \_ V_1}{\frac{1}{j \_ C_1}} - \frac{V_{out} \_ V_1}{R_2} = 0$$

$$\frac{V_{out} \_ V_1}{R_2} - \frac{V_{out}}{\frac{1}{j \_ C_2}} = 0$$

(iii) This can be simplified to

$$H \_ j \_ \_ = \frac{V_{out}}{V_{in}} = \frac{1}{1 \_ j \_ C_2 \_ R_1 \_ R_2 \_ \_ \_^2 R_1 R_2 C_1 C_2}$$

(iv) This can be easily identified as a low pass filter.
(v) R_3 has obviously no impact.
(vi) Considering the second configuration, we can either calculate the transfer function from scratch or recognize that R_1 is replaced by C_1, etc. and modify the transfer function accordingly:

$$H(j\omega) = \frac{V_{out}}{V_{in}} = \frac{1}{1 - \frac{1}{j\omega R_2}\left(\frac{1}{C_1} + \frac{1}{C_2}\right) - \frac{1}{\omega^2 R_1 R_2 C_1 C_2}}$$

This can be rearranged to

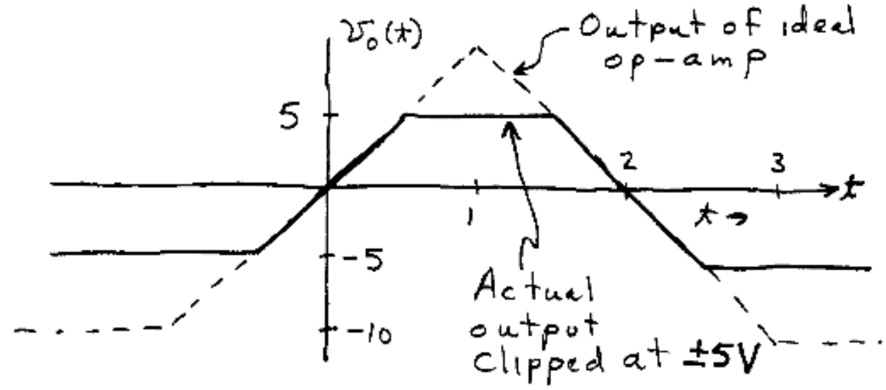
$$H(j\omega) = \frac{\omega^2 R_1 R_2 C_1 C_2}{\omega^2 R_1 R_2 C_1 C_2 + j\omega R_1 (C_1 + C_2) - 1}$$

(v) This is easily identified as a high pass filter.
(vi) Again, R_3 has no impact.

Positive Feedback (40 pts)

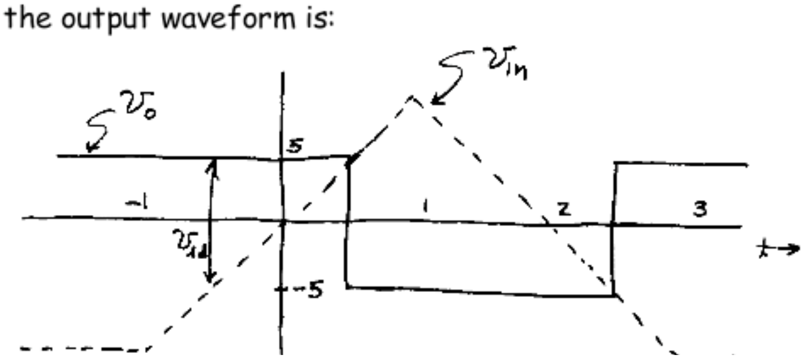
4. P14.29

(a) This circuit has negative feedback. It is the voltage follower and has unity gain except that the output voltage cannot exceed 5 V. The output waveform is:

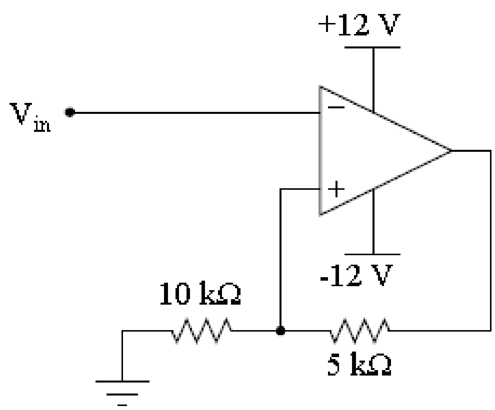


(b) This circuit has positive feedback, and v_o = +5 if the differential input voltage v_{id} is positive. On the other hand, v_o = -5 if v_{id} is negative. In this circuit, we have $v_{id} = v_o - v_{in}$

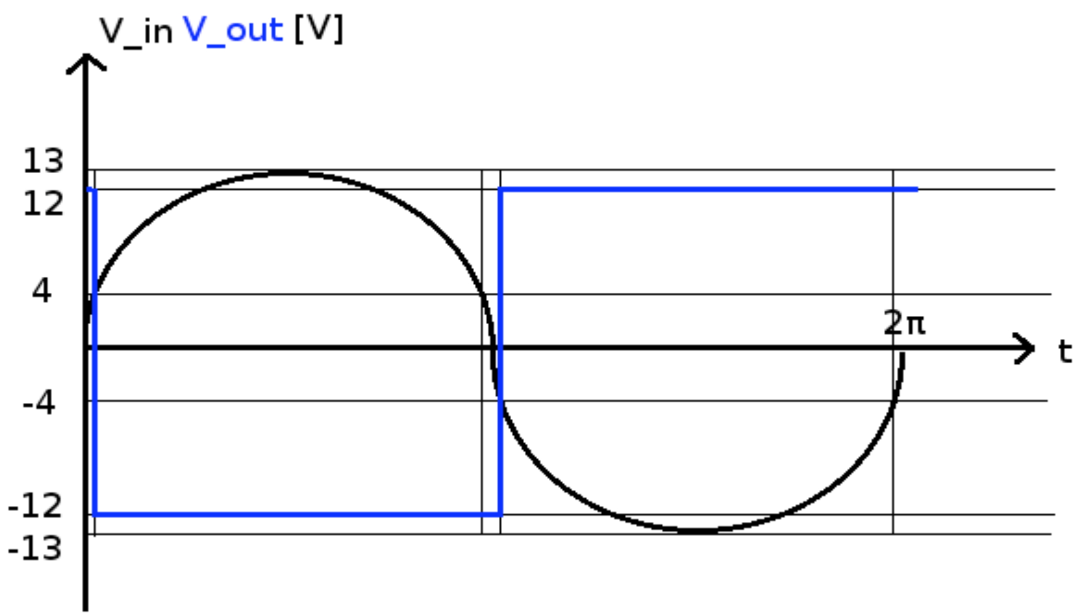
Thus, the output waveform is:



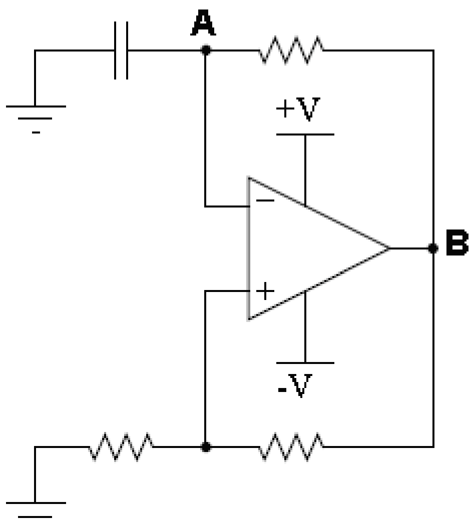
5. Assume the op-amp is ideal, except that the output voltage is limited to extremes of -12V or 12V. For input voltage 13 sin(2□ t), sketch the output voltage. (14 points)



If V_in is smaller than V+, then V_out is 12V. We can use the voltage divider equation to determine that V+ is 8V.
Analogously, if V_in is larger than V+, then V_out is -12V and thus V+ is -8V.
With the given sinusoidal input function, we receive a rectangular signal as output function. The result is sketched in the following plot:



6. Suppose in the following circuit that all resistors have resistances R and the capacitor has capacitance C. Assuming the output of the otherwise ideal op-amp is limited to be between *V* volts and –*V* volts. Sketch the voltage at nodes A and B as a function of time, assuming the circuit has been operating for some time. Be sure to mention the role of the RC constant. (18 points)



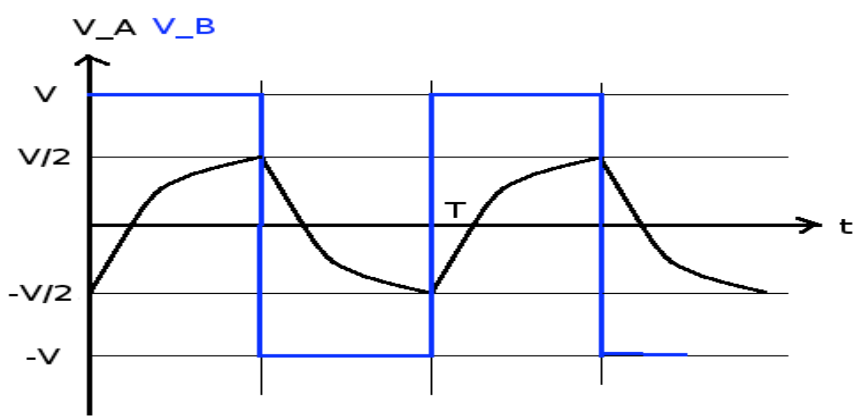
Let's assume that V+ > V-. Then the voltage at B is +V. This implies that V+ is V/2. V- is determined by the charging of the capacitor. Assuming that the initial voltage is v_i, we have

$$v_- = V_i + (V - V_i) e^{\frac{-t}{\tau}}$$

This state is left if V- gets larger than V/2. Then the voltage at B is -V implying that V+ is -V/2. V- is now determined by the discharging of the capacitor. We get

$$v_- = V/2 + (-V - V/2) e^{\frac{-t}{\tau}}$$

This state is left if V- gets smaller than -V/2. This makes clear that v_i=-V/2. The result is sketched in the following plot (8 points):

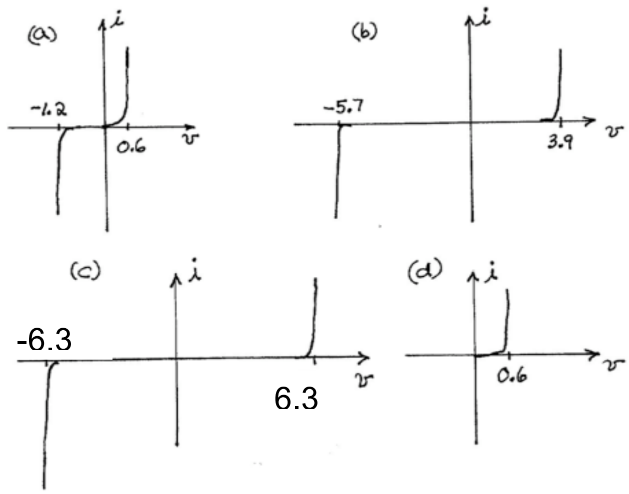


The RC constant determines the period of the oscillation. One charging process needs time T/2:

$$V = \frac{3\mathrm{V}}{2} e^{\frac{-T}{2\tau}} \text{ -->} T = 2\ln\left(\frac{3}{2}\right)\tau$$

Diodes (25 points)

7. P10.7 (8 points)



8. P10.17 (8 points)

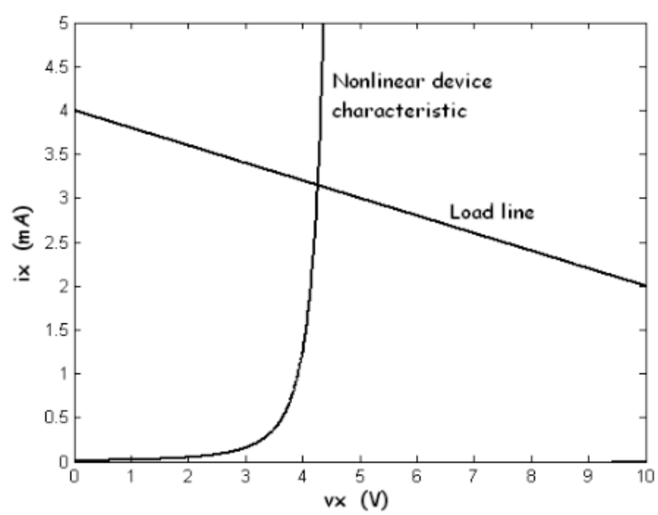
The load-line equation is

$$V_s = R_s i_x + v_x$$

Substituting values, this becomes

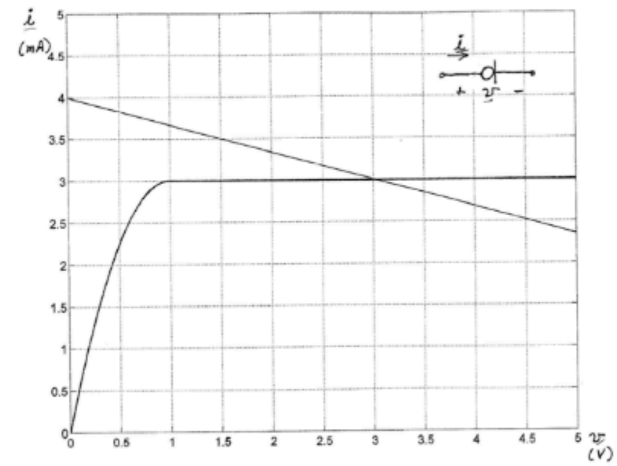
$$20 = 5 i_x + v_x$$

in which i_x is in millamperes and v_x is in volts. Next, we plot the nonlinear device characteristic equation and the load line on the same set of axes. Finally, the solution is at the intersection of the load line and the characteristic as shown:



9. P10.22 (9 points)

If we remove the diode, the Thévenin equivalent for the remaining circuit consists of a 12-V source in series with a 3-kΩ resistance. The load line is



At the intersection of the characteristic and the load line, we have the device current $i_1 \cong 3.0$ mA. Then, applying KCL to the original circuit, we have $i_2 = 6 - i_1 = 3.0\,\text{mA}$.