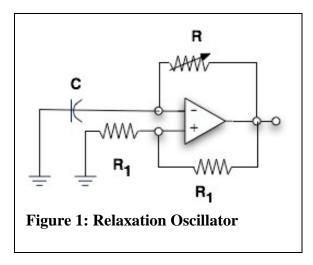
## **Op Amps II**

## Op-amp relaxation oscillator

Questions indicated by an asterisk (\*) should be answered before coming to lab.



Build the relaxation oscillator shown in Figure 1 above. The output should be a square wave with a frequency about 1/(2RC). Resistor  $R_1$  can be any value between  $1k\Omega$  and  $1M\Omega$ . Resistor R is one side of a potentiometer. Examine the voltages at (+) and (-) inputs and at the output and follow the action of the switching. It is useful to display  $v_+$  and  $v_-$  simultaneously on the same scale to illustrate that the switching occurs at the crossover of  $v_+$  and  $v_-$ .

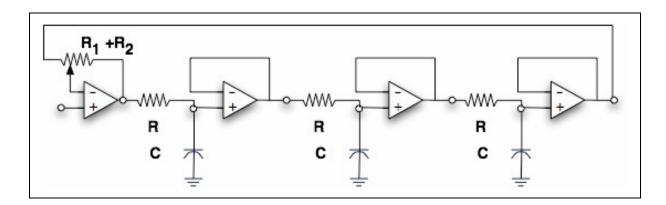


Figure 2: Low-pass Resonant Filter

\*Show that the transfer function for the low pass resonant filter, shown in Figure 2, is given by:

$$H(\omega) = \frac{1}{1 - x + x(1 + i\omega\tau)^3} \tag{1}$$

where  $\omega$  refers to the angular frequency of an oscillator connected to the non-inverting input of the first (leftmost) opamp,  $\tau = RC$  and x is the ratio of  $R_1$  to the total pot resistance  $R_1 + R_2$ . Here  $R_1$  is the part of the pot resistance between the output and the inverting input of the first opamp and  $R_2$  is the part of the pot resistance between the inverting input and output of the first opamp.

[Hint: Begin by naming the output voltages of each op amp, from left to right, as  $v_1$  through  $v_4$ . Then use the infinite gain assumption to show that:

$$\frac{(v_4 - v_{in})}{R_1} = \frac{(v_{in} - v_1)}{R_2} \tag{2}$$

Next, use what you know about RC filters to find v<sub>4</sub> in terms of v<sub>1</sub>.]

The resonance depends on both  $x=\frac{R_1}{R_1+R_2}$  and  $\omega\tau=\omega RC$ . Figure 3 shows the gain versus  $\omega\tau$  for four different values of x. It can be shown (you do not have to do this) that the real part of the denominator of equation 1 vanishes when  $3x(\omega\tau)^2=1$ . Furthermore, the gain is sharply peaked when  $\omega\tau=\sqrt{3}$  and  $x=\frac{1}{9}$ .

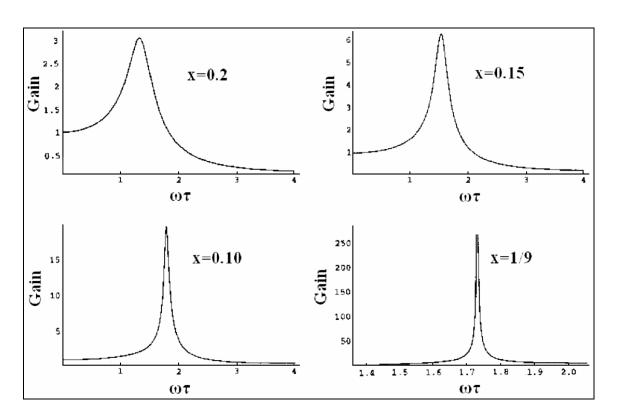


Figure 3

When you understand the equation for the transfer function, build the circuit. It is convenient to use a TL084 with four op amps in a package.

Choose RC so that the resonant frequency is 2 to 5 kHz. Tune the pot until the circuit nearly oscillates. See how close you can get. Notice how oscillations grow and die exponentially. Find the resonant frequency by feeding in a sine signal from a function generator. (You may need to decrease the input voltage considerably to avoid saturating the filter near resonance.) Check the high frequency roll off. It should be proportional to  $1/\omega^3$ . Estimate the gain at resonance. Make a Bode plot of the transfer function. (Spend your time wisely here by starting with a survey to find the frequencies where important features occur. Important features include resonance, high-frequency roll off and low-frequency constant region.)