Lab 9 Op Amps II

Questions indicated by an asterisk (*) should be answered before coming to lab. In this lab you will be using TL082/TL084 op-amp chips. Remember to provide -15V (V_{CC-}) and +15V (V_{CC+}) power voltage to the chips.

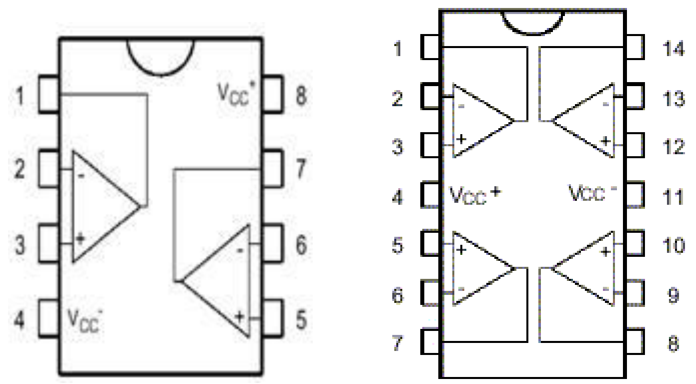

Figure 1: Pin-Out for TL082 and TL084 Chips.

It will be up to you to decide what specific resistor and capacitor values to use in the circuits.

1. Op-Amp Relaxation Oscillator

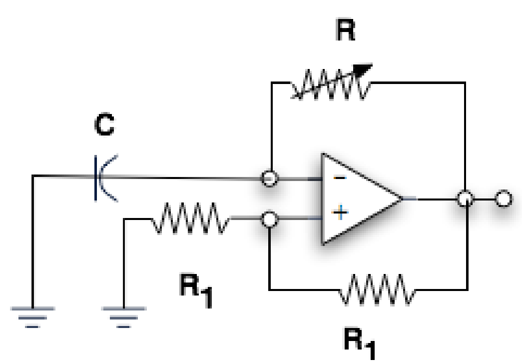

Figure 2: Relaxation oscillator.

Build the relaxation oscillator shown in Figure 2 above. The output should be a square wave with a frequency f of about 1/(2RC). Resistor R_1 can be any value between 1kΩ and 1MΩ. Resistor R is one side of a potentiometer.

(a) Indicate the values of the components you are using on a drawing in your notebook and compute the expected output frequency for x=0.5. [3 p]

(b) Connect an oscilloscope to display V_+ and V_- and the output signal simultaneously on the same scale, to illustrate that the switching occurs at the crossover of V_+ and V_-. Paste a plot of the 'scope display in your lab notebook. [4 p]

(c) Determine the frequency range of your oscillator [4 p]

(d) * How does this circuit work? Why does V_- resemble a triangular wave? [4 p]

(e) To make a musically useful signal, change the pot to a fixed resistor to get a frequency between 200 and 500 Hz. Record the value of the fixed resistor and the frequency. [3 p]

(f) **Do not** disassemble your circuit. You can have fun with it in Part 4 that follows.

2. Low-Pass Resonant Filter

This filter is made from a summer and three one-pole lowpass filters. All three filters have the same R and C.

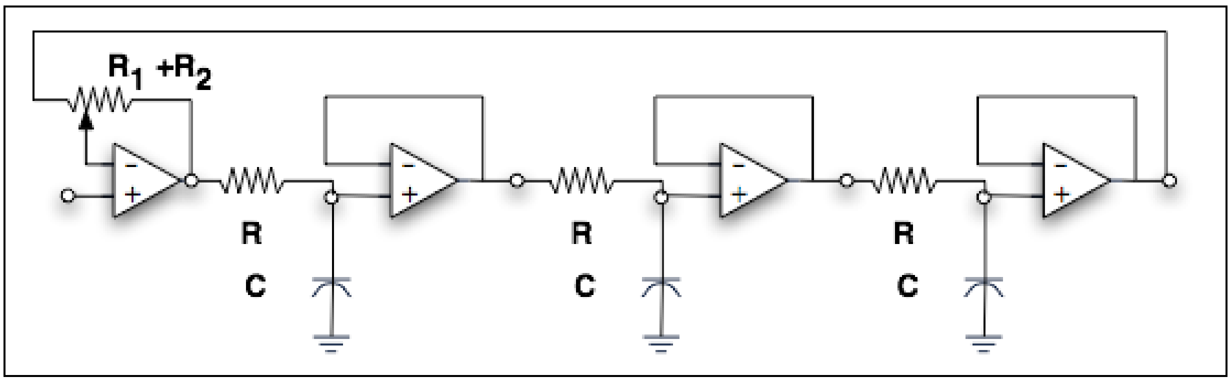

Figure 3: Low-pass resonant filter.

*(a) Show that the transfer function for the low-pass resonant filter, shown in Figure 3, is given by:

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

where ω refers to the angular frequency of an oscillator connected to the non-inverting input of the first (leftmost) op amp, $\tau = RC$, 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 filter main output (output of the final op-amp stage) and the sliding contact on the pot. The sliding contact is connected to the inverting input of the first op amp. Here R_2 is the part of the pot resistance between the sliding contact and output of the first op amp. [5 p].

[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:

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

Next, use what you know about RC filters to find v_4 in terms of v_1.]

The resonance depends on both $x = \frac{R_1}{R_1 + R_2}$ and $\omega\tau = \omega RC$. Figure 4 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 $3x(\omega\tau)^2 = 1$. That is the resonance condition. Furthermore, the gain is sharply peaked when $\omega\tau = \sqrt{3}$ and $x = \frac{1}{9}$.

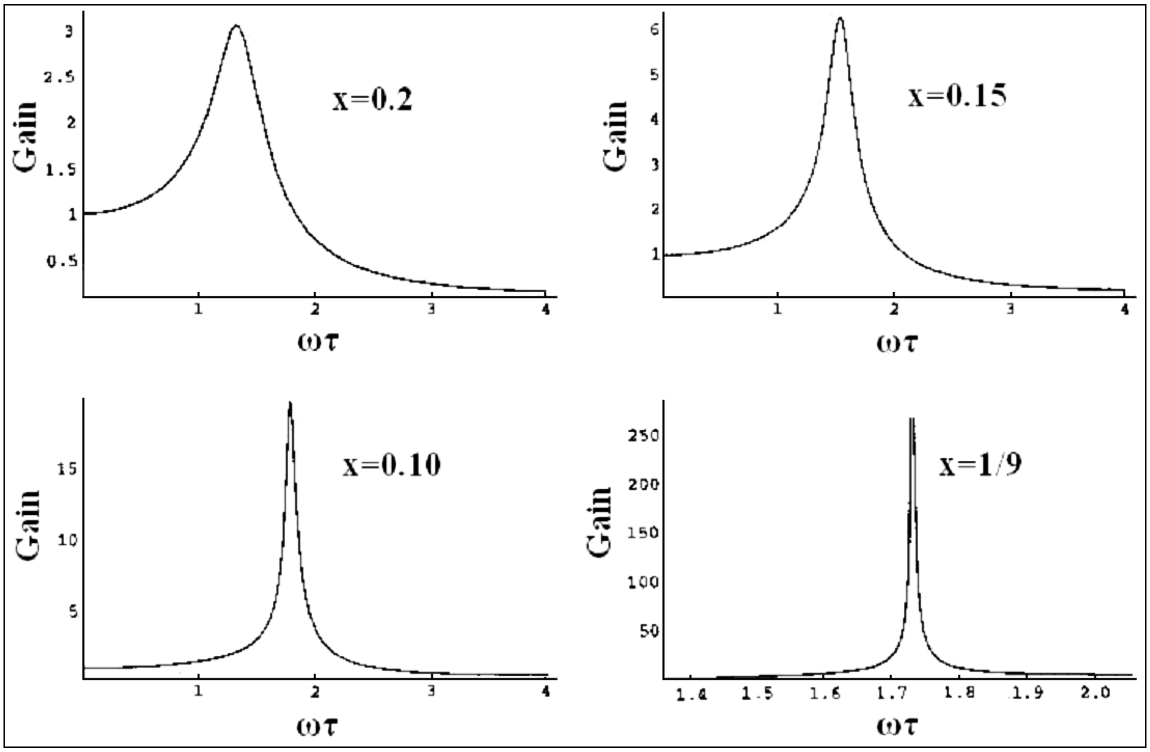

Figure 4: Gain of the low-pass resonant filter for different resistance ratios.

Note that parameter x controls both the resonant frequency and the Q of the filter. There are other filter circuits (e.g. the state variable filter) that afford independent control of the resonant frequency and the Q.

(b) 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, but you may also use two TL082 chips. Choose *RC* so that the resonant frequency is 2 to 5 kHz. (It is best to use a resistor ~ 5 kΩ). Begin by writing chip pin numbers on a hard copy of the circuit diagram. Examine the resonant behavior by feeding in a sine signal from a function generator. Specifically:

(1) Set the function generator to the $x = \frac{1}{9}$ resonance frequency of $f = \frac{\sqrt{3}}{2\pi RC}$.

(2) Adjust the pot to maximize the output amplitude (now you should be close to $x = \frac{1}{9}$).

Record the resonant frequency and the gain at resonance [4 p]

(3) Show your completed circuit to your instructor who will initial your drawing. [4 p]

(4) Find H(ω) at the resonance frequency and for 5 higher frequencies and for 5 lower frequencies to make a Bode plot of the transfer function (magnitude in dB and phase vs base-10 log of f). [4 p]

The Bode plot should show the character of the high-frequency roll off. To the extent that the theoretical transfer function is correct, the gain should be proportional to $1/f^3$ at high f. Compare that power law with your Bode plot high-frequency limit. [3 p]

4. Filtering the square wave.

Connect the output of the relaxation oscillator to the input of the filter using a voltage divider to reduce the oscillator output voltage by about a factor of 10..

(a) What resistors are you using for the voltage divider? [2 p]
(b) What does the filter do to the shape of the wave? [3 p]
(c) Listen to your output and observe on the 'scope as you adjust the filter frequency. What do you hear? [2 p]