EE 3101 ELECTRONICS I LABORATORY

EXPERIMENT 8 LAB MANUAL

APPLICATONS OF OPERATIONAL AMPLIFIERS

OBJECTIVES

In this experiment you will
- Learn how resonant circuits can be used to make band-pass and band-reject filters.
- Gain experience in measuring the frequency response of a simple network.
- Become familiar with the laboratory layout and equipment.

LAB NOTEBOOKS

The format of lab notebooks should be such that the information can be used to reproduce the lab, including what values were used in a circuit, why the values were used, how the values were determined, and any results and observations made. This lab manual will be used as a guide for what calculations need to be made, what values need to be recorded, and various other questions. The lab notebook does not need to repeat everything from the manual verbatim, but it does need to include enough information for a 3rd party to be able to use the notebook to obtain the same observations and answers. In the following numbered sections there are **bolded words and/or lines**. These bolded words and/or lines are statements and/or questions that the lab TA will be looking for an answer either in the lab preliminary, or lab notebook.

INTRODUCTION

Operational amplifiers (op-amp) can be used to perform a myriad of useful functions. These included amplifiers, analog summers and subtractors, differential amplifiers, buffers, and active filters. You have also experimented with amplifiers in a previous lab. In actual practice, the most-common applications are variations of amplifiers, active filters and the comparator. In this experiment, an active band-pass filter, the comparator and the Schmitt trigger will be studied. Parts of this experiment were suggested by the textbook author, Dr. D. A. Neamen.

PRELIMINARY

1. Figure 1 shows one of many possible band-pass filters that can be synthesized with an op-amp. With this design the filter can supply gain, and can change the center frequency by adjusting only one resistor. Design of this filter is best started by choosing a reasonable capacitance for C. The smaller the value of C, the larger the resistors can be. Choose a non-polarized capacitor for this capacitance. For this experiment, set *C* to 4.7 nF.

2. **Calculate R_2 to get the desired bandwidth, knowing that (BW = 200 Hz)**:
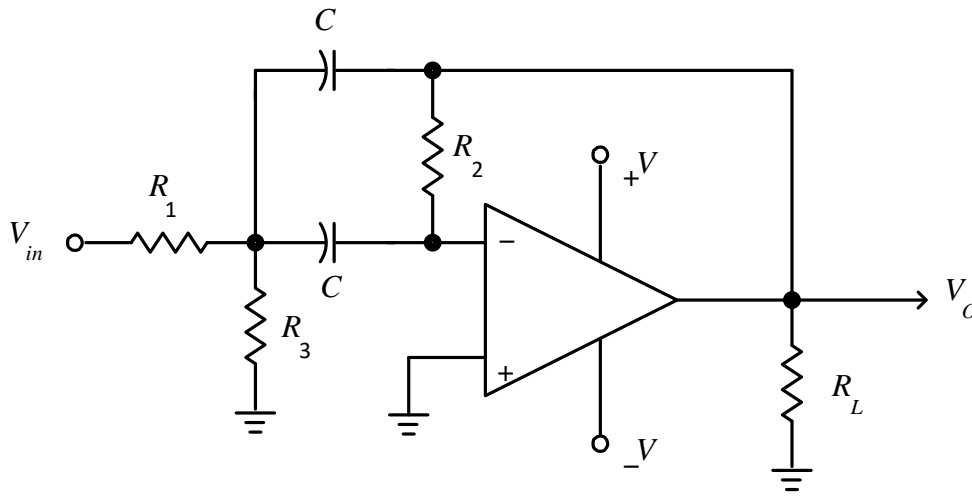
$$BW = \frac{1}{\pi C R_2}$$

Figure 1: An op-Amp band-pass filter.

3. **Calculate R₁ to get the required gain (A_V=10) at the center frequency:**

$$A_V = \frac{R_2}{2R_1}$$

4. **Calculate R₃, knowing that center frequency is:**

$$f_o = \frac{1}{2\pi} \sqrt{\frac{R_1 + R_3}{C^2 R_1 R_2 R_3}}$$

If any of the component values seem unreasonable (too small or too large), change the value of C and recalculate the resistors. Alternatively, you can use substitution of equations to reduce the design time.

EXPERIMENT

Part A – The Active Band-pass Filter

1. The Preliminary used the band-pass filter design criteria; center frequency f_o, of 2 kHz, bandwidth, BW of 200 Hz, and center frequency gain A_V, of 10. With the closest values of components available in the lab, **recalculate what the actual center frequency, bandwidth and gain should be**.

2. Breadboard the circuit of Figure 1 using the chosen components. Use a $\pm$ 12 V supply, and a 741 op-amp.   Check with the data sheet or lab instructor to get the op-amp pin assignments. And finally, set R_L to 3.3 k.

3. **Using the signal generator and the oscilloscope, determine the circuit's center frequency, 3 dB point frequencies (bandwidth), and the gain at the center frequency**.

Q1. **How do they compare with your calculated values?   Explain any major differences.**

4. Change R_3 to lower the center frequency from 2 kHz to 1 kHz. **Repeat the measurements of Step 3**.

Q2. **How do these compare with the calculated values?**

Q3. **What advantages do you see in this band-pass filter as compared to the LC filter like the one you designed in Experiment 1 (Resonant Circuits)?**

Part B – The Comparator and Schmitt Trigger

A circuit that compares two voltages and indicates which one is larger is extremely useful. This circuit is called a **comparator,** and Figure 2 shows how one can be built using an op-amp. Essentially it is just an op-amp running "open loop" – that is, without any negative feedback. Note that this class of circuit is nonlinear, and different methods are needed for analysis.

In this circuit, if the input voltage is greater than the reference voltage, V_{REF}, the output swings to positive saturation. If the input is lower than V_{REF}, the output swings to negative saturation. By observing the "state" of the output, a circuit can determine whether a threshold has been reached or not. If the reference voltage is set to zero (ground), this circuit is called a **zero-crossing detector**, since it changes state each time the input crosses zero. This circuit can be used to generate a quasi-square wave from a sine wave or trigger circuits at the zero crossing of the input signal. Note that an **inverting comparator** can be made by reversing the input connections.
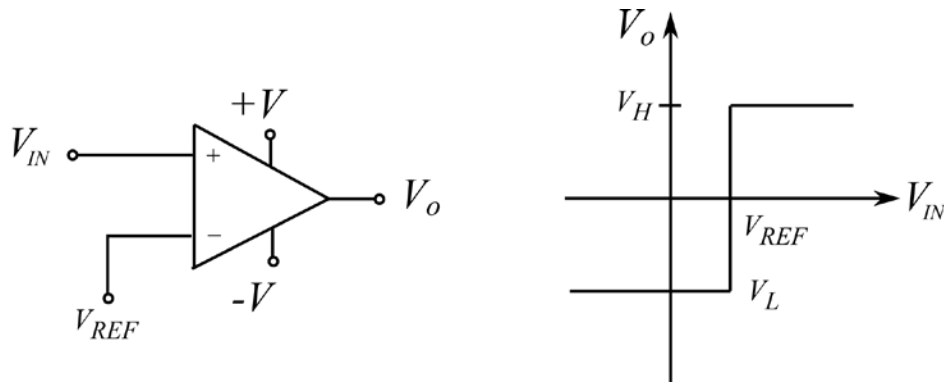
Figure 2: The non-inverting comparator and its transfer characteristic.

A problem arises with the comparator when the input signal is noisy. If the comparator is fast enough, the output can jitter back and forth between the HIGH and LOW states. This can be unacceptable if the output is to be connected to a high-speed digital circuit.

One way to minimize this problem is to apply a small amount of positive feedback to "re-enforce" the switching decision. This circuit can be configured for either an inverting or non-inverting output, and is called the **Schmitt Trigger**. Figure 3 shows the inverting Schmitt trigger and its transfer characteristic. The design equations can be found in your textbook.

Add
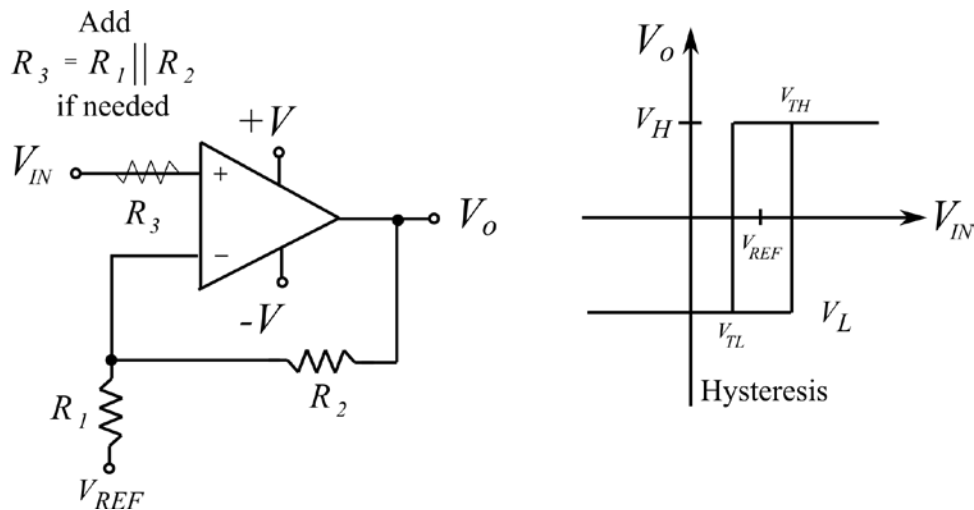$$R_3 = R_1 \| R_2$$
if needed

Figure 3: The inverting Schmitt Trigger and its transfer characteristic.

Basically, if the output is in the HIGH state, a small amount of positive feedback modifies the switching threshold, making it slightly more positive than V_{REF}. Once the threshold is crossed, the output state goes LOW and similarly, changes the input threshold to a slightly lower value. This prevents the op-amp from switching back unless the input signal changes by a certain amount. This amount is called the **Hysteresis** of the Schmitt trigger. A small amount of low-pass filtering can also be helpful on the input to attenuate high-frequency noise.

1. Breadboard the non-inverting comparator shown in Figure 2. Set $V_{REF} = 0$ (ground) and the power supplies equal to $\pm$ 12 volts.

2. Connect the signal generator output to the oscilloscope and set the output to 1 Vp-p and 1 kHz sine wave. Use a BNC Tee connector so that the sine wave can be seen on the oscilloscope, and applied to the input of the circuit.

3. Connect the output of the circuit to the other channel on the oscilloscope, and apply power. There should be an in-phase quasi-square wave at the output (**save the oscilloscope screen for both input and output waveforms**). Note that the output swing will not go all the way to $\pm$ 12 volts. This is due to the output configuration within the op-amp. [Note: If a full-swing output is desired, the designer would select a "rail-to-rail" CMOS op-amp which has this capability. This is often done when a 0 to + 5 Volt swing or lower is needed for logic compatibility.]

4. Turn off the power and change the circuit to that of Figure 4. Turn on the power and slowly change the input potentiometer and observe the output state change with your scope.

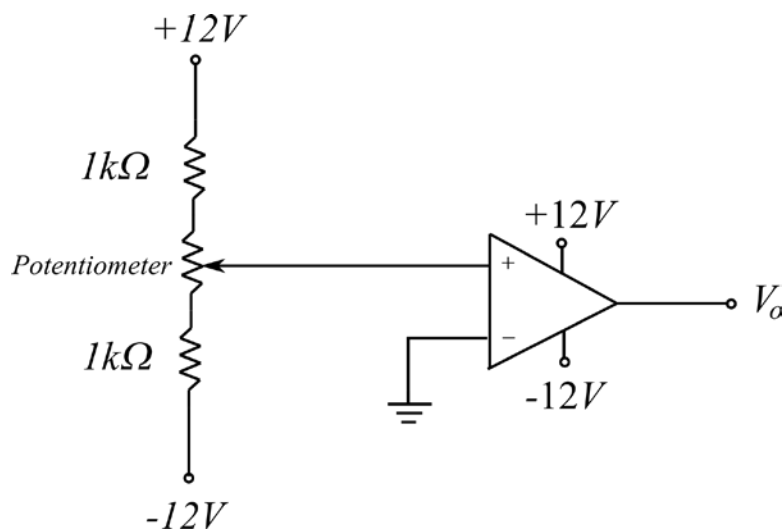**Q4.** **Can you see any erratic behavior?**

Figure 4: Noninverting comparator test circuit.

5. With the power off, construct the Schmitt trigger circuit of Figure 5. Use the input potentiometer as you did in Step 3 while monitoring the output. You should see clean switching unless you have a worn pot with discontinuous spots across it range.

6. Slightly change the input voltage (adjusted by the potentiometer) and measure the values of V_{TH} and V_{TL} and **sketch the Hysteresis of the circuit as in Figure 3.**
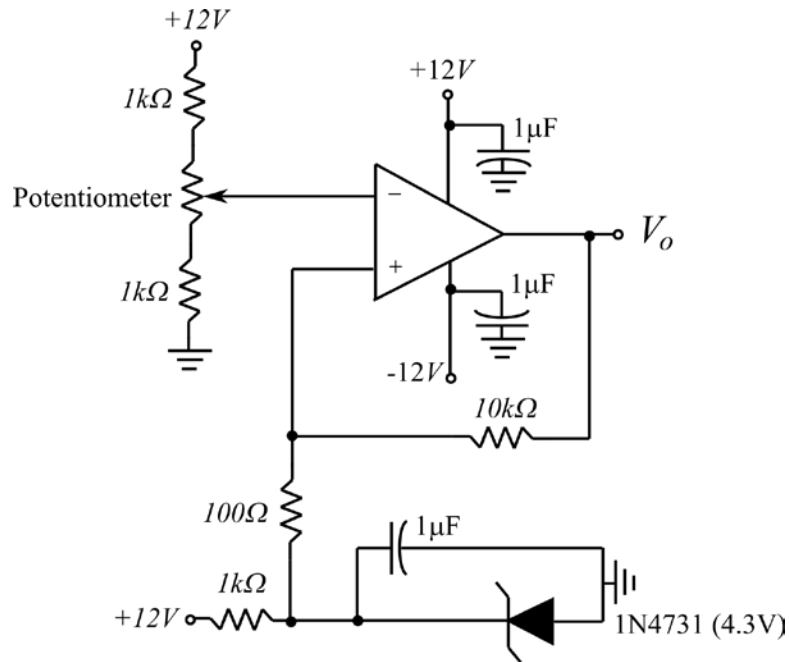
Figure 5: Inverting Schmitt Trigger test circuit.

COMMENTARY

The Schmitt trigger is used in many applications including waveform generators. Take a look at some of the applications in the textbook. Schmitt triggers are also available in some logic families, although the hysteresis cannot be varied. Make sure that you can identify both inverting and non-inverting comparator sand Schmitt triggers.