EE 255
ELECTRONICS I LABORATORY
EXPERIMENT 8
APPLICATIONS OF OPERATIONAL AMPLIFIERS

OBJECTIVES

In this experiment you will begin investigating some of the most important applications of the op-amp.

INTRODUCTION

In Electronics I and perhaps, in previous courses, you learned how the operational amplifier (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, we will investigate an active bandpass filter, the comparator and the Schmitt trigger. Parts of this experiment were suggested by the textbook author, Dr. D. A. Neamen.

PRELIMINARY TASKS

Before lab, read through this experiment and derive or look up any additional equations you might need to design the circuits in this lab. If you are familiar with the parts in the lab, you can go ahead and calculate the values needed ahead of time.

EXPERIMENT – PART I – THE ACTIVE BANDPASS FILTER

Figure 1 shows one of many possible bandpass filters that can be synthesized with an op-amp. With this design, you can not only supply gain, but you can also 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, setting $C = 0.0047\mu\text{F}$ might be good start.

Next, calculate the R_2 needed to get the desired bandwidth, knowing that:

$$BW = \frac{1}{\pi C R_2}$$

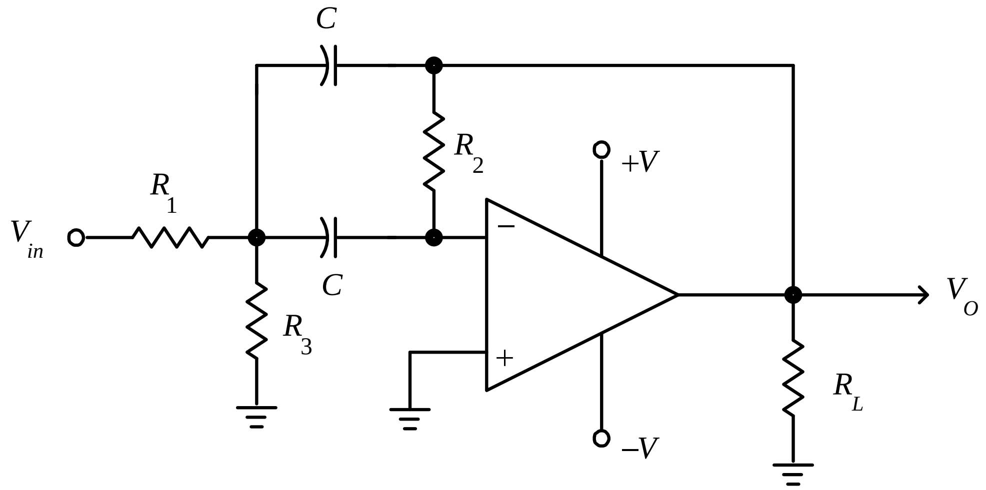

Fig. 1. An Op-Amp Bandpass Filter.

Now, you can calculate the value needed for R_1 to get the required gain at the center frequency:

$$A_V = R_2/(2R_1)$$

Resistor R_3 can be found, knowing that the 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.

PROCEDURE

1. Design a bandpass filter with a center frequency of 2 kHz and a bandwidth of 200 Hz. Let the center frequency gain by 10. Use the closest values you can find in the lab and recalculate what the actual center frequency, bandwidth and gain should be.

2. Breadboard the circuit of Fig. 1, using your chosen values. Use a ± 12 volt supply. A 741 op-amp can be used. Check with the data sheet or your lab instructor to make sure you have the correct pin assignments. R_L can be 3.3k.

3. Using the signal generator and the oscilloscope, determine the circuit's center frequency, 3dB points (i.e., the bandwidth) and the gain at the center frequency. You could also take a few more values and plot the response vs. frequency. How do they compare with your calculated values? Explain any major differences.

4. Now, change R_3 to lower the center frequency from 2kHZ to 1kHz. Repeat the measurements of Step 3. How do these compare with the calculated values?

5. Question: What advantages do you see in this bandpass filter as compared to the LC filter like the one you designed in Experiment 1 (Resonant Circuits)?

EXPERIMENT – PART II – THE COMPARATOR AND SCHMITT TRIGGER

Often, we want a circuit that compares two voltages and indicates which one is larger. This circuit is called a **comparator**. 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 circuits is nonlinear, and different methods are needed for analysis.

In this circuit, if the input voltage is greater than the reference voltage, the output swings to positive saturation. If the input is lower the V_{REF}, the output swings to negative saturation. By observing the "state" of the output, you (or a circuit) can determine whether a threshold has been reached or not. If the references voltage is set to zero (ground), this circuit is called a **zero-crossing detector**, since it changes state each time the input crosses zero. You can use this circuit 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 just reversing the input connections.

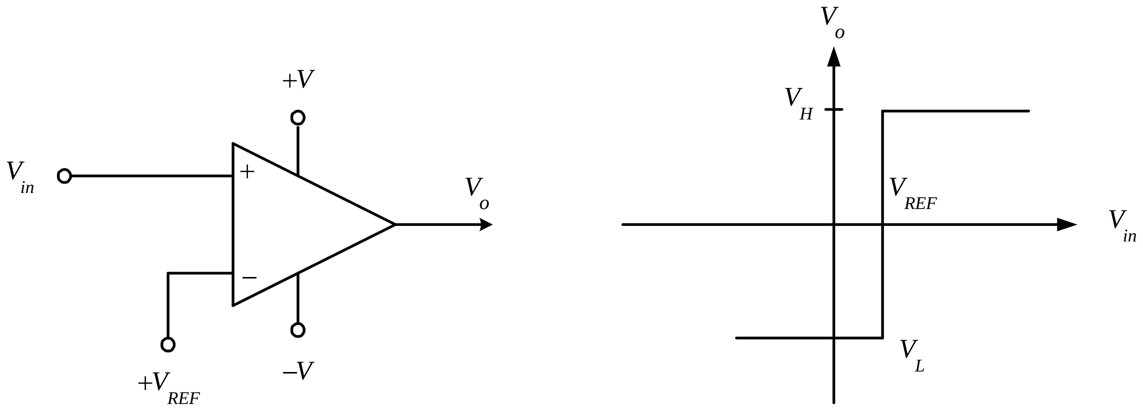

Fig. 2. The Non-inverting Comparator and Its Transfer Characteristic.

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.

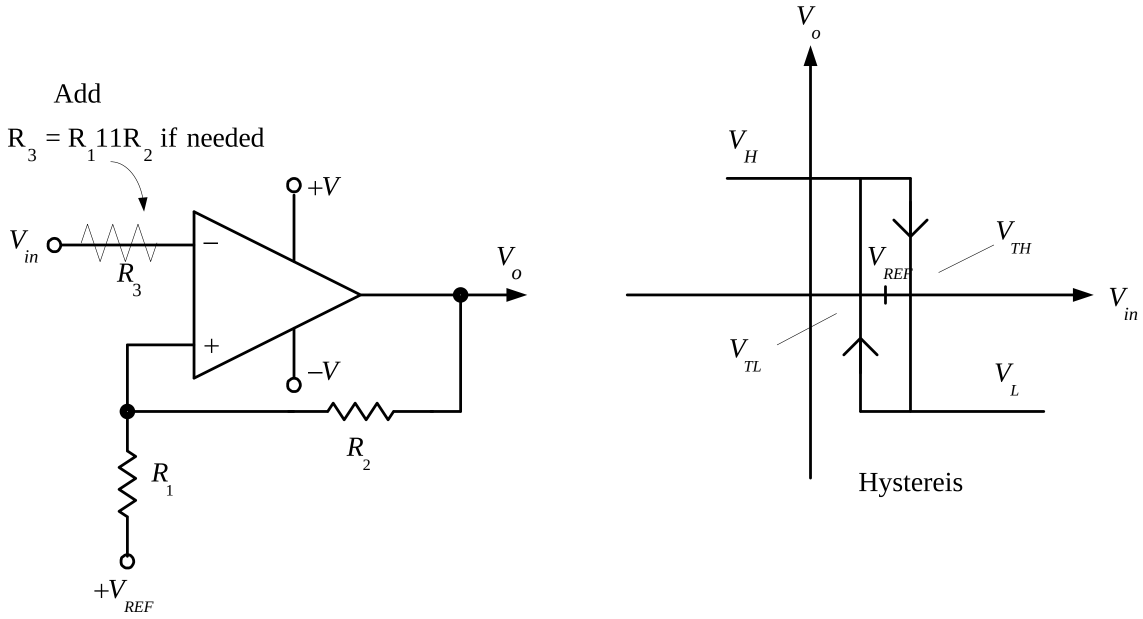

Fig. 3. The Inverting Schmitt Trigger and Its Transfer Characteristic.

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.

PROCEDURE

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

2. Apply power. With the signal generator set at a very low amplitude, apply a 1 kHz sine wave to the input. You should see an in-phase quasi-square wave at the output. Note that the output swing will not go all the way to ± 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.]

3. Turn off the power and change the circuit to that of Fig. 4. Turn on the power and slowly change the input pot and observe the output state change with your scope. Can you see any erratic behavior?

4. With the power off, construct the Schmitt trigger circuit of Fig. 5. Use the input pot 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.

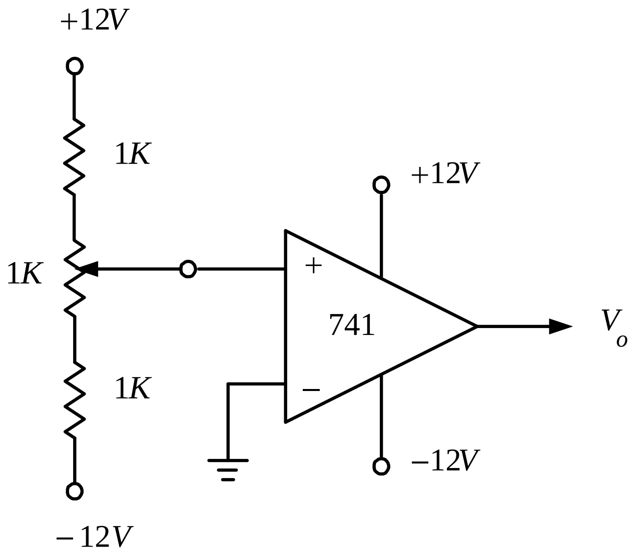

Fig. 4. Noninverting Comparator Test Circuit.

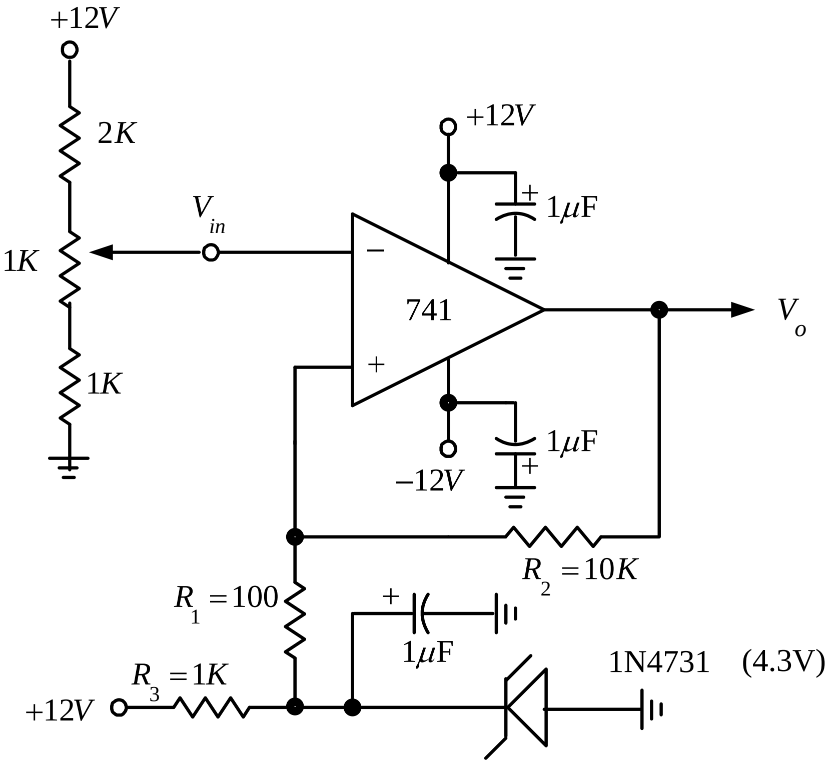

Fig. 5. Inverting Schmitt Trigger Test Circuit.

COMMENTARY

The Schmitt trigger is used in many applications including waveform generators. You will want to take a look at some of the applications in your 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.