# Lab Procedure

## 1. Objective
This project will show the versatile operation of an operational amplifier in a voltage comparator (Schmitt Trigger) circuit and a sample and hold circuit.

## 2. Components

| Qty | Device |
|---|---|
| 1 | 741 Op Amp |
| 1 | 2N7000 MOSFET |

## 3. Introduction
### 3.1. Comparators and Schmitt Triggers
A voltage comparator is a two-input circuit that compares the voltage at one input to the voltage at the other input. Usually one input is a reference voltage and the other input a time varying signal. If the time varying input is below or above the reference voltage, then the comparator provides a low or high output accordingly (usually the plus or minus power supply voltages). The ideal operation of a comparator is shown in Figure 1(a). If $V_{ref}$ is zero, the comparator can be used as a zero-crossing detector. If $V_{ref}$ is not zero, the comparator can be referred to as a level detector. The comparator is the basis for most A/D (analog-to-digital) circuits. In these A/D circuits, the reference voltage is gradually changed by a counter and compared to the analog input voltage until it equals the analog input voltage.

The Schmitt trigger circuit is a comparator that uses hysteresis to help reject noise. Figure 1(b) shows the input versus the output characteristic of the Schmitt trigger circuit. As the diagram shows, there is a buffer zone about the reference voltage to prevent small perturbations in the input signal from causing the comparator to flip continuously. Because of the buffer zone, the comparator no longer changes state from high to low at the same voltage that it changes from low to high. Hysteresis in the Schmitt trigger ensures that the output signal is the same frequency as the input signal for noisy input signals that may cross the threshold several times while rising and falling. The Schmitt trigger is especially useful for slowly varying and noisy input signals. The op amp in the comparator circuit in Figure 2 allows for flexibility in setting the gain, thresholds, and reference voltage.

### 3.2. Sample-and-Hold Circuits
For an analog signal to be processed by a digital system, it must be converted to a digital signal (discrete-time and discrete-amplitude). A sample and hold circuit makes it easier for us to record

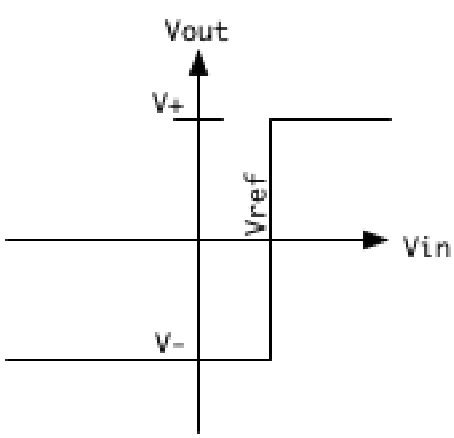

Figure 1(a). General comparator transfer function.

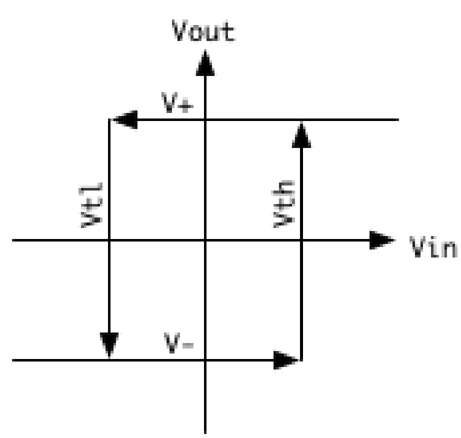

Figure 1(b). Comparitor transfer function with hysteresis.

the amplitude at each sample by holding the signal for a short period of time at a given amplitude. Two important properties of a sample-and-hold circuit are the highest possible sampling rate and how constant the sample remains during the hold interval.

The sample and hold circuit shown in Figure 3 uses an op-amp in the non-inverting configuration and a MOSFET. The square wave input determines the sampling rate and the length of time to hold the sample. The MOSFET acts as a switch, which is on during sampling and off during the hold time. When the square wave is positive, the MOSFET is on and circuit samples the input signal by passing it to the op-amp and charging the capacitor. When the square wave is negative, the circuit is in the hold mode. In this mode, the MOSFET turns off and the output is the value the capacitor charged to during the previous sampling interval.

### 3.3. Oscilloscope Triggering

Ever wonder what the trick is to making your waveform "lock up" so you can see it, instead of having it run across the screen continuously? The secret is the trigger circuit. The trigger circuit monitors the signal and looks for it to cross a voltage threshold. When it does, it starts drawing the wave on the screen—thus ensuring all of the traces line up perfectly on top of each other, creating a nice image on the screen. There are two key inputs to the trigger circuit that define its operation: the *trigger source*, and the *trigger level.*

The *trigger source* is the waveform that the trigger circuit monitors. If you are using multiple inputs to the scope, you must pick one to monitor for triggering. You can also use a separate input for the trigger source. You may want to use an external trigger source if you are looking at a very low amplitude or a very noisy signal. If your source is a function generator, there is a separate 0-5 V square wave output that is synchronized with the function generator output. This makes a very convenient trigger source. You can also trigger off of the ac line input, which is convenient when monitoring a signal derived from the power lines.

The *trigger level* is the threshold at which the oscilloscope trips and starts drawing the waveform. This is typically set with a knob on the front of the oscilloscope, and is shown on the screen (usually in a corner). After setting your trigger source, adjust this knob to a reasonable level and leave it there. You should now have a stable display on your screen.

## 4. Prelab Design Project

Please show all work, include your schematics, and sketch or print waveforms. Label all schematics and waveforms with name, date, axis scale, conditions, and any important information (peak voltage, cutoff frequency, etc.).

**4.1.** **(15 point)** Derive the equations for the comparator input threshold voltages ($V_{TL}$, $V_{TH}$) in terms of $V_{out}$, $V_{ref}$ and the circuit components. Show all work.

**4.2.** (10 point) Modify the above equations for a reference voltage ($V_{ref}$) equal to zero. Show all work.

**4.3.** (25 point) Design a comparator circuit based on Figure 2 such that the $V_{TL}$ = −1 V, $V_{TH}$ = +1 V, and $V_{ref}$ = 0 V. Assume that $V_{out,high}$ = 14.7 V and $V_{out,low}$ =-14.7 V. Verify the comparator design with LTspice. Use ±15 V supplies for the op-amp. Sweep the DC input voltage from −5 V to +5 V and from +5 V to −5 V.

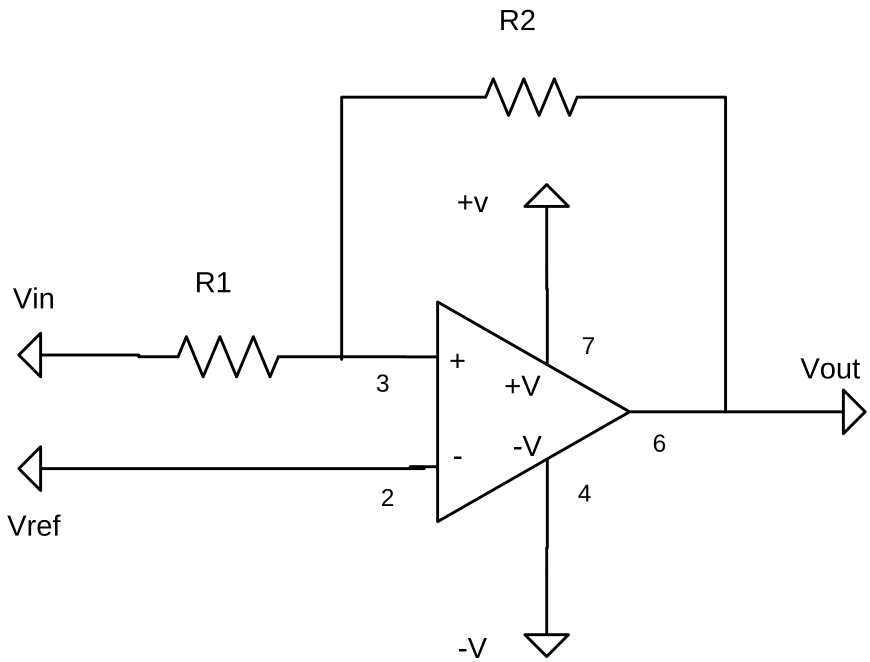

Figure 2: Comparator with hysteresis

**4.4.** (25 point) Use LTspice to find the slew rate and maximum frequency for the comparator above. Use a **sine** source with an input voltage of 2 $V_{pk}$ and a frequency of 3 kHz. Assume the minimum time at the high or low state is 0.5 µs. Include a plot with the input and output waveforms and mark the measurement point on the plot.

**4.5.** (25 point) Verify the operation of the sample-and-hold circuit in Figure 3 with LTspice. Use a time domain analysis to plot the input and output. Use an 2N7000 for the MOSFET, Rin = 100Ω, and set C to 1 µF. Use a 1 $V_{pk}$ **sine** at 60 Hz for the input waveform and use a 1 kHz, 20 $V_{p-p}$ square wave (use **pulse** Vinitial =-10V, Von = -10V, Ton = 0.5ms, Tperiod =1ms, Trise = 0, Tfall =0, Tdelay = 0, and series resistance = 50Ω) as the gate input. Use ±15 V supplies for the op-amp. Find the time delay from input to output and mark it on the plot.

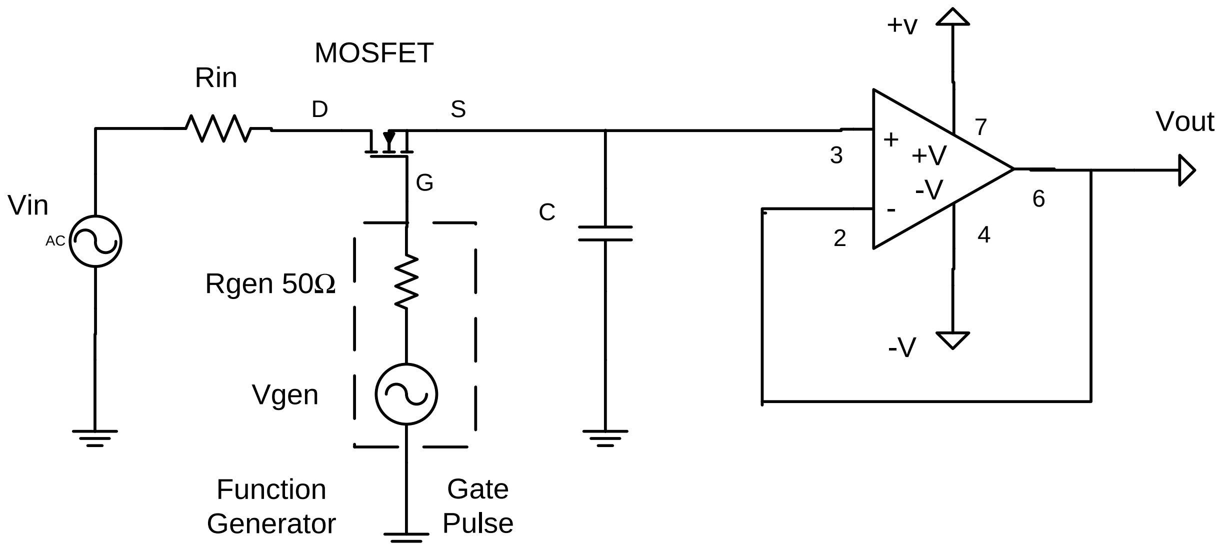


Figure 3: Sample and Hold

## 5. Lab Procedure

**5.1.** Construct the comparator circuit in Figure 2. Set the reference voltage to zero and the thresholds to ±1V. Use ±15V supplies for the op-amp (741). Be sure to bypass the power supplies with a 4.7 nF capacitor across the Op Amp (pin 4 to pin 7). **No printouts.**

**5.2.** Set the function generator to generate a 10 $V_{p-p}$ triangle wave and feed it into the comparator. Record the high and low threshold voltages and save the input and output waveforms. **Two printouts.**

**5.3.** Now use a 2 $V_{pk}$ sine wave at 3 kHz as the input. Monitor the input and output waveforms on the oscilloscope. Measure the slope of the line between the low to high output limits and the high to low output limits. Save this waveform and use this waveform and data to find the slew rate. Calculate the maximum frequency that the comparator can operate at if the minimum hold times at high and low are 0.5 μs. **One printout.**

**5.4.** Construct the sample and hold circuit in Figure 3. Use a 100 Ω resistor for $R_{in}$ and a 1 μF capacitor for C. *Remember that the Rgen = 50 Ω resistor is internal to the function generator and that you do not actually need to include it in your circuit.* Drive the gate of the MOSFET (2N7000) with a 1.2 kHz square wave from the function generator that has an upper limit of +10 V and a lower limit of –10 V. For the input signal source, $V_{in}$, use the VARIAC with the step-down transformer. Adjust the VARIAC until the secondary voltage from the transformer is 1 $V_{pk}$. Use ±15 V supplies for the op-amp (741). Be sure to bypass the power supplies with 4.7 nF capacitors.

Save the input and output waveforms on the oscilloscope. Be sure to trigger using the ac line input—ask your instructor if you need help with this. Do the two waveforms match? Be sure to note any voltage offset and time delay on your printout. **Two printouts.**

## 6. Postlab Questions

**6.1.** Determine the maximum frequency at which the Schmitt trigger can operate from the slew rate data collected. Assume the minimum time at high or low is 0.5 μs. What is the maximum frequency using the slew rate specification from the data sheet?

**6.2.** For the sample and hold circuit, determine the approximate decay rate of the capacitor voltage in mV/s during the hold mode for the data. Calculate the decay rate by using the input bias current from the data sheet of 80 nA. Remember that $i_c = C\frac{\mathrm{d}v}{\mathrm{d}t}$

**6.3.** What is the maximum hold time for the sample-and-hold circuit if the capacitor voltage cannot change by more than 10%? Assume initial capacitor voltage is 1 V.

**Data Sheet**

**Name:**______________________ **Lab Date:**______________ **Grade:**____________

**Partner (s):**__________________________________________________________________

Remember to include units for all answers and to label all printouts. There are a total of six (6) printouts in this lab. *Only one set of printouts is required per group.*

**5.1.** Schmitt trigger comparator circuit. **No printouts.**

**Design Values:** **$R_1$:** ________ **$R_2$:** ________

**Measured Values:** **$R_1$:** ________ **$R_2$:** ________

**5.2.** Schmitt trigger with a triangle wave input. **Two printouts**.

**High Threshold:** **$V_{TH}$:** ________

**Low Threshold:** **$V_{TL}$:** ________

**5.3.** Schmitt trigger with a sine wave input. **One printout**.

**Slew Rate, low-to-high:** ________

**Slew Rate, high-to-low:** ________

**5.4.** Sample-and-hold circuit. **Two printouts.**

**Delay time from input to output:** ________

**Change in amplitude from input to output:**

**Decay rate during hold time:** ________

**Postlab Questions**

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