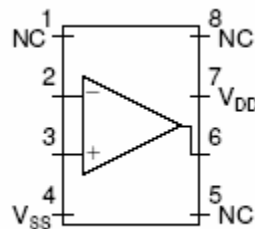


MASSACHUSETTS INSTITUTE OF TECHNOLOGY
6.071 Introduction to Electronics, Signals and Measurement
Spring 2006

Laboratory 22: Comparators and Schmitt Trigger

In electronics it is very common to compare a signal voltage level to some known reference level. The operational amplifier is an ideal device for performing this function. In this lab we will build and test various circuits for performing signal level comparisons. All of our circuits will be again based on the LF356 op-amp. The pinout of the 356 is:



Non-Inverting Comparator

In this first experiment we will examine the open loop behavior of the operational amplifier.

First, let's build the circuit below.

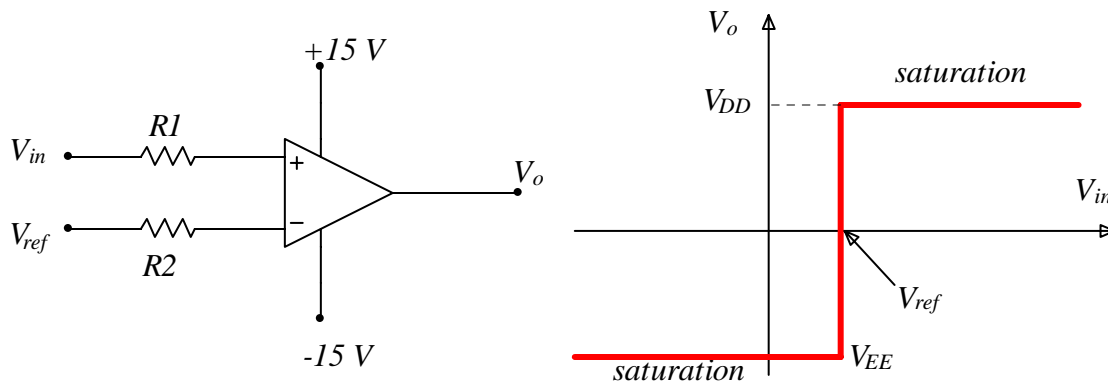


Fig. 1: Non-inverting Comparator and its voltage transfer characteristic.

Use the Variable power supply for supplying V_{ref} . The source voltage V_{in} will be supplied by the Analog output pin labeled DAC0.

For interfacing to your data acquisition system make the following connections:

ACH4 in order to measure V_{ref}

ACH5 in order to measure V_{in}

ACH3 in order to measure V_o

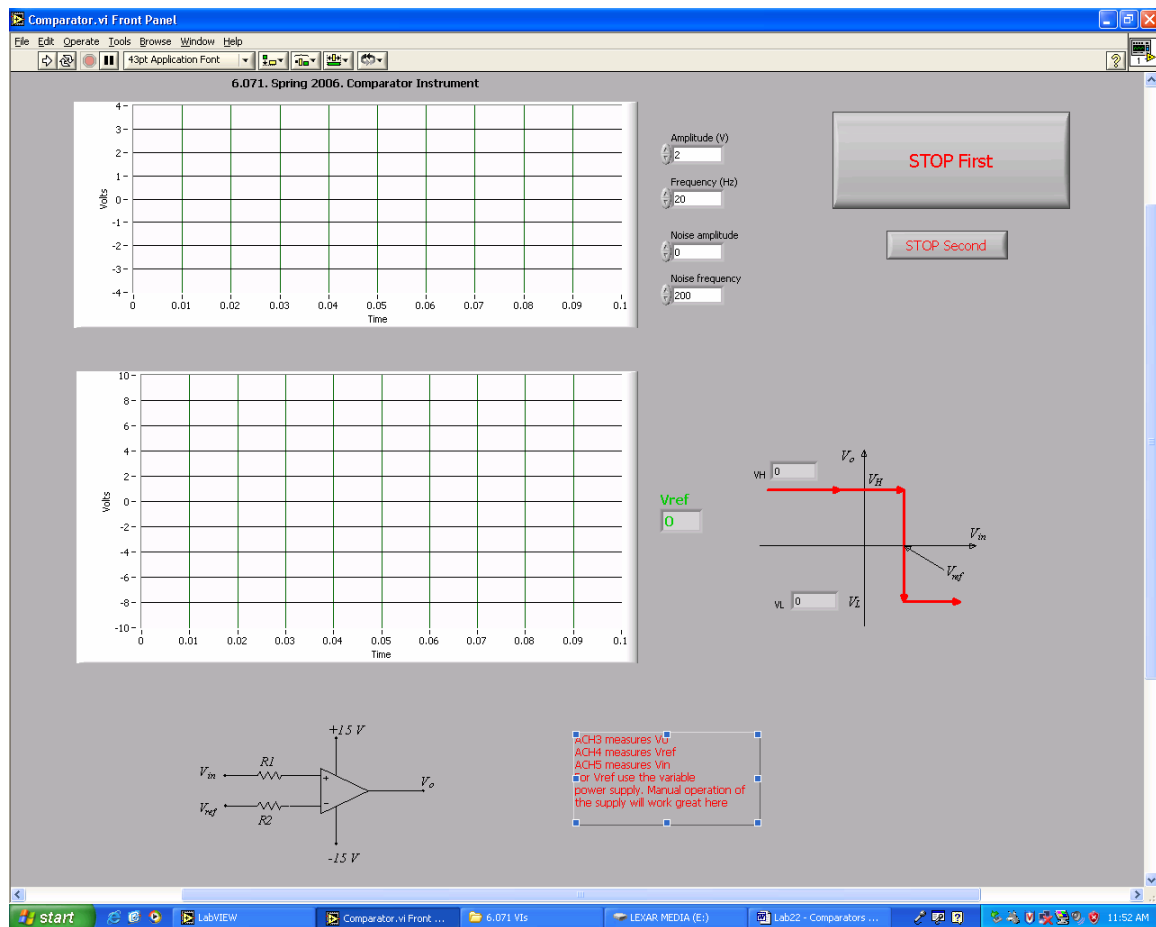
Use the +15V and the -15V DC to power your amplifier.
Before proceeding with the experiment answer the following questions:
How is V_o related to V_{in} and V_{ref} ?

Why is this circuit called a non-inverting comparator?

What do you think is the role of resistors $R1$ and $R2$?

Next let's run the experiment and observe the behavior of this circuit.

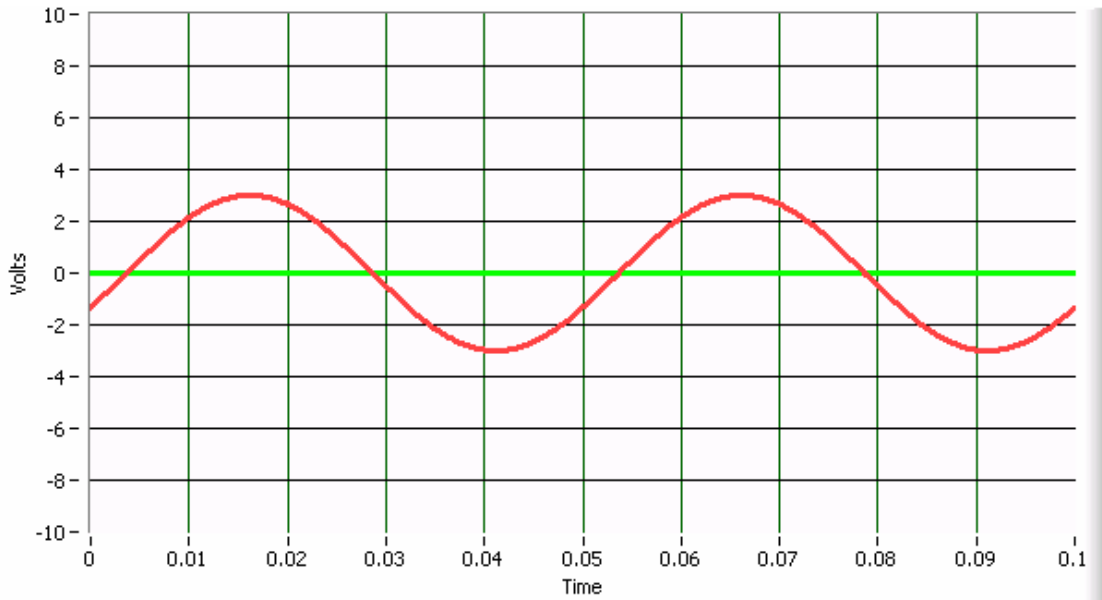
Download the virtual instrument called **Comparator** from the class web site.
Note that you will provide V_{ref} from the Variable Power Supply of your system while V_{in} is provided by the Analog Output pin labeled DAC0. The instrument looks like:



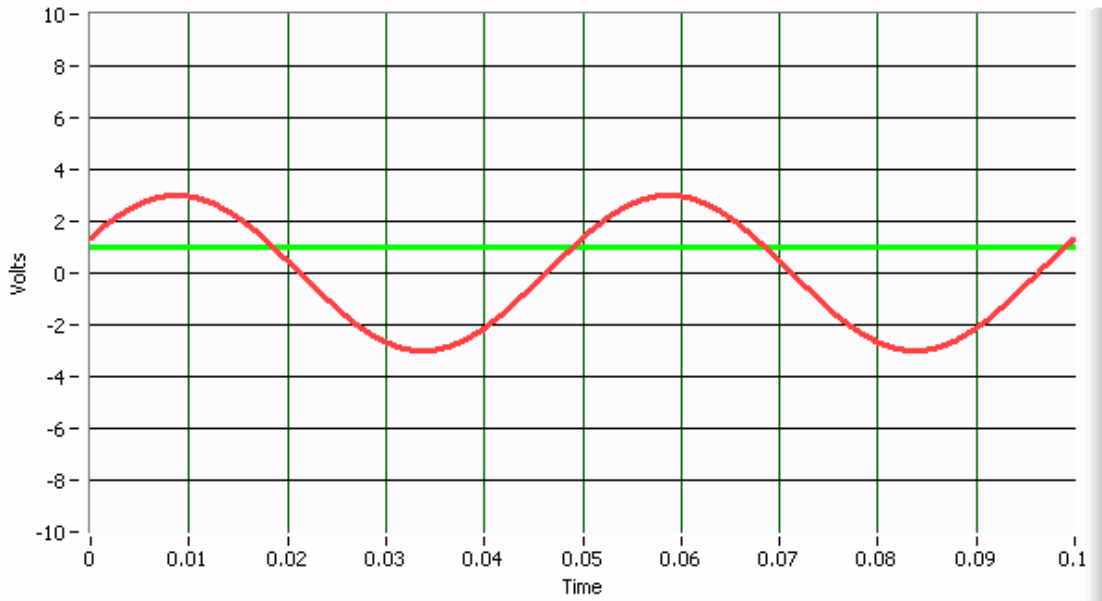
Courtesy of National Instruments. Used with permission.

Set $V_{ref} = 0$ Volts and for V_{in} use a sine wave with an amplitude of 3 V and frequency of 20Hz. Observe the output V_o . Draw the form of V_o on the graph below. Indicate the maximum and minimum values for V_o on the graph.

What do these maximum and minimum values correspond to?



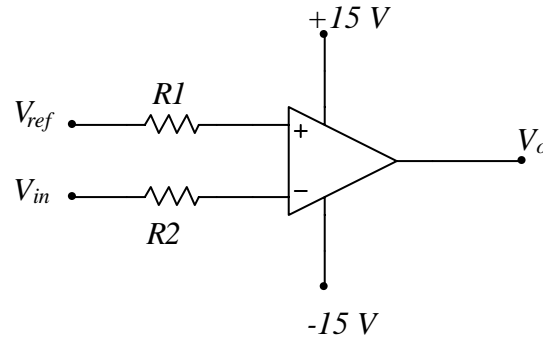
Now change V_{ref} to +1V. What is the output in this case? Draw the output on the graph below.



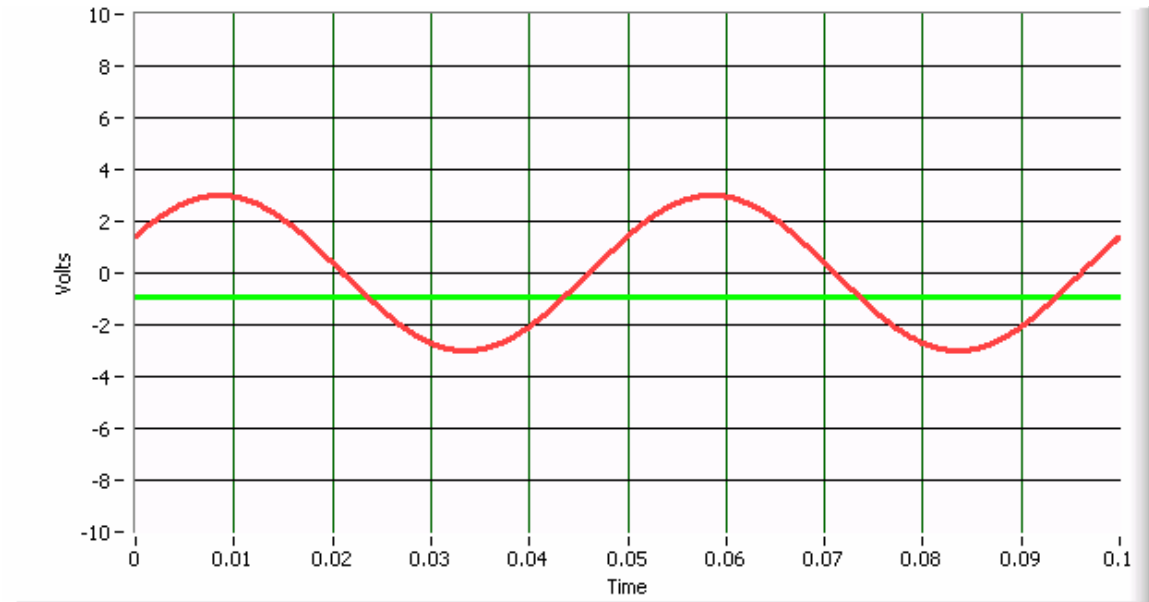
Now let's use our comparator to adjust the duty-cycle of the square wave output (the voltage V_o). From your experiment determine the value of V_{ref} that results in a square

wave output with a duty-cycle of 20% . If you wanted a duty cycle of 80% what would you do?

In addition to the non-inverting comparator, the open loop characteristics of the op-amp may also be exploited in the inverting comparator configuration. A typical inverting comparator circuit is shown below.

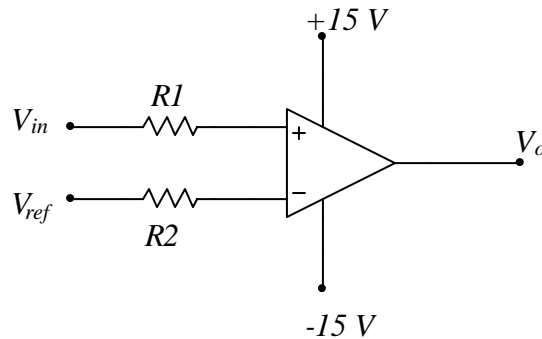


For this inverting case draw the response of the circuit on the graph below. (The thick horizontal solid line represents V_{ref} .)



Comparator and noise.

Next we will look at the response of the comparator in the presence of noise. The circuit is still the same non-inverting comparator as the one shown on Fig. 1., reproduced here for convenience.



Now the signal V_{in} has some form of noise associated with it and it might look like the one represented by the jagged line shown on Fig. 3.

A closer look at the signal shows that there are multiple times, within 1 cycle, that it goes above and below 1 Volt, the reference voltage in this case. Each of these transitions will be detected by the comparator and will be represented as a transition at the output. For the example below draw the expected form for the output.

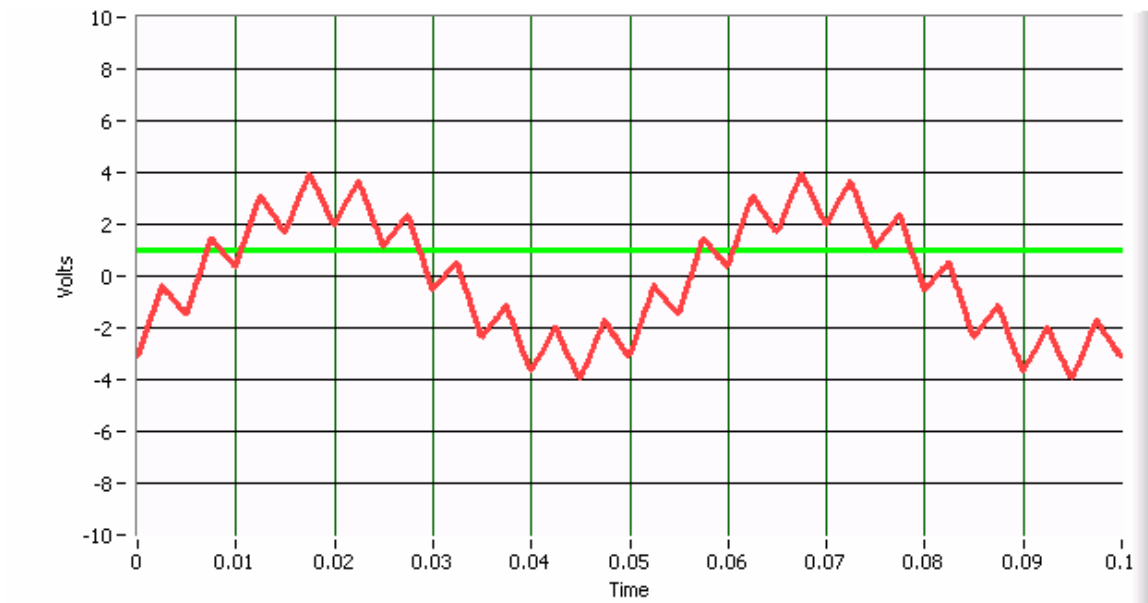
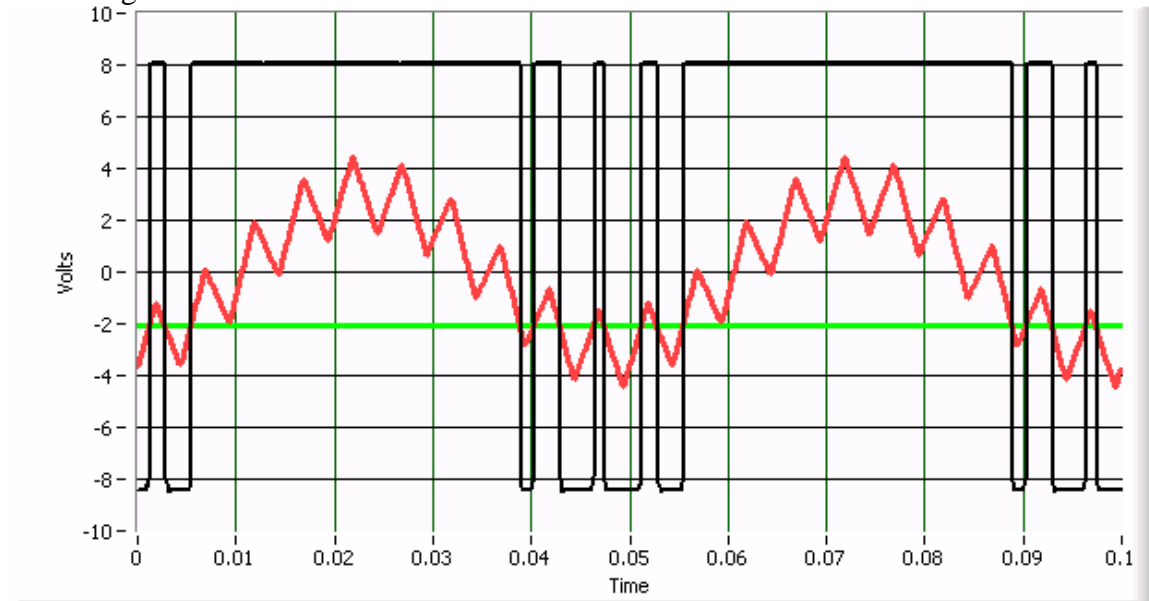


Figure 3. A signal with noise and a reference voltage.

Your **Comparator** virtual instrument is designed to provide a signal with simulated noise for the purpose of this laboratory. You can introduce the “noise” into your input signal by entering the desired noise amplitude.

Once you have generated your “noisy” signal the response of the comparator will look something like:



Notice the transitions resulting from the signal noise. Vary the reference voltage V_{ref} and observe the response of the circuit.

What happens when V_{ref} becomes greater than the maximum value of V_{in} ?

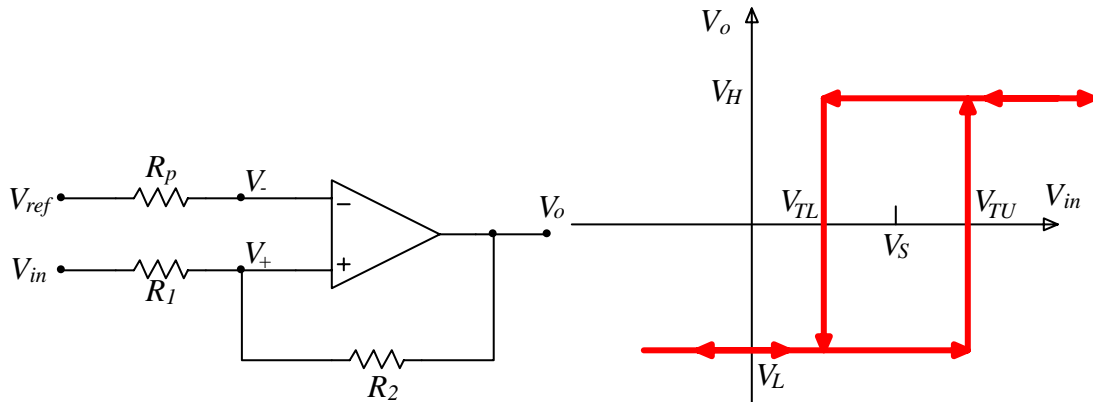
What happens when V_{ref} becomes less than the minimum value of V_{in} ?

If your application required the detection of a signal transition above or below a certain value the open-loop comparator circuit would be a useful as long as the signal is completely free of any noise. In the presence of noise, which is the case in all practical situations, the comparator exhibits unacceptable behavior. The solution to this problem is provided by positive feedback.

Schmitt Trigger. Positive Feedback

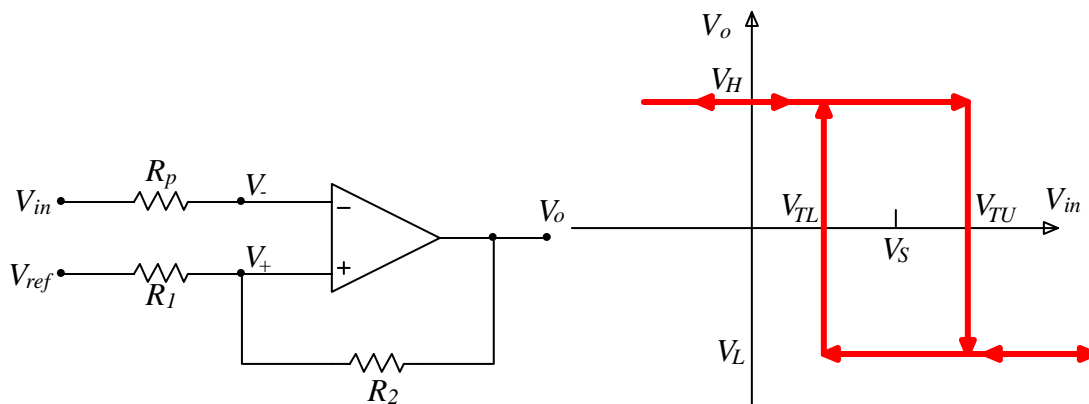
The Schmitt Trigger circuit, also called a bistable multivibrator, uses positive feedback with loop gain greater than 1 to produce a bistable (High – Low) response. The Schmitt trigger may be designed to be inverting or non-inverting. These two circuits with their corresponding characteristics are shown below.

Non-inverting Schmitt Trigger



$$V_S = \left(1 + \frac{R_1}{R_2}\right) V_{ref}, \quad V_{TU} = V_S - V_L \frac{R_1}{R_2}, \quad V_{TL} = V_S - V_H \frac{R_1}{R_2}$$

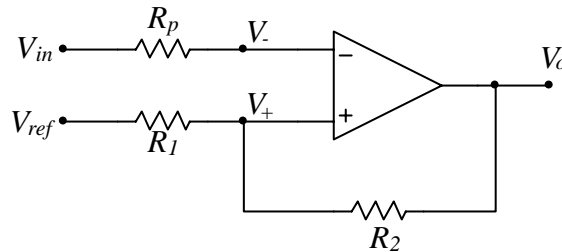
Inverting Schmitt Trigger



$$V_S = V_{ref} \frac{R_2}{R_1 + R_2}, \quad V_{TU} = V_S + V_H \frac{R_1}{R_1 + R_2}, \quad V_{TL} = V_S + V_L \frac{R_1}{R_1 + R_2}$$

For our experiment we will work with the inverting Schmitt Trigger configuration.

Construct the following circuit on your protoboard. Note that this may be accomplished with minor changes to your open loop comparator circuit used before.



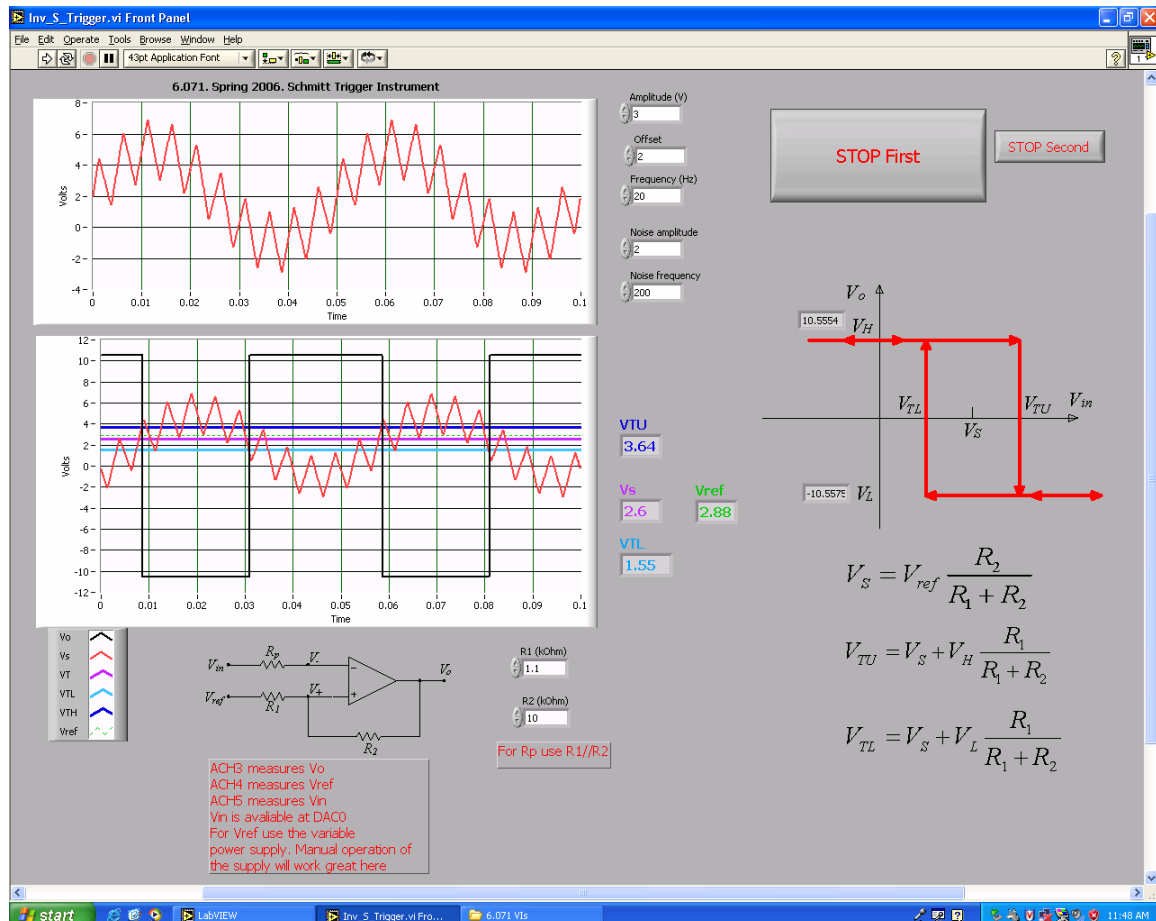
Again the connections to your protoboard are the same as the comparator case.

ACH4 measures Vref

ACH5 measures Vin

ACH3 measures Vo

Now download the virtual instrument called **Inv_S_Trigger** from the class web site. It will look like:



Courtesy of National Instruments. Used with permission.

This instrument is constructed in order to give you the opportunity to experiment with all parameters that characterize the behavior of the trigger circuit.

The width of the hysteresis loop determines the noise immunity of the trigger circuit. The position and width of the hysteresis may be designed for the problem of interest.

Have some fun, vary the circuit parameters and the signal characteristics and observe the output.

With $R_1=1k$ and $R_2=10k$, run the experiment with a clean signal (no noise) and with $V_{ref}=1$ Volt. You might also need to adjust the amplitude and the offset of input signal V_{in} . Observe the behavior of the circuit and determine V_s , V_{TU} and V_{TL} . Compare with measurement. Do you see any differences?