# Laboratory 8 : Comparators and Applications

## Concept

Operational amplifiers can be used as comparators, that is, the output will be either $+V_{cc}$ or $-V_{cc}$ when $V_+ > V_-$ or vice versa. Thus, when an input signal becomes larger than a fixed reference signal, the state of the opamp changes. However, since noise may be present, a Schmitt trigger circuit is need to provide adequate hysteresis. A comparator can also form the core of a monostable or astable multivibrator.

## Helpful hints and warnings

Operational amplifiers are integrated circuits (consisting of many internal transistor, diodes, resistors and capacitors) which require a bipolar power source. It is imperative that symmetric positive and negative potentials be applied to the + and - power pins, such as ±12.0 V or ±14.7 V. The power supply should provide ±15 V or less. Check the specification sheet for the absolute maximum power supply potential. Unlike the passive devices encountered in previous laboratory experiments, opamps can be destroyed by the application of excessive potential differences. Remember to connect the power supply ground to the oscilloscope ground. Besides the limitation on the power pins, the two signal inputs also have a limitation on the maximum applied potential. Check the specification sheet. The output of an op amp can be sensitive to changes in the potentials provided by the power supply, $\pm V_{cc}$. It is generally wise to include 100 nF capacitors between each power supply line and the system ground to dampen any such variations.

When measuring the response or gain function $A(\omega)$ for and opamp circuit (both amplitude and phase), one usually triggers the oscilloscope with the input signal. However, when the gain is high, the input signal needs to be small, and triggering can become unreliable. Switching the trigger source from the input to the output signal might make triggering more reliable, but an error can occur in measuring the relative phase when the trigger source is changed. The solution to this problem is to use the *pulse* or *clock* or *TTL* square-wave output of the function generator to trigger the oscilloscope. This signal is usually 0 to 5 V, and should be connected to the external trigger input on the scope. Be sure to set the trigger source switch to external.

If you need to create an input signal or DC level using a potential divider, be sure that the *source resistance* of the divider is at least 10 times less than the *input resistance* of the entire opamp circuit. If this condition is not satisfied, then the source you have created will be distorted by the opamp circuit.

# Experiments:

## 7.1 Simple Comparator

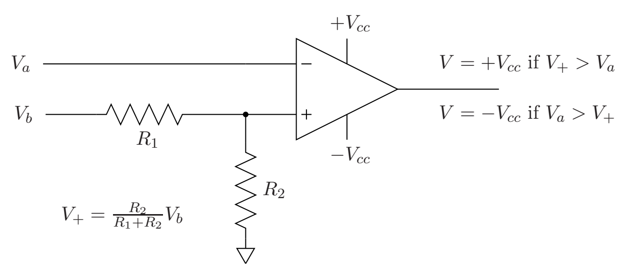
**Instructions:**

a. Build this circuit using $V_b = \pm V_{cc}$ and values of $R_1$ and $R_2$ such that $V_+$ lies within the range of variation of the input signal $V_a$. You can use a variable resistor (potentiometer or pot) for $R_1$ or $R_2$.

b. Observe and record the response of this circuit using a noiseless, bipolar sawtooth waveform from the function generator as the input signal $V_a$. Adjust the trigger level $V_+$ by varying one or both of the resistors for the two cases $V_b = +V_{cc}$ and $V_b = -V_{cc}$.

c. Observe and record the response using a 1 kHz sawtooth with about 10% 100 kHz "noise" (this is amplitude modulation, with the frequency of modulation at 100 kHz and the amplitude of modulation set to 10% of the amplitude of your sawtooth waveform). Repeat with 10% 10 kHz "noise".

d. Be sure you can answer all of the questions with the data collected and notes taken – it is better to be over-detailed then not have enough to answer the questions!




**Questions to answer:**

a. Describe the change in output of the circuit when the trigger level $V_+$ is varied in instruction b.

b. What is the uncertainty in the switching time for the 10 kHz and 100 kHz noise conditions?

c. Why is the 100 kHz noise less of a problem?

# 7.2 Schmitt Trigger

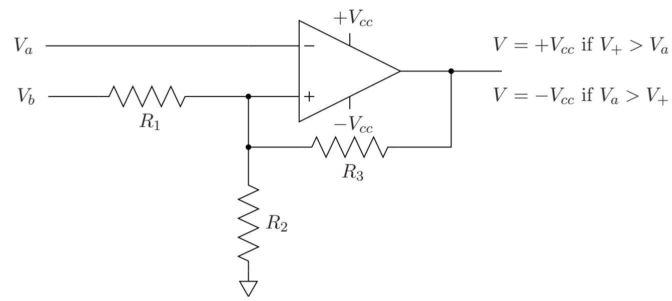
**Instructions:**

a. Build this circuit using $V_b = +V_{cc}$ and a variable resistor (potentiometer or pot) for $R_3$.

b. Observe and record the response of this circuit using a noiseless, bipolar sawtooth waveform from the function generator as the input signal $V_a$.

c. Set the oscilloscope to XY mode, using $X = V_a$ and $Y = V_{out}$. Observe the hysteresis loop as you vary its width by changing the value of $R_3$. Make careful measurements (see the questions).

d. Observe and record the response using a 1 kHz sawtooth with about 10% 10 kHz"noise" as the input signal $V_a$.




**Questions to answer:**

a. Verify that the width of the loop in Volts agrees with the theoretical value below (instruction c).

$$V_+^{(low)} = \frac{R_{123}}{R_1} V_b + \frac{R_{123}}{R_3} V_{cc} \text{ and } V_+^{(high)} = \frac{R_{123}}{R_1} V_b - \frac{R_{123}}{R_3} V_{cc} \ ,$$

where $\frac{1}{R_{123}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$.

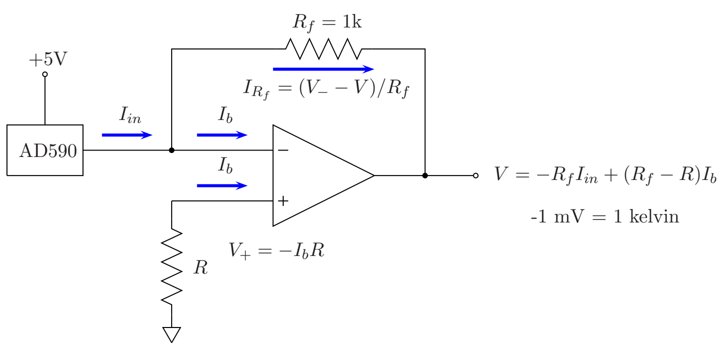
b. Is the uncertainty in the switching time less than that of the simple comparator circuit?

## 7.3 Application of the Schmitt trigger: controlling the temperature of a resistor

**Background:**
The Schmitt trigger circuit can be used to control the temperature of an object. In this case, a physically small resistor can be heated using the output of the op amp. A signal from a temperature sensor can be used as one input to the trigger, and a fixed reference potential can be applied to the second input. When the temperature exceeds a desired temperature $T_\circ$, the output of the op amp switches, and power to the object is turned off. When the temperature falls below the desired temperature $T_\circ$, the output of the op amp switches again, and power is applied to the object. A reasonable range of hysteresis is $\pm 2°$C, that is, power is applied when $T < T_\circ - 2°$C, and power is turned off when $T > T_\circ + 2°$C.

**Instructions:**

a. Design and build a circuit which measures the temperature of a small resistor using the AD592 and a transimpedance amplifier. Establish good thermal contact between the AD592 and the heated resistor. See lab 6 for more instruction.




b. Now design and build a Schmitt trigger circuit which will use the output of the transimpedance amplifier as input and provide a switching point of 40°C with a hysteresis range of $\pm 2°$C.

c. Using the output power of the Schmitt trigger is insufficient to heat a physically small resistor. The instructor will provide a simple transistor circuit to provide more current. You will need to use a diode on the output of the op amp to allow the current to flow only when either $V_{out} = +V_{cc}$ or $V_{out} = -V_{cc}$ and then choose an appropriate transistor. You can add an LED as an indicator of the heating condition.

**Questions to answer:**

a. Check in with a TA when an outcome is achieved. If the temperature varies over a larger range than suggested, **check in with a TA first**, then alter the circuit to get a smaller hysteresis.

b. Discuss the effect of the Schmitt Trigger and the application of the hysteresis.

c. Discuss other applications or uses of hysteresis loops.

d. Provide a description of transistors (no equations required) and why they are important in small signal situations. Read about transistor properties in Simpson, but this can be fairly light conversation.