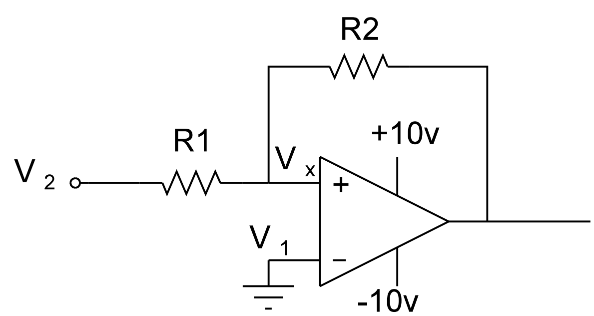
ENGR-356

HW# 5 - due at the start of lab (the day you have lab)

Because an op-amp has very high gain it can be used to compare two voltages. If one input (typically the inverting input) of the op-amp is connected to a known voltage (call this V_1 or the reference voltage), the other input V_2 is connected to a voltage that is changing, and there is no feedback, then as voltage V_2 becomes greater than V_1 by a small amount the output voltage will swing to a maximum (saturated) output voltage. If V_2 decreases and becomes less than V_1 by a small amount the output voltage will swing to a maximum (saturated) output voltage of the opposite polarity. Effectively the op-amp output is binary indicating if the unknown voltage is greater than or less than the reference voltage.

A potential problem can occur if the unknown voltage changes magnitude slowly as it approaches the reference voltage. If there is a little bit of noise on the unknown voltage the output may switch polarity back and forth as the noise voltage goes up/down.

To fix this switching problem positive feedback can be used. With positive feedback, as the unknown voltage V_2 reaches the reference voltage V_1 the op-amp output begins to change potential in the same direction as input V_2. With positive feedback the changing output voltage thus adds to the V_2 input voltage causing it to continue changing in the same direction.



A consequence of the positive feedback is that the V_2 voltage at which switching takes place changes from being nearly equal to reference V_1 to being equal to V_1 plus or minus some amount. This "some amount" is determined by a voltage divider relationship, i.e. Vout x (R1 / (R1 + R2)). And thus for an increasing V_2 voltage the op-amp output will switch at a different value of V_2 than for a decreasing V_2 input. This is called hysteresis.

Assuming op-amp input current is zero (ideal) the only path for current to flow is through R1 and R2. Also, because we have positive feedback rather than negative feedback we cannot say that the voltage at V_x is always zero or even close to zero. The voltage at V_x will change proportional to V_2 input. But Op-amp output will still change polarity when V_x becomes equal to V_1 which is zero in this circuit.

Example

Assume R1 is 10k ohms, R2 is 1 meg ohm, V_2 is zero volts, and that at present the op-amp output is saturated in the negative direction, i.e. -10 volts. What is the voltage at V_x ?

$$V_x = Vout \times (R1 / (R2 + R1)) = (-10) \times (10k / (1meg + 10k)) = -0.099 \text{ volts}$$

Problems to solve

Assume that the op-amp output saturates at +/- 10 volts (i.e. the power supply voltages).

1) Find reasonable values for R1 and R2 such that the op-amp will switch when $V_2 = +1.0$ volts and when $V_2 = -1.0$ volts.

2) Figure 2.26 in the text shows the Miller integrator circuit topology and on that page notes that the transfer function for this topology is that of a Single Time Constant (STC) network. Thus the Miller integrator topology can be used as a first order low-pass filter whose magnitude and phase response is that shown in figure 1.23 of the text.. On page 1016 of the text is example 14.2 that illustrates using this circuit topology to implement a first order low-pass filter. Note in figure 1.23 (a) there is a frequency labeled 1 where the magnitude is 3db less than at a frequency of 0.1 or less (on this diagram the frequencies have been normalized to one). When discussing filters we call this frequency the cut-off frequency where signal magnitude passing through the filter is reduced by 3db, i.e. is 0.707 times that at low frequency (this frequency in radians is the pole-frequency omega zero). Note that at frequencies above cut-off, signal magnitude coming out of the filter become less and less as frequency goes up. Hence the title low-pass. At very high frequency there should be nearly zero signal coming out.

   Follow example 14.2 to **design a low-pass filter** whose cut-off frequency (omega zero) is 2000 Hz and DC gain is 5 V/V. Use a 0.01 uF capacitance value.