EE 2010 Circuit Analysis
Lab 11: Signal Conditioning via Op-Amp

Lab Section: **Printed Name (Last, First):**

Learning Objectives:

- Understand the motivation for and function of signal conditioning.
- Understand the utility of an Op-Amp in DC Level Shifting.
- Realize a signal conditioning circuit in a simulation environment.
- Realize a signal conditioning circuit in a bench laboratory.

A. Before coming to lab:

1. Background:

Signal Conditioning is defined as manipulating an analog signal in such a way that it meets the requirements of the next system stage for further processing. Signal conditioning can include *filtering*, *amplification/attenuation*, *excitation*, *DC-shifting*, *linearization*, *electrical isolation*, etc. Analog-to-Digital Conversion (ADC) is a common example where signal conditioning is required.

2. Introduction to Signal Conditioning

1.1 Read this WIKIPEDIA article on signal conditioning.

1.2 Read this WIKIPEDIA article on analog-to-digital conversion.

1.3 Note that to fully utilize the ADC, the range of the analog signal should fill the entire input range of the ADC.

1.4 Recall the information in the LM741 data sheet (these are easily found on the web).

For an example, we will condition an input signal to match the requirements of an ADC. The ADC has an input range of 0V - 5V. It is useful to condition input signals to cover this entire range so as to achieve maximum resolution in the digital representations.

The "unconditioned" signal is modeled as a small-amplitude sinusoid balanced around 0V. Hence, the necessary conditioning consists of two operations: *amplification* to fill the 5V dynamic input range of the ADC and *level-shifting* to "move" the balanced sinusoid to range between 0V and 5V. In what follows, we treat these separately.

3. DC Level-Shifting

Figure 1 shows two signals. The blue signal is symmetric (zero DC) about the time axis. The red signal represents the desired level-shifted version of the original blue signal.

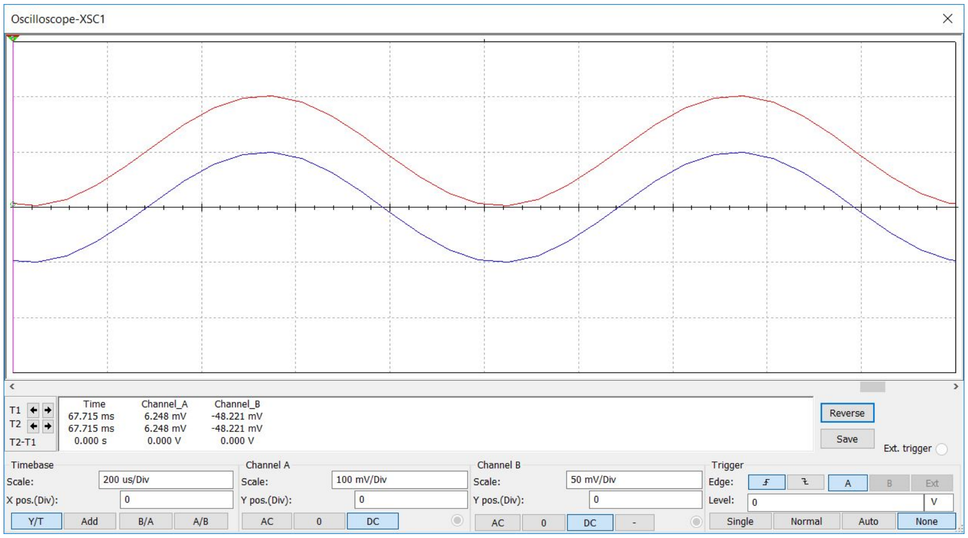

Figure 1: Input (blue) signal and level-shifted (red) signal

A common implementation of a level-shifter combines a DC voltage with an AC signal in a *difference amplifier configuration*. Figure 2 shows a difference amplifier realization in Multisim with a DC voltage (shifting) signal applied.

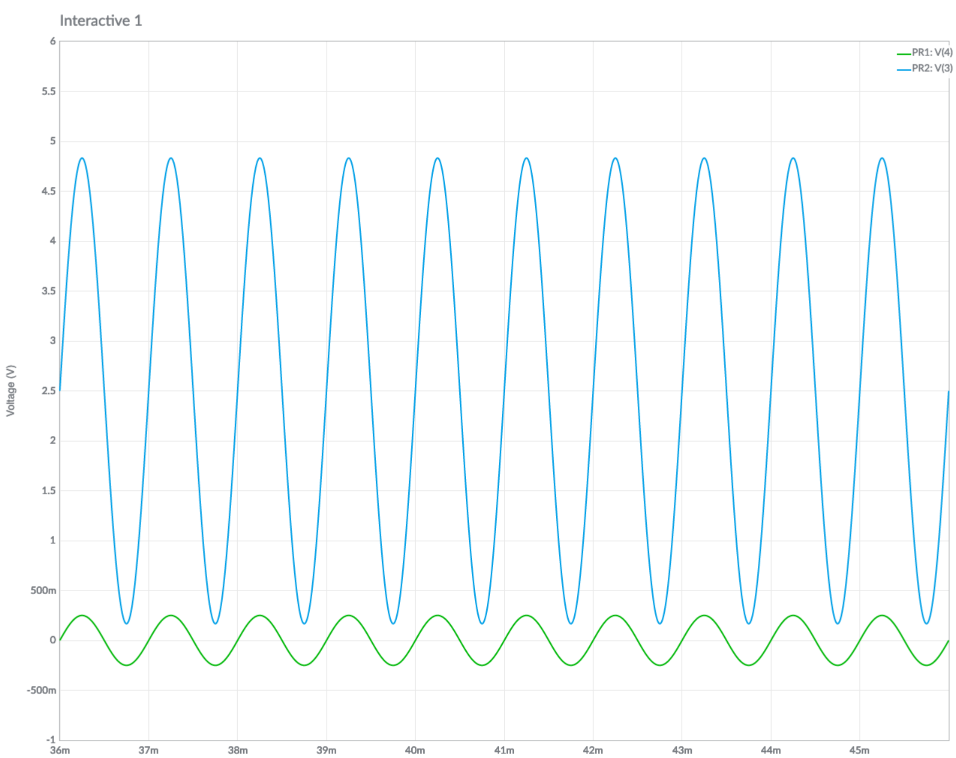

Figure 2: Difference amplifier with a shifting DC voltage input.

4. Construct the Signal Conditioning Circuit in Multisim

3.1 Construct the amplifier shown in Figure 4.

3.2 Initially, omit the -300mV source and connect the 12k Ω resistor directly to ground.

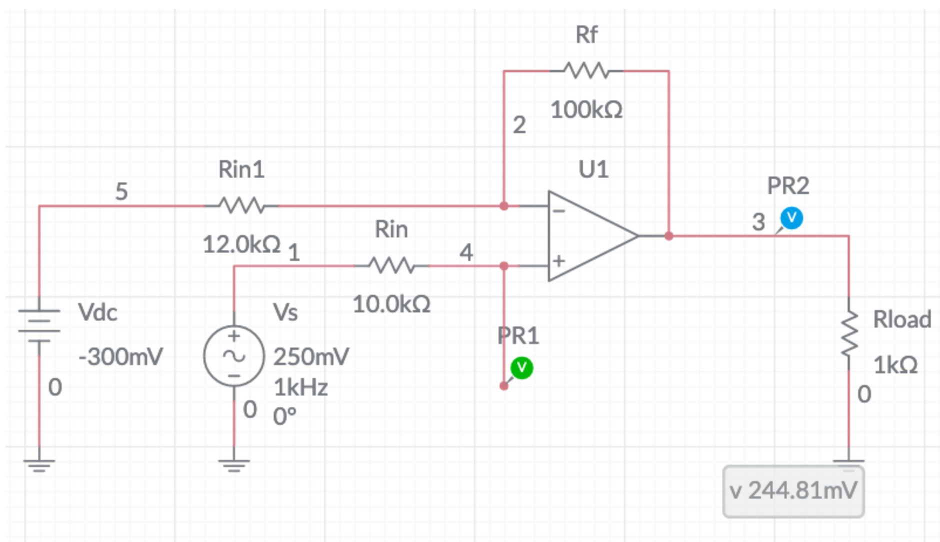

Figure 3: Amplifier with DC Level Shift

3.3 Use two "voltage probes" to simultaneously measure the input signal and the output signal.

3.4 Verify the minimum and maximum voltage of the input signal.

-249.62mv, 249.62mv

3.5 Find the minimum and maximum voltage of the output signal?

-2.32v,2.32v

3.6 Based on the peak-to-peak voltages found above, approximate the gain as:

$$Gain = A_v = \frac{Vout_{p-p}}{Vin_{p-p}} \tag{1}$$

9.29

3.7 The gain of a non-inverting amplifier such as in Figure 4 can be approximated with the following gain Equation.

$$\text{Gain} = A_v = 1 + \frac{R_f}{R_1} \tag{2}$$

Where R_f is the feedback resistor and R_1 is the resistor connected to the inverting input.

3.8 Calculate the observed gain and the predicted gain.

1+100/12 = 9.33

3.9 Compare the results of the observed gain 1 and predicted gain 2. Explain any differences.

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3.10 Now include the -300mV source energizing the 12k Ω resistor.

3.11 Again, use two "voltage probes" to simultaneously measure the input signal and the output signal.

3.12 Verify that the gain of the amplifier 1 has not changed but the DC-level of the output has indeed shifted.

yep

B. In-Lab Procedures

It is extremely important to follow the pinout specs carefully, especially when applying power to the LM741. Refer to the datasheet before energizing. Have the data sheet available during construction.

1. Constructing the amplifier

1.1 Construct the amplifier shown in Figure 4.

1.2 Omit the -300mV source until later.

Note: The pin numbers on the LM741 in Multisim correspond to the pin numbers on the actual IC. Notice that Pin 2 corresponds to the non-inverting input in the schematic and on the pinout diagram from the datasheet.

Resistors	DC Power	Signal Generator (XFG1)	Other
1k Ω (R1)	-15V Source (V1)	Amplitude: 250mV	Oscilloscope (XSC1)
12k Ω (R3)	+15V Source (V2)	Frequency: 1kHz	LM741 (U1)
100k Ω (R2)	-300mV Source (V3)		

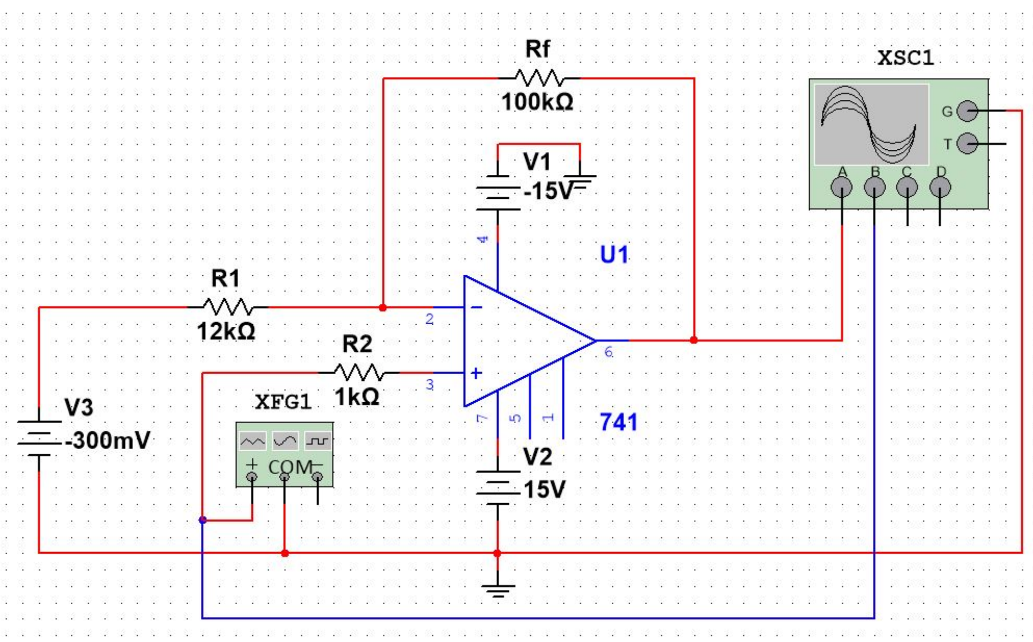

Figure 4: Amplifier with Level Shift

1.3 Connect the supply voltages to the Op-Amp.

1.4 Later, we'll need a third DC source to create the level shift for the output. This can be done in several ways including that shown to the right.

1.5 Note that since we are using a *difference amplifier*, a NEGATIVE DC VOLTAGE is required to achieve a POSITIVE VOLTAGE SHIFT.

1.6 If using the +6V output for the level shift, use the -6V (black) output and connect the +6V (red) output to ground.

1.7 Notice (Figure 5) that the black cable feeding in to the COM terminal is connected to the +6V output, and that the red cable is grounded to the COM terminal (i.e. the black and red cables for the 6V output terminals are switched).

1.8 Be sure to keep the 15V output terminals exactly as shown in Figure 5.

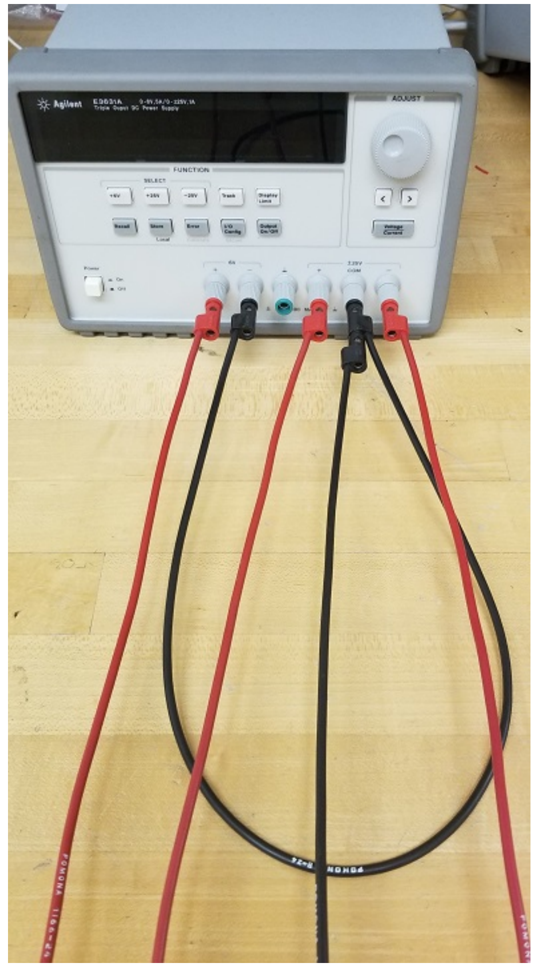

Figure 5: Triple DC voltage (+15, -15, -6) configuration.

1.9 Use the oscilloscope in a dual channel configuration to measure the input and output signal simultaneously.

1.9.1 Find the minimum and maximum voltage of the input signal.

-248mv, 248mv

1.9.2 Find the minimum and maximum voltage of the output signal.

-2.24v, 2.32v

1.9.3 Use these measurements to approximate the gain.

$$\text{Gain} = A_v = \frac{Vout_{p-p}}{Vin_{p-p}} \tag{3}$$

4.56/0.504 = about 9

1.9.4 The design formula for the gain of a non-inverting amplifier is given by:

$$\text{Gain} = A_v = 1 + \frac{R_f}{R_1} \tag{4}$$

where R_f is the feedback resistor and R_1 is the resistor in to the inverting input.

1.9.5 Use Equation 4 to approximate the gain.

1+100/12 = 9.33

1.9.6 Compare the results from Equation 3 and Equation 4.

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1.9.7 **Now include the -300mV source.** Detach the 12k Ω resistor from ground and connect it to the -6V output on the power supply set to 300mV (.3V).

1.9.8 Again, use the oscilloscope to display and measure the input and output signals.

1.9.8.1 Find the minimum and maximum voltage of the input signal?

-256mv , 256 mv

1.9.8.2 Find the minimum and maximum voltage of the output signal?

240mv, 4.8v

1.9.8.3 Calculate the gain of the amplifier using Equation 3.

4.56/0.512 = about 9

1.9.8.4 Compare these results for Gain with those including no level shift.

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C. Takeaways:

- Signal conditioning is a useful operation for almost every signal processing / instrumentation task.
- Among the common conditioning operations are *amplification* and *shifting*.
- These two operations can be realized simultaneously using common Op-Amp configurations.
- The operations of common Op-Amp configurations are well modeled by functional descriptions (gain equations).