CE3101: DIGITAL ELECTRONICS AND COMPUTER INTERFACING LABORATORY LW9: OP-AMP SIGNAL CONDITIONING CIRCUITS

INTRODUCTION

Computer engineers build electronic signal conditioning circuits that interface sensors and actuators to the computer in an embedded system. Signal conditioning circuits range voltages and currents to appropriate levels and protect the computer from any noise spikes in the environment. Figure 1 shows that input and output signals may require signal conditioning.

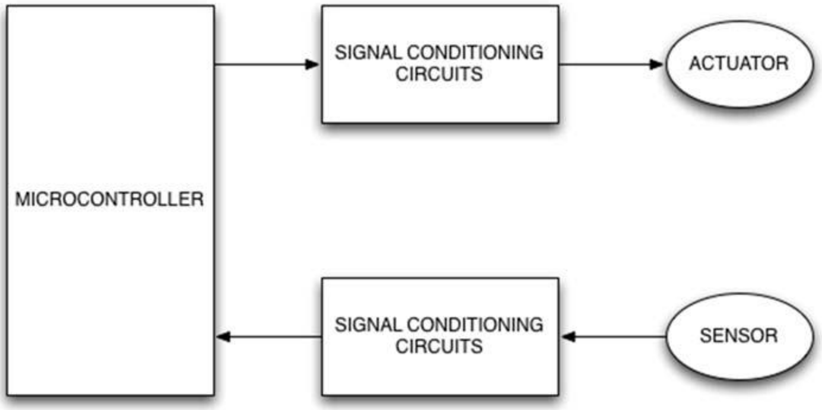
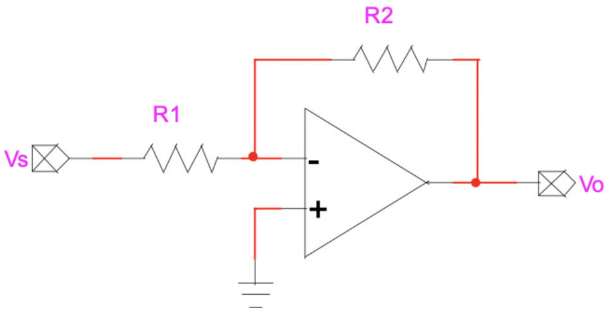


Figure 1: Basic embedded systems model

Analog Input sensor signal conditioning circuits are typically built using operational amplifiers operating in the linear region. Linearity ensures that the shape of the analog signal is maintained as it is ranged to appropriate levels for analog-to-digital conversion by the computer. The design task is to determine the equation that describes the mapping from the input sensor domain to the desired output range of the signal conditioning circuit. The equations will take one of four linear forms:

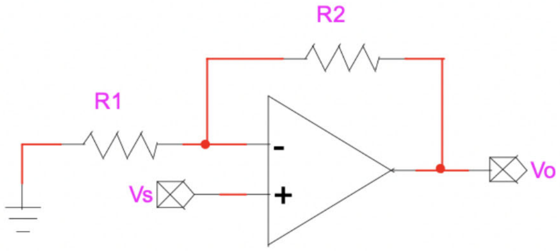
(1) $V_o = m * V_s + V_{offset}$
(2) $V_o = m * V_s - V_{offset}$
(3) $V_o = -m * V_s + V_{offset}$
(4) $V_o = -m * V_s - V_{offset}$

where the signal conditioning circuit output voltage is Vo, the input sensor voltage is V_s, the amplification factor is m, and the y-intercept is a DC voltage V_{offset}. Once the appropriate equation is derived, it can be implemented using standard operational amplifier configurations. All four equations can be implemented using single-supply or dual-supply op-amps. Standard op-amp circuit configurations are shown in Figures 2 through 5.



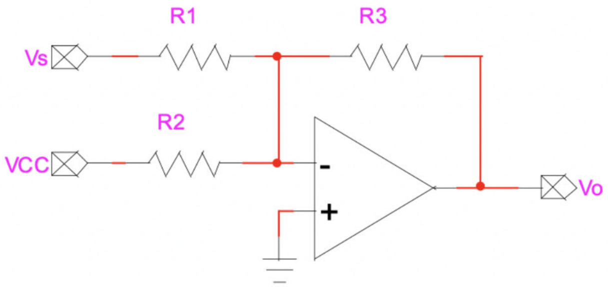
$$V_o = -\frac{R2}{R1} V_s$$

Figure 2: Inverting Configuration



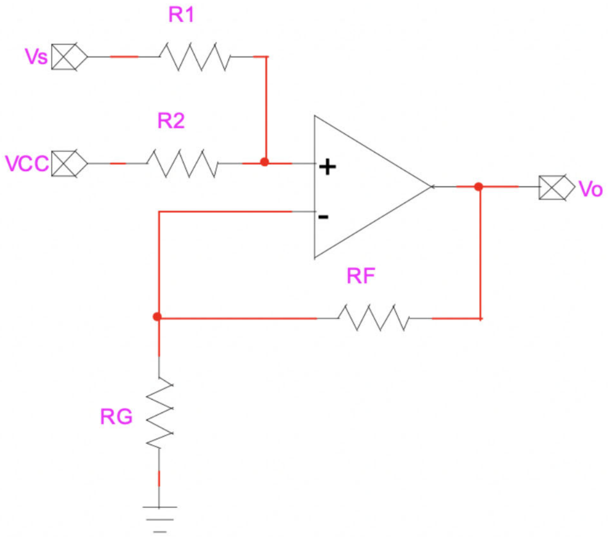
$$V_o = \left[\frac{R2}{R1} + 1\right] V_s$$

Figure 3: Non-inverting Configuration



$$V_o = -\left[\frac{R3}{R1}V_s + \frac{R3}{R2}V_{CC}\right]$$

Figure 4: Inverting Summation Configuration



$$V_o = \left[\frac{RF + RG}{RG}\right]\left[\frac{R2}{R1 + R2}\right]V_s + \left[\frac{RF + RG}{RG}\right]\left[\frac{R1}{R1 + R2}\right]V_{CC}$$

Figure 5: Non-Inverting Summing Configuration

$$\frac{R_F + R_G}{R_G} = \frac{b}{V_{cc}} + m$$

A linear function: $V_{out} = m \cdot V_s + b$

$$\frac{R_2}{R_1} = V_{cc} \cdot \frac{m}{b}$$

Noise and other unwanted signal frequency components can be removed by adding filter networks to the op-amp configurations. Unlike passive RC filters, op-amp filters are active because they can create transfer functions with a gain that is greater than unity. And, another benefit of active filters is that the op-amp output appears as an ideal source and thus the output response of the circuit is independent of the load that it drives. Figures 6 and 7 extend the non-inverting op-amp with first-order low-pass and high-pass filter networks. First-order filters have a gain roll-off of -20dB/decade. The figures also demonstrate buffering the input sensor to form an ideal sensor source. This prevents the output impedance of the sensor from affecting the corner frequency.

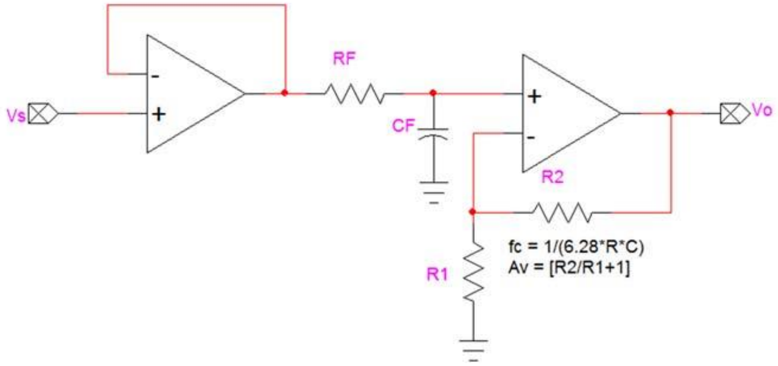


Figure 6: Buffered Input First-Order Active Low-Pass Filter with Gain

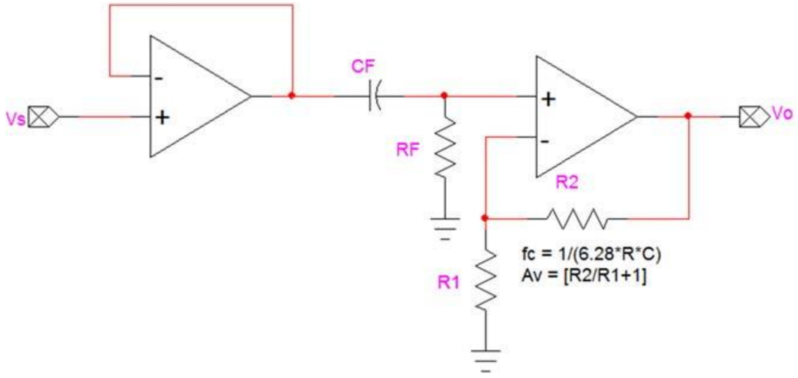


Figure 7: Buffered Input First-Order Active High-Pass Filter with Gain

LABORATORY OBJECTIVES

- Derive signal conditioning circuit equations from input and output voltage envelopes.
- Implement signal conditioning circuit equations using standard op-amp configurations.
- Add first-order filter behavior to signal conditioning circuits.
- Build and test signal conditioning circuits in the laboratory.

REQUIRED SOFTWARE

- Waveforms
- Word processor

REQUIRED HARDWARE FROM EECS TECH SUPPORT

- Blue Wire Box
- Two (1) UA741 op-amp
- Resistors as needed
- Analog Discovery USB instrumentation kit

LABORATORY EXERCISES

1. Signal Conditioning (Figure 3)

- **Design** a signal conditioning circuit that conditions an input sensor with envelope [0:0.4] V for ADC conversion if the output envelope is designed to be [0:2.5] V. Note this can be done with a non-inverting amplifier only.
- **Use** the nearest E12 or E24 resistor that does not cause overamplification. The E12 and E24 resistor values can be found here: (http://tinyurl.com/25ahj3). **Use** a 1KHz sine wave to simulate the sensor.

2. High Pass Filter (Figure 7)

- **Add** a buffered input first-order high-pass filter **network** with a corner frequency of 2KHz. (This filter will go behind the amplifier from part 1).
- **Verify** the filter performance using the Analog Discovery network analyzer to sweep AC frequency from 10Hz to 100KHz.
- **Use** the network analyzer to determine the gain experienced by 60Hz noise.

Hints:

You need 3 op-amps for part 2.

Questions:

In part 2, Why does the gain decline at both low **and** high frequencies?

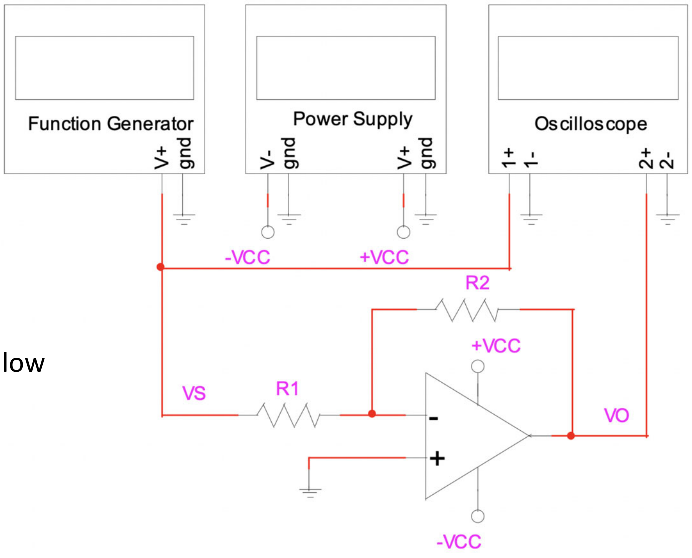


Figure 8: Test Circuit