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CE 3101
Lab 9
5/13/18

CE 3101 Lab Experiment 9

Abstract

In the electrical and computer engineering industries, design often involves making decisions from external sensors. While typical microcontrollers operate off 3.3 or 5 volts, the sensors that are used to measure external stimuli often output signals that can be in the millivolt range. Such signals would be difficult to operate on without any modification. This is because as the signal is received by the microcontroller, it goes through an analog to digital conversion, which modulates the signal into a binary representation that can be understood by the computer. For very small signals that have lots of variation smaller than the resolution of the ADC, the shape/details of the signal are lost. This can lead to undesired data compression, which could result in a data loss beyond an acceptable amount. To prevent this, small (or large) signals often undergo signal conditioning before they are fed to the microcontroller. This not only protects the microcontroller from unintended harm, but also ranges signals into an appropriate range for the microcontroller. Additionally, its often desired to filter out ranges of frequencies for removing noise from sensors. Both the amplification and filtration effects described can be achieved using op-amps in conjunction with resistor and capacitor configurations. This allows for signals to be properly ranged, while removing any data corrupting the actual data.

The purpose of this laboratory experiment was to explore these signal conditioning circuits. This experiment involved designing circuitry for properly ranging a sensor envelop, and then extending it to filter out low frequency noises. To achieve this, the circuits were first designed and simulated in PSPICE, and then were built and measured using an Analog Discovery Kit oscilloscope and network analyzer. All resistor values used in design and simulation were 5% standard resistor values, with resistive potentiometers used to fine tune the circuitry to work with the standard resistors provided by the MSOE EECS tech department. The results of the experiment can be found below.

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Experiment

[0:400] mV -> [0:4000] mV Using LM741 Op-Amp – No Filtration

Design

The requirements of the experiment stated that a [0:400] mV envelope should have been amplified to an envelope of [0:$UA741_{VOMAX}$]. The datasheet for this op-amp states that the output voltage will saturate at 1 volt less than the source voltage. With a source voltage of 5V being used, it meant that the signal should be amplified to [0:4000] mV.

With the ranging of [0:400] mV to [0:4000] mV, it meant that when an input signal of 400 mV occurred, a 4000 mV output of the SSC should occur. Since the SSC was being designed to be linear, this meant that the coefficient for input voltage to output voltage should be

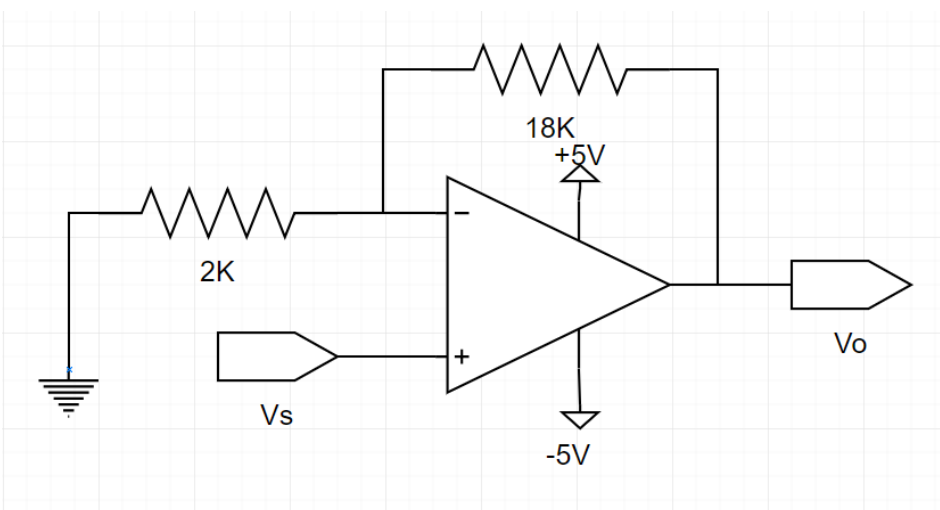
$$V_o = mV_s \rightarrow \frac{V_o}{V_s} = m = \frac{4000mV}{400mV} = 10$$

With a non-inverting op-amp configuration,

$$V_o = [\frac{R_2}{R_1} + 1]V_s = [(m-1)+1]V_s$$

$$\frac{R_2}{R_1} = m - 1 = 9$$

Picking two standard resistor values with a ratio of 9 resulted in R2 being 18 kΩ and R1 being 2 kΩ. Theoretically, the signal should have been perfectly amplified, with an exact coefficient of 9; in reality however, resistor variance would prevent a ratio of exactly 9. After deciding on the resistor values, the following circuit was designed.



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Simulation

PSPICE was used to simulate the designed circuit. The PSICE source code has been attached for viewing purposes. Simulation of the circuit resulted in the following plot traces.

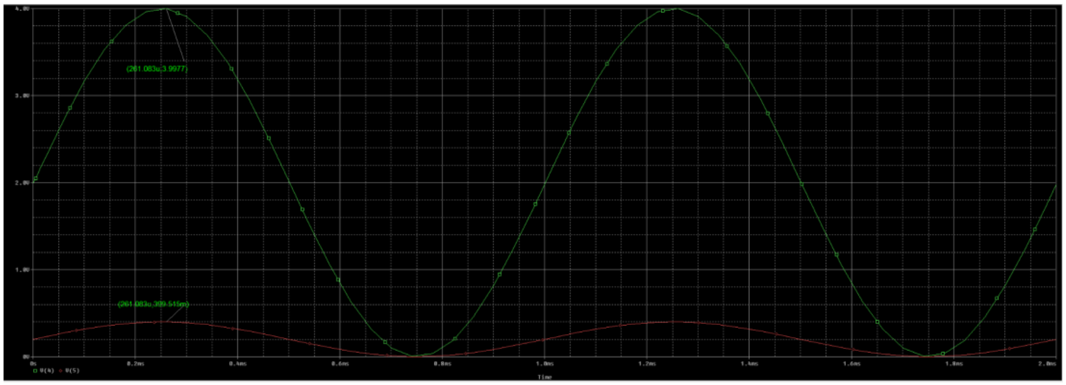


Figure 1 - Simulation results for SSC 1

From the resulting simulation, it could clearly be seen that a [0:400] mV signal was being amplified to a [0:4000] mV signal. There was very little error observed in the simulation, which was a result of using resistors yielding a ratio of exactly 9. Again, as already mentioned, this would not be the case in actual implementation due to imperfections in the components, but it provided validation of design, allowing assembly of the circuit to occur.

Implementation

When implementing the actual circuit, 18 kOhm and 2 kOhm resistors were not readily available for assembling the design circuit. As a result, a 2.2 kOhm resistor was used in place of the 2 kOhm resistor, and a 20 kOhm potentiometer was used in place of the 18 kOhm resistor. This allowed the potentiometer to be fine tuned to a value yielding a ratio of 9. In this case, it meant setting the potentiometer to 19.8 kOhms. Building this circuit and driving it with a 1 kHz sine wave with amplitude 400 mV resulted in the following oscilloscope view.

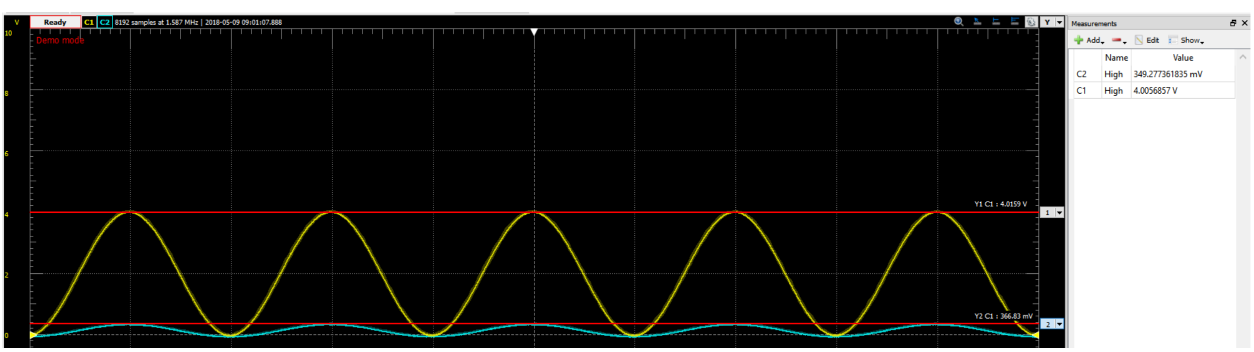


Figure 2 - Oscilloscope view of actual implementation

Even in its actual implementation, the output envelope of the signal conditioning circuit approached ideal values very closely. The maximum voltage observed was 4.0056857 V, or a 0.14% error – well within an acceptable range. The input range appeared to be off, with only a maximum of 349.2 mV. This was most likely a measuring error in the oscilloscope. Both the wave generation function, as well as the SSC seemed to suggest correct behavior. After building the ranging portion of the circuit, the next task was to build filtering capabilities.

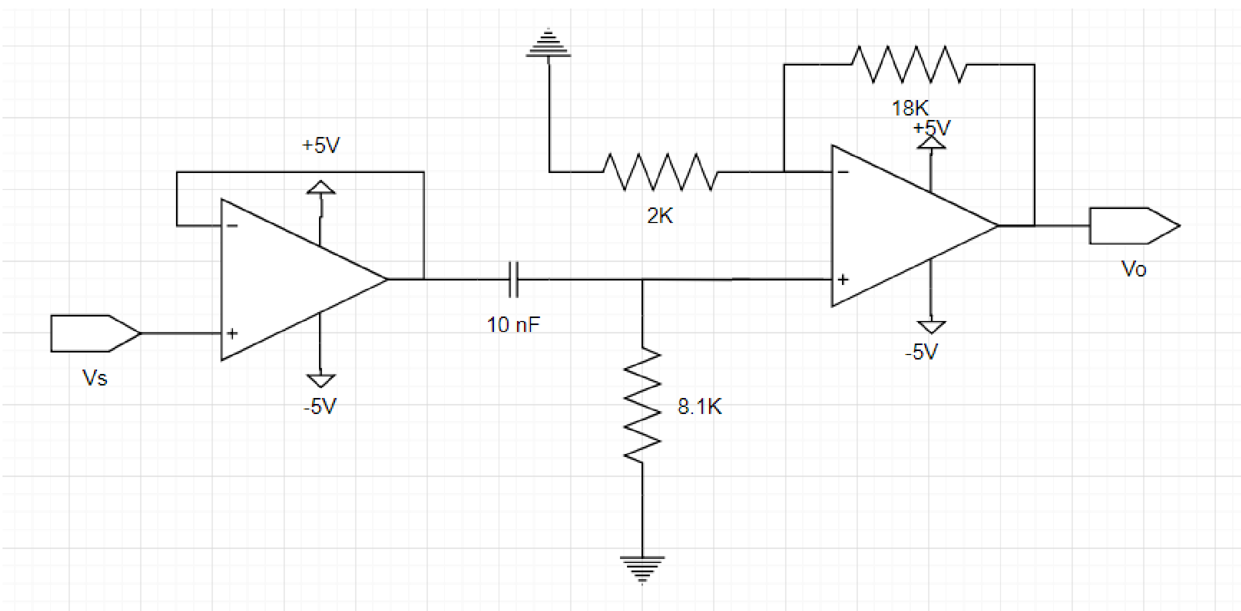
[0:400] mV -> [0:4000] mV Using LM324 Op-Amp – High Pass Filtering

Design

For the second part of the circuit, a RC configuration was to be designed so that a high pass filter with a corner frequency of 2 kHz would be achieved. In addition to this, the input was to be buffered from the output voltage, providing an ideal source to a load operating off the input voltage. To design for a corner frequency of 2 kHz, a capacitance of 10 nF was chosen, and the following equation was used to choose a resistor.

$$R_f = \frac{1}{2\pi(2000Hz)(10nF)} = 7957.75 \rightarrow 8.1k\Omega$$

Unlike the design for the ranging circuitry, the resistor did require rounding to achieve a standard resistor value. This would introduce error into the filtration, but since the resistance was only rounded by approximately 150 ohms, the impact was inferred to be relatively small in magnitude. After deciding a proper RC configuration, the following circuit was designed, providing high pass filtering and buffering:



Simulation

PSPICE was used to simulate the designed circuit. The PSICE source code has been attached for viewing purposes. Simulation of the circuit resulted in the following plot traces.

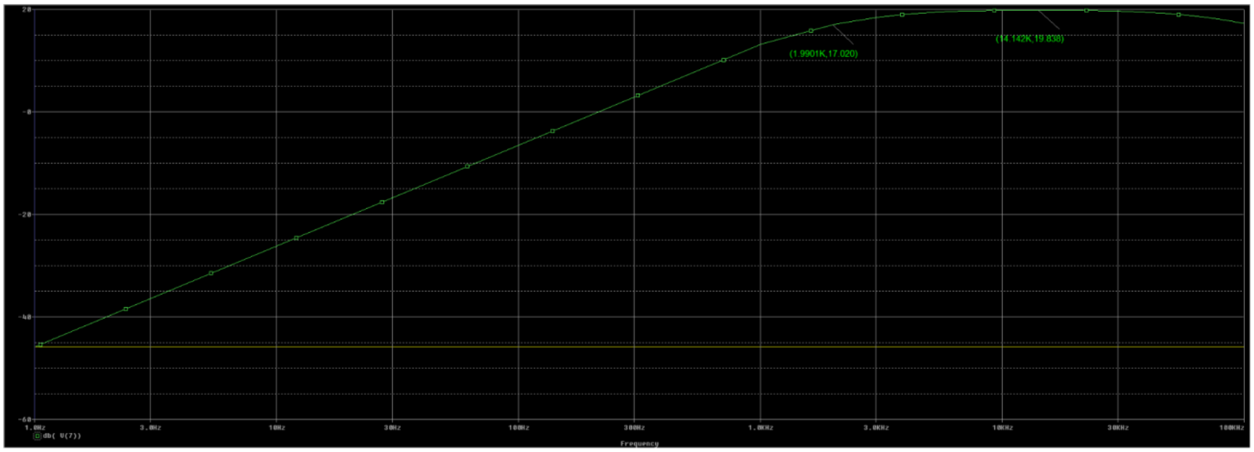


Figure 3 - Simulation results for SSC 2

The simulation reflected the error that resulted from rounding the resistor value up to 8.1 kOhms. As a result, the cutoff frequency (as defined by -3 dB from the max) was occurring about 10 Hz early, at 1.990 kHz. This can be translated to 0.5% error – well within the range of acceptance. Other than this, the circuit was demonstrating proper high pass filtration. Interestingly, around 30 kHz, the high pass behavior seems to begin to transition, which would cause a band pass filter rather than a high pass filter. This can be explained by the internal operation of the op-amp. Since the op-amp being used was designed for audio applications, extremely high frequencies above the human audible spectrum begin to be filtered out. This is expected behavior and will not be treated as unintended error. This simulation did appear to verify design, so the circuit was assembled next.

Implementation

The design circuit was implemented by using the existing ranging circuit, inserting a 10 nF capacitor, and using a 10 kOhm potentiometer, the Rf value was fine tuned to 8.1 kOhm. Using the network analyzing feature of the Analog Discovery Kit, a 200 mV input signal at varying frequency was fed into the circuit. The results are shown in the next figure.

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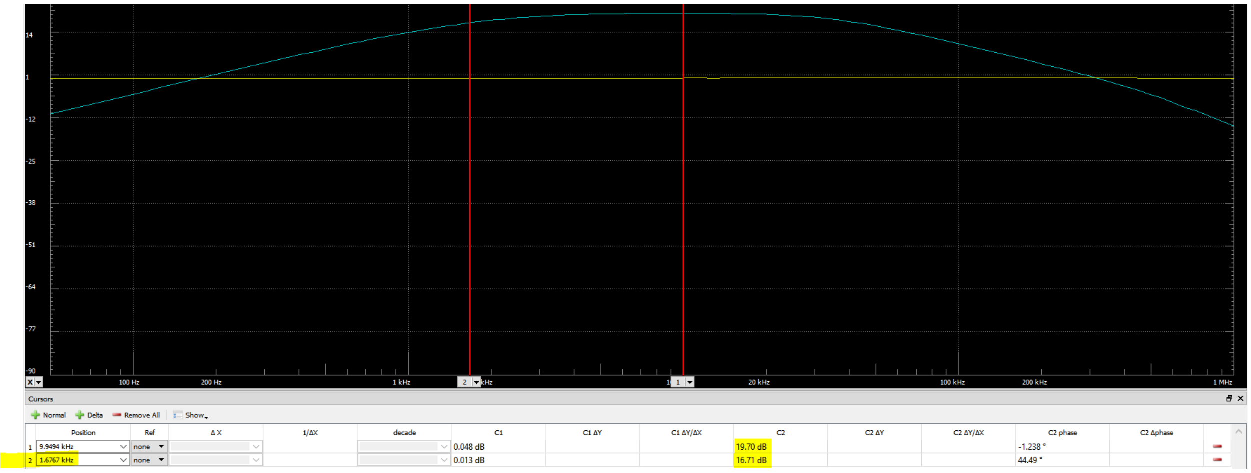
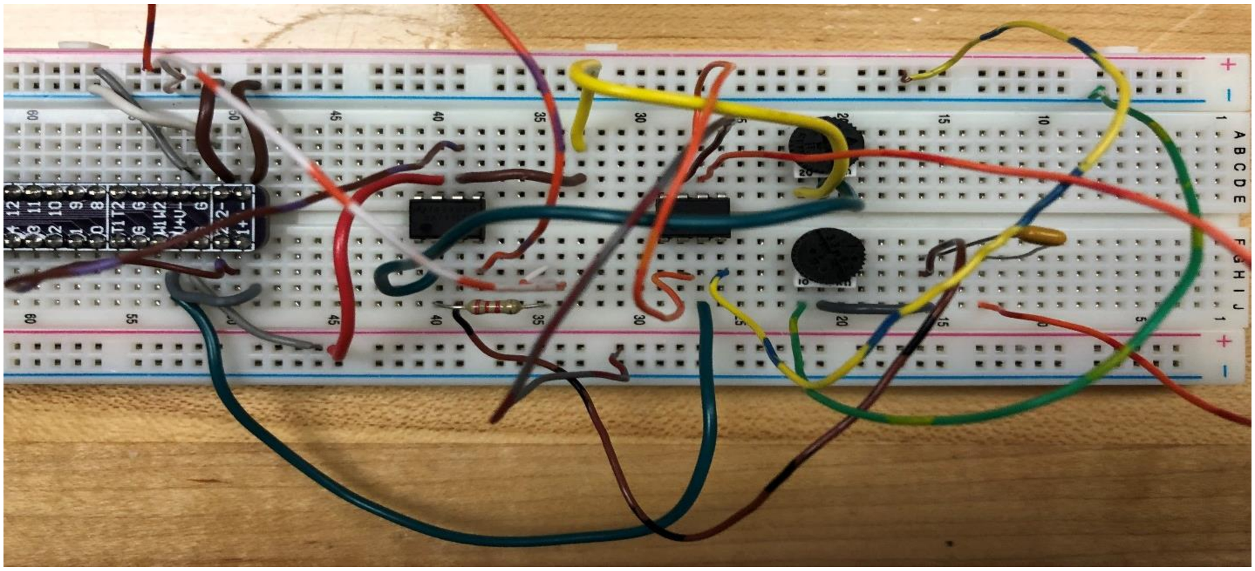


Figure 4 - Oscilloscope view of actual implementation for SSC2

As expected, the actual results deviated from the design and theoretical cutoff frequency. In the simulation, an error of 0.5% was observed – in the actual circuit it was closer to 16.2%. This is certainly higher than desired and would not be acceptable to use in a circuit being placed into production. This could be the result of many different factors, but most likely is compounding error in the components used in the circuit. All the resistors, capacitors, and op-amps in the circuit were subject to variation, and this is acknowledged by the manufactures of the parts. For a more accurate cutoff frequency, custom resistors, or higher precision resistors/capacitors would be required. Additionally, as expected, the circuit began to attenuate high frequency signal after approximately 30 kHz. This was seen in the simulation, and results in more of a bandpass filter than a high pass filter. For many applications however, this would be acceptable. If needed, higher quality op-amps could have been used in the circuit, but doing this would add (possibly unneeded) cost.



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Conclusion

This week's laboratory experiment was great for reinforcing the material taught in class. In class, the methodology for deriving amplification coefficients was covered, as well as the design equations needed for building the SSCs. The laboratory experiment went further than this, helping illustrate the effects of resistor choice, as well as filter design for eliminating unneeded signal and noise. As a result of this experiment, I feel much more confident in my ability to not only design proper signal conditioning circuits, but also be able to make appropriate decisions when choosing the right resistors to use for implementation of the circuits. Due to the value created by the laboratory experiment, as well as the results observed during the experiment, it was appropriate to declare this laboratory experiment to be a success.