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CE 3101
Lab 8
5/6/18

CE 3101 Lab Experiment 8

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. When doing this, op amps are often used in circuitry to amplify a signal and provide any offset if needed.

The purpose of this laboratory experiment was to explore these signal conditioning circuits. This experiment involved ranging 3 different signal envelopes to larger ranges, using 2 different types of op amp circuitry. When doing this, 3 different signal ranges were used, with one being a bipolar signal, which requires more advanced circuitry for offset. Design of the signal conditioning circuits were first implemented in PSPICE to verify design and were later implemented using components from the MSOE EECS tech department. Since EECS could only offer a limited amount of resistor values, resistance values from simulation were approximated using resistors in series as best as possible, while ensuring that overamplification did not occur. All resistor values used in design and simulation were 5% standard resistor values. The results of the experiment can be found below.

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Experiment

[0:275] mV -> [0:5000] mV Using LM741 Op-Amp

Design

With the ranging of [0:275] mV to [0:5000] mV, it meant that when an input signal of 275 mV occurred, a 5000 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

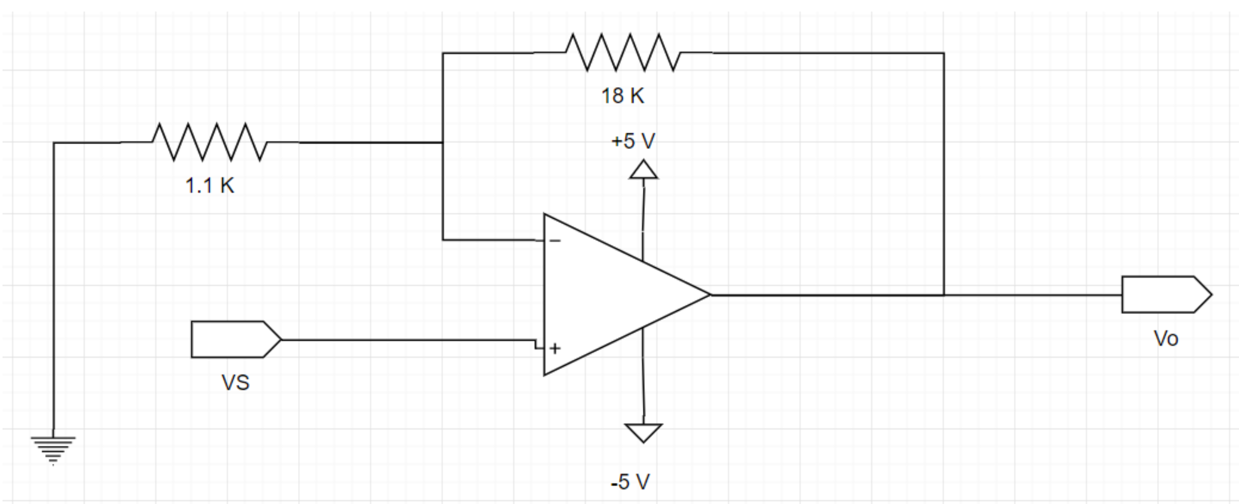
$$V_o = mV_s \rightarrow \frac{V_o}{V_s} = m = \frac{3300mV}{275mV} = 18.181$$

With a non-inverting op-amp configuration,

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

$$\frac{R_2}{R_1} = m - 1 = 17.181$$

Picking two standard resistor values with a ratio close to 17.181 resulted in R2 being 18 kΩ and R1 being 1.1 kΩ, with a ratio of 16.36. This wasn't a perfect ratio, with an error of -4.76%, but since it was within 5%, this was the ratio accepted for simulation. After deciding on the resistor values, the following circuit was designed.



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.

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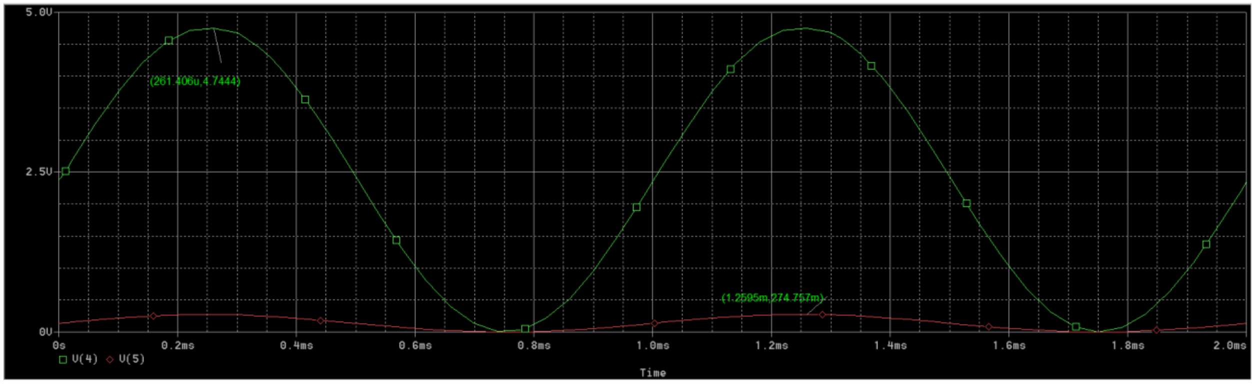

Figure 1 - Simulation results for SSC 1

From the resulting simulation, it could clearly be seen that a [0:275] mV signal was being amplified to a [0:4744] mV signal. The signal was not being fully amplified to 5 V, but this was expected because of the resistor choice. If a design was required in which the signal needed to be amplified closer to 5V, higher precision resistors would be required. Due to cost however, this trade off was selected.

While the simulation verified the amplification characteristics, it also verified that the shape of the input signal was being maintained. After verifying the SSC, a physical implementation could occur.

Implementation

Due to limited availability of resistors, when the actual circuit was implemented, the resistance values were doubled. Instead, R2 was approximated using 2 resistors with resistance values of 32.5 kΩ and 3.3 kΩ, equaling 35.8 kΩ and R1 was a 2.1 kΩ resistor. Using these resistance values, and the design shown above, an oscilloscope was used to capture the signal conditioning circuit outputs. A 1khz sine wave was used as an input.

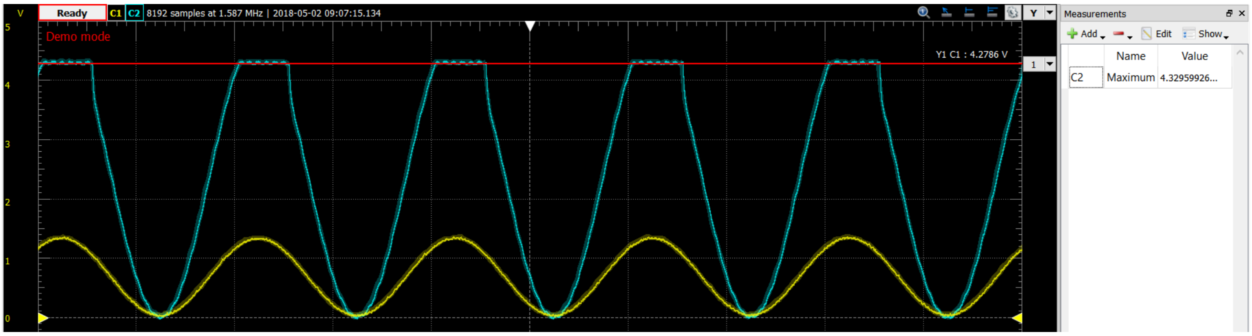

Figure 2 - Oscilloscope view of actual implementation

From the oscilloscope view, amplification of the input signal can be seen, however, there is one key difference between the simulated and actual results. In the view shown in figure 2, it appears that the SSC output gets cutoff at about 4.3V. This can be explained by op-amp saturation which occurs due to providing a 5V power source to the op-amp. Had a higher power been used for powering the op-amp, the SSC output would peak at roughly 5V, providing the ideal SSC characteristics. While the actual plot is not as smooth as the simulation, the oscilloscope view verifies design if the saturation is ignored.

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[0:275] mV -> [0:3300] mV Using LM324 Op-Amp

Design

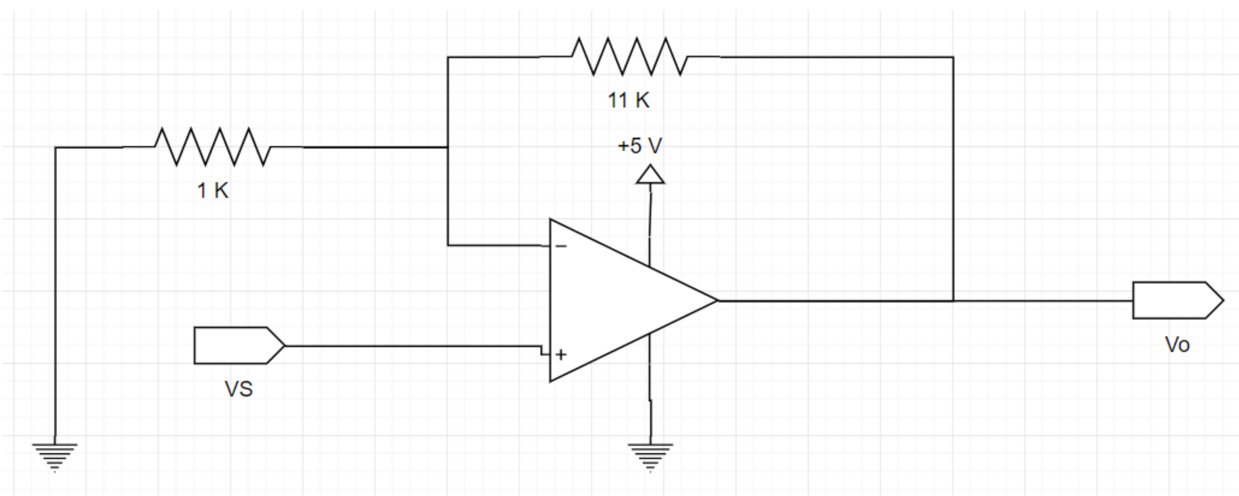
For the second circuit, a LM324 op-amp was swapped for the LM741 op-amp. The design requirements called for a maximum SSC output 0.2V below the saturation voltage of the LM324 op-amp when powered with a 5V source. Since the LM324 datasheets specify a saturation voltage 1.5V below the power voltage, this meant that a [0:275] mV signal was required to be scaled to [0:3300] mV. Using the same approach from design 1,

$$V_o = mV_s \rightarrow \frac{V_o}{V_s} = m = \frac{3300mV}{275mV} = 12$$

Since the op-amp was being used in a non-inverting configuration, with a linear transformation,

$$\frac{R_2}{R_1} = m - 1 = 11$$

To achieve this resistor ratio, R2 was chosen to be 11 kΩ, and R1 was chosen to be 1 kΩ, resulting in a ratio of 11 exactly (in reality due to resistor variability, this ratio would not be exactly 11). Using these resistors, the following circuit was designed:



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.

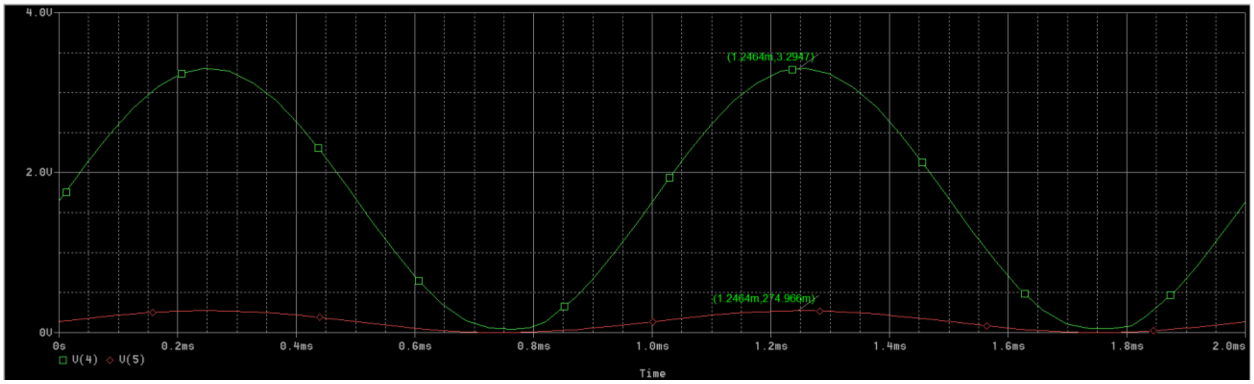


Figure 3 - Simulation results for SSC 2

The simulation results verified design, with an output envelope of [0:3294] mV resulting from an input envelope of [0:275] mV. In addition to the amplification characteristics, the output shape also was maintained. Because of the amplification coefficient for this design, proper resistors with a ratio much closer to the desired value were able to be used. This resulted in much less error than the first design, with a theoretical error of 0%.

Implementation

The design circuit was implemented without the need for combining resistors in series, greatly simplifying design. After wiring all connections and attaching an oscilloscope, the circuit was tested using the same input voltage source as design 1. This resulted in the following:

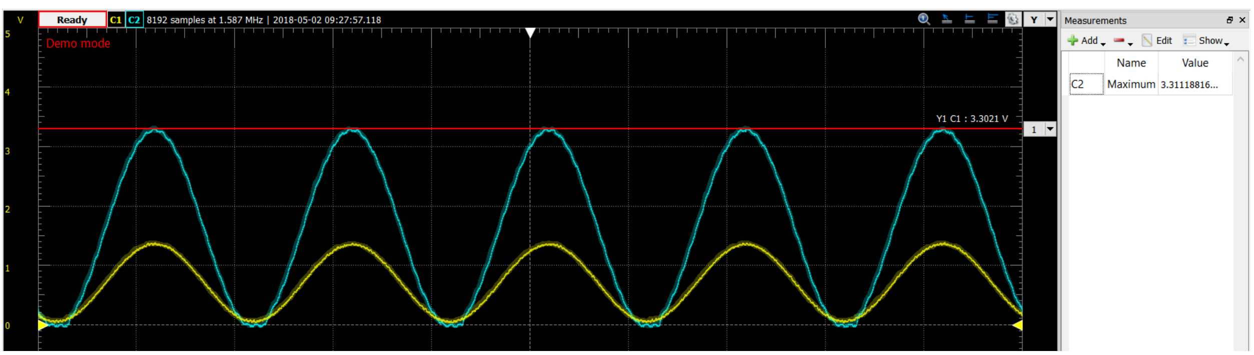


Figure 4 - Oscilloscope view of actual implementation for SSC2

As expected, the actual results were much closer to the desired output envelope than signal conditioning circuit 1. Again, this was due to the availability of the desired resistors, eliminating the need for resistor approximation. According to the actual results, output for the SSC circuit peaked at 3.31 V, slightly larger than desired. Unlike the first circuit, the effects of saturation were not seen because the saturation characteristics of the op-amp were incorporated into the circuit design to avoid them.

The slight overamplification observed in the measurements could have been due to many different factors, but they were most likely a result of variation in the actual resistance values of the resistors compared to their listed resistances. If such overamplification were to be damaging to a system, it would be important to use higher precision resistors, or design the SSC circuit as to amplify the input signal by an amount which would reduce the range of the output envelope. Outside of this slight variation, the results verified correct implementation and design of the signal conditioning requirements.

[-500:500] mV -> [0:3000] mV Using LM324 Op-Amp

Design

The design for this SSC was more complicated than the previous two due to the bipolar characteristics of the input envelope. Such an input envelope would require a voltage offset in the signal conditioning circuit, which requires different, more complicated design equations. Before considering this however, the amplification coefficient was determined using the same technique as the first two circuits.

$$V_o = mV_s \rightarrow \frac{V_o}{V_s} = m = \frac{(3000-0)mV}{(500--500)mV} = 3$$

This meant that

$$V_o = [\frac{R_2}{R_1}+1]V_s + 1500mV$$

Where 1500 mV accounted for the offset needed to transform the bipolar signal to a non-bipolar signal. When choosing the proper resistors to use for design in this circuit, the guidelines defined by Texas instruments were used (which can be found at http://www.ti.com/lit/an/sloa097/sloa097.pdf). This resulted in the following resistance values:

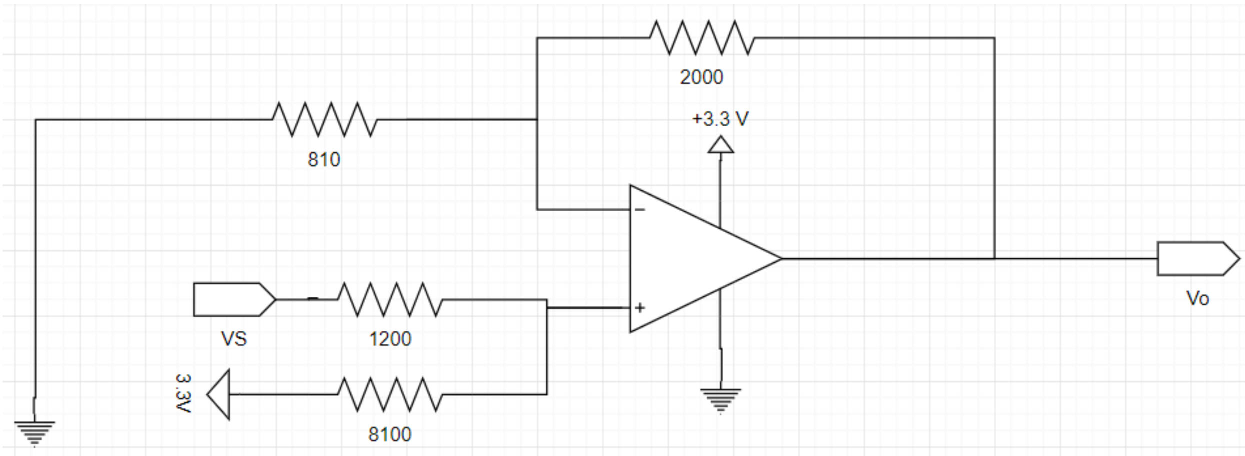
$$R_1 = 1200\Omega$$

$$R_2 = \frac{(v_{ref})(R_1)(m)}{offset} = \frac{(3.3V)(1200\Omega)(3)}{1.5V} = 7920\Omega \rightarrow 8.1k\Omega$$

$$R_f = 2000\Omega$$

$$R_g = \frac{(R_2)(R_f)}{(m)(R_1+R_2)-R_2} = \frac{(2200\Omega)(8100\Omega)}{3(1200\Omega+8100\Omega)-8100\Omega} = 810\Omega$$

Using these resistor values, the following circuit was designed:



Simulation

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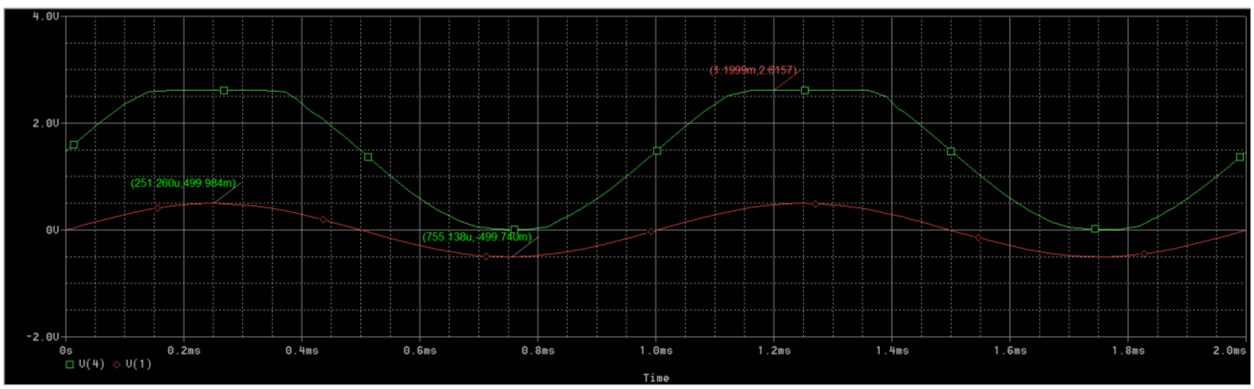

Figure 5 - Simulation results for SSC 2

From the simulation, it can be seen that the bipolar input signal is being properly transformed to a non-bipolar signal which bottoms out at 0V. The simulation results, however, indicate that saturation will occur when the signal is transformed. This could make sense, as the datasheet for the op-amp suggests that saturation occurs at 1.5V under the power voltage. With a power supply of 3.3V, saturation should begin to appear at 1.8 V. The simulation suggests that saturation will occur at 2.6V, but this is because of the way the op-amp is represented by the PSPICE program. Outside of the saturation effect, the shape of the input signal was maintained as it was transformed. Due to this, it was decided to implement the circuit.

Implementation

When implementing the circuit, several resistors were placed in series to approximate the design resistances since resistor choices were limited by the selection provided by the MSOE EECS tech department.

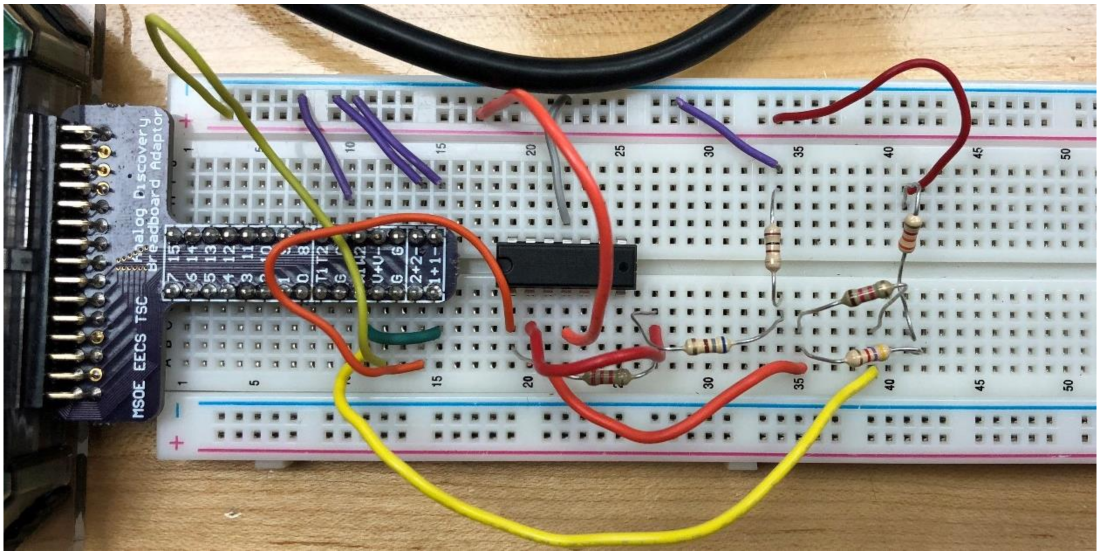

Figure 6 - Implementation of SSC3

An oscilloscope was attached to the design circuit, and a 1 kHz input sinusoidal voltage was used, resulting in the following capture.

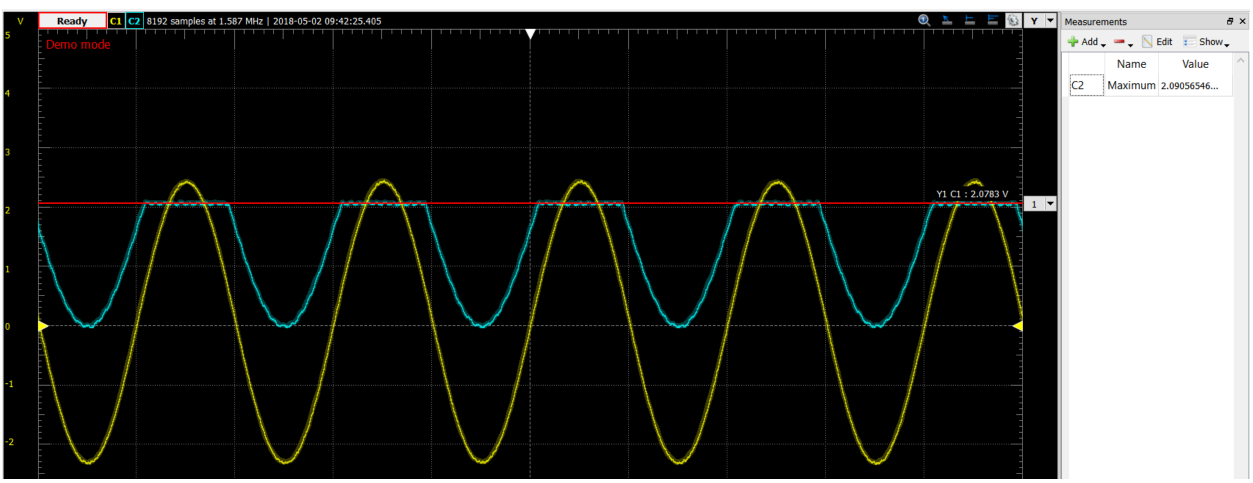

Figure 7 - Oscilloscope view of actual implementation for SSC3

As expected, the output envelope fell victim to the saturation effects of the op-amp. The datasheets suggest that saturation should have occurred at 1.8V, but the actual measurements suggest that saturation was occurring at roughly 2V. This could have been due to a variety of things, such as resistor approximations used when implementing the circuit. The output does, however, document proper conversion from bipolar signal to non-bipolar output signal. Further, the shape of the original input signal is being maintained through the conversion. To avoid the saturation seen in this oscilloscope view, the design would need to be modified so that output envelope was desired to max out at a lower voltage, or a larger supply voltage would need to be used for the op-amp.

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 the saturation effects that occur when choosing power supplies for op-amps. 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 – a skill that is not necessarily tested through lecture. 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.