PROBLEMS ENCOUNTERED

The largest problem I had with the pre-lab was consistently mixing up the positive and negative inputs of the T272 on LT spice, eventually fixing each mistake. Re-providing the chart showing what numbers 1-5 are could be helpful here since there are so many that are used.

INTRODUCTION

The purpose of this lab is to investigate several different applications and approaches of operational amplifiers including buffering, level shifting, and differential-to-single-ended signal conversion. LTspice simulations are utilized to analyze the behaviors of each of the circuits. This software also helps to demonstrate how op amps can shift voltage ranges, condition signals for electronic systems, and preserve signal integrity.

DISCUSSION

6.5 Pre-lab Requirements

6.5.1 Buffering

This section examines how voltage followers reduce loading effects by isolating sources from their loads. Each of the divider circuits determines the performances of each compared to using DC operating point analysis.

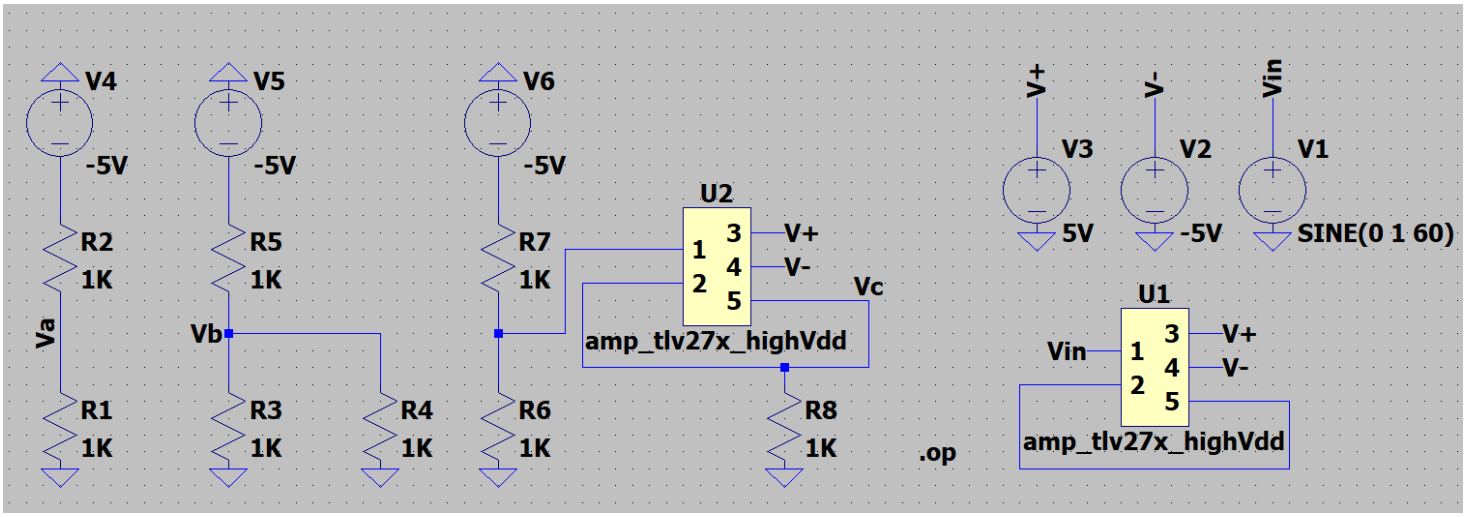


Figure 1: LTspice schematic of the three buffering circuits used to compare unloaded, loaded, and voltage-follower-buffered voltage dividers.

Node	Simulated Voltage (V)
Va	2.50 V
Vb	1.67 V
Vc	2.49 V

Table 1: Simulated node voltages V_A, V_B, and V_C obtained from the three voltage divider configurations using DC operating point analysis.

The voltages Va and Vc are approximately 2.5V because they are measured from either unloaded or buffered voltage dividers. In circuit a, the resistors divide the 5V supply equally which produces 2.5V. In circuit c, the voltage follower has a high input impedance which prevents the load from affecting the dividers voltage. Unlike these two, circuit b is lower due to the additional load that the resistor draws from the divider.

6.5.2 Level Shifting

This section demonstrates how op amp summing amplifiers can shift an input signal to a different voltage range while maintaining its characteristics.

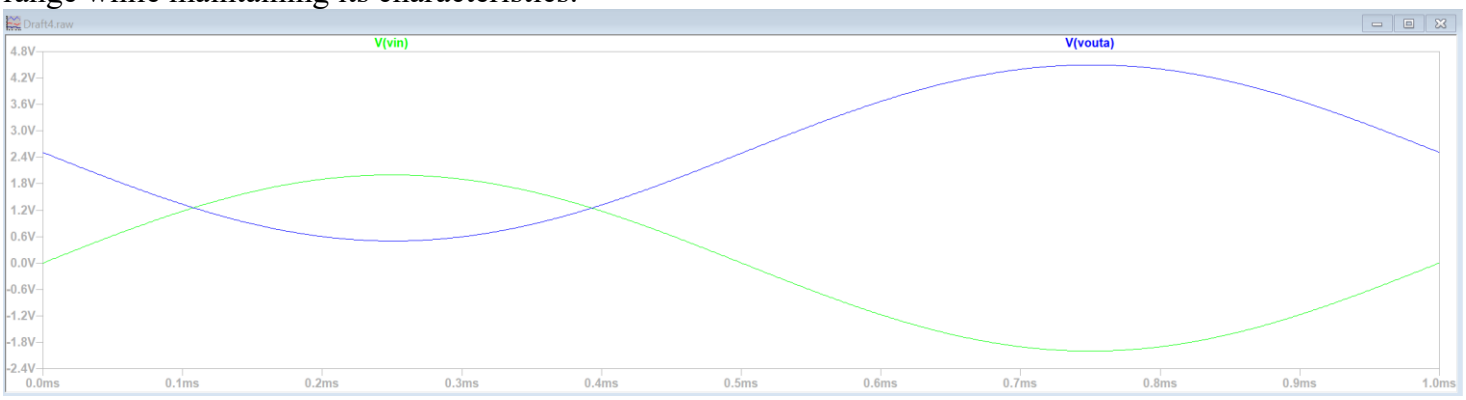


Figure 2: Simulated input and output voltages for the level shifting circuit using a fixed -2.5 V reference voltage.

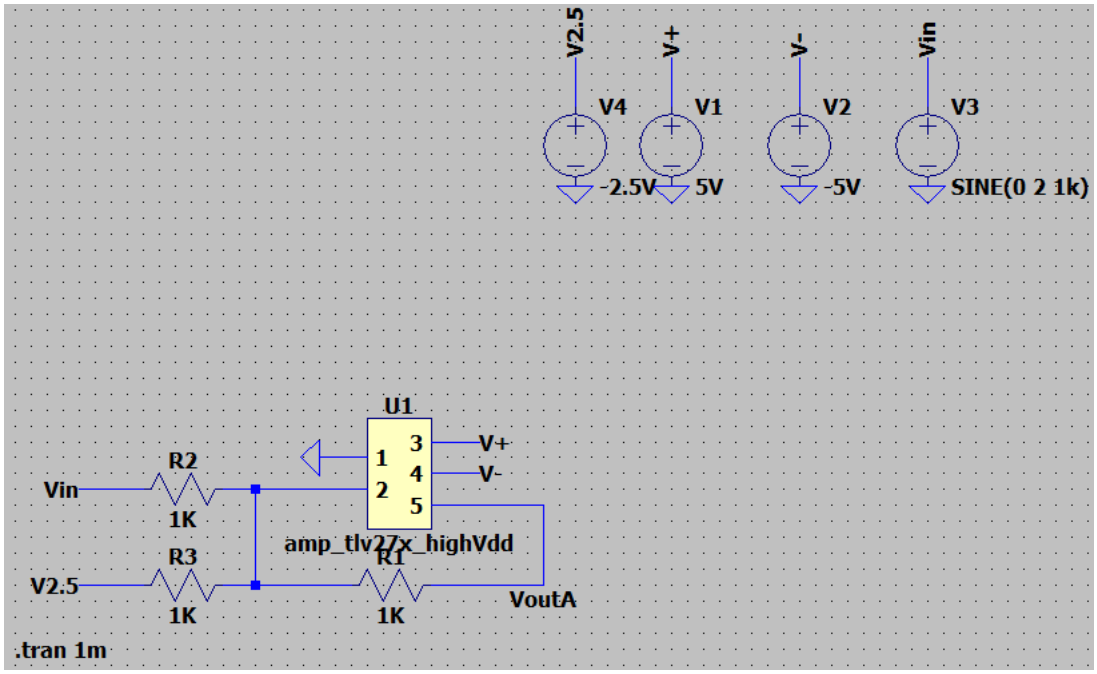


Figure 3: LTspice schematic of the inverting summing amplifier used to shift a bipolar input signal using a fixed -2.5 Vreference

The resistor divider uses -5V so that it generates a -2.5 reference voltage. If we were to use a +5V it would then generate a +2.5V reference, causing the output to shift in the wrong direction and potentially clip along the supply rails. Having this -2.5V reference allows for the output to range from roughly 0V to 5V.

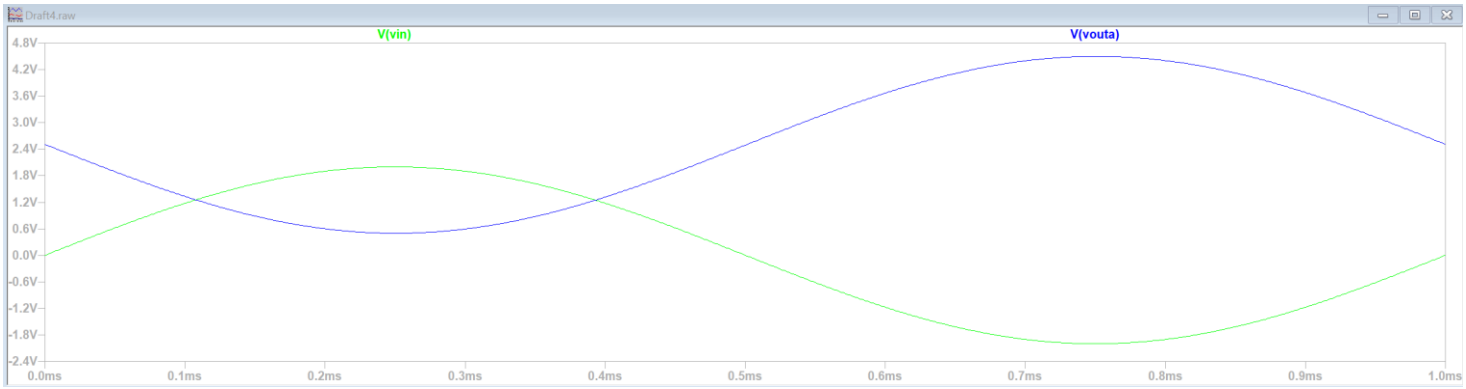


Figure 4: Simulated input and output voltages for the level shifting circuit utilizing a buffered voltage-divider-generated -2.5 Vreference.

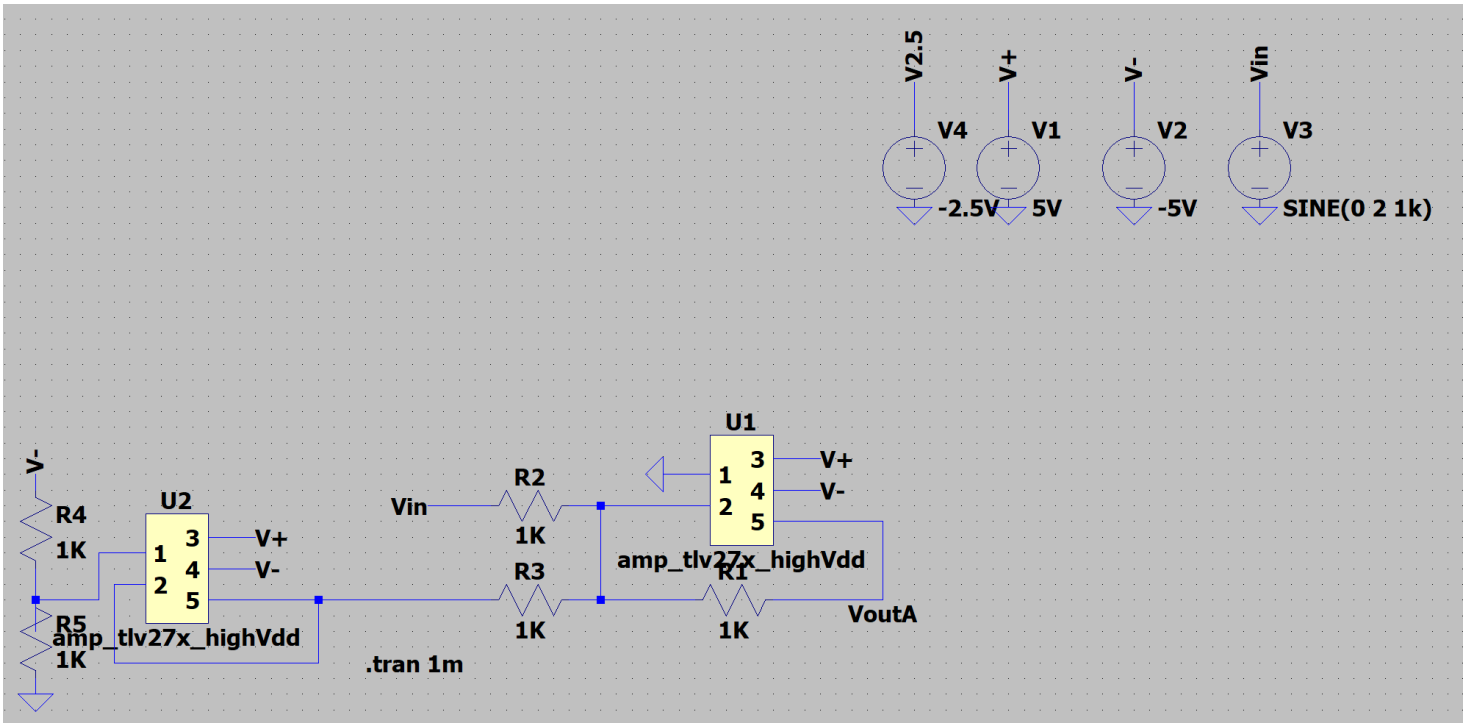


Figure 5: LTspice schematic of the level shifting circuit where the -2.5 Vreference is generated using a buffered voltage divider.

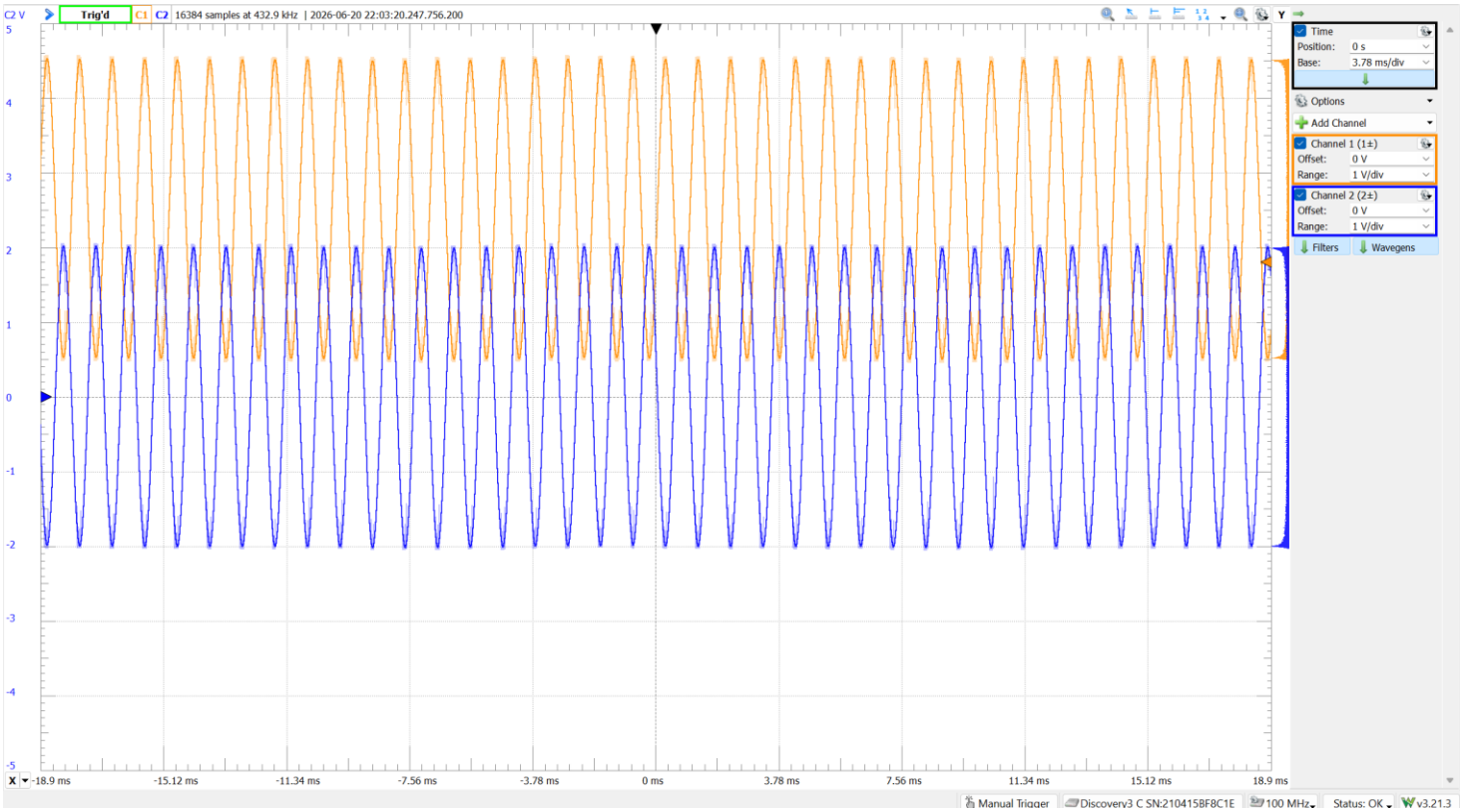


Figure 6: Oscilloscope capture of the practical level shifting circuit showing the input sine wave and the corresponding shifted output signal.

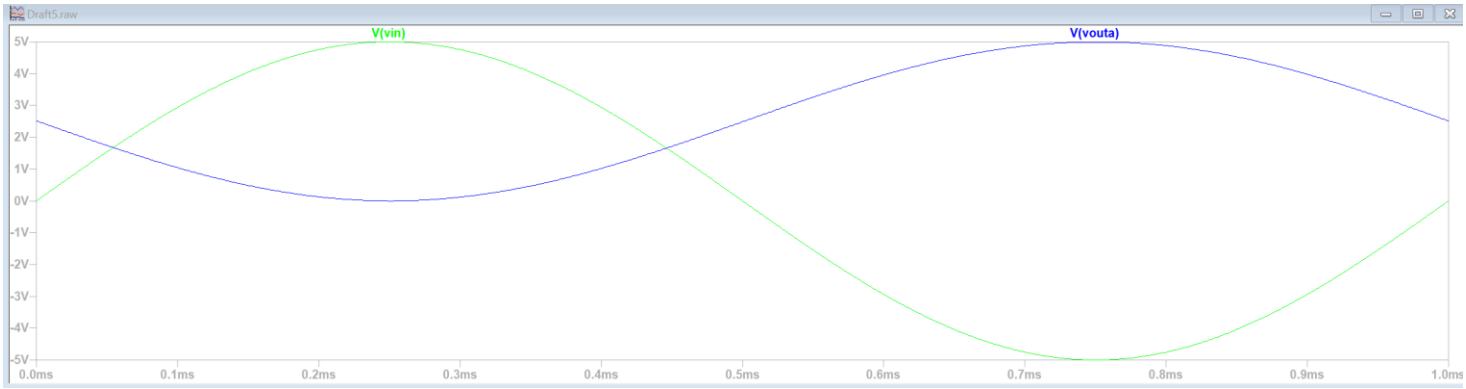


Figure 7: Simulated input and output voltages for the full-range DC level shifter converting a ± 5 V input into a 0 V to 5 V output.

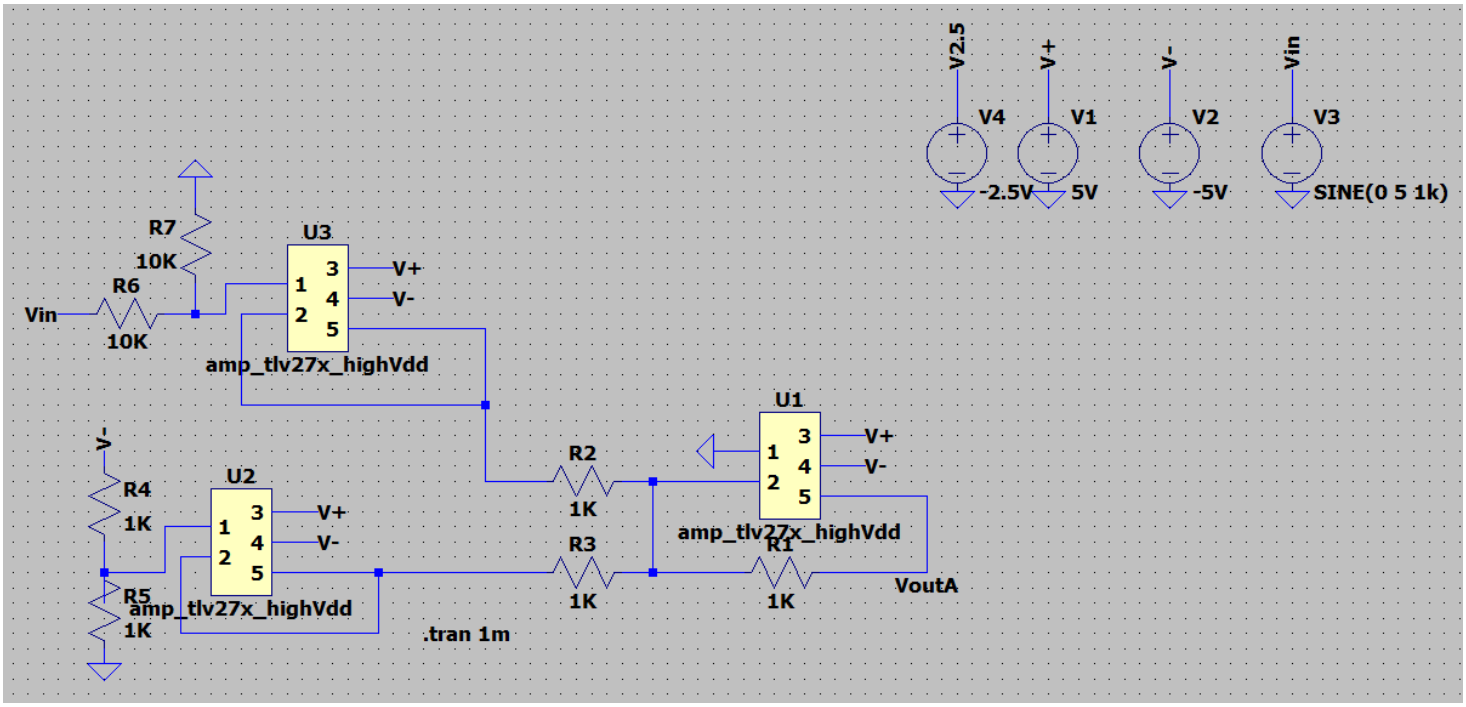


Figure 8: LTspice schematic of the three-op-amp DC level shifter used to convert the full ±5 V input range into a single-supply output range.

6.5.3 Differential to Single Ended Conversion

This section explores the usage of different amplifiers to convert differential signals to single-ended outputs. Combining level shifting and differential circuits are also used to produce a signal that fully utilizes the desired output voltage range.

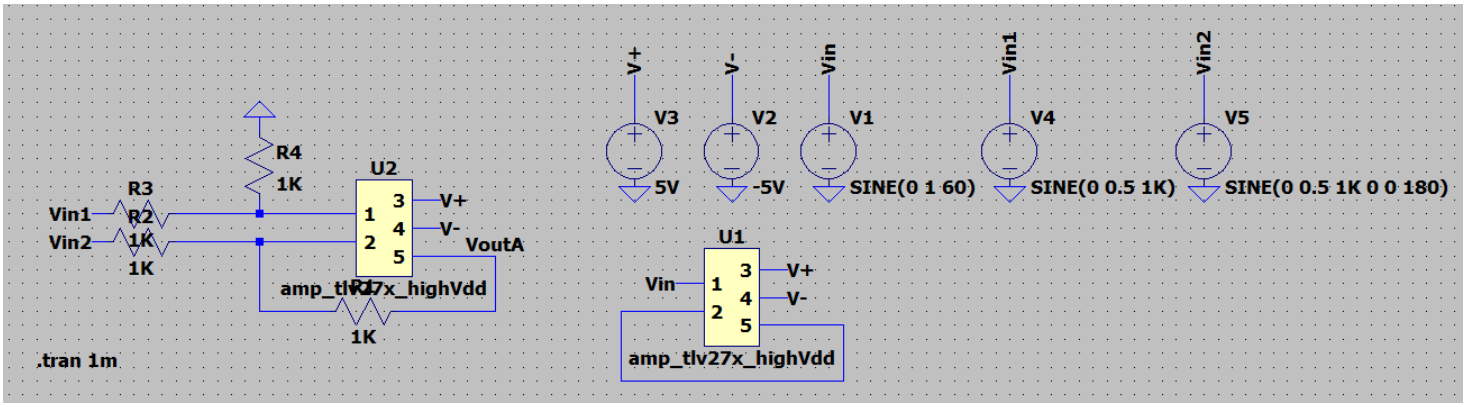


Figure 9: LTspice schematic of the differential amplifier used to convert differential input signals into a single-ended output.

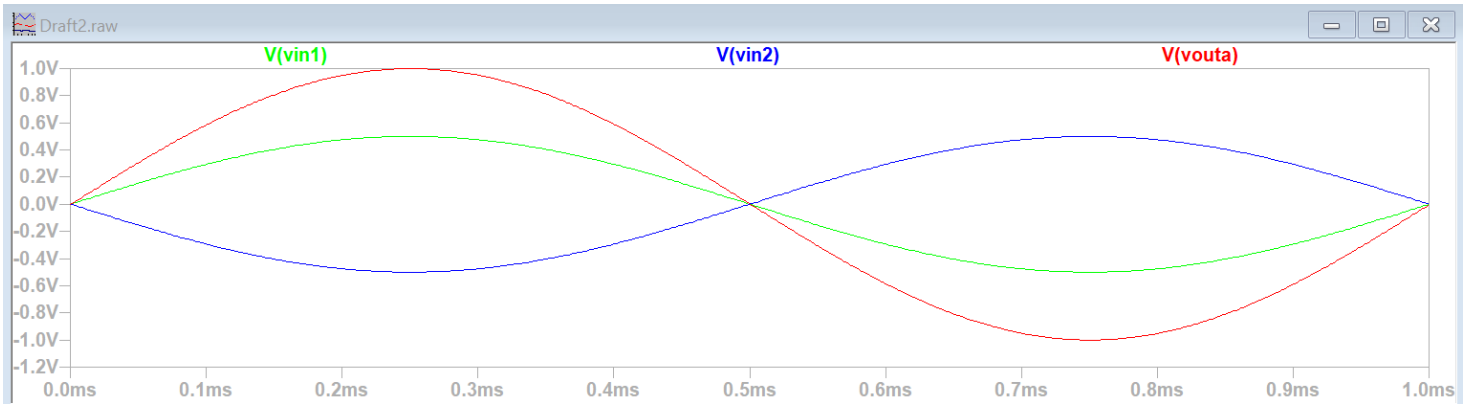


Figure 10: Simulated waveforms of V_{IN1}, V_{IN2}, and V_{OUTA} for the differential amplifier circuit.

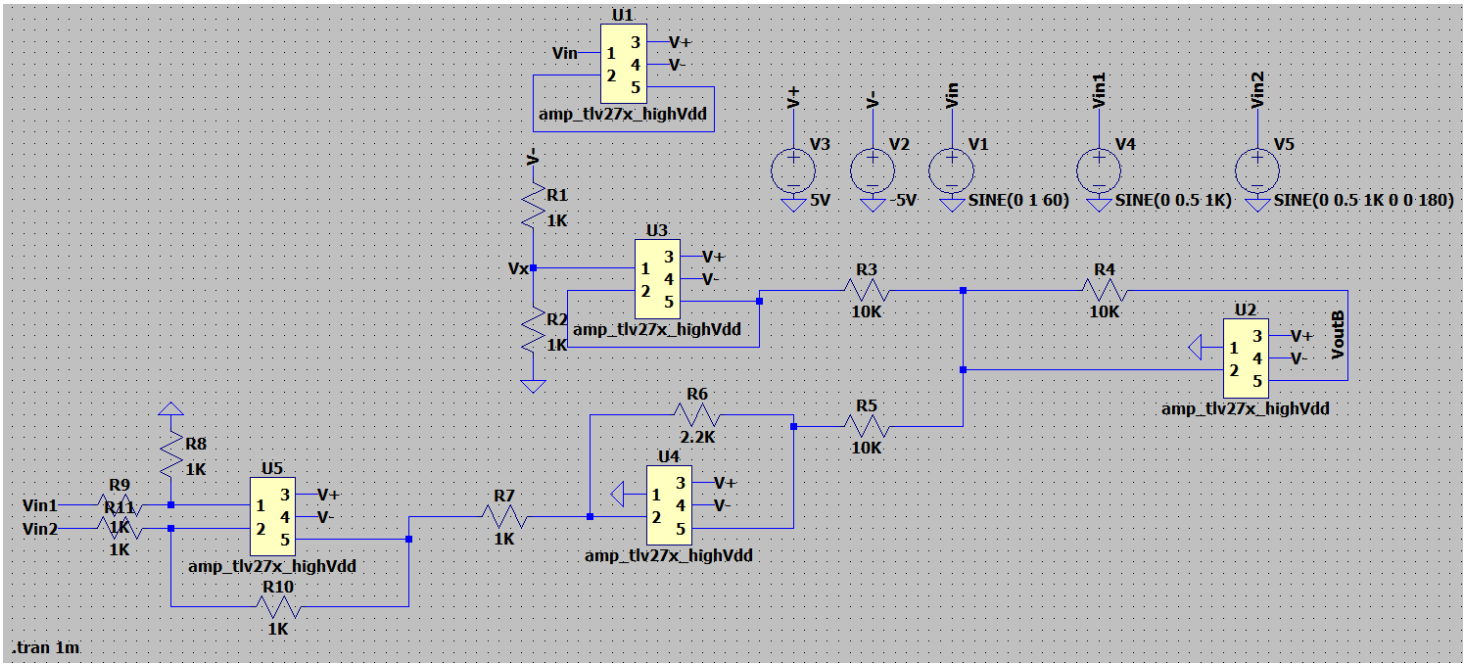


Figure 11: LTspice schematic of the combined differential amplifier and level shifting circuit used to maximize the available output voltage range.

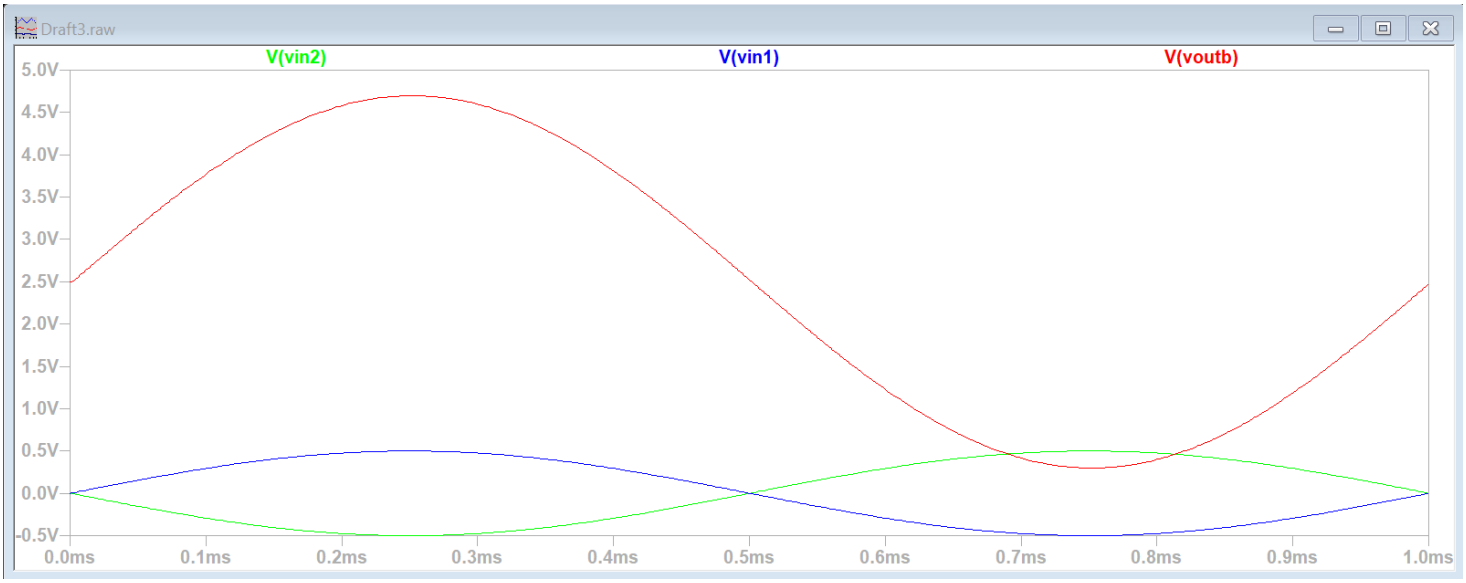


Figure 12: Simulated waveforms of V_{IN1}, V_{IN2}, and V_{OUTB} for the differential-to-single-ended conversion circuit with integrated level shifting.

The circuit in Figure 12 works by functioning as a differential amplifier that subtracts Vin2 from Vin1, producing a signal that is directly proportional to the difference of the two input voltages. The upper buffer creates a stable DC reference voltage using the voltage divider and the lower op amp scales the differential amplifier output to maximize the available output range. Finally, the summing amplifier on the right combines the amplified differential signal with the DC offset, producing a single output that approximately spans the entire 0 to 5V range.

6.6 In-lab Requirements

6.6.1 Construction

This section focuses on constructing and testing the DC level shifter and differential-to-single-ended converter in both Ltspice and hardware. The measured oscilloscope results are then compared with the simulated waveforms to verify proper circuit operation and evaluate the performance of each design.

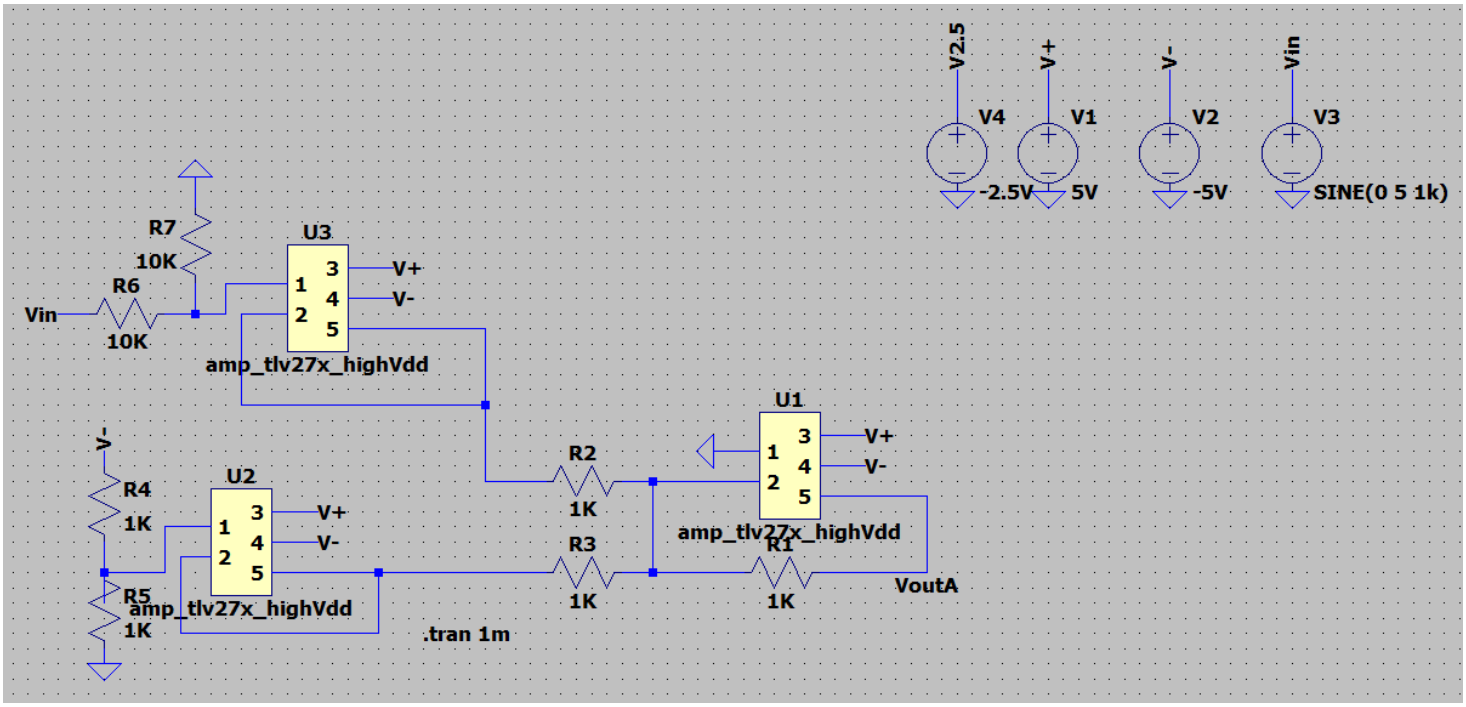


Figure 13: LTspice schematic of the three-op-amp DC level shifter used to convert the full ± 5 V input range into a single-supply output range.

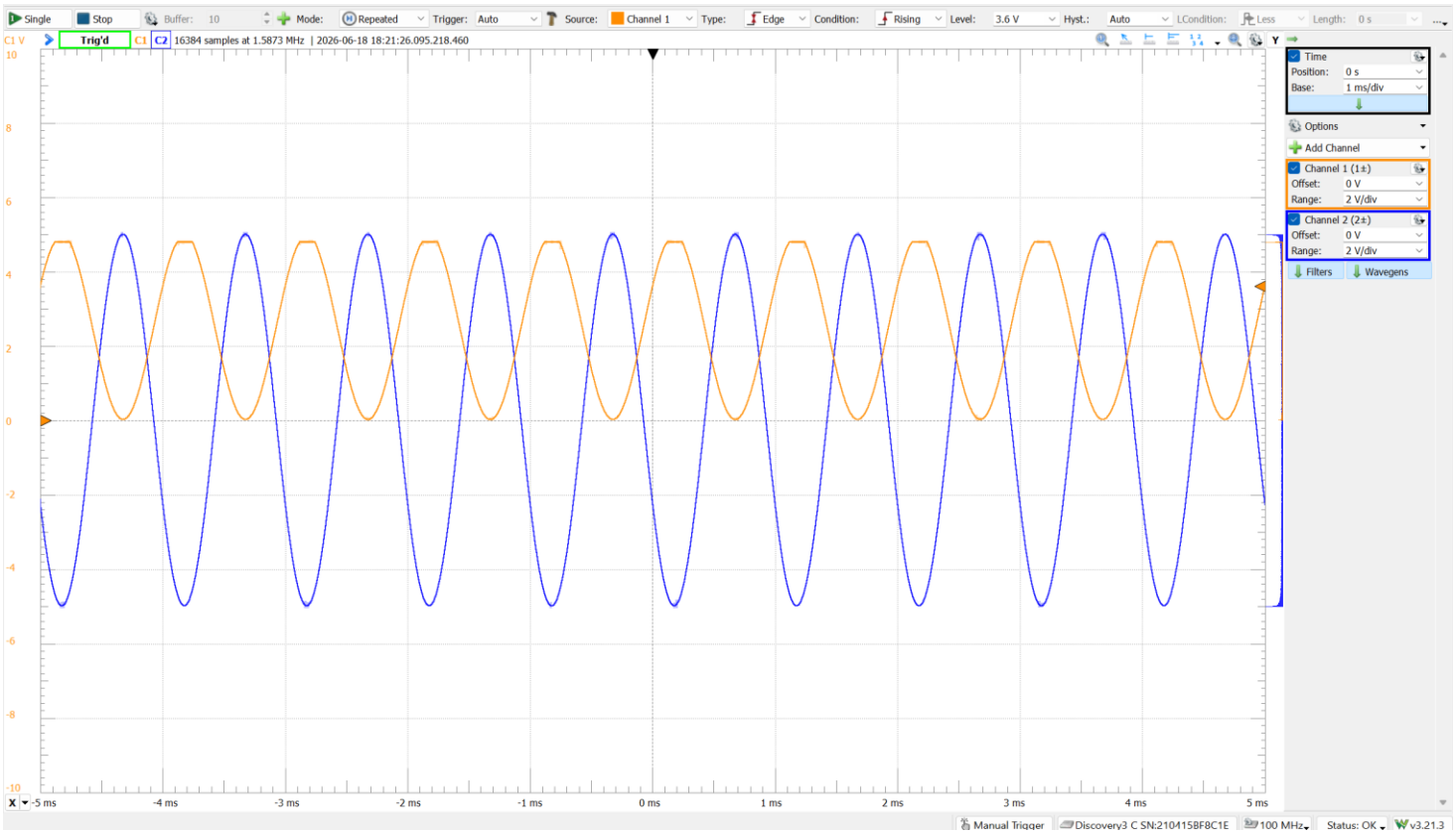


Figure 14: LTspice simulation and experimental oscilloscope comparison of the DC level shifter showing the measured input waveform and corresponding 0–5 V shifted output.

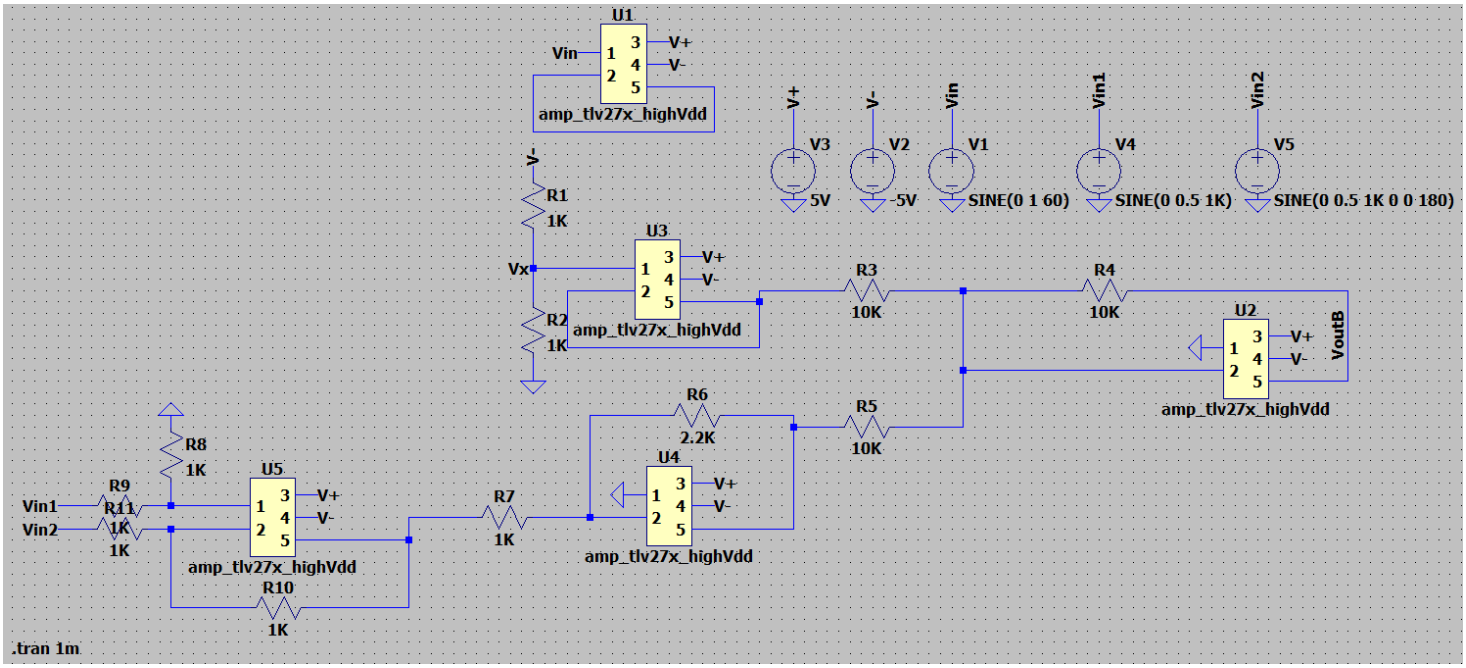


Figure 15: LTspice schematic of the combined differential amplifier and level shifting circuit used to maximize the available output voltage range.

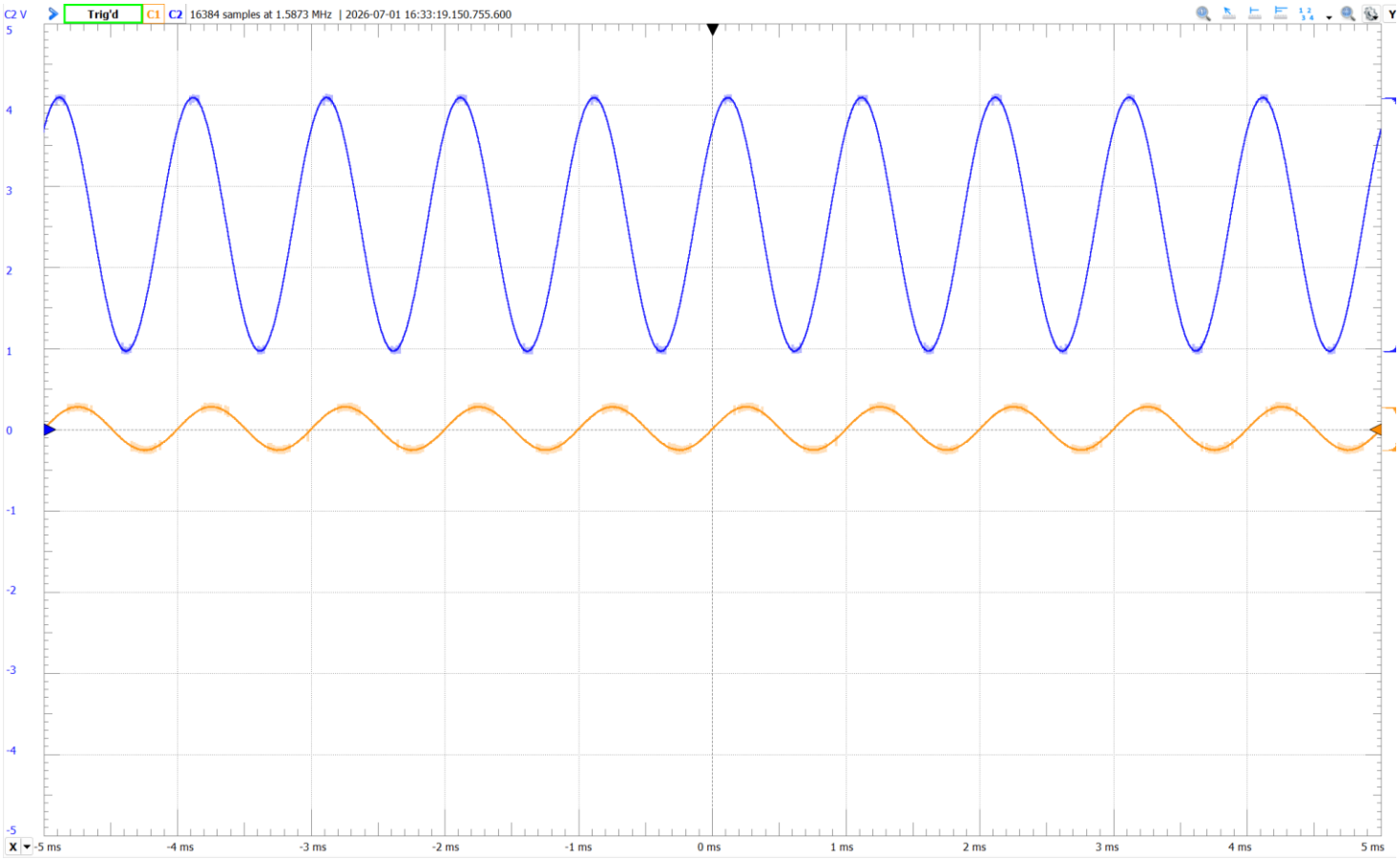


Figure 16: LTspice simulation and experimental oscilloscope comparison of the differential-to-single-ended converter showing the measured differential input signal and resulting single-ended output waveform.

Discussion Question:

The DC level shifter converts a bipolar input signal into a single-supply output by adding an offset while preserving the wave. This is done by generating a wave at a stable 2.5V reference with a voltage follower and combining it with the input via a summing amplifier. The differential-to-single-ended amplifier first subtracts the two out-of-phase input signals utilizing a differential amplifier which is made to reject any noise shared between them, resulting in a differential signal that is amplified and combined with a DC offset such that the final output uses most of the 0 to 5 V range.

The resistor tolerances can slightly change the gain in the circuit, leading to a small offset output and amplitude errors. This can be mitigated by choosing closely matched resistor values. Standard resistor values available in the lab kit were selected to closely match the calculated values while maximizing the output voltage range without clipping. If the resistor values used were much larger it could increase sensitivity to noise and input biased currents while having much smaller resistor values would draw much more current than if they were more normal and thus increase power consumption. Equal resistor values were utilized where equal weighting was required for voltages while the remaining resistor values were chosen to produce a 2.5V reference.

CONCLUSION

This lab explored several practical applications of operational amplifiers, including buffering, shifting, and differential-end-to-single-ended conversion. LTspice was used to simulate prior to making and testing physical circuits, demonstrating how operational amplifiers can preserve signal integrity, generate voltage offsets, and condition systems for other systems. The experimental results closely resembled the simulated behaviors, demonstrating the expected outputs for each circuit.