EE230 Electronics
Project 1: Fahrenheit to Celsius Analog Computer
April 4th, 2023

The Lab Rats

Christopher Scott
Cameron deLeeuw

Abstract:

In this project our goal was to build a celsius to fahrenheit converter. The formula for conversion is $F° = C° * (9/5) + 32$. Each degree being measured as 10mV / degree in either scale. To achieve this, we implemented a non-inverting amplifier with a gain of 1.8 and applied it to a second amplifier with a gain of 1. The second amplifier would be set up as a summing amplifier, this amp would add 320 mV to any signal applied to the non inverting terminal. With these implementations we were able to implement a circuit capable of celsius to fahrenheit conversion. While our circuit gave us some problems along the way, we were able to implement it successfully and create a circuit capable of producing a reliable output within the specified parameters.

Introduction:

Objective:

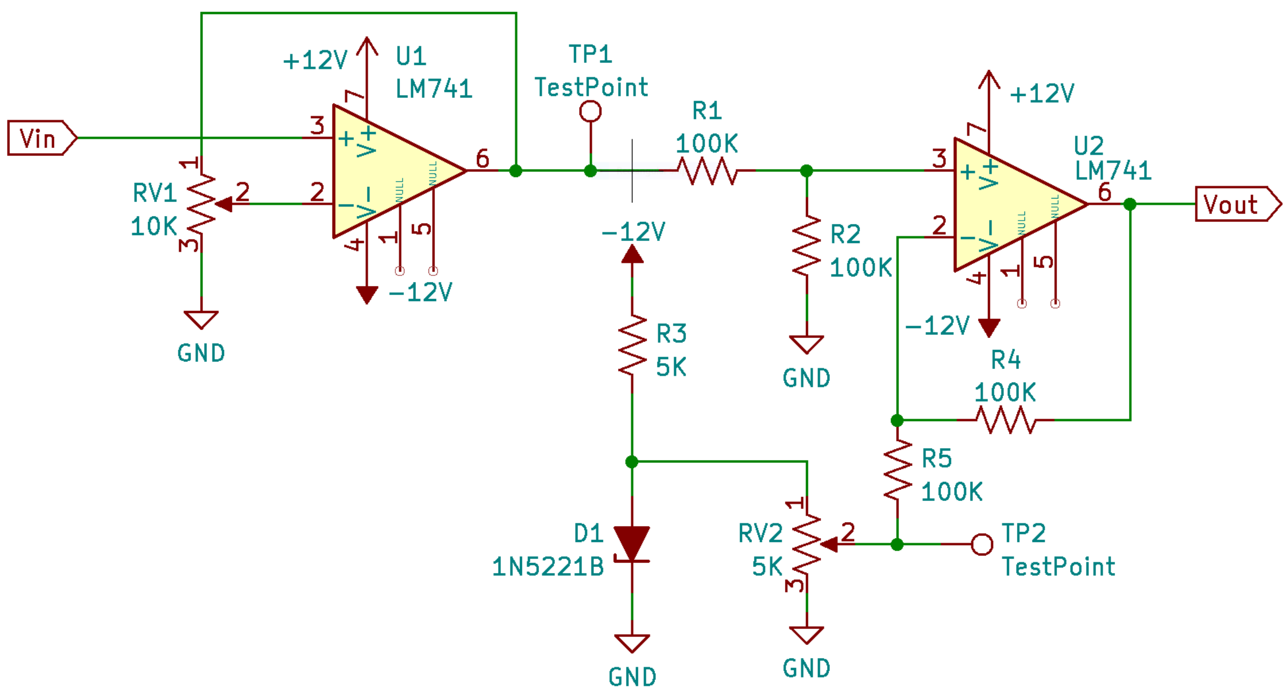
To implement a reliable circuit to convert celsius to fahrenheit within an accuracy of under 5%.

Materials:

Part	Schematic Name	Ideal Value	Measured Value	Percent Error
Resistor	R1	100 kΩ	99.09 kΩ	-0.91% ± 0.005
Resistor	R2	100 kΩ	99.68 kΩ	-0.32% ± 0.005
Resistor	R3	5 kΩ	5.001 kΩ	0.02% ± 0.01
Resistor	R4	100 kΩ	99.001 kΩ	-0.999% ± 0.0005
Resistor	R5	100 kΩ	100.0 kΩ	0% ± 0.5
Resistor	R6 (U1 offset pin 1)	-	3.957 kΩ	-
Resistor	R7 (U1 offset pin 5)	-	6.222 kΩ	-
Resistor	R8 (U2 offset pin 1)	-	1.534 kΩ	-
Resistor	R9 (U2 offset pin 5)	-	8.709 kΩ	-

Christopher Scott
Cameron deLeeuw

Potentiometer	RV1	10 kΩ	10.113 kΩ	1.13% ± 0.005
Potentiometer	RV2	5 kΩ	4.85 kΩ	-3% ± 0.08
Op-amp	U1	-	-	-
Op-amp	U2	-	-	-
Diode 1N5221B	D1	-	-	-



Circuit Schematic

Theoretical Analysis:

Operation of U1:

$A_V = 1 + (R_2/R_1)$

The First amplifier performs as a non-inverting amplifier with a closed loop grain described by the formula above. Adjusting the potentiometer, we found that the values of RV1 that would give us a gain of ≈1.8 is 5675Ω to ground, and 4562Ω to the output of the op amp. These values would give us a gain of 1.804V/V. This gain value can be more precise with resistance values of RV1 being 10kΩ and RV2 being 8KΩ This would give us a gain of 1.800 V/V

Operation of U2:

We needed to add 320mV to the signal from the output of U1. To do this, we implemented a summing amplifier. A negative feedback loop was added to the circuit connecting Vo to the inverting terminal of the amplifier making the device behave as we expected (not a comparator). To achieve a voltage addition of 320mV our gain has to be manipulated to = 2. With the requirement of a negative feedback loop, we created a voltage divider after the output of U1. This is necessary due to the gain formula of the amplifier $A_V = 1 + (R2/R1)$.

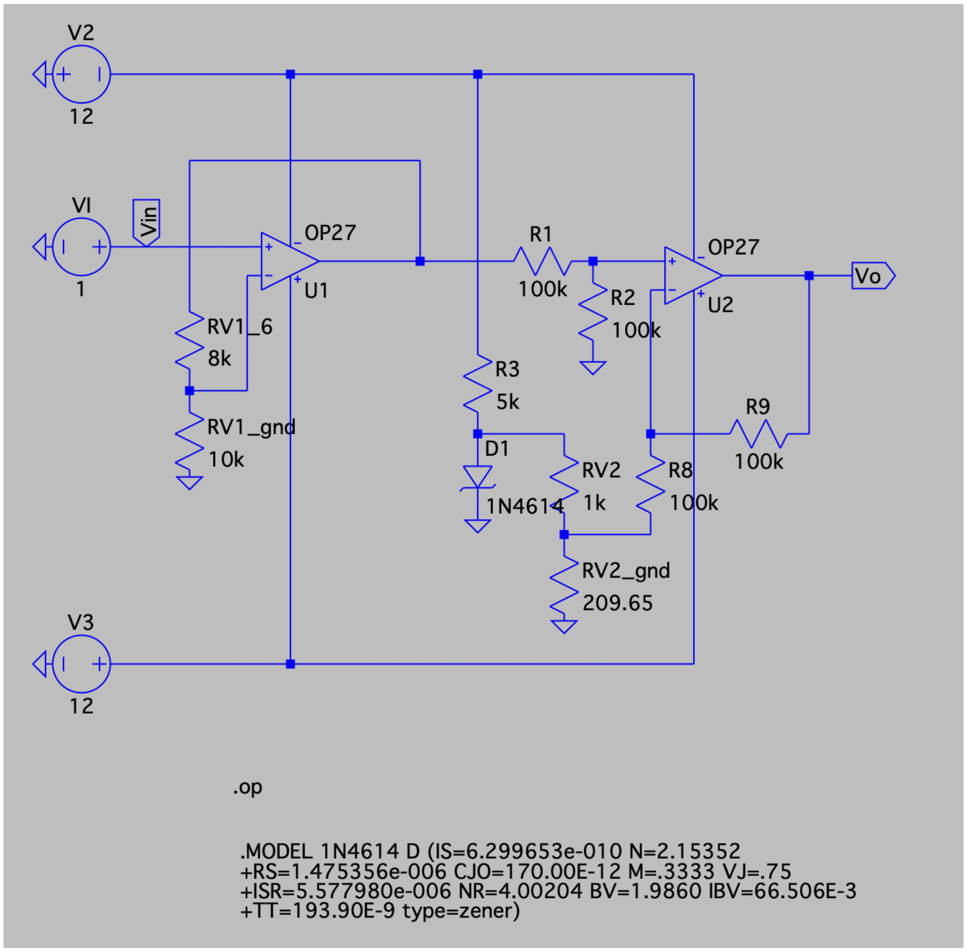
Simplified our gain is A_V = 1 + (1/1) = 2.

Due to the nature of our required gain. We could use any two resistors with the same value and achieve the desired gain.

To add voltage to the output of U1 we implemented a zener diode in parallel with a series of resistors. The resistors acted as a voltage divider and the zener diode acted as a voltage regulator. With the zener diode in reverse bias mode, the voltage across the diode will be equivalent to its zener voltage (V_z). With the 1N5221 zener installed into the circuit, V_z was found on the diodes datasheet to be 2.4V. Our potentiometer values to achieve a voltage of 320mV were 3.931kΩ and 963Ω. This implementation would add Voltage to the output. To achieve 0.320V exactly we would need to use the voltage divider formula

$Vo = Vin(R2/(R2 + R1))$

Christopher Scott
Cameron deLeeuw



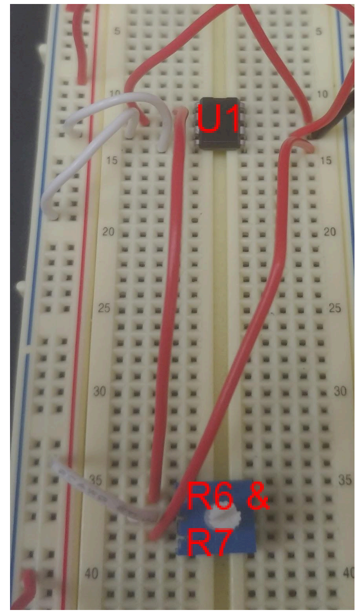
LTSpice Simulation

- During the simulation process, we used precise values to fix the gain and summation of the two amplifiers, RV1 was replaced by a 10kΩ resistor and RV2 was replaced with a 8kΩ resistor to achieve a gain of 1.800V/V.
- The only zener diode we knew how to implement into LTSpice was the 1N4614. This diode had a V_z around 1.85 so I adjusted the resistor values accordingly.

Christopher Scott
Cameron deLeeuw

Experimental Process:

Nulling the Offset:



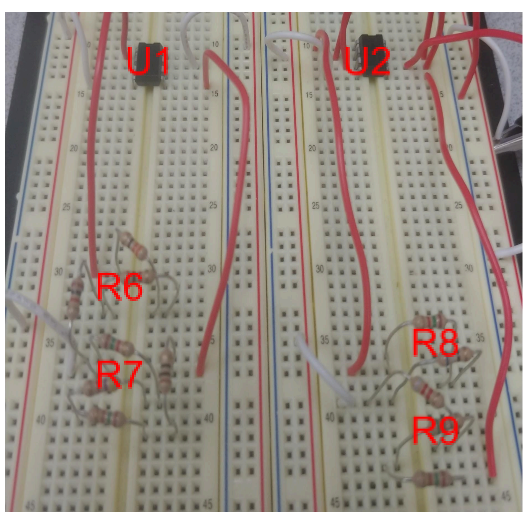
Knowing that the Op-Amps we were going to be using would likely need to be offset, we decided to null the offset voltage for each of them from the start rather than building the entire circuit first.

Following the same steps from a previous lab, we used a potentiometer in order to tune in the output voltage in order to get the value as close as possible to 0 for both Op-Amps

Once we tuned the potentiometer, we measured its resistance values and replaced it with chains of resistors for two reasons.

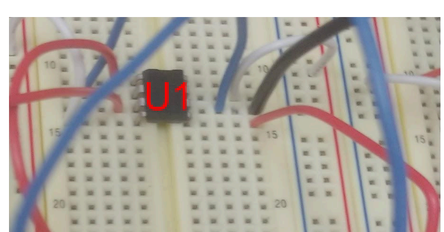
1) The potentiometer we used was very easily moved and may have changed value over time as a result of being jostled around in transport. So using resistors allowed us to tune in an exact value without worrying about it changing.

2) We had a limited supply of potentiometers and had to use them somewhat sparingly.



Op-Amps with Nulled Offsets

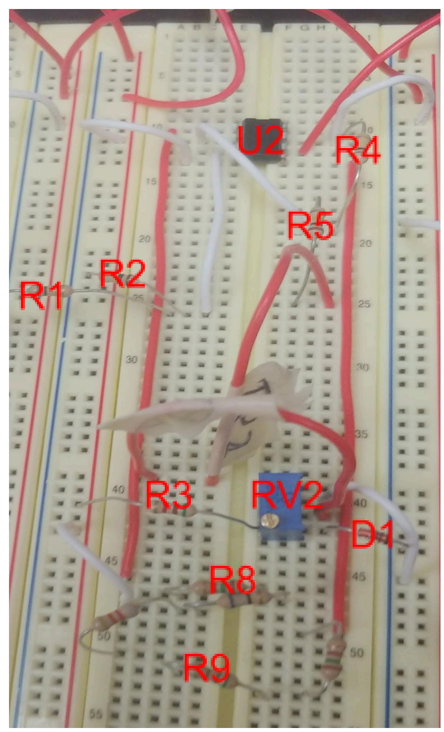
Stage 1:



Stage 1 of the circuit is a simple amplifier with a gain value of 1.8. So, after building the circuit up to test point one, it was as simple as tuning the potentiometer so that the output voltage was 1.8 times more than the input voltage. While this potentiometer could have been replaced with resistors, we wanted to keep it in place this time as we were no longer short on potentiometers and it enabled us to tune it’s value further if we encountered the need to do so down the line.

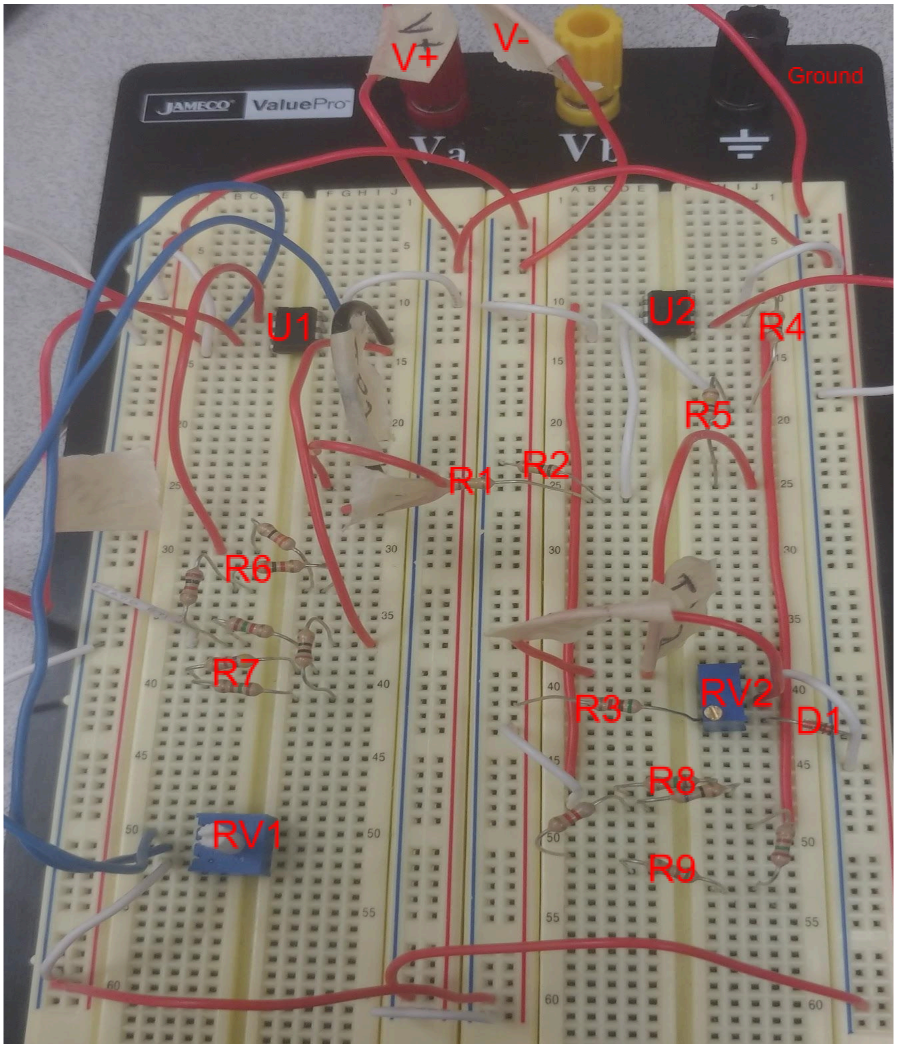
Stage 2:

Stage 2 was built and tested separately as its purpose was to add 320 mV. With a grounded input, we were able to tune the potentiometer such that Vout was a fixed value, specifically the 320 mV required.

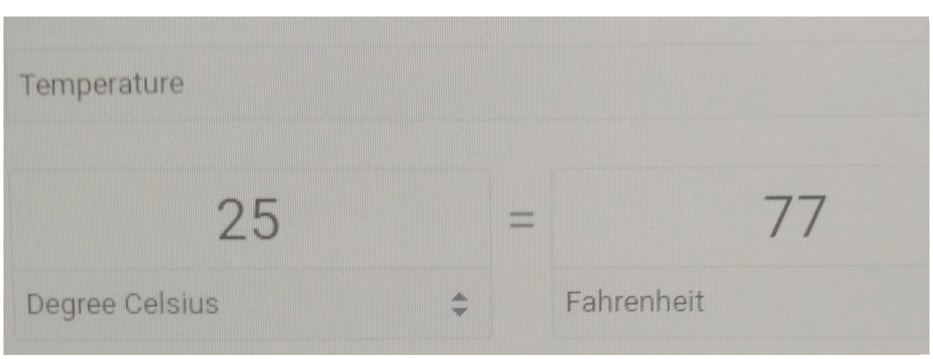


Full Circuit Operation:

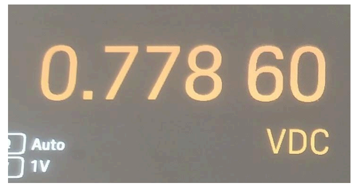
Once stages 1 and 2 were completed, the circuit worked as expected after simply connecting the two halves together. We verified this by running through various values between -5 V and 5 V for Vin and comparing our outputs against what the calculated values should be. These are two such outputs from that experimentation.



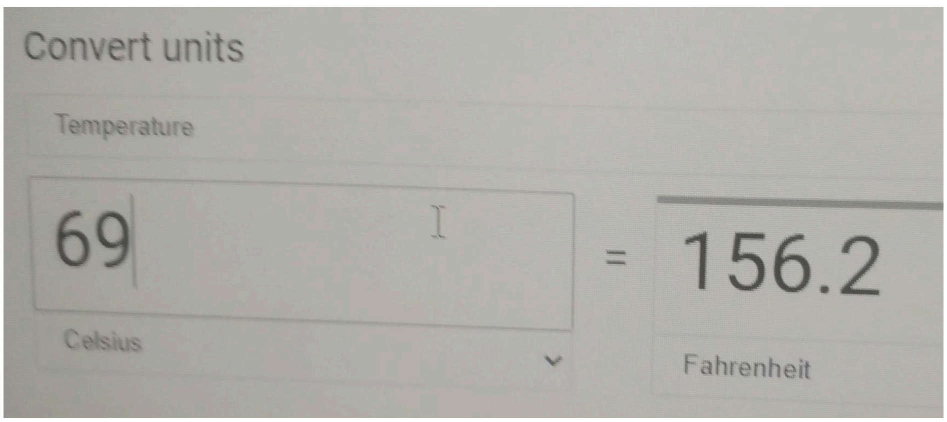
Built Circuit



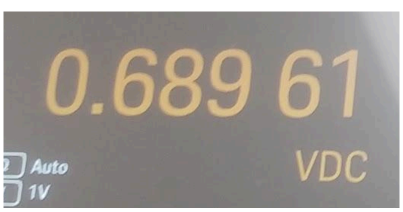
Theoretical Results



Measured Vin **Measured Vout**



Theoretical Results



Measured Vin **Measured Vout**

Conclusion:

Ultimately, we were in fact successful in creating the circuit as specified. While our output was perhaps less precise than it could have been, with some more slight tuning we could fairly easily have dialed in the output to be much more accurate. This inaccuracy was likely due to how difficult some of the potentiometers were to dial in with any precision, as well as how difficult it was to replace some of the potentiometers with perfectly exact resistor values. Even so, we were well within the 5% error that was set for us. If we were to do this again, we would likely buy more quality potentiometers to use, measure, and then replace with resistors on a circuit we would spend extra time on soldering together. In fact, this may be something we do in our spare time regardless.

References:

https://www.mouser.com/datasheet/2/268/SA5_41-1592147.pdf