The Electronic Scale

1. **… The voltage, Vout at the center nodes of each pair is the same. Can you see why? (Hint: what do two resistors in series form?).** Series circuits are voltage dividers and parallel circuits are current dividers (https://www.electronics-tutorials.ws/resistor/res_5.html).
   (Lab-report Q1) With respect to temperature changes, what advantage does the half-bridge configuration have over the quarter-bridge configuration?
   a. Resistivity r is a temperature-dependent property, so gage factor is not really constant (ME 120 Lecture 4: Strain and Force).
   b. Temperature effects can dominate strain effects; these result from thermal expansion or contradiction of the base material (in our case, base material is Aluminum) relative to the thermal expansion of the strain gage material (in our case, strain gage material is some metallic foil) (Carryer, "Introduction to Mechatronic Design", 1st edition, 2012, p. 303).
   c. By using two or four strain gages in a Wheatstone bridge, you can minimize the effect of temperature. These are called half-bridge and full-bridge configurations, respectively. See Figures 4 and 5. With all strain gages in a bridge at the same temperature and mounted on the same material, any changes in temperature affect all gages in the same way. Because the temperature changes are identical in the gages, the ratio of their resistance does not change, and the output voltage of the gage does not change. The simplest way you can correct for temperature drift is by using half-bridge or full-bridge configurations (http://www.ni.com/white-paper/3432/en/#toc4).
2. **(Lab-report Q2) Use the DMM to determine the nominal resistance of one of the gages. Figure 3 shows the schematic for the bridge. Record your results measuring the resistances between the black and red leads and between the black or red leads and either the green or the white leads (Black/red and green/white) [Black–green and then Black-white] [Red-green and then Red-white].**
   a. Between red and black leads is around 0.9994 kOhm
   b. Between red and white leads is around 0.7494 kOhm
   c. Between red and green leads is around 0.7493 kOhm
   d. Between black and white leads is around 0.7499 kOhm
   e. Between black and green leads is around 0.7496 kOhm
   f. Between white and green leads is around 0.9991 kOhm
3. **(Lab-report Q3) Apply 10 V across the red and black leads as shown in Figure 3. What voltage do you measure across the green and white leads?** Note: DMM's red cable (HI terminal) goes to strain gage's White wire, and DMM's black cable (LO terminal) goes to strain gage's green wire, so high voltage is at white wire and low voltage is at green wire. Anyways, with +10 V applied to the red and black leads of the scale, 0.523 mV was read on the white and green leads **(Lab-report Q4) If the resistances of all four strain gages were exactly the same, what voltage would you measure? What happens to this voltage if you *lightly* press on the scale platform?** If the resistances of all 4 strain gages were exactly the same, the voltage measured would be half the voltage source (https://www.electronics-tutorials.ws/blog/wheatstone-bridge.html). Again, without pressing anything, the voltage is 0.523 mV. If lightly pressing on the scale platform, the voltage increases slightly to around 1.45 mV, and the maximum voltage is around 2.27 mV, meaning resistance between the white and green leads decreased. However, amplification of the voltage is still required to get a sensitive scale reading.
4. N/A
5. *See circuit schematic and instructions* below. 100 Ohm == Brown Black Brown.

<u>In-amp (INA126), Strain Gage, Power Supply, and DMM Connection Instructions</u>

Power Supply Connections:

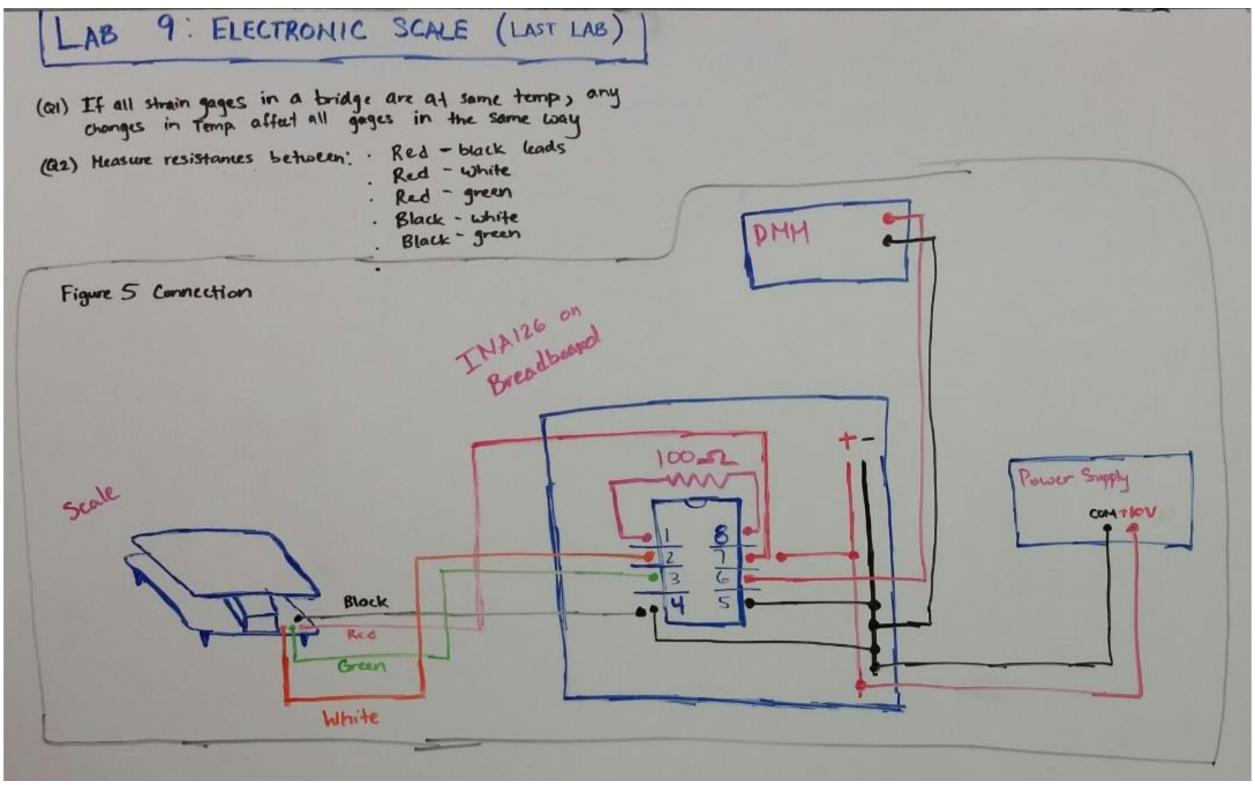
1. Make a +10 V rail on breadboard
2. Make a GND (AKA COMON GROUND) rail on breadboard
3. Connect -10 V of the power supply to GND rail

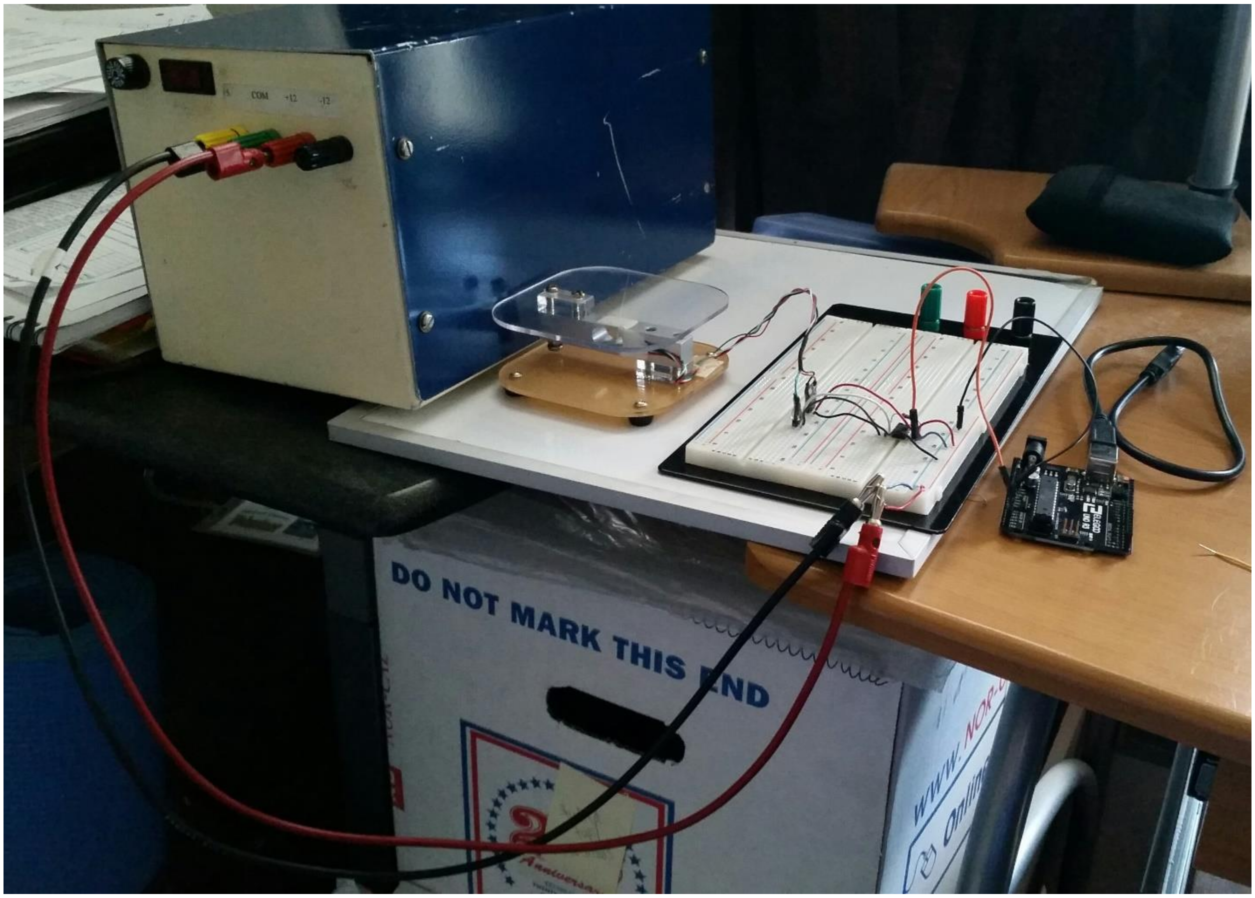
INA126, Strain Gage, Power Supply, and DMM Connections

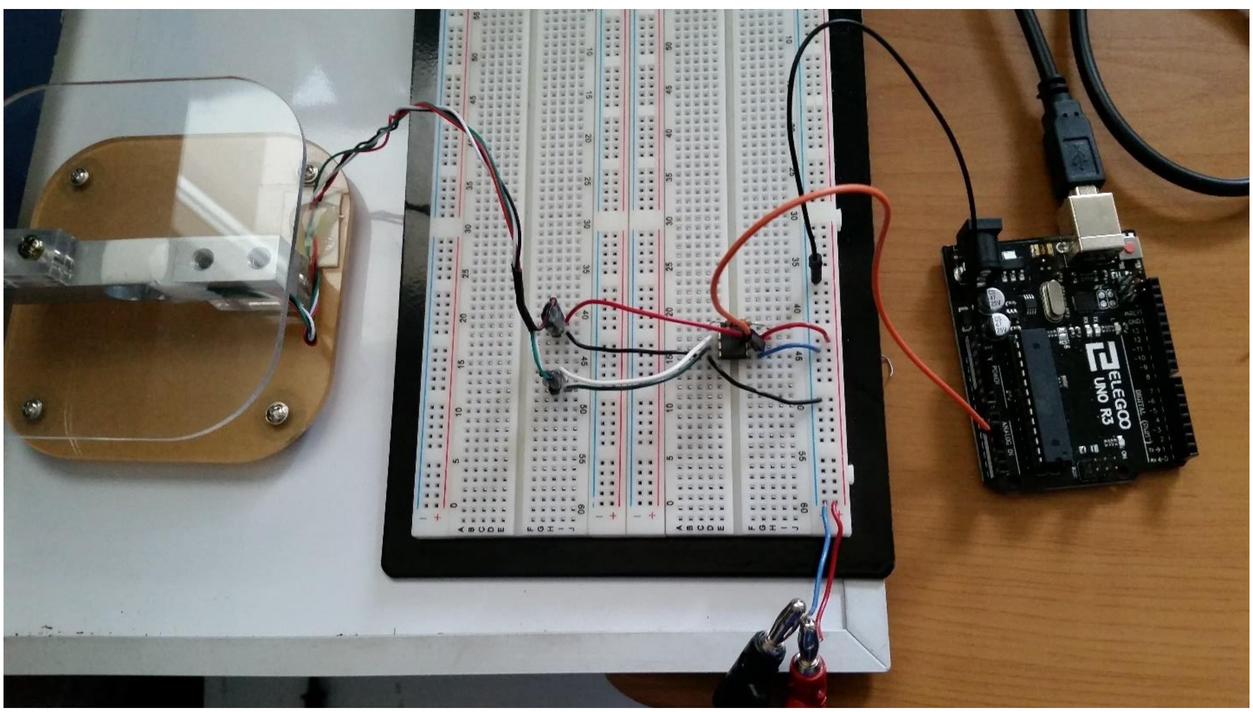
0. Place INA126 in the middle, between two rails, as shown in the *very colorful* Figure above
1. Connect INA126 Pin 1 (R_G) and INA126 Pin 8 (R_G) together with the 100 Ohm resistor
2. INA126 Pin 2 (V_{IN}^-) == connect to strain gage White wire
3. INA126 Pin 3 (V_{IN}^+) == connect to strain gage Green wire
4. INA126 Pin 4 (V^-) == connect to strain gage Black wire && GND rail
5. INA126 Pin 5 (Ref) == connect to GND rail
6. INA126 Pin 7 (V^+) == connect to strain gage Red wire && POWER rail
7. Connect DMM's red cable (HI terminal) to INA126 Pin 6 (V_{out})
8. Connect DMM's black cable (LO terminal) to INA126 Pin 5 (Ref)

Arduino Connections (For the next exercise "**Interfacing the Electronic Scale to the Arduino"**):

1. Disconnect DMM from INA126 Pin 6 and Pin 5
2. Connect Arduino Analog Pin A2 to INA126 Pin 6 (V_{out})
3. Connect Arduino GND to GND rail




COM
+12
-12
DO NOT MARK THIS END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It is always good practice to try to minimize the length of the input leads to the amplifier and the connection of the gain resistor. If you were going to design this scale as a product, you might want to locate the bridge and amplifier at the base of the cantilever, near the strain gages. (Why?) Positioning the Wheatstone bridge and in-amp at the base of the cantilever, near the strain gages, would prevent any delay in the signal to be passed through the Wheatstone bridge and ultimately through the amplifier, resulting in a falsely amplified signal. Also, this would shield against electromagnetic interference caused by sources such as transformers.

Measure the voltage at the output of the in-amp on pin 6. Verify that this voltage changes when you *lightly* press on the upper platform. If V_{out} exceeds 5 V for a load up to 1 kg, you will need to lower the gain of the amplifier before interfacing the output of the INA126 to the microcontroller. Verify this BEFORE proceeding to the next step, else you might need to buy a new Arduino! With +10 V applied to the red and black leads of the scale, and using the DMM, the maximum voltage output of the in-amp at pin 6 was around 2.5 mV.

Interfacing the Electronic Scale to the Arduino

6. **(Lab-report Q5a)** After connecting the output of the INA126 Pin 6 (V_{out}) to Arduino Analog Pin A2 and Arduino GND to GND rail, turn power supply on to supply +10 V. (Connecting the Arduino GND to the common GND rail stabilizes the reading). With no load applied, the max Serial monitor reading is around 164 (bits).

```
#define STRAIN_GAGE A2

void setup()
{
  Serial.begin(9600);
}

void loop()
{
  Serial.println(analogRead(STRAIN_GAGE));
  delay(500);
}
```

The Arduino has a 10-bit analog-to-digital (ADC) converter. This means that the ADC has a resolution equal to the reference voltage, V_{ref} = 5 V, divided by 2^{10}. For example, if the output from the scale circuit, V_{out} = 2.51 V, then the converted 10-bit result will be 514. What is the smallest voltage that can be detected by the Arduino's ADC? With a +5 V reference and a 10-bit ADC, the smallest voltage that can be detected by the Arduino's ADC, i.e. the Resolution of the Arduino ("Analog-to-Digital Converters"), is 0.004883 V:

$$Resolution = \frac{V_{ref}}{2^{10}}$$

$$Resolution = \frac{5\ Volts}{2^{10}}$$

$$\boxed{Resolution = 0.004883\ Volts = 4.883\ mV}$$

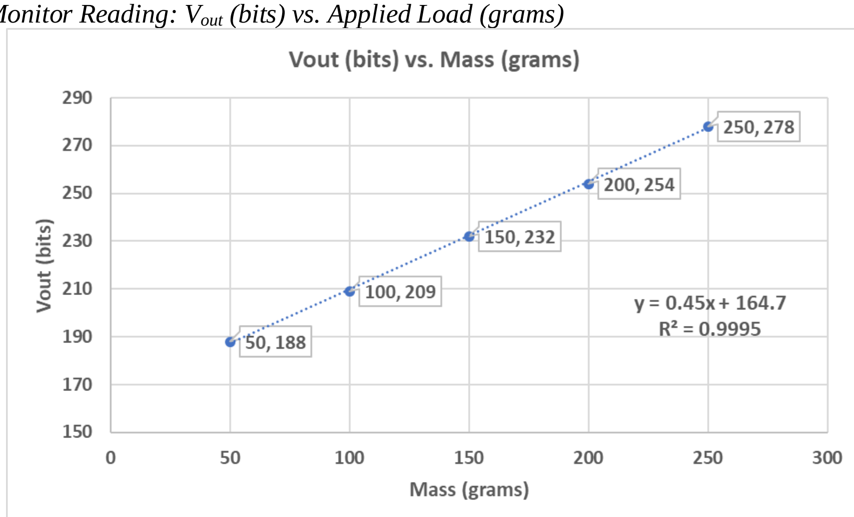
In theory, this is the smallest voltage that the analog to digital converter on the Arduino is capable of reading. Meaning that if a voltage any lower than 4.88mV was input to the Arduino analog pin, the Arduino would treat this as a value of 0 volts.

7. **Apply a set of known weights to the scale, and record Vo from the amplifier using the serial monitor value. Plot the analog reading vs. the applied load. How linear is your graph?** See the table below for tabulated data on Serial Monitor readings when a mass is placed on the scale. The resulting graph is linear,

with an R^2 value of 0.9995. R^2 value is the regression value, and it is a statistical measure of how close the data are to the fitted regression line. So the closer R^2 is to 1.00, the closer the values are to the trendline.

Mass (grams)	Serial Monitor reading of V_{out} of In-Amp (0-1023 bits)
50	188
100	209
150	232
200	254
250	278

Graph of Serial Monitor Reading: V_{out} (bits) vs. Applied Load (grams)



8. **(Lab-report Q5b) Write a program to run on the Arduino that will display the weight of any object on your scale.**
   a. Because the relationship between V_{out} and Mass is linear, you do not have to worry about inputting the equation of the line into the Arduino code; instead, you can simply add the offset value to the scale reading and input it into the Arduino code, and then use the map function (since the map function makes a linear proportion between two value ranges). However, note that if doing it this way, you can only get the weight of the, since you will input 0 to 500 into the map function
   b. Note that I also did it the more accurate way, which is using the equation of the line to print out the appropriate mass.
   c. Also, note that the program below has a calibration routing in the setup(), so it will only run once. The purpose of this is to get the zero value, so please don't place any masses on the scale platform during the calibration period (unless you want a certain mass to be the zero value). The calibration routine will take place in the first 5000 milliseconds (5 seconds) of the program; then, you can start placing masses on the scale platform and reading masses from the Serial Monitor.

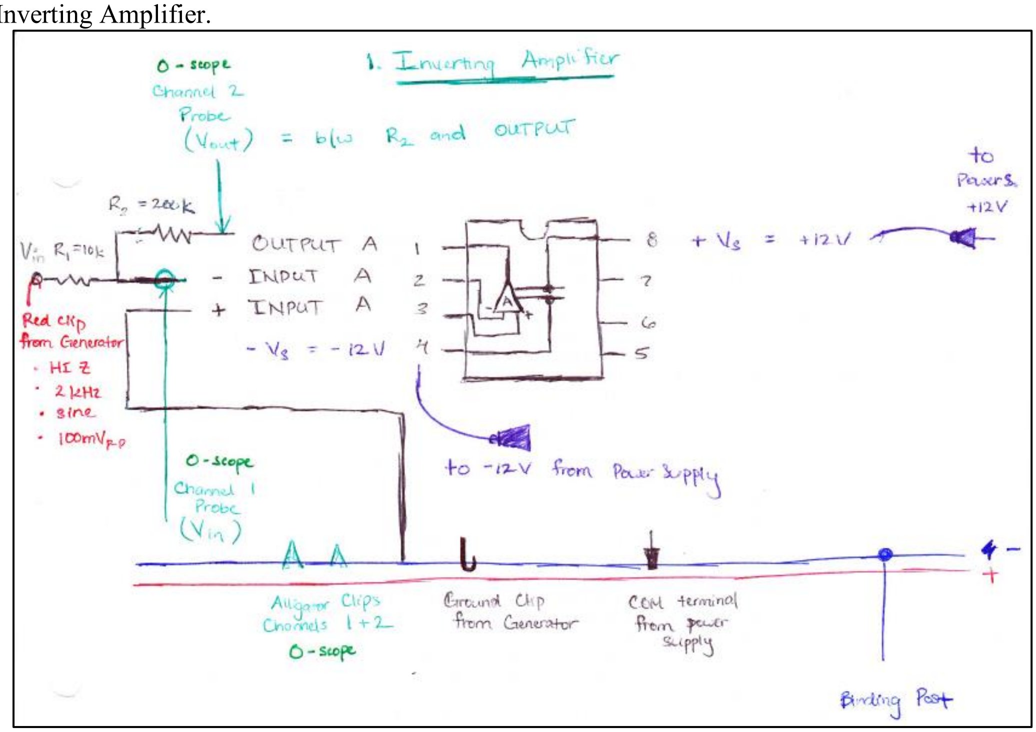
```
#define STRAIN_GAGE A2
int Zerovalue;
int Maxvalue;

void setup()
{
  Serial.begin(9600);

  /* Calibration Routine (getting the zero value):
   *   - Unless you want to make a certain mass the zero value,
   *     Do not place any masses on the scale platform
   *   - Takes place in the first 5000 ms (5 sec) of the program:
   */
  Serial.println("COMMENCE CALIBRATION ROUTINE \n");
  while (millis() <= 5000)
```

```
    {
      /* Get zero value (value when no load is on scale) */
      Zerovalue = analogRead(STRAIN_GAGE);
    }
    Serial.println("CALIBRATION ROUTINE ENDED \n");
    delay(3000);
}

void loop()
{
  /* With the Calibration Routine ended, start reading the masses. */
  int weight = analogRead(STRAIN_GAGE);

  /* Use the equation of the line to determine the masses. */
  weight = (weight-164)/0.45;

  /* Alternatively, use the fact that the relationship between Vout and Mass
     is linear, and account for the offset. If no load was applied, the Serial
     Monitor read 164, making this my Zero value. */
//   Maxvalue = Zerovalue + 164;
  /* Then, use the map function to make a linear proportion between Vout and
     Mass. 500 kg is the total mass of all the masses. */
//   weight = map(weight,Zerovalue,Maxvalue, 0, 500);

  Serial.println("Weight: " + String(weight));
  delay(500);
}
```

9. **(Lab-report Q6) <u>How linear is the relationship of V_{out} to the applied weight in lbs?</u> (Hint: If you plot in Excel, you ask for equation output and R^2 output.)** The resulting graph is linear, with an R^2 value of 0.9995. R^2 value is the regression value, and it is a statistical measure of how close the data are to the fitted regression line. So the closer R^2 is to 1.00, the closer the values are to the trendline.

Optional Extra Credit: Op-amps and Amplifier Circuits

1. Inverting Amplifier.



<u>Do the voltage peaks appear to be opposite each other?</u> <u>Does the amplitude of the output signal agree with your gain calculation?</u> The voltage peaks did appear opposite each other, as seen in Figure 5, consistent with the – sign in the gain. The amplitude of the output signal, compared to the amplitude of the input signal, agrees with the inverting amplifier's gain of -20.

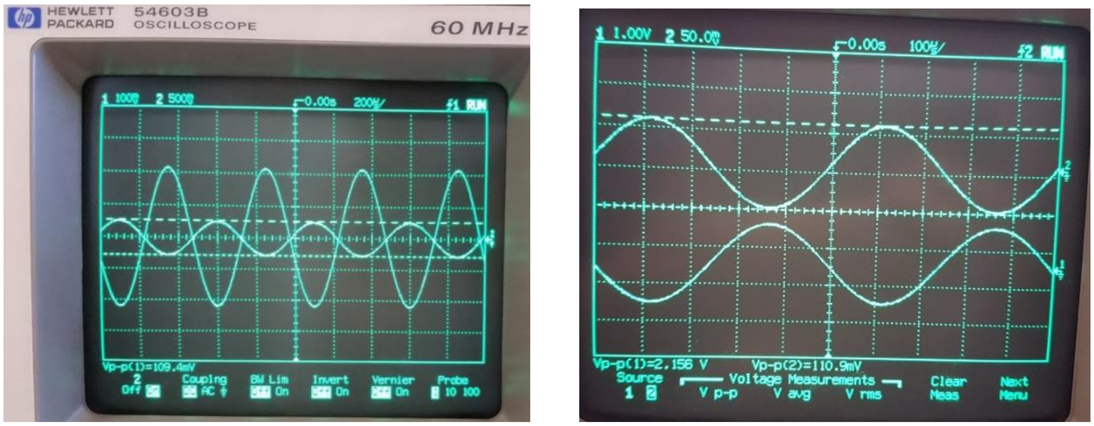


Figure 5. The first circuit constructed consisted of an inverting amplifier. Shown here is the oscilloscope monitor, displaying Channel 1 (input of the amplifier) and Channel 2 (output of the amplifier), given a sine wave from the function generator.

Increase the function generator amplitude until the op amp output appears to be chopped off at the peaks (also called, 'clipped'). At what input amplitude is the output clipped? <u>Explain why the output is clipped.</u> At an amplitude of 1.070 $V_{P\text{-}P}$ on the function generator, the output starts to get clipped, shown in Figure 6. The output was clipped because the output voltage of the OPAMP exceeded the supply voltage, which was $\pm 12\ V$. The reason why the output was larger was because the amplifier amplifies, or multiplies the amplitude of the input signal by -20. The output of the OPAMP was clipped at about 23.74 $V_{P\text{-}P}$, which is consistent with the theoretical clipping at 24 $V_{P\text{-}P}$.

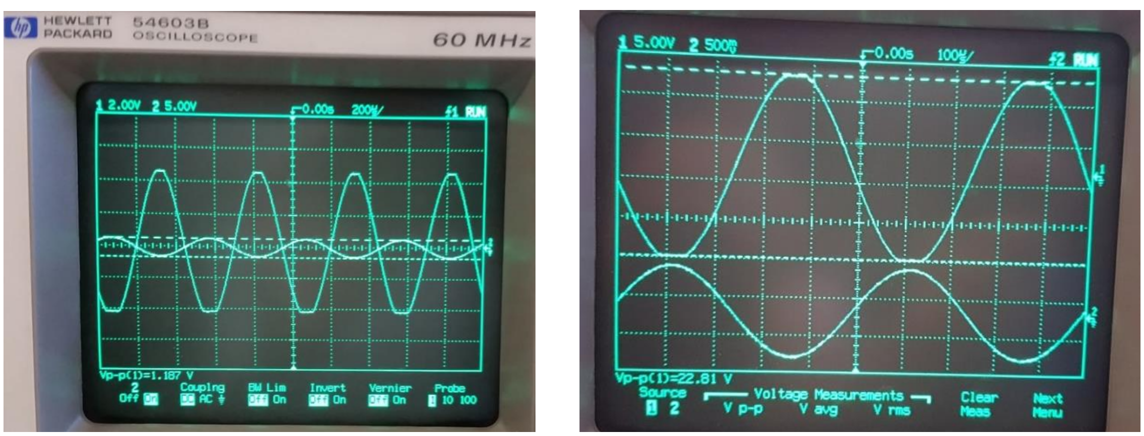
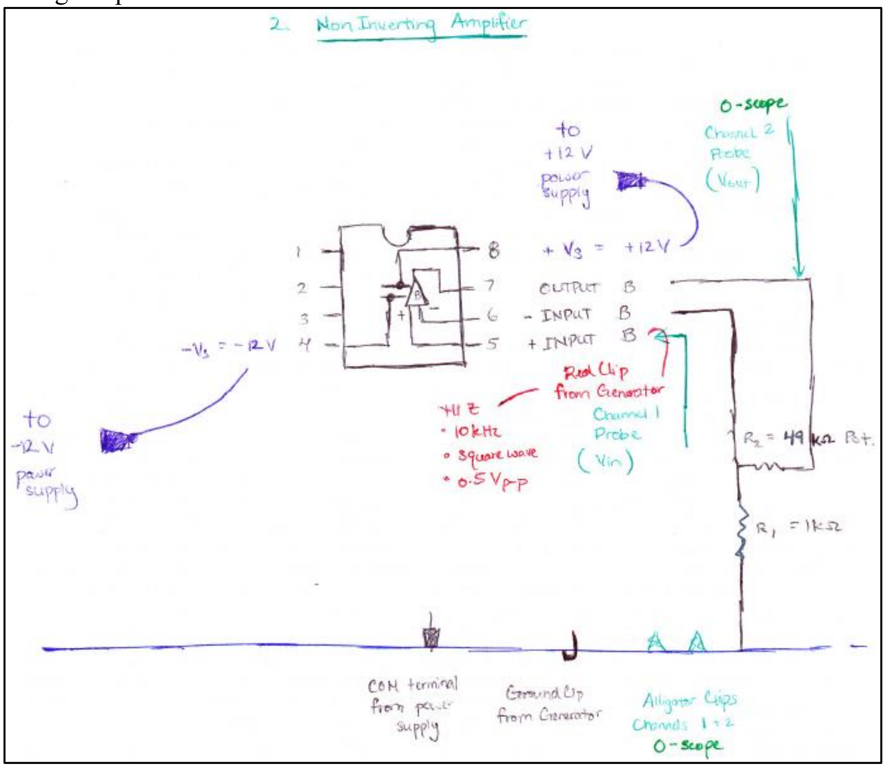


Figure 6. The first circuit constructed consisted of an inverting amplifier. Shown here is the oscilloscope monitor, displaying the result of increasing the function generator amplitude until the output of the amplifier was clipped.

2. Non-Inverting Amplifier.



<u>Are the voltage peaks synchronized?</u> <u>With a square-wave, how would you tell if the voltage peaks were being chopped off?</u> Most importantly, <u>what is the gain of this circuit?</u> As seen in Figure 10, the voltage peaks are indeed synchronized (in phase). In other words, the voltage peaks of the input are directly lined-up with the voltage peaks of the output waveform. This is characteristic of non-inverting amplifiers, which do not make the output signal opposite of the input signal.

With a square wave, at high enough voltage amplitudes, instead of clipping the output peak, the circuit simply lowered the peak value of the output waveform. In other words, clipped voltage peaks are noticed when one continues to increase the input's amplitude (from the function generator, for example), and then the output cannot go past a certain point and are again represented by a horizontal line at the peaks.

The measured gain of this circuit was 2.70.

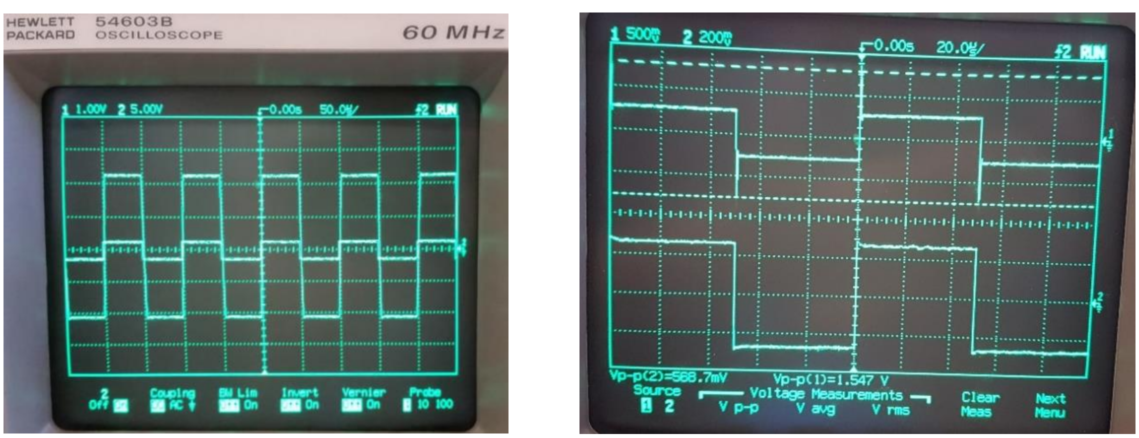


Figure 10. The second circuit constructed consisted of a non-inverting amplifier. Shown here is the oscilloscope monitor, displaying Channel 1 (input of the amplifier) and Channel 2 (output of the amplifier), given a square wave from the function generator.