The Electronic Scale

Learning Objectives

By the end of this laboratory experiment, the experimenter should be able to:

- Explain what an operational amplifier is and how it can be used in amplifying signal sources
- Configure, build, and test several common amplifier types.
- Explain what a Wheatstone bridge is and how it is used in measurement systems
- Interface an analog signal source to an A/D converter on a microcontroller and write a program to determine its voltage
- Build a digital electronic scale using strain gages, an amplifier, an A/D converter, and a microcontroller

Components

Qty.	Item
1	ATmega16 microcontroller with STK500 interface board, and serial cable
1	Solderless breadboard
1	LF353 dual operational amplifier
1	INA126 instrumentation amplifier
1	Cantilever beam assembly with strain-gauges mounted on the top and bottom surfaces near the base
1 ea.	1 k resistor, 4.7 k resistor
2 ea.	10 kΩ resistors, 200 k resistors
1 ea.	1 kΩ trim pot, 100 kΩ trim pot
1 ea.	0.1 μF capacitor, 10 μF capacitor

Introduction

The Devices

Figure 1 shows two common packages for operational amplifiers. The single package on the left contains one operational amplifier. The LF741 was one of the earliest IC op-amps and is still widely used. There are many, many varieties of op-amps available today (see http://focus.ti.com/lit/an/slod006b/slod006b.pdf for example). In this lab we will be dealing with op-amps designed for small signal amplification. There are also power op-amps that are designed to source or sink relatively large currents at relatively high voltages. Small-signal single op-amp IC's are usually pin-compatible with the '741, but one should always check the data sheets to be sure. One of the op-amps we will use in this lab experiment is the LF353. It contains two independent op-amps as shown. Some op-amps come in quad-packages that contain four independent op-amps.

Op-amps are active devices, which means they must be *powered* in order to function. The typical configuration for general purpose op-amps will use symmetrical positive and negative supply voltages ($\pm V_S$) typically in the range between ±5 V and ±15 V. There are some op-amps that are designed to work with single-sided supplies, i.e., where $-V_S$ is ground, and $+V_S$ is typically +5 V to +15 V. There are other op-amps that can be operated at lower and higher supply voltages.

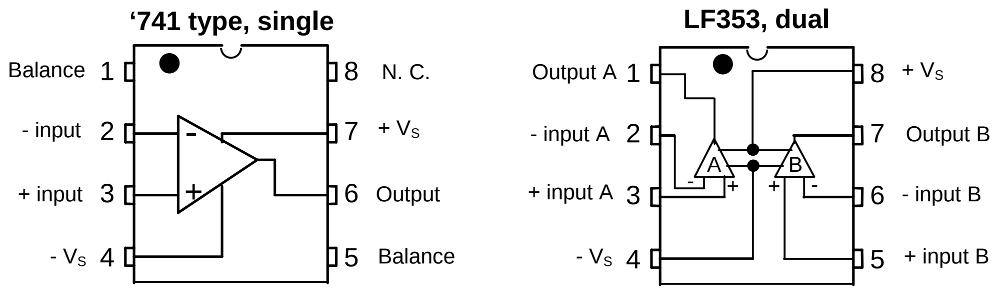


Figure 1 **Examples of single and dual op-amp IC packages.** The ‘741 was one of the earlier, but still very common, general purpose IC op-amps. Both the ‘741 and LF353 should be powered with symmetrical positive and negative power supplies (see their data sheets for maximum limits). We will use the LF353 dual op-amp in this experiment.

Procedure

1. Design and construct an inverting amplifier (see Figure 2) with a gain of -20. Use a 10k resistor for R1. This will save you time later). Note the minus sign on the gain. The output polarity is *inverted* from the input. This is why it is called an “inverting amplifier.” What must the resistance of R2 be? Set up the power supply for voltages of ±12 V ***before*** connecting the power supply to the op-amp. Turn off the power supply before you wire it to the op-amp. ***It is always a good idea to do whatever wiring you need with all power to the circuit turned off.***

   To test your circuit, first, set up the function generator with high-Z termination to output a **2 kHz** ***sine wave*** with an amplitude of 100 mV peak-to-peak (p-p). Check the output of the function generator with the ‘scope first before you connect it to the amplifier. Then, connect the ‘scope probe from Channel 1 to the input of your amplifier circuit, and the ‘scope probe from Channel 2 to the output of the amplifier. Where should the ground clips of the scope probe be clipped? Before you attach the clips, turn to the last page to check your answer.

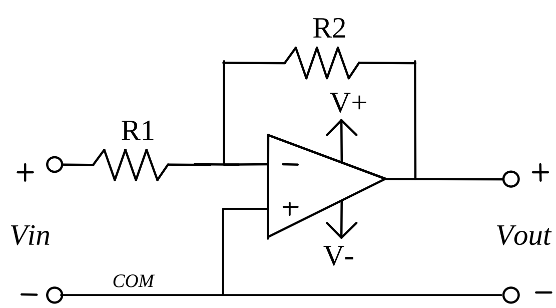


Figure 2 **An inverting amplifier.** The gain of the amplifier is -R2/R1. It is always a good idea to keep the leads to the inputs of the op-amp and the feedback loop short to minimize noise pickup.

Now apply power to the circuit, and connect the function generator to the input of the amplifier. Compare the signals from Channel 1 and 2 displayed on the screen. **Do the**

voltage peaks appear to be opposite each other? **Does the amplitude of the output signal agree with your gain calculation?** 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? **Explain why the output is clipped.**

2. Using the other op-amp on the LF353, construct a non-inverting amplifier with a gain of 50 as shown in Figure 3. Let R1=1k, and use a 100 k trim pot for R2. The gain of this circuit is (R1+R2)/R1.

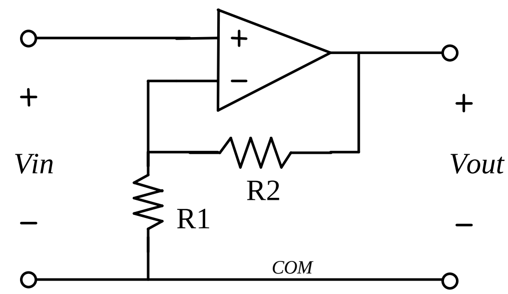


Figure 3 A non-inverting amplifier. The gain of the amplifier is (R1+R2)/R1.

Test this circuit in the same manner as before, then input a **10kHz** ***square-wave*** with an amplitude of ***0.5V p-p***. Compare the two signals displayed on the screen. **Are the voltage peaks synchronized?** **With a square-wave, how would you tell if the voltage peaks were being chopped off?** **Most importantly, what is the gain of this circuit?**

The Electronic Scale

3. Obtain a board with a cantilevered ***strain-gauge bracket*** from the instructor. These strain gauges convert mechanical strain into a proportional change in resistance. Here, we're going to incorporate the strain gauges into a circuit called a ***Wheatstone bridge*** as shown in Figure 4. Basically, a Wheatstone bridge uses four resistors, which are grouped into two pairs and connected to a voltage supply. The resistors in each pair are identical in value to each other, but not necessarily equal to the resistors in the other pair. For example, one pair might consist of two 10k resistors, and the other two might be 20k resistors. Even though the resistance of one pair is double in value of that of the other, the voltage, V_{out} at the center nodes of each pair is the same. Can you see why?

   In fact, the only way V_{out} will change is if one of the resistances changes, and this is where the strain gauge comes in to play. By replacing one of the pairs of resistors in the Wheatstone bridge circuit with the strain gauges that are mounted on the beam, the voltage at their common node will vary according to the strain in the beam. Since one strain gauge is on top, and the other is on the bottom directly beneath it, they will experience equal and opposite strains. Accordingly, their resistance will change by equal and opposite amounts. Also, because of this configuration, the bridge compensates itself for changes in temperature (how?). All of these factors ensure that the circuit behaves in a very linear fashion. We will also add a variable resistor, called a trim-pot, between the two fixed resistors, for the purpose of offset correction. That is, we want to make V_{out} = 0 V when no force is applied to the beam. (A question to ponder: why is the trim-pot needed if the nominal values of the pair of strain gages and pair of fixed resistors are the same?)

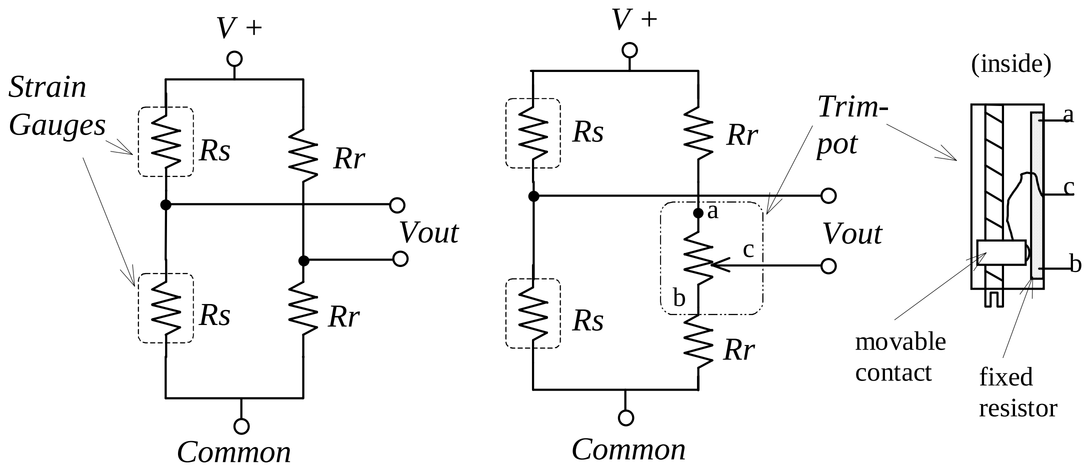


Figure 4 Wheatstone bridge (left) and Wheatstone bridge with offset adjustment (right). The construction of the trimpot (variable resistor) is also shown.

4. Construct the Wheatstone bridge with offset adjustment shown in Figure 4 using the strain gauged cantilever beam, a multi-turn, ***1 kΩ trimpot*** and ***two 10 kΩ** resistors* on the breadboard. There are 3 leads coming from the strain gauge fixture. One of the three connects to two wires coming from the strain gauges. V_{out} will be measured between this lead and the wiper of the trim pot as shown in Figure 4.

   Measure the nominal resistance of the strain gauges, both separately and in series, and record the values. Also, measure the value of the other resistance in series, and record these values as well.

   Arrange the leads from the strain gage fixture so that the voltage at the node where the two strain gages connect will ***decrease*** when a weight is hung on the beam. (To get this right, you will have to remember how a strain gage's resistance responds to strain. When you hang a weight on the beam, the upper gage stretches, and the lower gage shortens.) Once this is accomplished, apply 12 volts to the circuit. Use the voltmeter, and measure V_{out}. Turn the trimpot screw until V_{out} gets as close to zero as you can get it. With $V_{out} \approx 0$, the Wheatstone bridge is said to be "balanced." **What happens to the voltmeter reading if you press LIGHTLY on the end of the bar?** You now have an 'electronic scale' that produces a voltage which depends on the force applied to the cantilever beam.

5. Because the change of voltage across the bridge is relatively small for reasonably sized loads applied to the cantilever, it is desirable to amplify the bridge voltage to improve the sensitivity of the electronic scale. To do this, we will use an instrumentation amplifier. An instrumentation amplifier is specifically designed to amplify the difference in two signals, while ignoring the part of the signal that is common to both. The ratio of the gain of the differential signal to the gain of the common signal is called the Common Mode Rejection Ratio (or CMMR for short). For a good instrumentation amplifier, the CMRR can be on the order of 90 dB or more (i.e., a factor of 30,000 or better!) This is exactly what is needed here. Figure 5 shows a schematic of the INA126 instrumentation amplifier from Texas Instruments, which you will use.

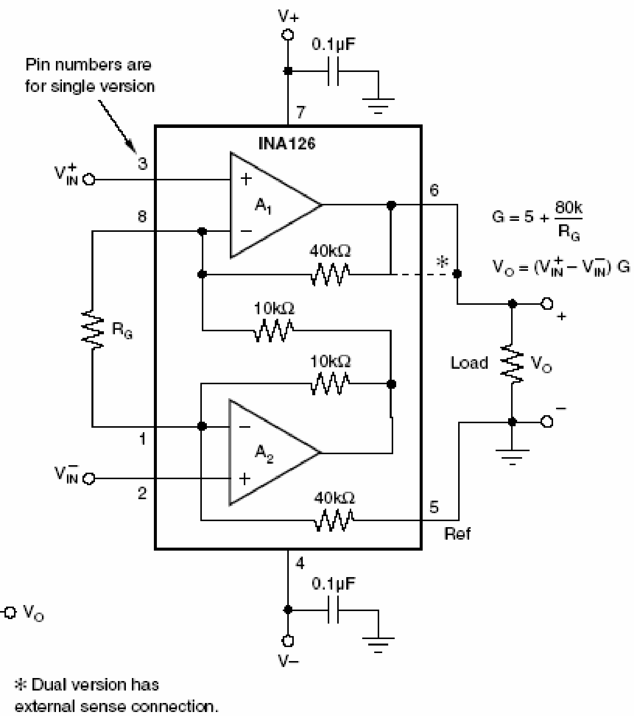
6. Implement the amplifier as shown in Figure 6 with a gain of approximately 1000. Use ±12 V for the supply voltages for the INA126 It is always good practice to try to minimize the

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?)

Measure the voltage at the output of the op-amp. Adjust the trim pot, and try to get the offset voltage as low as possible.

DESIRED GAIN (V/V)	R_G (Ω)	NEAREST 1% R_G VALUE
5	NC	NC
10	16k	15.8k
20	5333	5360
50	1779	1780
100	842	845
200	410	412
500	162	162
1000	80.4	80.6
2000	40.1	40.2
5000	16.0	15.8
10000	8.0	7.87

NC: No Connection.



Also drawn in simplified form:

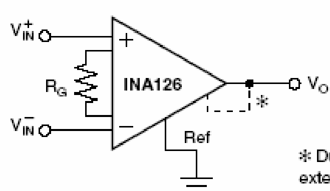


Figure 5 INA126 pinout and guide to configuring its gain. One resistor, R_G, is all that is needed to set the gain of the amplifier, which can range from 5 to 10,000. The internal connections of the pins are shown. Note that the actual physical location of the pins does not correspond to the location shown in the drawing. The ordering of pins 1-8 around the edges of the INA126 is like that for the chips shown in Figure 1.

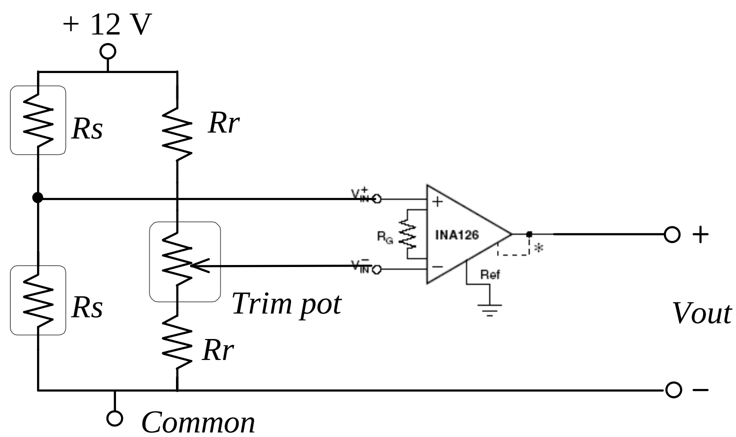


Figure 6 The electronic scale circuit schematic. The strain gauges are placed in a Wheatstone bridge, and an instrumentation amplifier amplifies the bridge voltage. Although not shown, the supply voltages for the INA126 are ±12 V.

7. Once this is done, press lightly on the bar. **What happens to V_{out}?** If V_{out} exceeds 5 V you will need to lower the gain of the amplifier before interfacing the output of the INA126 to the microcontroller.

8. As shown in Figure 7, add a low-pass filter to the output of the second amplifier. Use a 4.7k resistor and 10 μF capacitor. The idea is to filter out high-frequency noise. What is the corner frequency for this filter?

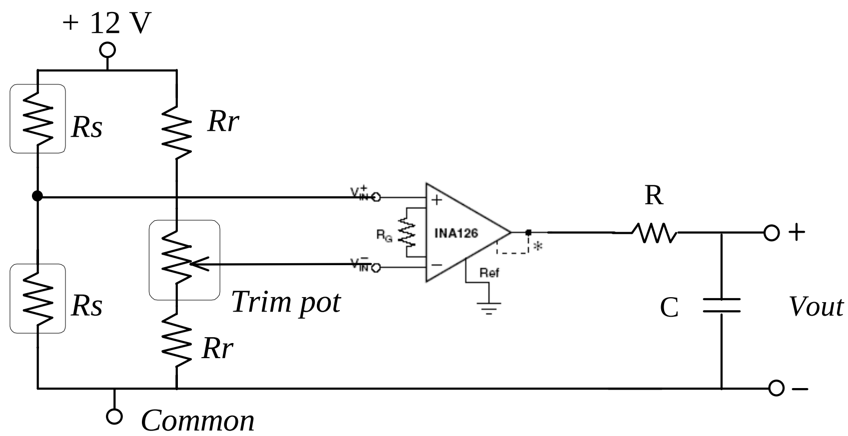


Figure 6 The electronic scale circuit with low-pass filter. The low-pass filter will attenuate high frequency noise.

11. **Determine the overall scale factor of V_{out} in Volts/lb by making a series of measurements of known weights.** The process of developing the scale factor is called "calibration". **<u>Finally, get the 'mystery' weight from the T.A and see if you can determine its weight using your calibrated scale.</u>**

Interfacing the Electronic Scale to the ATmega16 Using the ATmega16's A/D Converter

10. Once you are satisfied with the amplified bridge voltage from Step 9, you will interface the output of the scale to the analog-to-digital (A/D) converter on the ATmega16 chip. An A/D converter is a device that converts an analog voltage into a digital number. The range of numbers depends on the number of bits the converter has. The ATmega16 can support either 8 or 10-bit conversion, depending on the speed or accuracy you desire. If 8-bit conversion is selected, the converted voltage will thus be a binary number between 0 and 255 (i.e., 2^0 and 2^8-1, or 00000000 and 11111111. For a 10-bit conversion, the digital values will range between 0 and 1023. (There are actually eight, 10-bit A/D channels available on PORTA. PA0 through PA7 correspond to channels 0 – 7, respectively. See the ATmega16 datasheet pp. 204 and following for more details). So what voltage corresponds to which binary number? This correspondence depends on what V_{ref}, the A/D voltage reference, is. If the analog reference V_{ref} = 5 V, and the output from the scale circuit, V_{out} = 2.51 V, then the digital 8-bit result will be 128. **<u>What should the 10-bit result be?</u>**

    A code ***fragment*** that will setup the A/D inputs and perform an 8-bit conversion, storing the data in a variable is available on the ME 106 website (main_scale.c) Study the program, and understand it before proceeding further. Test your understanding by applying a DC voltage (<u>less than</u> 5 V) to one of the channels of the A/D converter on the ATmega16 using a jumper wire that your laboratory instructor will give you. Make sure that you are able to successfully read and display the voltage applied before going on.

11. Connect the output of the electronic scale to the appropriate pin of PORTA using the jumper from step 10. **Write a program that will display the weight of an object hanging on the scale.**

Final Questions

1. **How linear is the relationship of V_{out} to the applied weight in lbs?**

2. **How much did the offset change during your measurements? Why does this happen?**

Scope ground clips. If you remember from the first lab, because the circuit uses a *common ground*, we can attach the ground clips anywhere in the circuit. Actually, we only need to attach one of the ground clips to get a stable trace. Make sure that if you attach both ground clips, you attach them to the ***same point*** in the circuit. If you attach them to points at different voltages, you essentially create a short-circuit to earth ground through your circuit and the ‘scope. Such a condition will likely toast your circuit and damage the ‘scope, so always think carefully when using the ‘scope. For this experiment, it is recommended that you attach one of the ground clips to COM somewhere in your circuit.