ME 104
Sensors and Actuators

Laboratory 3
Strain Gage Sensors

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(Rev. 2007)

Introduction

In this laboratory, you will build an analog circuit that will enable you to use a strain gage[1] to measure the deflection of a metal ruler. You will then add a noninverting op-amp to amplify the voltage output from your circuit and an analog low-pass filter to remove voltage fluctuations caused by high-frequency noise. You will then use a LabVIEW program to compute the Power Spectrum of the output from your strain gage circuit before and after the low-pass filter.

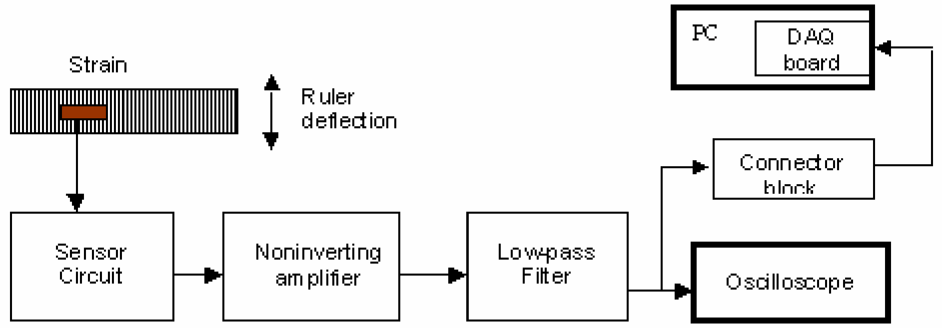

Figure 1. **Strain Gage sensor system**

Background Reading

1. Histand and Alciatore, **Introduction to Mechatronics**, sections 9.3.1-2.

Data Sheet, *LMC6484 CMOS Quad Rail-to-Rail Input and Output Operational Amplifier*, National Semiconductor Corporation. Available online at http://www.national.com/ds/LM/LMC6484.pdf.

Experiment #1: Build an Analog Circuit for Obtaining Deflection Measurements Using a Strain Gage

In this experiment, you will build an analog circuit for using a 350-Ω strain gage to measure the deflection of a metal ruler. You will then observe the voltage output from your deflection sensor circuit using an oscilloscope. The strain gage, which includes two wire leads, has already been attached (glued) to a bendable ruler.

First, listen to your TA discuss these following topic, and take notes:

- Importance of Strain Gauge
- How does Wheatstone Bridge work?
- Op Amp Review

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[1] Also spelled strain *gauge*.

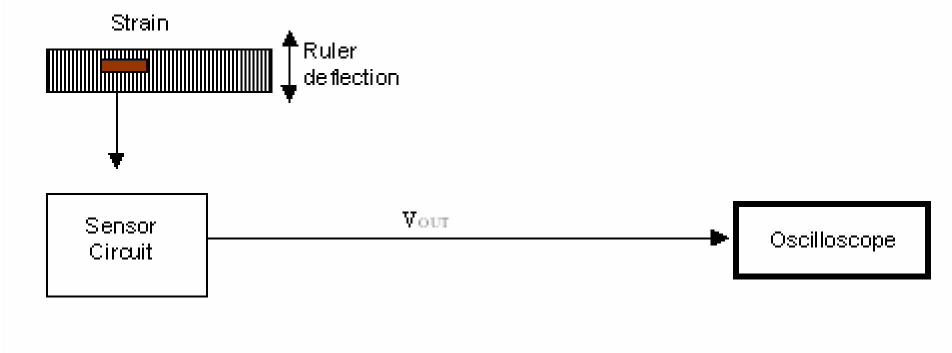

Figure 2. **Strain gage sensor**

1. Build the analog circuit shown in Figure 3 on an electronic breadboard. Remember to use red wire for positive power connections and black wire for ground connections. Since the strain gage has a resistance of (approximately) $R_{SG} = 350\Omega$, the resistors[2] on the remaining three arms of the Wheatstone bridge should be matched such that $R_{B1} = R_{B2} = R_{B3} = 350\Omega$. For this lab, you will actually use $R_{B1} = R_{B2} = R_{B3} = 348\Omega$ or $R_{B1} = R_{B2} = R_{B3} = 357\Omega$.

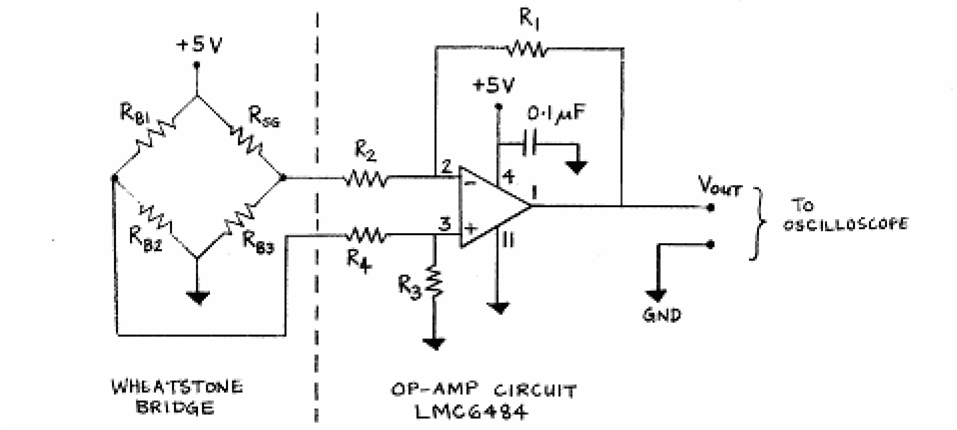

Figure 3. **Analog sensor circuit for using a strain gage as a deflection sensor**

The voltage output from the Wheatstone bridge is amplified by the LMC6484 operational amplifier, shown on the right side of the dotted line in Figure 3. Although the LMC6484 chip contains four op-amps with identical capabilities (see Figure 4), you will use only op-amp number one at this time (LMC6484 pins 1, 2, and 3). Choose the op-amp resistors such that $R_1 = R_3 = 1$ MΩ and $R_2 = R_4 = 100$ kΩ. Then, the voltage gain A_V of your op-amp circuit will be:

$$A_V = \frac{R_1}{R_2} = 10$$

Provide power (V_{CC} = +5 volts) and ground (GND) to your circuit board using the "5 V FIXED 3 A" output from your Tektronix PS280 DC Power Supply.

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[2] The R_B resistors are known as "bridge completion resistors".

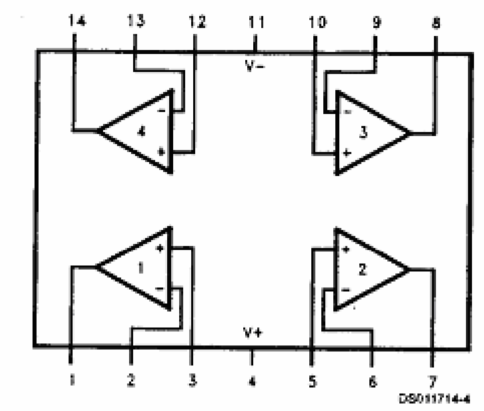

Figure 4. **LMC6484 op-amp connection diagram**

2. Place the ruler flat on your table so that it is not deflected. Turn on your oscilloscope and set its vertical scale to 50 millivolts/division and its horizontal scale to 400 milliseconds/division. Connect the voltage output V_{OUT} and ground (GND) from your circuit to the oscilloscope.
3. Take the ruler in your hand and deflect it upward and downward. Observe the resulting voltage output V_{OUT} on the oscilloscope. If you cannot see a clear deflection voltage (when you bend your ruler), adjust the vertical scale on your oscilloscope until you can see a clear deflection. V_{OUT} is the sum of two voltage components given by$V_{OUT} = V_{DC} + V_{defl}$, where V_{DC} is a roughly constant DC bias voltage and V_{defl} is a voltage that depends on the deflection of the metal ruler. For the resistor values you have used, your deflection voltage V_{defl} should have a magnitude of 50 mV or less[3], while the positive DC bias V_{DC} should be on the order of 150 mV or less (Figure 5).

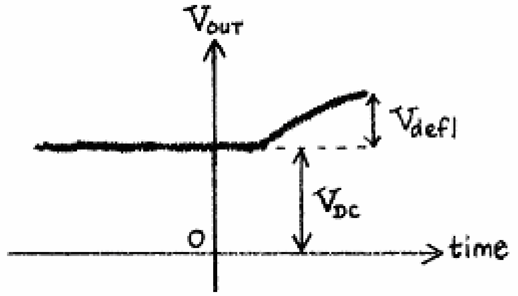

Figure 5. **Voltage output from strain gage circuit**

4. **Make a table to record the DC bias for each of the circuits in this lab.** Record the DC bias produced by this circuit. In theory, when the ruler is not deflected, and if all four resistors in the Wheatstone bridge are perfectly matched (equal to one another), the DC bias V_{DC} should be zero. In practice, however, the resistors are not exactly matched, so the circuit may have a nonzero DC bias even when the ruler is not deflected[4]. For the purposes of this experiment, we want the DC bias to be approximately 150 mV. If your DC bias is not approximately 150 mV, you can drive it towards 150 mV by adding an appropriate resistor in parallel with one of the resistors in the Wheatstone bridge. Recall that the equivalent resistance R_E across two parallel resistors R_α and R_β

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[3] If your deflection voltage magnitude is larger than 50 mV, you are bending your ruler too much.

[4] Since you have powered the LMC6484 with a high voltage of $V_+ = 5$ V (pin 4) and a low voltage of $V_- = 0$ V (pin 11), the output from your op-amp is physically restricted to the range 0-5 V.

is given by:

$$\frac{1}{R_E}=\frac{1}{R_\alpha}+\frac{1}{R_\beta}$$

5. If the DC bias V_{DC} in your circuit is between 125 to 175 mV, you **do not** need to adjust V_{DC} so you can skip the next three steps and proceed directly to Step 9.
6. If the DC bias V_{DC} in your circuit is **outside** of the range 125-175 mV, proceed as follows. Place the ruler flat on your table. Connect a 100 kΩ resistor in parallel with R_{B1} as shown in Figure 6(a). The DC bias should move either closer to or further away from the 150 mV mark. If the DC bias moves away from 150 mV, switch the 100 kΩ resistor so that it is connected in parallel with the strain gage R_{SG} as shown in figure 6(b). If adding a 100 kΩ resistor does not improve your DC bias, try using a 200 kΩ resistor instead. **Record the DC bias produced by this circuit.**

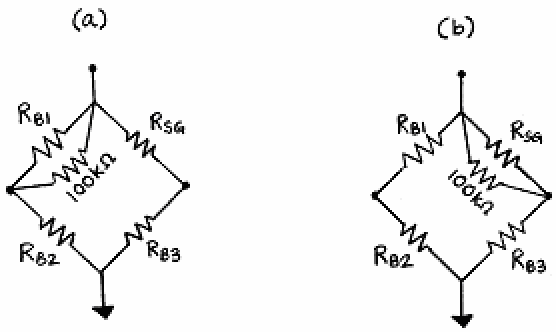

Figure 6. **Addition of a parallel resistor to alter DC bias**

7. Ultimately, you want the DC bias V_{DC} to be as close to 150 mV as possible, but for the purposes of this experiment, restricting V_{DC} to within 150±25 mV will suffice. Place the ruler flat on your table. Keep adding more 100kΩ resistors in parallel to either R_{B1} or R_{SG} until V_{DC} (as viewed on the oscilloscope) drops to within ±25 mV of 150 mV. If you cannot restrict V_{DC} to 150±25 mV using only 100kΩ resistors, try adding higher value resistors (for example, 200 kΩ) in parallel for better voltage resolution. **Record the DC bias produced by this circuit.**
8. Take the ruler in your hand and deflect it upward and downward. Verify that the resulting voltage output V_{OUT} on the oscilloscope is similar to what you observed in step 3 (above), but with a DC bias of approximately 150 mV.
9. Printout screen from oscillisope showing strain gage in action and **save for report**, be sure to label the DC offset as well.

Experiment #2: Amplify Voltage Output from Strain Gage Circuit

In this experiment, you will amplify the voltage output from your strain gage circuit using a noninverting operational amplifier.

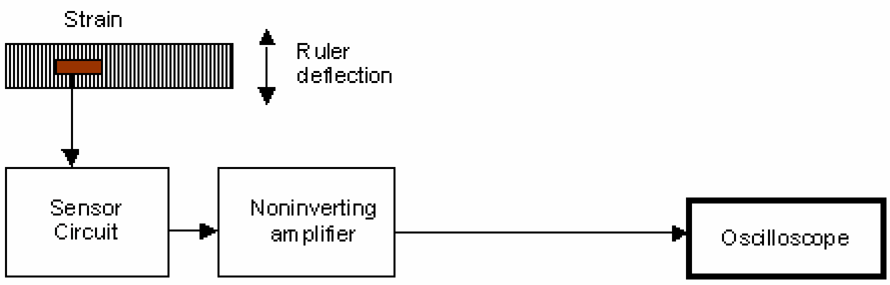

Figure 7. **Strain gage sensor with voltage amplification**

This amplification is necessary to increase the percentage accuracy of the voltage measurements made by the DAQ (data acquisition) board[5]. One way to amplify the voltage output is to increase the resistance of both R_1 and R_3 or to decrease the resistance of both R_2 and R_4. We will assume that the circuit you built in Experiment #1 cannot be modified, which is usually the case with many circuit boards you may encounter in industrial applications. Instead, amplification of the existing voltage output V_{OUT} could be done quite easily using a noninverting op-amp.

1. Add the circuit shown in Figure 8 to the circuit you built in Experiment #1. Use op-amp number three (pin numbers 8, 9, and 10) on the LMC6484 chip (Figure 4). Choose the source resistor R_S and the feedback resistor R_F such that $R_S = 10\ \text{k}\Omega$ and $R_F = 150\ \text{k}\Omega$. Then, the voltage gain A_V from the noninverting op-amp is given by

$$A_V = \frac{V'_{OUT}}{V_{OUT}} = 1 + \frac{R_F}{R_S} = 16$$

   The amplified voltage should be 16 times greater than what you viewed in Experiment #1.

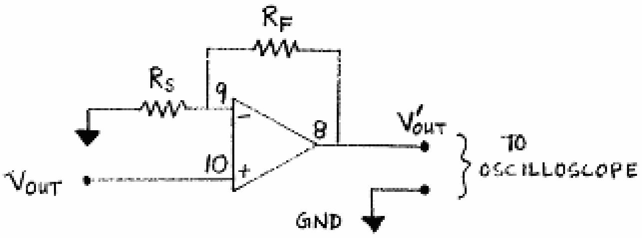

Figure 8. **Noninverting operational amplifier circuit diagram**

2. Place the ruler flat on your table so that it is not deflected. Increase the vertical scale on your oscilloscope to 1 volt/division. Connect the amplified voltage output V'_{OUT} and ground (GND) from your circuit to the oscilloscope.
3. Take the ruler in your hand and deflect it upward and downward. Verify that the amplified voltage output V'_{OUT} on the oscilloscope is similar to what you observed at the end of Experiment #1, but with a DC bias of approximately 2 V. **Record the DC bias produced by this circuit and printout screen from oscilliscope.**

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[5] Since the DAQ board has been configured to accept voltages in the range –10 V to +10 V, it has an absolute accuracy of approximately 10 mV.

Experiment #3: View Strain Gage Output on Computer Screen

In this experiment, you will use a *LabVIEW* VI to measure and display the voltage output from the strain gage sensor circuit.

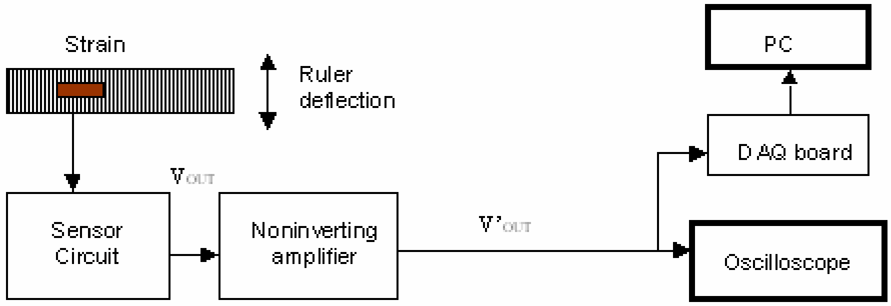

Figure 9. **Strain gage sensor with voltage amplification and computer interface**

1. Open **yourname_lab2_1Channel.vi**
2. To view the analog voltage signal from the strain gage circuit, connect the amplified voltage output V'_{OUT} (LMC6484 pin 8) from your sensor circuit to the CB-68LP connector block as shown in Table 1. Do not remove the connections to the oscilloscope.

Table 1. CB-68LP connector block pin assignment for measuring a voltage signal

External Signal	**Connect to:**
Amplified strain gage voltage output (LMC6484 pin 8)	Pin 68 (AI0)
Analog ground	Pin 67 (AI GND)

3. Click the **Run** button to see the output from the strain gage circuit. Verify that the deflection voltage shown by the Analog Voltage Value indicator corresponds to the deflection voltage shown by the Analog Voltage Chart.
4. **Save Front Panel and Block Diagram** with data running showing the ruler deflection, Remember to **record the DC Bias**.

For higher resolution readings, you can increase the digits of precision on your Analog Voltage Value indicator. Alternatively, you can add another digital indicator to your front panel and assign it a higher value for digits of precision.

Experiment #4: Add an Analog Low-Pass Filter to the Strain Gage Circuit

In this experiment, you will add an analog low-pass filter to your circuit to reduce the voltage fluctuations caused by high-frequency noise.

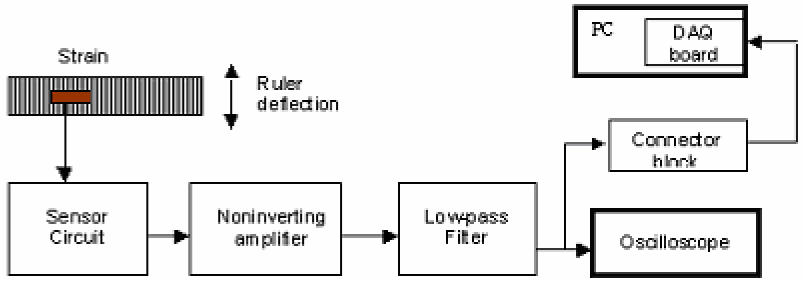

Figure 10 . **Strain gage sensor with voltage amplification and filter**

1. Add the RC low-pass filter shown in Figure 11 to the circuit you built in Experiment #2. Choose the resistor R_{LP} and the capacitor C_{LP} such that $R_{LP} = 100\ \text{k}\Omega$ and $C_{LP} = 0.1\ \mu\text{F}$. Then, the cutoff frequency ω_0 of the filter is given by

$$\omega_0 = \frac{1}{RC} = 100\ \text{rad/s} \quad \text{or} \quad f_0 = \frac{\omega_0}{2\pi} = 15.9\ \text{Hz.}$$

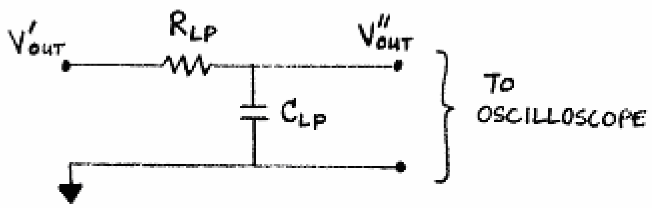

Figure 11. **RC Low-pass filter**

2. Connect the filtered voltage output V''_{OUT} and ground (GND) from your circuit to the oscilloscope.
3. Deflect the ruler upward and downward. Verify that the amplified voltage output V'_{OUT} on the oscilloscope is similar to what you observed at the end of Experiment #2.
4. To view the filtered voltage signal on your computer screen, connect the filtered voltage output V''_{OUT} from your sensor circuit to the CB-68LP connector block as shown in Table 2. **Do not** remove the connections to the oscilloscope (step 2 above) and **do not** remove the connections you made to the CB-68LP in Experiment #3 (Table 1).

Table 2. CB-68LP connector block pin assignment for measuring a second voltage signal

External Signal	Connect to:
Filtered strain gage voltage output	Pin 33 (AI 1)
Analog ground	Pin 67 (AI GND)

5. Open **`yourname_lab2_2Channel.vi,`** where an additional sample channel was added to simultaneously view both the non-filtered and filtered output from your circuit.
6. Click the **Run** button to see the output from the strain gage circuit. Verify that the deflection voltage viewed on the `Filtered Analog Input Chart` is similar to the deflection voltage (simultaneously) viewed on your oscilloscope.
7. **Save Front Panel and Block Diagram** with data running showing the ruler deflection, Remember to **record the DC Bias**.

The effect of the low-pass filter should be clear. The voltage fluctuations due to noise should be significantly less after filtering.

Saving Files

Before you leave, remember to save all of your files to your **ECI account** (for later use and backup purposes). For this laboratory, you should save the following files:

```
yourname_lab2_1Channel.vi
yourname_lab2_2Channel.vi
```

Laboratory Report

1. Oscilliscope printouts of EXP 1 & 2.
2. For the VI's you wrote in this laboratory (EXP 3 & 4), provide a printout that shows the front panel and block diagram, remember to record **DATA IN YOUR GRAPHS as well as a COMPLETE block diagram**.
3. Provide (draw) a **complete** circuit diagram for the strain gage circuit you built in Experiments 1 through 4.
4. In Experiment #1, you made sure that your DC bias was approximately 150 mV. If you had chosen a smaller DC bias, such as 10 mV, what would happen if you bent your ruler by a large amount in (a) the positive direction and (b) the negative direction? Illustrate your answer with a picture similar to Figure 5 above.
5. In Experiment #1, explain why connecting a parallel resistor as shown in Figure 6 allows you to move your DC bias.
6. In Experiment #2, you used a noninverting amplifier to amplify the voltage output. Explain why an inverting amplifier would not have worked in this situation. (Assume that you are not concerned whether the amplified output is positive or negative).
7. Create a table to list your DC bias values from Experiments 1-4. Compare the values and explain how they are related. In Experiment #4, explain why the filtered DC bias value is less than the non-filtered DC bias. If you used R_{LP} = 10 kΩ instead of R_{LP} = 100 kΩ, would you expect a different value for the filtered DC bias? Explain.

Your Lab Report should clearly state your name, Lab Report number, Lab date, and your laboratory partner's name (if any). Your lab report should be thorough, but concise. You will be graded on quality, not quantity. **Lab Report #2 is due at the beginning of Laboratory #3.**

Additional Reading and Practice

1. ***LabVIEW* Data Acquisition Basics Manual**, Pages **5-1 to 5-8**, Pages **6-1 to 6-2**, and Pages **7-1 to 7-3**. Available online at www.ni.com/pdf/manuals/320997e.pdf.

***LabVIEW* User Manual**, *Power Spectrum*, **Page 13-14**. Available online at www.ni.com/pdf/manuals/320999b.pdf.