

University of California Berkeley  
Department of Electrical Engineering and Computer Sciences  
EECS 100, Professor Leon Chua

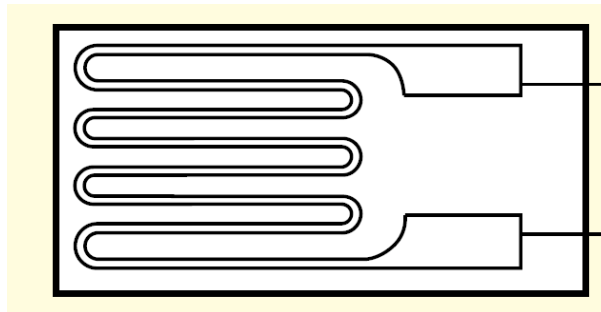
## LABORATORY 4 v2

### STRAIN GAGE

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In this laboratory we design our first electronic device, an electronic weight scale! The key component is a strain gage, a resistor that changes its value in response to mechanical stress. We will also use an instrumentation amplifier to gain up the signal.

Figure 1 shows a strain gage with two electrical leads on the right side. The serpentine structure consists of a resistive material (e.g. a metal) mounted on top of an insulator. Increasing the length of the resistor (e.g. by adding additional serpentines) increases its value. Question: what happens if we pull on the resistor to make it longer? Well, its value increases. In this laboratory we use this effect by gluing a strain gage on one side of a flexible beam. When the beam is bent, one side gets longer while the other gets shorter. The glue transfers this effect to the strain gage, which in turn changes its resistance value as a function of beam bending. Applications include airplane wings where strain gages are used to determine the degree of wing deformation during flight from the change of resistance. Strain gages are invaluable for evaluating not only airplane frames, but also automobiles, bridges, and buildings.



**Figure 1 Resistive strain gage with electrical leads on the right side**

In the laboratory we will be using a strain gage that is glued to an aluminum band. The end that is closer to the gage is clamped to the table. Adding weights to the other end bends the aluminum band. As a consequence, one side of the band gets slightly longer while the other one gets shorter. The weight scales you see along highways that are used to check the load of trucks use the same principle.

In the lab we will first characterize the resistance change and then gradually develop improved versions of the weight scale circuit to produce an amplified output voltage that is proportional to the applied weight.

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 LAB REPORT
 

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Lab Session:

Name 1:

SID:

Name 2:

SID:

**1. Strain Gage**

Clamp the strain gage to the lab bench and use the Ohm-meter to determine the resistance  $R_o$  of the unloaded gage. Load the gage with an increasing number of weights, re-measure the resistance  $R_N$  (for  $N$  weights) and calculate the relative change of resistance,  $\Delta r$ . Do not permanently deform the gage.

Note ppm is "parts per million" and is used for unitless fractions that are much smaller than 1%. Just like to get % you multiply the fraction by 100, for ppm, you multiply by one million.

$R_o$ : \_\_\_\_\_  $\Omega$  \_\_\_\_\_ of 1 M

Number of weights $N$	$R_N$ [ $\Omega$ ]	$\Delta r = \frac{R_N - R_o}{R_o}$ [ppm]
0		
1		
2		
3		
4		
5		
6		
7		
8		

\_\_\_\_\_ of 5 M

## 2. Half Bridge Circuit

Using a voltage divider, we can easily convert the output into a voltage. Form a divider consisting of the strain gage and a constant  $120\Omega$  resistor and put  $V_{DD}=5V$  across the bridge.

- Draw a voltage divider circuit showing the variable resistance strain gauge as one of the elements

\_\_\_ of 2 P

- Derive an expression for  $\Delta v$  as a function of  $\Delta r$  (as defined in part 1),  $R_0$  and  $V_{DD}$ . Start with the definition of  $\Delta v$  in the table below and replace  $V_R$  with the value found by analyzing the circuit described above. Remember that  $V_R$  is defined as the voltage across the  $120\Omega$  resistor! Derivation should be shown in prelab.

Expression for  $\Delta v$  \_\_\_\_\_

\_\_\_ of 5 P

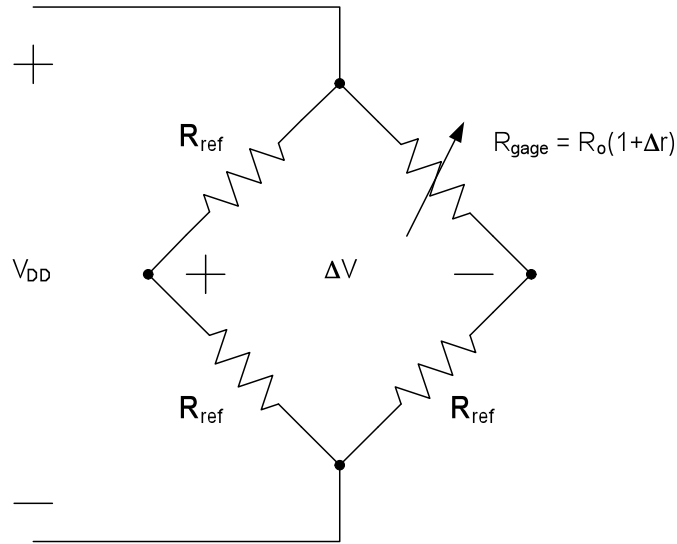
- Build the circuit on your breadboard
- Measure the voltage  $V_R$  across the  $120\Omega$  resistor
- Fill in the table below:

Number of weights	$V_R$ [V]	$\Delta v = \frac{2V_R - V_{DD}}{V_{DD}}$ [ppm]
0		
1		
2		
8		

\_\_\_ of 4 M

### 3. Full Bridge Circuit

The circuit from part 2 has a major problem: the output voltage is non-zero when the gage is not loaded. This problem is easily overcome with a second voltage divider that produces the reference voltage for an unloaded gage. The output is the voltage difference  $\Delta V$  between the two dividers.



- a) Derive an expression for  $\Delta V$  as a function of  $\Delta r$ ,  $R_o$ ,  $R_{ref}$ , and  $V_{DD}$ . Show derivation in prelab.

**Expression for  $\Delta V$ :**

\_\_\_\_\_

\_\_\_ of 5 P

- b) In practice  $\Delta V$  is still not exactly zero, even if the gage is not loaded. Give two reasons why.

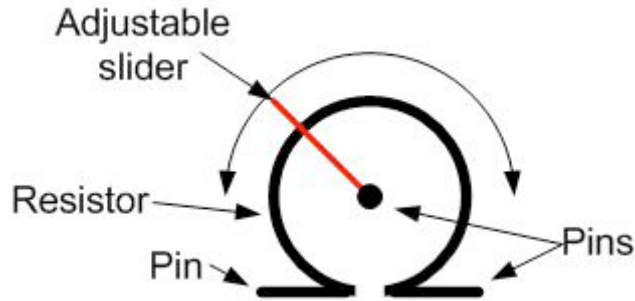
**Reason 1:**

\_\_\_ of 5 P

**Reason 2:**

\_\_\_ of 5 P

c) In order to reduce this error a manually adjustable resistor can be placed in the circuit to adjust the reference voltage. This adjustable resistor is called a potentiometer. See the figure below for an example of how potentiometers are made. The resistance between the two main pins is fixed, but the adjustable slider can be turned to change the resistance between the slider and the other pins.

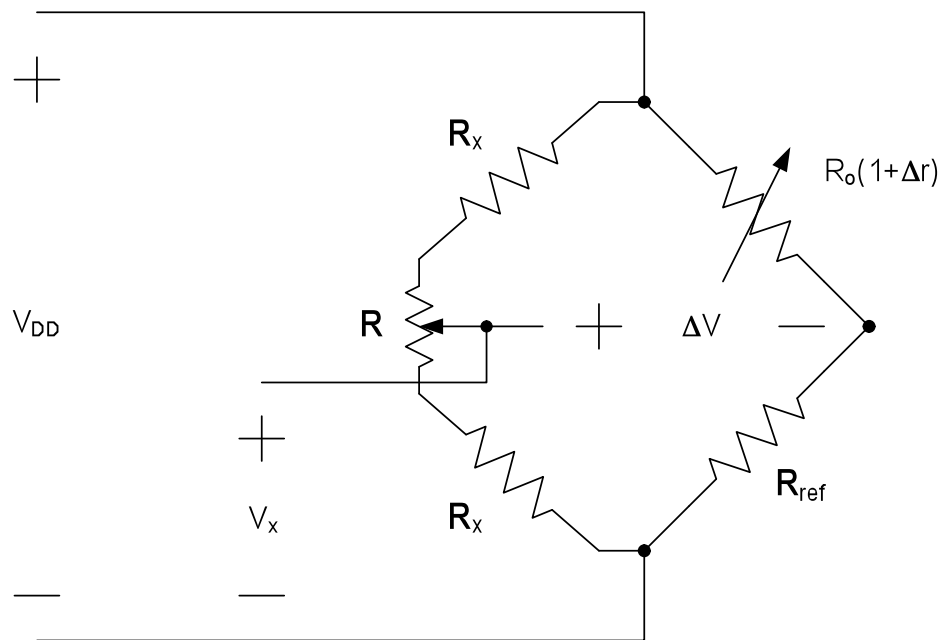


The circuit below adds a potentiometer to manually adjust the zero point. Calculate the value of  $R/R_x$  needed to result in a 5% adjustment range, e.g. by turning the slider of the potentiometer to the extreme positions  $V_x = V_{DD}/2 \pm 5\%V_{DD}$ . Thus, at the lowest setting of the potentiometer  $V_x$  should read  $.45*V_{DD}$ . At the highest setting,  $V_x$  should read  $.55*V_{DD}$ .

Expression for  $R/R_x$ :

\_\_\_\_\_

\_\_\_ of 5 P



d) A simpler circuit would connect the potentiometer directly to the supply, omitting the resistors  $R_x$ . Describe briefly the advantage of having  $R_x$ .

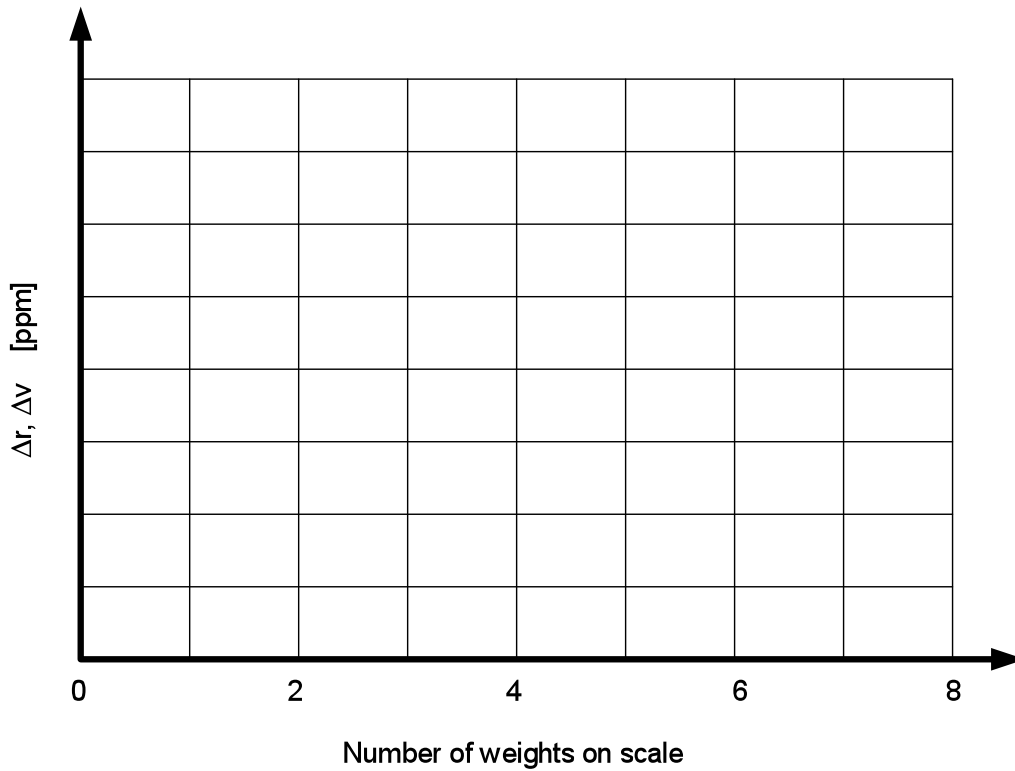
\_\_\_ of 5 P

e) Build the circuit from part (c) using  $R_{ref}=120\Omega$ ,  $R_x=1k\Omega$  and  $R=100\Omega$ . Adjust the potentiometer such that  $\Delta V=0V$  when the gage is not loaded. Then take measurements of  $\Delta V$  to fill in the table below:

Number of weights	$\Delta V$ [mV]	$\Delta v = \frac{\Delta V}{V_{DD}}$ [ppm]
0		
1		
2		
8		

\_\_\_ of 4 M

f) Summarize your measurement results for  $\Delta r$  and  $\Delta v$  from parts 1-3 in a graph.



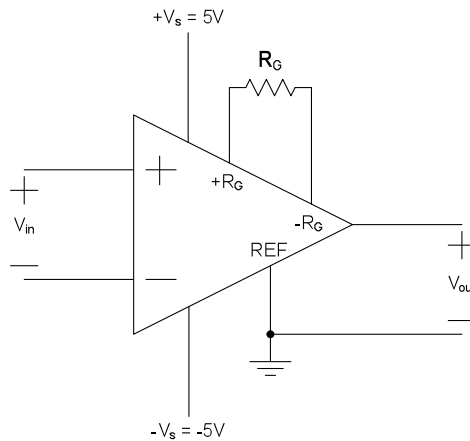
\_\_\_ of 8 M

**4. Instrumentation Amplifier**

In this part we add an instrumentation amplifier to amplify the gage output. Instrumentation amplifiers will be analyzed in the homework. The connections are shown in the circuit below. Resistor  $R_G$  sets the gain  $G=V_{out}/V_{in}$  according to the formula

$$R_G = \frac{100k\Omega}{G - 1}$$

You find this equation in the datasheet of the AD623 instrumentation amplifier.

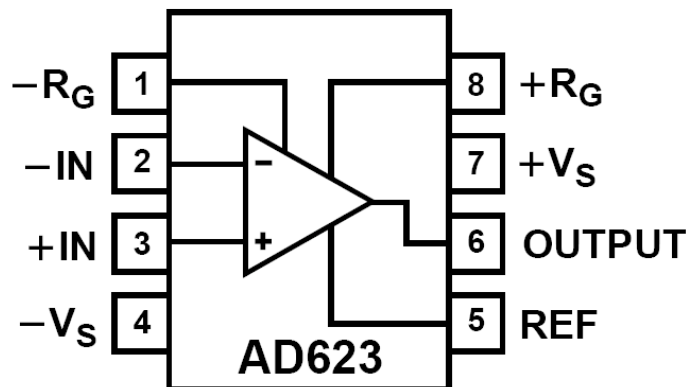


- a) What is the correct value of  $R_G$  for  $G=100$ ?

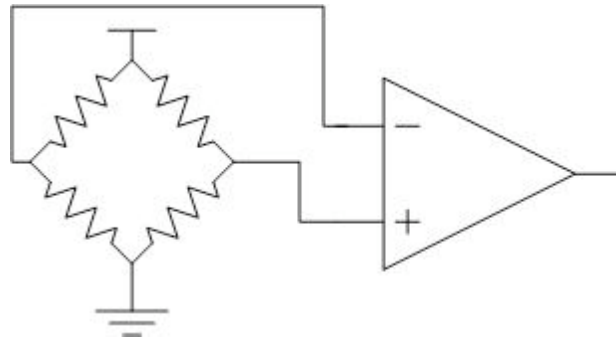
$R_G$ : \_\_\_\_\_

\_\_\_ of 5 P

- b) Add the instrumentation amplifier to the strain gage circuit. Use  $R_G=1k\Omega$ . The connection diagram of the AD623 is as follows (the datasheet has more information):



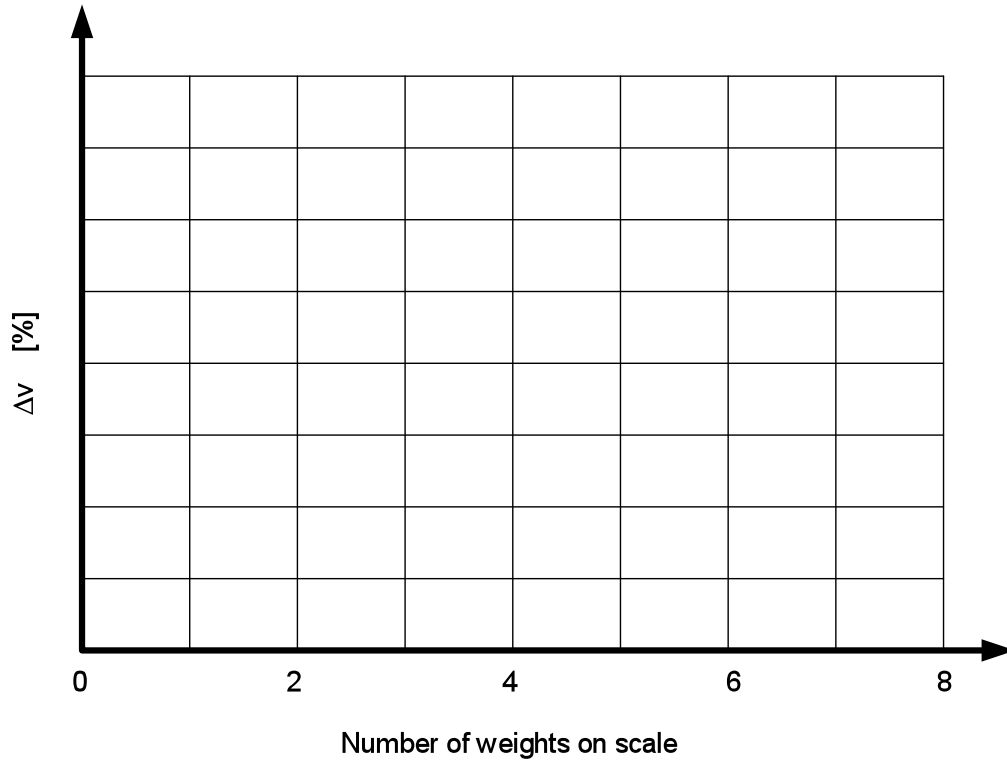
Hookup the output of your full bridge circuit to your amplifier circuit



Measure the amplifier output voltage as a function of the number of weights.

Number of weights	$V_{out}$ [mV]	$\Delta v = \frac{V_{out}}{V_{DD}}$ [%]
0		
1		
2		
3		
4		
5		
6		
7		
8		





\_\_\_ of 20 M

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## SUGGESTIONS AND FEEDBACK

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Time for completing prelab:

Time for completing lab:

Please explain difficulties you had and suggestions for improving this laboratory. Be specific, e.g. refer to paragraphs or figures in the write-up. Explain what experiments should be added, modified (how?), or dropped.

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PRELAB SUMMARY

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Lab Session:

Name 1:

SID:

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2. Half Bridge Circuit

Draw a voltage divider circuit showing the variable resistance strain gauge as one of the elements

\_\_\_ of 2 **P**

Derive an expression for  $\Delta v$  as a function of  $\Delta r$  (as defined in part 1),  $R_0$  and  $V_{DD}$ . Start with the definition of  $\Delta v$  in the table on page 3 and replace  $V_R$  with the value found by analyzing the circuit described above. Remember that  $V_R$  is defined as the voltage across the  $120\Omega$  resistor!

Expression for  $\Delta v$

\_\_\_\_\_

\_\_\_ of 5 **P**

### 3. Full Bridge Circuit

Derive an expression for  $\Delta V$  as a function of  $\Delta r$ ,  $R_o$ ,  $R_{ref}$ , and  $V_{DD}$ .

**Expression for  $\Delta V$ :** \_\_\_\_\_ **\_\_\_ of 5 P**

In practice  $\Delta V$  is still not exactly zero, even if the gage is not loaded. Give two reasons why.

**Reason 1:** \_\_\_\_\_ **\_\_\_ of 5 P**

**Reason 2:** \_\_\_\_\_ **\_\_\_ of 5 P**

Calculate the value of  $R/R_x$  needed to result in a 5% adjustment range, e.g. by turning the slider of the potentiometer to the extreme positions  $V_x = V_{DD}/2 \pm 5\%$ .

**Expression for  $R/R_x$ :** \_\_\_\_\_ **\_\_\_ of 5 P**

A simpler circuit would connect the potentiometer directly to the supply, omitting the resistors  $R_x$ . Describe briefly the advantage of having  $R_x$ .

\_\_\_\_\_ **\_\_\_ of 5 P**

### 4. Instrumentation Amplifier

What is the correct value of  $R_G$  for  $G=100$ ?

**$R_G$ :** \_\_\_\_\_ **\_\_\_ of 5 P**