AP185 Activity 1
Wheatstone Bridges part I

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1 Introduction

A Wheatstone bridge is made up of two voltage dividers powered by a dual-power supply or a single source. Among the junctions of the voltage dividers, a current meter (a galvanometer) is connected to monitor the current flow from one voltage divider to the other.

When current does not flow through the galvanometer, we say that the Wheatstone bridge is balanced.

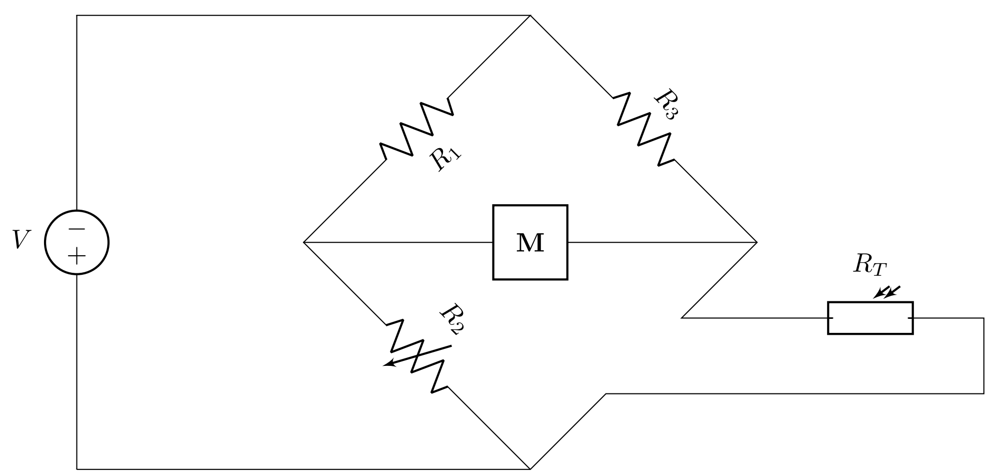

Figure 1: A Wheatstone bridge. **M** is usually a galvanometer.

1.1 Voltage Dividers

Given R_1 and R_T in the circuit below, the voltage V_s can be split depending on the ratio of the two resistors, hence the name voltage divider.

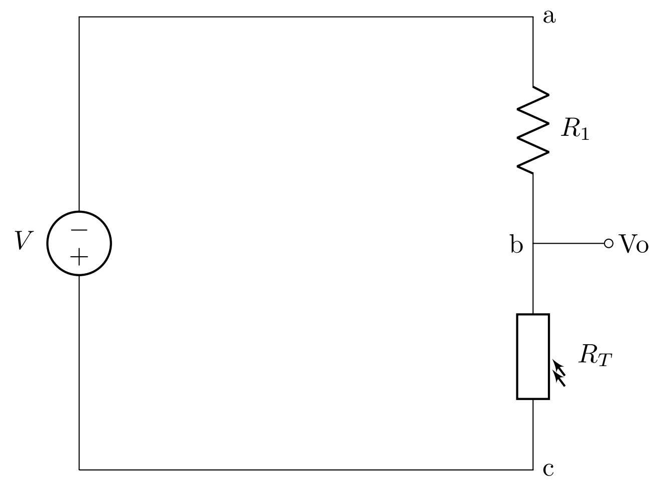

Figure 2: A voltage divider

$$V_{bc} = \frac{R_T}{R_1 + R_T} V_s \tag{1}$$

One can obtain the resistance of a sensor, e.g. a thermistor, a strain gauge or a photoresistor, by measuring V_{bc} if you know V_s and R_1. One of the problem that one can encounter is that it would be difficult to control the current that will pass through resistor R_T since whatever current that passes through R_1 is the same one that will pass through the sensing resistor R_T. High currents through resistor will cause Joule heating and can introduce significant measurement drift.

1.2 Voltage dividers to Wheatstone bridges

If one adds another voltage divider in parallel to R_1 and R_T then one can use the difference of the voltage measurements to improve the sensitivity of the sensor circuit. This has also has an additional advantage in reducing the current flow through the sensor resistor R_T.

Let us re-draw the Wheatstone bridge in Figure 1 in a more familiar voltage divider form.

If one changes the value of R_2 to make the current flow through the meter

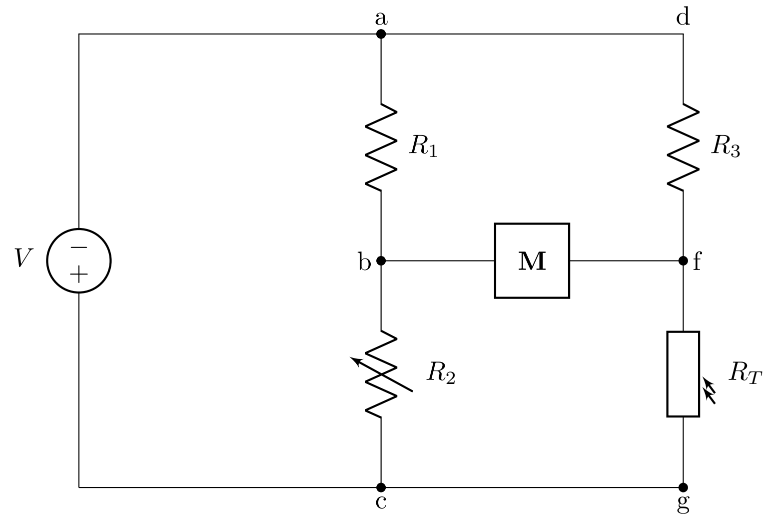

Figure 3: Re-drawn Wheatstone bridge circuit.

M to be zero ($I_{fb} = 0$) then the following equations will be true (KCL):

$$I_{fb} = 0$$

$$I_{ab} = I_{bc} \qquad \frac{V_{ab}}{R_1} = \frac{V_{bc}}{R_2} \qquad V_{ab} = V_{bc}\frac{R_1}{R_2}$$

$$I_{df} = I_{fg} \qquad \frac{V_{df}}{R_3} = \frac{V_{fg}}{R_T} \qquad V_{df} = V_{fg}\frac{R_3}{R_T}$$

Summing voltages (KVL) we will get:

$$\begin{aligned} V_s &= V_{ab} + V_{bc} \\ V_{ab} &= V_{df} + V_{fb} \\ V_{fg} &= V_{bc} + V_{fb} \\ V_s &= V_{ab} + V_{bc} = V_{df} + V_{fg} \end{aligned}$$

Solving for V_s we get:

$$V_s = V_{bc} = \left(1 + \frac{R_1}{R_2}\right) = V_{fg}\left(1 + \frac{R_3}{R_T}\right)$$

Finding V_{fb} in terms of V_s we get:

$$\begin{aligned} V_{fb} &= V_{fg} - V_{bc} \\ &= V_s\left(\frac{1}{1+\frac{R_3}{R_T}} - \frac{1}{1+\frac{R_1}{R_2}}\right) \\ &= V_s\left(\frac{R_T}{R_T+R_3} - \frac{R_2}{R_2+R_1}\right) \end{aligned}$$

When V_{fb} is zero, the bridge is said to be balanced and the meter reding for a galvanometer or a voltmeter in **M**. This will happen when $\frac{R_3}{R_T} = \frac{R_1}{R_2}$. If one chooses R_2 to be a variable resistor then one can set this zero near the nominal value of the variable to be measured. If that is not possible, one can choose the value of R_2 to be near the range of the sensor resistance. Voltage readings of V_{fb} can then be used to monitor changes of the sensor.

The sensor in general can be connected to the bridge can either be in 2-wire, 3 wire or 4 wire configurations.

2 Experiment

2.1 Preliminaries

Select several (2 or more) resistors in Table 2.1. If you cannot find the said values, pick a range where you can get the most number of resistors at hand (i.e. 100, 120... Ω or 10k, 12k, ... Ω).

Use an ohmmeter to measure directly the resistance values of the resistors and write the average on the corresponding column.

2.2 Voltage divider I

Build the following circuit. We shall replace the sensor with several known resistor values at the moment. Use a value of R_1 to be 100 Ω or if using a different range, ten percent (10 %) of the maximum resistance value.

Replace R in the circuit that you built with each resistor that you have and measure the voltage Vo with respect to the ground using a multimeter. Write this value on the cell corresponding to each of the resistors that you have collected.

Once you have compiled all the data, plot each voltage reading at the vs. the average resistance reading for that row.

2.3 Wheatstone bridge I

Find three 1 kΩ resistors[1] and use this to build the circuit in Figure 2.3.

[1] or three resistors of your highest value in your chosen range

		Voltage Vo		
Resistance	Average Ohmmeter reading	1	2	3
100 Ω				
120 Ω				
150 Ω				
180 Ω				
220 Ω				
270 Ω				
330 Ω				
380 Ω				
470 Ω				
560 Ω				
680 Ω				
820 Ω				
1 kΩ				

Table 1: Resistor table

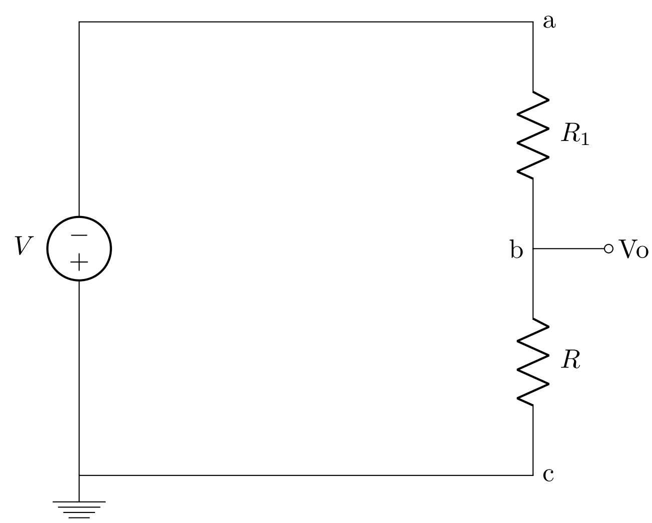

Figure 4: Experimental voltage divider circuit I

As with above, replace R in the circuit and now measure the voltage across M or V_{fb}. Write this value on the cell corresponding to each of the resistors that you have collected in Table 2.3

Once you have compiled all the data, plot each voltage reading at the vs. the average resistance reading for that row.

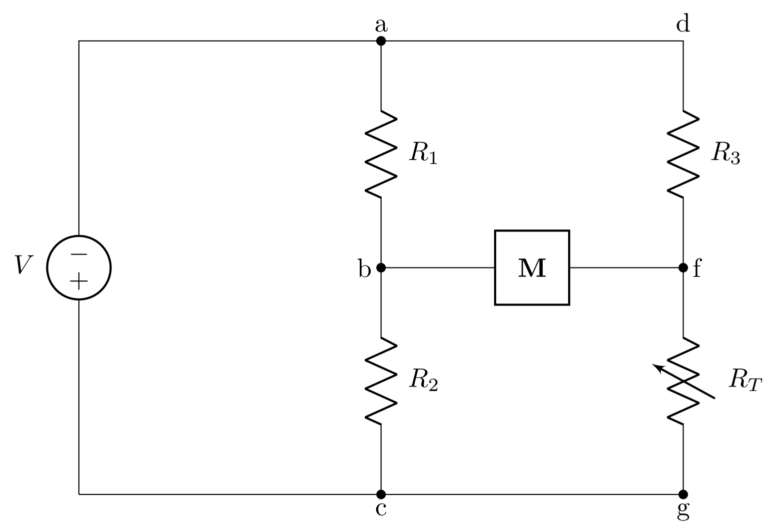

Figure 5: Experimental Wheatstone bridge circuit I

		Voltage V_{fb}		
Resistance	Average Ohmmeter reading	1	2	3
100 Ω				
120 Ω				
150 Ω				
180 Ω				
220 Ω				
270 Ω				
330 Ω				
380 Ω				
470 Ω				
560 Ω				
680 Ω				
820 Ω				
1 kΩ				

Table 2: Wheatstone voltage reading