

Experiment 4: Sensor Bridge Circuits

(tbc 1/11/2007, revised 2/20/2007, 2/28/2007)

Objective: To implement Wheatstone bridge circuits for temperature measurements using thermistors.

I. Introduction. From Voltage Dividers to Wheatstone Bridges

A. Voltage Dividers

- Using resistors R_1 and R_T , the voltage can be split depending on the ratio between the two resistors.

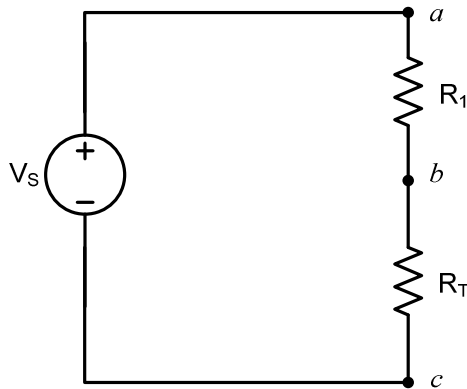


Figure 1. Voltage divider circuit.

$$\left. \begin{array}{l} I_{ab} = I_{bc} \\ V_s = V_{ab} + V_{bc} \end{array} \right\} \rightarrow \begin{array}{l} \frac{V_{ab}}{R_1} = \frac{V_{bc}}{R_T} \\ V_s = \frac{R_1}{R_T} V_{bc} + V_{bc} \\ V_{bc} = \frac{R_T}{R_1 + R_T} V_s \end{array} \quad (1)$$

- **Application:** if R_T is the resistance of a “resistance sensor”, e.g. an RTD (resistance temperature detector), a thermistor or a strain gauge, one can measure changes in R_T by measuring V_{bc} (with V_s and R_1 fixed).

B. Wheatstone Bridge

- **Main idea:** by adding another (comparator) voltage divider in parallel to that shown in Figure 1, one could use differential voltage measurements around zero for improved sensitivity in sensor

applications, while reducing current flow through component R_T . (Note that high electrical currents increase heat in resistors. These effects introduce measurement errors since they are unrelated to the variables being measured).

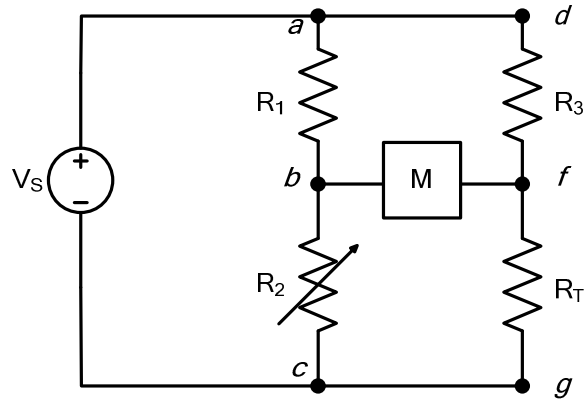


Figure 2. Wheatstone bridge. (**M** is the voltmeter)

- Assuming that very little current flows through the voltmeter, i.e. setting $I_{fb} = 0$,

$$\begin{array}{l}
 I_{ab} = I_{bc} \\
 I_{df} = I_{fg}
 \end{array}
 \rightarrow
 \begin{array}{l}
 \frac{V_{ab}}{R_1} = \frac{V_{bc}}{R_2} \\
 \frac{V_{df}}{R_3} = \frac{V_{fg}}{R_T}
 \end{array}
 \rightarrow
 \begin{array}{l}
 V_{ab} = V_{bc} \frac{R_1}{R_2} \\
 V_{df} = V_{fg} \frac{R_3}{R_T}
 \end{array}
 \quad (2)$$

Summing voltages around each loop,

$$\begin{array}{l}
 V_s = V_{ab} + V_{bc} \\
 V_{ab} = V_{df} + V_{fb} \\
 V_{bc} + V_{fb} = V_{fg}
 \end{array}
 \rightarrow
 \begin{array}{l}
 V_s = V_{ab} + V_{bc} = V_{df} + V_{fg}
 \end{array}
 \quad (3)$$

Substituting (2) into (3),

$$V_s = V_{bc} \left(1 + \frac{R_1}{R_2} \right) = V_{fg} \left(1 + \frac{R_3}{R_T} \right) \quad (4)$$

Applying (4) to the loop containing V_{bc} , V_{fb} and V_{fg} ,

$$\begin{aligned}
 V_{fb} &= V_{fg} - V_{bc} \\
 &= V_s \left(\frac{1}{1 + \frac{R_3}{R_T}} - \frac{1}{1 + \frac{R_1}{R_2}} \right) \\
 &= V_s \left(\frac{R_T}{R_T + R_3} - \frac{R_2}{R_2 + R_1} \right)
 \end{aligned} \tag{5}$$

The bridge is “balanced” when $V_{fb}=0$, i.e. voltage reading in meter **M** is zero. This occurs when $\frac{R_3}{R_T} = \frac{R_1}{R_2}$. Since R_2 is a variable resistor, the meter can be zeroed around the nominal value of the variable being sensed. For instance, if the component is an RTD, then the bridge is balanced around a nominal operating temperature T_0 . Voltage readings of V_{fb} can then monitor temperature changes from T_0 .

The sensor being connected to the Wheatstone-bridge can either be 2-wire, 3-wire or 4 wire systems, with the 3-wire being the more popular configuration, specially for RTDs (see Appendix A for more details about 2-wire and 3-wire configurations).

II. Experimental Setup

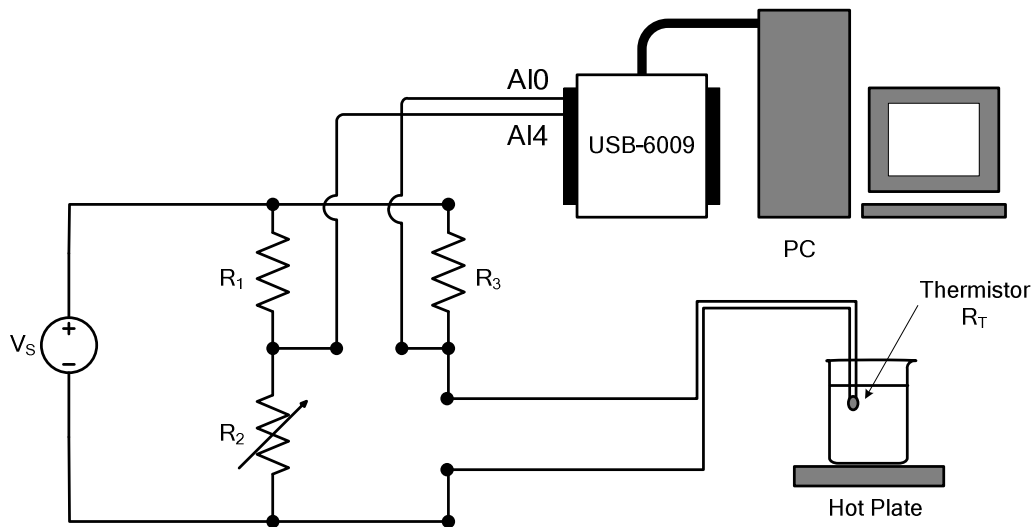


Figure 3

Components:

R_1	4.7 k Ω
R_2	10 k Ω Potentiometer
R_3	4.7 k Ω
V_s	6 V Power Supply
Thermistor	~ 2.80 k Ω @ 25°C

III. Labview Setups

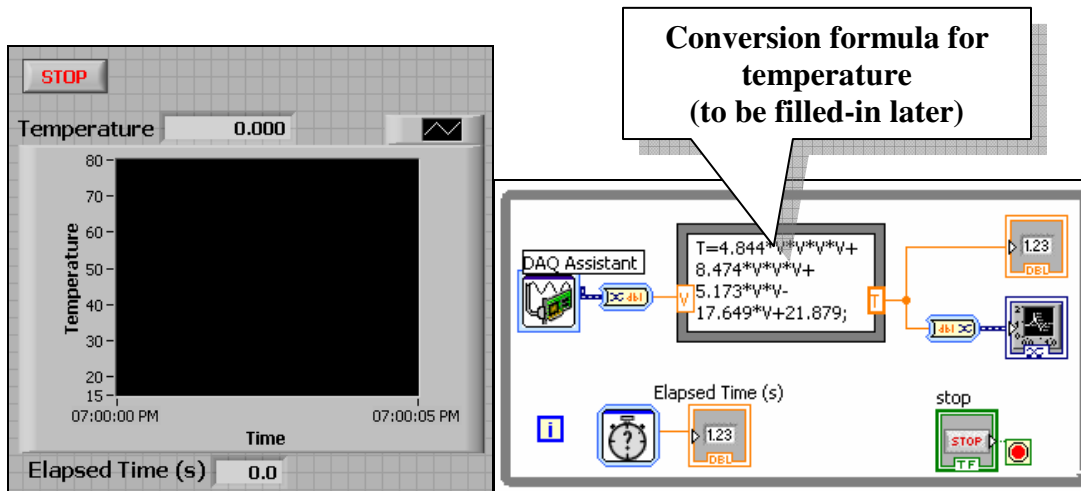


Figure 4. Thermistor VI

Note: There are two data conversion blocks obtained from [Express]→[Signal Manipulation] icon subdirectory. The one between the DAQ Assistant Block and the Formula Node Block is the “From DDT” block, while the other block between the Formula Node Block and the Chart Block is the “To DDT” block. For both these blocks, select “Single Scalar”.

III. Procedure

1. Prepare the setup shown in Figure 3 and the **Thermistor VI** in Figure 4.

Note: for the voltage readings in step 2 and 3, you can use a multi-meter.

2. Tune the 10 kW potentiometer until voltage reading is approximately 0 volts (approximately ± 0.05 volts) at room temperature. Note: there is no need to be very exact since we will further calibrate the thermistor later.
3. Using a digital thermometer, record the voltage readings corresponding to temperature readings at approximately 5°C intervals. (see Table 2 as example)

Table 2.

Temperature (°C)	Voltage (volts)
30	
35	
...	
65	
70	

4. Obtain a polynomial fit of temperature as a function of voltage. (see Figure 5 for an example Excel spreadsheet where the model is a fourth-order polynomial given by : $T = a V^4 + b V^3 + c V^2 + d V + e$, then use SOLVER to minimize RMS).

Alternatively, you could first plot V vs T as data points in MS Excel. Then **[RIGHT-CLICK]** on any data point, and select **[Add trendline...]** . When the window appears,

- 1) under the **[Type]** tab, choose **[Polynomial]** with order = 4
- 2) under the **[Options]** tab, check the box for **[Display equation on chart]**.

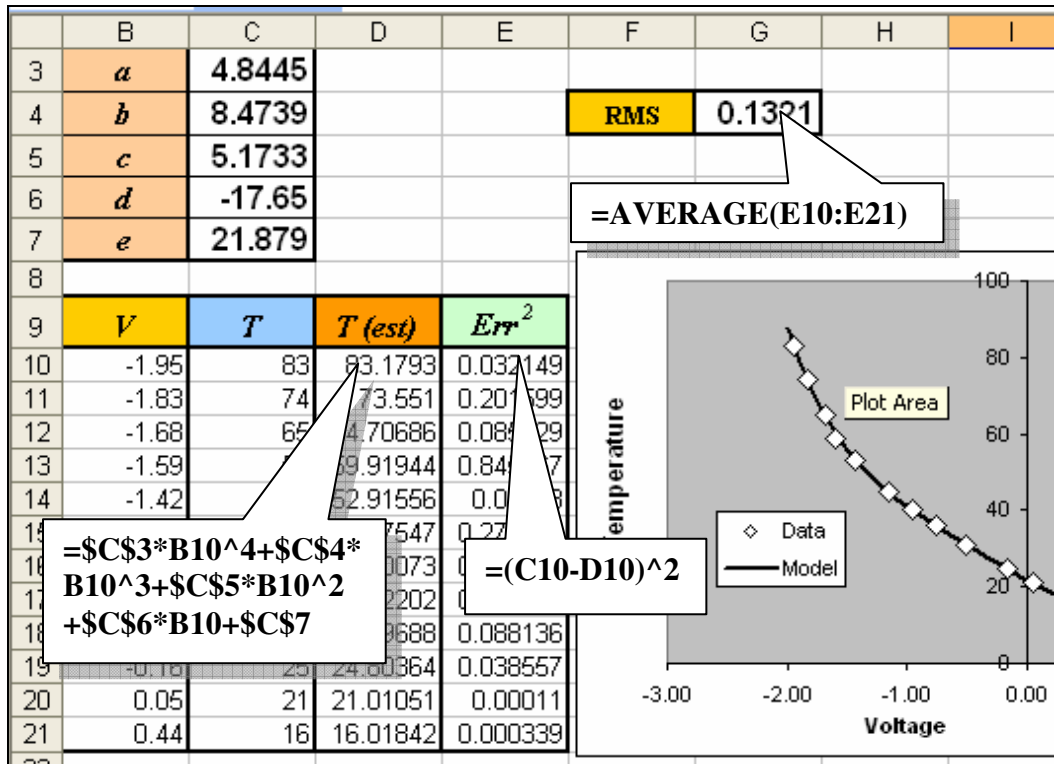


Figure 5.

- Modify the entry in the “Formula Node” block shown in Figure 4, using the conversion formula obtained in step 4.

Note: for exponential powers, use “**”, e.g. $3.2v^4 \rightarrow “3.2*v**4”$.

- Test the obtained **Thermistor VI**.

Appendix A. 2-wire and 3-wire Resistance-Sensor Configurations.

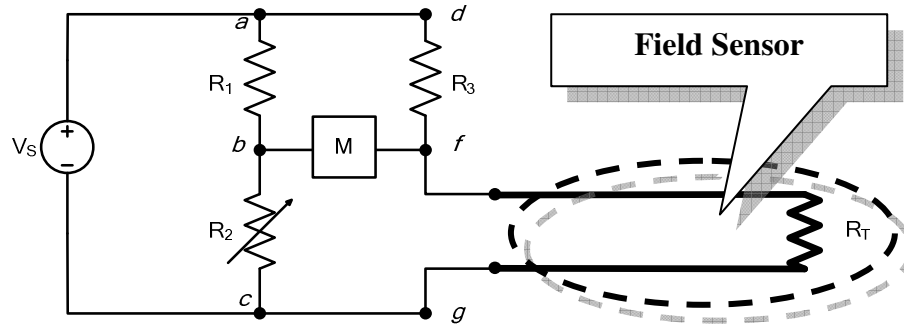


Figure A1. 2-wire sensor configuration.

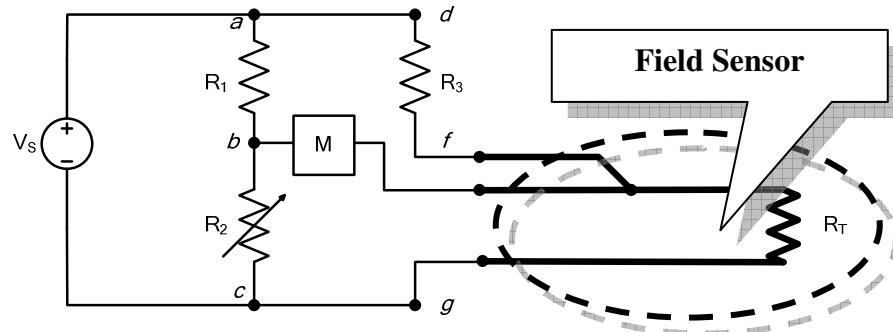


Figure A1. 3-wire sensor configuration.

The main advantage of the 3-wire configuration is that it allows the resistance in all the three leads that are included with the sensor to be surrounded at the same temperature environment. Temperature affects the resistance of the lead wires, and these effects become more significant when the sensor is located far away from the Wheatstone-bridge. By letting the resistance in three lead wires change to the same degree, the bridge will be able to measure the ratio of R_3 to R_T more accurately (although still not exact).