# Experiment 4: Sensor Bridge Circuits

(tbc 1/11/2007, revised 2/20/2007, 2/28/2007, 2/3/2009,2/15/2009, 2/9/2011)

**Objective:** To implement Wheatstone bridge circuits for temperature measurements using RTD (Resistance Temperature Detectors).

## 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.

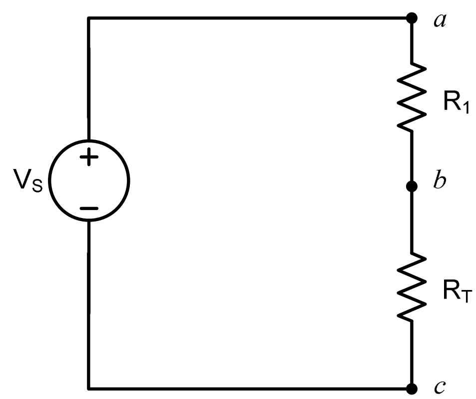


Figure 1. Voltage divider circuit.

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

- **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 that could improve the sensitivity in sensor applications, while at the same time reducing current flow through component $R_T$. (High electrical currents increase heat in resistors and may introduce significant measurement errors).

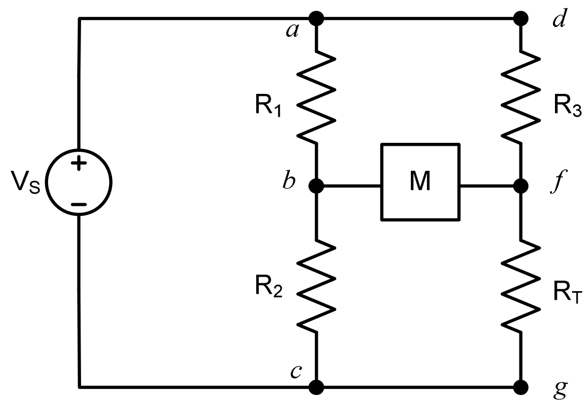


Figure 2. Wheatstone bridge. ( **M** is the meter or DAQ device).

- Assuming negligible current flows through the voltmeter, the circuit paths $abc$ and $dfg$ can be assumed parallel and we can apply (1) to obtain

$$V_{bc} = \frac{R_2}{R_2 + R_1} V_S \quad \text{and} \quad V_{fg} = \frac{R_T}{R_T + R_3} V_S \tag{2}$$

- Now we can measure the voltage difference between nodes $f$ and $g$ to be

$$V_{fb} = V_{fg} - V_{bc} = \left( \frac{R_T}{R_T + R_3} - \frac{R_2}{R_1 + R_2} \right) V_S \tag{3}$$

The bridge is "balanced" when $V_{fb} = 0$, i.e. voltage reading in meter **M** is zero. This occurs when $R_T/R_3 = R_2/R_1$. If $R_2$ 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 can be balanced around a nominal operating temperature $T_0$.

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

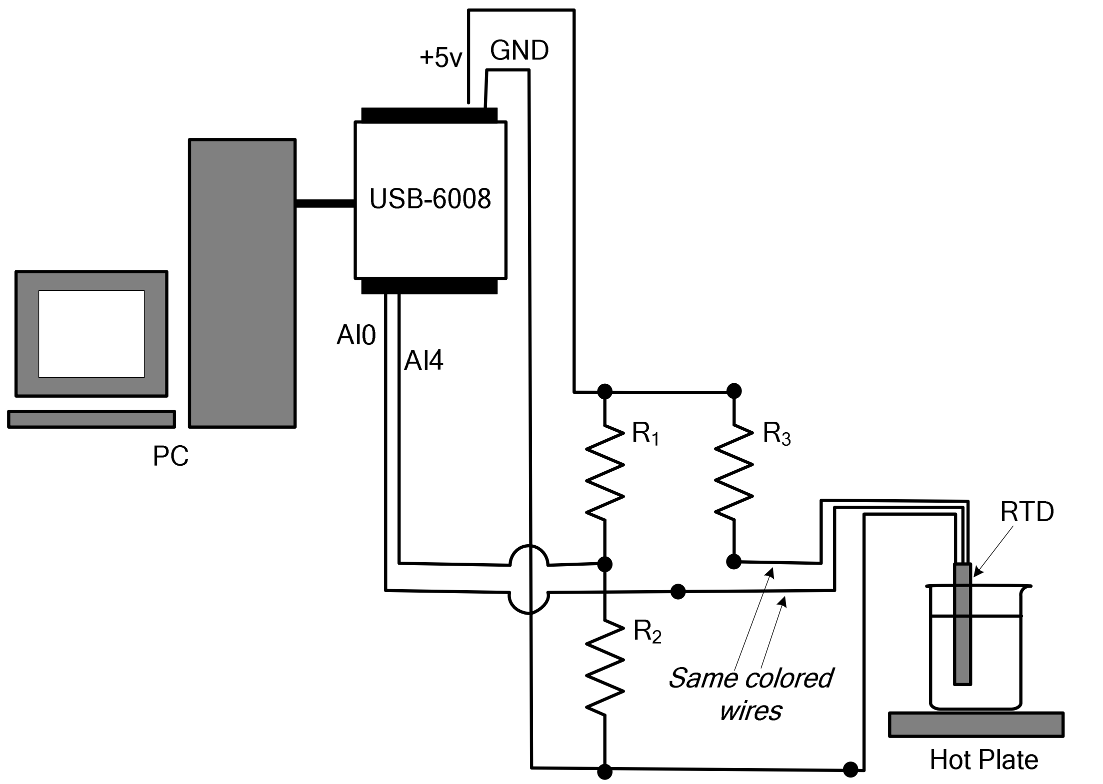


Figure 3

**Components:**

| | |
|---|---|
| $R_1$ | 1 $K\Omega$ |
| $R_2$ | 100 Ω + 10 Ω |
| $R_3$ | 1 $K\Omega$ |
| RTD | ~110 Ω @ 25°C |

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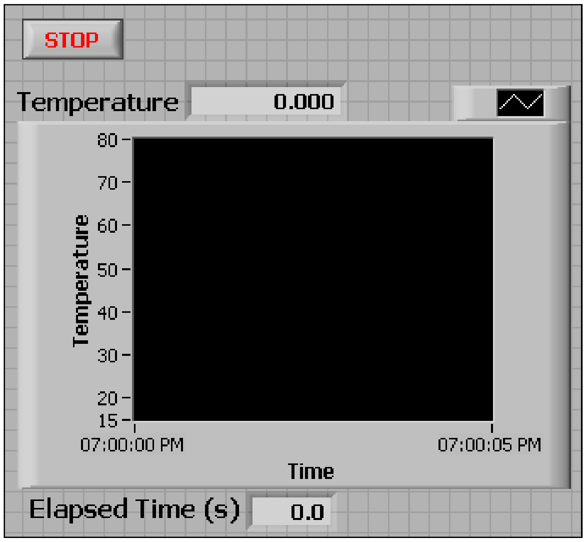
## III. Labview Setups



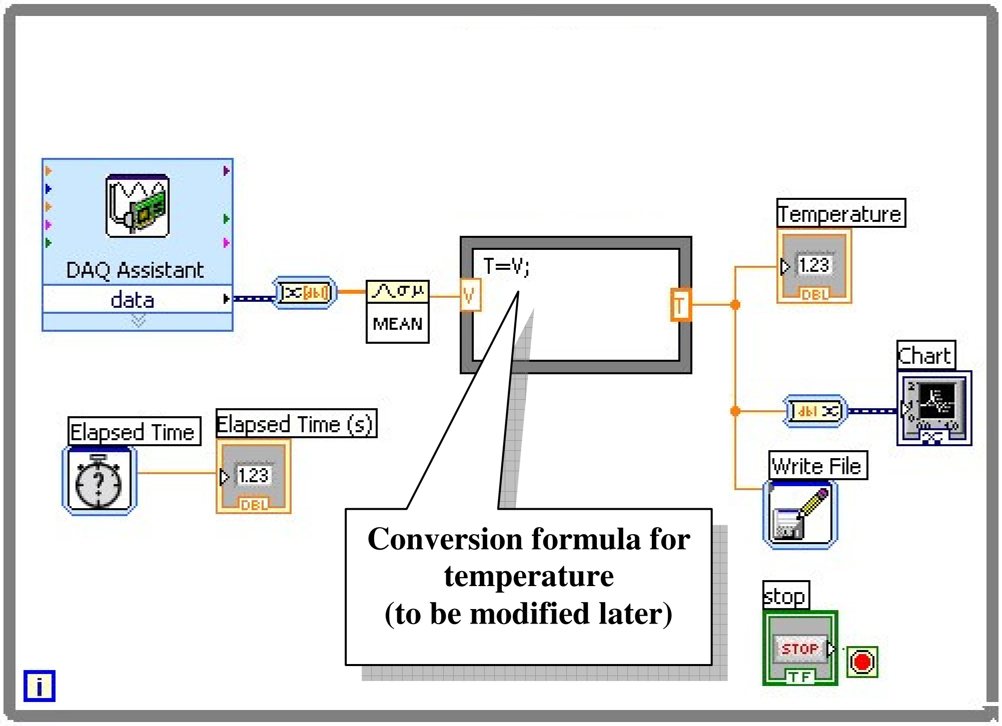




Figure 4. RTD VI

**Notes:**

1. For **DAQ Assistant** blocks, select **Functions → Express → Input → DAQ Assistant**:

    - Choose **analog input → voltage → ai0**
    - Input **max**=1, **min**=0, **acquisition mode=continuous**, **samples to read=10**, **rate=100 Hz**.

2. For the averaging function, go to **[Mathematics]→[Prob & Stat]→[Mean.vi]**.

3. There are two data conversion blocks obtained from **[Express]→[Signal Manipulation]** icon subdirectory:

    a. The one between the **[DAQ Assistant]** block and the [**Mean.vi]** block is the [**From DDT**] block and choose the "**1D array of scalars - single channel**".

    b. The block between the [**Formula Node]** block and the **[Chart]** block is the [**To DDT**] block and choose "**single scalar**".

## III. Procedure

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

   **Note**: for the voltage readings in step 2 and 3, you can temporarily input the formula: " **T=V;** " inside the formula box and change the scale of the chart to be maximum of +0.1 and minimum of 0.0, then run the VI to read the voltage.

2. Calibrate the your RTD by using the ice-water point and the boiling water points.

Table 2.

| Temperature ($^oC$) | Voltage (volts) |
|---|---|
| $0°C$ | |
| $100°C$ | |

3. Obtain a linear fit of temperature as a function of voltage, i.e. determine the slope $m$ and intercept $b$ such that

$$T = m\,V + b;$$

4. Modify the entry in the "**Formula Node**" block shown in Figure 4, using the conversion formula obtained in step 3, and change the chart scale back to minimum of -1$°C$ and maximum of 100 $°C$.

5. Test the obtained **RTD VI**.

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

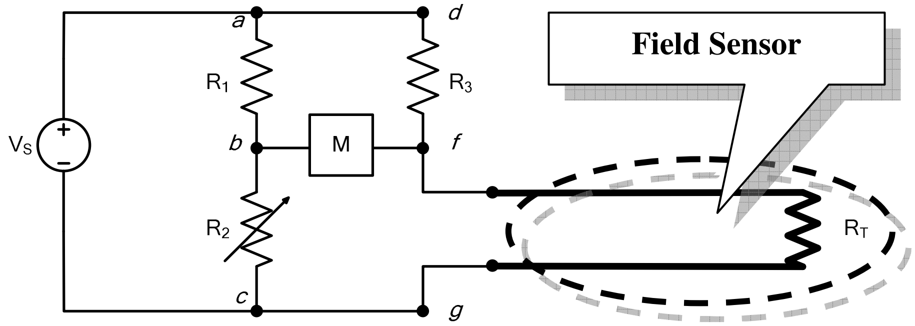



Figure A1. 2-wire sensor configuration.

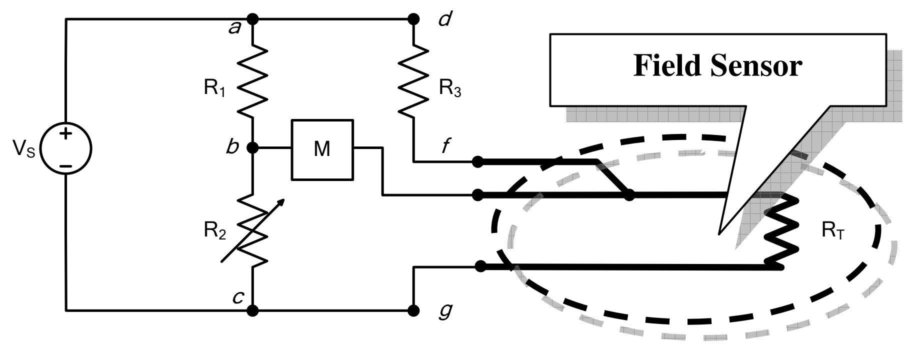



Figure A1. 3-wire sensor configuration.

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 measure the ratio of $R_3$ to $R_T$ more accurately (although still not exact).

## Appendix B. RTDs vs. Thermocouples

| | **RTDs** | **Thermocouples** |
|---|---|---|
| Temperature | $-200\ °C \leq T \leq 600\ °C$ | Some can go beyond |
| Time constant | Seconds | Fractions of second |
| Accuracy | Tolerance $\leq 2°C$ | Tolerance $\geq 2°C$ |
| Drift | Very stable | Can drift after few hours |
| Size | Sheath size $\approx 1/8"$ to $1/4"$ Dia | Can be smaller |