Electronics – 96032

POLITECNICO DI MILANO





Wheatstone Bridge Circuits

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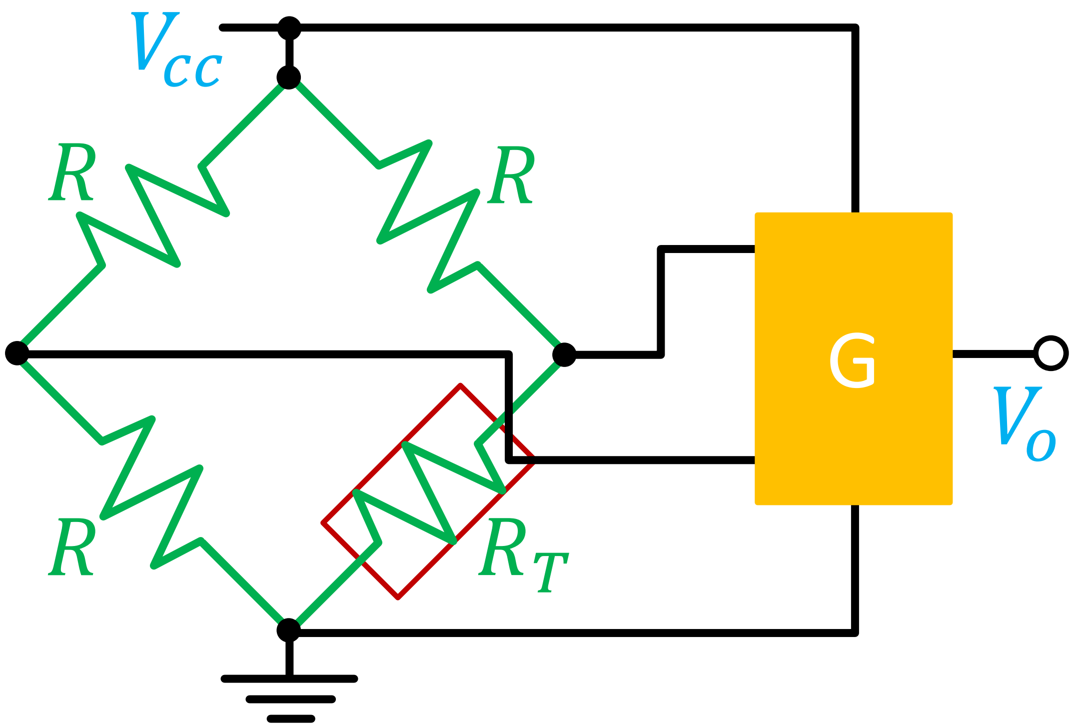
Outline

- Temperature sensor + INA
- Linearized Wheatstone bridge

Temperature sensor + INA



- $R_T = 30\ \Omega + 0.15\ T$
- $V_{cc} = 5\ \text{V}$
- $T = 0 - 100°\text{C}$

1. Find the bridge resistor values
2. Find the gain of the INA
3. Keep the sensor dissipation below 50 mW

Gain

One choice could be $R = 30\ \Omega$. We have then:

$$R_T = R\left(1 + \frac{0.15}{30}T\right) = R(1 + \alpha T) = R(1 + x); x^{max} = 0.5$$

$$V_i^{max} = \frac{V_{cc}}{4} x^{max} = \frac{V_{cc}}{8} \Rightarrow G = 8$$

Actually, x is too large $\Rightarrow$ non-linear behavior should be checked:

$$R_T(100°\mathrm{C}) = 45\ \Omega$$

$$V_i^{max} = V_{cc}\left(\frac{45}{75} - 0.5\right) = \frac{V_{cc}}{10} \Rightarrow G = 10$$

Output dynamics

- Previous analysis assumes $V_o = 0$ when $V_i = 0$
- A better choice is to set $V_i = 0$ at mid-range, i.e., when $T = 50°\text{C}$ and $R_T = 37.5\ \Omega$. This means picking the bridge resistor $R = 37.5\ \Omega$ and:

$$V_i^{max} = V_{cc}\left(\frac{45}{82.5} - 0.5\right) = 0.0455\ V_{cc}$$

$$V_i^{min} = V_{cc}\left(\frac{30}{67.5} - 0.5\right) = -0.0556\ V_{cc}$$

$$\Rightarrow G = 9.89$$

- The reference input of the single-supply INA must be set to a proper value to avoid clipping of the output

Dissipated power

- Maximum power dissipation happens for $R = R_T$:

$$P = \left(\frac{V_{cc}}{R + R_T}\right)^2 R_T = \begin{matrix} 208.3\text{ mW } (T = 0) \\ (R = R_T = 30\ \Omega) \end{matrix} \text{ or } \begin{matrix} 166.7\text{ mW } (T = 50°) \\ (R = R_T = 37.5\ \Omega) \end{matrix}$$

- To limit P, we could reduce V_{cc}:

$$\frac{V_{cc}^2}{4R} = 0.05 \Rightarrow V_{cc} = \begin{matrix} 2.45\text{ V} \\ (R = 30\ \Omega) \end{matrix} \text{ or } \begin{matrix} 2.74\text{ V} \\ (R = 37.5\ \Omega) \end{matrix}$$

- Note that G needs not to be changed, as the same V_{cc} value is used for both bridge and amplifier (ratiometric measurement)
- Of course, we are reducing the bridge output signal

Unbalanced bridge

- We change the upper resistors to $R_1 > R_T$
- Maximum power dissipation now happens for $R_T = 45\ \Omega$

$$P = \left(V_{cc}\frac{R_T}{R_T + R_1}\right)^2 \frac{1}{R_T} = 0.05 \Rightarrow R_1 = 105\ \Omega$$

- The INA input voltage becomes

$$V_i = V_{cc}\left(\frac{R(1+x)}{R(1+x)+R_1} - \frac{R}{R+R_1}\right)$$

Output voltage and gain

New values for the output voltage range are:

$R = 37.5\ \Omega$:

$$\left.\begin{aligned} V_i^{max} &= V_i(x = 0.2) = 36.8 \times 10^{-3}\ V_{cc} \\ V_i^{min} &= V_i(x = -0.2) = -40.9 \times 10^{-3}\ V_{cc} \end{aligned}\right\} \Rightarrow G = 12.9$$

$R = 30\ \Omega$:

$$\left.\begin{aligned} V_i^{max} &= V_i(x = 0.5) = 77.8 \times 10^{-3}\ V_{cc} \\ V_i^{min} &= V_i(x = 0) = 0 \end{aligned}\right\} \Rightarrow G = 12.86$$

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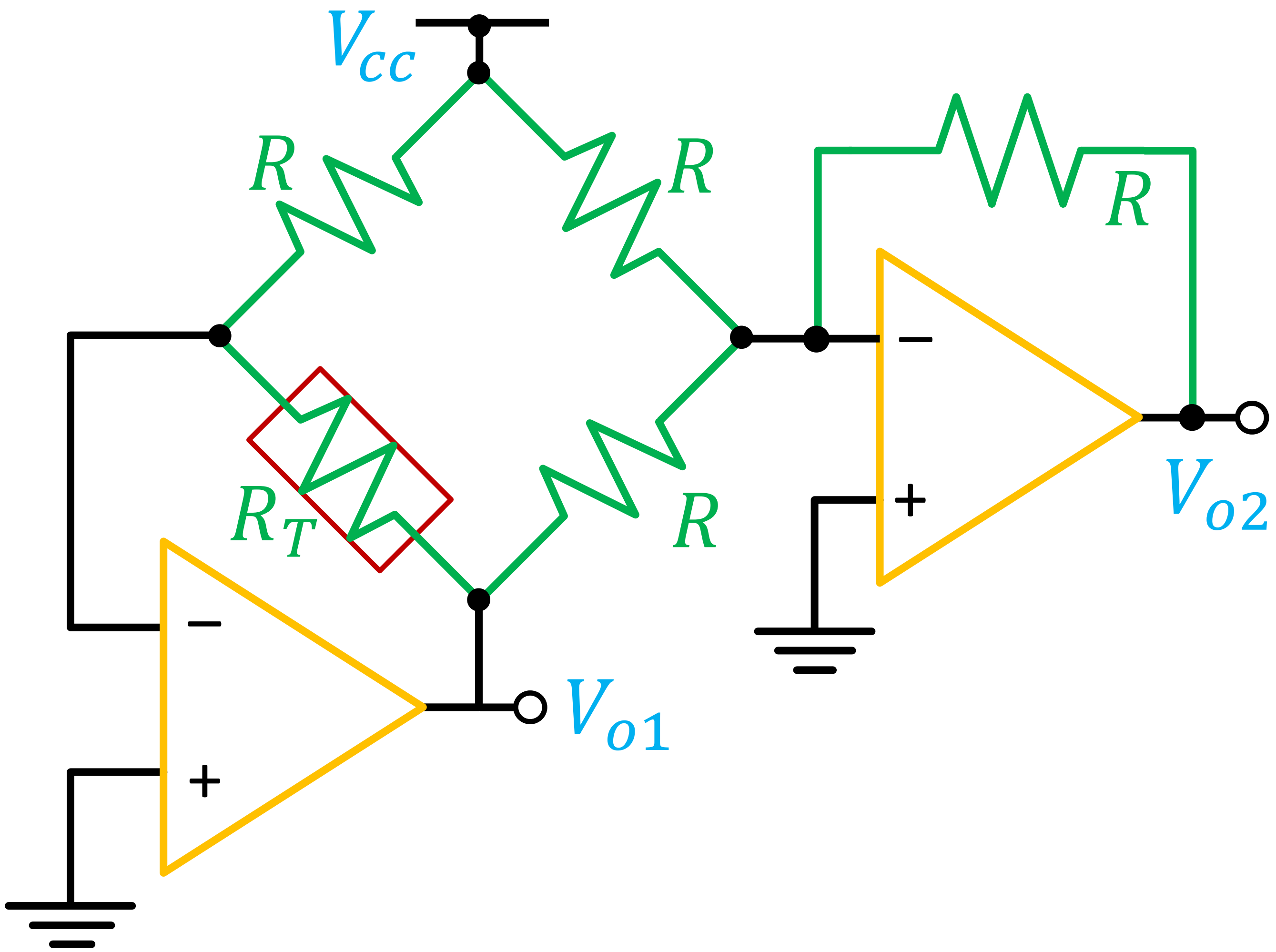
Linearized Wheatstone bridge



- $V_{cc} = 10\ \text{V}$
- $R = 250\ \Omega$
- $\alpha = 4{\times}10^{-3}/°\text{C}$
- $\Delta T_{min} = 0.1\ °\text{C}$

1. Pick between V_{o1} and V_{o2}
2. Compute the total output offset voltage

Results

$$V_{o1} = -V_{cc}\frac{R_T}{R} = -V_{cc}(1+x) \qquad V_{o2} = -V_{cc} - V_{o1} = V_{cc}x$$

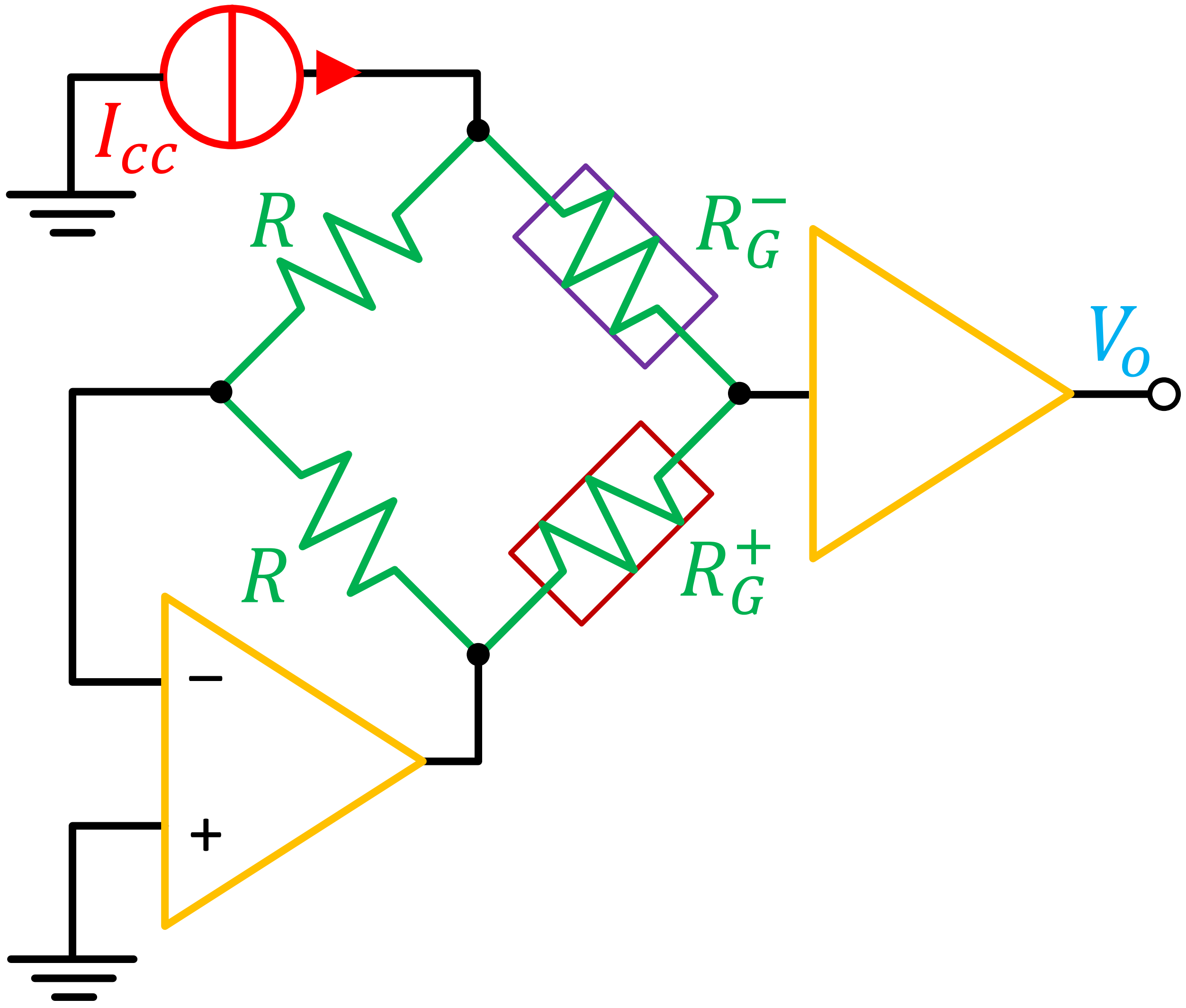
$$V_{o2}^{min} = V_{cc}\alpha\Delta T_{min} = 4\text{ mV}$$

Offset contributions (assuming bias currents are compensated by resistors $R/2$ and $R/3$ in series to the non-inv. inputs of the OAs:

$$V_o = 2V_{OS}^1 + I_{OS}^1 R_T + 3V_{OS}^2 + I_{OS}^2 R \approx 5V_{OS}$$

To reduce the error, $V_{OS} \ll 0.8$ mV $\Rightarrow$ Precision OpAmp (can go down to 50 µV). Offset drift must also be checked!

Linearized Wheatstone bridge



- $R = 150\ \Omega$
- $\alpha = 3{\times}10^{-3}/°\mathrm{C}$
- $GF = 2$
- $\varepsilon = 10\ \mu\mathrm{strain} = 10^{-5}$

1. Compute the output voltage
2. Evaluate the effect of temperature variations

Results

$$R_G^+ = R(1+x); R_G^- = R(1-x)$$

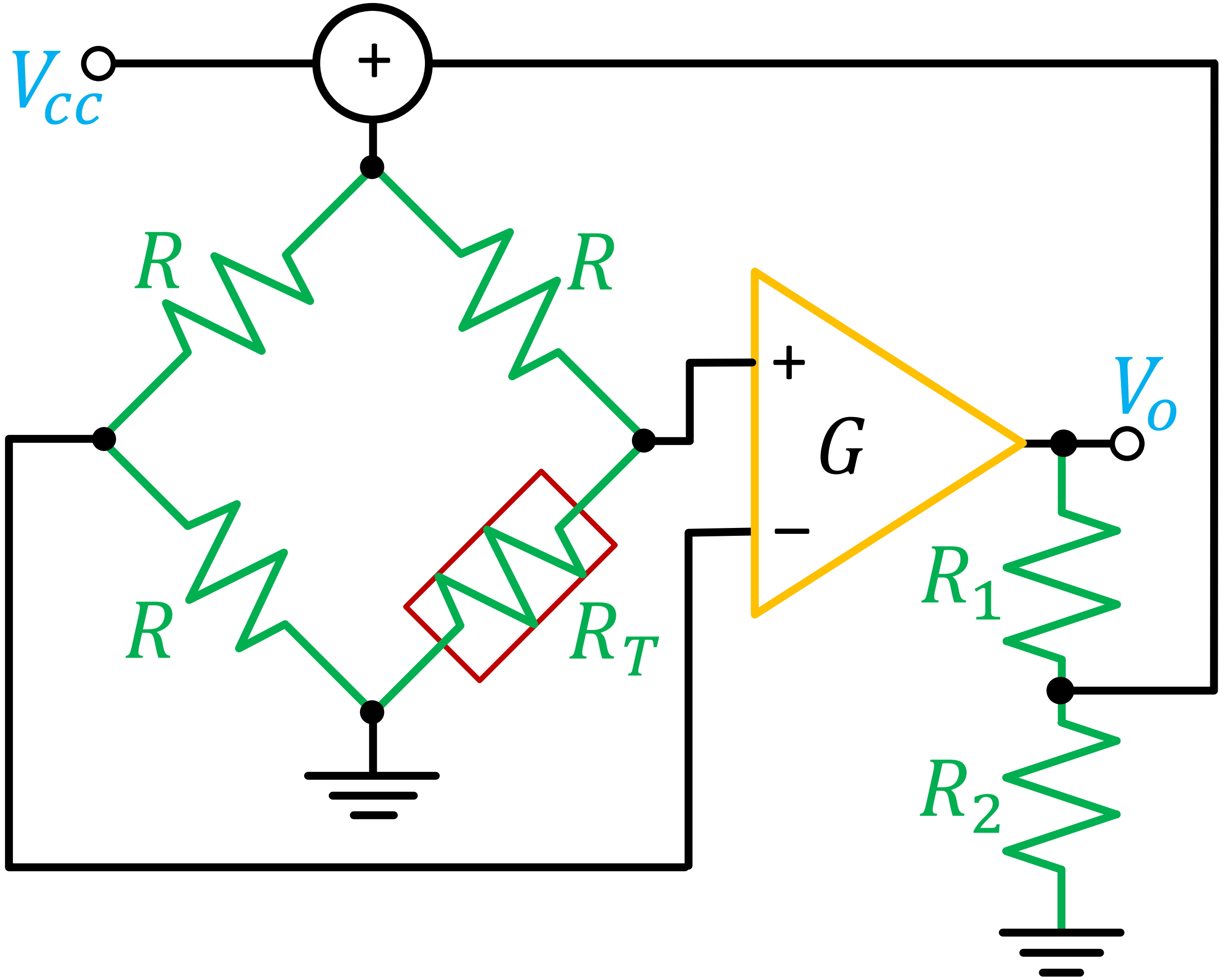
$$I_L 2R = I_R\left(R_G^+ + R_G^-\right) = 2RI_R \Rightarrow I_L = I_R = \frac{I_{cc}}{2}$$

$$V_o = \left(R - R_G^-\right)\frac{I_{cc}}{2} = RI_{cc}\frac{x}{2} = RI_{cc}\frac{GF\ \varepsilon}{2}$$

If ΔT is accounted for (under unstrained conditions), we have

$$V_o = R(1 + \alpha\ \Delta T)I_{cc}\frac{x}{2} = 0$$

Linearized Wheatstone bridge



- $R = 1\ \text{k}\Omega$
- $\alpha = 3.9 \times 10^{-3}/°\text{C}$
- $T = 0 \div 500°\text{C}$
- $V_{cc} = 1\ \text{V}$

1. Find parameter values to obtain a linear $V_o - T$ relationship

Results

The bridge supply voltage is

$$V'_{cc} = V_{cc} + kV_o \qquad k = \frac{R_2}{R_1 + R_2}$$

and the output can be expressed as

$$V_o = GV'_{cc}\left(\frac{1+x}{2+x} - \frac{1}{2}\right) = GV'_{cc}\frac{x}{2(2+x)}$$

leading to

$$V_o = V_{cc}\frac{Gx}{4 + (2 - Gk)x} \Rightarrow Gk = 2$$

Homework