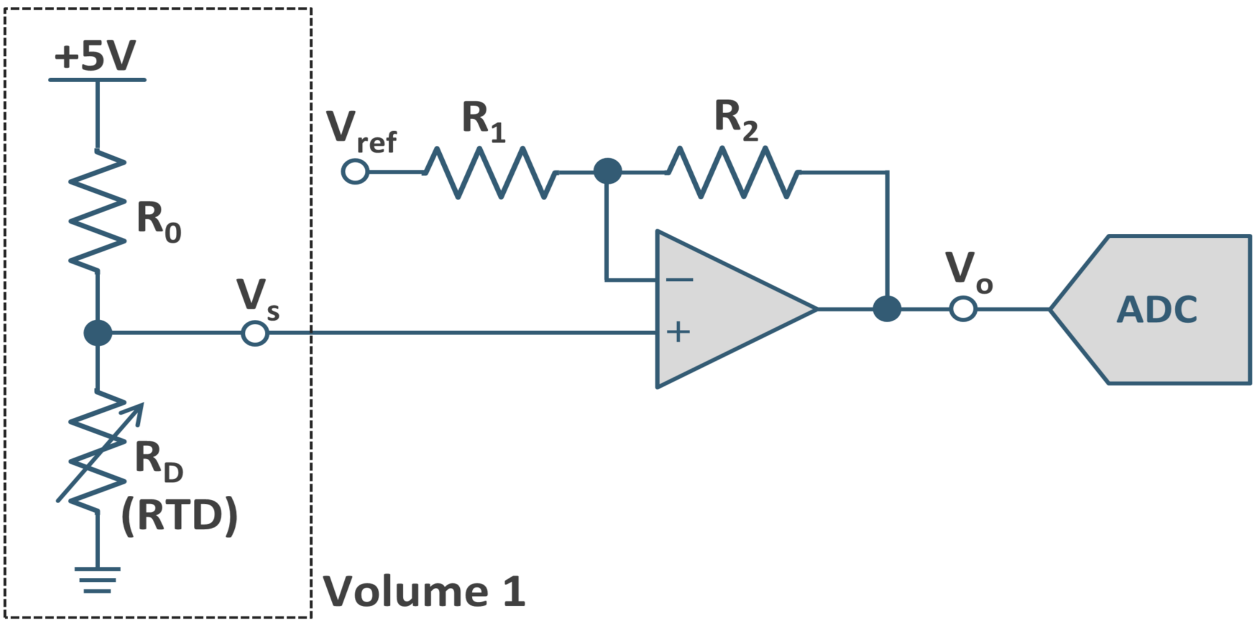
Sensor interface design with Worst case analysis - Volume 1

In this application, the worst case analysis for the temperature sensor interface circuit is performed. The circuit consists of a thin film Resistance Temperature Detector (RTD), op-amp and other passive devices in order to convert temperature to voltage and adjust voltage to the input voltage range of AD converter.
This worksheet shows the analysis to obtain the maximum and minimum output voltage from the temperature sensor circuit as volume 1.



1. Resistance Temperature Detector (RTD)

As the first step of the analysis, the thin film Resistance Temperature Detector's characteristic is reviewed in this section.
In this example, ZNI1000 is selected for a RTD.

Reference : Datasheet of ZNI1000 (Diodes Incorporated)

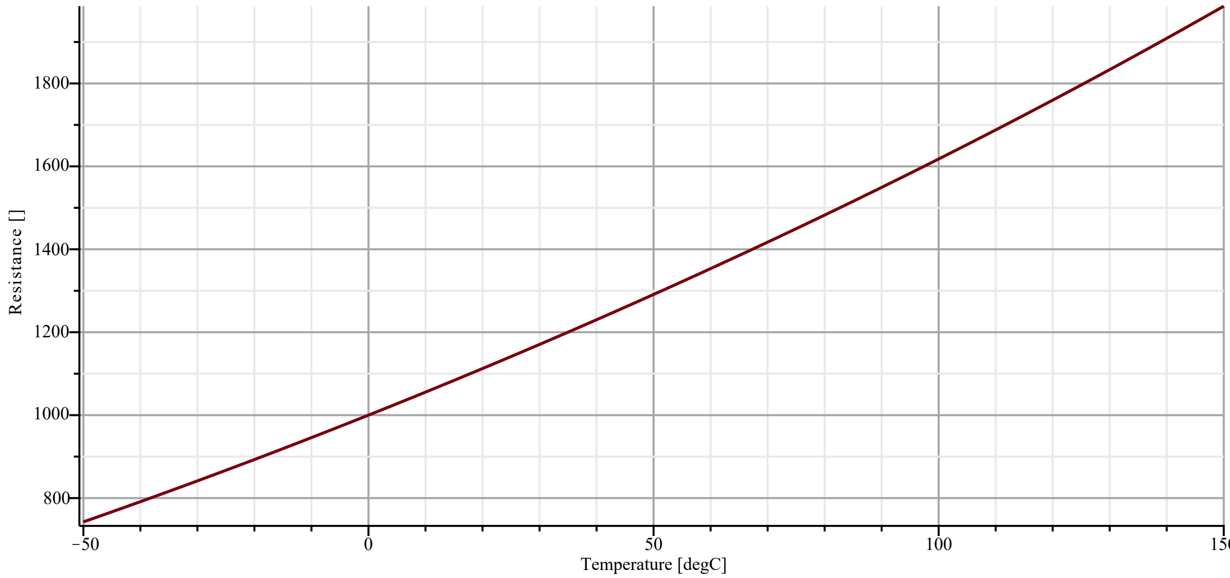
Based on the reference, the resistance of RTD is defined with the following equation.

$$Eq_{RTD1} := R_D = R_{D0} \cdot \left(1 + A \cdot T + B \cdot T^2 + C \cdot T^4 + D \cdot T^6\right)$$

$$Par_{RTD} := \left[R_{D0} = 10^3, A = 5.485 \cdot 10^{-3}, B = 6.65 \cdot 10^{-6}, C = 2.805 \cdot 10^{-11}, D = -2.0 \cdot 10^{-17}\right]$$

Thus, the nominal characteristic of Sensor Resistance vs Temperature is shown as follow.

$\mathrm{plot}\left(\mathrm{eval}\left(\mathrm{rhs}\left(Eq_{RTD1}\right), Par_{RTD}\right), T = -50..150, \mathrm{gridlines}, \mathrm{axes} = \text{"framed"},\right.$
$\left.\mathit{labels} = \left[\text{"Temperature [degC]"}, \text{"Resistance [}\Omega\text{]"}\right], \mathrm{labeldirections} = \left[\mathrm{horizontal}, \mathrm{vertical}\right]\right) =$



The tolerance for Temperature is provided as the following equation

$$Eq_{RTD2} := \begin{cases} 0.4 + 0.028 \cdot \mathrm{abs}(T) & T \leq 0 \\ 0.4 + 0.07 \cdot \mathrm{abs}(T) & \text{otherwise} \end{cases}$$

Additionally, the long term stability is given as 0.1 % for 1000 h at 150 degC.
Therefore, the max/min characteristic of Sensor resistance can be obtained with the following equation.

$$Eq_{RTD3} := \mathrm{lhs}\left(Eq_{RTD1}\right) = (1 + 0.1) \cdot \mathrm{eval}\left(\mathrm{rhs}\left(Eq_{RTD1}\right), \left[T = T + Eq_{RTD2}\right]\right)$$

$$Eq_{RTD4} := \mathrm{lhs}\left(Eq_{RTD1}\right) = (1 - 0.1) \cdot \mathrm{eval}\left(\mathrm{rhs}\left(Eq_{RTD1}\right), \left[T = T - Eq_{RTD2}\right]\right)$$

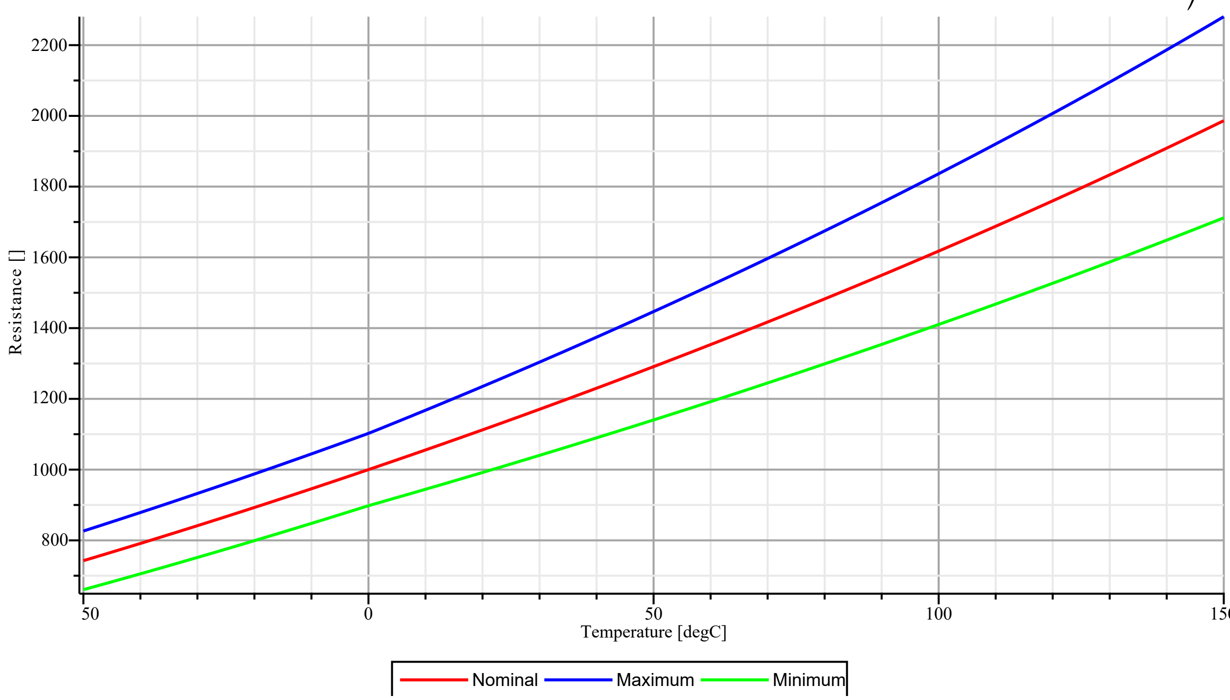
So, the following plot shows the nominal and maximum, minimum characteristic.

$$p_{RTD1} := \mathrm{plot}\left(\mathrm{eval}\left(\mathrm{rhs}\left(Eq_{RTD1}\right), Par_{RTD}\right), T = -50\,..150, \mathrm{legend} = \text{"Nominal"}, \mathrm{color} = \mathrm{red}\right)$$

$$p_{RTD2} := \mathrm{plot}\left(\mathrm{eval}\left(\mathrm{rhs}\left(Eq_{RTD3}\right), Par_{RTD}\right), T = -50\,..150, \mathrm{legend} = \text{"Maximum"}, \mathrm{color} = \mathrm{blue}\right)$$

$$p_{RTD3} := \mathrm{plot}\left(\mathrm{eval}\left(\mathrm{rhs}\left(Eq_{RTD4}\right), Par_{RTD}\right), T = -50\,..150, \mathrm{legend} = \text{"Minimum"}, \mathrm{color} = \mathrm{green}\right)$$

$$\mathrm{plots{:}\text{-}display}\left(\left[p_{RTD1}, p_{RTD2}, p_{RTD3}\right], \mathrm{gridlines}, \mathrm{axes} = \text{"framed"}, \textit{labels} = \left[\text{"Temperature [degC]"}, \text{"Resistance [}\Omega\text{]"}\right], \mathrm{labeldirections} = \left[\mathrm{horizontal}, \mathrm{vertical}\right]\right) =$$



2. Output voltage of Temperature sensor circuit

The output voltage V_s can be calculated with the following.

$$Eq_{vout} := V_s = \frac{R_D}{R_0 + R_D} \cdot V_{sup}$$

The supply voltage V_{sup} and the resistance R_0 are given as follow.

$$V_{sup} := 5 \qquad R_0 := 1.5 \cdot 10^3$$

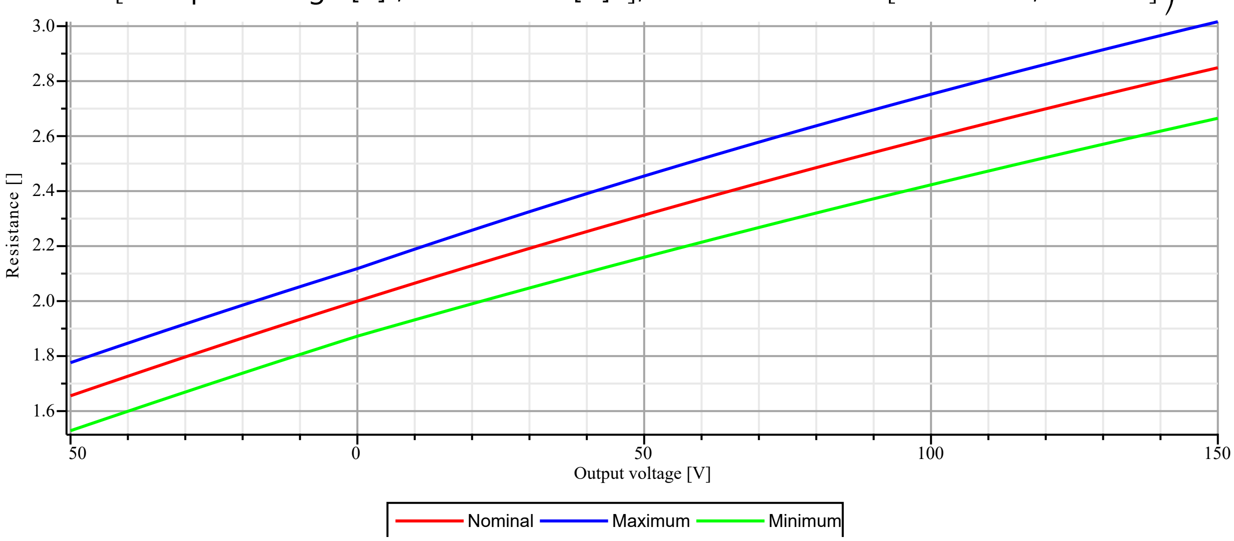
Thus, the following plot shows the output voltage of temperature sensor circuit for Nominal/Maximum/Minumum.

$$p_{vout1} := \mathrm{plot}\left(\mathrm{eval}\left(\mathrm{rhs}\left(Eq_{vout}\right), \left[R_D = \mathrm{eval}\left(\mathrm{rhs}\left(Eq_{RTD1}\right), Par_{RTD}\right)\right]\right), T = -50\,..150, \text{legend} = \text{"Nominal"}, \text{color} = \text{red}\right)$$

$$p_{vout2} := \mathrm{plot}\left(\mathrm{eval}\left(\mathrm{rhs}\left(Eq_{vout}\right), \left[R_D = \mathrm{eval}\left(\mathrm{rhs}\left(Eq_{RTD3}\right), Par_{RTD}\right)\right]\right), T = -50\,..150, \text{legend} = \text{"Maximum"}, \text{color} = \text{blue}\right)$$

$$p_{vout3} := \mathrm{plot}\left(\mathrm{eval}\left(\mathrm{rhs}\left(Eq_{vout}\right), \left[R_D = \mathrm{eval}\left(\mathrm{rhs}\left(Eq_{RTD4}\right), Par_{RTD}\right)\right]\right), T = -50\,..150, \text{legend} = \text{"Minimum"}, \text{color} = \text{green}\right)$$

plots:-display([p_{vout1}, p_{vout2}, p_{vout3}], gridlines, axes = "framed", *labels* = ["Output voltage [V]", "Resistance [Ω]"], labeldirections = [horizontal, vertical]) =



3. Range of Output voltage of Temperature sensor circuit

In order to do the worse case analysis of the op-amp circuit to adujst the input voltage for AD converter, the maximum/minimum output voltage of Temperature sensor circuit is calculated as follow. Regarding the range of sensing temperature, -30 to 70 [degC] is required in this case.

$$dat := [0, 0, 0, 0, 0, 0]$$

Nominal output voltage

$$dat[1] := \text{maximize}\left(\text{eval}\left(\text{rhs}\left(Eq_{vout}\right), \left[R_D = \text{eval}\left(\text{rhs}\left(Eq_{RTD1}\right), Par_{RTD}\right)\right]\right), T = -30\,..70\right)$$

$$dat[2] := \text{minimize}\left(\text{eval}\left(\text{rhs}\left(Eq_{vout}\right), \left[R_D = \text{eval}\left(\text{rhs}\left(Eq_{RTD1}\right), Par_{RTD}\right)\right]\right), T = -30\,..70\right)$$

Maximum output voltage

$$dat[3] := \text{maximize}\left(\text{eval}\left(\text{rhs}\left(Eq_{vout}\right), \left[R_D = \text{eval}\left(\text{rhs}\left(Eq_{RTD3}\right), Par_{RTD}\right)\right]\right), T = -30\,..70\right)$$

$$dat[4] := \text{minimize}\left(\text{eval}\left(\text{rhs}\left(Eq_{vout}\right), \left[R_D = \text{eval}\left(\text{rhs}\left(Eq_{RTD3}\right), Par_{RTD}\right)\right]\right), T = -30\,..70\right)$$

Minimum output voltage

$$dat[5] := \text{maximize}\left(\text{eval}\left(\text{rhs}\left(Eq_{vout}\right), \left[R_D = \text{eval}\left(\text{rhs}\left(Eq_{RTD4}\right), Par_{RTD}\right)\right]\right), T = -30\,..70\right)$$

$$dat[6] := \text{minimize}\left(\text{eval}\left(\text{rhs}\left(Eq_{vout}\right), \left[R_D = \text{eval}\left(\text{rhs}\left(Eq_{RTD4}\right), Par_{RTD}\right)\right]\right), T = -30\,..70\right)$$

Thus, the range of output voltage of Temperature sensor circuit is obtained.

Maximum voltage: $\max(dat) = 2.578$

Minimum voltage: $\min(dat) = 1.669$