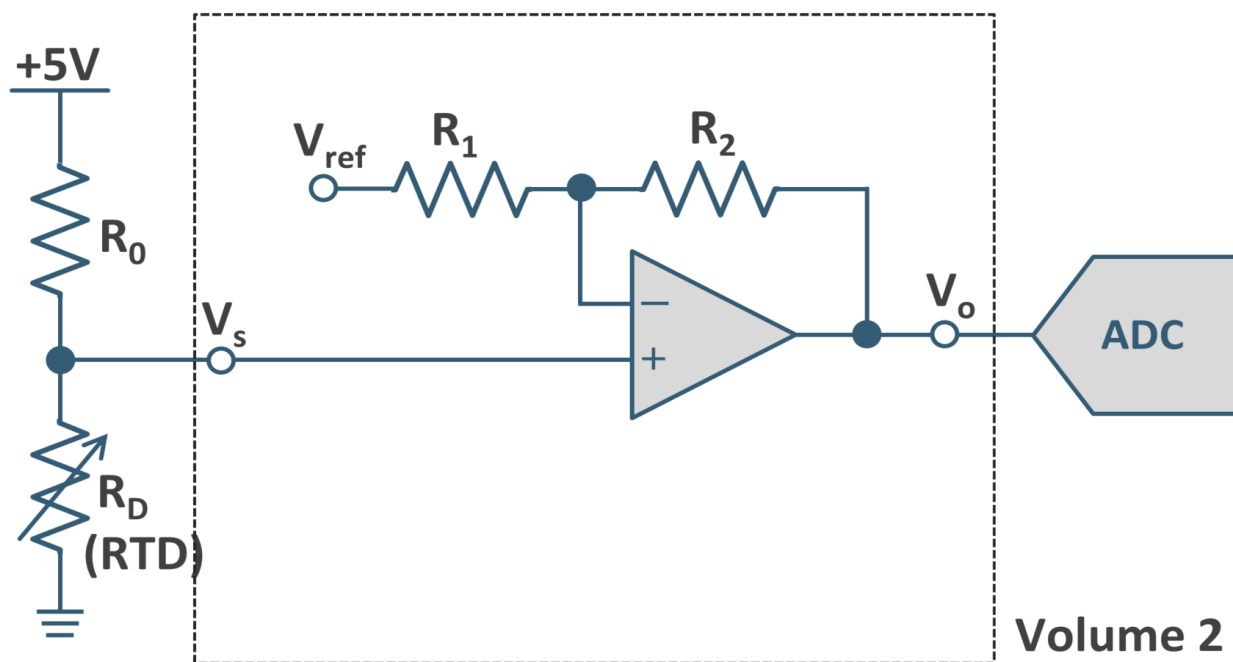


# Sensor interface design with Worst case analysis - Volume 2

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.

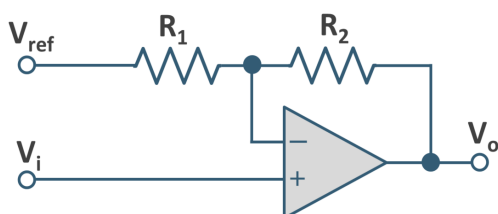
This worksheet shows how to select a circuit to adjust the input voltage for AD converter with the worst case analysis as volume 2.



## 1. Level shifting circuits with Op-amp

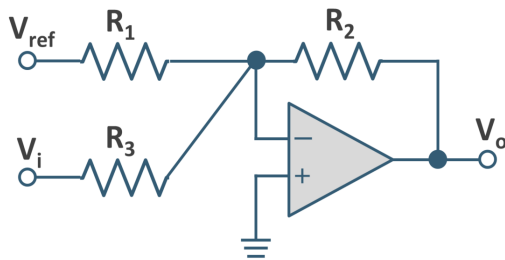
The level shifting circuit is determined to fit to the specification of input voltage of AD converter. And, there are types of the circuits in terms of how to fit the voltage to the spec. 3 types of circuits are shown below.

Non-inverting



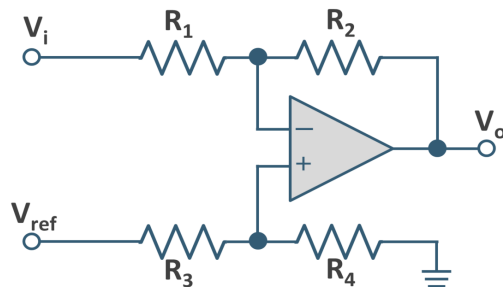
$$V_o = \left( 1 + \frac{R_2}{R_1} \right) \cdot V_i - \frac{R_2}{R_1} \cdot V_{ref}$$

Inverting



$$V_o = -\frac{R_2}{R_1} \cdot V_i - \frac{R_2}{R_3} \cdot V_{ref}$$

Inverting



$$V_o = -\frac{R_2}{R_1} \cdot V_i + \left( \frac{R_4}{R_3 + R_4} \right) \cdot \left( 1 + \frac{R_2}{R_1} \right) \cdot V_{ref}$$

## 2. Determine parameters of the circuit

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In the volume 1 worksheet, we obtained the range of output voltage from Temperature sensor circuit part as follow.

Maximum output voltage  $V_{i_{max}} := 2.578 \text{ V}$

Minimum output voltage  $V_{i_{min}} := 1.669 \text{ V}$

In this example, the AD converter's input voltage range is specified with:

Maximum input voltage  $V_{AD_{max}} := 5 \text{ V}$

Minimum input voltage  $V_{AD_{min}} := 0 \text{ V}$

Thus, the voltage need to be offseted and amplified. In the case, we can select "non-inverting" circuit of the previous section.

If the resistance  $R_1$  is  $1 \text{ k}[\Omega]$ , a set of ideal parameter value can be obtained with the following calculations.

Output voltage equation  $Eq_{vout} := V_o = \left( 1 + \frac{R_2}{R_1} \right) \cdot V_i - \frac{R_2}{R_1} \cdot V_{ref}$

Equations for maximum and minimum input voltage

$$\text{Eq}_{\text{obj}} := [0, 0]$$

$$\text{Eq}_{\text{obj}}[1] := \text{eval}\left(\text{Eq}_{\text{vout}} \left[ V_i = V_{i_{\text{max}}}, V_o = V_{\text{AD}_{\text{max}}}, R_1 = 1000 \Omega \right] \right)$$

$$\text{Eq}_{\text{obj}}[2] := \text{eval}\left(\text{Eq}_{\text{vout}} \left[ V_i = V_{i_{\text{min}}}, V_o = V_{\text{AD}_{\text{min}}}, R_1 = 1000 \Omega \right] \right)$$

Solution for  $R_2$  and  $V_{\text{ref}}$

$$\text{sol} := \text{fsolve}\left(\text{Eq}_{\text{obj}}\right) = \left\{ R_2 = 4.501 \times 10^3 \Omega, V_{\text{ref}} = 2.040 \text{ V} \right\}$$

Base on the standard parameter of resistances, the following parameter values are selected.

$$\text{Resistance } R_2 \quad R_{2a} := 3700 \Omega$$

$$\text{Referenve voltage } V_{\text{ref}} \quad V_{\text{ref}_a} := 2.00 \text{ V}$$

So, the input voltage for AD converter will be adjusted as follows.

Maximum voltage of AD converter input

$$\text{eval}\left(\text{Eq}_{\text{vout}} \left[ V_i = V_{i_{\text{max}}}, V_{\text{ref}} = V_{\text{ref}_a}, R_1 = 1000 \Omega, R_2 = R_{2a} \right] \right) = V_o = 4.717 \text{ V}$$

Minimum voltage of AD converter input

$$\text{eval}\left(\text{Eq}_{\text{vout}} \left[ V_i = V_{i_{\text{min}}}, V_{\text{ref}} = V_{\text{ref}_a}, R_1 = 1000 \Omega, R_2 = R_{2a} \right] \right) = V_o = 0.444 \text{ V}$$

### 3. Extreme value analysis

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As the next step, the extreme value analysis is applied in order to check the effect of tolerance of parameter values.

Define the conditions of parameters.

Parameters	$\text{Par} := [R_{1'}, R_{2'}, V_{\text{ref}}]$
Nominal value	$\text{Nom} := [1000 \Omega, R_{2a'}, V_{\text{ref}_a}]$
Tolerance	$\text{Tol} := [1, 1, 3]$

List of parameters based on tolerance

$$\text{PList} := \left[ \text{seq} \left( \text{Nom} + \sim \text{Nom} \cdot \sim \text{Tol} \cdot \sim (\text{Bits}:-\text{Split}(i, \text{bits} = \text{nops}(\text{Nom})) \cdot 2 - \sim 1) \cdot 0.01, \right. \right. \\ \left. \left. i = 1 \dots \text{nops}(\text{Nom})^2 \right) \right]$$

Results of voltage calculation

$$\text{Res}_{\text{max}} := \left[ \text{seq} \left( \text{eval}(\text{rhs}(\text{Eq}_{\text{vout}}), [V_i = V_{i_{\text{max}}'} \text{ seq}(\text{Par}[i] = \text{PList}[j][i], i = 1 \dots \text{nops}(\text{Par}))]), \right. \right. \\ \left. \left. j = 1 \dots \text{nops}(\text{PList}) \right) \right]$$

$$\text{Res}_{\text{min}} := \left[ \text{seq} \left( \text{eval}(\text{rhs}(\text{Eq}_{\text{vout}}), [V_i = V_{i_{\text{min}}'} \text{ seq}(\text{Par}[i] = \text{PList}[j][i], i = 1 \dots \text{nops}(\text{Par}))]), \right. \right. \\ \left. \left. j = 1 \dots \text{nops}(\text{PList}) \right) \right]$$

Search max/min value and the position of parameter values in the list.

$$\text{maxvalue}, \text{maxpos} := \text{ListTools}:-\text{FindMaximalElement} \left( \right. \\ \left. \left[ \text{seq} \left( \text{Res}_{\text{max}}[i] \cdot \left( \frac{1}{V} \right), i = 1 \dots \text{nops}(\text{Res}_{\text{max}}) \right) \right], \text{position} \right)$$

$$\text{maxvalue2} := \text{maxvalue} \cdot V$$

$$\text{minvalue}, \text{minpos} := \text{ListTools}:-\text{FindMinimalElement} \left( \right. \\ \left. \left[ \text{seq} \left( \text{Res}_{\text{min}}[i] \cdot \left( \frac{1}{V} \right), i = 1 \dots \text{nops}(\text{Res}_{\text{min}}) \right) \right], \text{position} \right)$$

$$\text{minvalue2} := \text{minvalue} \cdot V$$

$\text{nomvalue} := \text{eval}(\text{rhs}(\text{Eq}_{\text{vout}}), [V_i = V_{i\_max}, \text{seq}(\text{Par}[i] = \text{Nom}[i], i = 1 \dots \text{nops}(\text{Par}))])$

$\text{MaxPattern} := \text{seq}(\text{Par}[i] = \text{PList}[\text{maxpos}][i], i = 1 \dots \text{nops}(\text{Par}))$

$\text{NomPattern} := \text{seq}(\text{Par}[i] = \text{Nom}[i], i = 1 \dots \text{nops}(\text{Par}))$

$\text{MinPattern} := \text{seq}(\text{Par}[i] = \text{PList}[\text{minpos}][i], i = 1 \dots \text{nops}(\text{Par}))$

Final result of Maximum/Nominal/Minimum

$\text{nomvalue} = 4.717 \text{ V}$

$\text{NomPattern} = R_1 = 1000 \Omega, R_2 = 3700 \Omega, V_{\text{ref}} = 2.000 \text{ V}$

$\text{maxvalue2} = 4.892 \text{ V}$

$\text{MaxPattern} = R_1 = 1.010 \times 10^3 \Omega, R_2 = 3.663 \times 10^3 \Omega, V_{\text{ref}} = 1.940 \text{ V}$

$\text{minvalue2} = 0.686 \text{ V}$

$\text{MinPattern} = R_1 = 1.010 \times 10^3 \Omega, R_2 = 3.663 \times 10^3 \Omega, V_{\text{ref}} = 1.940 \text{ V}$

Thus, both maximum and minimum voltage satisfy the range of AD converter's voltage (0 - 5 V) with the set of parameters.