# Temperature Sensing with PTC Circuit

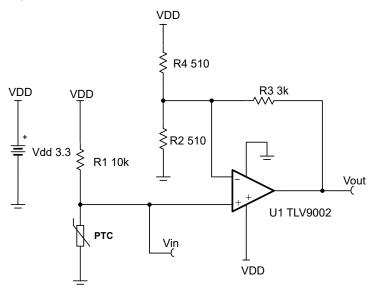


## **Design Goals**

Temperature		Output voltage		Supply	
T <sub>Min</sub>	T <sub>Max</sub>	V <sub>outMin</sub>	V <sub>outMax</sub>	V <sub>dd</sub>	V <sub>ee</sub>
0 ℃	50 °C	0.05V	3.25V	3.3V	0V

#### **Design Description**

This temperature sensing circuit uses a resistor in series with a positive—temperature—coefficient (PTC) thermistor to form a voltage—divider, which has the effect of producing an output voltage that is linear over temperature. The circuit uses an op amp in a non—inverting configuration with inverting reference to offset and amplify the signal, which helps to utilize the full ADC resolution and increase measurement accuracy.



## **Design Notes**

- 1. Use the op amp in a linear operating region. Linear output swing is usually specified under the  $A_{OL}$  test conditions. TLV9002 linear output swing 0.05 V to 3.25 V.
- 2. The connection, V<sub>in</sub>, is a positive temperature coefficient output voltage. To correct a negative–temperature–coefficient (NTC) output voltage, switch the position of R<sub>1</sub> and PTC thermistor.
- 3. Choose R<sub>1</sub> based on the temperature range and the PTC's value.
- 4. Using high–value resistors can degrade the phase margin of the amplifier and introduce additional noise in the circuit. It is recommended to use resistor values around  $10k\Omega$  or less.
- 5. A capacitor placed in parallel with the feedback resistor will limit bandwidth, improve stability and help reduce noise.



#### **Design Steps**

$$V_{out} = V_{dd} \times \frac{R_{PTC}}{R_{PTC} + R_1} \times \frac{(R_2 \mid \mid R_4) + R_3}{(R_2 \mid \mid R_4)} - \left(\frac{R_3}{R_4} \times V_{dd}\right)$$

1. Calculate the value of R<sub>1</sub> to produce a linear output voltage. Use the minimum and maximum values of the PTC to obtain a range of values for R<sub>1</sub>.

$$R_{PTCMax} = R_{PTC @ 50C} = 11.611 \ k\Omega, \ R_{PTCMin} = R_{PTC @ 0C} = 8.525 \ k\Omega$$

$$R_1 = \sqrt{R_{PTC @ 0C} \times R_{PTC @ 50C}} = \sqrt{8.525 \ k\Omega \times 11.611 \ k\Omega} = 9.95 \ k\Omega \approx 10 \ k\Omega$$

2. Calculate the input voltage range.

$$V_{inMin} = V_{dd} \times \frac{R_{PTCMin}}{R_{PTCMin} + R_1} = 3.3 \quad V \times \frac{8.525 \quad k\Omega}{8.525 \quad k\Omega + 10 \quad k\Omega} = 1.519 \quad V$$

$$V_{inMax} = V_{dd} \times \frac{R_{PTCMax}}{R_{PTCMax} + R_1} = 3.3 \quad V \times \frac{11.611 \quad k\Omega}{11.611 \quad k\Omega + 10 \quad k\Omega} = 1.773 \quad V$$

3. Calculate the gain required to produce the maximum output swing.

$$G_{ideal} = \frac{V_{outMax} - V_{outMin}}{V_{inMax} - V_{inMin}} = \frac{3.25 \ V - 0.05 \ V}{1.773 \ V - 1.519 \ V} = 12.598 \frac{V}{V}$$

4. Solve for the parallel combination of  $R_2$  and  $R_4$  using the ideal gain. Select  $R_3$ = 3 k $\Omega$  (Standard Value).

$$(R_2 \mid \mid R_4)_{ideal} = \frac{R_3}{G_{ideal} - 1} = \frac{3 \ k\Omega}{12.598 \ V/V - 1} = 258.665 \ \Omega$$

5. Calculate R<sub>2</sub> and R<sub>4</sub> based off of the transfer function and gain.

$$R_4 = \frac{R_3 \times V_{dd}}{V_{inMax} \times G_{ideal} - V_{outMax}} = \frac{3 \ k\Omega \times 3.3 \ V}{1.773 \ V \times 12.598 \ V/V - 3.25 \ V} = 518.698 \ \Omega$$

$$R_2 = \frac{(R_2 \mid \mid R_4)_{ideal} \times R_4}{R_4 - (R_2 \mid \mid R_4)_{ideal}} = \frac{258.665 \ \Omega \times 518.698 \ \Omega}{518.698 \ \Omega - 258.665 \ \Omega} = 515.969 \ \Omega$$

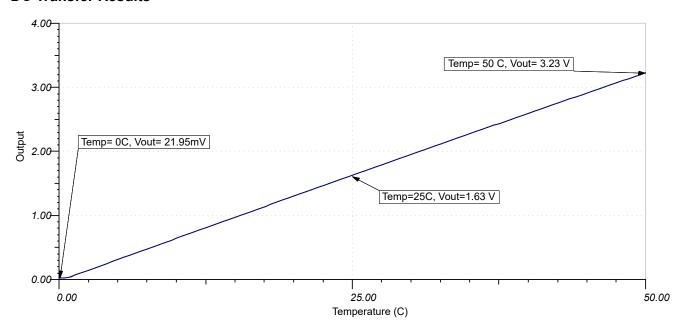
6. Calculate the actual gain with the standard values of  $R_2$  (510  $\Omega$ ) and  $R_4$  (510  $\Omega$ ).

$$G_{actual} = \frac{(R_2 \mid \mid R_4) + R_3}{(R_2 \mid \mid R_4)} = \frac{255 \Omega + 3 k\Omega}{255 \Omega} = 12.764 \frac{V}{V}$$



## **Design Simulations**

#### **DC Transfer Results**



Design References www.ti.com

## **Design References**

- 1. Analog Engineer's Circuit Cookbooks
- 2. SPICE Simulation File SBOMAV5
- 3. TI Precision Labs

### **Design Featured Op Amp**

TLV9002				
V <sub>cc</sub>	1.8 V to 5.5 V			
V <sub>inCM</sub>	Rail–to–rail			
V <sub>out</sub>	Rail-to-rail			
V <sub>os</sub>	1.5mV			
Iq	0.06mA			
I <sub>b</sub>	5pA			
UGBW	1MHz			
SR	2V/μs			
#Channels	1, 2, 4			
http://www.ti.com/product/TLV9002				

# **Design Alternate Op Amp**

OPA333				
V <sub>cc</sub>	1.8 V to 5.5 V			
V <sub>inCM</sub>	Rail-to-rail			
V <sub>out</sub>	Rail-to-rail			
V <sub>os</sub>	2μV			
Iq	17μΑ			
I <sub>b</sub>	70pA			
UGBW	350kHz			
SR	0.16V/µs			
#Channels	1, 2, 4			
http://www.ti.com/product/OPA333				

# **Design Featured Thermistor**

TMP61				
V <sub>cc</sub>	Up to 5.5 V			
R <sub>25</sub>	10kΩ			
R <sub>TOL</sub>	1%			
I <sub>SNS</sub>	400 μΑ			
Operating Temperature Range	-40°C to 125°C			
http://www.ti.com/product/TMP61				

www.ti.com Revision History

### **Revision History**

NOTE: Page numbers for previous revisions may differ from page numbers in the current version.

Changes from Revision A (May 2019) to Revision B (May 2021)	Page
Updated VREF with voltage divider, changed schematic, and equations	1
Changes from Revision * (December 2018) to Revision A (May 2019)	Page
Added Design Featured Thermistor table	4

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