

# Analog Engineer's Circuit Amplifiers

## Temperature Sensing with PTC Circuit

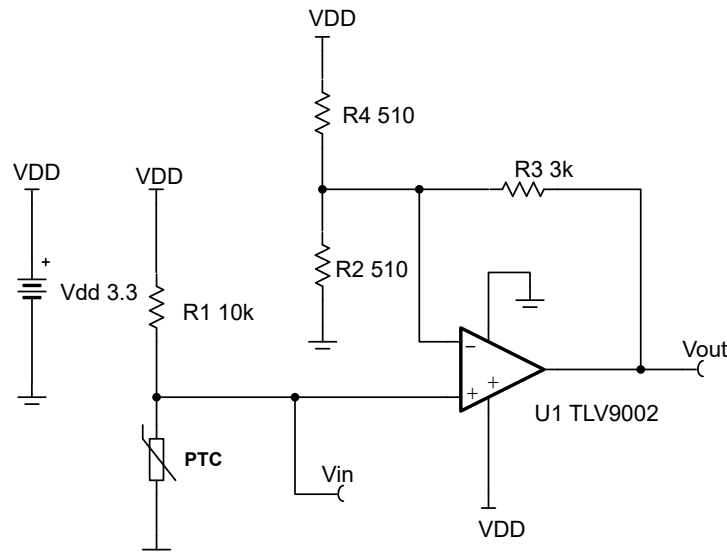


### Design Goals

Temperature		Output voltage		Supply	
$T_{Min}$	$T_{Max}$	$V_{outMin}$	$V_{outMax}$	$V_{dd}$	$V_{ee}$
0 °C	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,  $V_{in}$ , is a positive temperature coefficient output voltage. To correct a negative-temperature-coefficient (NTC) output voltage, switch the position of  $R_1$  and PTC thermistor.
3. Choose  $R_1$  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

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

1. Calculate the value of  $R_1$  to produce a linear output voltage. Use the minimum and maximum values of the PTC to obtain a range of values for  $R_1$ .

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

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

2. Calculate the input voltage range.

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

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

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

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

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

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

5. Calculate  $R_2$  and  $R_4$  based off of the transfer function and gain.

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

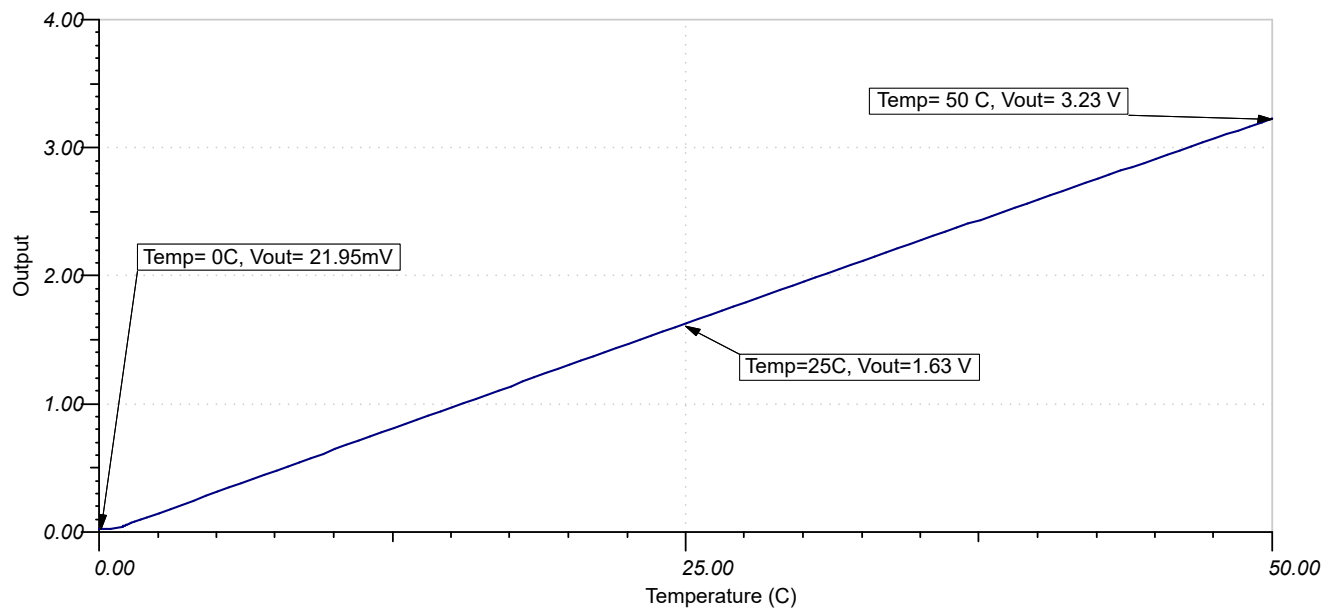
$$R_2 = \frac{(R_2 || R_4)_{ideal} \times R_4}{R_4 - (R_2 || R_4)_{ideal}} = \frac{258.665 \text{ }\Omega \times 518.698 \text{ }\Omega}{518.698 \text{ }\Omega - 258.665 \text{ }\Omega} = 515.969 \text{ }\Omega$$

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

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

## Design Simulations

### DC Transfer Results



## Design References

1. [Analog Engineer's Circuit Cookbooks](#)
2. SPICE Simulation File [SBOMAV5](#)
3. [TI Precision Labs](#)

## Design Featured Op Amp

TLV9002	
$V_{CC}$	1.8 V to 5.5 V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{OS}$	1.5mV
$I_q$	0.06mA
$I_b$	5pA
UGBW	1MHz
SR	2V/ $\mu$ s
#Channels	1, 2, 4
<a href="http://www.ti.com/product/TLV9002">http://www.ti.com/product/TLV9002</a>	

## Design Alternate Op Amp

OPA333	
$V_{CC}$	1.8 V to 5.5 V
$V_{inCM}$	Rail-to-rail
$V_{out}$	Rail-to-rail
$V_{OS}$	2 $\mu$ V
$I_q$	17 $\mu$ A
$I_b$	70pA
UGBW	350kHz
SR	0.16V/ $\mu$ s
#Channels	1, 2, 4
<a href="http://www.ti.com/product/OPA333">http://www.ti.com/product/OPA333</a>	

## Design Featured Thermistor

TMP61	
$V_{CC}$	Up to 5.5 V
$R_{25}$	10k $\Omega$
$R_{TOL}$	1%
$I_{SNS}$	400 $\mu$ A
Operating Temperature Range	-40°C to 125°C
<a href="http://www.ti.com/product/TMP61">http://www.ti.com/product/TMP61</a>	

## Revision History

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

<b>Changes from Revision A (May 2019) to Revision B (May 2021)</b>	<b>Page</b>
• Updated VREF with voltage divider, changed schematic, and equations.....	<a href="#">1</a>
<b>Changes from Revision * (December 2018) to Revision A (May 2019)</b>	<b>Page</b>
• Added <i>Design Featured Thermistor</i> table.....	<a href="#">4</a>

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