*Analog Engineer's Circuit*

# *Temperature sensing with NTC circuit*

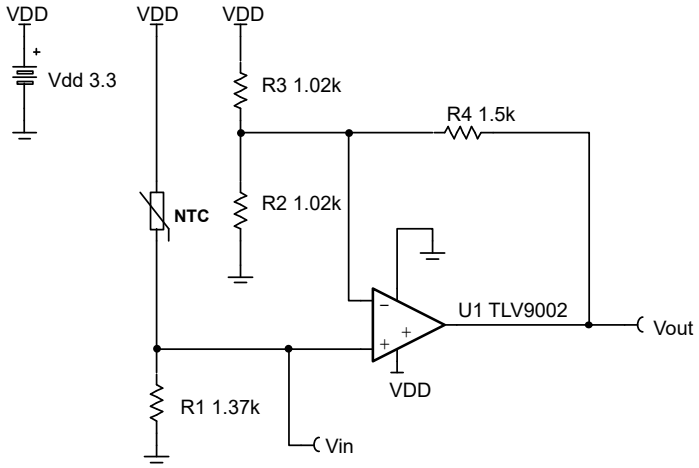
*Amplifiers*

## Design Goals

| Temperature | | Output Voltage | | Supply | |
|---|---|---|---|---|---|
| $T_{Min}$ | $T_{Max}$ | $V_{outMin}$ | $V_{outMax}$ | $V_{dd}$ | $V_{ee}$ |
| 25°C | 50°C | 0.05V | 3.25V | 3.3V | 0V |

## Design Description

This temperature sensing circuit uses a resistor in series with a negative–temperature–coefficient (NTC) 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 gain 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, Vin, is a positive temperature coefficient output voltage. To correct a negative temperature coefficient (NTC) output voltage, switch the position of $R_1$ and the NTC thermistor.
3. Choose $R_1$ based on the temperature range and the value of NTC.
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 10 kΩ or less.
5. A capacitor placed in parallel with the feedback resistor will limit bandwidth, improve stability and help reduce noise.



Copyright © 2021 Texas Instruments Incorporated

## Design Steps

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

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

$$R_{NTCMax} = R_{NTC\ @\ 25C} = 2.252 \quad k\Omega, \quad R_{NTCMin} = R_{NTC\ @\ 50C} = 819.7 \quad \Omega$$

$$R_1 = \sqrt{R_{NTC\ @\ 25C} \times R_{NTC\ @\ 50C}} = \sqrt{2.252 \quad k\Omega \times 819.7 \quad \Omega} = 1.359 \quad k\Omega \approx 1.37 \quad k\Omega$$

2. Calculate the input voltage range.

$$V_{inMin} = V_{dd} \times \frac{R_1}{R_{NTCMax} + R_1} = 3.3 \quad V \times \frac{1.37 \quad k\Omega}{2.252 \quad k\Omega + 1.37 \quad k\Omega} = 1.248 \quad V$$

$$V_{inMax} = V_{dd} \times \frac{R_1}{R_{NTCMin} + R_1} = 3.3 \quad V \times \frac{1.37 \quad k\Omega}{819.7 \quad \Omega + 1.37 \quad k\Omega} = 2.065 \quad V$$

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

$$G_{ideal} = \frac{V_{outMax} - V_{outMin}}{V_{inMax} - V_{inMin}} = \frac{3.25 \quad V - 0.05 \quad V}{2.065 \quad V - 1.248 \quad V} = 3.917 \frac{V}{V}$$

4. Solve for the parallel combination of $R_2$ and $R_3$ using the ideal gain. Select $R_4$= 1.5 kΩ (Standard Value).

$$(R_2||R_3)_{ideal} = \frac{R_4}{G_{ideal} - 1} = \frac{1.5 \quad k\Omega}{3.917 \quad V/V - 1} = 514.226 \quad \Omega$$

5. Calculate $R_2$ and $R_3$ based off of the transfer function and gain.

$$R_3 = \frac{R_4 \times V_{dd}}{V_{inMax} \times G_{ideal} - V_{outMax}} = \frac{1.5 \quad k\Omega \times 3.3 \quad V}{2.065 \quad V \times 3.917 \quad V/V - 3.25 \quad V} = 1023.02 \quad \Omega$$

$$R_2 = \frac{(R_2||R_3)_{ideal} \times R_3}{R_3 - (R_2||R_3)_{ideal}} = \frac{514.226 \quad \Omega \quad \times 1023.02 \quad \Omega}{1023.02 \quad \Omega - 514.226 \quad \Omega} = 1033.941 \quad \Omega$$

6. Calculate the actual gain with the standard values of $R_2$ (1.02 kΩ) and $R_3$ (1.02 kΩ).

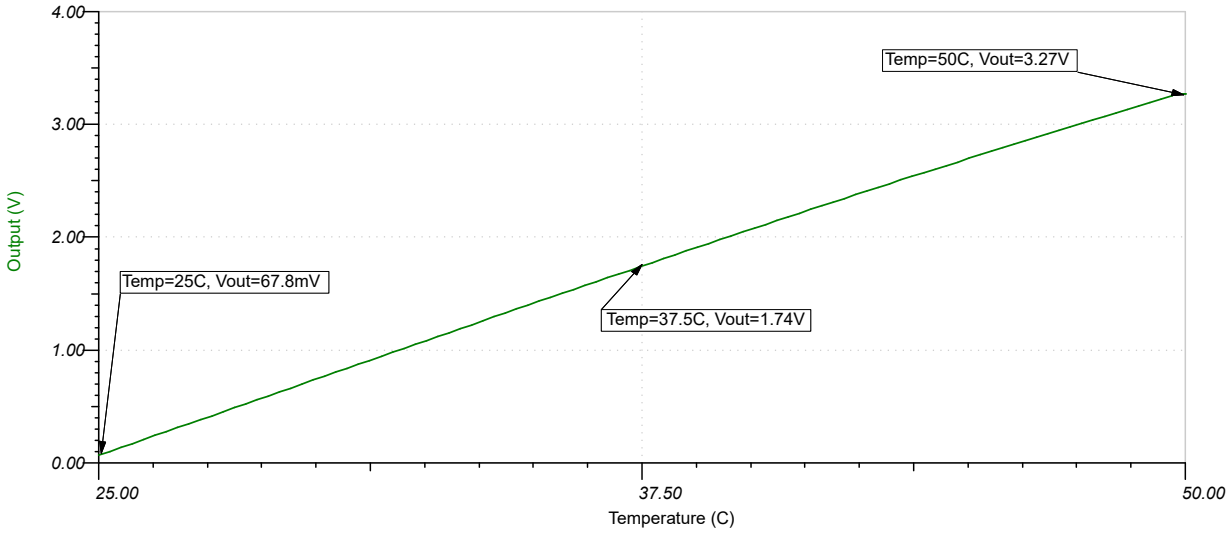
$$G_{actual} = \frac{(R_2||R_3) + R_4}{(R_2||R_3)} = \frac{510 \quad \Omega \quad + 1.5 \quad k\Omega}{510 \quad \Omega} = \quad 3.941 \frac{V}{V}$$



Copyright © 2021 Texas Instruments Incorporated

# Design Simulations

## DC Transfer Results





Copyright © 2021 Texas Instruments Incorporated

## Design References

1. See the Analog Engineer's Circuit Cookbooks for TI's comprehensive circuit library.
2. SPICE Simulation file: SBOMAV6
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/µs |
| #Channels | 1, 2, 4 |
| http://www.ti.com/product/TLV9002 | |

## Design Alternate Op Amp

| OPA333 | |
|---|---|
| $V_{cc}$ | 1.8 V to 5.5 V |
| $V_{inCM}$ | Rail–to–rail |
| $V_{out}$ | Rail–to–rail |
| $V_{os}$ | 2µV |
| $I_q$ | 17µA |
| $I_b$ | 70pA |
| UGBW | 350kHz |
| SR | 0.16V/µs |
| #Channels | 1, 2, 4 |
| http://www.ti.com/product/OPA333 | |



Copyright © 2021 Texas Instruments Incorporated

## Revision History

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

| Changes from Revision * (December 2018) to Revision A (June 2021) | Page |
|---|---|
| • Updated VREF with voltage divider, updated schematic, and equations | 1 |


Copyright © 2021 Texas Instruments Incorporated

# IMPORTANT NOTICE AND DISCLAIMER

TI PROVIDES TECHNICAL AND RELIABILITY DATA (INCLUDING DATASHEETS), DESIGN RESOURCES (INCLUDING REFERENCE DESIGNS), APPLICATION OR OTHER DESIGN ADVICE, WEB TOOLS, SAFETY INFORMATION, AND OTHER RESOURCES “AS IS” AND WITH ALL FAULTS, AND DISCLAIMS ALL WARRANTIES, EXPRESS AND IMPLIED, INCLUDING WITHOUT LIMITATION ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE OR NON-INFRINGEMENT OF THIRD PARTY INTELLECTUAL PROPERTY RIGHTS.

These resources are intended for skilled developers designing with TI products. You are solely responsible for (1) selecting the appropriate TI products for your application, (2) designing, validating and testing your application, and (3) ensuring your application meets applicable standards, and any other safety, security, or other requirements. These resources are subject to change without notice. TI grants you permission to use these resources only for development of an application that uses the TI products described in the resource. Other reproduction and display of these resources is prohibited. No license is granted to any other TI intellectual property right or to any third party intellectual property right. TI disclaims responsibility for, and you will fully indemnify TI and its representatives against, any claims, damages, costs, losses, and liabilities arising out of your use of these resources.

TI’s products are provided subject to TI’s Terms of Sale (https:www.ti.com/legal/termsofsale.html) or other applicable terms available either on ti.com or provided in conjunction with such TI products. TI’s provision of these resources does not expand or otherwise alter TI’s applicable warranties or warranty disclaimers for TI products.

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265
Copyright © 2021, Texas Instruments Incorporated