Analog Engineer's Circuit Amplifiers

Temperature Sensing with NTC Circuit

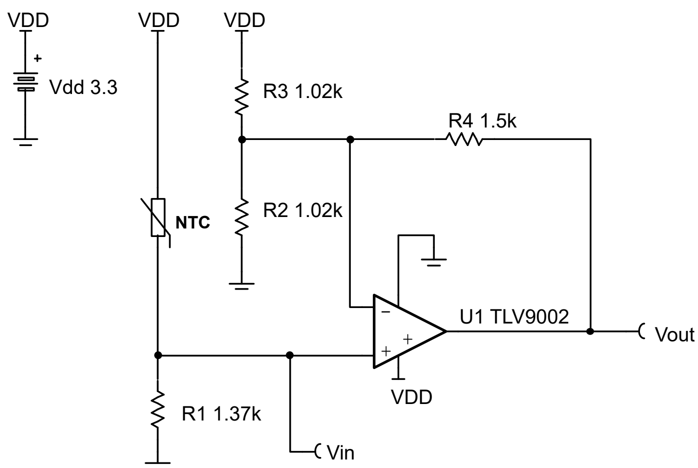
TEXAS INSTRUMENTS

Design Goals

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

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.

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.

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

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

2. Calculate the input voltage range.

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

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

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

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

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

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

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

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

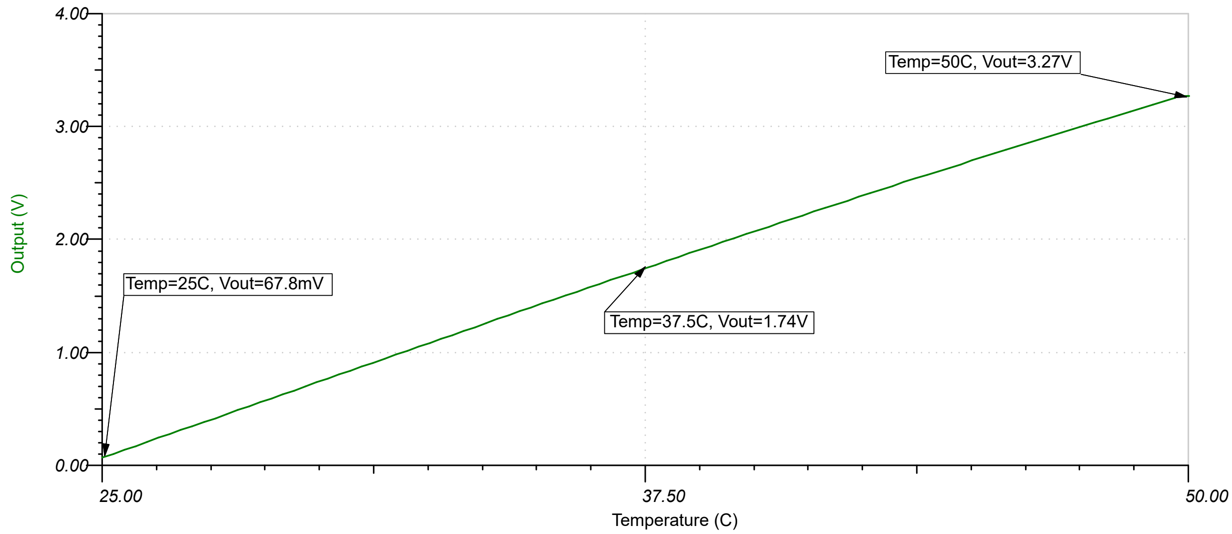
$$R_2 = \frac{(R_2||R_3)_{ideal} \times R_3}{R_3 - (R_2||R_3)_{ideal}} = \frac{514.226\ \ \Omega\ \ \times 1023.02\ \ \Omega}{1023.02\ \ \Omega - 514.226\ \ \Omega} = 1033.941\ \ \Omega$$

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

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

Design Simulations

DC Transfer Results



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	

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

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