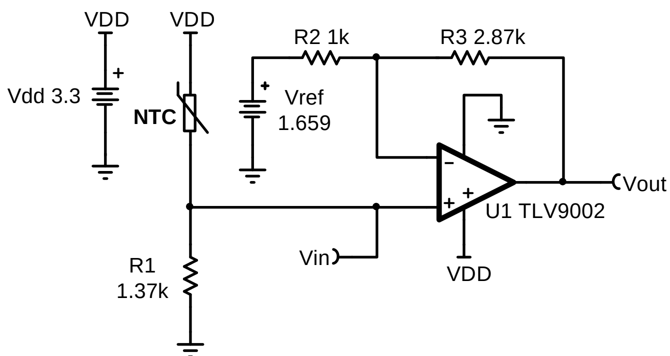
Temperature sensing with NTC circuit

Design Goals

Temperature		Output Voltage		Supply		
T_{Min}	T_{Max}	V_{outMin}	V_{outMax}	V_{dd}	V_{ee}	V_{ref}
25 ℃	50 ℃	0.05V	3.25V	3.3V	0V	1.659V

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.
2. The connection, Vin, is a positive temperature coefficient output voltage. To correct an NTC output voltage, switch the position of R_1 and the NTC thermistor.
3. R_1 is chosen based on the temperature range and the NTC's value.
4. V_{ref} can be created using a DAC or voltage divider. If a voltage divider is used the equivalent resistance of the voltage divider will influence the gain of the circuit.
5. 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.
6. A capacitor placed in parallel with the feedback resistor will limit bandwidth, improve stability and help reduce noise.

Design Steps

$$V_{out} = V_{dd} \times \frac{R_1}{R_{NTC} + R_1} \times \frac{R_2 + R_3}{R_2} - \frac{R_3}{R_2} \times V_{ref}$$

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.

$$R_{NTC\_max} = R_{NTC\ @25℃} = 2.252\ k\Omega, \quad R_{NTC\_min} = R_{NTC\ @50℃} = 819.7\ \Omega$$

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

2. Calculate the input voltage range.

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

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

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. Select R_2 and calculate R_3 to set the gain in Step 3.

$$Gain = \frac{R_2 + R_3}{R_2}$$

$$R_2 = 1\ k\Omega\ \text{(Standard value)}$$

$$R_3 = R_2 \times (G_{ideal} - 1) = 1\ k\Omega \times (3.917\frac{V}{V} - 1) = 2.917\ k\Omega$$

$$\text{Choose}\ R_3 = 2.87\ k\Omega\ \text{(Standard value)}$$

5. Calculate the actual gain based on standard values of R_2 and R_3.

$$G_{actual} = \frac{R_2 + R_3}{R_2} = \frac{1\ k\Omega + 2.87\ k\Omega}{1\ k\Omega} = 3.87\ \frac{V}{V}$$

6. Calculate the output voltage swing based on the actual gain.

$$V_{out\_swing} = (V_{inMax} - V_{inMin}) \times G_{actual} = (2.065\ V - 1.248\ V) \times 3.87\ \frac{V}{V} = 3.162\ V$$

7. Calculate the maximum output voltage when the output voltage is symmetrical around mid–supply.

$$V_{outMax} = V_{mid-supply} + \frac{V_{out\_swing}}{2} = \frac{V_{dd} - V_{ee}}{2} + \frac{V_{out\_swing}}{2} = \frac{3.3\ V - 0\ V}{2} + \frac{3.162\ V}{2} = 3.231\ V$$

8. Calculate the reference voltage.

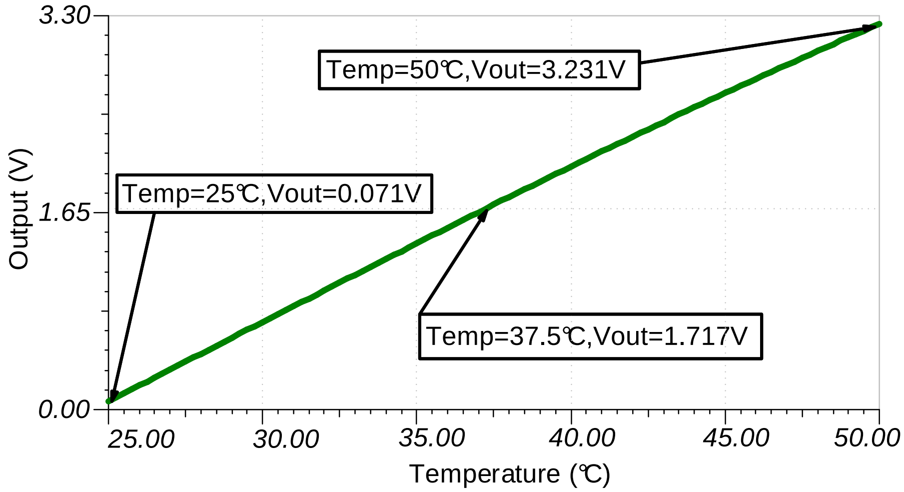
$$V_{outMax} = V_{inMax} \times G_{actual} - \frac{R_3}{R_2} \times V_{ref}$$

$$3.231\ V = 2.065\ V \times 3.87\ \frac{V}{V} - \frac{2.87\ k\Omega}{1\ k\Omega} \times V_{ref}$$

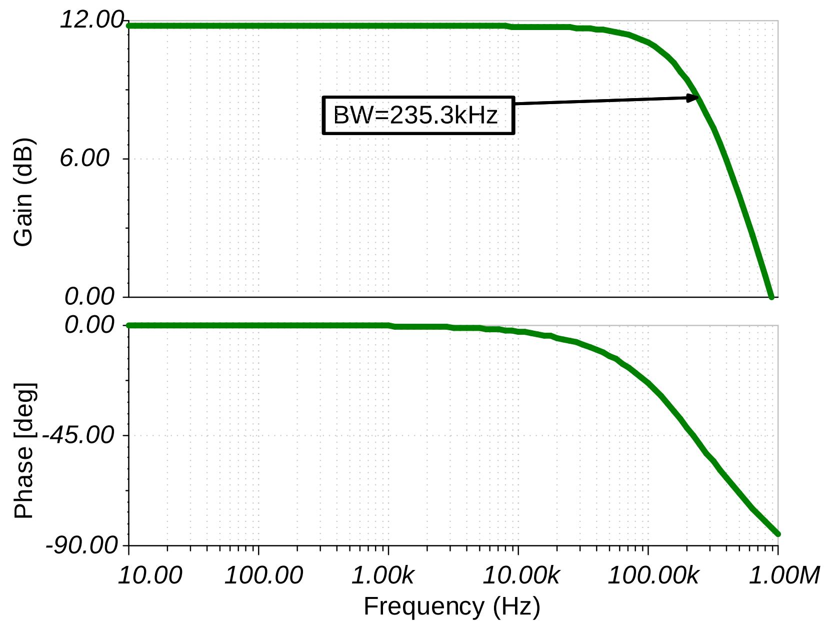
$$V_{ref} = \frac{2.065\ V \times 3.87\ \frac{V}{V} - 3.231\ V}{\frac{2.87\ k\Omega}{1\ k\Omega}} = 1.659\ V$$

Design Simulations

DC Transfer Results



AC Simulation Results



References:

1. Analog Engineer's Circuit Cookbooks
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	