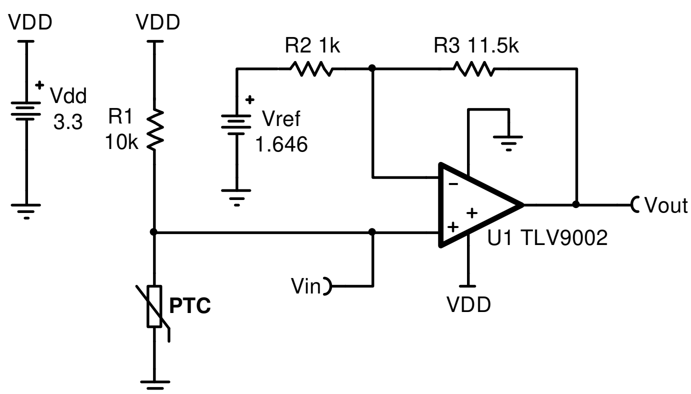
Temperature sensing with PTC circuit

Design Goals

Temperature		Output voltage		Supply		
T_{Min}	T_{Max}	V_{outMin}	V_{outMax}	V_{dd}	V_{ee}	V_{ref}
0 °C	50 °C	0.05V	3.25V	3.3V	0V	1.646V

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.
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 resistor.
3. Choose R_1 based on the temperature range and the PTC'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 alter the gain of the circuit and should be accounted for.
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 10kΩ or less.
6. A capacitor placed in parallel with the feedback resistor will limit bandwidth, improve stability and help reduce noise.

Design Steps

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

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.

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

2. Calculate the input voltage range.

$$V_{inMin} = V_{dd} \times \frac{R_{PTC\_Min}}{R_{PTC\_Min} + R_1} = 3.3\ V \times \frac{8.525\ k\Omega}{8.525\ k\Omega + 10\ k\Omega} = 1.519\ V$$
$$V_{inMax} = V_{dd} \times \frac{R_{PTC\_Max}}{R_{PTC\_Max} + R_1} = 3.3\ V \times \frac{11.611\ k\Omega}{11.611\ k\Omega + 10\ k\Omega} = 1.773\ V$$

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

$$Gain = \frac{R_2 + R_3}{R_2}$$
$$R_2 = 1\ k\Omega$$
$$R_3 = R_2 \times (G_{ideal} - 1) = 1\ k\Omega \times (12.598 - 1) = 11.598\ k\Omega$$
$$\text{Choose}\quad R_3 = 11.5\ k\Omega\ \ (\text{Standard value})$$

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

$$G_{actual} = \frac{R_2 + R_3}{R_2} = \frac{1\ k\Omega + 11.5\ k\Omega}{1\ k\Omega} = 12.5\ \frac{V}{V}$$

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

$$V_{out\_swing} = (V_{inMax} - V_{inMin}) \times G_{actual} = (1.773\ V - 1.519\ V) \times 12.5\ \frac{V}{V} = 3.175\ V$$

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

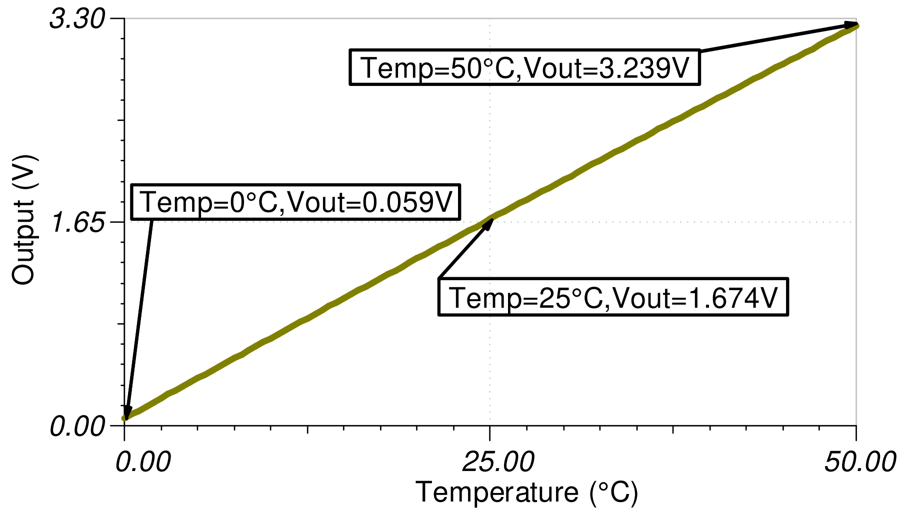
$$V_{outMax} = V_{mid-supply} + \frac{V_{out\_swing}}{2} = \frac{V_{dd} - V_{ee}}{2} + \frac{V_{out\_swing}}{2} = \frac{3.3\ V - 0\ V}{2} + \frac{3.175\ V}{2} = 3.238\ V$$

8. Calculate the reference voltage.

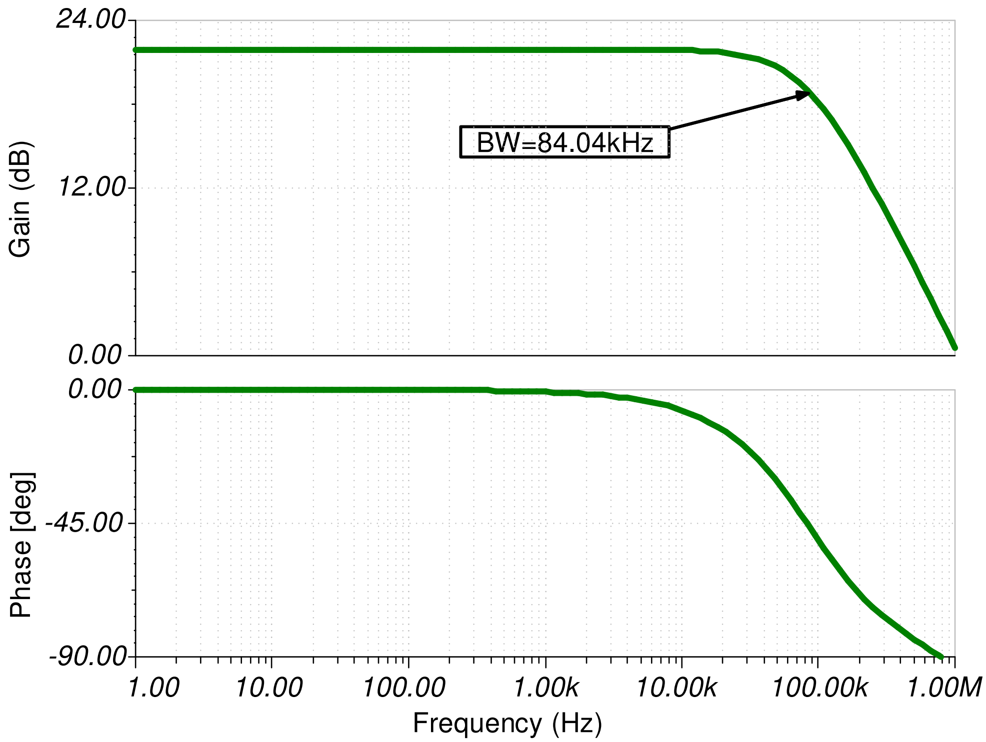
$$V_{outMax} = V_{inMax} \times G_{actual} - \frac{R_3}{R_2} \times V_{ref}$$
$$3.238\ V = 1.773\ V \times 12.5\ \frac{V}{V} - \frac{11.5\ k\Omega}{1\ k\Omega} \times V_{ref}$$
$$V_{ref} = \frac{1.773\ V \times 12.5\ \frac{V}{V} - 3.238\ V}{\frac{11.5\ k\Omega}{1\ k\Omega}} = 1.646\ V$$

Design Simulations

DC Transfer Results



AC Simulation Results



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/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	

Design Featured Thermistor

TMP61	
V_{CC}	Up to 5.5 V
R_{25}	10 kΩ
R_{TOL}	1%
I_{SNS}	400 µA
Operating Temperature Range	–40°C to 125°C
http://www.ti.com/product/TMP61	

Revision History

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

Changes from Original (December 2018) to A Revision **Page**