CIRCUIT060002

# How to Design
# Temperature sensing with NTC thermistor circuit

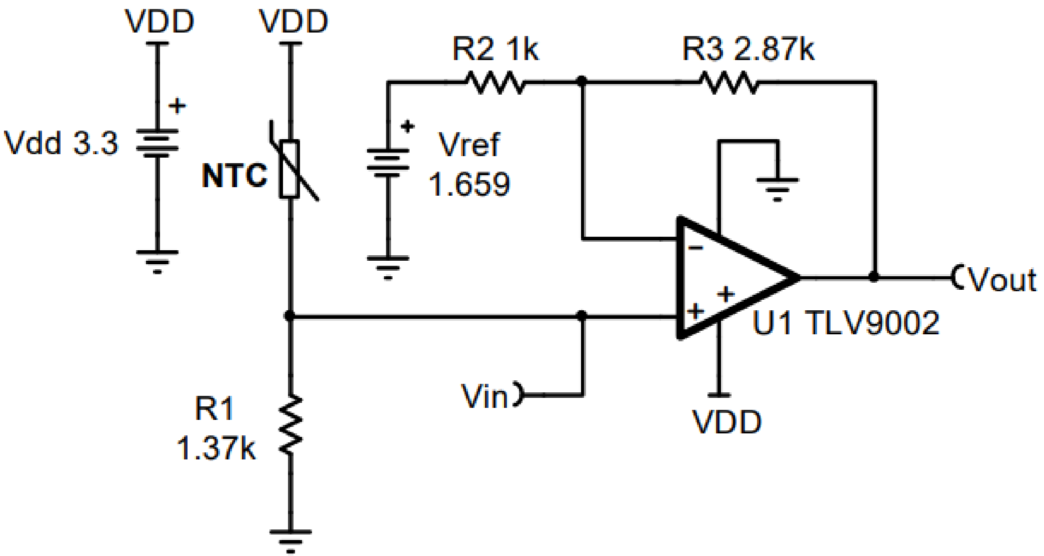
Analog Engineer's Circuit Cookbook: Op Amps

## General Purpose Amplifiers

www.ti.com/general-amps

www.ti.com/circuitcookbooks

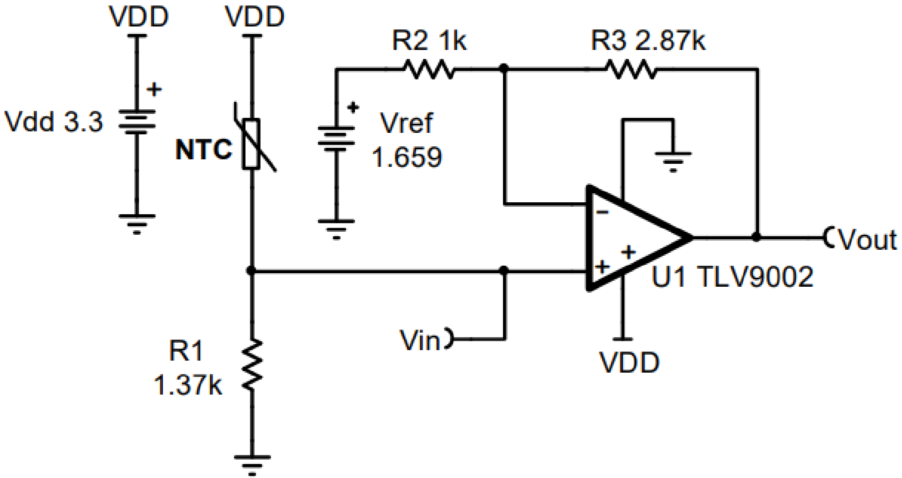
# Circuit Description




$$V_O = VDD \times \frac{R1}{R1+RNTC} \times \frac{R3+R2}{R2} - \mathrm{Vref} \times \frac{\mathrm{R3}}{\mathrm{R2}}$$

# Design Goals

| Temperature | | Output | | Supply | | |
|---|---|---|---|---|---|---|
| $T_{Min}$ | $T_{max}$ | $V_{outMin}$ | $V_{outMax}$ | $V_{dd}$ | $V_{ee}$ | $V_{ref}$ |
| 25 °C | 50 °C | 50mV | 3.25V | 3.3V | 0V | 1.659V |




NTC Voltage Divider, Vin

Inverting gain times Vref

$$V_O = VDD \times \frac{R1}{R1+RNTC} \times \frac{R3+R2}{R2} + \mathrm{Vref} \times \left(-\frac{\mathrm{R3}}{\mathrm{R2}}\right)$$

Non-inverting amplifier gain

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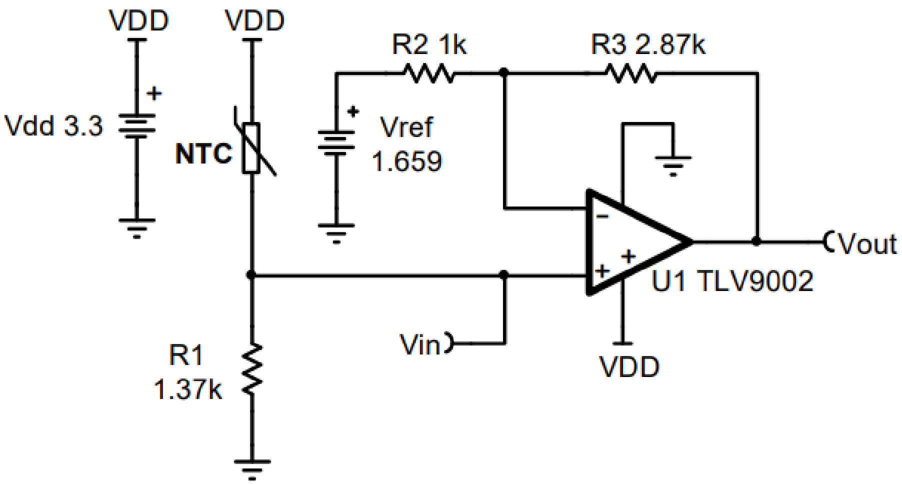
# Design Steps

| Temperature | | Output | | Supply | | |
|---|---|---|---|---|---|---|
| $T_{Min}$ | $T_{max}$ | $V_{outMin}$ | $V_{outMax}$ | $V_{dd}$ | $V_{ee}$ | $V_{ref}$ |
| 25 °C | 50 °C | 50mV | 3.25V | 3.3V | 0V | 1.659V |




$$RNTC\_\max = RNTC@25°C = 2.252\ k\Omega$$

$$RNTC\_\min = RNTC@50°C = 819.7\ \Omega$$

$$R1 = \sqrt{RNTC@25° + RNTC@50°C}$$

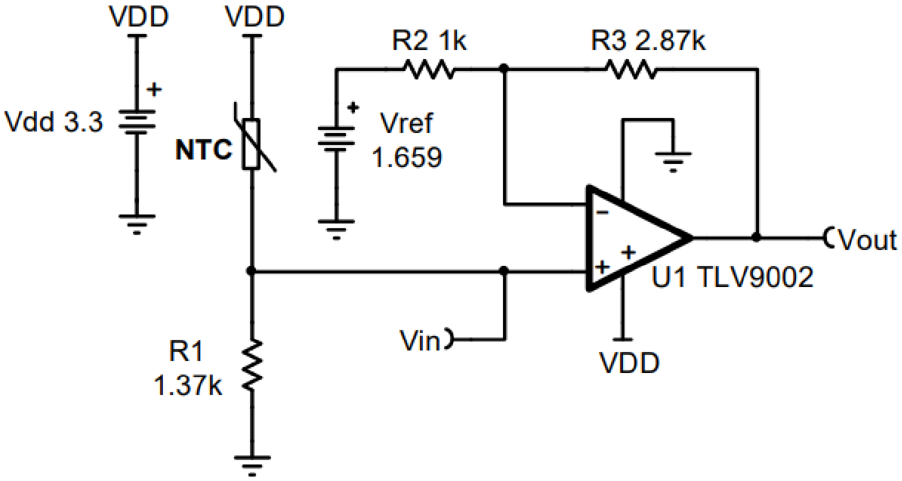
$$R1 = \sqrt{2.252\ k\Omega + 819.7\ \Omega} = 1.359\ k\Omega$$

$$VinMin = Vdd \times \frac{R1}{RNTC\_max + R1} = 1.248V$$

$$VinMax = Vdd \times \frac{R1}{RNTC\_min + R1} = 2.065V$$

# Design Steps

| Temperature | | Output | | Supply | | |
|---|---|---|---|---|---|---|
| $T_{Min}$ | $T_{max}$ | $V_{outMin}$ | $V_{outMax}$ | $V_{dd}$ | $V_{ee}$ | $V_{ref}$ |
| 25 °C | 50 °C | 50mV | 3.25V | 3.3V | 0V | 1.659V |




$$Gain\_ideal = \frac{VoutMax - VoutMin}{VinMax - VinMin} = 3.917V/V$$

$$Gain = \frac{R2 + R3}{R2}$$

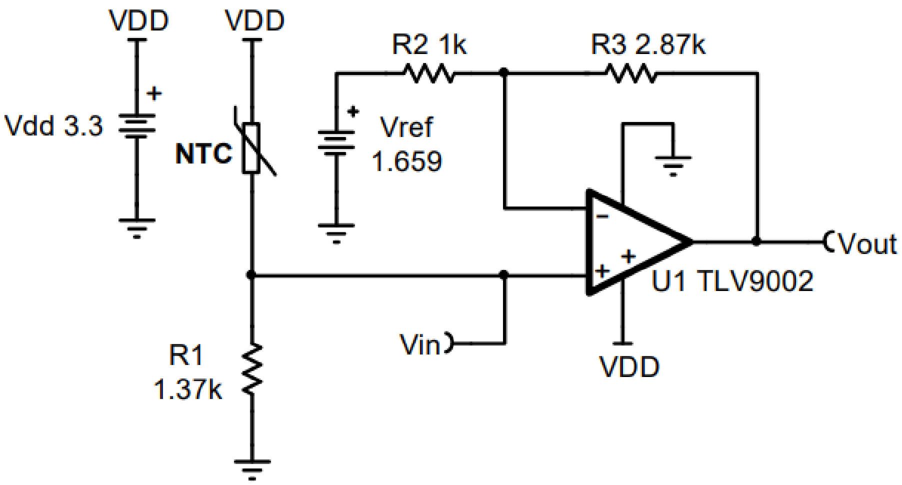
$$R2 = 1\ k\Omega$$

$$R3 = R2 \times (Gain\_ideal - 1) = 2.917\ k\Omega$$

$$Gain\_actual = \frac{R2 + R3}{R2} = 3.87V/V$$

# Design Steps

| Temperature | | Output | | Supply | | |
|---|---|---|---|---|---|---|
| $T_{Min}$ | $T_{max}$ | $V_{outMin}$ | $V_{outMax}$ | $V_{dd}$ | $V_{ee}$ | $V_{ref}$ |
| 25 °C | 50 °C | 50mV | 3.25V | 3.3V | 0V | 1.659V |




$$Vo\_swing = (VinMax - VinMin) \times Gain\_actual$$

$$Vo\_swing = (2.065\,V - 1.248\,V) \times 3.87\frac{V}{V} = 3.162V$$

$$VoMax = Vmid - supply + \frac{Vo\_swing}{2}$$

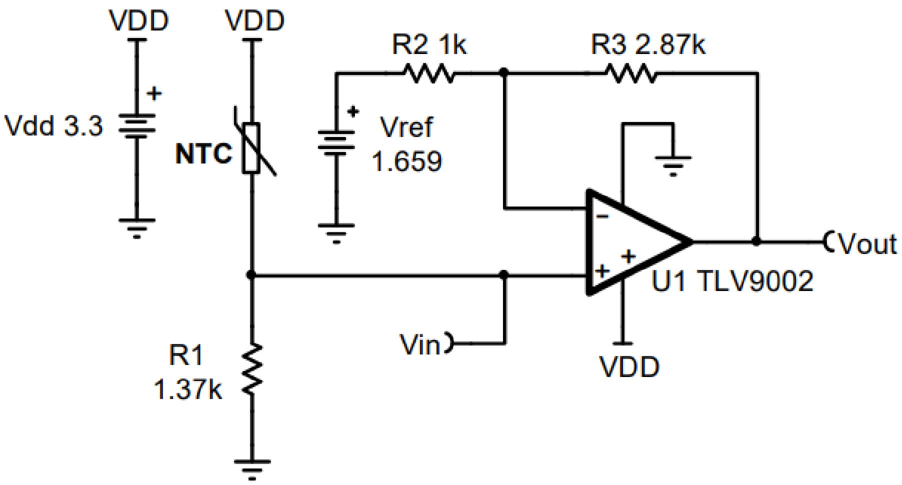
$$VoMax = 1.65\,V + \frac{3.162V}{2} = 3.231V$$

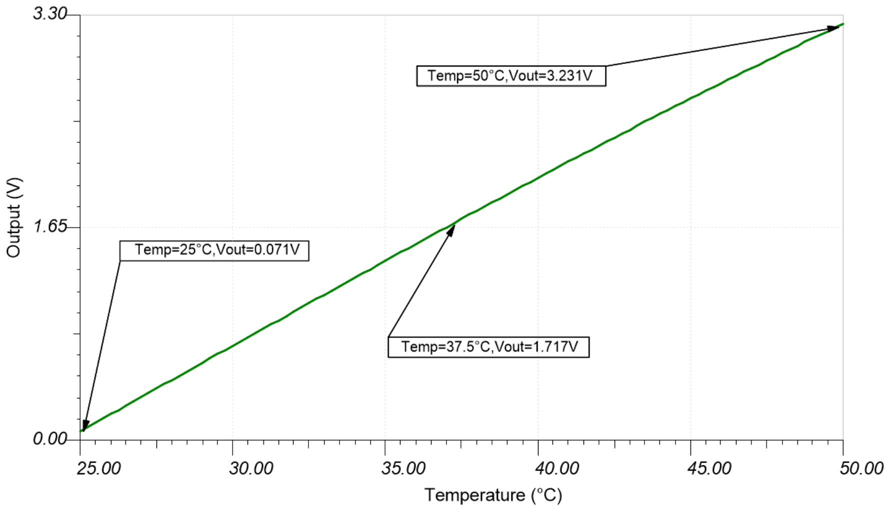
$$VoMax = VinMax \times Gain\_actual - \mathrm{Vref} \times \frac{\mathrm{R3}}{\mathrm{R2}}$$

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

# DC Results

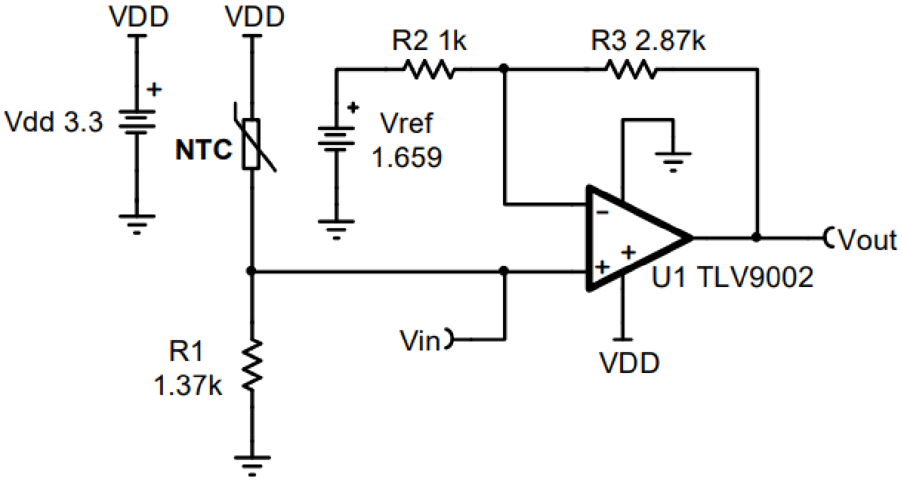
| Temperature | | Output | | Supply | | |
|---|---|---|---|---|---|---|
| $T_{Min}$ | $T_{max}$ | $V_{outMin}$ | $V_{outMax}$ | $V_{dd}$ | $V_{ee}$ | $V_{ref}$ |
| 25 °C | 50 °C | 50mV | 3.25V | 3.3V | 0V | 1.659V |

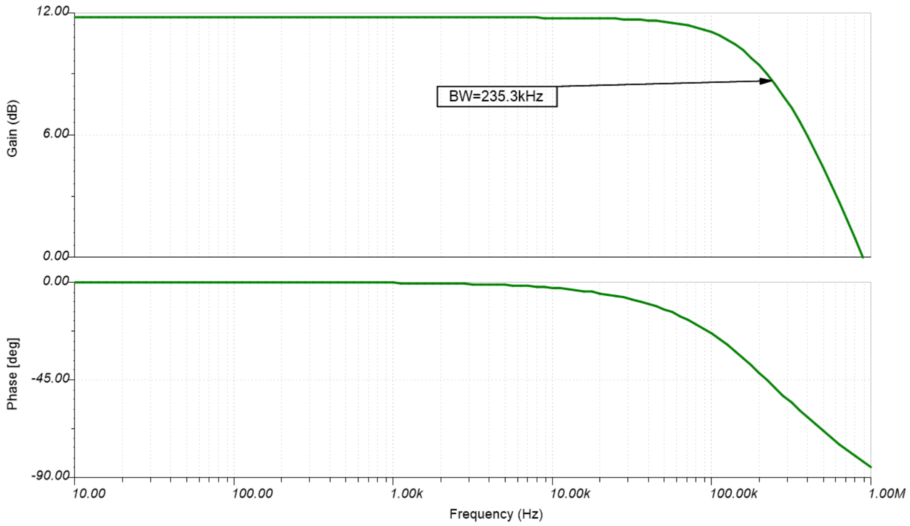


# AC Results

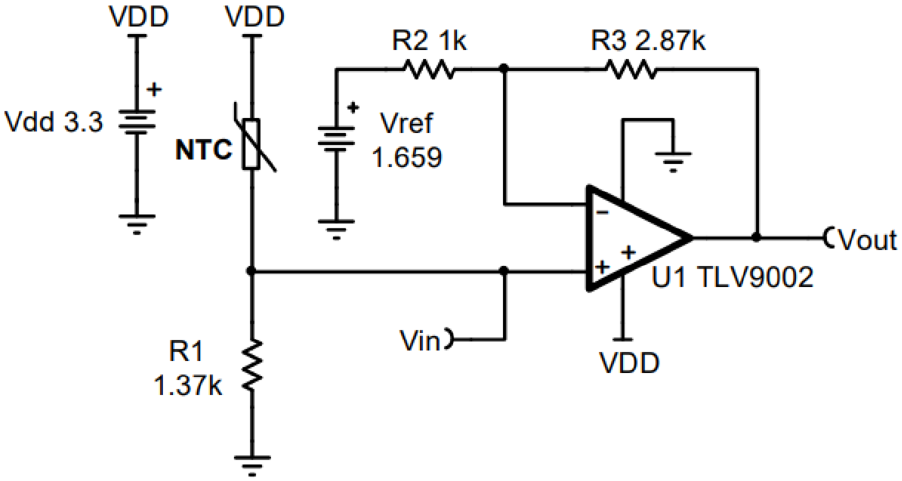
| Temperature | | Output | | Supply | | |
|---|---|---|---|---|---|---|
| $T_{Min}$ | $T_{max}$ | $V_{outMin}$ | $V_{outMax}$ | $V_{dd}$ | $V_{ee}$ | $V_{ref}$ |
| 25 °C | 50 °C | 50mV | 3.25V | 3.3V | 0V | 1.659V |



# Design Notes

| Temperature | | Output | | Supply | | |
|---|---|---|---|---|---|---|
| $T_{Min}$ | $T_{max}$ | $V_{outMin}$ | $V_{outMax}$ | $V_{dd}$ | $V_{ee}$ | $V_{ref}$ |
| 25 °C | 50 °C | 50mV | 3.25V | 3.3V | 0V | 1.659V |




## Design Notes:

1. For temperature sensing using an NTC thermistor, the resistor, R1, is chosen based on the temperature range and the NTC's value.

2. Operate within the linear output voltage swing (See $A_{OL}$ specification) to minimize non-linearity errors.

3. The reference voltage, Vref, 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.

# Design Resources

**EE Cookbook: Op Amp**
**www.ti.com/circuitcookbooks**
Step-by-step circuit design of common op amp building block circuits.

**TI Designs**
www.TI.com/tidesigns
Ready-to-use reference designs with
theory, calculations, simulations
schematics, PCB files, bench test results

***Analog Engineer's Pocket Reference***
www.TI.com/analogrefguide
PDF, iTunes app and hardcopy available
PCB, analog, mixed signal design formulae
Conversions, tables, equations

**TI Precision Labs**
www.TI.com/precisionlabs
Quiz questions, problems, solutions
Labs and evaluation module (EVM) available

**TINA-TI™ simulation software**
www.TI.com/tool/tina-ti
Complete SPICE simulator DC, AC, transient, noise analysis
Schematic entry and post-processor for waveform math

**DIYAMP-EVM**
www.TI.com/DIYAMP-EVM
Evaluation module providing engineers with SC70, SOT23, SOIC packaging and 12 popular amplifier configurations

***The Signal***
www.TI.com/signalbook
PDF, iTunes app and hardcopy available
A compendium of blog posts on op amp design topics including
offset voltage, input bias current, stability, noise and more

***Analog Wire* Blog**
www.TI.com/analogwire
Technical blogs written by analog experts
Tips, tricks, and design techniques

**TI E2E™ Community**
www.TI.com/e2e
Support forums for all TI products

**Op Amp Parametric Quick Search**
www.TI.com/amplifiers
Search for precision, high-speed, general-purpose, ultra-low-power, audio and power op amps

**Op Amp Parametric Cross-Reference**
www.TI.com/opampcrossreference
Find similar TI op amps using competitive part numbers