Sensors

Temperature Sensor Application Design Assistance

Temperature Measurement
The NTC thermistor offers a practical, low-cost solution to most temperature measurement and control applications. High sensitivity and accuracy can be obtained by placing a thermistor in contact with the material that one wishes to measure the temperature of. Sensing circuitry can use the thermistor as one leg of a Wheatstone bridge for linear voltage outputs, or as a single, simple voltage divider. In the voltage divider, if the resistance of the fixed resistor is chosen to equal the thermistor's resistance at the mid-point of a temperature range, the output voltage is fairly well linearized for temperature ranges under 50°C

The output of either the Wheatstone bridge or voltage divider can be routed to an A/D pin on any microprocessor equipped for extremely accurate temperature measurement.
In temperature measuring applications, the current through the NTC is limited to a value so that appreciable self-heating does not occur. The device may be calibrated to read directly as a thermometer or used in a control circuit. The high resistance of a thermistor, as compared to the resistance of long runs of wire, makes possible accurate temperature measurements and control from remote locations.

An example of temperature measurement is in battery charging applications. Despite many claims from various silicon semiconductor manufacturers, NTC thermistors remain one of the most economical, simple and reliable methods used to determine termination of the fast-charge cycle for rechargeable batteries.

Temperature Compensation
NTC thermistors are effective in offsetting the effect of temperature on other circuit components. Unlike the NTC thermistor, the resistance of most circuit components increases as the circuit heats up. Thermistor temperature compensation improves the performance of these thermally sensitive circuits and extends their useful operating range. Thermistors can be used to stabilize the gain of a solid state amplifier or to provide temperature compensation in circuits where copper coils are used.

Thermistors used in compensation circuits typically will have fixed resistors used in parallel and series combinations with the NTC. Note that the resulting R-T curve is much shallower and linear than the non-networked NTC.

Thermistors can be used to accomplish temperature compensation of transistor circuits. Use of an NTC thermistor in shunt with R2 in the following circuit is an example of this application.

Airflow and Liquid-Level Sensing
The small size and fast response of NTC thermistors make them ideal for liquid and airflow detection circuitry. A thermistor dissipates significantly more heat in a liquid or in an air stream than it does in still air. A liquid-level or airflow circuit can use the difference in the voltage drop across an exposed thermistor. A liquid-level or airflow circuit can use the difference in the voltage drop across an exposed thermistor as input to a comparator or to actuate a signal.

Another design uses a Wheatstone bridge with a thermistor in opposing legs, where the input voltage keeps both thermistors in their self-heating range. The bridge is balanced when both thermistors are in identical environments. When liquid covers the sensing thermistor's housing or the air begins to flow past it, the bridge becomes unbalanced.

Design Assistance
Temperature Accuracy – Because the resistance of the thermistor changes at a fairly large amount compared to the temperature, it is possible to achieve fairly high temperature accuracy with fairly loose resistance tolerances. For example, the 'Grade 1' NTC sensors change at a rate of approximately -4.4%/C at 25°C. Therefore, a +/-5% part has an accuracy of about +/-1.1°C at 25°C. Similarly, a +/-1% part has an accuracy of about +/-0.2°C at 25°C

As the rate of resistance change varies with temperature, the tolerance required to achieve a certain accuracy of temperature also varies. For instance, to achieve a +/- 1°C accuracy at 100°C, resistance tolerance of about +/-2.8% is required, while a +/-5% tolerance at 0°C will also achieve the same precision.

Working Example: Suppose a 10K-ohm part with a +/-1°C accuracy at 50°C is required. Through either the multiplier tables or the R-T formula, we determine the resistances at 49°, 50° and 51°C (50+/- 1°C):
49°C = 3743 ohms nom
50°C = 3603 ohms nom
51°C = 3469 ohms nom
For an accuracy of +/-1°C, we would want a minimum of 3469 ohms and a maximum of 3743 ohms, or 3603 ohms +3.9%/-3.7%.

A deviation of +1.2% is possible on the tolerance at 50°C. If we subtract 1.2% from 3.7%, we find we would need a guard-banded part of at least +/-2.5% at 25°C. The closest standard 10K ohms part would be the 10K +/-2% ohms part, which offers a +/-2% tolerance at 25°C. If a large volume of parts are required and cost is of the essence, it would probably be worthwhile to have a special part number with a +/- 2.5% tolerance not listed here to be selected by a Zettler sales engineer.

Resistance Tolerance Over Temperature – As the temperature deviates from 25°C, the tolerance increases. If a specific tolerance at a temperature other than 25°C is required, parts can be either"guard band" selected for a tighter tolerance at 25°C that will allow parts to fall within specifications at the desired selected for a tighter tolerance at 25°C that will allow parts to fall within specifications at the desired temperature, or they can be selected by Therm-O-Disc specifically at that temperature.

Explanation of Thermal Time Constant
Thermal Time Constant – This is not how fast a thermistor will respond to a change in temperature. It is a method of comparing the relative speeds of thermistors with each other. By definition, the thermal time constant is the amount of time required for a thermistor to change 63.2% of the temperature difference between its initial and final sensing temperatures in a step-function change in temperature. This value is dependent on the sensing medium – still air, moving air, liquid, etc.

Working with Dissipation Constants – For this example, we will use Zettler part number NTS221003, which has a published dissipation constant of 2mW/°C. For this example we will use a temperature range of 0° to 100°C and a desired temperature error of 0.1°C. To determine the maximum voltage applied to the circuit, we need to know the minimum resistance of the NTC. For the 1H103T, it would be 680Ω at the upper limit of 100°C. This means the series resistance of the NTC and R1 would be 4280Ω. And since $P=E^2/R$ and $E=\sqrt{PR}$ and if P=0.2mW=0.1°C self-heating, then $E= \sqrt{0.0002*4280}=0.925$volts.

Interfacing NTC Thermistors – Thermistors require control circuitry to act on a power circuit. To replace a bimetal thermostat, a thermistor requires a few fixed resistors and a transistor/power semiconductor as a minimum. Since thermistors are solid state, they are much less prone to fatigue and can last hundreds of thousands of cycles with minimal change in characteristics, providing very high system reliability.

Comparing NTC Thermistors with other sensors – Thermistors still provide a very versatile and economical means of temperature sensing for electronic circuits. Automotive, appliance, electronic and industrial markets continue to increase their usage of these devices despite the numerous options available for temperature sensing.

A summary of the most popular temperature sensing options:
The “Wind Chill” Fact – Because many people are concerned with weather, the wind chill index is a very familiar concept. Many engineers using thermistors are concerned that moving air will effect the temperature reading of the thermistors. The question is: “Does the wind chill factor effect thermistors in sensing the correct ambient temperature?” The answer is no—at least not the way most people would believe

For a working example, consider a car with a thermistor mounted to the outside to sense temperature outside the car. This is a fairly standard automotive application. Let’s say the car has a digital display that converts the thermistor’s resistance to read directly in °C. Now pretend this car is in a heated garage where the temperature is 12°C and the temperature outside the garage and surrounding area is 0°C. Inside the garage, the digital display reads 12°C. Now if the car is driven outside the garage and parked in the 0°C ambient, the gauge will slowly change from 12°C to 0°C, as we would expect

Now consider what would happen if this was repeated except that the car kept moving once outside. This movement creates an artificial wind over the thermistor. This 0°C wind cools the once 12°C thermistor down to 0°C much quicker than still air and the gauge would change from 12°C to 0°C that much faster. In fact, the faster the car was moving, the quicker the 12°C to 0°C transition would take place.

Does the temperature gauge ever go below 0°C? No, because the ambient temperature never goes below 0°C and therefore no ?T is ever created which is necessary to change the readout To lower the temperature of the thermistor, a ?T must be created. Simply moving the same temperature of air across the thermistor does not create the necessary △T. The only difference the moving air makes is the rate at which the display changes.

So the wind chill factor is at work in getting the thermistor to its final temperature quicker, but it does not allow a mis-reading of temperature due to it.
Wind chill is the effect of a cooler wind blowing on a heated object such as the human body or a house. Because cooler-moving air is able to move more heat away from a heated object than in still air, it can act in the same manner as colder, yet still air. The key factors are a △T between the air and the human body and the fact that the body is heated and warmer to the surrounding air. In the thermistor, the still air has the same temperature as the moving air (no △T) and the fact that the thermistor is not heated artificially above the ambient temperature.

TEMPERATURE MEASUREMENT WITH MICROPROCESSORS
Many individuals designing temperature-measuring circuits are apprehensive to use thermistors because they have a non-linear resistance versus temperature curve. There are three basic methods of temperature measurement using NTC thermistors and microprocessors. Two methods involve software linearization and minimal circuitry (usually a single resistor voltage divider into the ADC). The third method involves hardware linearization and minimal software.

1. Software linearization using the Steinhart equation NTC Thermistors resistance vs. temperature characteristics track the following equation: /T = a + b (ln R) + c (ln R) where T is in °K (°K = 273.15 + °C) and a, b, c are constants particular to an individual thermistor curve and resistance at 25°C
2. Software linearization using a look up table. Rather than calculating temperature, a lookup table can be used to minimize calculation cycle time. This is very simple to program in assembly language, it is the most popular method with our customers and much less demanding on a microprocessor than calculating the Steinhart-Hart equation.
3. Hardware Linearization using a basic bridge circuit (see figure 1).

Voltage into the bridge should be in the area of two volts to keep any self-heating of the thermistor to a minimum. R2 and R4 in the bridge circuit should be of equal value and equal to RT at its mid-point in the intended temperature range. For a 0° to 50°C range, (32° to 122°F), a 10K ohm resistor is chosen A circuit reading 0° to 100°C (32° to 212°F), should use 3.6K ohm resistors f2 and R4. Trimmer R3 should be set to yield a 0 volt output for 0°C. In both cases, this would be approximately 33K ohms. This can be calibrated with ice water and a thermometer. Care should be taken that the water does not short out the thermistor.

Analog to Digital Conversion
Interfacing this circuit with a microprocessor requires an analog to digital converter. An ADC with an adjustable voltage reference and a differential analog voltage input is preferred. The support circuitry will vary with the microprocessor used. If this type of ADC is not available, the voltage output of the bridge may be fed into a 741-type op-amp as shown (see figure 2).

A Programming Tip
One may notice the 0°C to 50°C circuit is more linear than the 0°C to 100°C circuit. Likewise, a short segment of 15°C on the 0°C to 50°C circuit is even more linear. Most applications call for reading temperatures between 10°C and 30°C (50°F to 86°F) or a similar interval. Under those conditions, the reading is very linear. Programs over wide ranges that require critical readings should be divided into four or five ranges with a different formula, however slight, to calculate actual temperature. It should be noted that self-heating of the thermistor may also give a false reading 0.1°C higher than the actual ambient temperature

Another hardware trick to maximize voltage output in all three linearization methods is to pulse a 5V logic signal to the input of the bridge or voltage divider instead of a steady 2V input. With a short pulse, a reading can be made before self heating can effect the thermistor's resistance, thus reducing the amount of signal amplification required.

Important Notice
The user must determine the suitability of thermistors for the application and assumes all risk and liability associated therewith.