Thermistor Application notes:

Overview:

The operation of the industrialized world depends to a great extent on the ability to measure and control a variety of physical parameters. Temperature is one of the most important of those parameters. In the present era of inexpensive, compact microcontrollers, display modules and versatile electronic instrumentation, the scope of potential applications has grown enormously. Inexpensive NTC thermistor elements are being utilized extensively as sensors, probes and components in complex circuits in a variety of applications.

NTC Thermistor devices are extremely versatile components in electronic circuits. They offer distinct advantages in terms of matching impedance levels to available instrumentation or compensation circuit needs. The thermistor material composition, for example, can be adjusted and customized to achieve a desired resistivity-temperature response, within certain constraints, for a sensing device.

Precision NTC thermistors offer designers the greatest sensitivity to temperature of any electronic temperature sensing component. They exhibit a negative temperature coefficient of resistance in the region of -3%/^{o}C to -5%/^{o}C at 25^{o}C. This is roughly an order of magnitude higher than the sensitivity of positive temperature coefficient (PTC) metal resistors or thermocouple sensor elements. This provides some distinct advantages in system designs where sensitivity, circuit simplicity and overall system cost are important.

Drawbacks of NTC Thermistor devices include a non-linear resistance versus temperature characteristic and the fact that small bead and chip element devices have limited power handling capability. These disadvantages, however, are often overcome with innovative circuit designs. Presently, NTC thermistors are the preferred sensing element for many applications where precise measurement and control are required. Inexpensive microprocessor and display components are now being coupled with NTC thermistors and hybrid circuits. Such designs dominate industrial applications and can offer high performance temperature measurement and control capabilities for very reasonable overall system cost

NTC thermistor reliability, performance and life expectancy has improved significantly since the introduction of such devices in the 1930's. At present, long-term stability and reliability of NTC Thermistors have been demonstrated in many critical medical, scientific instrumentation, military/aerospace and industrial applications. ***BetaTHERM*** implements in-process monitoring and control methods that assure NTC device stability and performance throughout the manufacturing process.

Thermistor applications make use of the basic thermistor features, such as Resistance versus Temperature characteristics, zero-power characteristics, self heating effects and thermal characteristics like heat capacity and dissipation constant. A knowledge of these factors is important in understanding the principles of thermistor applications.

The ***Applications*** section of this catalog provides an overview of the use of thermistor properties in practical situations.

While an in-depth discussion of application principles at text-book level is beyond the scope of the catalog, the application notes provide a general overview of methods of using thermistors. **Key words** and **headings** are used that may serve as pointers towards more detailed sources of information.

The application notes cover temperature measurement, control and circuit compensation applications for NTC thermistors based on chip elements. In addition, several applications involving thermistor device characteristics such as *voltage-current and current-time* characteristics, which are also relevant for rod and disc thermistors, are discussed.

The thermistor application principles covered in the next sections can be classified in three categories. These categories are applications based on **Zero Power Sensing Mode**, applications based on **Self-Heat Sensing Mode**, and applications based on the **Time Dependency** of thermistor characteristics.

In discussing these topics, the notes on thermistor characteristics from the earlier section of the catalog are relevant in understanding the principles involved.

Zero Power Sensing Applications:

Temperature Measurement:

Temperature measurement is the most common application for NTC thermistors. Such devices have found wide acceptance as sensors in the -100^{o}C to +300^{o}C temperature range.

A common circuit that uses NTC thermistor elements is the **Wheatstone bridge circuit** shown in Figure # App 1. A later section of the catalog covers ***"Thermistor Circuit Configurations"*** and discusses bridge circuits in more detail.

The notes presented in this section concentrate on the application principles rather than on the details of implementation.

Thermistor selection for a bridge circuit is based on the temperature range to be measured, thermal sensitivity, working environment, time response and dimensional constraints. Input voltage must be low enough to prevent self-heating of the NTC element within the desired temperature span. Self-heating can cause serious errors in temperature sensing, so it is important that the thermistor is in Zero Power mode. As the sensor temperature changes, current will flow through the indicating meter, which is typically a sensitive current meter.

The detection meter can be calibrated directly in temperature for properly designed bridge circuits. Precision temperature measurements are often performed by comparing the thermistor and the adjustable (calibrated) bridge resistance at zero current flow through the detection meter. Multiple location measurements using interchangeable thermistors are feasible using switching or multiplexing equipment. Signals may also be input to amplifiers, A/D converters or control circuitry.

Wheatstone Bridge Circuit:

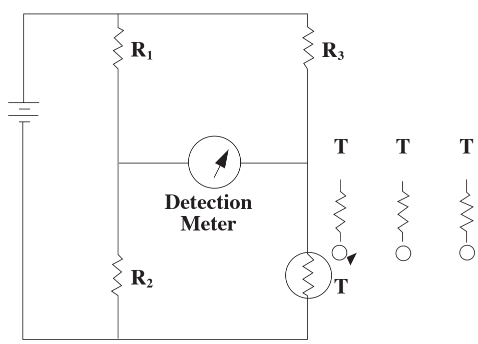


Figure # App 1

A revolution in circuitry design occurred with the introduction of integrated circuitry. Custom microprocessors, A/D converters, interface electronics and displays are now readily available. Inexpensive circuit modules with built-in thermistor Resistance-Temperature algorithms, as depicted in Figure # App 2, are now available for precision temperature measurement.

Microprocessor - NTC Thermistor Circuit Schematic:

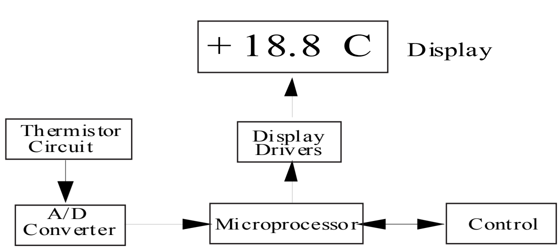


Figure # App 2

Temperature Alarm

The replacement of the bridge detection meter with a sufficiently sensitive relay will produce a temperature alarm circuit. The bridge output is sufficiently small and would not energize the relay at temperatures below the alarm set point which is determined by the fixed resistor legs of the bridge circuit. At a sufficiently high temperature, the thermistor resistance would be reduced causing circuit imbalance and sufficient current to actuate the relay. Relay selection and circuit considerations are important concerns for temperature alarm design.

Temperature Control

A simple on-off control system utilizing a relay actuated by a Wheatstone bridge control circuit is depicted in Figure # App 3. The thermistor bridge circuit provides a large voltage output (typically 18mV/^{o}C) so that signal amplification is not necessary to energize the control relay. When the limit point is reached or exceeded, the heater circuit will turn "off". A calibrated metering relay placed in the circuit would also provide a means of indication and control.

Temperature Control Circuit:

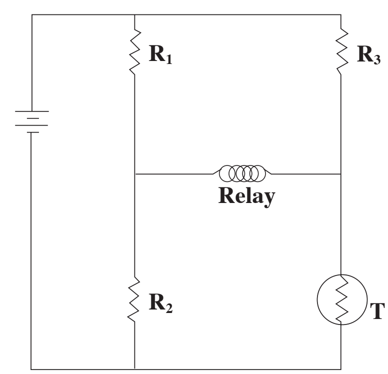


Figure # App 3

Further notes and details of bridge circuits are given in the section of this catalog that deals with "Thermistor Circuit Configurations". This section provides some guidelines on calculating the voltage output from a bridge circuit and on the selection of resistance values for limit setting.

While bridge circuits are still very important in the implementation of thermistor applications, it should be noted that the availability of Integrated Circuit instrumentation has made more sophisticated control options economical for temperature control applications. However, it is still useful to be aware of simpler options for less critical applications.

Linear Thermistor Networks

In certain situations, thermiator applications may require a **linearized electrical response** to temperature change. The topic of linearization is also dealt with in more detail in the section of the catalog that deals with ***"Thermistor Circuit Configurations".***

The discussion in this present section is concerned with the basic principles of linear circuits and discusses standard assembled sensing products that are produced by BetaTHERM. The topics covered in the section of the catalog that deals with ***"Thermistor Circuit Configurations"*** relate to design considerations for developing simple linearization circuits based on discrete thermistors and discrete resistors.

Although the area of linearization is a very broad one, it is of major importance for sensing applications. A linearized circuit has a **response** that is **linear** with respect to temperature. The linearized circuit consists of a **network of precision resistors and thermistors.** The response may be a resistance change of the complete network or a voltage change across a component of the network in a biased circuit. The linear response applies over a limited range, typically up to a 100 ^{O}C range. The simplest linear network consists of a single resistor and a single thermistor, but this is linear over a very limited range. In order to achieve a larger linear range a more extensive network of components is required.

BetaTherm **produce a range of linearized products using linear thermistor networks. They are in the form of bead sensors that contain the network of thermistors and are supplied with flying leads (percision resistors are added at board level). These linear networks are described in the product section of the catalog as the *"BetaLINEAR"* series of devices. They are shown in schematic form in the following diagrams.**

The definition of a **linear** response with respect to temperature is that the relationship is of the form:

$$T = m \times A + c$$

where: **T** is the temperature of the sensor (usually ^{O}C),
A represents the measured variable (voltage across a network component, or resistance of the network).
m is the slope of the line
c is a linear constant.

It should be noted that because the relationship between the measured variable and Temperature is a linear one, the equation could also be expressed in terms of the circuit parameter A, which represents Voltage or Resistance.

In this situation the equation could be expressed as:

$$A = m_1 \times T + c_1$$

where: ***m_1 is the slope ($m_1 = 1/m$)***
c_1 is the linear constant ($c_1 = -c/m$)

(In some cases the equations for a linear network may be presented in this format and the user should be aware of the form of the equation that is relevant.)

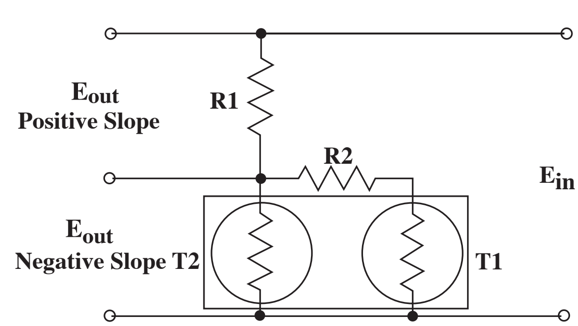
The two circuits designs included here consist of two precision resistors and two precision thermistors. **Figure # App 4** shows a network that is used in the **voltage mode**. In it's physical form it is a three terminal device. When a bias voltage E_{IN} is present then a voltage output that varies in a linear manner with temperature is available at the output terminals. The voltage across the resistor R2 has a positive slope with respect to temperature. The voltage across the Thermistor T2 has a negative slope.

The circuit schematic shown in **Figure # App 5** is for use in **resistance mode**. It is a two-terminal device. The resistance of the network varies in a linear manner with temperature.

In both circuits, the characteristics of the two thermistor elements are critical to achieve optimized linearity over the desired temperature range and the circuits are intended for use with the thermistors in **Zero Power Mode**.

Values of the linear parameters and other relevant details for these products are provided in the product section of the catalog that describes BetaLINEAR products.

BetaLINEAR NTC Thermistor-Resistor Network Circuits:



Voltage Mode Schematic
Figure # App 4

Resistance Mode Schematic

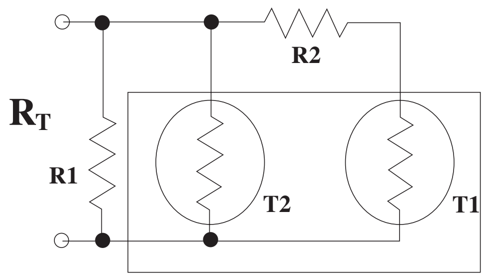


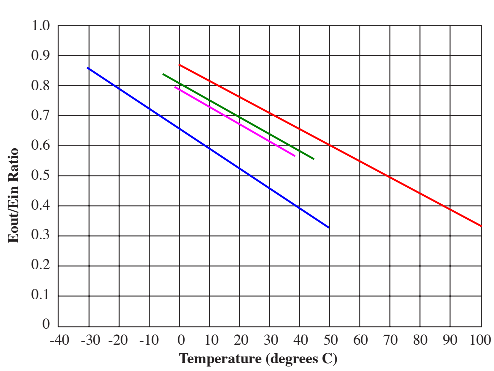
Figure # App 5

Linear thermistor networks provide a sensitivity that is roughly two orders of magnitude greater than thermocouples and wire-wound resistor components. The network circuit needs no reference or cold junction compensation. Further details of linear thermistor network design may be found in thermistor design literature.

As mentioned previously the topic of linearization is also discussed in the section of the catalog that deals with ***"Thermistor Circuit Configurations"***. The notes in that section are mainly concerned with linearization using a **single resistor** and a **single thermistor**, for use over a limited range.

In contrast, the **linear networks (BetaLINEAR series)** discussed in this section are presented as **discrete** components with the thermistor composite circuit encapsulated in bead form. Resistors are usually added at circuit board level. Characteristics are described by the specifications in the product section of this catalog. A sample graph from the *BetaLINEAR* product section is included to indicate operating ranges and sensitivity of linearized sensors.

Resistance Mode Output for sample BetaLinear Networks.



Self-Heat Sensing Applications:

Overview

Thermistor **self heat mode** sensing applications are based on the **voltage-current characteristics** of the thermistor, and on **the thermal characteristics** of the thermistor device and it’s environment.

Applications involving both static and time dependent conditions have been developed. This section will describe the principles of the use of thermistors in self-heat mode for liquid level sensing, flow sensing and voltage regulation.

Liquid Level Sensing

When a thermistor is in self-heat mode it heats up and dissipates energy, and it will have thermal characteristics that depend on it’s environment, as discussed earlier. For example, if the thermistor is in a **static gas** environment, the thermistor might have a voltage-current characteristic similar to **Curve G_0** of **Graph # App 1**.

Heat dissipation in **static liquids** is roughly **ten times** greater than that of a static gas environment, and **Curve L_0** of **Graph # App 1**. represents the voltage-current characteristic of a thermistor in a static liquid.

If the thermistor sensor is immersed in such a liquid, the increased heat dissipation will cool the thermistor and it’s resistance will increase. This difference in resistance value of the thermistor, due to the difference in thermal characteristics in **self heat mode**, between being in a static gas (air) and being in a static liquid is the basis of self-heat liquid level sensing applications.

Fluid Flow Sensing

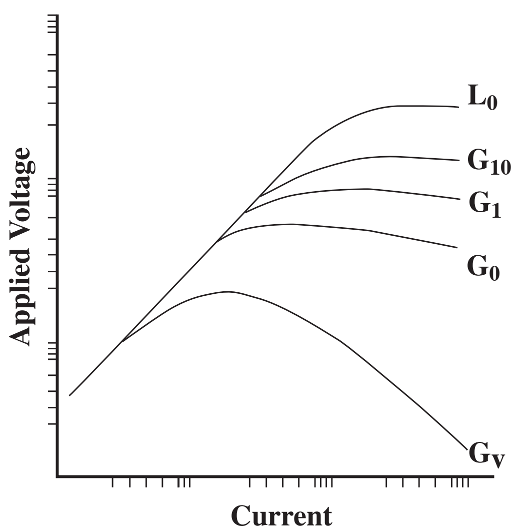
An important range of thermistor applications are based on heat transfer differences between **static** and **moving fluids**. These applications depend on an understanding of mathematical expressions describing the heat transfer behaviour at the interface of the sensing element and the fluid. Heat transfer behaviour at such fluid/sensor interfaces has been determined for many gases and liquids under **laminar flow conditions**.

The difference in voltage-current characteristic of a thermistor sensor in self-heat mode between static and moving fluids can be significant. This is indicated in ***Graph # App 1***, where **Curve G_0** represents the thermistor in a static gas environment, **Curve G_1** represents the thermistor in a flowing gas, and **Curve G_{10}** represents the thermistor in a faster flowing gas, for laminar flow conditions.

In flow sensing applications, voltage levels may be used to govern power dissipation when a constant current is applied to the thermistor element. This principal is the basis for computerized automotive air/fuel control and fluid flow monitoring.

Thermistors can also be used for measurements where the pressure of the fluid medium may vary. Such applications include measurements on low pressure gasses and at vacuum levels. **Curve G_V** of ***Graph # App 1*** represents typical voltage-current characteristics for a thermistor in self-heat mode in a vacuum environment. It shows that heat dissipation is substantially reduced compared to a static atmospheric air environment which is represented by **Curve G_0**.

Voltage-Current Behaviour for Level and Flow Sensing Applications:



Graph # App 1

Gas Analysis using thermistors in self heat mode:

A modified Wheatstone bridge circuit utilizing two extremely small, fast response "matched" self-heated thermistor elements has been developed for gas thermal conductivity and chromatography analysis. Gasses of different molecular weights have different dissipation constants if other conditions are kept constant. This is an important principle of gas analysis using thermistors.

The general principle is that one of the sensors is placed in a reference gas while the other is used to monitor a gas that is to be analyzed. The use of a matched pair of sensors ensures that the deflection of the bridge is due to differences in thermal characteristics between the reference gas and the gas being analyzed, rather than being due to differences in the thermistors. Properties of the gas being analyzed can then be compared with properties of the reference gas for characterization of it's parameters or of it's physical state. Practical implementation details, such as **instrumentation** selection and **calibration** of the measurement system for applications of this nature are beyond the scope of this catalog, but relevant information can be found in literature on thermistor applications.

Time Dependency Applications:

The current-time characteristics of NTC thermistors provide a means of introducing time-dependency into electrical circuits. There is a wide range of applications associated with time dependant effects and these represent some of the earliest applications of thermistors in practical electronics.

The current-time characteristics are due to the thermal heat capacity of an energized thermistor. It takes a certain amount of time for the body of the thermistor to heat up and for the associated drop in resistance to take place.

This time associated effect can be useful for surge suppression, timing delay and other time dependent applications. The factors that influence the time response of thermistors in an electronic circuit include: power consumption, thermal heat capacity, thermal heat dissipation to the surroundings and thermistor material characteristics as discussed in previous sections of the catalog.

Surge Suppression

The protection of circuits from high initial current surge during system start-up is a significant thermistor function. Most of these applications require the dissipation of **high power**, requiring large thermistor elements of the rod, disc and washer type. *BetaTHERM's* "Chip" element products are generally not suitable for this application.

Surge suppression devices are capable of withstanding line voltages and limit initial system surge current for a predetermined time interval. The surge protection time interval is related to the device thermal Time Constant (T.C.), base resistance and R-T slope characteristics.

Device construction plays an integral role in the thermal response of the system function. In general, the high power devices have relatively large thermal masses. Device T.C. values are typically 10 to 1000 seconds. Product configurations that thermally couple the thermistor element to high thermal inertia heat sinks have been developed by thermistor suppliers.

Time Delay

Time delay devices behave similarly to components used for surge suppression. A thermistor is placed in series with the circuit components whose operation is to be delayed and a fixed voltage is applied to the network. A timed current build-up occurs as the thermistor element is self-heated. The current builds up to the level required to activate components such as relays in the circuit. The rate at which the current changes is complex and related to the thermal Time Constant (T.C.) of the thermistor component.

Considerations for selection of thermistor devices for time delay applications include thermistor configuration, R value and R-T slope, device thermal inertia and power dissipation. Device characterization for the application is recommended and with due care it is possible to provide any reasonable time delay.

Voltage Regulation

Thermistor devices may be used to stabilize an output voltage against input voltage variations subject to the constraints of their power handling capabilities.

A typical circuit for this application consists of two fixed resistors and a thermistor as depicted in ***Figure # App 6.*** Quantitive details of circuit design and the selection of thermistor characteristics for voltage regulation applications may be found in thermistor circuit design literature.

The sensitivity of the thermistor to voltage gradients is directly related to it's thermal mass and to it's temperature coefficient. Thermistors are generally limited to voltage regulation in circuits with low voltages and highly resistive loads.

Voltage Regulation Circuit Schematic:

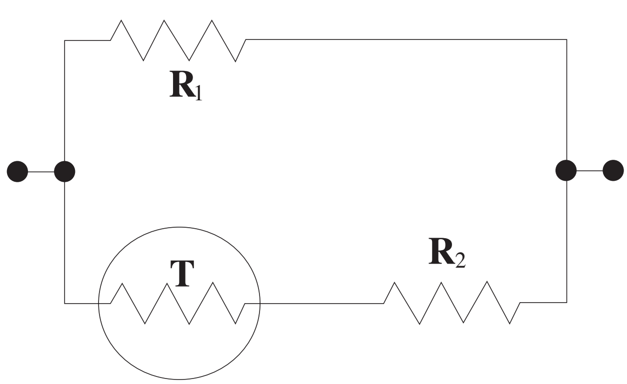


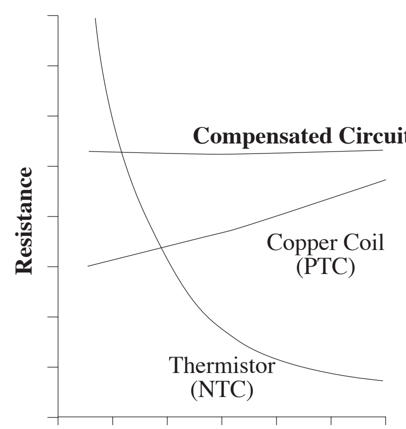
Figure # App 6

Temperature Compensation

Circuit temperature compensation is often required to extend the operational range of a particular system, or to protect components against a sudden surge in power during "cold" start-up This is a major area of application for NTC thermistors, where the Negative Temperature Characteristic is used to offset the Positive Temperature Characteristic of other electrical components in a circuit. The thermistor is connected in series with the component to be compensated. Other resistors may also be added to the compensation circuit to achieve the desired characteristic.

A simple graph for copper coil compensation versus network and components is shown in ***Graph # App 2***. The compensated network with an NTC thermistor as the main component has a significantly improved temperature response over the individual PTC copper coil characteristic. Selection of the thermistor value is based on consideration of power to be dissipated, characteristics of device to be compensated and overall circuit resistance characteristics.

Sample Temperature Compensating Curve:



Graph # App 2

Thermistor elements can also provide compensation and improved performance for thermally sensitive transistor and I.C. circuits. For example, a thermistor can stabilize transistor amplifier gain to make it relatively constant with temperature. In such applications it is important to consider the Resistance vs. Temperature characteristics of the thermistor relative to the characteristics of the device to be compensated over the temperature range of interest.

The next section of the catalog discusses some **circuit configurations** that are of relevance in the practical implementation of thermistor applications and in interfacing thermistors to control instrumentation.