Technical Notes

Negative Temperature Coefficient(NTC) Thermistors

Thermistor Definition

The word thermistor is derived from its description: "thermal sensitive resistor". Thermistors are passive semiconductors, which produce resistance values dependent on temperature.

A Negative Temperature Coefficient (NTC) thermistor decreases in resistance as its body temperature increases. In fact, NTC thermistors exhibit two characteristics, which make them extremely useful in a variety of applications. Their change in resistance is predictable and it is relatively large per degree change in temperature.

Manufacturing Process

This is a two-step process of chip manufacturing and thermistor assembly. Manufactured chips are processed by metal oxide powders into ceramic sheets. These sheets are metalized with silver to allow for electrical contact. After metalization, the ceramic sheets are diced into chips. Each chip is tested to meet our superior quality standards.

After a chip has been manufactured and tested, leads are attached. The chip is trimmed to match the specified tolerance, and then a protective coating is added. Further customizing of the assembly can be done by adding housings, cables and connectors.

Thermistor quality is assured with in-process inspection and Statistical Process Control (SPC). This process takes place at each manufacturing and assembly step. All finished products are 100% tested both electrically and mechanically to guarantee all specifications are met.

Resistance-Temperature(R/T) Curves and Negative Temperature Coefficient

Nine different materials are made, each with its own unique and predictable resistance-temperature characteristics. These characteristics are called "curves". Thermistors are most often specified by their curve and by their resistance value at 25°C.

The NTC (Negative Temperature Coefficient) is the negative percent resistance change per degree C. Our thermistors have NTC values at 25°C ranging from -3.9%/°C to -6.4%/°C. Resistance values at 25°C range from 300 ohms to 40 meg ohms. The tables on pages 23 through 25 detail this information.

Thermal Time Constant

Time constant, expressed in seconds, is the time required for a thermistor to indicate 63.2% of a newly impressed temperature. The time constant of a thermistor is directly affected by the mass of the thermistor and thermal coupling to the environment. An epoxy or phenolic coated thermistor with a 0.095" O.D. will typically have a time constant of 0.75 seconds in stirred oil and 10 seconds in still air.

Dissipation Constant

Dissipation constant is the power required to raise the temperature of a thermistor 1°C above the surrounding environment. Power is expressed in watts. The dissipation constant of a thermistor with a 0.095" O.D., coated with epoxy or phenolic, is typically 13 mW/°C in stirred oil and 2 mW/°C in still air.

Voltage/Current Requirements

Very low current is required for a thermistor being used in temperature measurement, control or compensation applications. Current levels should typically be less than 100mA for a thermistor to dissipate "zero power". As previously discussed, power dissipation for a thermistor in still air is approximately 2mW/°C. Therefore, in order to keep the thermal error (self-heat) below 0.1°C,the power dissipation must be less than 0.2mW.

Self-heating is desirable in applications such as air flow measurement and liquid level control. Standard epoxy or phenolic coated thermistors with a 0.095" O.D. have a maximum power rating of 30 milliwatts at 25°C to 1 milliwatt at 100°C.

Beta

The Beta value of a thermistor is one way to characterize its resistance temperature relationship. Beta is calculated as follows:

$$\beta_{T2/T1} = \ell n(R_{T2}/R_{T1})/(1/T_2 - 1/T_1)$$

Temperature is in degrees Kelvin; R_{T1} is the resistance at temperature T_1 ; R_{T2} is the resistance at temperature T_2.

Steinhart-Hart Equation

The Steinhart-Hart Equation is an empirically developed polynomial which best represents the resistance-temperature relationships of NTC thermistors. The Steinhart-Hart Equation is more accurate than previously methods; as well, it is more accurate over wider temperature ranges. To solve for temperature when resistance is known, the form of the equation is:

$$1/T=a+b(\ell nR)+c(\ell nR)^3$$

To solve for resistance when temperature is known, the form of the equation is:

$$R=e(exp)[(-\alpha/2+(\alpha^2/4+\alpha^3/27)^{-2})^{-3}+(-\alpha/2-(\alpha^2/4+\alpha^3/27)^2)^3]$$

where alpha=(a-1/T)/c and β=b/c

For both forms of the equation T is temperature expressed in degrees Kelvin;a,b and c can be solved simultaneously using the following:

$$1/T_1=a+b(\ell nR_1)+c(\ell nR_1)^3$$

$$1/T_2=a+b(\ell nR_2)+c(\ell nR_2)^3$$

$$1/T_3=a+b(\ell nR_3)+c(\ell nR_3)^3$$

The data calculated by these equations will be accurate to better than ±0.01°C when -40°C is less than or equal to 150°C and $|T1-T2|$ is less than or equal to 50°C and $|T2-T3|$ is less than or equal to 50°C and T1,T2 and T3 are evenly spaced.

Maximum Temperature Rating/ Recommended Operating Ranges

Our thermistors may be intermittently cycled at temperatures from -50°C to 150°C. Stability is achieved when the thermistors are stored at temperatures less than 50°C and operated continuously at temperatures less than 100°C. For interchangeable thermistors, optimum stability is achieved when the thermistors are operated at temperatures within the specified interchangeable temperature range.

Stability

Years of experience in thermistor manufacturing, coupled with stringent process controls, ensures that highly stable thermistors are produced. In fact, our thermistors typically exhibit less than 0.02°C thermometric drift per year when stored or operated at temperatures less than 50°C. The stability of a thermistor is greatly dependent on environmental conditions such as humidity, excessive temperatures and thermal shock; these effects should be minimized to guarantee stability.

NTC THERMISTOR APPLICATIONS
Introduction

Our NTC chip thermistors outperform all other temperature sensors in applications requiring temperature measurement and compensation from -50°C to 150°C. RTDs,thermocouples and silicon semiconductors cannot compete with the thermistor's high sensitivity response to temperature. This sensitivity is crucial for temperature measurement and control applications.

Unlike RTDs and thermocouples,thermistors are virtually unaffected by lead resistance. This makes NTC thermistors the sensor of choice for remote sensing applications.With their excellent long term stability characteristics, design engineers are allowed to utilize thermistors in critical applications such as medical, military, aerospace, industrial and scientific industries. Systems utilizing thermistors are less expensive to produce because few associated components are required to provide a high performance system. Chip thermistors can be ordered with tight tolerances to ±0.05°C,eliminating the costly calibration process required by temperature sensors such as silicon semiconductors,RTDs,thermocouples and glass beaded and disk thermistors with loose tolerances.

NTC thermistors provide the design engineer with desirable sensor performance advantages in a variety of applications. The following notes provide a few examples of how to utilize the NTC thermistor.

"ZERO POWER"SENSING

When utilizing a thermistor for temperature measurement, control and compensation applications,it is very important not to "self-heat" the thermistor. Power,in the form of heat,is porduced when current is passed through the thermistor. Since a thermistor's resistance changes when temperature changes,this "self generated heat" will change the resistance of the thermistor,producing an erroneous reading.

The power dissipation constant is the amount of power required to raise a thermistor's body temperature 1°C. A standard chip thermistor has a power dissipation constant of approximately 2 mW/°C in still air. In order to keep the "self-heat" error below 0.1°C power dissipation must be below 0.2mW. Very low current levels are required to obtain such a low power dissipation factor. This mode of operation is called "zero power" sensing.

Figure 1: wheatstone Bridge - Voltage Mode

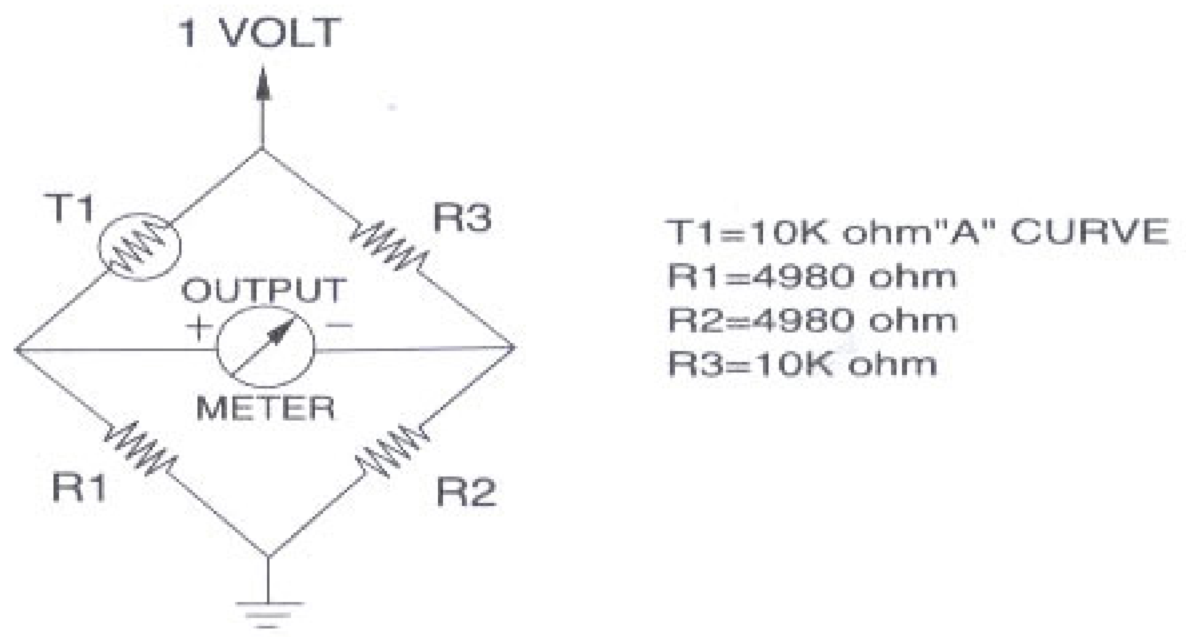


Figure 2: wheatstone Bridge - Voltage Mode

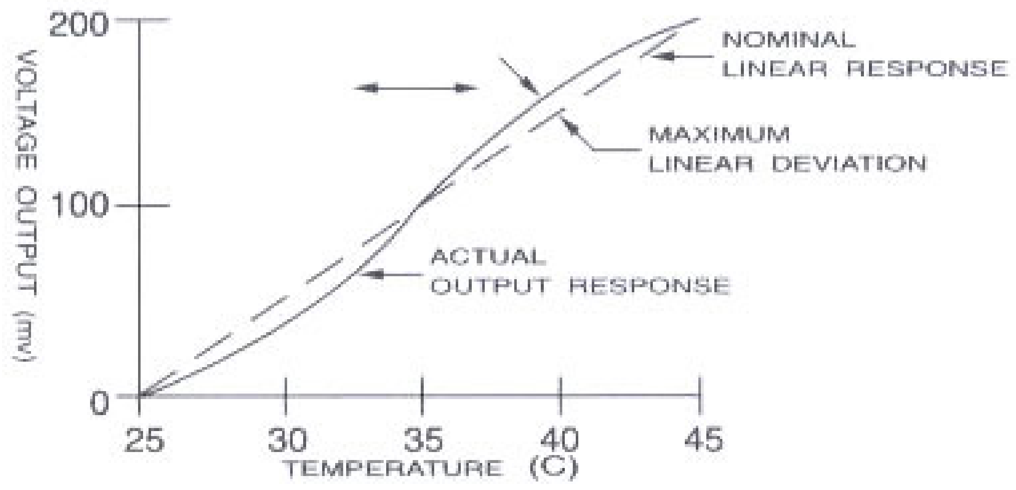
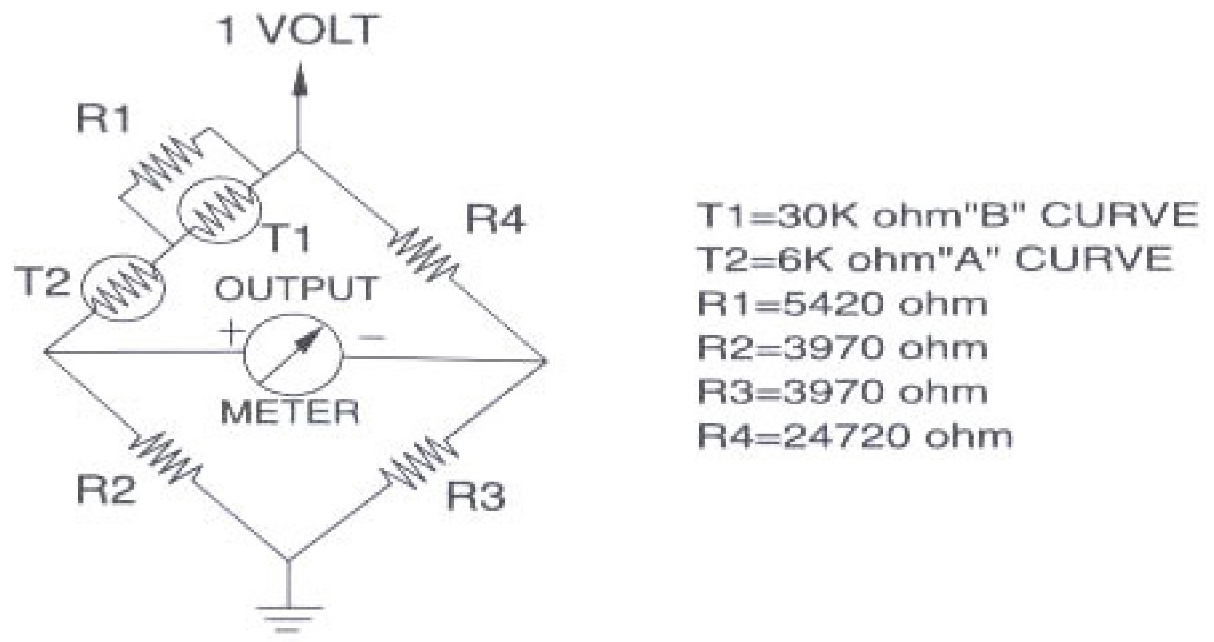


Figure 3: wheatstone Bridge - Voltage Mode



THERMISTOR LINEARIZATION-Voltage Mode
Wheatstone Bridge-Voltage Mode

To produce a voltage output that varies linearly with temperature, utilize the NTC thermistor as the active leg in a Wheatstone Bridge. As temperature increases,the voltage output increases. The circuit in **Figure 1** produces an output voltage that is linear within ±0.06°C from 25°C to 45°C. This circuit is designed to produce 1 V at 25°C and 200 mV at 45°C;this is achieved by the selection of R2 and R3. The value of R1 is selected to best provide linearization of the 10K ohm thermistor over the 25°C to 45°C temperature range.

Figure 2 illustrates the output voltage of the Wheatstone Bridge as a function of temperature.

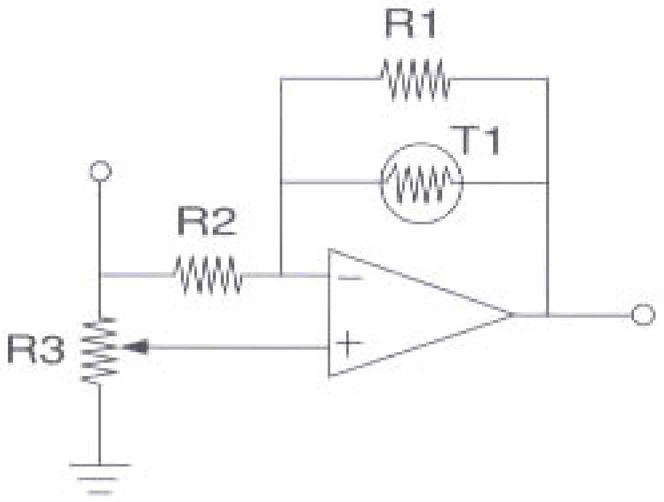
The circuit in **Figure 3** provides improved output accuracy over a wide temperature range by substituting a 6K/30K ohm thermistor network in place of the single thermistor in the Wheatstone Bridge. This circuit is designed to produce 0 V at 0°C and 537 mV at 100°C. The maximum linear deviation of this circuit is ±0.234°C from 0°C to 100°C.

THERMISTOR LINEARIZATION

Operational Amplifier (Resistance mode)

A linear voltage output that varies with temperature can also be produced by utilizing an operational amplifier and a linearized thermistor network as illustrated in **Figure 4**.The voltage output decreases linearly as temperature increases. This circuit may be calibrated by adjusting R3 for an output voltage of 200mV at 25°C and 0 V at 45°C.

Figure 4: Linearization - Resistance Mode



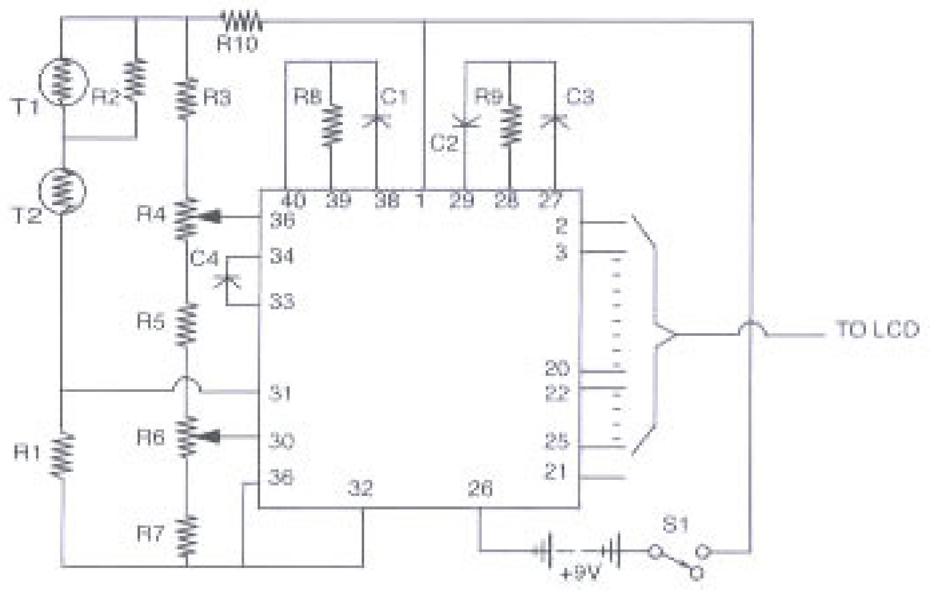
T1=10K ohm"A" CURVE
R1=4980 ohm
R2=5K ohm
R3=10K ohm potentiometer

TEMPERATURE MEASUREMENT AND CONTROL

Digital Thermometer

The most common application for the NTC thermistor is temperature measurement. Accurate temperature maasurement can easily be accomplished by interfacing a Wheatstone Bridge,6K/30K ohm thermistor network and a digital voltmeter integrated circuit as illustrated in **Figure 5**.The IC is comprised of an analog to digital converter with built-in 3-1/2 digit LCD driver providing resolution of 0.1°C.Using the 6K/30K ohm thermistor network makes it possible to achieve an overall system accuracy of ±0.4°C from 0°C to 100°C. This digital thermometer can easily be interfaced with additional circuitry to provide a temperature control circuit with a digital display.

Figure 5: Digital Thermometer



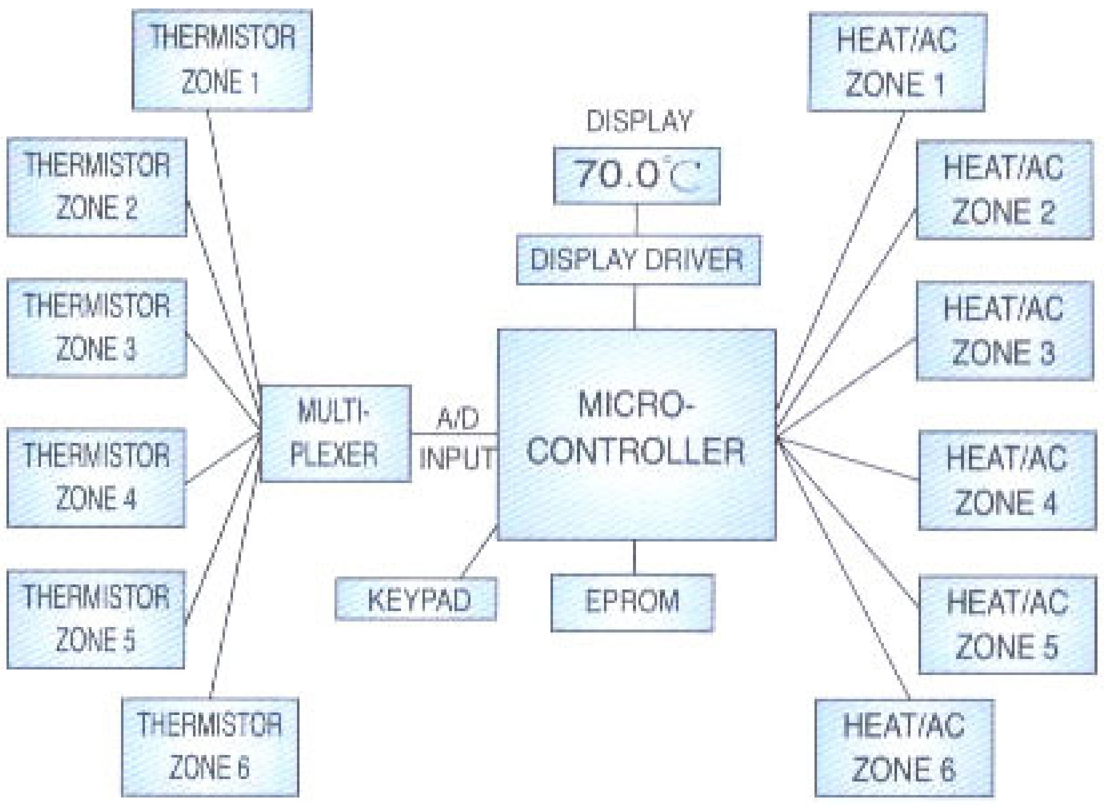
R7=1.50K ohm
R8=100K ohm
R9=470K ohm
R10=15K ohm
C1=100 pF
C2=0.1
C3=0.22
C4=0.1

Micro controller System

The advent of low cost micro controllers used with precision interchangeable NTC thermistors,provides the design engineer with unlimited design possibilities for temperature measurement and control systems. These systems are relatively inexpensive to produce yet offer very high temperature accuracy and various software controlled outputs.

For example, a micro controller system utilizing remote thermistor sensors can monitor and control the temperature in several locations in an office building.

Figure 6: Microcontroller System



The micro controller is comprised of a built-in microprocessor, analog to digital converter, RAM and several digital inputs/outputs. The complete system **(Figure 6)** utilizes the micro controller, multiplexer, EPROM, digital display, keypad and display driver.

The micro controller is programmed in assembler language. The temperature measurement is calculated within the micro controller using the resistance versus temperature algorithm and the a, b and c constants for the specific thermistor resistance and curve material. Refer to the Stein-hart Equation on page 5. An alternative method to convert the thermistor resistance to temperature is to program a "look-up" table in EPROM. After programming, the micro controller tells the multiplexer to send back temperature data from a particular zone (room in the office building) and converts the resistance of the thermistor into a temperature reading.

The micro controller can then turn on or off the heating or air conditioning systems in that zone.

The thermistor/micro controller system can be used for security, temperature control, monitoring activities and many other application. The possibilities are endless.

TEMPERATURE COMPENSATION

NTC thermistors can be used to compensate for the temperature coefficient response of various components such as crystal oscillators, mechanical meters and infrared LEDs. A thermistor/resistor network (**Figure 7**)is placed in series with a PTC component requiring compensation. The resistor values are selected to provide the proper NTC slope to offset the PTC component. The net effect is a constant circuit response that is independent of temperature.

"SELF-HEAT" SENSING APPLICATIONS

To "self-heat" a thermistor, it must be subjected to power levels that raise the thermistor's body temperature above the environmental surroundings. Self-heat applications include the sensing of liquid and air level and flow rates. The application is dependent on the fact that the environment surrounding a thermistor directly affects the amount of power the thermistor can dissipate. For example, submerged in liquid, a thermistor can typically dissipate 500% to 600% more power than it can in air. Therefore, a thermistor being "self-heated" in air is able to dissipate much more power when transferred to a fluid environment. This increase in power dissipation generates a significant increase in resistance. It is this change in resistance, which makes it possible to sense the fluid level.

A simple liquid level control system can be designed by putting a themistor in series with a coil **(Figure 8)**, which operates a valve that releases the liquid in the tank. The thermistor is placed in the tank and operated in a "self-heat" mode.

In air, the thermistor's resistance is low and allows enough current flow to energize the relay coil and keep the relay contact closed. When the fluid level in the tank surrounds the thermistor, its resistance increases and de-energizes the relay, which opens a valve and releases the fluid. As the fluid is released from the tank, the thermistors's resistance decreases and the relay coil energizes and closes the valva.

Fuel injection in automobiles utilize the thermistor in the "self-heat" mode in order to properly control the air/fuel mixture. Forced air heaters may use the NTC thermistor in the "self-heat" mode in order to maintain proper air flow characteristics. This technology is utilized to monitor the flow rate and level of air and fluids in a variety of applications.

Figure 7: Temperature Compensation

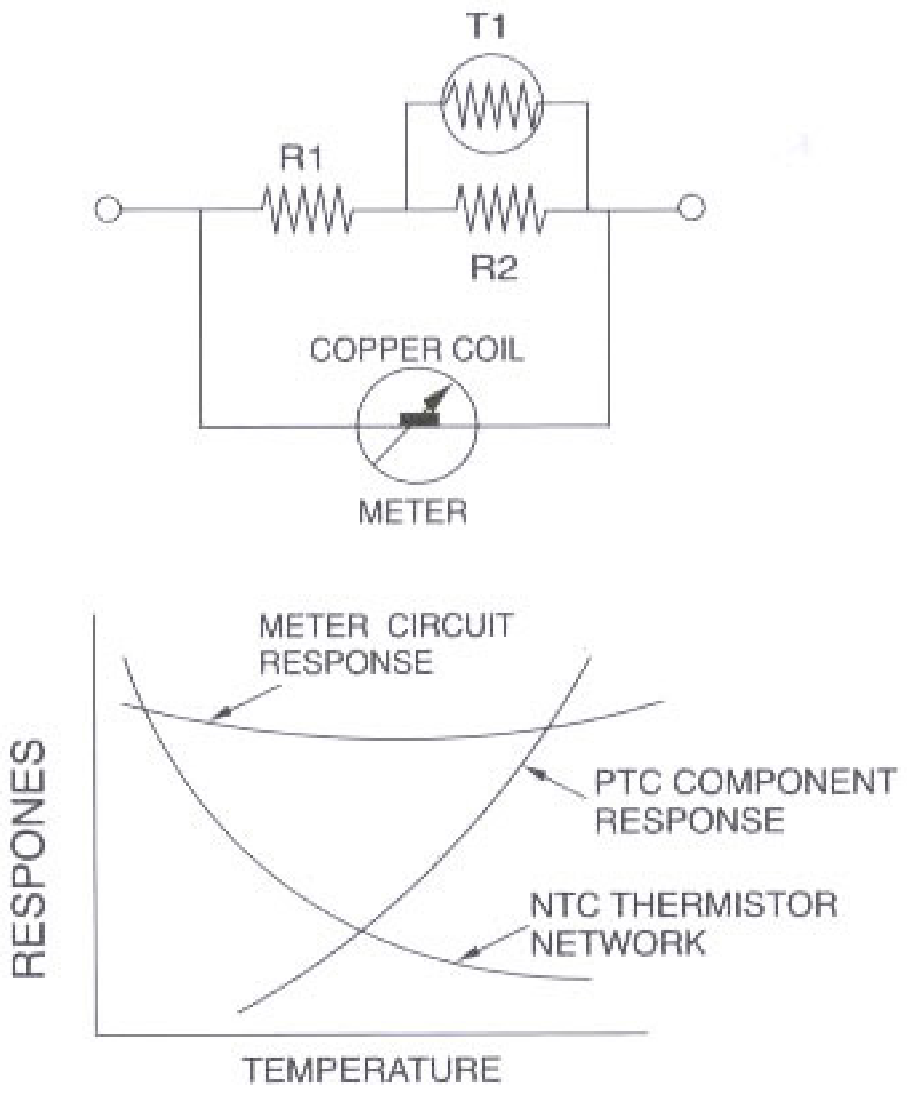


Figure 8: Self - Heat Applications