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Company Profile:

BetaTHERM Corporation was founded in 1983 at Shrewsbury, Massachusetts, USA. The company started operations on a small scale but steadily built up an extensive customer base and a broad range of products. This growth and development was due to the technical expertise of the company and also to the customer service it provided. Becoming an established force in the NTC Thermistor Industry, it participated in the general economic growth associated with the electronics sector from the mid-1980's onwards. During this period, the growth of BetaTHERM exceeded the industry average and the company developed additional expertise in producing high specification sensors for an expanding global market.

BetaTHERM has shown itself to be a dynamic company that is committed to progress. With "state of the art" facilities in Europe and the United States, BetaTHERM is well positioned to meet the demands of global customers.

Significant milestones in the development of the company include:

- *The establishment of a **European** division in **Ireland** in 1987 to serve the European market.*
- *Achieving **ISO-9001** and **ISO-9002** approval as a supplier of NTC Thermistors and assemblies in 1994.*
- *Becoming a supplier of components for major projects in the Aerospace Industry and implementing a program to achieve European Space Agency (ESA) approval in 1999.*

BetaTHERM is dedicated to providing the best technological and innovative approach to all of our served markets.



Headquarters at Galway, Ireland.

BetaTHERM Products:

Probe Products

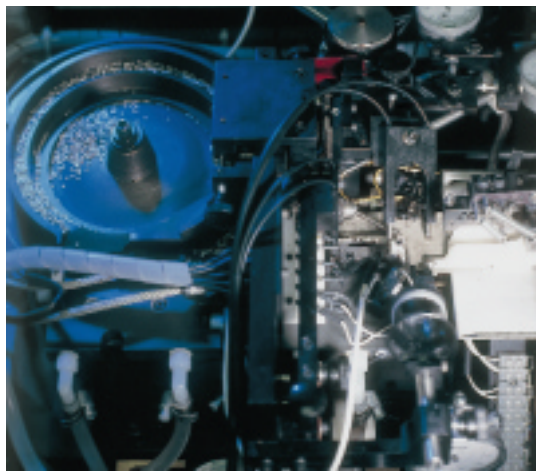
BetaTHERM's NTC thermistor products extends from chip thermistor elements to precision epoxy or glass coated discrete devices with wire leads. These discrete devices can be used for the manufacture of complex probe assemblies. Our thermistors provide solutions to thermal sensing problems ranging from basic to complex applications. These assemblies are suitable for temperature measurement and sensing from -80°C to $+300^{\circ}\text{C}$. BetaTHERM's customised probe assembly design service and expertise provides solutions to a wide variety of thermal applications in all market segments.

As part of our program to become a solutions provider, we are focused on expanding our range of products and services. Our company will continue to expand and market its own unique precision sensors and extend its capabilities into other related global markets.

BetaTHERM continues to serve its customers with the introduction of new sensor products, materials and manufacturing innovations. New products introduced in this catalog include ; disc thermistor , inrush current limiters, DO-35 packages, tape and reel components and also a selection of application specific probes.

Quality Assurance:

BetaTHERM has an ongoing commitment to quality as demonstrated by its continued compliance with ISO standards and its participation in the qualification process to achieve ESA (European Space Agency) approval.



Automatic Component Testing

To supply the highest quality products, BetaTHERM has invested in automated manufacturing and test equipment. We manufacture our own thermistor elements from transition metal oxides using proprietary formulations. Having complete control of the entire manufacturing process allows us to perform in-process quality monitoring and implement statistical process control (SPC). These controls ensure the production of superior thermistor elements and assemblies.



Component Burn-in chamber

Continuous investment in electrical and environmental test equipment allows BetaTHERM to maintain the accuracy and reliability of our products. Precision temperature baths and resistance measurement equipment are employed during all stages of manufacture.

Using in-process quality checks, 100% final testing, mechanical and visual inspection, we reinforce our commitment to excellence and our endless commitment to quality.

Engineering and Sales:

BetaTHERM is also aware of the importance of the Engineering and Sales functions in maintaining key accounts and developing business. The company has in-house capability in Materials Technology, in the development of custom test equipment, in Information Technology, in CAD and in the development of prototype thermistor assemblies. BetaTHERM promotes an atmosphere where the sales and application team work closely with Quality Assurance and production groups in developing process flows for new products.

BetaTHERM's applications engineering group encourages inquiries concerning innovative applications and are interested in discussing non-standard or special NTC thermistor requirements with customers. In most cases it is possible for BetaTHERM to supply sample thermistors or probe assemblies free of charge to customers for evaluation and testing. Inquiries can be submitted by phone, fax or E-mail and BetaTHERM undertake to reply promptly to all such inquiries.

About this Catalog:

The catalog is an important element in imparting the BetaTHERM corporate philosophy to customers. It is intended to serve primarily as a guide to BetaTHERM's products and also to provide some background information on thermistor theory and terms that are used in the thermistor industry. In compiling the catalog, efforts have been made to provide background information that is not readily available in other thermistor catalogs. This information is presented in the form of a general overview and is intended to serve as a source of key words and pointers for users who need to find more in-depth information on thermistor topics.

We believe that we have provided a comprehensive listing of products together with generic information so that customers can understand the product functions and descriptor codes. We have provided a substantial section on thermistor characteristics and terminology. We have provided definitions of the most significant terms and included information on modeling thermistor characteristics.

While the information in the theory and applications section is not at text-book level, it is intended to be used as a general starting point so that key words and concepts can be used to locate information at the level of detail that some readers require.

Overview of Markets and Applications

The market / applications for thermal sensing solutions may be segmented by either major type of user or by industry. A market segment can be defined as a group of people who share a common need and who will repeatedly accept a common fulfillment of this need, or more briefly, a group of users with similar problems who will accept similar solutions.

Betatherm can offer either standard or custom product to provide the ideal solution to specific temperature measurement or sensing problems.

Temperature sensing and measurement is of particular importance to the following key market segments :

1. Medical.

- Esophageal tubes.
- Incubator temperature control.
- Internal body temperature monitor.
- Thermodilution catheter.
- Skin temperature measurement.
- Respiration rate measurement.
- Blood dialysis.
- Rectal temperature monitoring.



2. Automotive

- Oil level sensors.
- External air temperature monitor.
- Ice warning system.
- Engine coolant and management systems.
- Cabin climate control.
- Air conditioning.
- Water level sensor.
- Heated car and truck seating.
- Side mirror defrost.



3. Aerospace and Military.

- Missiles and spacecraft temperature.
- Satellites.
- Aircraft temperature.
- Fire control equipment.
- Atmospheric temperature monitor.



4. Consumer Products.

Clothes dryers.
Air conditioning units.
Fire detection equipment.
Refrigeration cabinets.
Electric blanket controls.
Water heater units.
Thermostats.
Oven temperature control.
Pool and spa control.
Coffee makers.
Deep fryers.
Microwave ovens.

**5. Industrial.**

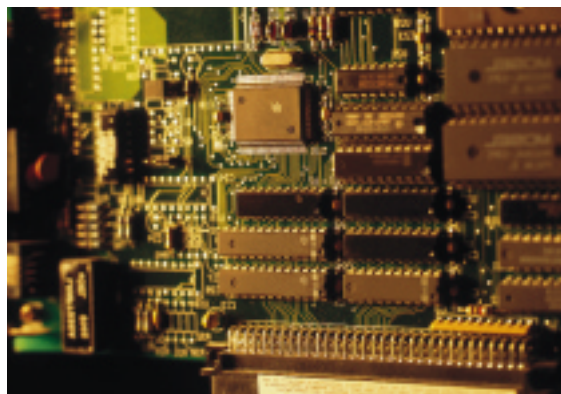
Industrial process control.
Copy Machines.
HVAC equipment.
Fluid and gas flow measurement.
Liquid level indication.
Thermoplastic mould equipment.
Color printing machines.
Solar systems.
Fire detection systems.
Plastic laminating equipment.

**6. Instrumentation.**

Laboratory analysis equipment.
Platen temperature.
Infrared sensing temperature compensation.
Portable temperature gauge.
Light power monitoring.
Cold junction compensation.

**7. Computer and Communications.**

Wavelength Division Multiplexing (WDM) frequency control.
Hybrid circuit temperature compensation.
Battery packs.
Cellular telephones.
Oscillator temperature compensation.
Power supplies



Thermistors:

The term "**Thermistor**" is used to describe a range of electronic components whose principle characteristic is that their electrical resistance changes in response to changes in their temperature.

The word "**Thermistor**" derives from the description "**thermally sensitive resistor**".

Thermistors are further classified as "Positive Temperature Coefficient" devices (**PTC devices**) or "Negative Temperature Coefficient" devices (**NTC devices**).

PTC devices are devices whose resistance increases as their temperature increases.

NTC devices are devices whose resistance decreases as their temperature increases.

NTC thermistors are manufactured from proprietary formulations of ceramic materials based on transition metal oxides. A brief outline of the manufacturing process for the production of **chip thermistors** at BetaTHERM is shown inside the front cover of this catalog.

A discrete thermistor such as a chip, disc or rod is a fundamental electrical component.

BetaTHERM's "**chip**" thermistor elements are the foundation of a major proportion of BetaTHERM's products.

To understand the applications of thermistors and the selection of thermistor components in the design of thermistor circuits it is necessary to be aware of some basic concepts and definitions that are used in the thermistor industry. The next sections of the catalog cover some of these topics with reference to chip-based NTC products to provide some background to thermistor theory and to assist in the selection of products for applications. Product specifications are given in a separate section of the catalog.

The topics to be considered in this discussion on thermistors are:

- **Chip Configuration.**
- **Volume Resistivity of material.**
- **Electrical Resistance.**
- **Slope (Resistance Ratio).**
- **Modelling relationship between Temperature and Resistance.**
- **Thermal Time Constant, Dissipation Constant.**
- **Resistance-Temperature Characteristics.**
- **Voltage-Current Characteristics.**
- **Precision, Tolerance and Stability of Thermistors**
- **Current-Time Characteristics.**
- **Application notes .**
- **Circuit Guidelines.**

Chip Configuration:

The basic configuration of "**chip**" thermistor elements is shown in Figure #1. The thermistor material is metalized on the top and bottom surfaces for electrical contact. Metalization of the thermistor material is performed by dipping or screen printing with conductive ink based on materials such as silver or gold. The ink is fired to the wafers of the thermistor material. The wafers are then diced by mechanical saw or by laser scribing to produce chips of specific sizes. The length, width and thickness are controlled dimensions for specific chip element products. Typical chip dimensions are 1mm x 1mm x 0.25mm thick.

BetaTHERM supplies leadless "chip" thermistor elements for applications where die bonding and wire bonding assembly techniques are used for circuit connections. The elements can be supplied in vials or "waffle" packs.

TYPICAL CHIP THERMISTOR

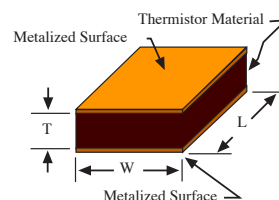


Figure # 1

Figure # 1

BetaTHERM's chip elements are used to produce components with wire leads which are coated with thermally conductive epoxy as illustrated in Figure # 2.

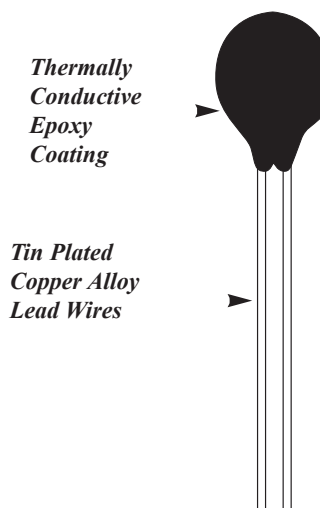


Figure # 2

Volume Resistivity:

The volume resistivity of a material is a parameter that indicates the electrical resistance of a piece of the material. It is defined in a manner that allows the calculation of the resistance in **Ohms** of a piece of material when the **physical dimensions** are known.

Resistivity is specified in units of resistance (ohms) multiplied by units of length (usually cm). Resistivity is then expressed in units of ohm-cm. (Ω-cm). Resistivity is usually represented by the Greek Letter ρ, (rho).

At first, the units of resistivity (ohm-cm) may not seem convenient. To develop the concept and improve understanding, it is essential to relate the material parameter **resistivity** with the actual resistance in **ohms** of a piece of material. The relationship between them is:

$$R \text{ (ohms)} = \frac{\rho \text{ (ohm-cm)} \times \text{thickness(cm)}}{\text{cross-sectional area (cm}^2\text{)}} = \frac{\rho \times T \text{ ohms}}{L \times W}$$

(Equation #1)

where: ρ is material resistivity in ohm-cm,
T is the thickness of the conductor (chip) (cm)
L is the length of the conductor (chip) (cm)
W is the width of the conductor (chip) (cm)

Resistance is proportional to thickness (length of current path) because for a uniform cross-sectional area, increasing the thickness of a conductor is similar to combining resistors in series. Likewise, the resistance is inversely proportional to the cross-sectional area as increasing the cross-sectional area is similar to combining resistors in parallel, which reduces the overall resistance.

Resistivity is essentially an engineering parameter and it is an extremely important. It is useful because when it is known for a particular material, the resistance of a piece of that material can be calculated if the dimensions of the piece are known also. These calculations are demonstrated in a numerical example, but first, the concept of volume resistivity of materials is developed further.

The resistivity of thermistor material is treated as a **constant** for standard materials. The resistivity varies with temperature, so it is specified at particular temperatures (usually 25°C). Thermistor manufacturers produce many different thermistor materials to cover an extensive range of resistance values (100 ohms to 1 Mega-ohm) for chips of various sizes.

A simple representation of the manufacturing process for BetaTHERM thermistors is shown on the inside of the front cover of this catalog.

When the metallization stage is complete, the thermistor material is in the form of a ceramic sheet or wafer of typical dimensions 50mm x 50mm x 0.25mm which is metallized on both sides. The resistivity of a piece of the material can be calculated by dicing a chip of regular shape (square or rectangular faces), measuring the resistance of that chip at the relevant temperature (usually 25 °C) and applying the definition of resistivity as follows:

Volume resistivity formula:

$$\rho = \frac{L \times W \times R_{25}}{T} \text{ (ohm-cm)}$$

(Equation #2)

Where: ρ = volume resistivity (ohm-cm)
L = length of chip element cm
W = width of chip element cm
T = thickness of chip element (cm)
R₂₅ = measured resistance @ 25°C (ohms)

A typical calculation based on resistivity is illustrated in the following example. In such calculations it is important to **observe consistency of measurement units and dimensions** especially where some dimensions are given in inches and others are in centimetres. For instance in the thermistor industry it is common to express resistivity in units of ohm-cm, but to give chip dimensions in inches.

Example: Calculate the volume resistivity for BetaTHERM Curve 3 Material with dimensions of 0.04" x 0.04" and thickness 0.01" with measured resistance value 8120 ohms at 25°C.

$$\rho = \frac{0.04(\text{inches}) \times 2.54(\text{cm/inch}) \times 0.04(\text{inches}) \times 2.54(\text{cm/inch}) \times 8120 \text{ (ohms)}}{0.01(\text{inches}) \times 2.54 \text{ (cm/inch)}}$$

$$\rho = 3299.96 \text{ ohm-cm.}$$

When resistivity is specified in **ohm-cm** and the other dimensions are in **inches** then the equation can be written as :

$$\rho \text{ (ohm-cm)} = \frac{L(\text{inches}) \times W(\text{inches}) \times 2.54 \times R_{25}(\text{ohms})}{T(\text{inches})}$$

(2.54 is the conversion factor to relate cm and inches)

The concept of material resistivity is extremely important in the selection of thermistor material in relation to chip size in applications. The equations indicate that for material of the same resistivity, required resistance values

BetaTHERM Sensors

can be achieved with different chip sizes, within the constraints of the equations relating resistance and resistivity. This provides flexibility for developing custom solutions in relation to chip sizes in applications.

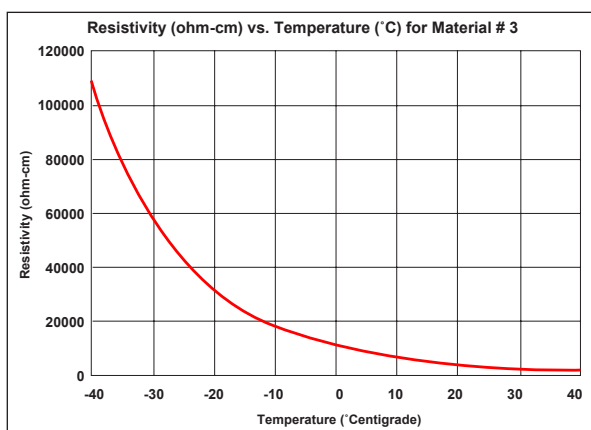
Material resistivities of BetaTHERM thermistors at 25 °C are listed in Table #1 below. The use of resistivity values in calculating the resistance of thermistor elements is of major importance in the thermistor industry. These values have been determined by accurate measurements.

BetaTHERM Standard Material Resistivities at 25°C.

Material Curve	Resistivity (ohm-cm)
1	65
2	50
3	3300
4	3500
5	5500
6	18000
7LoRo	300
7HiRo	3000
9	325000

Table # 1:

Since a thermistor is a component whose resistance varies with temperature, the variation of resistivity with temperature is a critical material property. This relationship is indicated graphically below for Betatherm Material #3 over a limited temperature range (-40°C to +40 °C).



Resistance:

Thermistors are devices that obey **Ohms Law**, which relates the current through a resistor to the voltage across it. **Ohms law is usually stated as: $V=IR$** ,

where V is the voltage across the resistor in units of **Volts**,
 I is the current through the resistor in units of **Amps**,
 R is the resistance of the resistor in units of **Ohms**.

The word Thermistor is derived from the term Thermally sensitive resistor. The resistance of the thermistor depends on the temperature of the thermistor, **and at temperature points in it's useful range, the thermistor obeys Ohms Law.**

Thermistors exhibit a relatively large negative change in resistance with a change in body temperature, typically -3% to -6% per °C. This sensitivity is a major advantage of thermistors over other electrical temperature sensing devices.

The concept of **electrical resistivity** and the material resistivity constants that were introduced in the previous section can be used to calculate the **resistance** of thermistor components. The physical dimensions of the thermistor and the material resistivity at the relevant temperature are required. The reference temperature is usually taken to be 25°C. Referring to **Equation #1** and the definition of resistivity, the resistance (**R**) of the thermistor at the reference temperature of 25°C is calculated from **Equation # 1** which is repeated below:

$$R = \frac{\rho \times T}{L \times W} \quad \text{ohms}$$

Equation #1: (Resistance formula repeated)

Where: **R** is the resistance of the component in ohms.

ρ is the material resistivity in ohm-cm

T is the thickness of the component (cm). (This dimension represents the current path through the thermistor.).

L is the length of the metalized surface of the thermistor (cm).

W is the width of the metalized surface of the thermistor (cm).

While the equation represents a common calculation in general electronic applications, it is a very important one in the Thermistor industry, in particular where the dimensions of the component are critical. It can be used to determine the dimensional options available to produce the required thermistor. It is very important in the use of equation 1 to maintain consistency of measurement units.

Example: Calculate the resistance at 25°C of a thermistor chip made from *BetaTHERM's* Curve 3 Material. The resistivity of the material is 3300 ohm-cm (at 25°C) and the chip dimensions are 0.04" x 0.04" x 0.01" thick.

$$R = \frac{3300(\text{ohm-cm}) \times 0.01(\text{inches}) \times 2.54 (\text{cm/inch})}{(0.04 (\text{inches}) \times 2.54 (\text{cm/inch}) \times 0.04 (\text{inches}) \times 2.54 (\text{cm/inch}))}$$

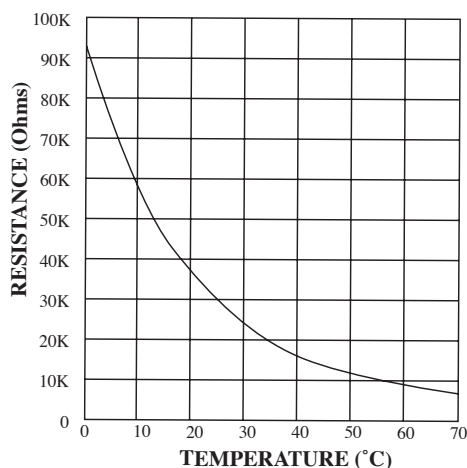
$$R = \frac{33}{0.004064} = 8120 \text{ ohms}$$

The required resistance and resistivity for a given material dictate the realistic size of the finished product. For instance, a thermistor made from *BetaTHERM's* material curve # 3 can have a practical resistance range, at 25°C, from 2000 ohms to 100000 ohms. Values outside this resistance range are not practical to produce because of the calculated size of the thermistor element.

The 2000 ohm thermistor has a calculated size of approximately (0.070" x 0.050" x 0.006" thick) and the 100000 ohm thermistor has a calculated size of approximately (0.014" x 0.014" x 0.015" thick). The sizes are feasible to manufacture, but are at the limits where chip handling becomes difficult.

The discussion so far has effectively considered the resistance of thermistors at a **single temperature point**. The next stage in understanding thermistor operation is to consider the electrical behaviour over an **extensive temperature range**.

The Resistance-Temperature Characteristics for a common thermistor (30K5) are displayed in **Graph 1** below over a range from 0°C to 70°C.



Graph # 1

Slope: (Resistance Ratio)

In considering the relationship between **resistance** and **temperature** of thermistors there are some important concepts that are used in the thermistor industry. One such concept is **slope**, which is an indication of the rate of change of the resistance of the component with temperature.

The slope or resistance ratio for thermistors is defined as the ratio of resistance at one temperature (usually 0°C) to the resistance at a second and higher temperature (usually 70°C).

Specified slope (resistance ratio) information for *BetaTHERM* standard thermistor materials at temperatures 0/50°C, 0/70°C and 25/125°C are listed on page 50.

The concept of resistance / slope is demonstrated in **Graph # 2**, (next page), where the 0/70°C slope line connects the resistance value at 0°C to the resistance value at 70°C. This provides an indication of the rate of change of resistance with temperature and the potential thermal sensitivity of the component.

Slope measurements are used as a qualification step in the process of manufacturing "chip" thermistors. This is a monitoring step at an early stage of the process to ensure that the thermistor material will meet required specifications.

The following example illustrates how the slope value of a thermistor can be calculated using the Resistance versus Temperature tables provided in the catalog.

Slope: (Resistance Ratio) Example of calculations:

For *BetaTHERM's* 30K5 thermistors (which have a nominal resistance of 30000 ohms at 25°C) (Curve 5 Material) the nominal R_0/R_{70} ratio will equal 17.73

Per the R-T tables on pages 43 to 47 the nominal 30K5 resistance at 0°C = 94980 ohms and the nominal resistance at 70°C = 5358 ohms:

$$\frac{R_0}{R_{70}} = \frac{94980 \text{ ohms}}{5358 \text{ ohms}} = 17.7267 = 17.73$$

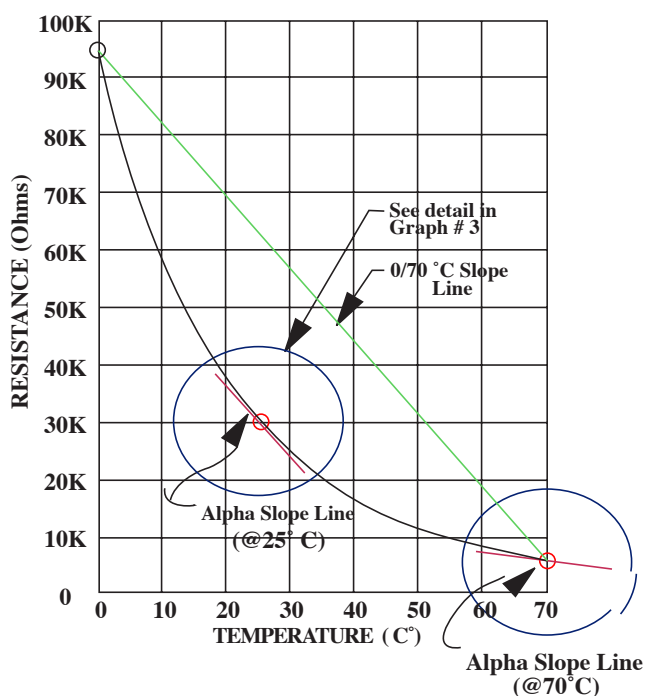
Slope or resistance ratio provides an introduction to the concept of rate of change of resistance with temperature and the sensitivity of the resistance of thermistors to temperature change. This concept is developed further by considering the more general case of thermal sensitivity in terms of percentage resistance change of a component per degree centigrade increase in temperature.

In the thermistor industry, this topic is dealt with by the definition of a material parameter known as **Alpha (α)**

Alpha (α) (Temperature coefficient): Alpha, a material characteristic, is defined as the percentage resistance change per degree Centigrade. Alpha is also referred to as the temperature coefficient. For Negative Temperature Coefficient (NTC) Thermistors, typical values of alpha are in the range $-3\%/^{\circ}\text{C}$ to $-6\%/^{\circ}\text{C}$. The temperature coefficient is a basic concept in thermistor calculations.

Because the resistance of NTC thermistors is a nonlinear function of temperature, the alpha value of a particular thermistor material is also nonlinear across the relevant temperature range, as illustrated in **graph # 2** below.

**Curve for 30K5 Thermistor
0 $^{\circ}\text{C}$ to 70 $^{\circ}\text{C}$ Range with Slope and Alpha details.**



Graph # 2

For example, BetaTHERM's Standard Curve 5 thermistor material has an alpha of $-4.30\%/^{\circ}\text{C}$ at 25°C , and an alpha of $-3.42\%/^{\circ}\text{C}$ at 70°C . The alpha value is a material constant and is independent of the resistance of the component at that temperature.

Calculation of alpha values:

The relevance of alpha values to the Resistance vs Temperature curve of particular material is illustrated in

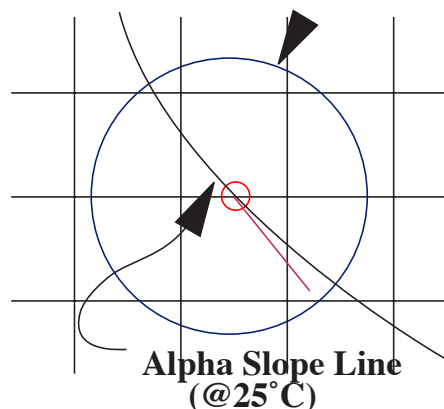
Graph # 3. In this graph, a tangent line is drawn along the R-T curve at 25°C . This line represents the gradient or "steepness" of the curve at 25°C . From the definition of Alpha given above, it may be calculated as follows :

$$\alpha = \frac{1}{R_T} \times \frac{dR}{dT} \times 100 \text{ (\% / } ^{\circ}\text{C)}.$$

(Equation # 3) Definition of Alpha:

Where R_T is the resistance of the component at the relevant temperature T ($^{\circ}\text{C}$), dR/dt is the gradient of the Resistance vs Temperature curve at that temperature point, and **alpha** is expressed in units of "percentage change per degree Centigrade". (*Note:* In some texts the "100" term is omitted from the equation, but it is understood or implied in the units in which alpha values are specified.)

**Detail from Graph # 2 showing Alpha Slope Line of the
30K5 Thermistor @ 25°C .**



Graph # 3

The purpose of the concepts that have been introduced and discussed so far is to enable some basic calculations to be performed. The most important calculations required in the thermistor industry are those that relate the resistance of thermistor components to their temperature. An example illustrating typical use of alpha value to do this is given next:

Example:

A thermistor made from BetaTHERM material 3 has a resistance of 10000 ohms at 25°C . The alpha value for this material at 25°C is listed in the catalog to be $-4.39\%/^{\circ}\text{C}$. If

the resistance of the device in a stable environment at ideal measurement conditions (discussed later) is measured as 10200 ohms, what temperature is the device at ?

By re-writing Equation 3 in the form:

$$\alpha = \frac{1}{RT} \times \frac{\Delta R}{\Delta T} \times 100$$

where $\Delta R/\Delta T$ is used as an approximation for the true derivative dR/dt , the reference temperature is 25°C , on re-arranging, the equation becomes:

$$\Delta T = \frac{\Delta R}{RT} \times \frac{100}{\alpha}$$

Inserting the numerical values given above, the value for ΔT , the temperature difference from 25°C , is given by :

$$\Delta T = \frac{200}{10000} \times \frac{100}{-4.39} = -0.456^{\circ}\text{C}$$

so that the temperature of the thermistor is:
 $(25^{\circ}\text{C} - 0.456^{\circ}\text{C}) = 24.554^{\circ}\text{C}$

The example is applicable for certain thermistor resistance and temperature calculations. In particular, because of the approximation used for the differential of the R / T curve, it is **of relevance for small percentage changes in resistance around the temperature value for which the particular alpha value is quoted.**

The alpha value is a very useful parameter provided it is used in a logical way and that it is applied with the constraints in mind.

Limitations in the use of temperature coefficients:

The approach of using temperature coefficient values is adequate provided that accurate alpha values and resistance values are available for a range of temperature points for the thermistor materials. Tables of alpha values for various temperature points for various BetaTHERM NTC thermistor materials are given in this catalog. The use of such look-up tables and substitution in equation 3 are useful for initial selection of thermistors for applications. The method is somewhat slow and highlights the need for a **mathematical model** that can be used to relate the resistance and temperature of thermistors by a single equation. The need for such a model is especially relevant to allow computation of R/T values using modern calculators, computers or microcontrollers.

To discuss the issue further it is instructive to look at a typical NTC thermistor R/T curve, as shown in graph #1 on page 8. The curve is non-linear, and that presents certain difficulties in developing a useful model. Modelling of the R/T curve is discussed in the next section of the catalog.

Modelling of Conduction in Thermistors:

A plot of Resistance vs Temperature for a typical NTC Thermistor is shown in **graph # 1**, on page 8. The relationship between Resistance and Temperature is non-linear so modelling this relationship physically and mathematically can be a complex procedure.

In considering **modelling** the Resistance versus Temperature characteristics of NTC thermistor devices it is useful to briefly review some of the principles of **solid state physics** associated with NTC thermistor materials. At this stage the reader may proceed directly to **page 13** where modelling equations are listed if an overview of the modelling process is not required.

Detailed descriptions of the electrical conduction mechanism for metal-oxide thermistor materials are beyond the scope of this catalog, but a brief overview is adequate to outline some concepts here.

The exact conduction mechanisms are not fully understood. The metal oxide NTC thermistors behave like **semiconductors**, as shown in the decrease in resistance as temperature increases.

The **physical models** of electrical conduction in the major NTC thermistor materials are generally based on one of two theories. Detailed treatment of these models can be found in reference books on ceramic materials. Brief summaries of these theories are outlined below.

A model of conduction called **"hopping"** is relevant for some materials, especially ferrites and manganites that have a spinel crystal structure. It is a form of Ionic conductivity where ions (oxygen ions) "hop" between point defect sites in a spinel crystal structure. The probability of point defects in the crystal lattice increases as temperature increases, hence the "hopping" is more likely to occur and so material resistivity decreases as temperature increases.

A second model of conduction is based **on the band gap model of solid state physics**. This model is of particular relevance in the semiconductor industry for materials like Silicon and Gallium-Arsenide. This model describes the availability of charge carriers in terms of the distribution of physical impurities in the crystal lattice. This model works very well for materials like Silicon which can be produced in monocrystalline structures with a high degree of purity. The silicon can then be "doped" with required impurities like Boron or Phosphorous to produce materials with characteristics that can be modelled mathematically, from basic theoretical principles, with accuracy.

For metal oxide thermistors the crystal structure is much more complex. The material structure is polycrystalline and granular. The materials are composed of several metal oxide components and are generally very difficult to model from basic principles.

The approach that is used for predicting the behaviour of thermistor materials, is to make accurate measurements of Resistance and Temperature of components and to apply curve fitting techniques to model the relationship between them. The physical models of conduction are used in conjunction with this approach to provide direction in developing the mathematical models.

Mathematical Modelling of Thermistors:

One of the core physical assumptions of the band gap theory of solid state physics is that charge carrier concentration has an exponential dependence on absolute temperature. The charge carriers can be either negatively charged (n-type) electrons, or positively charged (p-type) holes. The p-type conduction mechanism is the trapping of electrons by fixed positively charged sites. The electrons move between these sites so that the **net effect** is that of mobile positively charged carriers moving in an electric field, in the opposite direction to negatively charged electrons.

It can be demonstrated theoretically from the chemical composition of the components and experimentally from Hall effect measurements that the metal oxide thermistor materials are p-type semiconductors. More details on the determination of carrier types can be found in reference text books on ceramic materials.

The expression for the density of carriers available in "ideal" semiconductor material can be derived directly from application of **Quantum Mechanics** to Solid State theory. This involves applying the **Fermi-Dirac** distribution to the calculation of energy states for charge carriers in the material. The process leads to an equation that describes the intrinsic carrier density in terms of some material constants and physical constants. The results derived in this way are expressed in an equation of the form:

$$n_i \propto \exp(-1/(2kT))$$

Where : n_i is the intrinsic carrier density in appropriate units
 T is the absolute temperature in Kelvin.
 k is Boltzmann's constant (1.38066×10^{-23}) J/K

Further analysis of "ideal" semiconductor materials using principles of solid state physics relates the electrical resistivity of the material to the carrier density. The resulting expression is in the form of :

$$\rho \propto 1/n_i \Rightarrow \rho \propto \exp(1/(2kT))$$

Where ρ is the material resistivity, in appropriate

units, such as ohm-cm.

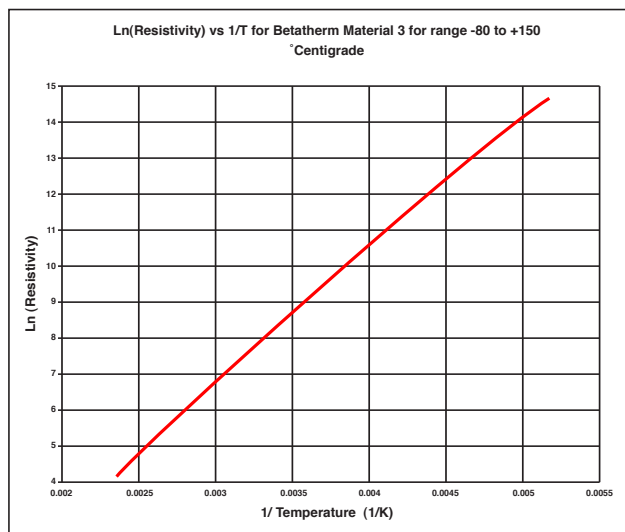
The equation can be reduced to a simpler format by writing it as:

$$\rho \propto \exp(1/T)$$

This equation relates the resistivity of semiconductor material to the exponential of the reciprocal of absolute temperature, directly from fundamental principles of solid state physics.

As stated previously, an equation of this form is relevant for an "ideal" material with a regular crystal structure. Although the metal oxide thermistor materials are not "ideal", intuition based on the foregoing discussion would suggest that there should be an **exponential** aspect to the relationship between **material resistivity and the reciprocal of absolute temperature**.

Inspection of a graph of the natural log of measured Resistivity values versus the reciprocal of absolute temperature for thermistor materials, indicate that such a model is appropriate.



Graph # 4

The Resistance (R) of a piece of material of resistivity ρ (ohm-cm) is proportional to this resistivity value.

$$R = \rho \times (t/A)$$

where: R is the resistance in ohms,
 t is thickness of the material (length of current path),
 A is the cross-sectional area.

It follows that the expression for resistance as a function of temperature can be stated as:

$$R_T \propto \exp(1/T)$$

Where R_T denotes Resistance in ohms at temperature T Kelvin.

Exponential Model of NTC Thermistors: 0/50 Beta Value (β) or Sensitivity Index:

As outlined in the previous section, a simple approximation for the relationship between Resistance and Temperature for an NTC thermistor assumes an exponential relationship between them. This approximation is based on simple curve fitting to experimental data and also on an intuitive feel for electrical behaviour of semiconductor devices.

The exponential approximation is a mathematical model that applies an equation that can be expressed in the form:

$$R_T = A \exp(\beta/T) \quad \text{..... (equation \# 4)}$$

Where:

R_T is the Resistance in ohms at temperature T

T is the absolute Temperature in Kelvin

A is a linear factor

"exp" is the exponential function

β is the exponential factor known as "beta" value or sensitivity index of the thermistor material.

The β value is a very important parameter in the description and specification of thermistor materials and thermistor components. When the natural log of both sides of the equation is taken, the relationship becomes:

$$\ln(R_T) = C + (\beta/T) \quad \text{..... (equation \# 5)}$$

Where C is a constant factor, ($C = \ln(A)$) from the equation above.

If $\ln(R_T)$ is plotted versus $1/T$, (as in graph #4) then the **slope** of the resulting curve will be equal to **beta**, β .

This equation provides a reasonable approximation to measured data, but as mentioned in the previous section, the thermistor materials are not ideal materials. For the exponential model to apply over a large temperature range (greater than 50 °C) the beta value has to vary, therefore the beta value is not constant over extensive ranges. In fact, **the beta value is also temperature dependent and it decreases with temperature.**

Although this simple exponential model for the relationship between Resistance and Temperature of a

thermistor is limited over large temperature spans, concepts derived from it are of importance in the thermistor industry and in the specification of NTC thermistors. Some of these concepts are developed in the following sections with the intention of explaining some of the basic calculations and specifications used in the industry.

Practical application of the beta value:

It is common practice to specify thermistor materials in terms of beta value over a particular temperature span.

For a temperature T_1 and thermistor resistance R_1 at this temperature T_1 : $R_1 = A \exp(\beta/T_1)$.

For a temperature T_2 and thermistor resistance R_2 at this temperature T_2 : $R_2 = A \exp(\beta/T_2)$

Taking the ratio: $R_1 / R_2 = \exp(\beta(1/T_1 - 1/T_2))$

The expression for β then becomes:

$$\beta = \frac{1}{1/T_1 - 1/T_2} \times \ln(R_1 / R_2) \quad \text{..... (equation \# 6)}$$

Where:

β has units of temperature (Kelvin)

"ln" represents the natural logarithm (log base e) inverse of the exponential function.

In this form, published beta values can be used to calculate resistance or temperature values when other items in the equation are known.

The beta value can then be regarded a quantitative value of thermistor materials that is assigned as a material constant and that indicates the relationship of material resistivity to temperature.

Application of the beta value is demonstrated in a numerical example at the end of this section.

The general information on sensitivity of material resistivity to temperature that can be interpreted from the beta value is indicated in **Graph # 5**. This shows the resistivities of BetaTHERM's Standard Thermistor Materials versus their 0/50 °C Beta Values.

BetaTHERM Sensors

The beta value is derived from a mathematical approximation. For this mathematical approximation to apply over a large temperature range, beta has to vary with temperature. This variation of beta value with temperature is indicated in **Graph # 6**. The variation is greater at the low temperature end of the curve. This variation should be borne in mind when using beta values for calculations over temperature ranges.

Because the beta value is an indication of the relationship between the resistivity of thermistor material and temperature, it can also be used to calculate alpha (α) value (temperature coefficient) for a thermistor made from the same material. *Recalling the definition of the alpha value as the percentage change in resistance per °C, given by equation # 3*

$$\alpha = \frac{1}{R_T} \times \frac{dR_T}{dT} \times 100 \text{ (\% per } ^\circ\text{C)}.$$

and, expressing R as a function of T using the exponential model, it can be shown that a good approximation for the temperature coefficient or alpha value, at a temperature T Kelvin, in terms of beta is :

$$\alpha = -\frac{\beta}{T^2} \times 100 \text{ (\% per } ^\circ\text{C)}. \text{ (equation \# 7)}$$

The beta value is a single expression that can be regarded as a **material** constant. It depends on basic material properties, and beta values derived from measurements provide an indication of general thermistor material quality.

Although deviations in beta value from nominal values affect the tolerance of thermistors and are indicative of material quality, such deviations are not widely published by thermistor manufacturers. Typically, manufacturers will list the nominal Beta Value only or will list the nominal Beta Value with a tolerance expressed in K.

BetaTHERM provide information on beta value deviations for the range of thermistor materials that it produces. This information is contained in **Table # 2**. This lists the beta values and deviations for high precision BetaCURVE thermistors and includes data for low precision tolerance BetaCHIP thermistors also.

Graphs of Material resistivity versus Beta value, and Beta Value versus temperature are included also to illustrate how Beta is regarded as a material characteristic that is related to resistivity. The relationship between Beta value and temperature shows the temperature regions for which Beta value is approximately constant for different

materials.

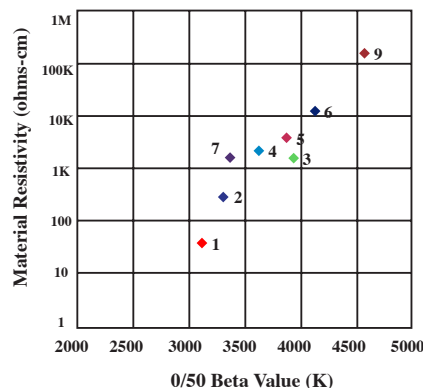
Sample calculations are included in this section also to illustrate some typical engineering uses of beta values.

Beta Values and tolerances for BetaCURVE and BetaCHIP series Thermistors.

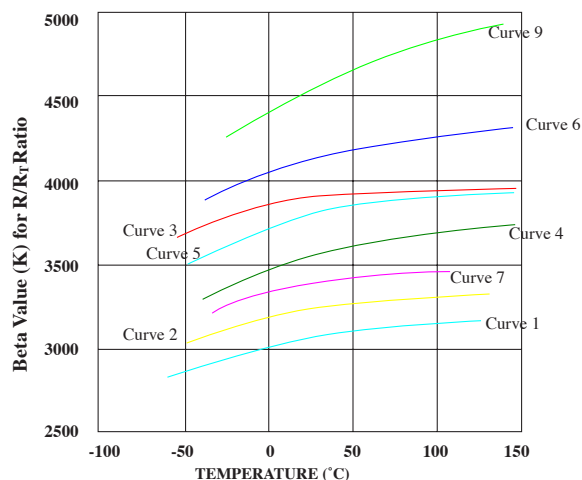
Material Curve #	0/50 Beta Value (K)	
	BetaCURVE	BetaCHIP
1	3108 +/-0.40%	3108 +/-1.7%
2	3263 +/-0.38%	3263 +/-0.9%
3	3892 +/-0.32%	3892 +/-1.0%
4	3575 +/-0.30%	3575 +/-1.0%
5	3811 +/-0.33%	3811 +/-0.9%
6	4143 +/-0.30%	4143 +/-1.3%
7	3422 +/-0.36%	3422 +/-1.0%
9	4582 +/-0.63%	4582 +/-1.9%

Table # 2

Material Resistivity vs. Beta Value for BetaTHERM Thermistor Materials (Curves)



Graph # 5



Beta Values vs. temperature for Betatherm Materials

Graph # 6

Examples of calculations using Beta values:

(The 0/50 Beta value means a Beta value calculated from resistance data at 0°C and at 50°C)

Example: Calculate the 0/50 Beta value for BetaTHERM's 30K5A1 thermistor, given the following information:

R₁ is resistance value measured at T₁, 0°C = 94980 ohms

R₂ is resistance value measured at T₂, 50°C = 10969 ohms

The relevant formula for calculating the beta value is:

$$\beta = \frac{1}{1/T_1 - 1/T_2} \times \ln(R_1 / R_2)$$

Where:

β has units of temperature (Kelvin)

ln represents the natural logarithm (log base e)

inverse of the exponential function.

Temperatures are expressed in Kelvin.

This can then be written as:

$$\begin{aligned} \beta_{0-50} &= \frac{1}{1/273.15 - 1/323.15} \times \ln(94980 / 10969) \\ &= 1765.36847706 \times 2.1587611778 \\ \Rightarrow \beta_{0-50} &= \mathbf{3811 \text{ K}} \end{aligned}$$

Since the Beta value of a thermistor material is derived from an exponential model, it can also be used to

calculate resistance values of a thermistor at a particular temperature when the resistance at another temperature is known. This is demonstrated in the following example:

Example: Calculate the resistance of a BetaTHERM 10K3 thermistor at 33°C using the following information:

The resistance of the thermistor at 25 °C is 10000 ohms, the 0-50 Beta value is 3892 K

Using the equation:

$$R_1 / R_2 = \exp(\beta (1/T_1 - 1/T_2))$$

and writing it in the form:

$$R_2 = R_1 / (\exp(\beta (1/T_1 - 1/T_2)))$$

where **T₁ = 25°C = 298.15 K**, **R₁ = 10000 ohms**,
T₂ = 33°C = 306.15 K, **β = 3892 K**

Using these values, the value of R₂ is calculated as:

$$R_2 = 10000 / (\exp(0.3411094421367))$$

Resistance at 33°C calculated using Beta value:

$$R_2 = \mathbf{7109.81 \text{ ohms.}}$$

The value of resistance of a 10K3 device that is published in the R / T tables in this catalog is **7097.2 ohms**. The sensitivity of the resistance of the device to temperature in this region is 304 ohms per °C. The difference between the published resistance value and the resistance value that is calculated using the beta value is equivalent to **.04 °C**.

Using the Beta 0-50 value in the range 0-50 °C, the maximum errors are at the ends of the range, and are of the order of **0.22 °C**.

When the **tolerance of the Beta value** is taken into account, then the errors at the ends of the range for **material 3 BetaCHIP** products are of the order of **0.45 °C**, while the errors at the ends of the range for **material 3 BetaCURVE** products are of the order of **0.29 °C**.

The main purposes of these examples were :

- To show some typical uses of Beta values in calculations.
- To demonstrate the difference between BetaCHIP and BetaCURVE product. In particular to show that the tighter tolerance BetaCURVE product has lower errors than the BetaCHIP product in converting from Resistance to temperature using the exponential model.
- To establish the relevance of Beta as a material characteristic.
- To show some of the limitations of the exponential model so that **further modelling** of the R / T characteristics of thermistors can be considered.

Further Modelling of NTC Thermistor R/T Characteristics:

The concepts introduced so far to relate the resistance of a thermistor to the temperature have been primarily based on the characterization and specification of **materials** and on the use of material parameters rather than on **component** parameters.

While the **temperature coefficient or alpha value** can be used to calculate the temperatures corresponding to various resistance values of a thermistor, the method is rather limited. A look-up table of Resistance versus Temperature values for the thermistor is required and details of alpha values at various points are needed also. It is very useful and relevant in certain situations.

The use of **Beta Values or sensitivity index**, and the associated exponential model are useful for material specification, and for the comparison of the sensitivity of bulk materials. The method is somewhat limited for general use in relating the resistance of a thermistor to temperature over extensive ranges mainly because of the temperature dependence of the Beta Value itself.

In general applications NTC thermistors are used to measure temperature, and this is accomplished by measuring the resistance of the thermistor and then using that resistance value to make an estimate of temperature. The various means of relating resistance of a thermistor to the temperature that have been discussed so far are not ideally suited to this, as outlined above. **The requirement is for a single equation that can be used easily to relate resistance and temperature of thermistors.** The requirement is all the more important to optimize the use of programmable calculators, computer spreadsheets and microcontrollers.

Because the conduction mechanism in metal oxide semiconductors is a complex one, it is difficult to explain accurately by applying mathematics to a physical model. **The method used for accurate mathematical modelling of the Resistance versus Temperature characteristic of a thermistor is to obtain accurate measurements of Resistance and Temperature of components and to apply curve fitting techniques to model the relationship between them.**

The next section of this catalog describes the mathematical model, which is in general use throughout the industry, to give a single equation that relates the Resistance and Temperature of an NTC thermistor component. The equation is called the **Steinhart-Hart Equation**, and it is used by all thermistor manufacturers.

The Steinhart-Hart Thermistor Equation:

The Steinhart-Hart thermistor equation is named for two oceanographers associated with Woods Hole Oceanographic Institute on Cape Cod, Massachusetts.

The first publication of the equation was by **I.S. Steinhart & S.R. Hart** in "**Deep Sea Research**" vol. 15 p. 497 (1968).

The equation is derived from mathematical curve-fitting techniques and examination of the Resistance versus Temperature characteristic of thermistor devices.

In particular, using the plot of the natural log of resistance value, **ln(R)** versus **(1/T)** for a thermistor component to consider **(1/T)** to be a polynomial in **ln(R)**, an equation of the following form is developed:

$$\frac{1}{T} = A_0 + A_1(\ln(R)) + \dots + A_N(\ln(R))^N$$

(where T is the temperature in Kelvin, and $A_0 \dots A_N$ are polynomial coefficients that are mathematical constants.)

The order of the polynomial to be used to model the relationship between R and T depends on the accuracy of the model that is required and on the non-linearity of the relationship for a particular thermistor.

It is generally accepted that use of a third order polynomial gives a very good correlation with measured data, and that the "squared" term is not significant.

The equation then is reduced to a simpler form, and it is generally written as:

$$\frac{1}{T} = A + B(\ln(R)) + C(\ln(R))^3$$

Equation # 8

where: A, B, and C are constant factors for the thermistor that is being modelled.

This is the Steinhart-Hart equation, with Temperature as the main variable.

The equation is presented explicitly in resistance on page 19, which is a summary page of information on the Steinhart-Hart equation. Before summarizing the situation, some general points of relevance in understanding the practical issues associated with it are discussed:

BetaTHERM Sensors

The equation is relevant for the complete useful temperature range of a thermistor.

The coefficients A, B, and C are constants for the **individual** thermistors. Unlike Alpha and Beta they should **not be regarded as material constants**.

The A, B, and C constants are established for individual thermistors in a particular temperature range as follows:

The equation is considered for three temperature points in the range – usually at the low end, the middle and the high end of the range. This ensures best fit along the full range. (The smaller the temperature range, the better the calculations will match measured data.) The temperature values are usually taken to be 0°C, 25 °C and 70 °C therefore these values are used to illustrate the principle.

Precisely controlled measurements of temperature and associated resistance value of the thermistor are made in a temperature controlled medium at these three calibration points.

These accurately measured values of Resistance and Temperature are inserted into the equation to form three simultaneous equations as follows: (**note: 0°C = 273.15K**)

$$\frac{1}{T_0} = \frac{1}{273.15} = A + B(\ln(R_0)) + C(\ln(R_0))^3$$

$$\frac{1}{T_{25}} = \frac{1}{298.15} = A + B(\ln(R_{25})) + C(\ln(R_{25}))^3$$

$$\frac{1}{T_{70}} = \frac{1}{343.15} = A + B(\ln(R_{70})) + C(\ln(R_{70}))^3$$

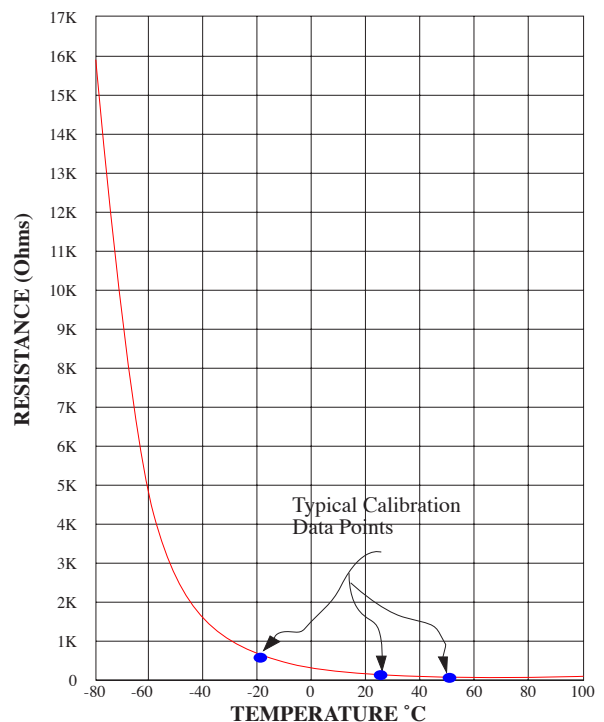
Since the resistance values are measured numerical quantities, the equations are a system of three simultaneous equations in three unknowns namely A, B and C. The values for A, B and C can be found by standard mathematical techniques for solving simultaneous equations, or by use of analytical software tools.

This is a brief summary of the origins and techniques used to derive the A, B and C coefficients for thermistor components. These values are sometimes referred to as the "Steinhart Coefficients" for a thermistor. Thermistor manufacturers publish data for these coefficients for their thermistor products. Values of the Steinhart Coefficients for *BetaTHERM* products are listed on page 19 of this catalog.

Software is available at *BetaTHERM* to calculate the Steinhart coefficients for thermistors measured at calibration points other than the standard ones used in the example. This is useful when modelling thermistors over limited ranges or when using customized thermistor components.

It should be noted that the Steinhart-Hart equation produces a good approximation to the relationship between T and R for the complete range of a thermistor based on data from just three calibration points.

R-T Graph for BetaTHERM part # 0.1K1A Thermistors. Full Temperature range from -80 °C to +100 °C Maximum.



Graph # 7

Because the Steinhart-Hart equation is a mathematical approximation, it is instructive to do some calculations using the equation for a thermistor and to compare the resulting temperature or resistance values with the published R / T data in the catalog. The published R / T tables are based on actual measurements, but the difference between values calculated from the Steinhart-Hart equation and the published data should typically be less than $\pm 0.01^{\circ}\text{C}$.

This is illustrated for a 10K3 device over a limited range in the table on this page. The table was generated by using the published Resistance versus Temperature data for this device, and inserting the Resistance values into the Steinhart-Hart equation to calculate the Temperature. This calculated Temperature can then be compared with the reference Temperatures at which the resistance was measured.

Relevant information for the practical use of the Steinhart-Hart equation to model thermistors is given on page 19. This includes a statement of the equation explicitly in resistance form and a listing of the Steinhart coefficients for a range of *BetaTHERM* components.

It should be noted that Steinhart-Hart coefficients that are in the summary table on page 19 were not all derived from measurements at 0°C , 25°C and 70°C . For devices with higher resistance values (for example 1M9A1), which are generally used at higher temperatures, the Steinhart-Hart coefficients were derived from measurements at 25°C , 100°C and 150°C . These temperature values are more representative of the temperature range where these thermistors are used. The values of the calibration temperatures are included in the table.

The Steinhart-Hart equation is a very useful means of modelling the Resistance versus Temperature characteristics of a Thermistor but it should be remembered that it provides good correlation with actual measurements for a thermistor in ideal measurement conditions. This concept of "ideal" measurement conditions and factors that affect the measured value of resistance of a thermistor is explained in the sections of the catalog that follow the summary page relating to the Steinhart-Hart equation.

Comparison of actual (measured) data and calculated temperature values using measured resistances in Steinhart-Hart equation for BetaTHERM 10K3 device:

Measured Resistance (Ohms)	Actual Temperature ($^{\circ}\text{C}$)	Temperature Calculated ($^{\circ}\text{C}$)
49633.00	-8	-7.999
47047.00	-7	-6.999
44610.00	-6	-5.999
42314.60	-5	-5.000
40149.50	-4	-4.000
38108.50	-3	-3.000
36182.80	-2	-2.000
34366.10	-1	-1.000
32650.80	0	-0.001
31030.40	1	1.000
29500.10	2	2.000
28054.20	3	3.000
26687.60	4	3.999
25395.50	5	4.999
24172.70	6	5.999
23016.00	7	7.000
21921.70	8	7.999
20885.20	9	8.999
19903.50	10	9.999
18973.60	11	10.999
18092.60	12	11.999
17257.40	13	12.999
16465.10	14	13.999
15714.00	15	14.999
15001.20	16	15.999
14324.60	17	17.000
13682.60	18	17.999
13052.80	19	19.033
12493.70	20	19.999
11943.30	21	20.999
11420.00	22	22.000
10922.70	23	23.000
10449.90	24	24.000
10000.00	25	25.000

Summary of Steinhart-Hart equation for modelling Resistance vs. Temperature characteristics of thermistors:

(In the listings below A, B, and C are constant factors for the thermistor, R is resistance in ohms, T is temperature in Kelvin.)

Steinhart-Hart Equation with temperature as main variable:

$$\frac{1}{T} = A + B(\ln(R)) + C(\ln(R))^3 \quad \text{..... Equation \# 8 (repeated)}$$

Steinhart-Hart Equation in terms of Resistance, suitable for programmable computation.

$$R = \exp \left[\sqrt[3]{ - \left[\frac{(A - T^{-1})}{C} + \sqrt[2]{ \left[\frac{(A - T^{-1})^2}{C^2} + \frac{(B/C)^3}{27} \right] } \right] } + \sqrt[3]{ - \left[\frac{(A - T^{-1})}{C} - \sqrt[2]{ \left[\frac{(A - T^{-1})^2}{C^2} + \frac{(B/C)^3}{27} \right] } \right] } \right]$$

Equation # 9

BetaTHERM Steinhart Coefficients , A, B and C constants for Standard Part Numbers.

Part No.	"A" Constant	"B" Constant	"C" Constant	Temperature reference points °C
0.1K1A	1.942952 x 10 ⁻³	2.989769 x 10 ⁻⁴	3.504383 x 10 ⁻⁷	-20°C, 25 °C and 50 °C
0.3K1A	1.627660 x 10 ⁻³	2.933316 x 10 ⁻⁴	2.870016 x 10 ⁻⁷	-20°C, 25 °C and 50 °C
1K2A	1.373168 x 10 ⁻³	2.772261 x 10 ⁻⁴	1.997412 x 10 ⁻⁷	-20°C, 25 °C and 50 °C
1K7A	1.446059 x 10 ⁻³	2.683626 x 10 ⁻⁴	1.643561 x 10 ⁻⁷	-20°C, 25 °C and 50 °C
2K3A	1.498872 x 10 ⁻³	2.379047 x 10 ⁻⁴	1.066953 x 10 ⁻⁷	0°C, 25 °C and 70 °C
2.2K3A	1.471388 x 10 ⁻³	2.376138 x 10 ⁻⁴	1.051058 x 10 ⁻⁷	0°C, 25 °C and 70 °C
3K3A	1.405027 x 10 ⁻³	2.369386 x 10 ⁻⁴	1.012660 x 10 ⁻⁷	0°C, 25 °C and 70 °C
5K3A	1.287450 x 10 ⁻³	2.357394 x 10 ⁻⁴	9.505200 x 10 ⁻⁸	0°C, 25 °C and 70 °C
10K3A	1.129241 x 10 ⁻³	2.341077 x 10 ⁻⁴	8.775468 x 10 ⁻⁸	0°C, 25 °C and 70 °C
10K4A	1.028444 x 10 ⁻³	2.392435 x 10 ⁻⁴	1.562216 x 10 ⁻⁷	0°C, 25 °C and 70 °C
30K5A	9.331754 x 10 ⁻⁴	2.213978 x 10 ⁻⁴	1.263817 x 10 ⁻⁷	0°C, 25 °C and 70 °C
30K6A	1.068981 x 10 ⁻⁴	2.120700 x 10 ⁻⁴	9.019537 x 10 ⁻⁸	0°C, 25 °C and 70 °C
50K6A	9.657154 x 10 ⁻⁴	2.106840 x 10 ⁻⁴	8.585481 x 10 ⁻⁸	0°C, 25 °C and 70 °C
100K6A	8.271111 x 10 ⁻⁴	2.088020 x 10 ⁻⁴	8.059200 x 10 ⁻⁸	0°C, 25 °C and 70 °C
1M9A	7.402387 x 10 ⁻⁴	1.760865 x 10 ⁻⁴	6.865999 x 10 ⁻⁸	25°C, 100°C and 150°C

Table # 3

Factors affecting measured resistance values of Thermistors:

In the notes relating to the use of published data tables for resistance versus temperature of Thermistors and to the use of the Steinhart-Hart equation, reference was made to "ideal" measurement conditions for determining the resistance of a thermistor. The following section discusses factors that affect the measured resistance value of a thermistor. These factors are associated with thermistor properties or characteristics that are the basis of general thermistor applications.

It is essential that developers of thermistor circuits have an understanding of these characteristics to exploit relevant thermistor properties in a particular application and to minimize the influence of other properties that could adversely affect thermistor performance in the application.

Self Heating effect of Thermistors:

To fully avail of the information in the published tables of Resistance versus temperature for thermistors and to optimize the accuracy of the Steinhart-Hart Equation it is essential to consider the **electrical power levels** in the thermistor during measurements. When the resistance of a thermistor is being measured there is a voltage across it and a current passing through it (from Ohm's Law).

Ohms Law states that for a resistive component: $V = I \times R$

where, V is the voltage across the component in Volts,

I is the current through the component in Amps

R is the resistance of the component in Ohms.

The power in the component is defined as the product of the current and voltage: $P = I \times V$

where P is the **power** in **Watts**, I is in Amps, V is in Volts.

This power is dissipated in the component, and for a thermistor the power causes heating of the thermistor. The heating effect in turn causes the resistance of the thermistor to decrease. **This power dissipation is known as self-heating of the thermistor.**

If the power levels are moderate (of the order of several milli-Watts (mW)), the self-heating will not continue indefinitely, because the thermistor will reach thermal equilibrium with it's environment. The stage at which this equilibrium is reached depends on the thermal characteristics of the system.

It should be noted that when this "steady" state is reached, the resistance of the thermistor will not accurately represent the temperature of it's environment. Instead, the resistance of the thermistor will be lower than expected, because of the self heating effect. To obtain a resistance reading from the thermistor that accurately represents the

temperature of it's environment it is critical that the power levels (essentially the current levels) associated with the measurement are low enough not to cause appreciable self heating.

The self heating effect should be considered in all thermistor applications and even in basic resistance measurements using a digital ohm-meter (multi-meter). Most manufactures of measuring instruments specify the magnitude of current used on the various resistance measuring ranges and it is important to be aware of these values in performing resistance measurements on thermistors.

The self-heating effect is a disadvantage in attempting to make accurate resistance measurements, but it is the basis of other applications. These applications are discussed in a later section of the catalog.

Because the self-heating effect can influence the measured resistance value of a thermistor it is important to quantify it in some manner. This is done by using the concept of **"Zero-power resistance characteristic."**

Zero-power resistance characteristic

The "zero-power resistance characteristic" is a description of "ideal" conditions for resistance measurement - it can be defined as follows:

The Zero-Power Resistance (R_0) at a specific temperature T , is the measured DC (Direct Current) resistance when the power dissipation is negligible.

Mil-T-23648 considers the power to be negligible when "any further decrease in power will result in not more than a 0.1% change in resistance".

In practical terms, a thermistor is generally considered to be dissipating Zero-power when the current through it is less than **100 micro-Amps (μA)**. On modern multimeters resistance measurements in the kilo-Ohm range can be performed with adequate resolution (± 0.1 Ohm) with measuring currents of the order of tens of micro-amps. There is generally a compromise in measuring instruments or measurement circuits between resolution and magnitude of measuring current, but for thermistor measurements the self-heating effect must be considered also.

Zero-power sensing refers to applications that use thermistors in such a way that the resistance of the thermistor will reflect the temperature of the medium. Zero-power sensing can be based on the published R/T data for a thermistor, or on the use of the Steinhart-Hart equation to relate Resistance to Temperature.

The measured resistance value of a thermistor in a

medium is affected by the **thermal characteristics** of the **system** which is comprised of the thermistor coupled with the medium being measured. This topic is discussed next:

Thermal Time Constant (T.C.):

When a thermistor is being used to monitor the temperature of its environment then the accuracy of measurement of the resistance of the thermistor is critical.

While the power dissipated in the thermistor is an important factor in this measurement as discussed in the previous section, the thermal characteristics of the system and the thermistor are important also. This is especially relevant in systems where the temperature is changing with time. The **dynamic thermal response** of the thermistor must be considered in these situations. To quantify this dynamic response, the concept of a **Thermal Time Constant (T.C.)** is used in the thermistor industry and it is defined as follows:

The Thermal Time Constant for a thermistor is the time required for a thermistor to change its body temperature by 63.2% of a specific temperature span when the measurements are made under zero-power conditions in thermally stable environments.

This concept is illustrated in the example below:

Example: A thermistor is placed in an oil bath at 25°C and allowed to reach equilibrium temperature. The thermistor is then rapidly moved to an oil bath at 75°C.

The T.C. is the time required for the thermistor to reach 56.6°C (63.2% of the temperature span).

The dominant factors that affect the T.C. of a thermistor are:

- The mass and the thermal mass of the thermistor itself.
- Custom assemblies and thermal coupling agents that couple the thermistor to the medium being monitored.
- Mounting configurations such as a probe assembly or surface mounting.
- Thermal conductivity of the materials used to assemble the thermistor in probe housings.
- The environment that the thermistor will be exposed to and the heat transfer characteristics of that environment. Typically, gases are less dense than liquids so that thermistors have greater time constants when monitoring temperature in a gaseous medium than in a liquid one.

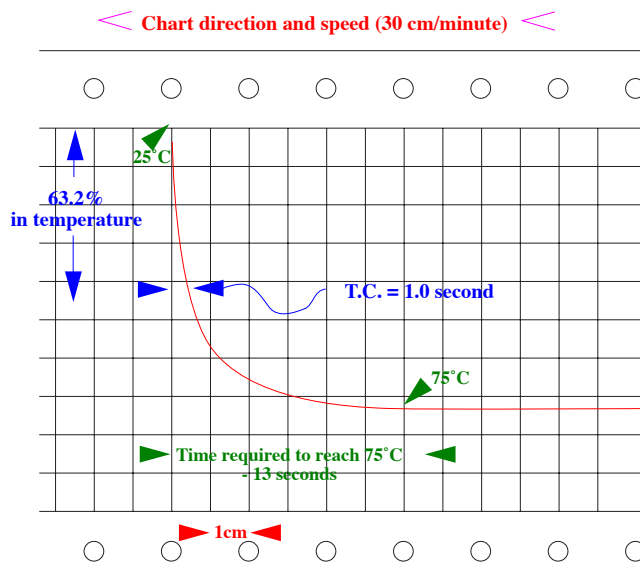
The definition of Thermal Time Constant arises from the exponential nature of the rate of transfer of heat

between the thermistor and the medium that it is monitoring. It is similar in principle to the definition of time constants in describing the responses of systems where physical effects have an exponential response with respect to time.

BetaTHERM offers a wide variety of thermistor devices with T.C.s ranging from 100 milli-seconds to 10 or even 20 seconds depending on test conditions.

Graph # 8 illustrates determination of T.C. for the thermistor of the previous example using a strip chart recorder. When the thermistor is transferred from a 25°C oil bath to a 75°C oil bath its resistance will change and the voltage drop across it can be measured using the chart recorder. By measuring the graph and the speed of the chart recorder the T.C. for the device in a stable oil bath environment can be determined.

Time Constant recording of a thermistor element using a strip chart recorder.



Graph # 8

The value of resistance of a thermistor that is measured in a physical system depends on the power dissipated in the thermistor due to the measurement method and also on the thermal characteristics of a dynamic temperature system. It is important to consider both effects in implementing thermistor sensing systems.

It is useful to combine aspects of both effects in a single parameter and this can be achieved by definition of a **Thermal Dissipation Constant** as described in the next section:

Thermal Dissipation Constant (D.C.):

Because the measured resistance of a thermistor at a particular time depends on the power dissipated in the thermistor during measurement and on the thermal dynamics of the system being measured, it is useful to quantify the combined effect of these two factors. This leads to the concept of **Thermal Dissipation Constant (D.C.)**, which is defined as follows:

The Thermal Dissipation Constant of a thermistor is defined as the power required to raise the thermistor's body temperature by 1°C in a particular measurement medium. The D.C. is expressed in units of mW/°C (milliWatts per degree Centigrade).

BetaTHERM specify the D.C. for Epoxy Coated BetaCURVE and BetaCHIP Thermistor series (which are described later) as typically 0.5mW/°C to 1.0mW/°C in still air at 25°C, and 7mW/°C to 8mW/°C in a well stirred oil bath at 25°C.

The D.C. is a very important parameter in circuit design and application considerations. In practical applications the D.C. will be affected by:

- the mass or thermal mass of a thermistor.
- the mounting of the thermistor in a probe assembly.
- the thermal dynamics of the environment that the thermistor is to monitor.
- the "ranging" of measuring instruments that change current levels as measurement ranges change to track resistance changes of thermistors.

The D.C. is an important factor in applications that are based on the **self-heating effect** of thermistors. In particular, the resistance change of a thermistor due to change in D.C. can be used to monitor levels or flow rates of liquids or gasses. For example as flow rate increases, D.C. of a thermistor in a fluid path will increase and the resistance will change in a manner that can be correlated to flow rate.

The three factors, **zero-power resistance (Ro)**, **time constant (T.C.)**, and **dissipation constant (D.C.)** influence the measured value of the resistance of a thermistor which will affect temperature values that are calculated from the resistance measurements. An understanding of these factors is critical in developing thermistor applications and in measurement of thermistors.

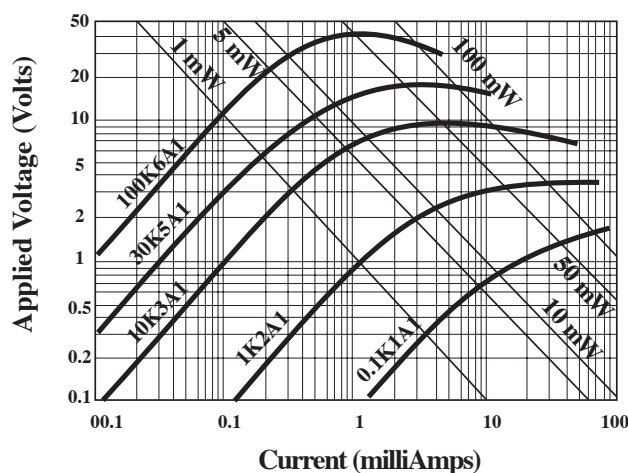
The importance of the three factors discussed previously can be understood more completely by studying the Voltage-Current characteristics of thermistors. This is discussed in the next section:

Voltage –Current Characteristics – (E.I. behaviour)

As stated previously, thermistors are devices that obey Ohm's law at temperature points within their useful range. Since Ohm's law relates Voltage and Current of a component, ($V = I \times R$) it is useful to consider the voltage versus current characteristics of thermistor components.

Typical voltage-current characteristics for selected BetaTHERM thermistors are illustrated in **Graph # 9**, below. The unique characteristic of thermistors where the body temperature increases as current passes through it can be seen by considering the power levels in the thermistor. This is the **"self-heat" mode**, and it is indicated by the inflection of the graph at higher power levels.

Voltage-Current Characteristics for Selected BetaTHERM Thermistors:



Graph # 9

For thermistors being used for temperature sensing, control or compensation, it is required that very low current levels be utilized. Typical values are less than 100 microamps. These are generally **"zero-power"** sensing applications.

Applications where thermistors are used in **self-heat mode** include Liquid Level Control, Air Flow Measurements, Voltage Control, Gas Chromatography and Time Delay. These applications are based on detecting changes in the Dissipation Constant (D.C.) of the system being measured.

The next section of the catalog discusses the specification of thermistors in terms of precision relative to nominal R/T characteristics, this relates to **tolerance of thermistors**.

Tolerance of Thermistors

Having considered some of the factors and conditions that affect the measured value of the resistance of a thermistor, it is important to consider inherent thermistor properties that affect the measured value of resistance of a thermistor at a particular temperature. In this respect, the concept of **tolerance** is essential in selecting and specifying thermistors for an application.

Tolerance for thermistors is the specified resistance percentage or temperature deviation from curve nominal values. Tolerance can be specified as a +/- percentage at a single temperature point or as a temperature value in degrees Centigrade over a particular temperature range.

Standard low precision tolerance thermistors are typically specified as a percentage of resistance (+/-5% or +/-10%) at 25°C. **Standard high precision tolerance** thermistors are specified as a temperature tolerance of (+/-0.1°C or +/-0.2°C) over the temperature range 0°C to 70°C.

Because thermistors of Standard tolerances do not solve all application requirements, *BetaTHERM* will customize temperature tests at temperatures other than 25°C for single point measurements. *BetaTHERM* will also perform multiple temperature tests. For applications that require ranges other than the standard 0°C to 70°C range. Requirements for high precision tolerance thermistors specified as a percentage (+/-1%) at a single point at 25°C or at a temperature other than 25°C can be accommodated also.

It is most economical to use Standard thermistors when ever possible, but if requirements cannot be satisfied by standard thermistors then *BetaTHERM* Applications Engineering Group can assist in solving special temperature tolerance needs.

BetaCURVE and BetaCHIP product:

BetaTHERM use two designations in specifying tolerance of thermistor product. These designations are the **BetaCURVE** series and the **BetaCHIP** series.

BetaCURVE thermistors are standard "interchangeable" (high precision tolerance) devices with tolerance specified over a temperature range.

To simplify ordering these thermistors BetaTHERM supply them in 4 temperature tolerance classifications, A, B, C and D.

- Class A (+/-0.1°C from 0°C to 70°C);
- Class B (+/-0.2°C from 0°C to 70°C);
- Class C (+/-0.5°C from 0°C to 70°C);
- Class D (+/-1.0°C from 0°C to 70°C).

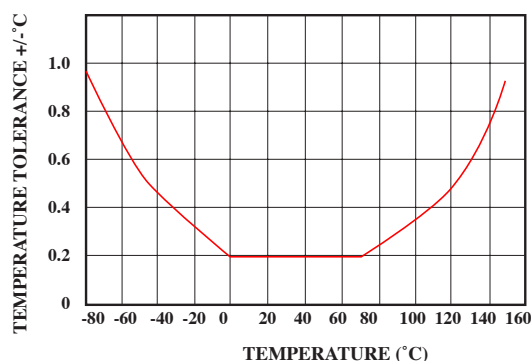
Graphs # 10 and # 11 represent the thermistor tolerance for BetaTHERM Curve # 3 *BetaCURVE* thermistors over the temperature range (-80°C to 150°C).

In the graphic display of the temperature tolerance (ΔT) **Graph # 10**, it can be seen that the deviation or tolerance which is (+/-0.2°C, from 0°C to 70°C) for BetaCURVE material # 3 is wider outside the 0°C to 70°C range.

Graph # 11 also depicts *BetaCURVE* material # 3 with the deviation or tolerance expressed as a percentage (ΔR %) over the range -80°C to 150°C. The range and tolerance information for all of BetaTHERM's material curves is listed in the Temperature and Deviation Tolerance Tables on pages 48 and 49 of the catalog.

Temperature Tolerance Curve (ΔT) for BetaTHERM Material Curve # 3 BetaCURVE Thermistors.

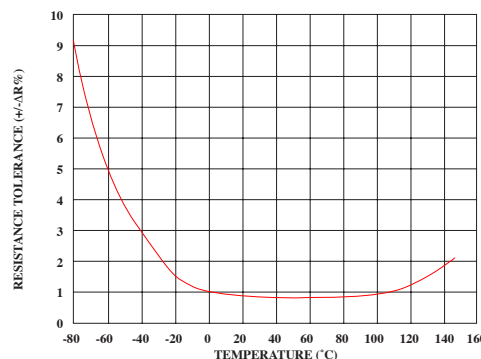
(Standard tolerance, +/-0.2°C from 0°C to 70°C)



Graph # 10

Percent Tolerance Curve (ΔR %) for BetaTHERM Material Curve # 3 BetaCURVE Thermistors.

(Standard tolerance, +/-0.2°C from 0°C to 70°C)



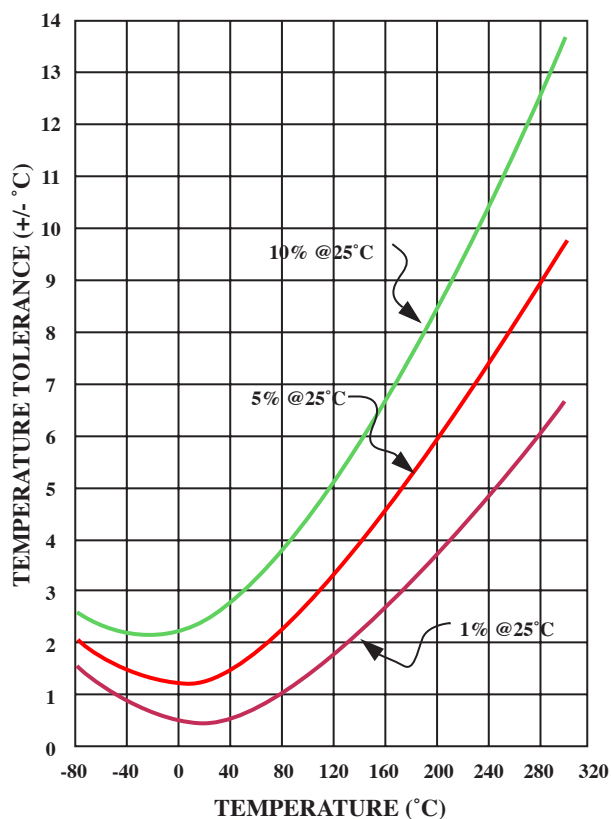
Graph # 11

BetaTHERM Sensors

BetaCHIP thermistors are low precision tolerance thermistors with tolerance specified at a single point temperature and tolerance. The "worst case" deviation or tolerance for temperatures -80°C to $+300^{\circ}\text{C}$ are depicted in **Graph # 12** for temperature deviation and in **Graph # 13** for percent deviation from curve nominal values for 1%, 5% and 10% @ 25°C Material Curve # 3 thermistors. The scale of the Graphs extends to 300°C to display the tolerance for high temperature (glass coated BetaCHIP and DO-35 packaged BetaCHIP) thermistors.

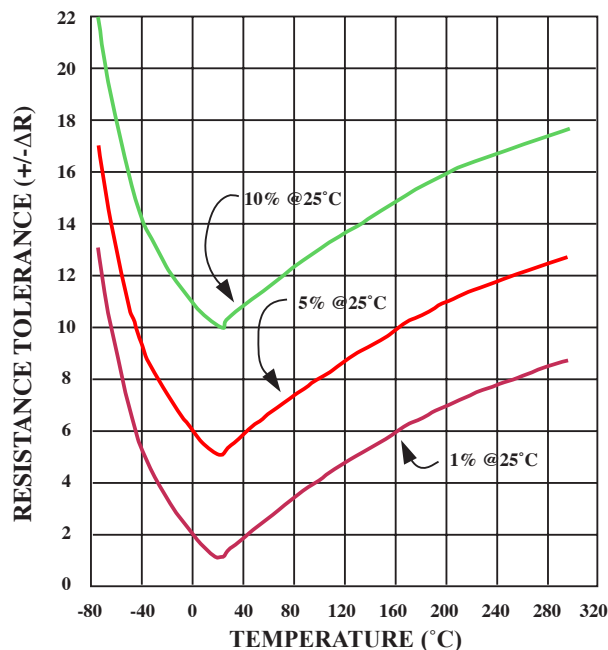
The values displayed in the graphs are also listed in the Temperature and Deviation Tolerance Tables on pages 48 and 49.

Temperature Tolerance Curve (ΔT) for BetaTHERM Material Curve # 3 BetaCHIP (Standard 1%, 5% and 10% tolerance @ 25°C) Thermistors.



Graph # 12

Percent Tolerance Curve (ΔR %) for BetaTHERM Material Curve # 3 BetaCHIP (Standard 1%, 5% and 10% tolerance @ 25°C) thermistors.



Graph # 13

Curve Matching Accuracy and Interchangeability:

The issue of tolerance of components becomes important where the interchangeability of components is being considered. One of the original motivations for having interchangeable devices was to be able to replace failed devices easily. With improvements in manufacturing techniques, thermistor products are now much more reliable, so replacement is not such a major issue.

While replacement of devices is still an important consideration, the issue of interchangeability is presently more likely to be concerned with using similar devices in individual units of large volume products where thermistors are interfaced to a control system. It is important in such cases that systems in individual product items will all behave in a similar manner.

BetaTHERM's BetaCURVE devices are available in volume quantities with curve matching accuracy of $\pm 0.2^{\circ}\text{C}$ over a temperature range from 0°C to $+70^{\circ}\text{C}$, which makes them suitable for use in high volume production products.

Stability and Reliability of Thermistors:

The issue of Long Term Stability of components is a critical one in most temperature sensing applications. Systems Designers are usually concerned with developing circuitry and thermistor sensor specifications which assure accurate, long-term measurement capability. It is extremely important therefore that the Resistance versus Temperature characteristics of the thermistors used in such critical applications do not change or drift over time.

BetaTHERM's range of BetaCurve product exhibit very low drift in the R/T characteristic with respect to time at elevated temperatures. This is indicated in the table below.

The long-term stability is achieved by control of materials in the manufacturing process and by "ageing" the chips at elevated temperatures prior to assembly.

Information on stability with respect to time is included in the product section of the catalog for relevant products.

For customized applications, BetaTHERM can provide advice on aging methods and on the selection of products with optimum long term stability.

AgingTime (years) at 75°C For Material # 3	Change in resistance value ΔR %	Change in temperature value ΔT %
(Initial) 0	0.00	0.000
1	+ 0.05	- 0.011
2	+ 0.10	- 0.022
3	+ 0.15	- 0.033
4	+ 0.20	- 0.044
5	+ 0.25	- 0.056
6	+ 0.30	- 0.067
7	+ 0.35	- 0.077
8	+ 0.40	- 0.087
9	+ 0.45	- 0.097

Table # 4

For applications where tolerance and stability are critical, BetaTHERM's BetaCURVE series of products are superior to the BetaCHIP range. Most manufacturers offer ranges of product that are classified as either high precision and high stability or low precision devices. It is generally more economical to use low precision components where possible, but for more critical applications it is advisable to use high precision devices.

Specification of thermistors for applications:

The preceding sections of the catalog have covered topics relating to the factors that affect the measured value of resistance of a thermistor and to issues that affect the correlation between this measured resistance value and temperature of the thermistor. The next major topics concern the **specification** of thermistors and the implementation of **applications** that use thermistors.

The **specification** of thermistors in terms of part numbers and product ranges is dealt with in the product section of the catalog. This section provides information on the specification of Material Curve number, nominal resistance value, tolerances, lead wire options and associated factors. All of these attributes affect the performance of a thermistor in an application.

For situations where the specification of a **component part-number** are not clear-cut, BetaTHERM applications engineering group can provide advice and customer support.

In terms of **applications**, thermistors represent a mature product range and there are many "standard" application methods in existence. However, it can be difficult to find information on specific aspects of thermistor applications, as the published literature on the topic is diverse and not well catalogued.

The application notes that are in the next sections of the catalog attempt to address this situation. While an in-depth discussion at text-book level is beyond the scope of the catalog, the application notes provide a general overview of methods of using thermistors and provide **key words** and **headings** that may serve as **pointers** towards more detailed sources of information.

The applications section concludes with some notes on interfacing thermistors to instrumentation. This section is also presented as an overview of some relevant topics, so that the key-words and headings can be used to source more detailed information on particular items.

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. It follows that a knowledge of these factors is important in understanding principles of thermistor applications.

Once the general principle of an applications is understood, then the concepts of tolerance and stability and product specification become relevant in selecting the actual component to be used in the application.

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 $-3\%/^{\circ}\text{C}$ to $-5\%/^{\circ}\text{C}$ at 25°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°C to $+300^{\circ}\text{C}$ 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:

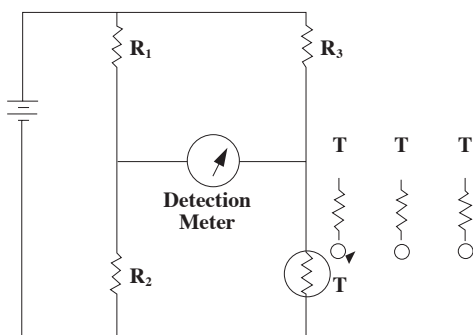


Figure # App 1

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:

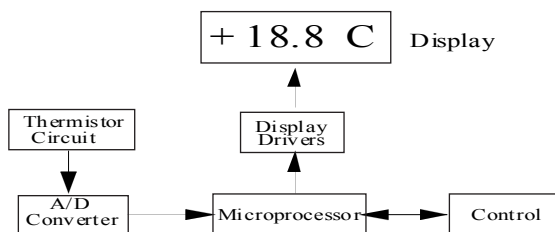


Figure # App 2

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/°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:

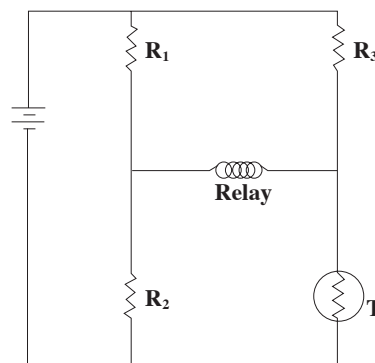


Figure # App 3

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, thermistor 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 °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 (precision 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 °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: ***m₁*** is the slope ($m_1 = 1/m$)

c₁ 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.)

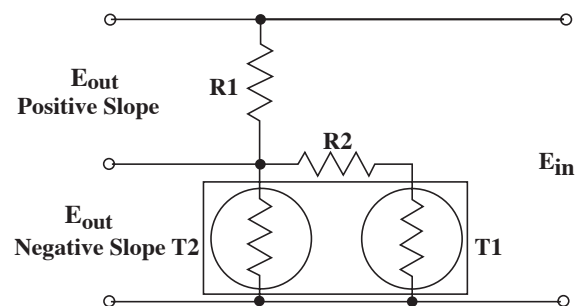
The two circuits designs included here consist of two precision resistors and two precision thermistors. **Figure # App 4** shows a network that is used in the **voltage mode**. In its physical form it is a three terminal device. When a bias voltage E_{IN} is present then a voltage output that varies 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

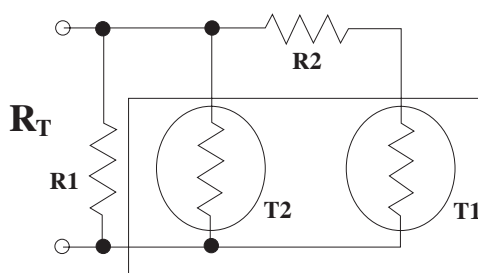


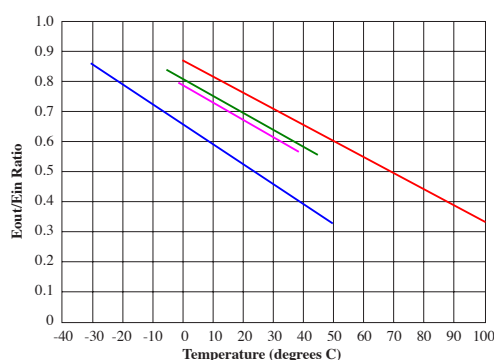
Figure # App 5

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 its 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 its 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 G₀** of **Graph # App 1**.

Heat dissipation in **static liquids** is roughly **ten times** greater than that of a static gas environment, and **Curve L₀** 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 its 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 G₀** represents the thermistor in a static gas environment, **Curve G₁** represents the thermistor in a flowing gas, and **Curve G₁₀** represents the thermistor in a faster flowing gas, for laminar flow conditions.

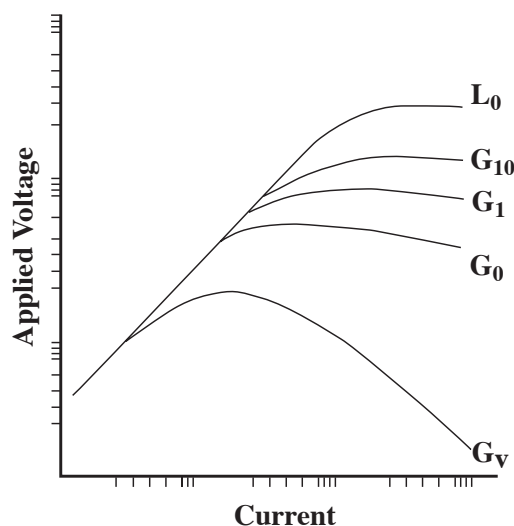
In flow sensing applications, voltage levels may be

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 its parameters or of its 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 its thermal mass and to its temperature coefficient. Thermistors are generally limited to voltage regulation in circuits with low voltages and highly resistive loads.

Voltage Regulation Circuit Schematic:

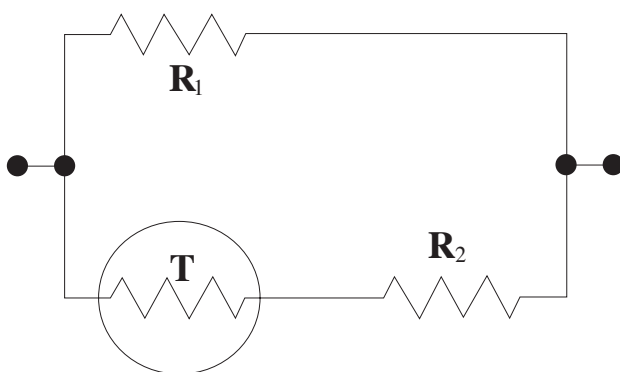


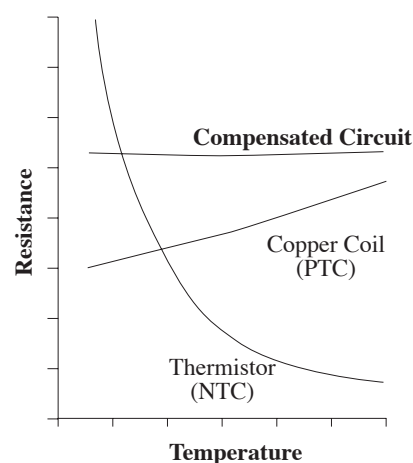
Figure # App 6

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.

Circuit notes for thermistors:

N.T.C. Thermistors are used in a multitude of diverse customer applications. The most common applications are based on the "**zero-power resistance characteristics**" Thermistors have temperature coefficients (percentage change in resistance per °C), or alpha values of the order of -3%/°C to -6%/°C. This is a major advantage of thermistors over other electronic temperature sensing components. Thermistors have the greatest temperature sensitivity of any electronic sensing component over their temperature range of application. **For soldered thermistor elements with wire leads (both BetaCURVE and BetaCHIP) the range is -80°C to +150°C. For Glass Coated thermistors with bare leads such as BetaCHIP, DO-35, Glass Probes and Glass Beaded Thermistors the range extends from -80°C to +300°C.**

Circuit Design Considerations:

The successful implementation of thermistor sensing applications requires a certain level of circuit knowledge to utilize the electrical characteristics of thermistors. The following section introduces some of the circuit concepts and outline typical and practical applications of thermistors.

N.T.C. thermistors are resistors which obey Ohm's Law at any temperature point in their operating range. Ohm's Law states the relationship between the voltage across a resistor and the current through it as follows:

$$V = IR$$

where V is the voltage across the resistor in units of Volts, I is the current through the resistor in Amps and R is the resistance of the resistor in ohms.

The power dissipated in the resistor is defined as :

$$P = IV$$

where P is the Power in Watts.

Ohm's Law can be used directly to determine the resistance of a thermistor in a circuit. However, a known precise voltage source and a precision current meter are required to measure the very small changes in current flow that occur when the temperature and resistance of a thermistor changes. Practical implementation of thermistors for temperature sensing use circuit configurations that make the measurement process less dependent on the ancillary instrumentation.

The most common circuit design that simplifies the measurement process is the **Wheatstone Bridge Circuit** shown in **Figure # App 13**. The bridge circuit is formed by voltage dividers R_X , R_1 and R_2 , R_3 . When all the resistors

are of equal resistance values, the volt meter V will read zero (null) and the bridge network is in balance.

Wheatstone Bridge Circuit:

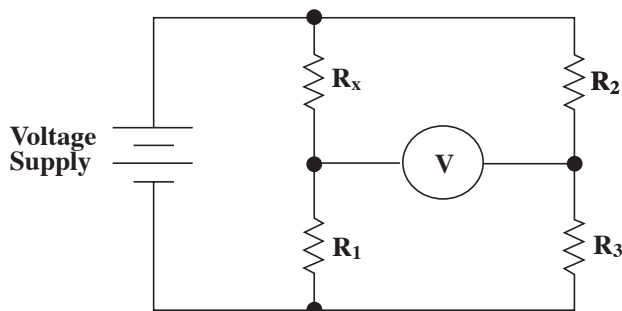


Figure # App 13

In **Figure # App 14** the resistor R_X has been replaced with a thermistor of resistance R_T and the volt meter has been replaced with an amp meter. When the resistance values in the arms of the bridge are equal, the bridge is balanced and there is zero current flow through the amp meter. As the thermistor changes temperature, its resistance will change also, the bridge will not be balanced and the amp meter will indicate current flow.

Thermistor Bridge Circuit:

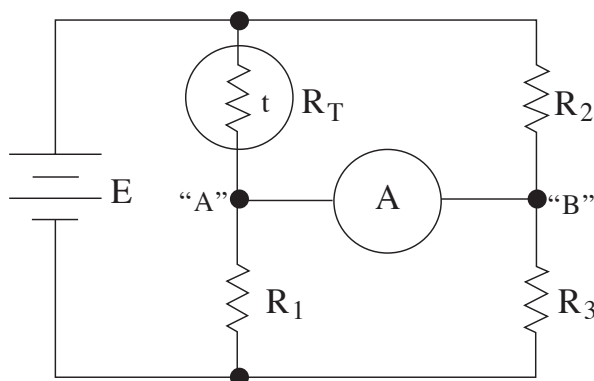


Figure # App 14

The amp meter can be **calibrated** directly to indicate temperature rather than amps (or microamps) to make a simple temperature indicating circuit. Input voltages must be low enough to avoid excessive power across the thermistor as **self-heating** of the thermistor element can occur when power levels are as low as 20μW (microWatts). Typical meters have

BetaTHERM Sensors

100mA measurement current and as such do not pose a problem when thermistors are tested and calibrated in precision liquid temperature baths. BetaTHERM BetaCURVE thermistors have a Dissipation Constant of $8mW/^{\circ}C$ typical in a well stirred oil bath at $25^{\circ}C$.

Thermistor selection for a bridge circuit application is based on the resistance value, temperature range, sensitivity, environment, time response and dimensional constraints.

For example in **Figure # App 9** a BetaTHERM thermistor (10K3A1B) has been selected as R_T and the temperature range is $0^{\circ}C$ to $50^{\circ}C$. From the Resistance-Temperature tables for this thermistor relevant resistance values are as follows:

At: $0^{\circ}C$, $R_T = 32650.8$ ohms
 $25^{\circ}C$, $R_T = 10000$ ohms
 $50^{\circ}C$, $R_T = 3601$ ohms

The mid point of the temperature range is $25^{\circ}C$ and the thermistor value at the mid point is 10000 ohms. R_1 is selected to be the same value as the thermistor at the mid point temperature, which in this case is 10000 ohms. A supply voltage of 1.5 volts is low enough to prevent any significant self-heating of the thermistor as discussed in a previous section of the catalog.

R_2 and R_3 are selected to be 10000 ohms so that the bridge will be in balance at $25^{\circ}C$.

In **Figure # App 10** the requirements of the application are altered so that the temperature range is now from $0^{\circ}C$ to $70^{\circ}C$ and the mid point temperature is now $35^{\circ}C$. Assuming the same thermistor (10K3A1B), the applicable thermistor resistance values are as follows.

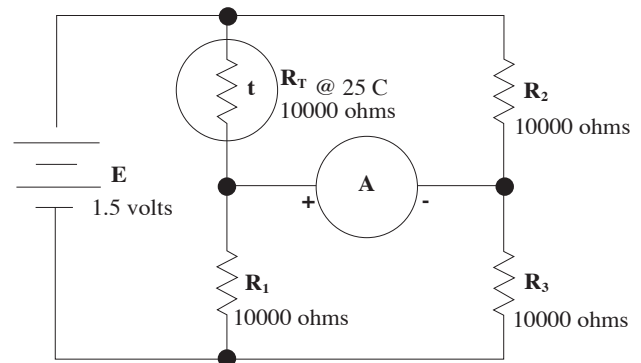
At: $0^{\circ}C$, $R_T = 32650.8$ ohms
 $35^{\circ}C$, $R_T = 6530.1$ ohms
 $70^{\circ}C$, $R_T = 1751.6$ ohms

The resistor values are selected to be equal to the thermistor value (6530.1 ohms) at $35^{\circ}C$.

It is not necessary to have the resistance value of R_1 equal the thermistor value at $35^{\circ}C$. However, at this temperature the ratio of the voltage dividers R_T/R_1 must equal the ratio of R_2/R_3 .

The circuit shown in **Figure # App 11** shows an additional resistor in parallel with R_T . This is to limit the current in R_T and the bridge calculations are performed using the resistance value of this parallel combination.

**Thermistor Bridge Circuit:
Figure # App 9**



Thermistor Bridge Circuit:

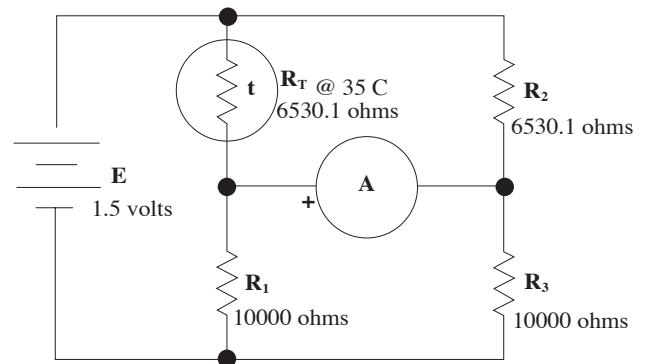


Figure # App 10

Thermistor Bridge Circuit:

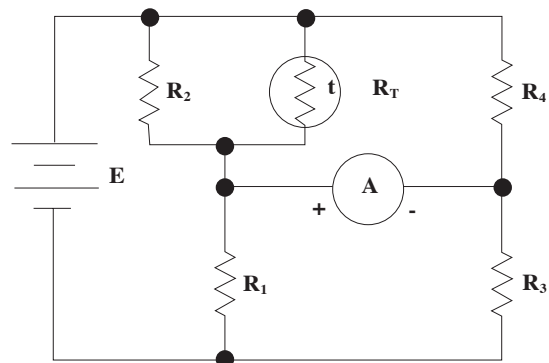


Figure # App 11

While thermistor bridge circuit options are numerous, the guidelines given here are included to assist circuit designers in developing functional circuits for applications. (More details of general bridge circuits can be found in text books that refer to topics such as: *Wheatstone Bridges, Thevenin's Theorem and Kirchoff's Laws.*)

A bridge can be designed so that it will be balanced at any required temperature value. The voltage output from the bridge will be **zero** at the balance point. The condition for balance is that the ratio R_T/R_1 must equal ratio R_2/R_3 .

The bridge circuit examples that have been referred to so far have their origins in applications based on **moving coil instruments**. Their use for temperature indication requires calibration at numerous temperature points to get a useful indicating scale. They can be used more easily to detect **temperature limit** values.

The concepts are useful in understanding the principles involved. For the use of thermistors in bridge circuits with instrumentation based on **Integrated Circuits** the Voltage Output from the bridge is the critical measurement parameter.

For practical applications it is necessary to relate the voltage output from the bridge to the resistance (and temperature) of the thermistor. It can be shown that the voltage between the points labelled "A" and "B" in *Figure # App 14* is given by:

$$V_{AB} = E \times ((R_T/(R_T+R_1)) - (R_2/(R_2+R_3)))$$

This equation can also be written as:

$$V_{AB} = E \times (1/(1+(R_1/R_T)) - 1/(1+(R_3/R_2)))$$

(Equation # App 2)

Equation # App 2 can be used to determine the range of voltage across points **A** and **B** by solving when R_T = minimum thermistor resistance value in range of interest, and solving when R_T = max thermistor resistance value in range. (It is usual to have the bridge balanced, $V_{AB} = 0$ at the minimum temperature (maximum thermistor resistance) value).

Equation # App 2 can be used to determine voltage values corresponding to temperatures for limit setting in applications that depend on a voltage comparator principle.

For thermistors in resistance bridge circuits it is important to consider the need to limit electrical power to minimize self-heating effects. This is influenced by the supply voltage to the bridge, E , by the minimum resistance value of the thermistor in the range of interest and by the value of the resistance R_1 which is in series with the

thermistor. The equation that relates these parameters to the maximum power dissipation, w , is:

$$E^2 \times (R_T/(R_T+R_1)^2) \leq w$$

Equation # App 3

The value of the ratio R_2/R_3 in bridge circuits is not of major importance in typical bridge designs for thermistor sensing applications. It affects the **linearity** of the bridge and further details on this topic can be found in circuit design text-books.

Interpretation of Results:

The interpretation of results from bridge measurements in control systems is dealt with in the following sections, while linearization of thermistor characteristics is covered in a later section.

Bridge circuits are useful in measuring temperatures or in comparing the resistance of two thermistors. If the resistor that is shown (*Figure # App 2*) as R_1 is replaced with a thermistor (*Figure # App 12*) R_{T1} , then the voltage output of the bridge depends on the ratio of the resistance of the two thermistors and so can be used to monitor the temperature difference between them. This principle is used where it is required to monitor the difference between two temperatures where the reference temperature (monitored by the thermistor in position R_{T1}) is not precisely fixed, but may vary by a few degrees, like a room temperature. Thermistors in a bridge circuit provide a **robust** measurement system where **limit calculations** can be performed readily and ancillary hardware can be concentrated on the control function rather than in signal conditioning and amplification.

Thermistor Bridge Circuit with two thermistors:

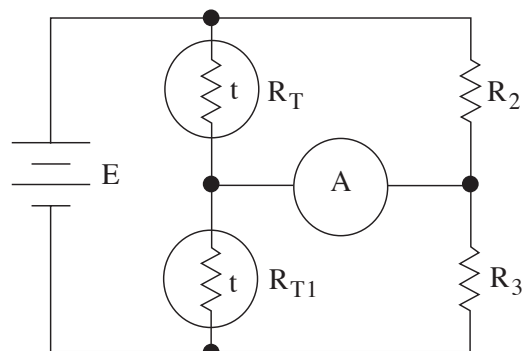


Figure # App 12

The voltage output of a resistance bridge containing thermistor sensing elements is generally non-linear with respect to the temperature of the thermistor. Applications that require the temperature value to be calculated across the range of the application, for example for display or precision control of temperature, are generally **microprocessor based**. The embedded control software relates the measured variable, the voltage output from the bridge, to the temperature of the thermistor by the use of look-up tables **or** by the use of mathematical functions to apply relevant calculations such as *equation # App 2* or the Steinhart-Hart Equation. The general principles of measurement/control systems based on embedded controllers is illustrated in *Diagram # App 1*.

Advanced Microprocessor-NTC Thermistor Schematic. (Control System Design)

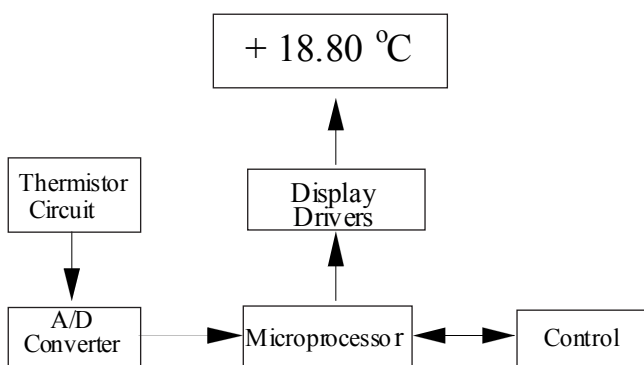


Diagram # App 1

The use of thermistors in control/display systems as described above is dependent on the use of Analog to Digital converters to interface with the controller. Accuracy of conversion is critical to allow custom systems to relate the measured voltage to the temperature of the sensor using embedded control software. One important principle in conversion is the resolution of the system. This depends on the number of **bits** available in the converter. As an example, for thermistor operating in a 100°C range a 12-bit ADC can give a resolution of 0.025°C (= 100/(2¹²)). Likewise an 8-bit ADC can give a resolution of 0.40°C.

While an in-depth discussion of Analog to Digital conversion techniques is beyond the scope of this catalog, *BetaTHERM* recommend conversion products from **Analog Devices**. Details of conversion techniques and application

notes can be obtained from Analog Devices or from their website at <http://www-corp.analog.com>. For measurements on thermistor bridges the Analog Devices AD7813 (8-bit) and AD7892 (12-bit) ADC's are suitable. These ADC's are parallel output devices and full data sheets and application sheets are available from Analog Devices.

Converters that are serial output devices are also available. An example of a serial output converter that is suitable for use with thermistors is the **Analog Devices AD7711 Sigma-Delta ADC**. This product also provides on-board circuitry for bias voltage and signal conditioning. Analog Devices provide a technical note for "Temperature Measurement using a Thermistor and the AD7711 Sigma-Delta ADC". This application note is included as a stand alone reference at the end of this section of the catalog. However, the application note from Analog Devices is not really concerned with bridge circuits, although the AD7711 can be interfaced to a bridge. It is more relevant for use with **Voltage Divider Circuits** which are discussed in the next section of the catalog.

Voltage Divider Circuits and Linearization:

The preceding discussion has been concerned mainly with principles of thermistors in resistive bridge circuits which reflects the importance of bridge circuits in the interfacing of thermistors to instrumentation. Modern instrumentation also makes extensive use of voltage divider circuits (as illustrated in *Figure # App 13*). *Relevant circuit theory can be found in standard text books on Electronics.*

Some of the principles are similar to those of the bridge circuits, but some critical considerations for typical applications are outlined in the following section:

The voltage **across** the **thermistor** is given by:

$$e_{01} = E_1 \times (R_1 / (R_1 + R_T)) \quad \text{.....(Equation # App 3)}$$

This has a positive slope with respect to temperature.

The voltage across the thermistor is given by:

$$e_{02} = E_1 \times (R_T / (R_1 + R_T)) \quad \text{.....(Equation # App 4)}$$

This has a negative slope with respect to temperature.

It is useful to normalize the output voltage e_{01} with respect to the supply voltage E_1 , and the relevant equation is:

$$\frac{e_{01}}{E_1} = \frac{R_1}{R_1 + R_T} = \frac{1}{1 + \left(\frac{R_T}{R_1}\right)}$$

(Equation # App 5)

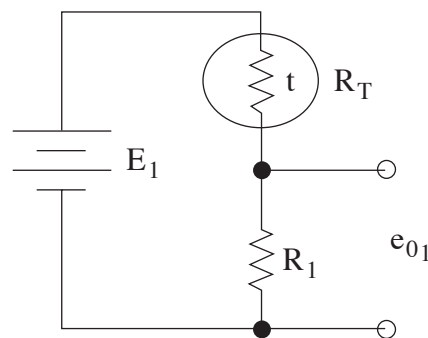
This ratio is called the **standard function** of the circuit, **F(T)**, as a function of the resistance and hence temperature of the thermistor. When **F(T)** **verses T** is plotted as shown in **Graph # App 3**, for various values of the fixed resistor **R₁** a series of curves is obtained as shown in the graph for a *BetaTHERM 5K3* thermistor. From these curves it can be seen that a good approximation to a linear relationship between **F(T)** and **T** can be found for particular values of **R₁**. This topic of linearization of the output is an important one that is discussed next.

The voltage divider circuit of **Figure # 8** is useful for limiting the current in the thermistor to avoid self-heating effects. For this configuration the voltage across the thermistor is found by replacing the term for **R_T** with the term for the parallel combination of **R_T** and **R₂**, which is:

$$R_C = (R_T \times R_2) / (R_T + R_2).$$

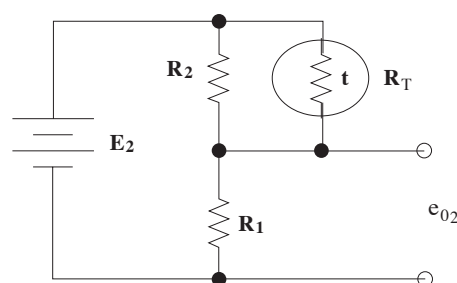
The principles of interfacing the voltage divider circuits to instrumentation such as Analog to Digital Converters are similar to those outlined previously for bridge circuits. Modern ADC's provide on-board circuitry for bias voltage and signal conditioning of thermistor voltage divider circuits. In particular, **Analog Devices** provide a Technical Note for "Temperature Measurement using a Thermistor and the AD7711 Sigma-Delta ADC". This application note refers to interfacing the converter to voltage divider circuits, and it also provides notes on linearization. **The application note is included as a stand alone reference at the end of this section.**

The AD7711 converter is a sophisticated design that produces a 24-bit serial digital word as output. If a parallel output word is required then the Analog Devices AD7813 (8-bit) and AD7892 (12-bit) ADC's are suitable.



Voltage Divider Circuit:

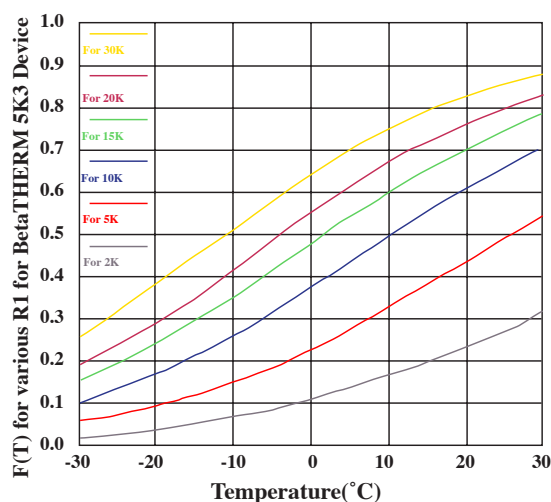
Figure # App 13



Voltage Divider Circuit:

Figure # App 14

F(T) for BetaTHERM 5K3 Thermistor in series with various resistors.



Graph # App 3

BetaTHERM Sensors

A significant advantage of thermistors in a voltage divider circuit is that the voltage across the resistor can be **linearized** with respect to thermistor resistance (and hence to temperature) for particular choice of resistor value. This means that the relationship between the voltage across the resistor (or thermistor) is in the form of:

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

Where T is the temperature of the thermistor (in appropriate units), m is the slope, e is the voltage across the resistor (or thermistor) and c is the intercept with the temperature axis.

The equation can also be expressed with voltage as the main variable

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

$$\text{Where } m_1 = 1/m \text{ and } c_1 = -c/m$$

More complete details of linearization of thermistors are included in the technical note "Temperature Measurement using a Thermistor and the AD7711 Sigma-Delta ADC" from Analog Devices, and a section of this technical note is quoted in italics below:

"Using this method the nonlinear negative temperature characteristics of a thermistor are converted into a linear relationship with peak errors of +/- 12%. If the temperature range is reduced the errors become appreciably smaller +/- 0.01°C over a 10°C range, +/- 0.05°C over a 30°C range and +/- 2.0°C over a 60°C range."

The value for R_1 is calculated as follows:

$$R1 = \{R_{T(MID)} * (R_{T(LOW)} + R_{T(HIGH)}) - (2 * R_{T(LOW)} * R_{T(HIGH)})\} - \{R_{T(LOW)} + R_{T(HIGH)} - 2 * R_{T(MID)}\}$$

Where:

$R_{T(MID)}$ is the thermistor impedance at the middle of the range.

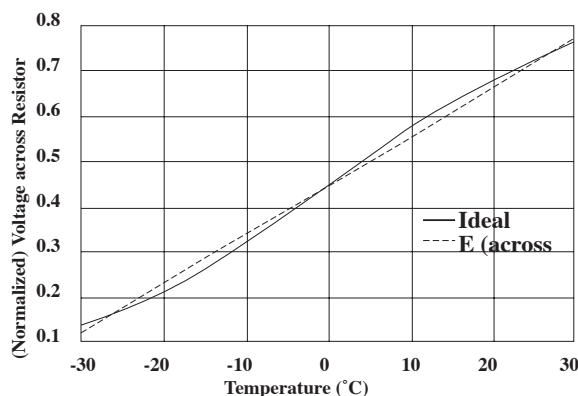
$R_{T(LOW)}$ is the thermistor impedance at the low end of the range.

$R_{T(HIGH)}$ is the thermistor impedance at the high end of the range."

For linearized thermistor / resistor networks (consisting of a single resistor and thermistor) the maximum error in the linear relationship is determined by the temperature range of the application. The errors are approximately +/- 0.01°C over a 10°C range, +/- 0.05°C over a 30°C range, and +/- 2.0°C over a 60°C range. Sample tables are included on this page to provide a quantitative estimate of the scale of potential errors due to linearization. The sensitivity can be typically **10-50 mV/°C**.

The foregoing discussion was intended to provide some background for circuit designers that want to implement a linearized temperature response in a circuit.

Voltage across Resistor vs Temperature for BetaTHERM 5K3 Thermistor linearized with a single resistor.



Graph # App 4

Sample values for voltage linearization (1V bias, range 32-44°C) for device 2.2K3A1 (Curve #3 Thermistor Material) with nominal resistance of 2252 ohms @ 25°C.

Temp. (°C)	Resistance @ temp. (ohms)	R (series)	E (across R)	m (slope)	C (intercept)
32.0	1666.9		0.3697733	100.809321	-5.2765957
38.0	1300.2	978.021	0.4292916	100.809321	-5.2765957
44.0	1022.8		0.4888099	100.809321	-5.2765957

Error due to linearization

with ideal resistor

with 1% resistor

Temp. (°C)	Resistance (ohms) @ temp.	E (across R) volts	Calculated temp. (°C)	Difference (°C)	Calculated temp. (°C)	Difference (°C)
25	2252.00	0.3028	25.25	0.25	25.04	0.04
26	2155.60	0.3121	26.19	0.19	25.97	0.03
27	2063.90	0.3215	27.14	0.14	26.92	0.08
28	1976.60	0.3310	28.09	0.09	27.87	0.13
29	1893.40	0.3406	29.06	0.06	28.83	0.17
30	1814.20	0.3503	30.03	0.03	29.81	0.19
31	1738.80	0.3600	31.01	0.01	30.78	0.22
32	1666.90	0.3698	32.00	0.00	31.77	0.23
33	1598.30	0.3796	32.99	0.01	32.76	0.24
34	1532.90	0.3895	33.99	0.01	33.75	0.25
35	1470.60	0.3994	34.99	0.01	34.75	0.25
36	1411.10	0.4094	35.99	0.01	35.75	0.25
37	1354.40	0.4193	36.99	0.01	36.75	0.25
38	1300.20	0.4293	38.00	0.00	37.75	0.25
39	1248.50	0.4439	39.00	0.00	38.76	0.24
40	1199.20	0.4492	40.01	0.01	39.76	0.24
41	1152.00	0.4592	41.01	0.01	40.76	0.24
42	1107.00	0.4691	42.01	0.01	41.76	0.24
43	1063.90	0.4790	43.01	0.01	42.76	0.24
44	1022.80	0.4888	44.00	0.00	43.75	0.25
45	983.42	0.4986	44.99	0.01	44.74	0.26
46	945.81	0.5084	45.97	0.03	45.72	0.28
47	909.83	0.5181	46.95	0.05	46.70	0.3
48	875.40	0.5277	47.92	0.08	47.67	0.33
49	842.47	0.5372	48.88	0.12	48.63	0.37

For more extended temperature spans, combinations of two or three resistors and thermistors can be used in resistor/thermistor networks allowing up to 100°C coverage. *BetaTHERM* produce a range of such networks, called the ***BetaLINEAR*** series that are described in the product section of the catalog.

This is a series of interchangeable thermistor composites and precision fixed resistors that are designed to produce a change in resistance or voltage output that varies linearly with temperature over specified temperature ranges. Linearized thermistor/resistor networks can be used in Resistance Mode, where the resistance of the composite varies in a linear manner with temperature over the relevant range, or Voltage Mode where the composite circuit is under voltage bias and the voltage across one of the components varies in a linear manner with temperature over the relevant range. Additional information is provided on pages 27 and 28 in the application notes, and in the product section of the catalog that describes *BetaLINEAR Composites and Networks*.

Thermistors Interfaced to Computers:

An important application sector for thermistors involve interfacing such sensors directly to Computers for laboratory studies, temperature recording or control applications. This sector is becoming increasingly relevant, due to the power of processing, analysing, recording and sharing data that computers provide.

The basic principles are very similar to those outlined above for thermistors in bridge circuits or in voltage divider circuits, but there are some other features that are relevant for successful development of applications.

The concept is based on **Computer Input Cards**. These are cards that fit into a PC expansion slot and generally terminate in a connector that allows connection to external instrumentation. There are a wide range of such cards available from a range of suppliers. Further information can be obtained from the Internet and most suppliers maintain their own web sites.

The computer input cards generally contain multiple input channels (up to 16) that allow signals to be processed through Analog to Digital Converters (ADC's). The processed signal can then be read into computer memory for processing in programs. These are called **Analog Input Cards** and exhibit most of the features of ADC's, with the added benefit of interfacing to software for analysis in the digital domain. This facilitates the use of **look-up tables** or **equations** to convert the measured value to a **temperature** value. Most suppliers provide custom software with advanced Graphical User Interfaces

and facilities for data analysis, importation into spread sheets and general computation.

When used in conjunction with **Computer Output Cards** the temperature sensor and input cards can form part of a powerful control system.

Computer based systems also allow advanced characterization of thermistor devices and temperature systems and can be used to implement functions that previously required chart-recorders or oscilloscopes.

Other relevant computer cards for **Data Acquisition** operate like computer-controlled multi-meters and allow **direct** measurement of the **Resistance** of the thermistor. These also allow advanced data analysis features, but the developers of control software should keep power dissipation of the thermistor in mind when specifying measurement conditions such as measurement current, burden voltage and integration time.

Computer cards are useful for evaluations on samples of thermistor products to characterize them and to develop applications while allowing easy data storage in formats that are compatible with most spread-sheets.

Applications that require such computer-based systems and cards are usually innovative ones and *BetaTHERM* can provide support and advice for customers who want to avail such advanced technology in thermistor-based sensing applications.

Temperature Measurement using a Thermistor and the AD7711 Sigma Delta ADC

by Albert O'Grady

INTRODUCTION

Thermistors are electrical circuit elements formed with semiconducting materials that are characterized by a high negative temperature coefficient (NTC) or positive temperature coefficient (PTC). An NTC thermistor acts like a resistor with temperature coefficients of typically -3 to -5 %/°C. Thermistors offer the benefits of high stability, precision, size and compatibility at a competitive price in many applications. They also offer fast response times and are among the highest sensitivity temperature transducers available. Thermistors can be excited by using either voltage or current methods. Thermistors are used as thermal sensors or thermal probes in communications, instrumentation, automotive, medical, aerospace and consumer market segments.

In medical applications for example thermistors are used in skin sensors, renal dialysis, blood and urine analysers, incubators and respirators and also clinical and domestic thermometers. In communication applications they are used for temperature monitoring and compensation in mobile phones, base stations and laser drives. They are also used extensively in the protection of mobile phone battery packs against overcharging.

In data acquisition applications, high resolution analog to digital converters are required to digitize the signal produced from the measurement circuit incorporating the thermistor. The AD7711, a signal conditioning analog-to-digital converter from Analog Devices is an ideal choice in temperature measurement applications using thermistors and RTDs. The AD7711 as shown in Figure 1 is a complete analog front end for low frequency measurement applications. The device accepts low level signals directly from a transducer and outputs a serial digital word. It employs a sigma-delta conversion technique to realize up to 24 bits of no missing codes performance. The input signal is applied to a proprietary programmable gain front end based around an analog modulator. The AD7711 on-chip programmable gain amplifier (PGA) with gains from 1 to 128 is used in applications to amplify the signal from the front end transducer in order to use the full dynamic range of the ADC. With a 2.5V reference and a gain range of 1 to 128 the AD7711 can accept unipolar signals between 0 to 20mV and 0 to 2.5V and bipolar signal ranges from +/- 20mV to +/-2.5V. The modulator output is processed by an on-chip digital filter. The first notch of this digital filter can be programmed via the on-chip control register allowing

features one differential analog input and one single ended analog input as well as a differential reference input. Normally, one of the input channels will be used as the main channel with the second channel used as an auxiliary input to periodically measure a second voltage. It can be operated from a single supply (by tying the VSS pin to AGND) provided that the input signals on the analog inputs are more positive than -30 mV. By taking the VSS pin negative, the part can convert signals down to -VREF on its inputs. The part provides two current sources that

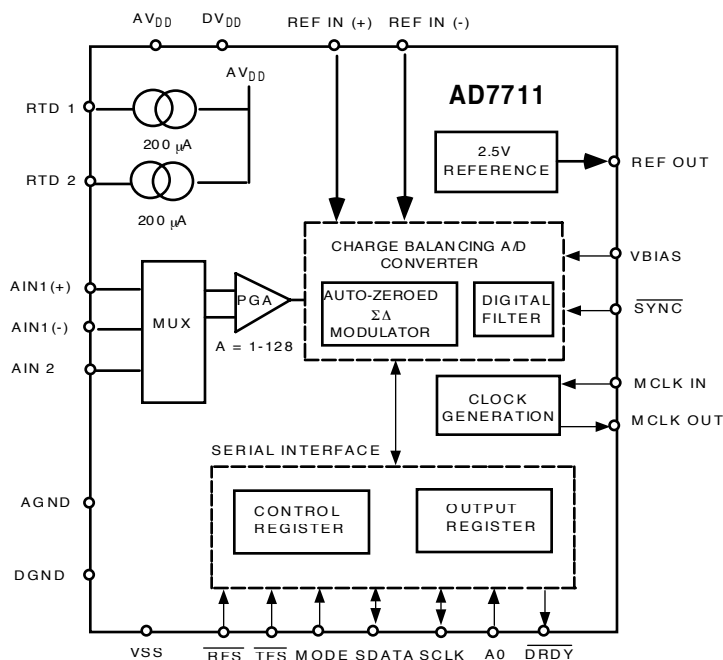


Figure 1. AD7711 Signal Conditioning Analog-To-Digital Converter.

can be used to provide excitation in three-wire and four-wire RTD configurations. A full data sheet on the AD7711 can be found on the Analog Devices web site at : <http://www-corp.analog.com>.

THERMISTOR APPLICATIONS USING CURRENT EXCITATION

Figure 2. shows a circuit using the AD7711 to digitize the output voltage generated across a thermistor using the AD7711s on-chip 200uA current source.

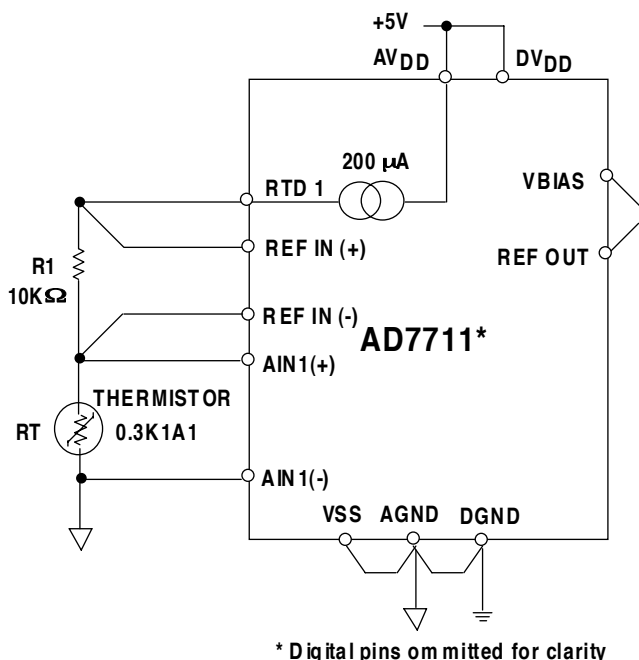


Figure 2. Temperature Measurement Application Using Current Excitation of the Thermistor

The thermistor chosen in this example is the 0.3K1A1 from Betatherm*. Appendix 1 shows a table of the R-T characteristics of this device. This device has a nominal resistance of 300 ohms at 25°C. In this example the same 200uA current source used to excite the thermistor is also used to generate the reference voltage for the AD7711. As a result variations in the excitation current do not affect performance. The most common wiring arrangement in these applications is a 4-wire force/sense configuration in order to reduce the effects of lead resistances on system performance. Lead resistance of the drive wires only shift the common mode voltage and do not degrade the performance of the circuit. Lead resistance of the sense wires is immaterial as no current flow in these wires due to the high input impedance of the AD7711 analog inputs. However, the reference setting resistor must have a low temperature coefficient to avoid errors in the reference voltage over temperature. The operating temperature range of this circuit is from -35°C to + 100°C, the limitation on the lower end is due to voltage headroom in the circuit associated with the impedance of the thermistor increasing as the temperature decreases and the output compliance of the current source. The output voltage from the thermistor seen by the analog inputs of the AD7711 varies from 7mV at 100°C to 0.75V at -35°C. The AD7711 on-chip programmable gain amplifier (PGA) with gains from 1

to 128 is used in this application to amplify the signal from the thermistor in order to maximize the signal-to-noise ratio (SNR) of the system. With a 2V reference and a gain range of 1 to 128 the AD7711 can accept unipolar signals between 0 to 15mV and 0 to 2V. For example if the operating range is from 25°C and to 100°C, the maximum output voltage generated across the thermistor is 60mV, this allows a gain of 32 to be used in covering this entire range.

THERMISTOR APPLICATIONS USING VOLTAGE EXCITATION

Figure 3 shows a circuit where the thermistor is excited using a voltage source which is obtained from the AD7711. The thermistor shown is the 10K3A1 thermistor from

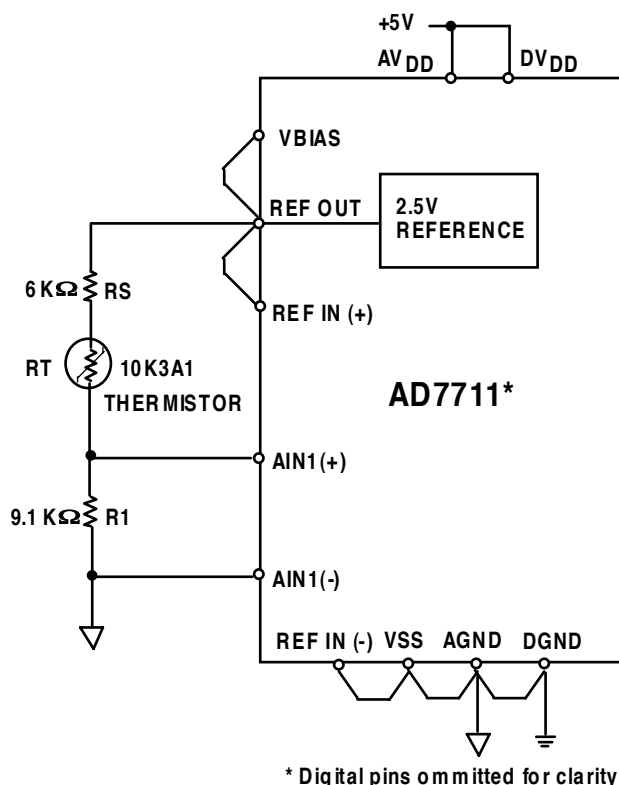


Figure 3. Temperature Measurement Application Using Voltage Excitation of the Thermistor and Linearizing the Output in the Analog Domain.

Betatherm which has a nominal impedance of 10k Ω at 25°C. Appendix 2 shows a table of the R-T characteristics of this device.

The circuit shown uses two resistors RS and R1 in series with the thermistor. Resistor RS is used to limit the thermistor power dissipation - see section on eliminating self heating effects. Resistor R1 is used to linearize the output of the thermistor. The output voltage across R1 varies from 33mV at -50°C to +2.329V at + 100°C. The AD7711 operating at a gain of 1 in unipolar operating

mode accommodates an input signal range of 0V to 2.5V. If the application requires the full dynamic range of the ADC to be used, then the system calibration feature on the ADC can be used to calibrate out the 33mV at the low end. Therefore, when the ADC sees 33mV on its input its output digital code would be all zeroes. Likewise at the top end a system fullscale can be used so that an input voltage of 2.329V outputs all ones from the AD7711. The AD7711 on-chip programmable gain amplifier (PGA) with gains from 1 to 128 can be used in this application to amplify the signal generated across R1 in order to maximize the signal-to-noise ratio (SNR) of the system.

LINEARIZING A THERMISTORS OUTPUT

Thermistors are non-linear devices and require linearization techniques to obtain accurate measurements. In general applications, linearization techniques can be implemented in one of two ways. Linearization can be performed in the digital domain using a look up table containing the manufacturer's device characteristics to linearize the thermistor output. Linearization can also be performed in the analog domain with the addition of series or parallel resistors which forces the voltage or the resistance of a simple fixed-resistor-thermistor to have zero error along a linear temperature scale at three equidistant points.

Figure 3 uses a resistor R1 in series with the thermistor to linearize the output of the thermistor. This approach forces the voltage across R1 to have zero error along a linear temperature scale at three points across the required temperature range. The maximum error is determined by the temperature range of the application. In this application the temperature range is taken to be -50°C to +100°C. The errors are zero at -50°C, 25°C and +100°C and the errors elsewhere are distributed in an S-shaped curve.

Using this method the nonlinear negative temperature characteristics of a thermistor are converted into a linear relationship with peak errors of +/-12%. If the temperature range is reduced the errors become appreciably smaller +/-0.01°C over a 10°C range, +/-0.05°C over a 30°C range and +/-2.0°C over a 60°C range.

The value for R1 is calculated as follows:

$$R1 = \frac{\{RT_{(MID)} * [RT_{(LOW)} + RT_{(HIGH)}] - [2 * RT_{(LOW)} * RT_{(HIGH)}]\}}{\{RT_{(LOW)} + RT_{(HIGH)} - 2 * RT_{(MID)}\}}$$

Where:

$RT_{(MID)}$ is the thermistor impedance at the middle of the range.

$RT_{(LOW)}$ is the thermistor impedance at the low end of the range.

$RT_{(HIGH)}$ is the thermistor impedance at the high end of the range.

ELIMINATE SELF HEATING EFFECTS

Self-heating effects of the thermistor can become significant and degrade the overall system performance. Self-heating effects are more pronounced in still air. If the thermistor is located in moving air, liquids or solids then the self-heating error is much lower. In order to keep the self-heating error within 0.1°C max, the current in the circuit should be limited so as to give a dissipation of 0.1mW max in the thermistor RT. In the circuit in Figure 2 which uses current

at 25°C. To keep the power dissipation to within 0.1mW the operating temperature range should be limited to operating above -27°C.

In Figure 3 the point of maximum power dissipation and thus self heating effects are worst when the value of RT is equal to R1. A series resistor Rs as shown in Figure 3 will limit the current in the circuit and thus keep the power dissipated in the thermistor to acceptable levels so that self heating effects in the thermistor can be ignored. A value of 6kΩ is sufficient to limit the current in the circuit and ensure that the max power dissipated in the thermistor is less than 0.1mW.

LAYOUT TECHNIQUES FOR OBTAINING OPTIMUM PERFORMANCE IN HIGH RESOLUTION APPLICATIONS

The printed circuit board which houses the AD7711 should be designed such that the analog and digital sections are separated and confined to certain areas of the board. This facilitates the use of ground planes which can be separated easily. A minimum etch technique is generally best for ground planes as it gives the best shielding. Digital and analog ground planes should only be joined in one place. If the AD7711 is the only device requiring an AGND to DGND connection, then the ground planes should be connected at the AGND and DGND pins of the AD7711. If the AD7711 is in a system where multiple devices require AGND to DGND connections, the connection should still be made at one point only, a star ground point which should be established as close as possible to the AD7711.

Avoid running digital lines under the device as these will couple noise onto the die. The analog ground plane should be allowed to run under the AD7711 to avoid noise coupling. The power supply lines to the AD7711 should use as large a trace as possible to provide low impedance paths and reduce the effects of glitches on the power supply line. Fast switching signals like clocks should be shielded with digital ground to avoid radiating noise to other sections of the board and clock signals should never be run near the analog inputs. Avoid crossover of digital and analog signals. Traces on opposite sides of the board should run at right angles to each other. This will reduce the effects of feedthrough through the board. A microstrip technique is by far the best but is not always possible with a double-sided board. In this technique, the component side of the board is dedicated to ground planes while signals are placed on the solder side.

Good decoupling is important when using high resolution ADCs. All analog supplies should be decoupled with 10μF tantalum in parallel with 0.1μF capacitors to AGND. To achieve the best from these decoupling components, they have to be placed as close as possible to the device, ideally right up against the device. All logic chips should be decoupled with 0.1μF disc ceramic capacitors to DGND. In systems where a common supply voltage is used to drive both the AV_{DD} and DV_{DD} of the AD7711, it is recommended that the system's AV_{DD} supply is used. This supply should have the recommended analog supply decoupling capacitors between the AV_{DD} pin of the AD7711 and AGND and the recommended digital supply decoupling capacitor between the DV_{DD} pin of the AD7711 and

DGND

APPENDIX 1.

R-T Specifications for Betatherm 0.3K1A1 Thermistor

Temp (°C)	Resistance (Ω)	Temp (°C)	Resistance (Ω)	Temp (°C)	Resistance (Ω)
-80	50763	-19	1735	42	170
-79	47473	-18	1659	43	164.7
-78	44417	-17	1586	44	159.6
-77	41576	-16	1516	45	154.7
-76	38935	-15	1451	46	149.9
-75	36477	-14	1388	47	145.3
-74	34190	-13	1328	48	140.9
-73	32060	-12	1272	49	136.6
-72	30076	-11	1218	50	132.5
-71	28227	-10	1167	51	128.5
-70	26503	-9	1118	52	124.7
-69	24895	-8	1071	53	121
-68	23394	-7	1027	54	117.5
-67	21993	-6	984.5	55	114
-66	20684	-5	944.2	56	110.7
-65	19461	-4	905.8	57	107.5
-64	18318	-3	869.1	58	104.4
-63	17249	-2	834.2	59	101.4
-62	16248	-1	800.8	60	98.5
-61	15312	0	769	61	95.7
-60	14436	1	738.6	62	93
-59	13614	2	709.5	63	90.4
-58	12845	3	681.8	64	87.8
-57	12123	4	655.3	65	85.4
-56	11447	5	630	66	83
-55	10812	6	605.8	67	80.7
-54	10216	7	582.7	68	78.5
-53	9656	8	560.5	69	76.4
-52	9131	9	539.4	70	74.3
-51	8637	10	519.1	71	72.3
-50	8173	11	499.7	72	70.4
-49	7737	12	481.2	73	68.5
-48	7326	13	463.4	74	66.7
-47	6940	14	446.4	75	64.9
-46	6576	15	430.1	76	63.2
-45	6234	16	414.5	77	61.6
-44	5911	17	399.6	78	60
-43	5607	18	385.2	79	58.4
-42	5320	19	371.5	80	56.9
-41	5050	20	358.3	81	55.4
-40	4795	21	345.7	82	54
-39	4554	22	333.5	83	52.7
-38	4327	23	321.9	84	51.3
-37	4113	24	310.7	85	50
-36	3910	25	300	86	48.8
-35	3719	26	289.7	87	47.6
-34	3538	27	279.8	88	46.4
-33	3367	28	270.3	89	45.3
-32	3205	29	261.2	90	44.1
-31	3052	30	252.4	91	43.1
-30	2907	31	244	92	42
-29	2769	32	235.9	93	41
-28	2639	33	228.1	94	40
-27	2516	34	220.6	95	39.1
-26	2400	35	213.4	96	38.1
-25	2289	36	206.5	97	37.2
-24	2184	37	199.8	98	36.4
-23	2085	38	193.4	99	35.5
-22	1990	39	187.2	100	34.7
-21	1901	40	181.3		
-20	1816	41	175.5		

APPENDIX 2.

R-T Specifications for Betatherm 10K3A1 Thermistor

Temp (°C)	Resistance (Ω)	Temp (°C)	Resistance (Ω)	Temp (°C)	Resistance (Ω)
-80	7296874.00	-3	38108.50	74	1530.28
-79	6677205.00	-2	36182.80	75	1480.12
-78	6114311.00	-1	34366.10	76	1431.87
-77	5602677.00	0	32650.80	77	1385.37
-76	5137343.00	1	31030.40	78	1340.68
-75	4713762.00	2	29500.10	79	1297.64
-74	4327977.00	3	28054.20	80	1256.17
-73	3966352.00	4	26687.60	81	1216.23
-72	3655631.00	5	25395.50	82	1177.75
-71	3362963.00	6	24172.70	83	1140.71
-70	3095611.00	7	23016.00	84	1104.99
-69	2851363.00	8	21921.70	85	1070.58
-68	2627981.00	9	20885.20	86	1037.40
-67	2423519.00	10	19903.50	87	1005.40
-66	2236398.00	11	18973.60	88	974.56
-65	2064919.00	12	18092.60	89	944.81
-64	1907728.00	13	17257.40	90	916.11
-63	1763539.00	14	16465.10	91	888.41
-62	1631173.00	15	15714.00	92	861.70
-61	1509639.00	16	15001.20	93	835.93
-60	1397935.00	17	14324.60	94	811.03
-59	1295239.00	18	13682.60	95	786.99
-58	1200732.00	19	13052.80	96	763.79
-57	1113744.00	20	12493.70	97	741.38
-56	1033619.00	21	11943.30	98	719.74
-55	959789.00	22	11420.00	99	698.82
-54	891689.00	23	10922.70	100	678.63
-53	828865.00	24	10449.90	101	659.10
-52	770880.00	25	10000.00	102	640.23
-51	717310.00	26	9572.00	103	622.00
-50	667828.00	27	9164.70	104	604.36
-49	622055.00	28	8777.00	105	587.31
-48	579718.00	29	8407.70	106	570.82
-47	540530.00	30	8056.00	107	554.86
-46	504230.00	31	7720.90	108	539.44
-45	470609.00	32	7401.70	109	524.51
-44	439445.00	33	7097.20	110	510.06
-43	410532.00	34	6807.00	111	496.08
-42	383712.00	35	6530.10	112	482.55
-41	358806.00	36	6266.10	113	469.45
-40	335671.00	37	6014.20	114	456.76
-39	314179.00	38	5773.70	115	444.48
-38	294193.00	39	5544.10	116	432.58
-37	275605.00	40	5324.90	117	421.06
-36	258307.00	41	5115.60	118	409.90
-35	242195.00	42	4915.50	119	399.08
-34	227196.00	43	4724.30	120	388.59
-33	213219.00	44	4541.60	121	378.44
-32	200184.00	45	4366.90	122	368.59
-31	188026.00	46	4199.90	123	359.05
-30	176683.00	47	4040.10	124	349.79
-29	166091.00	48	3887.20	125	340.82
-28	156199.00	49	3741.10	126	332.11
-27	146959.00	50	3601.00	127	323.67
-26	138322.00	51	3466.90	128	315.48
-25	130243.00	52	3338.60	129	307.53
-24	122687.00	53	3215.60	130	299.82
-23	115613.00	54	3097.90	131	292.34
-22	108991.00	55	2985.10	132	285.08
-21	102787.00	56	2876.90	133	278.03
-20	96974.00	57	2773.20	134	271.19
-19	91525.00	58	2673.90	135	264.54
-18	86415.00	59	2578.50	136	258.09
-17	81621.00	60	2487.10	137	251.82
-16	77121.00	61	2399.40	138	245.74
-15	72895.00	62	2315.20	139	239.82
-14	68927.00	63	2234.70	140	234.08
-13	65198.00	64	2156.70	141	228.50
-12	61693.00	65	2082.30	142	223.08
-11	58397.00	66	2010.80	143	217.80
-10	55298.00	67	1942.10	144	212.68
-9	52380.00	68	1876.00	145	207.70
-8	49633.00	69	1812.60	146	202.86
-7	47047.00	70	1751.60	147	198.15
-6	44610.00	71	1693.00	148	193.57
-5	42314.60	72	1636.63	149	189.12
-4	40149.50	73	1582.41	150	184.79

INTERCHANGEABLE BetaCURVE R – T SPECIFICATION

.1K1A1

100 Ohms @ 25°C ± 0.2° -20 to 50°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80	16,921	0	256.3	71	24.10
-79	15,824	1	246.2	72	23.46
-78	14,806	2	236.5	73	22.83
-77	13,859	3	227.3	74	22.23
-76	12,978	4	218.4	75	21.64
-75	12,159	5	210.0	76	21.07
-74	11,397	6	201.9	77	20.52
-73	10,687	7	194.2	78	19.98
-72	10,025	8	186.8	79	19.47
-71	9,409	9	179.8	80	18.97
-70	8,834	10	173.0	81	18.48
-69	8,298	11	166.6	82	18.01
-68	7,798	12	160.4	83	17.55
-67	7,331	13	154.5	84	17.11
-66	6,895	14	148.8	85	16.68
-65	6,487	15	143.4	86	16.26
-64	6,106	16	138.2	87	15.86
-63	5,750	17	133.2	88	15.47
-62	5,416	18	128.4	89	15.09
-61	5,104	19	123.8	90	14.72
-60	4,812	20	119.4	91	14.36
-59	4,538	21	115.2	92	14.01
-58	4,282	22	111.2	93	13.67
-57	4,041	23	107.3	94	13.34
-56	3,816	24	103.6	95	13.02
-55	3,604	25	100.0	96	12.71
-54	3,405	26	96.57	97	12.41
-53	3,219	27	93.27	98	12.12
-52	3,044	28	90.11	99	11.84
-51	2,879	29	87.07	100	11.56
-50	2,724	30	84.15		
-49	2,579	31	81.34		
-48	2,442	32	78.64		
-47	2,313	33	76.04		
-46	2,192	34	73.54		
-45	2,078	35	71.14		
-44	1,970	36	68.83		
-43	1,869	37	66.61		
-42	1,773	38	64.47		
-41	1,683	39	62.41		
-40	1,598	40	60.43		
-39	1,518	41	58.52		
-38	1,442	42	56.68		
-37	1,371	43	54.91		
-36	1,303	44	53.20		
-35	1,240	45	51.55		
-34	1,179	46	49.97		
-33	1,122	47	48.44		
-32	1,068	48	46.96		
-31	1,017	49	45.54		
-30	968.9	50	44.17		
-29	923.1	51	42.85		
-28	879.8	52	41.57		
-27	838.8	53	40.34		
-26	799.9	54	39.15		
-25	763.0	55	38.00		
-24	728.1	56	36.89		
-23	694.9	57	35.82		
-22	663.5	58	34.79		
-21	633.6	59	33.79		
-20	605.3	60	32.83		
-19	578.4	61	31.89		
-18	552.8	62	30.99		
-17	528.6	63	30.12		
-16	505.5	64	29.28		
-15	483.5	65	28.46		
-14	462.7	66	27.68		
-13	442.8	67	26.91		
-12	423.9	68	26.18		
-11	406.0	69	25.46		
-10	388.8	70	24.77		
-9	372.6				
-8	357.0				
-7	342.2				
-6	328.2				
-5	314.7				
-4	301.9				
-3	289.7				
-2	278.1				
-1	266.9				

.3K1A1

300 Ohms @ 25°C ± 0.2° -20 to 50°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80	50,763	0	769.0	71	72.3
-79	47,473	1	738.6	72	70.4
-78	44,417	2	709.5	73	68.5
-77	41,576	3	681.8	74	66.7
-76	38,935	4	655.3	75	64.9
-75	36,477	5	630.0	76	63.2
-74	34,190	6	605.8	77	61.6
-73	32,060	7	582.7	78	60.0
-72	30,076	8	560.5	79	58.4
-71	28,227	9	539.4	80	56.9
-70	26,503	10	519.1	81	55.4
-69	24,895	11	499.7	82	54.0
-68	23,394	12	481.2	83	52.7
-67	21,993	13	463.4	84	51.3
-66	20,684	14	446.4	85	50.0
-65	19,461	15	430.1	86	48.8
-64	18,318	16	414.5	87	47.6
-63	17,249	17	399.6	88	46.4
-62	16,248	18	385.2	89	45.3
-61	15,312	19	371.5	90	44.1
-60	14,436	20	358.3	91	43.1
-59	13,614	21	345.7	92	42.0
-58	12,845	22	333.5	93	41.0
-57	12,123	23	321.9	94	40.0
-56	11,447	24	310.7	95	39.1
-55	10,812	25	300.0	96	38.1
-54	10,216	26	289.7	97	37.2
-53	9,656	27	279.8	98	36.4
-52	9,133	28	270.3	99	35.5
-51	8,637	29	261.2	100	34.7
-50	8,173	30	252.4		
-49	7,737	31	244.0		
-48	7,326	32	235.9		
-47	6,940	33	228.1		
-46	6,576	34	220.6		
-45	6,234	35	213.4		
-44	5,911	36	206.5		
-43	5,607	37	199.8		
-42	5,320	38	193.4		
-41	5,050	39	187.2		
-40	4,795	40	181.3		
-39	4,554	41	175.5		
-38	4,327	42	170.0		
-37	4,113	43	164.7		
-36	3,910	44	159.6		
-35	3,719	45	154.7		
-34	3,538	46	149.9		
-33	3,367	47	145.3		
-32	3,205	48	140.9		
-31	3,052	49	136.6		
-30	2,907	50	132.5		
-29	2,769	51	128.5		
-28	2,639	52	124.7		
-27	2,516	53	121.0		
-26	2,400	54	117.5		
-25	2,289	55	114.0		
-24	2,184	56	110.7		
-23	2,085	57	107.5		
-22	1,990	58	104.4		
-21	1,901	59	101.4		
-20	1,816	60	98.5		
-19	1,735	61	95.7		
-18	1,659	62	93.0		
-17	1,586	63	90.4		
-16	1,516	64	87.8		
-15	1,451	65	85.4		
-14	1,388	66	83.0		
-13	1,328	67	80.7		
-12	1,272	68	78.5		
-11	1,218	69	76.4		
-10	1,167	70	74.3		
-9	1,118				
-8	1,071				
-7	1,027				
-6	984.5				
-5	944.2				
-4	905.8				
-3	869.1				
-2	834.2				
-1	800.8				

1K2A1

1,000 Ohms @ 25°C ± 0.2° 0 - 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80	233,516	0	2,691	71	224.5
-79	217,298	1	2,579	72	218.1
-78	202,147	2	2,472	73	212.0
-77	188,227	3	2,371	74	206.1
-76	175,258	4	2,274	75	200.4
-75	163,454	5	2,182	76	194.9
-74	152,435	6	2,094	77	189.5
-73	142,234	7	2,009	78	184.3
-72	132,779	8	1,929	79	179.3
-71	124,017	9	1,853	80	174.5
-70	115,888	10	1,780	81	169.8
-69	108,347	11	1,710	82	165.2
-68	101,343	12	1,643	83	160.8
-67	94,837	13	1,579	84	156.6
-66	88,793	14	1,519	85	152.4
-65	83,171	15	1,460	86	148.4
-64	77,942	16	1,405	87	144.6
-63	73,075	17	1,351	88	140.8
-62	68,544	18	1,300	89	137.2
-61	64,321	19	1,252	90	133.6
-60	60,386	20	1,205	91	130.2
-59	56,717	21	1,160	92	126.9
-58	53,294	22	1,118	93	123.7
-57	50,099	23	1,077	94	120.6
-56	47,116	24	1,038	95	117.5
-55	44,329	25	1,000	96	114.6
-54	41,725	26	964.0	97	111.7
-53	39,289	27	929.5	98	109.0
-52	37,012	28	896.3	99	106.3
-51	34,881	29	864.6	100	103.7
-50	32,886	30	834.2	101	101.2
-49	31,016	31	804.9	102	98.7
-48	29,266	32	776.9	103	96.3
-47	27,624	33	750.0	104	94.0
-46	26,085	34	724.1	105	91.7
-45	24,642	35	699.3	106	89.6
-44	23,286	36	675.5	107	87.4
-43	22,014	37	652.6	108	85.4
-42	20,819	38	630.6	109	83.4
-41	19,697	39	609.5	110	81.4
-40	18,641	40	589.2	111	79.5
-39	17,649	41	569.6	112	77.7
-38	16,716	42	550.8	113	75.9
-37	15,837	43	532.8	114	74.2
-36	15,010	44	515.4	115	72.5
-35	14,231	45	498.7	116	70.8
-34	13,498	46	482.6	117	69.2
-33	12,806	47	467.1	118	67.7
-32	12,154	48	452.2	119	66.1
-31	11,540	49	437.8	120	64.7
-30	10,960	50	424.0	121	63.2
-29	10,412	51	410.7	122	61.8
-28	9,896	52	397.8	123	60.5
-27	9,408	53	385.5	124	59.2
-26	8,947	54	373.5	125	57.9
-25	8,511	55	362.0	126	56.6
-24	8,100	56	351.0	127	55.4
-23	7,709	57	340.3	128	54.2
-22	7,341	58	330.0	129	53.0
-21	6,992	59	320.0	130	51.9
-20	6,662	60	310.4	131	50.8
-19	6,350	61	301.2	132	49.7
-18	6,053	62	292.3	133	48.7
-17	5,773	63	283.6	134	47.7
-16	5,507	64	275.3	135	46.7
-15	5,255	65	267.3	136	45.7
-14	5,016	66	259.5	137	44.8
-13	4,709	67	252.0	138	43.9
-12	4,574	68	244.8	139	43.0
-11	4,369	69	237.8	140	42.1
-10	4,175	70	231.0	141	41.2
-9	3,991			142	40.4
-8	3,816			143	39.6
-7	3,649			144	38.8
-6	3,491			145	38.0
-5	3,341			146	37.3
-4	3,198			147	36.5
-3	3,061			148	35.8
-2	2,932			149	35.1
-1	2,808			150	34.4

INTERCHANGEABLE BetaCURVE R – T SPECIFICATION

1K7A1

1,000 Ohms @ 25°C ± 0.2° 0 - 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80		0	2,825	71	209.6
-79		1	2,702	72	203.5
-78		2	2,585	73	197.5
-77		3	2,473	74	191.8
-76		4	2,367	75	186.2
-75		5	2,266	76	180.9
-74		6	2,170	77	175.7
-73		7	2,079	78	170.7
-72		8	1,992	79	165.8
-71		9	1,909	80	161.2
-70		10	1,830	81	156.6
-69		11	1,755	82	152.3
-68		12	1,683	83	148.0
-67		13	1,615	84	144.0
-66		14	1,549	85	140.0
-65		15	1,487	86	136.2
-64		16	1,428	87	132.5
-63		17	1,371	88	128.9
-62		18	1,317	89	125.4
-61		19	1,265	90	122
-60		20	1,216	91	118.8
-59		21	1,169	92	115.6
-58		22	1,124	93	112.6
-57		23	1,081	94	109.6
-56		24	1,039	95	106.7
-55	54,143	25	1,000	96	104.0
-54	50,785	26	962.3	97	101.3
-53	47,657	27	926.2	98	98.7
-52	44,741	28	891.7	99	96.1
-51	42,022	29	858.7	100	93.7
-50	39,486	30	827.0	101	91.3
-49	37,119	31	796.7	102	89.0
-48	34,908	32	767.6	103	86.8
-47	32,843	33	739.8	104	84.6
-46	30,914	34	713.2	105	82.5
-45	29,109	35	687.6	106	80.4
-44	27,421	36	663.1	107	78.4
-43	25,842	37	639.6	108	76.5
-42	24,364	38	617.1	109	74.6
-41	22,979	39	595.4	110	72.8
-40	21,681	40	574.7	111	71.1
-39	20,465	41	554.8	112	69.4
-38	19,324	42	535.6	113	67.7
-37	18,255	43	517.3	114	66.1
-36	17,250	44	499.6	115	64.5
-35	16,308	45	482.7	116	63.0
-34	15,422	46	466.4	117	61.5
-33	14,590	47	450.7	118	60.1
-32	13,809	48	435.7	119	58.7
-31	13,073	49	421.3	120	57.3
-30	12,382	50	407.4	121	56.0
-29	11,731	51	39.4	122	54.7
-28	11,118	52	381.1	123	53.4
-27	10,541	53	368.7	124	52.2
-26	9,998	54	356.8	125	51.0
-25	9,485	55	345.4	126	49.9
-24	9,092	56	334.3	127	48.8
-23	8,547	57	323.7	128	47.7
-22	8,117	58	313.5	129	46.6
-21	7,712	59	303.6	130	45.6
-20	7,329	60	294.1	131	44.6
-19	6,967	61	285.0	132	43.6
-18	6,626	62	276.1	133	42.7
-17	6,303	63	267.6	134	41.7
-16	5,998	64	259.4	135	40.8
-15	5,709	65	251.5	136	39.9
-14	5,436	66	243.9	137	39.1
-13	5,178	67	236.6	138	38.3
-12	4,933	68	229.5	139	37.4
-11	4,702	69	222.6	140	36.6
-10	4,482	70	216.0	141	35.9
-9	4,275			142	35.1
-8	4,078			143	34.4
-7	3,891			144	33.7
-6	3,714			145	33.0
-5	3,546			146	32.3
-4	3,386			147	31.6
-3	3,235			148	31.0
-2	3,091			149	30.4
-1	2,955			150	29.8

2K3A1B

2,000 Ohms @ 25°C ± 0.2° 0 - 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80	144,351	0	6,530.3	71	338.60
-79	1,321,342	1	6,206.3	72	327.33
-78	1,210,414	2	5,900.3	73	316.49
-77	1,109,594	3	5,611.1	74	306.07
-76	1,017,816	4	5,337.7	75	296.03
-75	934,245	5	5,079.2	76	286.38
-74	858,099	6	4,834.7	77	277.10
-73	788,647	7	4,603.4	78	268.16
-72	725,287	8	4,384.5	79	259.55
-71	667,436	9	4,177.3	80	251.26
-70	614,575	10	3,980.9	81	243.28
-69	566,242	11	3,794.9	82	235.17
-68	522,033	12	3,618.6	83	228.17
-67	481,566	13	3,451.6	84	221.04
-66	444,506	14	3,293.2	85	214.15
-65	410,531	15	3,142.9	86	207.52
-64	379,380	16	3,000.3	87	201.12
-63	350,786	17	2,865.1	88	194.96
-62	324,544	18	2,736.6	89	189.01
-61	300,425	19	2,614.6	90	183.27
-60	278,258	20	2,498.8	91	177.73
-59	257,873	21	2,388.7	92	172.39
-58	239,106	22	2,284.0	93	167.24
-57	221,803	23	2,184.5	94	162.26
-56	205,913	24	2,090.0	95	157.82
-55	191,239	25	2,000.0	96	152.82
-54	177,703	26	1,914.4	97	148.34
-53	165,213	27	1,832.9	98	144.01
-52	153,681	28	1,755.4	99	139.83
-51	143,024	29	1,681.5	100	135.79
-50	133,177	30	1,611.2	101	131.89
-49	124,068	31	1,544.1	102	128.12
-48	115,640	32	1,480.3	103	124.47
-47	107,838	33	1,419.4	104	120.94
-46	100,611	34	1,361.3	105	117.53
-45	93,914	35	1,306.0	106	114.24
-44	87,704	36	1,253.2	107	111.05
-43	81,945	37	1,202.8	108	107.96
-42	76,599	38	1,154.7	109	104.98
-41	71,635	39	1,108.8	110	102.09
-40	67,023	40	1,064.9	111	99.29
-39	62,738	41	1,023.0	112	96.59
-38	58,753	42	983.02	113	93.97
-37	55,044	43	944.78	114	91.43
-36	51,595	44	908.25	115	88.98
-35	48,382	45	873.31	116	86.60
-34	45,388	46	839.90	117	84.29
-33	42,598	47	807.95	118	82.06
-32	39,997	48	777.37	119	79.90
-31	37,571	49	748.12	120	77.80
-30	35,306	50	720.13	121	75.77
-29	33,192	51	693.33	122	73.80
-28	31,217	52	667.66	123	71.89
-27	29,372	53	643.07	124	70.04
-26	27,647	54	619.53	125	68.25
-25	26,034	55	596.96	126	66.51
-24	24,524	56	575.34	127	64.82
-23	23,111	57	554.61	128	63.18
-22	21,789	58	534.73	129	61.59
-21	20,549	59	515.67	130	60.05
-20	19,388	60	497.38	131	58.56
-19	18,299	61	479.84	132	57.10
-18	17,278	62	463.00	133	55.69
-17	16,320	63	446.85	134	54.32
-16	15,421	64	431.34	135	53.00
-15	14,576	65	416.44	136	51.70
-14	13,783	66	402.14	137	50.45
-13	13,038	67	388.40	138	49.23
-12	12,337	68	375.20	139	48.05
-11	11,678	69	362.51	140	46.90
-10	11,058	70	350.32	141	45.79
-9	10,475			142	44.70
-8	9,926.0			143	43.65
-7	9,408.8			144	42.62
-6	8,921.8			145	41.63
-5	8,462.6			146	40.66
-4	8,029.8			147	39.72
-3	7,621.7			148	38.80
-2	7,236.7			149	37.91
-1	6,873.2			150	37.04

2.2K3A1B

2,252 Ohms @ 25°C ± 0.2° 0 - 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80	1,643,356	0	7,353.0	71	381.26
-79	1,503,707	1	6,988.1	72	368.57
-78	1,376,943	2	6,643.4	73	356.36
-77	1,261,723	3	6,317.8	74	344.62
-76	1,156,930	4	6,010.0	75	333.32
-75	1,061,539	5	5,719.1	76	322.46
-74	974,660	6	5,443.7	77	311.99
-73	893,222	7	5,183.2	78	301.92
-72	823,248	8	4,936.8	79	292.23
-71	757,339	9	4,703.3	80	282.89
-70	697,132	10	4,482.3	81	273.89
-69	642,127	11	4,272.9	82	265.23
-68	591,821	12	4,074.5	83	256.89
-67	545,777	13	3,886.4	84	248.84
-66	503,637	14	3,707.9	85	241.09
-65	465,020	15	3,538.8	86	233.62
-64	429,620	16	3,378.3	87	226.42
-63	397,149	17	3,225.9	88	219.47
-62	367,340	18	3,081.3	89	212.77
-61	339,971	19	2,939.5	90	206.31
-60	314,815	20	2,813.6	91	200.07
-59	291,688	21	2,689.6	92	194.06
-58	270,405	22	2,571.8	93	188.25
-57	250,815	23	2,459.8	94	182.64
-56	232,771	24	2,353.3	95	177.23
-55	216,145	25	2,252.0	96	172.01
-54	200,808	26	2,155.6	97	166.96
-53	186,660	27	2,063.9	98	162.08
-52	173,602	28	1,976.6	99	157.37
-51	161,538	29	1,893.4	100	152.83
-50	150,395	30	1,814.2	101	148.43
-49	140,087	31	1,738.3	102	144.18
-48	130,553	32	1,666.9	103	140.07
-47	121,727	33	1,598.3	104	136.10
-46	113,553	34	1,532.9	105	132.26
-45	105,981	35	1,470.6	106	128.55
-44	98,963	36	1,411.1	107	124.95
-43	92,452	37	1,354.4	108	121.48
-42	86,412	38	1,300.2	109	118.12
-41	80,803	39	1,248.5	110	114.87
-40	75,593	40	1,199.2	111	111.72
-39	70,753	41	1,152.0	112	108.67
-38	66,252	42	1,107.0	113	105.72
-37	62,066	43	1,063.9	114	102.86
-36	58,171	44	1,022.8	115	100.10
-35	54,542	45	983.42	116	97.418
-34	51,164	46	945.81	117	94.822
-33	48,017	47	909.83	118	92.308
-32	45,081	48	875.40	119	89.873
-31	42,343	49	842.47	120	87.511
-30	39,789	50	810.94	121	85.224
-29	37,404	51	780.75	122	83.007
-28	35,176	52	751.85	123	80.857
-27	33,095	53	724.16	124	78.772
-26	31,150	54	697.65	125	76.752
-25	29,331	55	672.24	126	74.792
-24	27,629	56	647.88	127	72.890
-23	26,036	57	624.53	128	71.046
-22	24,545	58	602.15	129	69.256
-21	23,148	59	580.68	130	67.520
-20	21,839	60	560.09	131	65.836
-19	20,611	61	540.34	132	64.200
-18	19,461	62	521.38	133	62.613
-17	18,381	63	503.18	134	61.071
-16	17,368	64	485.70	135	59.575
-15	16,416	65	468.94	136	58.122
-14	15,522	66	452.82	137	56.711
-13	14,683	67	437.35	138	55.340
-12	13,893	68	422.48	139	54.008
-11	13,151	69	408.20	140	52.715
-10	12,453	70	394.47	141	51.458
-9	11,796			142	50.237
-8	11,177			143	49.049
-7	10,595			144	47.895
-6	10,146			145	46.774
-5	9,529.2			146	45.684
-4	9,041.7			147	44.623
-3	8,582.0			148	43.592
-2	8,148.4			149	42.589
-1	7,739.2			150	41.614

INTERCHANGEABLE BetaCURVE R – T SPECIFICATION

3K3A1B

3,000 Ohms @ 25°C ± 0.2° 0 - 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80	2,189,062	0	9,795.2	71	507.90
-79	2,003,162	1	9,309.1	72	490.99
-78	1,834,293	2	8,850.0	73	474.72
-77	1,680,803	3	8,416.3	74	459.08
-76	1,541,203	4	8,006.3	75	444.04
-75	1,414,129	5	7,618.7	76	429.56
-74	1,298,393	6	7,251.8	77	415.61
-73	1,189,906	7	6,904.8	78	402.20
-72	1,096,689	8	6,576.5	79	389.29
-71	1,008,889	9	6,265.6	80	376.85
-70	928,683	10	5,971.1	81	364.87
-69	855,409	11	5,692.1	82	353.33
-68	788,394	12	5,427.8	83	342.21
-67	727,056	13	5,177.2	84	331.50
-66	670,919	14	4,939.5	85	321.17
-65	619,476	15	4,714.2	86	311.22
-64	572,319	16	4,500.3	87	301.62
-63	529,062	17	4,297.4	88	292.37
-62	489,352	18	4,104.8	89	283.44
-61	452,892	19	3,915.9	90	274.83
-60	419,380	20	3,748.1	91	266.52
-59	388,572	21	3,583.0	92	258.51
-58	360,219	22	3,426.0	93	250.78
-57	334,123	23	3,276.8	94	243.31
-56	310,086	24	3,135.0	95	236.10
-55	287,937	25	3,000.0	96	229.14
-54	267,507	26	2,871.6	97	222.41
-53	248,660	27	2,749.4	98	215.92
-52	231,264	28	2,633.1	99	209.65
-51	215,193	29	2,522.3	100	203.59
-50	200,348	30	2,416.8	101	197.73
-49	186,617	31	2,316.3	102	192.07
-48	173,916	32	2,220.5	103	186.60
-47	162,159	33	2,129.2	104	181.31
-46	151,269	34	2,042.1	105	176.19
-45	141,183	35	1,959.0	106	171.24
-44	131,833	36	1,879.8	107	166.46
-43	123,160	37	1,804.3	108	161.83
-42	115,114	38	1,732.1	109	157.35
-41	107,642	39	1,663.2	110	153.02
-40	100,701	40	1,597.5	111	148.82
-39	94,254	41	1,534.7	112	144.77
-38	88,258	42	1,474.6	113	140.83
-37	82,682	43	1,417.3	114	137.03
-36	77,492	44	1,362.5	115	133.34
-35	72,658	45	1,310.07	116	129.775
-34	68,159	46	1,259.96	117	126.317
-33	63,966	47	1,212.02	118	122.969
-32	60,055	48	1,166.16	119	119.724
-31	56,408	49	1,122.30	120	116.578
-30	53,005	50	1,080.30	121	113.531
-29	49,827	51	1,040.08	122	110.577
-28	46,860	52	1,001.58	123	107.713
-27	44,088	53	964.69	124	104.937
-26	41,497	54	929.38	125	102.246
-25	39,073	55	895.52	126	99.634
-24	36,806	56	863.08	127	97.100
-23	34,684	57	831.97	128	94.644
-22	32,697	58	802.16	129	92.260
-21	30,836	59	773.56	130	89.946
-20	29,092	60	746.12	131	87.703
-19	27,458	61	719.82	132	85.524
-18	25,924	62	694.55	133	83.410
-17	24,486	63	670.31	134	81.356
-16	23,136	64	647.02	135	79.363
-15	21,868	65	624.69	136	77.427
-14	20,678	66	603.23	137	75.547
-13	19,559	67	582.62	138	73.721
-12	18,508	68	562.81	139	71.947
-11	17,519	69	543.78	140	70.225
-10	16,589	70	525.49	141	68.550
-9	15,714			142	66.923
-8	14,890			143	65.341
-7	14,114			144	63.804
-6	13,383			145	62.309
-5	12,694.4			146	60.857
-4	10,044.8			147	59.445
-3	11,432.6			148	58.071
-2	10,854.8			149	56.735
-1	10,309.8			150	55.436

5K3A1B

5,000 Ohms @ 25°C ± 0.2° 0 - 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80	3,648,437	0	16,325.4	71	846.50
-79	3,338,603	1	15,515.2	72	818.31
-78	3,057,155	2	14,750.0	73	791.21
-77	2,801,338	3	14,027.1	74	765.17
-76	2,568,672	4	13,343.8	75	740.06
-75	2,356,881	5	12,697.8	76	715.93
-74	2,163,988	6	12,086.3	77	692.68
-73	1,983,176	7	11,508.0	78	670.34
-72	1,827,816	8	10,960.8	79	648.82
-71	1,681,481	9	10,422.6	80	628.09
-70	1,547,805	10	9,951.8	81	608.11
-69	1,425,681	11	9,486.8	82	588.88
-68	1,313,991	12	9,046.3	83	570.36
-67	1,211,760	13	8,628.7	84	552.50
-66	1,118,199	14	8,232.5	85	535.29
-65	1,032,459	15	7,857.0	86	518.70
-64	953,864	16	7,500.6	87	502.70
-63	881,770	17	7,162.3	88	487.28
-62	815,586	18	6,841.3	89	472.40
-61	754,820	19	6,536.4	90	458.06
-60	698,967	20	6,246.8	91	444.20
-59	647,619	21	5,971.6	92	430.85
-58	600,366	22	5,710.0	93	417.96
-57	556,872	23	5,461.3	94	405.51
-56	516,809	24	5,225.0	95	393.49
-55	479,895	25	5,000.0	96	381.89
-54	445,844	26	4,786.0	97	370.69
-53	414,433	27	4,582.4	98	359.87
-52	385,440	28	4,388.5	99	349.41
-51	358,655	29	4,203.9	100	339.32
-50	333,914	30	4,028.0	101	329.55
-49	311,028	31	3,860.5	102	320.12
-48	289,859	32	3,700.8	103	311.00
-47	270,265	33	3,548.6	104	302.18
-46	252,115	34	3,403.5	105	293.65
-45	235,305	35	3,265.1	106	285.41
-44	219,722	36	3,133.1	107	277.43
-43	205,266	37	3,007.1	108	269.72
-42	191,856	38	2,886.9	109	262.26
-41	179,403	39	2,772.1	110	255.03
-40	167,835	40	2,662.4	111	248.04
-39	157,089	41	2,557.8	112	241.28
-38	147,096	42	2,457.7	113	234.38
-37	137,803	43	2,362.1	114	228.38
-36	129,153	44	2,270.8	115	222.24
-35	121,097	45	2,183.45	116	216.29
-34	113,598	46	2,099.93	117	210.53
-33	106,609	47	2,020.04	118	204.95
-32	100,092	48	1,943.60	119	199.54
-31	94,013	49	1,870.50	120	194.30
-30	88,342	50	1,800.49	121	189.22
-29	83,046	51	1,733.46	122	184.30
-28	78,100	52	1,669.30	123	179.52
-27	73,480	53	1,607.81	124	174.89
-26	69,161	54	1,548.96	125	170.41
-25	65,122	55	1,492.54	126	166.06
-24	61,343	56	1,438.46	127	161.83
-23	57,807	57	1,386.62	128	157.74
-22	54,496	58	1,336.93	129	153.77
-21	51,394	59	1,289.26	130	149.91
-20	48,487	60	1,243.53	131	146.17
-19	45,763	61	1,199.70	132	139.02
-18	43,207	62	1,157.59	133	135.59
-17	40,810	63	1,117.18	134	135.59
-16	38,561	64	1,078.37	135	132.27
-15	36,447	65	1,041.15	136	129.04
-14	34,464	66	1,005.38	137	125.91
-13	32,599	67	971.03	138	122.87
-12	30,846	68	938.02	139	119.91
-11	29,199	69	906.30	140	117.04
-10	27,649	70	875.81	141	114.25
-9	26,190			142	111.54
-8	24,817			143	108.90
-7	23,523			144	106.34
-6	22,305			145	103.85
-5	21,157.3			146	101.43
-4	20,074.7			147	99.074
-3	19,054.3			148	96.785
-2	10,091.4			149	94.559
-1	17,183.1			150	92.393

10K3A1B

10,000 Ohms @ 25°C ± 0.2° 0 - 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80	7,296,874	0	32,650.8	71	1,693.00
-79	6,677,205	1	31,030.4	72	1,636.63
-78	6,114,311	2	29,500.1	73	1,582.41
-77	5,602,677	3	28,054.2	74	1,530.28
-76	5,137,343	4	26,687.6	75	1,480.12
-75	4,713,762	5	25,395.5	76	1,431.87
-74	4,327,977	6	24,172.7	77	1,385.37
-73	3,966,352	7	23,016.0	78	1,340.68
-72	3,655,631	8	21,921.7	79	1,297.64
-71	3,362,963	9	20,855.2	80	1,256.17
-70	3,095,611	10	19,903.5	81	1,216.23
-69	2,851,363	11	18,973.6	82	1,177.75
-68	2,627,981	12	18,092.6	83	1,140.71
-67	2,423,519	13	17,257.4	84	1,104.99
-66	2,236,398	14	16,465.1	85	1,070.58
-65	2,064,919	15	15,714.0	86	1,037.40
-64	1,907,728	16	15,001.2	87	1,005.40
-63	1,763,539	17	14,324.6	88	974.56
-62	1,631,173	18	13,682.6	89	944.81
-61	1,509,639	19	13,052.8	90	916.11
-60	1,397,935	20	12,493.7	91	888.41
-59	1,295,239	21	11,943.3	92	861.70
-58	1,200,732	22	11,420.0	93	835.93
-57	1,113,744	23	10,922.7	94	811.03
-56	1,033,619	24	10,449.9	95	786.99
-55	959,789	25	10,000.0	96	763.79
-54	891,689	26	9,572.0	97	741.38
-53	828,865	27	9,164.7	98	719.74
-52	770,880	28	8,777.0	99	698.82
-51	717,310	29	8,407.7	100	678.63
-50	667,828	30	8,056.0	101	659.10

INTERCHANGEABLE BetaCURVE R – T SPECIFICATION

10K4A1B

10,000 Ohms @ 25°C ± 0.2° 0 - 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80		0	29,490	71	1,928
-79		1	28,157	72	1,868
-78		2	26,891	73	1,810
-77		3	25,689	74	1,754
-76		4	24,547	75	1,700
-75		5	23,462	76	1,648
-74		6	22,430	77	1,598
-73		7	21,450	78	1,550
-72		8	20,517	79	1,503
-71		9	19,631	80	1,458
-70		10	18,787	81	1,414
-69		11	17,983	82	1,372
-68		12	17,219	83	1,332
-67		13	16,490	84	1,293
-66		14	14,797	85	1,255
-65		15	15,136	86	1,218
-64		16	14,507	87	1,183
-63		17	13,906	88	1,149
-62		18	13,334	89	1,116
-61		19	12,788	90	1,084
-60		20	12,268	91	1,053
-59		21	11,771	92	1,023
-58		22	11,297	93	994.5
-57		23	10,845	94	966.6
-56		24	10,413	95	939.6
-55	608,583	25	10,000	96	913.5
-54	570,307	26	9,606	97	888.2
-53	534,660	27	9,229	98	863.8
-52	501,462	28	8,869	99	840.1
-51	470,511	29	8,525	100	817.2
-50	441,667	30	8,197	101	795.0
-49	414,755	31	7,882	102	773.5
-48	389,650	32	7,581	103	752.7
-47	366,209	33	7,293	104	732.6
-46	344,314	34	7,018	105	713.0
-45	323,859	35	6,754	106	694.1
-44	304,743	36	6,501	107	675.8
-43	286,859	37	6,260	108	658.0
-42	270,136	38	6,028	109	640.8
-41	254,485	39	5,806	110	624.1
-40	239,831	40	5,594	111	607.9
-39	226,105	41	5,390	112	592.2
-38	213,243	42	5,198	113	577.0
-37	201,187	43	5,007	114	562.2
-36	189,887	44	4,828	115	547.9
-35	179,280	45	4,256	116	534.0
-34	169,330	46	4,490	117	520.6
-33	159,990	47	4,332	118	507.5
-32	151,219	48	4,180	119	494.8
-31	142,978	49	4,034	120	482.5
-30	135,233	50	3,893	121	470.5
-29	127,952	51	3,759	122	458.9
-28	121,104	52	3,629	123	447.6
-27	114,662	53	3,505	124	436.7
-26	108,599	54	3,386	125	426.0
-25	102,890	55	3,271	126	415.7
-24	97,513	56	3,160	127	405.7
-23	92,449	57	3,054	128	395.9
-22	87,675	58	2,954	129	386.4
-21	83,173	59	2,854	130	377.2
-20	78,930	60	2,760	131	368.3
-19	74,926	61	2,669	132	359.6
-18	71,148	62	2,582	133	351.1
-17	67,581	63	2,498	134	342.9
-16	64,212	64	2,417	135	334.9
-15	61,030	65	2,339	136	327.1
-14	58,024	66	2,264	137	319.6
-13	55,182	67	2,191	138	312.2
-12	52,495	68	2,122	139	305.1
-11	49,549	69	2,055	140	298.1
-10	47,459	70	1,990	141	291.4
-9	45,274			142	284.8
-8	43,119			143	278.4
-7	41,079			144	272.1
-6	39,147			145	266.0
-5	37,316			146	260.1
-4	35,580			147	254.4
-3	33,935			148	248.8
-2	32,375			149	243.3
-1	30,895			150	238.0

30K5A1B

30,000 Ohms @ 25°C ± 0.2° 0 - 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80		0	94,980	71	5,179
-79		1	90,413	72	5,007
-78		2	86,090	73	4,841
-77		3	81,996	74	4,682
-76		4	78,119	75	4,528
-75		5	74,445	76	4,381
-74		6	70,964	77	4,239
-73		7	67,664	78	4,102
-72		8	64,534	79	3,970
-71		9	61,749	80	3,843
-70		10	58,749	81	3,721
-69		11	56,076	82	3,603
-68		12	53,539	83	3,489
-67		13	51,129	84	3,380
-66		14	48,841	85	3,274
-65		15	46,666	86	3,172
-64		16	44,600	87	3,074
-63		17	42,637	88	2,979
-62		18	40,769	89	2,888
-61		19	38,993	90	2,800
-60		20	37,304	91	2,715
-59		21	35,696	92	2,633
-58		22	34,166	93	2,554
-57		23	32,709	94	2,477
-56		24	31,321	95	2,403
-55	2,308,769	25	30,000	96	2,332
-54	2,221,831	26	28,741	97	2,263
-53	2,074,434	27	27,541	98	2,197
-52	1,937,724	28	26,398	99	2,132
-51	1,810,800	29	25,307	100	2,070
-50	1,692,965	30	24,268	101	2,010
-49	1,583,477	31	23,276	102	1,952
-48	1,481,708	32	22,329	103	1,896
-47	1,387,068	33	21,426	104	1,842
-46	1,140,800	34	20,564	105	1,789
-45	1,217,107	35	19,741	106	1,739
-44	1,140,827	36	18,955	107	1,690
-43	1,069,754	37	18,204	108	1,642
-42	1,003,525	38	17,486	109	1,596
-41	941,778	39	16,801	110	1,552
-40	884,197	40	16,146	111	1,509
-39	830,463	41	15,519	112	1,467
-38	780,300	42	14,920	113	1,427
-37	733,456	43	14,347	114	1,388
-36	689,696	44	13,799	115	1,350
-35	648,789	45	13,274	116	1,314
-34	610,543	46	12,772	117	1,278
-33	574,779	47	12,292	118	1,244
-32	541,398	48	11,831	119	1,211
-31	509,962	49	11,391	120	1,178
-30	480,618	50	10,969	121	1,148
-29	453,134	51	10,564	122	1,117
-28	427,366	52	10,176	123	1,087
-27	403,211	53	9,805	124	1,059
-26	380,561	54	9,449	125	1,031
-25	359,302	55	9,107	126	1,005
-24	339,357	56	8,780	127	978.8
-23	320,629	57	8,466	128	953.6
-22	303,036	58	8,164	129	929.2
-21	286,505	59	7,875	130	905.6
-20	270,968	60	7,597	131	882.6
-19	256,360	61	7,331	132	860.3
-18	242,618	62	7,075	133	838.7
-17	229,695	63	6,829	134	817.7
-16	217,525	64	6,593	135	797.3
-15	206,067	65	6,366	136	777.5
-14	195,277	66	6,148	137	758.3
-13	185,111	67	5,939	138	739.6
-12	175,530	68	5,738	139	721.5
-11	166,495	69	5,544	140	703.9
-10	157,974	70	5,358	141	686.8
-9	149,937			142	670.2
-8	142,352			143	654.1
-7	135,191			144	638.4
-6	128,428			145	623.1
-5	122,041			146	608.3
-4	116,006			147	593.9
-3	110,300			148	579.9
-2	104,907			149	566.3
-1	99,806			150	553.0

30K6A1B

30,000 Ohms @ 25°C ± 0.2° 0 - 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80	29,683,550	0	105,305	71	4,483.4
-79	27,090,830	1	99,787	72	4,323.1
-78	24,740,930	2	94,588	73	4,169.2
-77	22,609,770	3	89,689	74	4,021.6
-76	20,676,860	4	85,069	75	3,879.8
-75	18,920,900	5	80,713	76	3,743.8
-74	17,325,230	6	76,604	77	3,613.2
-73	15,874,100	7	72,726	78	3,487.7
-72	14,554,130	8	69,064	79	3,367.1
-71	13,352,130	9	65,608	80	3,215.4
-70	12,257,060	10	62,347	81	3,140.1
-69	11,258,450	11	59,257	82	3,033.3
-68	10,347,660	12	56,346	83	2,930.5
-67	9,516,359	13	53,585	84	2,831.7
-66	8,756,854	14	50,978	85	2,736.7
-65	8,062,708	15	48,511	86	2,645.4
-64	7,428,082	16	46,178	87	2,557.5
-63	6,847,255	17	43,969	88	2,472.9
-62	6,315,525	18	41,877	89	2,391.5
-61	5,828,316	19	39,895	90	2,313.2
-60	5,381,736	20	38,019	91	2,237.8
-59	4,972,029	21	36,240	92	2,165.2
-58	4,596,240	22	34,554	93	2,095.3
-57	4,251,001	23	32,955	94	2,028.0
-56	3,933,851	24	31,438	95	1,963.2
-55	3,642,297	25	30,000	96	1,900.7
-54	3,374,123	26	28,635	97	1,840.5
-53	3,127,359	27	27,339	98	1,782.5
-52	2,900,141	28	26,108	99	1,726.6
-51	2,690,822	29	24,939	100	1,672.7
-50	2,497,829	30	23,828	101	1,620.7
-49	2,319,849	31	22,773	102	1,570.6
-48	2,155,662	32	21,770	103	1,522.3
-47	2,004,078	33	20,816	104	1,475.6
-46	1,864,043	34	19,909	105	1,430.6
-45	1,734,646	35	19,046	106	1,387.2
-44	1,615,012	36	18,226	107	1,345.3
-43	1,504,321	37	17,444	108	1,304.9
-42	1,404,886	38	16,700	109	1,265.8
-41	1,307,057	39	15,992	110	1,228.1
-40	1,219,169	40	15,317	111	1,191.7
-39	1,137,708	41	14,674	112	1,156.5
-38	1,062,201	42	14,062	113	1,122.5
-37	992,141	43	13,478	114	1,089.7
-36	927,112	44	12,921	115	1,058.0
-35	866,735	45	12,390	116	1,027.3
-34	810,638	46	11,884	117	997.7
-33	758,498	47	11,400	118	969.1
-32	710,018	48	10,939	119	941.3
-31	664,944	49	10,499	120	914.6
-30	622,944	50	10,079	121	888.6
-29	583,864	51	9,677.6	122	863.6
-28	547,457	52	9,294.4	123	839.4
-27	513,542	53	8,928.1	124	815.9
-26	481,921	54	8,578.1	125	793.2
-25	452,430	55	8,243.6	126	771.3
-24	424,905	56	7,923.8	127	750.0
-23	399,222	57	7,618.0	128	729.4
-22	375,228	58	7,325.3	129	709.5
-21	352,814	59	7,045.5	130	690.2
-20	331,876	60	6,777.7	131	671.5
-19	312,294	61	6,521.5	132	653.4
-18	293,980	62	6,276.1	133	635.9
-17	276,843	63	6,041.2	134	618.9
-16	260,805	64	5,816.2	135	602.4
-15	245,785	65	5,600.6	136	586.5
-14	231,716	66	5,394.2	137	571.0
-13	218,526	67	5,196.3	138	556.0
-12	206,168	68	5,006.7	139	541.5
-11	194,575	69	4,825.0	140	527.4
-10	183,697	70	4,625.6	141	513.7
-9	173,488			142	500.5
-8	163,907			143	487.6
-7	154,905			144	475.2
-6	146,448			145	463.0
-5	138,502			146	451.3
-4	131,030			147	439.9
-3	124,003			148	428.9
-2	117,390			149	418.1
-1	111,165			150	407.1

INTERCHANGEABLE BetaCURVE R – T SPECIFICATION

50K6A1B

100K6A1B

1M9A1B

50,000 Ohms @ 25°C ± 0.2° 0 - 70°C

100,000 Ohms @ 25°C ± 0.2° 0 - 70°C

1,000,000 Ohms @ 25°C ± 0.2° 0 to 70°C

Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)	Temp. (°C.)	R Value (ohms)
-80		0	175,508	71	7,472.2	-80		0	351,017	71	14,944	-80		0	3,965,970	71	118,280
-79		1	166,310	72	7,205.0	-79		1	332,619	72	14,410	-79		1	3,740,810	72	113,490
-78		2	157,644	73	6,948.5	-78		2	315,288	73	13,897	-78		2	3,529,430	73	108,910
-77		3	149,480	74	6,702.3	-77		3	298,959	74	13,405	-77		3	3,330,940	74	104,540
-76		4	141,779	75	6,466.1	-76		4	283,558	75	12,932	-76		4	3,144,560	75	100,360
-75		5	134,521	76	6,239.3	-75		5	269,041	76	12,479	-75		5	2,969,450	76	96,370
-74		6	127,669	77	6,021.6	-74		6	255,337	77	12,043	-74		6	2,804,860	77	92,550
-73		7	121,207	78	5,812.5	-73		7	242,414	78	11,625	-73		7	2,650,190	78	88,900
-72		8	115,105	79	5,611.7	-72		8	230,210	79	11,223	-72		8	2,504,700	79	85,410
-71		9	109,344	80	5,418.7	-71		9	218,688	80	10,837	-71		9	2,367,890	80	82,080
-70		10	103,903	81	5,233.2	-70		10	207,807	81	10,466	-70		10	2,239,180	81	78,890
-69		11	98,761	82	5,055.0	-69		11	197,521	82	10,110	-69		11	2,118,030	82	75,830
-68		12	93,901	83	4,883.8	-68		12	187,803	83	9,767.6	-68		12	2,003,990	83	72,910
-67		13	89,307	84	4,719.1	-67		13	178,613	84	9,438.1	-67		13	1,896,630	84	70,120
-66		14	84,962	85	4,560.7	-66		14	169,924	85	9,121.4	-66		14	1,795,480	85	67,440
-65		15	80,851	86	4,408.4	-65		15	161,702	86	8,816.9	-65		15	1,700,200	86	64,880
-64		16	76,961	87	4,261.9	-64		16	153,923	87	8,523.8	-64		16	1,610,400	87	62,430
-63		17	73,280	88	4,120.9	-63		17	146,560	88	8,241.9	-63		17	1,525,780	88	60,080
-62		18	69,794	89	3,985.4	-62		18	139,588	89	7,970.7	-62		18	1,445,950	89	57,830
-61		19	66,492	90	3,854.8	-61		19	132,984	90	7,709.7	-61		19	1,370,690	90	55,670
-60		20	63,364	91	3,729.2	-60		20	126,729	91	7,458.3	-60		20	1,299,670	91	53,600
-59		21	60,400	92	3,608.2	-59		21	120,799	92	7,216.3	-59		21	1,232,650	92	51,620
-58		22	57,589	93	3,491.7	-58		22	115,179	93	6,983.4	-58		22	1,169,400	93	49,720
-57		23	54,925	94	3,379.5	-57		23	109,850	94	6,758.9	-57		23	1,109,680	94	47,900
-56		24	52,398	95	3,271.4	-56		24	104,796	95	6,542.7	-56		24	1,053,280	95	46,160
-55	6,081,436	25	50,000	96	3,167.3	-55	12,162,871	25	100,000	96	6,334.5	-55		25	1,000,000	96	44,480
-54	5,633,225	26	47,724	97	3,066.9	-54	11,266,450	26	95,449	97	6,133.8	-54		26	946,660	97	42,870
-53	5,220,802	27	45,564	98	2,970.3	-53	10,441,605	27	91,128	98	5,940.5	-53		27	902,070	98	41,330
-52	4,841,088	28	43,513	99	2,877.0	-52	9,682,176	28	87,026	99	5,754.0	-52		28	857,100	99	39,850
-51	4,491,300	29	41,565	100	2,787.2	-51	8,982,600	29	83,129	100	5,574.3	-51		29	814,570	100	38,430
-50	4,168,934	30	39,714	101	2,700.5	-50	8,337,869	30	79,428	101	5,401.1	-50		30	774,330	101	37,070
-49	3,871,700	31	37,956	102	2,617.0	-49	7,743,400	31	75,912	102	5,234.1	-49		31	736,270	102	35,760
-48	3,597,413	32	36,283	103	2,536.4	-48	7,194,826	32	72,567	103	5,072.9	-48		32	700,250	103	34,510
-47	3,344,182	33	34,695	104	2,458.7	-47	6,688,364	33	69,389	104	4,917.3	-47		33	666,150	104	33,300
-46	3,110,277	34	33,183	105	2,383.7	-46	6,220,553	34	66,365	105	4,767.3	-46		34	633,860	105	32,140
-45	2,894,227	35	31,744	106	2,311.3	-45	5,788,455	35	63,489	106	4,622.6	-45		35	603,300	106	31,020
-44	2,694,439	36	30,376	107	2,241.4	-44	5,388,878	36	60,752	107	4,482.9	-44		36	574,340	107	29,950
-43	2,509,656	37	29,074	108	2,174.0	-43	5,019,313	37	58,149	108	4,348.1	-43		37	546,900	108	28,920
-42	2,338,634	38	27,834	109	2,108.9	-42	4,677,268	38	55,668	109	4,217.8	-42		38	520,900	109	27,930
-41	2,180,318	39	26,653	110	2,046.1	-41	4,360,636	39	53,307	110	4,092.1	-41		39	496,250	110	26,980
-40	2,033,606	40	25,529	111	1,985.4	-40	4,067,212	40	51,058	111	3,970.7	-40		40	472,880	111	26,070
-39	1,897,671	41	24,457	112	1,926.7	-39	3,795,342	41	48,915	112	3,853.5	-39		41	450,710	112	25,190
-38	1,771,643	42	23,436	113	1,870.1	-38	3,543,286	42	46,873	113	3,740.2	-38		42	429,680	113	24,340
-37	1,654,711	43	22,463	114	1,815.4	-37	3,309,422	43	44,927	114	3,660.7	-37		43	409,730	114	23,530
-36	1,546,208	44	21,535	115	1,762.5	-36	3,092,416	44	43,071	115	3,525.0	-36		44	390,800	115	22,750
-35	1,445,422	45	20,650	116	1,711.4	-35	2,890,843	45	41,301	116	3,422.8	-35		45	372,820	116	21,990
-34	1,351,835	46	19,807	117	1,662.0	-34	2,703,671	46	39,613	117	3,324.0	-34		46	355,750	117	21,270
-33	1,264,836	47	19,001	118	1,614.3	-33	2,529,672	47	38,003	118	3,228.5	-33		47	339,550	118	20,570
-32	1,183,950	48	18,233	119	1,568.1	-32	2,367,900	48	36,465	119	3,136.2	-32		48	324,150	119	19,890
-31	1,108,711	49	17,499	120	1,523.4	-31	2,217,423	49	34,999	120	3,046.6	-31		49	309,520	120	19,250
-30	1,038,697	50	16,799	121	1,480.3	-30	2,077,394	50	33,598	121	2,960.6	-30		50	295,610	121	18,620
-29	973,503	51	16,130	122	1,438.5	-29	1,947,006	51	32,260	122	2,877.0	-29		51	282,400	122	18,020
-28	912,784	52	15,491	123	1,398.1	-28	1,825,568	52	30,983	123	2,796.2	-28		52	269,830	123	17,440
-27	856,200	53	14,881	124	1,359.0	-27	1,712,400	53	29,761	124	2,718.0	-27		53	257,880	124	16,890
-26	803,455	54	14,297	125	1,321.2	-26	1,606,911	54	28,595	125	2,642.4	-26		54	246,510	125	16,350
-25	754,265	55	13,740	126	1,284.6	-25	1,508,530	55	27,479	126	2,569.2	-25		55	235,690	126	15,830
-24	708,373	56	13,207	127	1,249.2	-24	1,416,745	56	26,413	127	2,498.3	-24		56	225,400	127	15,330
-23	665,530	57	12,697	128	1,214.9	-23	1,331,059	57	25,394	128	2,429.7	-23		57	215,600	128	14,850
-22	625,540	58	12,209	129	1,181.6	-22	1,251,079	58	24,419	129	2,363.3	-22		58	206,270	129	14,380
-21	588,164	59	11,743	130	1,149.5	-21	1,176,328	59	23,486	130	2,298.9	-21		59	197,390	130	13,940
-20	553,243	60	11,297	131	1,118.3	-20	1,106,485	60	22,593	131	2,236.7	-20		60	188,930	131	13,500
-19	520,587	61	10,869	132	1,088.2	-19	1,041,173	61	21,739	132	2,176.3	-19		61	180,870	132	13,090
-18	490,050	62	10,460	133	1,058.9	-18	980,100	62	20,921	133	2,117.9	-18		62	173,190	133	12,680
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BetaTHERM Sensors

		Material (Curve) #1				Material (Curve) #2				Material (Curve) #3				Material (Curve) #4			
deg F	deg C	Resistance Multiplier	Alpha (-%/ °C)	Max. Deviation (%) from Curve Nom.		Resistance Multiplier	Alpha (-%/ °C)	Max. Deviation (%) from Curve Nom.		Resistance Multiplier	Alpha (-%/ °C)	Max. Deviation (%) from Curve Nom.		Resistance Multiplier	Alpha (-%/ °C)	Max. Deviation (%) from Curve Nom.	
				BetaCHIP	BetaCURVE			BetaCHIP	BetaCURVE			BetaCHIP	BetaCURVE			BetaCHIP	BetaCURVE
-112	-80	169.20	-6.72	13.5	6.55	233.5	-7.16	13.0	6.98	729.68	-8.90	14.0	8.68				
-103	-75	121.59				163.5				471.37							
-94	-70	88.34	-6.28	11.0	5.65	115.9	-6.69	10.0	6.02	309.56	-8.29	10.5	7.46				
-85	-65	64.87				83.17				206.49							
-76	-60	48.12	-5.88	8.8	3.53	60.39	-6.26	8.0	3.76	139.79	-7.69	8.5	4.61				
-67	-55	36.04				44.33				95.978				60.86			
-58	-50	27.24	-5.51	7.3	3.03	32.89	-5.85	6.0	3.22	66.782	-7.14	6.5	3.93	44.17	-6.30	5.3	3.47
-49	-45	20.778				24.64				47.061				32.39			
-40	-40	15.983	-5.16	6.3	2.53	18.641	-5.47	4.8	2.68	33.5668	-6.61	5.3	3.24	23.983	-5.92	4.6	2.90
-31	-35	12.395				14.231				24.2193				17.928			
-22	-30	9.689	-4.85	5.3	1.94	10.960	-5.12	4.0	2.05	17.6682	-6.21	4.5	2.48	13.523	-5.56	3.9	2.22
-13	-25	7.630				8.511				13.0242				10.289			
-4	-20	6.053	-4.56	4.3	1.46	6.662	-4.82	3.3	1.54	9.6973	-5.81	3.7	1.86	7.893	-5.23	3.3	1.67
5	-15	4.835				5.255				7.2894				6.1030			
14	-10	3.888	-4.29	3.5	1.07	4.175	-4.54	2.6	1.14	5.5297	-5.51	3.0	1.38	4.7549	-4.94	2.7	1.24
23	-5	3.147				3.341				4.2314				3.7316			
32	0	2.563	-4.04	2.7	0.81	2.691	-4.25	2.1	0.85	3.2651	-5.20	2.4	1.04	2.9490	-4.65	2.2	0.93
41	5	2.100				2.182				2.5395				2.3462			
50	10	1.730	-3.82	2.0	0.76	1.780	-4.02	1.6	0.80	1.9903	-4.80	1.8	0.96	1.8787	-4.40	1.7	0.88
59	15	1.434				1.460				1.5714				1.5136			
68	20	1.194	-3.60	1.3	0.72	1.205	-3.78	1.2	0.76	1.2494	-4.52	1.3	0.90	1.2268	-4.16	1.2	0.83
77	25	1.0000	-3.50	1.0	0.70	1.0000	-3.68	1.0	0.74	1.0000	-4.39	1.0	0.88	1.0000	-4.04	1.0	0.81
86	30	0.8414	-3.41	1.3	0.68	0.8342	-3.57	1.2	0.71	0.80560	-4.26	1.3	0.85	0.81966	-3.92	1.2	0.78
95	35	0.7114				0.6993				0.65301				0.67539			
104	40	0.6034	-3.22	1.9	0.64	0.5892	-3.39	1.6	0.68	0.53249	-4.03	1.7	0.81	0.55937	-3.73	1.6	0.75
113	45	0.5155				0.4987				0.43669				0.46557			
122	50	0.4417	-3.05	2.4	0.61	0.4240	-3.21	2.0	0.64	0.36010	-3.80	2.2	0.76	0.38933	-3.53	2.0	0.71
131	55	0.3800				0.3620				0.29851				0.32707			
140	60	0.3283	-2.89	2.9	0.58	0.3104	-3.04	2.3	0.61	0.24871	-3.61	2.6	0.72	0.27599	-3.36	2.3	0.67
149	65	0.2846				0.2673				0.20823				0.23387			
158	70	0.2477	-2.74	3.4	0.55	0.2310	-2.88	2.7	0.58	0.17516	-3.42	3.0	0.68	0.19900	-3.19	2.7	0.64
167	75	0.2164				0.2004				0.14801				0.17000			
176	80	0.1897	-2.60	3.8	0.65	0.1745	-2.73	3.0	0.68	0.12562	-3.25	3.3	0.81	0.14579	-3.05	3.0	0.76
185	85	0.1668				0.1524				0.10706				0.125483			
194	90	0.1472	-2.47	4.2	0.77	0.1336	-2.58	3.3	0.80	0.091610	-3.07	3.7	0.95	0.108395	-2.91	3.3	0.90
203	95	0.1302				0.1175				0.078698				0.093960			
212	100	0.1156	-2.35	4.7	0.82	0.1037	-2.49	3.7	0.87	0.067863	-2.92	4.0	1.02	0.081719	-2.78	3.5	0.97
221	105					0.0917				0.058730				0.071303			
230	110					0.0814	-2.40	4.0	0.96	0.051006	-2.77	4.3	1.11	0.062409	-2.65	3.8	1.06
239	115					0.0725				0.044448				0.054792			
248	120					0.0647	-2.25	4.4	1.24	0.038859	-2.64	4.6	1.45	0.048246	-2.52	4.0	1.39
257	125					0.0579				0.034082				0.042603			
266	130					0.0519	-2.23	4.7	1.34	0.029982	-2.51	4.9	1.51	0.037723	-2.42	4.3	1.45
275	135					0.0467				0.026454				0.033492			
284	140					0.0421	-2.03	5.0	1.62	0.023408	-2.41	5.1	1.93	0.029812	-2.32	4.5	1.86
293	145					0.0380				0.020770				0.026604			
302	150					0.0344	-2.01	5.3	1.91	0.018478	-2.31	5.4	2.19	0.023798	-2.23	4.7	2.12
311	155									0.016457				0.021338			
320	160					0.014713				0.014713	-2.21	5.8		0.019177	-2.11	5.1	
329	165					0.013187				0.013187				0.017273			
338	170					0.011847	-2.17	6.1		0.011847	-2.17	6.1		0.015592	-2.03	5.5	
347	175					0.010667				0.010667				0.014103			
356	180					0.009626	-2.03	6.4		0.009626	-2.03	6.4		0.012783	-1.95	5.8	
365	185					0.008705				0.008705				0.011609			
374	190					0.007888	-1.95	6.7		0.007888	-1.95	6.7		0.010564	-1.87	6.0	
383	195					0.007163				0.007163				0.009630			
392	200					0.006517	-1.87	6.9		0.006517	-1.87	6.9		0.008795	-1.80	6.2	
401	205					0.005940				0.005940				0.008046			
410	210					0.005425	-1.80	7.1		0.005425	-1.80	7.1		0.007374	-1.73	6.6	
419	215					0.004963				0.004963				0.006769			
428	220					0.004548	-1.73	7.3		0.004548	-1.73	7.3		0.006224	-1.66	7.0	
437	225					0.004175				0.004175				0.005732			
446	230					0.003839	-1.66	7.5		0.003839	-1.66	7.5		0.005287	-1.60	7.3	
455	235					0.003536				0.003536				0.004884			
464	240					0.003261	-1.60	7.7		0.003261	-1.60	7.7		0.004518	-1.54	7.6	
473	245					0.003013				0.003013				0.004185			
482	250					0.002787	-1.54	7.9		0.002787	-1.54	7.9		0.003882	-1.49	7.8	
491	255					0.002582				0.002582				0.003606			
500	260					0.002396	-1.49	8.1		0.002396	-1.49	8.1		0.003354	-1.44	8.0	
509	265					0.002226				0.002226				0.003124			
518	270					0.002070	-1.43	8.3		0.002070	-1.43	8.3		0.002913	-1.39	8.3	
527	275					0.001929				0.001929				0.002720			
536	280					0.001799	-1.38	8.4		0.001799	-1.38	8.4		0.002542	-1.34	8.5	
545	285					0.001679				0.001679				0.002379			
554	290					0.001570	-1.34	8.6		0.001570	-1.34	8.6		0.002229	-1.29	8.7	
563	295					0.001469				0.001469				0.002090			
572	300					0.001377	-1.29	8.7		0.001377	-1.29	8.7		0.001962	-1.25	8.8	

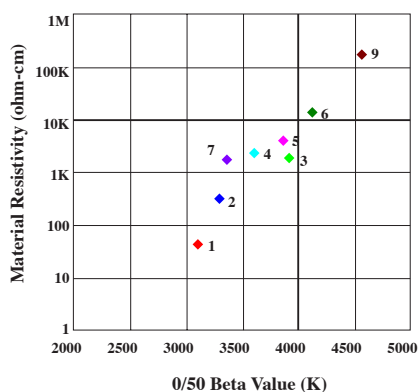
BetaTHERM Sensors

		Material (Curve) #5				Material (Curve) #6				Material (Curve) #7				Material (Curve) #9			
Temperature deg F. deg C.		Resistance Multiplier	Alpha (-%/ °C)	Max. Deviation (%) from Curve Nom.		Resistance Multiplier	Alpha (-%/ °C)	Max. Deviation (%) from Curve Nom.		Resistance Multiplier	Alpha (-%/ °C)	Max. Deviation (%) from Curve Nom.		Resistance Multiplier	Alpha (-%/ °C)	Max. Deviation (%) from Curve Nom.	
				BetaCHIP	BetaCURVE			BetaCHIP	BetaCURVE			BetaCHIP	BetaCURVE			BetaCHIP	BetaCURVE
-112	-80																
-103	-75																
-94	-70																
-85	-65																
-76	-60																
-67	-55	79.36				121.63				54.14							
-58	-50	56.43	-6.67	5.70	3.67	83.38	-7.40	7.0	4.07	39.49	-6.67	6.7	3.67				
-49	-45	40.57				57.89				29.11							
-40	-40	29.47	-6.26	4.61	3.07	40.672	-6.83	6.1	3.35	21.68	-5.55	5.3	2.72				
-31	-35	21.63				28.909				16.31							
-22	-30	16.02	-5.91	3.92	2.36	20.774	-6.45	5.1	2.58	12.38	-5.43	4.5	2.17				
-13	-25	11.98				15.085				9.485							
-4	-20	9.032	-5.57	3.29	1.78	11.065	-6.08	4.2	1.95	7.329	-5.08	3.7	1.63				
5	-15	6.869				8.1938				5.709							
14	-10	5.266	-5.25	2.71	1.31	6.1237	-5.74	3.4	1.44	4.482	-4.76	3.0	1.19				
23	-5	4.068				4.6169				3.546							
32	0	3.166	-4.94	2.17	0.99	3.5102	-5.40	2.6	1.08	2.825	-4.48	2.4	0.90	3.966	-5.86	3.5	1.17
41	5	2.481				2.6904				2.266				2.969			
50	10	1.958	-4.67	1.68	0.93	2.0781	-5.10	2.0	1.02	1.830	-4.21	1.8	0.84	2.239	-5.58	2.3	1.12
59	15	1.556				1.6170				1.487				1.700			
68	20	1.243	-4.41	1.22	0.88	1.2673	-4.81	1.3	0.96	1.216	-3.99	1.3	0.80	1.300	-5.31	1.3	1.06
77	25	1.0000	-4.30	1.00	0.86	1.0000	-4.68	1.0	0.94	1.0000	-3.87	1.0	0.77	1.0000	-5.18	1.0	1.04
86	30	0.8089	-4.18	1.21	0.84	0.79428	-4.55	1.3	0.91	0.8270	-3.76	1.3	0.75	0.7734	-5.05	1.7	1.01
95	35	0.6580				0.63489				0.6876				0.6033			
104	40	0.5382	-3.96	1.61	0.79	0.51058	-4.30	1.9	0.86	0.5747	-3.56	1.7	0.71	0.4729	-4.81	2.8	0.96
113	45	0.4425				0.41301				0.4827				0.3728			
122	50	0.3656	-3.77	1.98	0.75	0.33598	-4.08	2.4	0.82	0.4074	-3.36	2.2	0.67	0.2956	-4.59	3.5	0.92
131	55	0.3036				0.27480				0.3454				0.2357			
140	60	0.2532	-3.58	2.33	0.72	0.22593	-3.87	2.9	0.77	0.2941	-3.17	2.6	0.63	0.1889	-4.37	4.3	0.88
149	65	0.2122				0.18669				0.2515				0.1522			
158	70	0.1786	-3.42	2.66	0.68	0.15502	-3.68	3.3	0.74	0.2160	-2.99	3.0	0.60	0.1233	-4.17	5.2	0.84
167	75	0.1509				0.12932				0.1862				0.1004			
176	80	0.1281	-3.25	2.97	0.81	0.10837	-3.49	3.7	0.87	0.1612	-2.84	3.3	0.71	0.0821	-3.97	5.9	0.99
185	85	0.1091				0.091215				0.1400				0.0674			
194	90	0.09333	-3.10	3.26	0.96	0.077097	-3.33	4.1	1.03	0.1220	-2.69	3.7	0.83	0.0557	-3.79	6.6	1.18
203	95	0.08011				0.065428				0.1067				0.0462			
212	100	0.06900	-2.95	3.53	1.03	0.055744	-3.17	4.5	1.11	0.0937	-2.54	4.0	0.89	0.0384	-3.62	7.3	1.26
221	105	0.05964				0.047674				0.0825				0.0321			
230	110	0.05173	-2.81	3.79	1.12	0.040921	-3.04	4.9	1.22	0.0728	-2.36	4.3	0.94	0.0270	-3.46	8.0	1.38
239	115	0.04500				0.035251				0.0645				0.0228			
248	120	0.03928	-2.68	4.03	1.47	0.030469	-2.91	5.2	1.60	0.0573	-2.31	4.6	1.20	0.0193	-3.30	8.6	1.82
257	125	0.03438				0.026424				0.0510				0.0164			
266	130	0.03019	-2.59	4.26	1.55	0.022990	-2.87	5.5	1.72	0.0456	-2.12	4.9	1.29	0.0139	-3.16	9.3	1.90
275	135	0.02658				0.020064				0.0408				0.0119			
284	140	0.02346	-2.49	4.48	1.99	0.017563	-2.74	5.8	2.19	0.0366	-2.00	5.1	1.60	0.0102	-3.02	9.7	2.41
293	145	0.02077				0.015419				0.0330				0.0088			
302	150	0.01843	-2.39	4.69	2.27	0.013575	-2.60	6.1	2.47	0.0298	-1.88	5.4	79	0.0076	-2.89	10.3	2.75
311	155	0.01646				0.011966				0.0269				0.00660			
320	160	0.01468	-2.26	5.1		0.010590	-2.42	6.5		0.0244	-1.95	5.8		0.00573	-2.78	10.9	
329	165	0.01313				0.009396				0.0221				0.00499			
338	170	0.01177	-2.15	5.3		0.008358	-2.32	6.9		0.0201	-1.87	6.1		0.00436	-2.67	11.3	
347	175	0.01058				0.007453				0.0184				0.00382			
356	180	0.009522	-2.08	5.6		0.006661	-2.22	7.3		0.0168	-1.79	6.4		0.00336	-2.57	11.7	
365	185	0.008592				0.005967				0.0154				0.00295			
374	190	0.007768	-2.00	5.9		0.005357	-2.14	7.7		0.0141	-1.72	6.7		0.00261	-2.47	12.2	
383	195	0.007037				0.004820				0.0129				0.00231			
392	200	0.006388	-1.92	6.1		0.004345	-2.05	8.1		0.0119	-1.65	7.0		0.00205	-2.38	12.8	
401	205	0.005809				0.003925				0.0110				0.00182			
410	210	0.005293	-1.84	6.3		0.003553	-1.97	8.4		0.0101	-1.58	7.3		0.00162	-2.29	13.2	
419	215	0.004831				0.003223				0.00936				0.00145			
428	220	0.004417	-1.77	6.5		0.002928	-1.90	8.7		0.00867	-1.52	7.6		0.00129	-2.20	13.7	
437	225	0.004045				0.002665				0.00804				0.00116			
446	230	0.003711	-1.71	6.7		0.002430	-1.83	9.0		0.00747	-1.46	7.8		0.001045	-2.12	14.1	
455	235	0.003410				0.002220				0.00695				0.000941			
464	240	0.003138	-1.65	6.9		0.002031	-1.76	9.3		0.00647	-1.41	8.0		0.000848	-2.05	14.5	
473	245	0.002892				0.001862				0.00604				0.000767			
482	250	0.002669	-1.59	7.1		0.001709	-1.70	9.6		0.00564	-1.35	8.3		0.000694	-1.98	14.9	
491	255	0.002467				0.001571				0.00527				0.000629			
500	260	0.002284	-1.53	7.3		0.001446	-1.64	9.9		0.00494	-1.31	8.5		0.00057	-1.91	15.3	
509	265	0.002117				0.001333				0.00463				0.000520			
518	270	0.001965	-1.48	7.4		0.001231	-1.58	10.2		0.00434	-1.26	8.7		0.000474	-1.84	15.6	
527	275	0.001826				0.001138				0.00408				0.000432			
536	280	0.001699	-1.43	7.5		0.001054	-1.53	10.4		0.00384	-1.21	8.9		0.000395	-1.78	15.9	
545	285	0.001583				0.000977				0.00361				0.000362			
554	290	0.001477	-1.38	7.7		0.000907	-1.48	10.6		0.00341	-1.17	9.1		0.000332	-1.72	16.3	
563	295	0.001379				0.000843				0.00321				0.000304			
572	300	0.001290	-1.33	7.8		0.000785	-1.43	10.9		0.00304	-1.13	9.3		0.000280	-1.67	16.6	

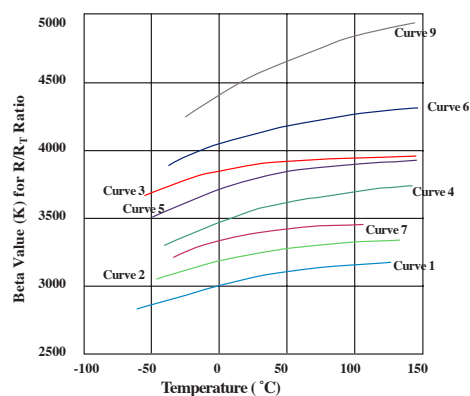
Resistance ratio, Slope and Beta specifications

Material (Curve) Number	1	2	3	4	5	6	7	9
Typical Resistance Range (ohms @ 25 °C)	50 to 500	100 to 1K	2K to 20K	5K to 30K	10K to 50K	50K to 100K	100 to 10K	100K to 1Meg
0/50 Nominal Beta Value	3108	3263	3892	3575	3811	4143	3422	4582
Max % Deviation								
BetaCHIP	1.7	0.92	1.4	1.0	0.94	1.3	1.0	1.9
BetaCURVE	0.4	0.38	0.32	0.30	0.33	0.30	0.36	0.63
25/85 Nominal Beta Value	3187	3348	3976	3694	3942	4261	3499	4799
Max % Deviation								
BetaCHIP	1.75	0.97	1.45	1.05	0.99	1.35	1.05	1.95
BetaCURVE	0.45	0.43	0.37	0.35	0.38	0.35	0.41	0.68
Nominal 0/50 R Ratio	5.8	6.35	9.06	7.58	8.65	10.45	6.95	13.40
Max % Deviation								
BetaCHIP	3.2	2.1	2.5	2.2	2.2	3.1	2.5	3.4
BetaCURVE	0.9	0.7	0.7	0.9	0.9	0.9	0.7	1.1
Nominal 0/70 R Ratio	10.35	11.65	18.65	14.82	17.73	22.65	13.08	32.17
Max % Deviation								
BetaCHIP	4.2	2.8	3.4	2.9	2.9	4.1	3.4	4.7
BetaCURVE	1.1	1.0	1.0	1.1	1.1	1.1	1.1	1.2
Nominal 25/125 R Ratio	10.35	17.33	29.27	23.51	29.15	38.07	19.05	61.96
Max % Deviation								
BetaCHIP	NA	3.7	3.9	3.3	3.3	4.6	3.9	5.2
BetaCURVE	NA	1.5	1.4	1.3	1.3	1.3	1.4	1.4

Material Resistivity - Beta Characteristics for BetaTHERM Thermistors Materials (Curves)



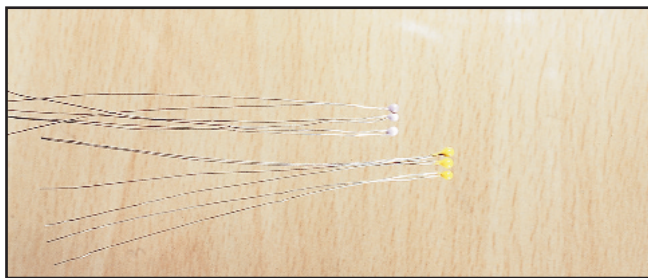
Beta Value vs Temperature for BetaTHERM Thermistors Materials (Curves)



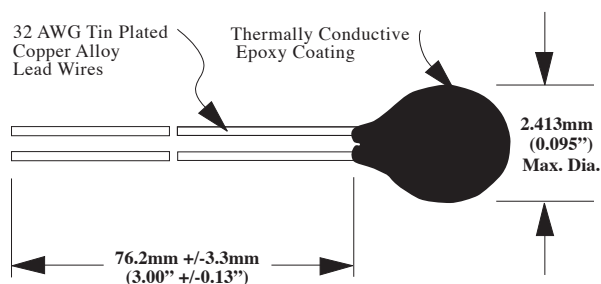
BetaTHERM Sensors

Products and Data

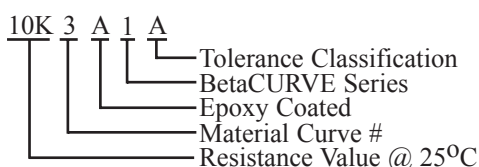




Thermistor Configuration



Example: BetaCURVE Series I Part Number



BetaCurve Interchangeable Thermistor Series I

Applications

- Temperature sensing, control and compensation.
- Medical equipment and patient monitoring.
- Aerospace instrumentation and crystal oscillator compensation.
- Liquid or gas temperature control and monitoring.
- Assembly into probes for a wide variety of applications.

Features

- Rapid Time Response (1 second typical in liquids).
- DC (Dissipation Constant) = 0.75mW/°C typical in still air at 25°C.
- Min./Max. Temperature Exposure = -80°C to 150°C.
- Available in custom probe assemblies.
- Proven Stability and Reliability.
- Alloy Lead Wires for reduced thermal conductivity ("stem effect").
- Choice of 4 temperature tolerance classifications.

Tolerance Code:

Specification:

A	+/-0.1°C, 0°C to 70°C
B	+/-0.2°C, 0°C to 70°C
C	+/-0.5°C, 0°C to 70°C
D	+/-1.0°C, 0°C to 70°C

The *BetaCURVE Thermistor Series I* are small epoxy coated devices with solid tin plated lead wires. The series offers a choice of precision temperature tolerance classifications for a wide variety of customer applications, such as temperature measurements, temperature indication, temperature control, and thermal compensation.

The *BetaCURVE* Series history of "long term" stability and reliability performance have been demonstrated in critical medical, scientific instrumentation, military/aerospace and industrial applications.

Thermistor interchangeability has become an important factor for cost efficiency in advanced thermal performance applications. The need for expensive individual thermistor calibration is not necessary. The *BetaCURVE* Series interchangeability means that each device will match the published Resistance-Temperature Characteristics (R-T Tables pages 43 to 47) for a given thermistor and will be within the specified deviation (tolerance, ie. +/-0.1°C, +/-0.2°C, +/-0.5°C and +/-1.0°C) limits over the temperature range 0°C to 70°C.

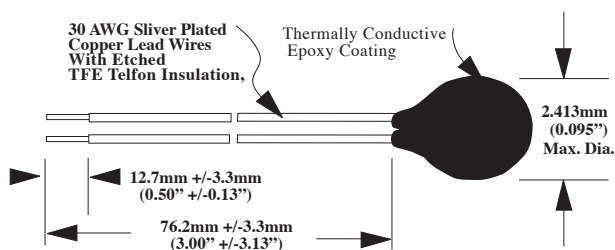
With the demands of JIT (just in time) deliveries expected in today's manufacturing sector. *BetaTHERM* maintains high finished goods inventory and dedicated manufacturing to continuously produce the *BetaCURVE* Series.

BetaCURVE Series I Part Numbers and Specifications

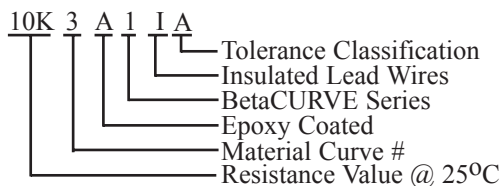
Part Number	Color Code	Resistance ohms @ 25°C	Resistance Tolerance@ 25°C	Temperature Tolerance and Range	Alpha @ 25°C	0/50 °C Beta Value	Curve #
2.2K3A1A	Brown	2252	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.39 %/°C	3892	3
2.2K3A2B	Brown	2252	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
2.2K3A3C	Brown	2252	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.39 %/°C	3892	3
2.2K3A4D	Brown	2252	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.39 %/°C	3892	3
3K3A1A	Red	3000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.39 %/°C	3892	3
3K3A1B	Red	3000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
3K3A1C	Red	3000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.39 %/°C	3892	3
3K3A1D	Red	3000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.39 %/°C	3892	3
5K3A1A	Orange	5000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.39 %/°C	3892	3
5K3A1B	Orange	5000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
5K3A1C	Orange	5000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.39 %/°C	3892	3
5K3A1D	Orange	5000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K3A1A	Yellow	10000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K3A1B	Yellow	10000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K3A1C	Yellow	10000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K3A1D	Yellow	10000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K4A1A	Black	10000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.04 %/°C	3575	4
10K4A1B	Black	10000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.04 %/°C	3575	4
10K4A1C	Black	10000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.04 %/°C	3575	4
10K4A1D	Black	10000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.04 %/°C	3575	4
30K5A1A	White	30000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.30 %/°C	3811	5
30K5A1B	White	30000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.30 %/°C	3811	5
30K5A1C	White	30000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.30 %/°C	3811	5
30K5A1D	White	30000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.30 %/°C	3811	5
30K6A1A	Green	30000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.68 %/°C	4143	6
30K6A1B	Green	30000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6
30K6A1C	Green	30000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.68 %/°C	4143	6
30K6A1D	Green	30000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.68 %/°C	4143	6
50K6A1A	Blue	50000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.68 %/°C	4143	6
50K6A1B	Blue	50000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6
50K6A1C	Blue	50000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.68 %/°C	4143	6
50K6A1D	Blue	50000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.68 %/°C	4143	6
100K6A1A	Violet	100000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.68 %/°C	4143	6
100K6A1B	Violet	100000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6
100K6A1C	Violet	100000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.68 %/°C	4143	6
100K6A1D	Violet	100000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.68 %/°C	4143	6



Thermistor Configuration



Example: BetaCURVE Series II Part Number



BetaCurve Interchangeable Thermistor Series II

Applications

- Temperature sensing, control and compensation.
- P.C. board mounting for over temperature protection.
- Automotive car seat heater control and engine management.
- Assembly into probes for a wide variety of applications in industrial temperature control and instrumentation.

Features

- Rapid Time Response (1 second typical in liquids).
- DC (Dissipation Constant) = 0.85mW/ °C typical in still air at 25°C.
- Min./Max. Temperature Exposure = -80 to 150°C.
- Available in custom probe assemblies.
- Proven Stability and Reliability.
- Teflon Insulated lead wires.
- Choice of 4 temperature tolerance classifications:

Tolerance Code:	Specification:
A	+/-0.1°C, 0°C to 70°C
B	+/-0.2°C, 0°C to 70°C
C	+/-0.5°C, 0°C to 70°C
D	+/-1.0°C, 0°C to 70°C

Similar to the *BetaCURVE Thermistor Series I*, the *Series II* thermistors are small epoxy coated devices. The same quality thermistor elements are used during assembly. Series II are manufactured using 30 AWG teflon insulated lead wires. They offer the same choice of precision temperature tolerance classifications for a wide variety of customer applications.

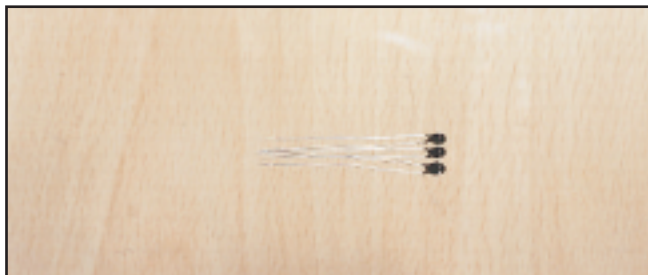
The *Series II* differs from *Series I* marginally with respect to D.C. The typical value of 0.85mW/°C in still air at 25°C is due to the larger lead wire diameter made of pure copper.

The insulated lead wires offer customers the added protection of TFE teflon insulation that has the highest temperature rating (150°C) of the most common insulating materials. TFE teflon is a material that does not bond easily with epoxies or adhesives. For this reason the surface of the teflon wire is etched, which enhances bondability for applications that require mounting or potting the thermistor with epoxies or adhesives.

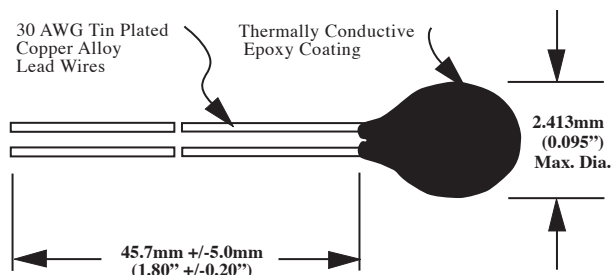
The series is produced in high volume as a Standard configuration. Other configurations are available on a custom basis. Larger or smaller lead wires can be used with the same chip elements and with insulating materials of PVC, Kynar, Tefzel, Nylon/Polyurethane, etc. Contact Applications Engineering Group for support if requirements differ from the standard configuration as shown above.

BetaCURVE Series II Part Numbers and Specifications:

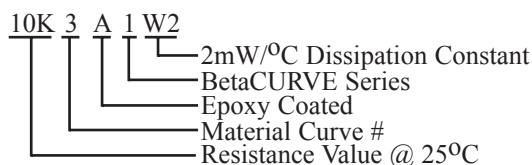
Part Number	Color Code	Resistance ohms @ 25°C	Resistance Tolerance@ 25°C	Temperature Tolerance and Range	Alpha @ 25°C	0/50 °C Beta Value	Curve #
2.2K3A1IA	Brown	2252	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.39 %/°C	3892	3
2.2K3A2IB	Brown	2252	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
2.2K3A3IC	Brown	2252	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.39 %/°C	3892	3
2.2K3A4ID	Brown	2252	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.39 %/°C	3892	3
3K3A1IA	Red	3000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.39 %/°C	3892	3
3K3A1IB	Red	3000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
3K3A1IC	Red	3000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.39 %/°C	3892	3
3K3A1ID	Red	3000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.39 %/°C	3892	3
5K3A1IA	Orange	5000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.39 %/°C	3892	3
5K3A1IB	Orange	5000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
5K3A1IC	Orange	5000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.39 %/°C	3892	3
5K3A1ID	Orange	5000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K3A1IA	Yellow	10000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K3A1IB	Yellow	10000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K3A1IC	Yellow	10000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K3A1ID	Yellow	10000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K4A1IA	Black	10000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.04 %/°C	3575	4
10K4A1IB	Black	10000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.04 %/°C	3575	4
10K4A1IC	Black	10000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.04 %/°C	3575	4
10K4A1ID	Black	10000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.04 %/°C	3575	4
30K5A1IA	White	30000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.30 %/°C	3811	5
30K5A1IB	White	30000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.30 %/°C	3811	5
30K5A1IC	White	30000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.30 %/°C	3811	5
30K5A1ID	White	30000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.30 %/°C	3811	5
30K6A1IA	Green	30000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.68 %/°C	4143	6
30K6A1IB	Green	30000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6
30K6A1IC	Green	30000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.68 %/°C	4143	6
30K6A1ID	Green	30000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.68 %/°C	4143	6
50K6A1IA	Blue	50000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.68 %/°C	4143	6
50K6A1IB	Blue	50000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6
50K6A1IC	Blue	50000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.68 %/°C	4143	6
50K6A1ID	Blue	50000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.68 %/°C	4143	6
100K6A1IA	Violet	100000	+/- 0.25%	+/- 0.1 °C (0 to 70 °C)	-4.68 %/°C	4143	6
100K6A1IB	Violet	100000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6
100K6A1IC	Violet	100000	+/- 1.00%	+/- 0.5 °C (0 to 70 °C)	-4.68 %/°C	4143	6
100K6A1ID	Violet	100000	+/- 2.00%	+/- 1.0 °C (0 to 70 °C)	-4.68 %/°C	4143	6



Thermistor Configuration



Example: BetaCURVE SeriesIII Part Number



BetaCURVE Interchangeable Thermistor Series III

Applications

- Temperature sensing, control and compensation.
- Applied to applications where higher Dissipation Constant is required (2.0mW/°C).

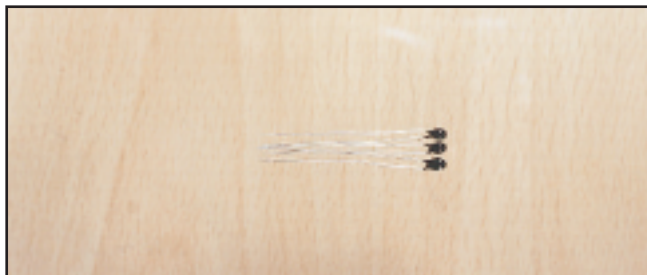
Features

- Rapid Time Response (1.3 second typical in liquids).
- DC (Dissipation Constant) = 2.0mW/°C typical in still air at 25°C.
- Min./Max. Temperature Exposure = -80°C to 150°C.
- Available in custom probe assemblies.
- Proven Stability and Reliability
- Larger lead wires ease assembly requirements.

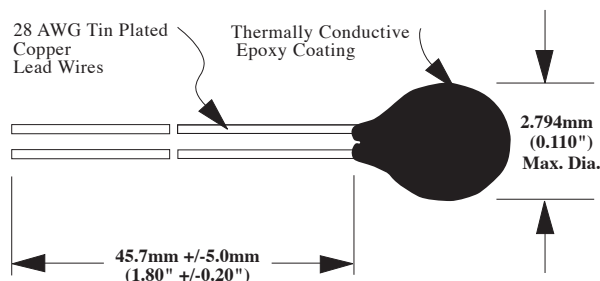
BetaCURVE Thermistor Series III are similar in construction to Series I except for the use of larger (30 AWG) copper leads. This allows the Dissipation Constant (D.C.) to be raised from 0.75mW/°C to 2.0mW/°C. Larger leads also facilitate easier handling during assembly operations. The Thermal Time Constant is raised to 14 seconds in air. Custom resistance values and tolerances are available upon request.

BetaCURVE Series III Part Numbers and Specifications:

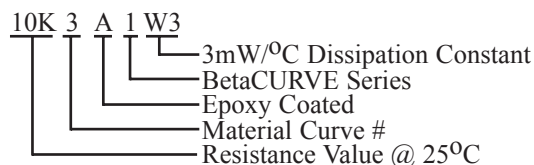
Part Number	Color Code	Resistance ohms @ 25°C	Resistance Tolerance @ 25°C	Temperature Tolerance and Range	Alpha @ 25°C	0/50°C Beta Value	Curve #
2.2K3A1W2	Brown	2252	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
3K3A1W2	Red	3000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
5K3A1W2	Orange	5000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K3A1W2	Yellow	10000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K4A1W2	Black	10000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.04 %/°C	3575	4
30K5A1W2	White	30000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.30 %/°C	3811	5
30K6A1W2	Green	30000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6
50K6A1W2	Blue	50000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6
100K6A1W2	Violet	100000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6



Thermistor Configuration



Example: BetaCURVE Series IV Part Number



BetaCURVE Interchangeable Series IV

Applications:

- Temperature sensing, control and compensation.
- Applications where a Dissipation Constant of 3.0 mW/°C is required.

Features:

- Rapid Time Response (1.5 second, typical in liquids).
- DC (Dissipation Constant) = 3.0mW/°C typical in still air at 25°C.
- Min./Max. Temperature Exposure = -80°C to 150°C.
- Available in custom probe assemblies.
- Proven Stability and Reliability

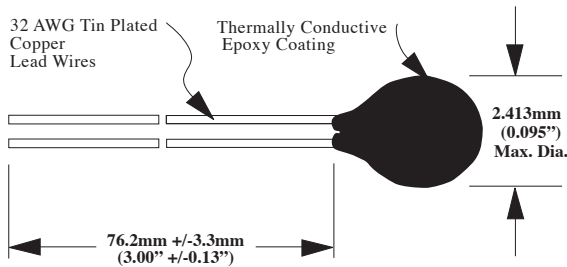
BetaTherm Thermistor Series IV provides a higher Dissipation Constant (3.0mW/°C) allowing design engineers greater flexibility on sensor design projects. The higher D.C. is achieved using 28 AWG tin plated copper lead wires and also larger chip thermistor elements. These chip elements are manufactured using the same high quality materials and manufacturing process as *Series I*. Custom resistance values and tolerances are available upon request.

BetaCURVE Series IV Part Numbers and Specifications:

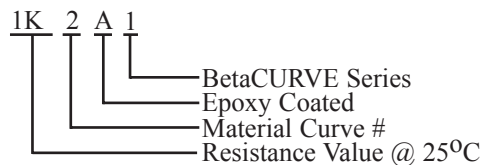
Part Number	Color Code	Resistance ohms @ 25°C	Resistance Tolerance @ 25°C	Temperature Tolerance and Range	Alpha @ 25°C	0/50 °C Beta Value	Curve #
2.2K3A1W3	Brown	2252	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
3K3A1W3	Red	3000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
5K3A1W3	Orange	5000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K3A1W3	Yellow	10000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.39 %/°C	3892	3
10K4A1W3	Black	10000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.04 %/°C	3575	4
30K5A1W3	White	30000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.30 %/°C	3811	5
30K6A1W3	Green	30000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6
50K6A1W3	Blue	50000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6
100K6A1W3	Violet	100000	+/- 0.50%	+/- 0.2 °C (0 to 70 °C)	-4.68 %/°C	4143	6



Thermistor Configuration



Example: BetaCURVE Series V Part Number



BetaCURVE Interchangeable Thermistor Series V

Applications

- Widely used for cold temperature environments.
- Artificial snow making equipment.
- Temperature compensation.
- Automotive air conditioning.

Features

- Rapid Time Response (1 second typical in liquids).
- DC (Dissipation Constant) = 0.75mW/°C typical in still air at 25°C.
- Min./Max. Temperature Exposure = -80°C to 125°C.
- Available in custom probe assemblies.
- Proven Stability and Reliability

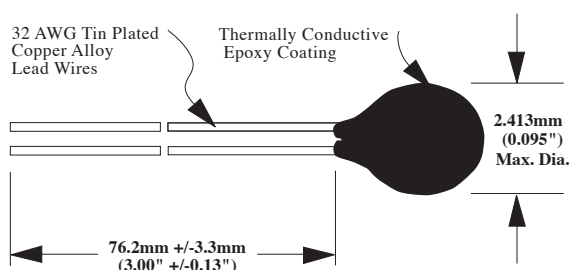
The BetaCURVE Thermistor Series V are small epoxy coated devices with solid tin plated lead wires. Due to the low nominal resistance values, these devices are suitable for measurement applications at the lower temperature ranges. The use of tin plated copper wires minimize the effects of lead wire resistance. Series V is specified with a temperature tolerance of +/-0.2°C over the range -20°C to 50°C. Resistance - temperature tables are given on pages 43 to 47 for each of the thermistor types listed below. The series does not offer color coding (all thermistor in this series are coated with black epoxy).

BetaCURVE Interchangeable Series V Part Numbers and Specifications:

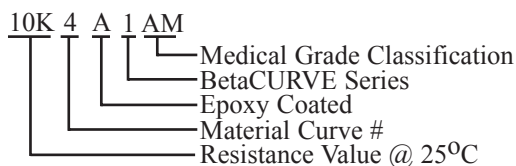
Part Number for +/- 5% @ 25 °C	Color Code	Resistance @ 25 °C (ohms)	Resistance Tolerance @ 25 °C	Temperature Tolerance and Range	Alpha @ 25 °C	0/50°C Beta Value	Curve #
0.1K1A1	Black	100	+/-0.50%	+/-0.2 °C 0 °C to 50 °C	-3.50%	3108	1
0.3K1A1	Black	300	+/-0.50%	+/-0.2 °C 0 °C to 50 °C	-3.50%	3108	1
1K2A1	Black	1000	+/-0.50%	+/-0.2 °C 0 °C to 50 °C	-3.68%	3263	2
1K7A1	Black	1000	+/-0.50%	+/-0.2 °C 0 °C to 50 °C	-3.87%	3422	7



Thermistor Configuration



Example: BetaCURVE Series VI Part Number



BetaCURVE Medical Grade Thermistor Series VI:

Applications

- Oxygen sensing equipment and instruments.
- Esophageal Catheters
- Skin sensors
- Oral and Rectal Probes
- Pharmaceutical manufacturing equipment

Features

- Rapid Time Response (1 second typical in liquids).
- DC (Dissipation Constant) = 0.75mW/°C typical in still air at 25°C.
- Min./Max. Temperature Exposure = -80°C to 150°C.
- Available in custom probe assemblies.
- Proven Stability and Reliability

The BetaCURVE Thermistor Series VI are small epoxy coated devices with solid tin plated lead wires. The Series VI is specified with a temperature tolerance of +/- 0.05°C over the range from 32°C to 44°C and is available in different nominal resistance values. Each thermistor element is manufactured using high quality materials and processes. High accuracy temperature baths (+/-0.005°C) are used during all stages of assembly and final testing.

This special series is offered to the **Medical Industry** for both new and existing applications. These devices are also useful in the pharmaceutical manufacturing equipment sector.

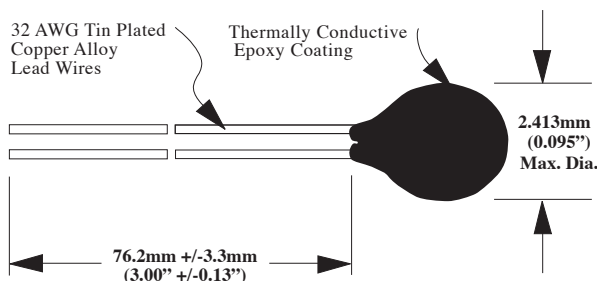
Custom resistance values and tolerances are available upon request.

BetaCURVE Medical Grade Series VI Part Numbers and Specifications:

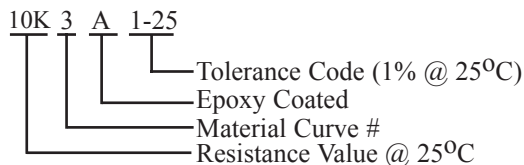
Part Number +/- 5% @ 25°C	Color Code	Resistance @ 25°C (ohms)	Temperature Tolerance and Range	Alpha @ 25°C	0/50°C Beta Value	Curve #
2.2K3A1AM	Brown	2252	+/-0.05 °C 32 °C to 44 °C	-4.39%	3892	3
10K3A1AM	Yellow	10000	+/-0.05 °C 32 °C to 44 °C	-4.39%	3892	3
10K4A1AM	Black	10000	+/-0.05 °C 32 °C to 44 °C	-4.04%	3575	4



Thermistor Configuration



Example: BetaCHIP Series VII Part Number



BetaCHIP Thermistor Series VII

Applications

- Ambient temperature sensing, control and compensation.
- Aerospace instrumentation and crystal oscillator compensation.
- Liquid or gas temperature control and monitoring.
- Assembly into probes for a wide variety of applications.

Features

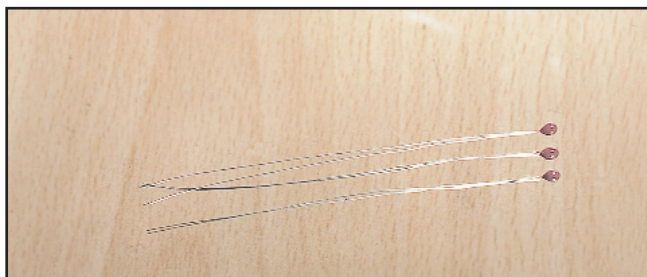
- **Rapid Time Response** (1 second typical in liquids).
- **DC (Dissipation Constant) = 0.75mW/°C** typical in still air at 25°C.
- **Min./Max. Temperature Exposure = -80°C to 150°C.**
- **Available in custom probe assemblies.**
- **Proven Stability and Reliability.**
- **Alloy Lead Wires for reduced thermal conductivity ("stem effect").**

The BetaCHIP +/-1% @ 25°C Thermistor Series are small epoxy coated devices with solid tin plated lead wires. The series offers an economical alternative to the precision BetaCURVE Series for a wide variety of customer applications such as temperature control and thermal compensation where less precision will perform in the application.

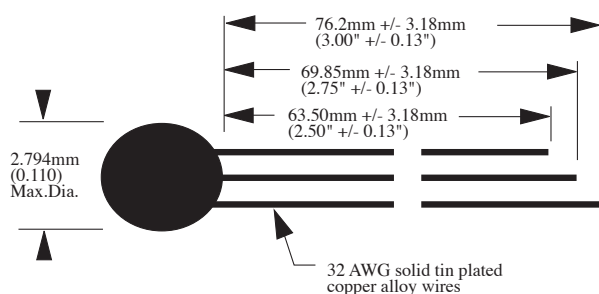
The series is useful in applications where the temperature range is near room temperature (25°C). Predicted deviations across the complete temperature range are given in BetaTHERM Resistance Multipliers-Temperature and Deviation Tolerance Tables on pages 48 and 49.

BetaCHIP Series VII Part Numbers and Specifications:

Part Number	Resistance @ +25°C	Alpha @ +25 °C	0/50 °C Beta Value	Curve #
0.1K1A1-25	100	-3.50%	3108	1
0.3K1A1-25	300	-3.50%	3108	1
1K2A1-25	1000	-3.68%	3263	2
1K7A1-25	1000	-3.87%	3422	7
2K3A1-25	2000	-4.39%	3892	3
2.2K3A1-25	2252	-4.39%	3892	3
3K3A1-25	3000	-4.39%	3892	3
5K3A1-25	5000	-4.39%	3892	3
10K3A1-25	10000	-4.39%	3892	3
10K4A1-25	10000	-4.04%	3575	4
30K5A1-25	30000	-4.30%	3811	5
30K6A1-25	30000	-4.68%	4143	6
50K6A1-25	50000	-4.68%	4143	6
100K6A1-25	100000	-4.68%	4143	6
1M9A1-25	1000000	-5.18%	4582	9

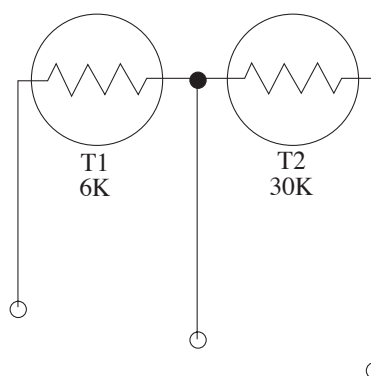


36K53A1 Configuration

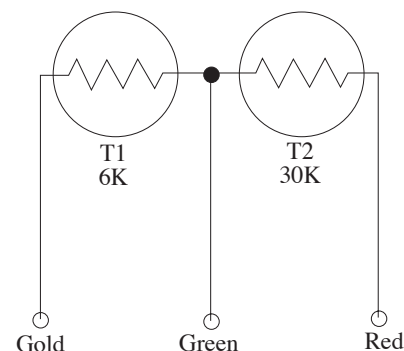
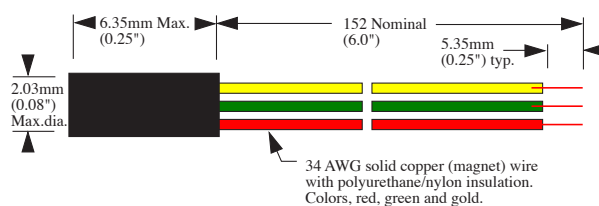


The *BetaLINEAR Series* is offered in different configurations which allows customers a choice for various applications. The configuration options shown are standard and are referred to as linear composites to which precision resistors of specific value are added to create a linear response of voltage or resistance verses a change in body temperature. The linear response is limited to specific temperature ranges. Also, the degree of accuracy (tolerance) will vary depending on the temperature span.

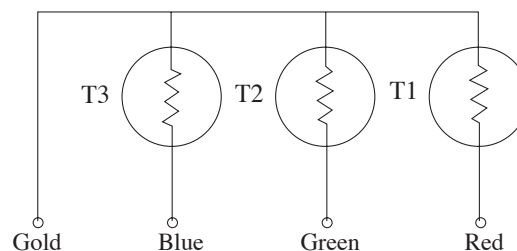
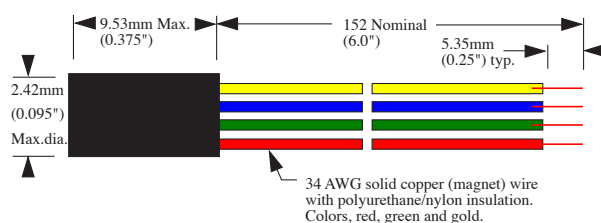
The linear composite is made from two or three sensor elements. The most popular composite (36K53A1 or D1) is made with two elements (30K5 and 6K3), hence the three lead composite. To assist the identification of the elements, the leads are cut at different lengths for the 36K53A1 composite and are color coded for the D1 composites.



36K53D1 and 11K2M4D1 Configuration



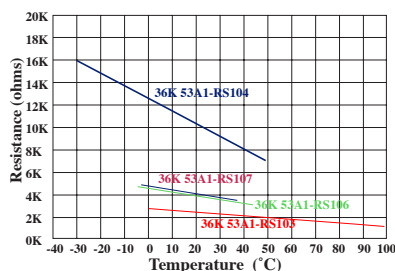
62K345D1 Configuration



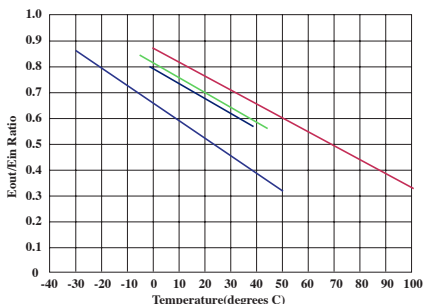
The **BetaLINEAR** circuit designs consist of two sub groupings - precision resistors and thermistors - which when connected can be operated as a single device for either linear voltage or linear resistance response vs. temperature. The circuit designs shown can accommodate a wide variety of circuit mounting options. Options include remote locations of custom thermistor probes and P.C. board mounting precision resistors or packaging resistors and thermistors within a custom probe design.

Linear thermistor network circuits are ideally suited for digital readout systems to measure temperatures in the range from -30°C to 100°C. Sensitivity is superior to Platinum and other metal RTD devices with minimum effect of lead resistance on accuracy. **BetaLINEAR** thermistor circuits can provide up to 400 times the output of a thermocouple with no need for junction temperature or lead wire compensation.

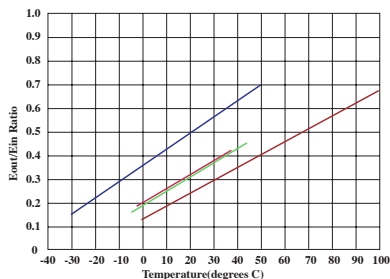
Resistance Mode Output for 36K53A1 (D1) Networks.



Voltage Mode Negative slope output for 36K53A1(D1) Networks

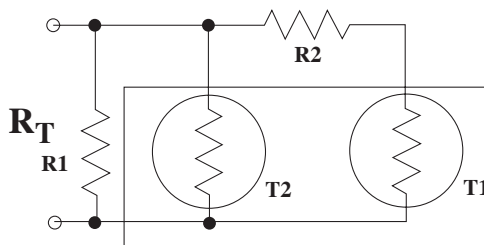


Voltage Mode Positive slope output for 36K53A1(D1) Networks



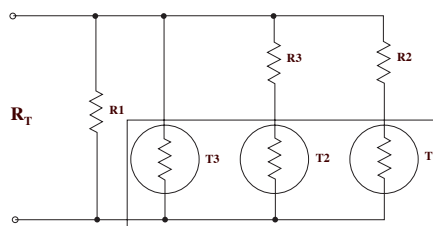
Resistance Mode Schematic

For BetaLINEAR 36K53A1, D1 and 11K2M4D1 composites with assigned resistor sets.



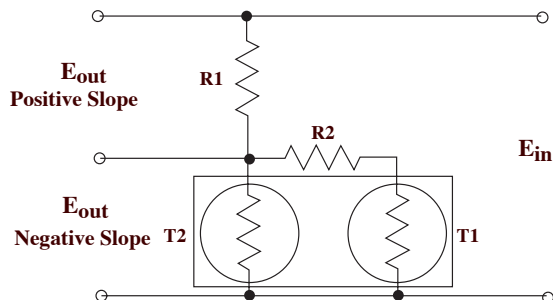
Resistance Mode Schematic

For 62K345D1 with assigned resistor set.



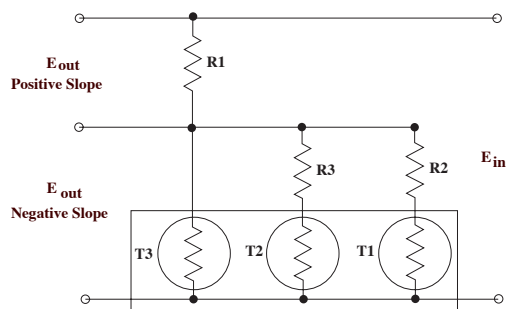
Voltage Mode Schematic

For 36K53A1 (D1) and 11K2M4D1 composites with assigned resistor sets.



Voltage Mode Schematic

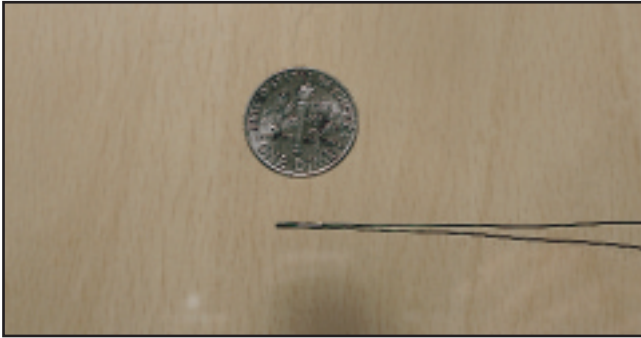
For 62K345D1 composite with assigned resistor set.



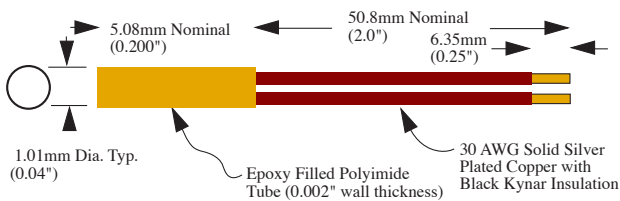
BetaLINEAR Part Numbers and Specifications.

Temp. Range	Composite Part Numbers	Network Part Number	Resistor Set Part Number (ohms)	Eout Positive Slope Eout Negative Slope	Resistance Mode	E _{in} Max.	I _T Max microAmps	Linearity Deviation degrees °C
0 to 100 °C	36K53A1 36K53D1	36K53A1-RS103 36K53D1-RS1030	RS103 R1=3200 +/-0.1% R2=6250 +/-0.1%	E _o = (+0.0053482E _{in})T+0.13494E _{in} E _o = (-0.0053482E _{in})T+0.86506E _{in}	R _t =(-17.114)T+2768.24	2.0Volts	624	+/-0.217
-30 to 50 °C	36K53A1 36K53D1	36K53A1-RS104 36K53D1-RS104	RS104 R1=18700 +/-0.1% R2=35250 +/-0.1%	E _o = (+0.0067967E _{in})T+0.34892E _{in} E _o = (-0.0067967E _{in})T+0.65106E _{in}	R _t =(-127.095)T+12176	3.0Volts	474	+/-0.161
-5 to 45 °C	36K53A1 36K53D1	36K53A1-RS106 36K53D1-RS106	RS106 R1=5700 +/-0.1% R2=12000 +/-0.1%	E _o = (+0.0056847E _{in})T+0.19414E _{in} E _o = (-0.0056847E _{in})T+0.805857E _{in}	R _t =(-32.403)T+4593.4	3.5Volts	610	+/-0.070
-2 to 38 °C	36K53A1 36K53D1	36K53A1-RS107 36K53D1-RS107	RS107 R1=5700 +/-0.1% R2=12400 +/-0.1%	E _o = (+0.00563181E _{in})T+0.192435E _{in} E _o = (-0.00563181E _{in})T+0.807561E _{in}	R _t =(-32.101)T+4603.15	4.0Volts	680	+/-0.035
-55 to 85 °C	11K2M4D1	D1-RS105 11K2M4	RS105 R1=3550 +/-0.1% R2=6025 +/-0.1%	E _o = (+0.005069E _{in})T+0.3410E _{in} E _o = (-0.005069E _{in})T+0.6590E _{in}	R _t =(-18.0)T+2338	2.0Volts	830	+/-1.12
-50 to 50 °C	62K345D1	62K345D1-RS108	RS108 R1=23100 +/-0.1% R2=88200 +/-0.1% R2=88200 +/-0.1%	E _o = (+0.0055915E _{in})T+0.407E _{in} E _o = (-0.0055915E _{in})T+0.593E _{in}	R _t =(-129.162)T+13698.2	3.5Volts	675	+/-0.10

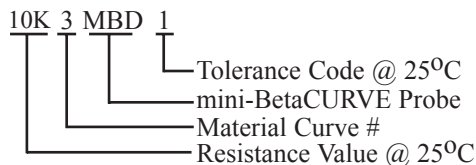
- The overall accuracy of the linear networks are a combination of the thermistor element precision (+/-0.2°C from 0°C to 70°C), uncertainty due to +/-0.1% resistor tolerance and the linearity deviation.
- E_{in} Max and I_T Max values are assigned to control thermistor self-heat errors. Thermistor Dissipation Constant of 8mW/°C in a well stirred oil bath is typical for each thermistor.
- Higher E_{in} Max and I_T Max values may be used when thermistor mounting methods increase the D.C. or an increase of the error is acceptable. E_{in} Max and I_T Max values may be exceeded without any damage to the thermistor elements.



Thermistor Configuration



Sample Part Number:



Interchangeable mini-BetaCURVE Probe:

Applications:

- Reduced size allows localized temperature sensing.
- Small Medical probes.
- Micro-flow sensing.
- Aerospace temperature sensing.

Features:

- Rapid Time Constant (400 milliseconds in liquids).
- Standards supplied with $\pm 0.2^\circ\text{C}$ tolerance (0 to 70°C).
- Other tolerances available.
- $0.5 \text{ mW}/^\circ\text{C}$ typ. Dissipation Constant in air at 25°C .
- Smaller than regular BetaCURVE Series

The mini-BetaCURVE Probe is an extension of the BetaCURVE Series for applications that require smaller size. Although the mini-BetaCURVE Probe is packaged in polyimide tubing it is recommended that a moisture protection barrier should be used in applications where high humidity is present. The probes relatively small size allows for high precision sensing where the standard BetaCURVE series products are too large or too slow with respect to their thermal Time Constant. The size is compatible with mounting in stainless steel probe housings that have a nominal outside diameter of 1.524mm (0.06").

Interchangeable mini-BetaCURVE Probe Part Numbers and Specifications:

Part Number	Resistance @ 25 °C (Ohms)	Alpha @ 25 °C	0/50 °C Beta Value	Curve #
0.1K1MBD1	100	-3.50%	3108	1
0.3K1MBD1	300	-3.50%	3108	1
1K2MBD1	1000	-3.68%	3263	2
1K7MBD1	1000	-3.87%	3422	7
2.2K3MBD1	2252	-4.39%	3892	3
3K3MBD1	3000	-4.39%	3892	3
5K3MBD1	5000	-4.39%	3892	3
10K3MBD1	10000	-4.39%	3892	3
10K4MBD1	10000	-4.04%	3575	4
30K5MBD1	30000	-4.30%	3811	5
30K6MBD1	30000	-4.68%	4143	6
50K6MBD1	50000	-4.68%	4143	6
100K6MBD1	100000	-4.68%	4143	6
1M9MBD1	1000000	-5.18%	4582	9



Micro-BetaCHIP Probe:

Applications

- Low volume flow sensors (liquids or gases).
- Laboratory animal research.
- Peltiere (thermal cooler) temperature tracking sensors.
- Temperature control for bath showers.
- DNA research sensors.
- Medical catheters.

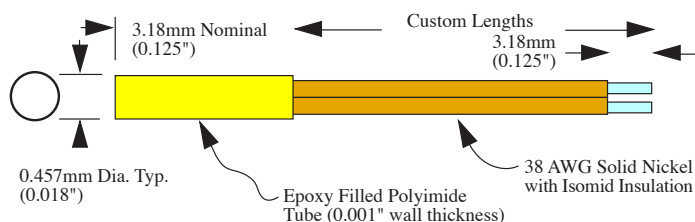
Features:

- Rapid Time Constant (200 milliseconds in liquids).
- Custom tolerances available.
- 0.3 mW/°C typ. Dissipation Constant in air at 25°C.
- Smaller than our mini-BetaCURVE device.

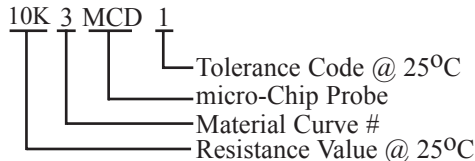
The micro-BetaCHIP probe is BetaTHERM's smallest packaged thermistor device. The probe is produced for applications that require rapid temperature response and applications where space is very limited. The probes are extremely small (0.457mm dia.) and fragile. The sensor is potted in a polyimide tube with epoxy. Adequate moisture protection should be provided when using the device in high humidity applications. The size of the micro-BetaCHIP thermistors allows it to be installed in 20 AWG (0.914mm dia.) thin wall hypodermic tubing. Custom probe assemblies protect the thermistor element from high humidity and mechanical shock.

The small mass of the unit allows the sensor to respond very rapidly to temperature changes. This makes the micro-BetaCHIP thermistor suitable for low volume gas or liquid flow sensing. The probes are also small enough to be mounted inside Medical catheters.

Thermistor Configuration

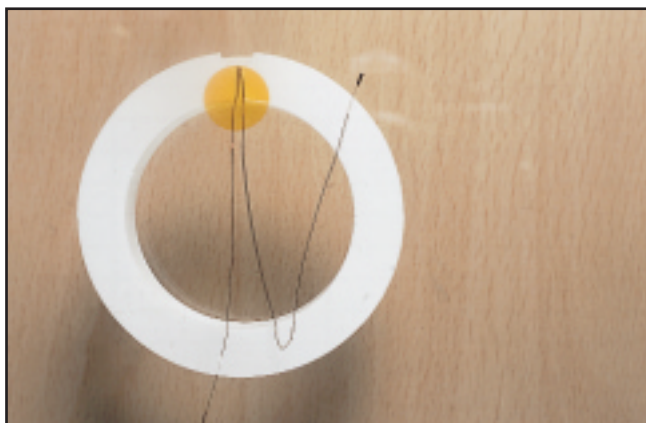


Sample Part Number:

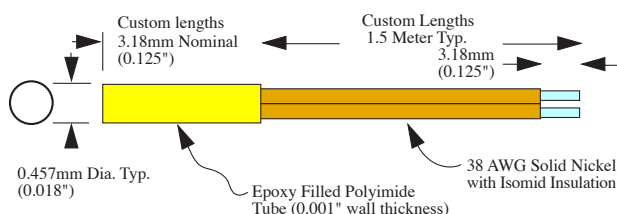


Interchangeable mini-BetaCURVE Probe Part Numbers and Specifications:

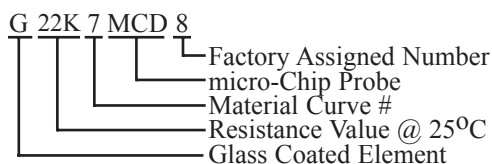
Part Number	Resistance @ 25 °C (ohms)	Temperature Tolerance	Alpha @ 25 °C	0/50 °C Beta Value	Curve #
2K7MCD1	2000	+/-0.2 °C @ 25 °C	-3.87%	3422	7
10K3MCD1	10000	+/-0.2 °C @ 25 °C	-4.39%	3892	3
100K6MCD1	100000	+/-0.2 °C @ 25 °C	-4.68%	4143	6



Thermistor Configuration



Sample Part Number:



Medical Catheter micro-BetaCHIP Probe:

Applications

- **Thermodilution catheters and other medical applications.**
- **General Medical applications.**

Features:

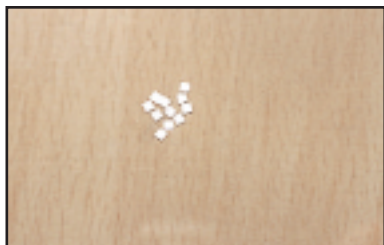
- **Rapid Time Constant (200 milliseconds in liquids).**
- **Custom tolerances available.**
- **0.3 mW/°C typ. Dissipation Constant in air at 25°C.**
- **Smaller than the mini-BetaCURVE device.**
- **Custom designs available.**

The *Medical Catheter micro-BetaCHIP* probe is packaged similar to the standard micro-BetaCHIP Probe except that the thermistor element is a glass coated thermistor of specific resistance value. The glass coated thermistor adds extra moisture protection to the probe design.

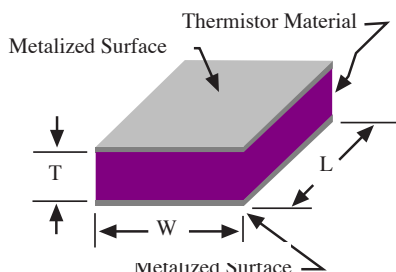
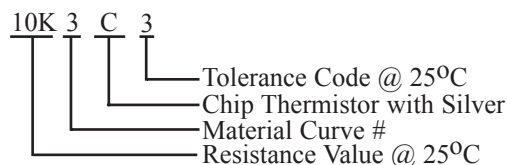
The probe is produced for Medical applications which require rapid temperature response and very small size. When used in thermodilution catheters, the thermistor measures blood flow characteristics in the human body. Supplied with custom lead lengths near 1.5 meters on small reels (spools) with calibration data at 37°C. The standard thermistor is denoted as G22K7MCD8. Many other custom versions have been produced by *BetaTHERM* to meet customers specific design criteria.

Medical Catheter micro-BetaCHIP Probe Part Number and Specifications:

Part Number	Resistance @ 25 °C (ohms)	Resistance (ohms) and Tolerance @ 37 °C	Alpha @ 25 °C	0/50 °C Beta Value	Curve #
G22K7MCD8	22000	14004 +/- 15%	-3.87%	3422	7

Silver Terminations (Contacts)

TYPICAL CHIP THERMISTOR

Example: Silver Terminated Leadless BetaCHIPPart NumberBetaCHIP Leadless Chip Thermistors:Applications:

- Automotive temperature controls.
- Surface mounting on hybrid circuits.
- Temperature compensation of crystal oscillators.

Features:

- Rapid Time Response (< 1 second typical in liquids).
- Standards supplied with 5% and 10% tolerance.
- 1% and 2% available upon request.
- Surface Mount Capability.
- 1 mW/°C Dissipation Constant in air at 25°C.
- Uniformly Sized for Pick & Place Assembly.

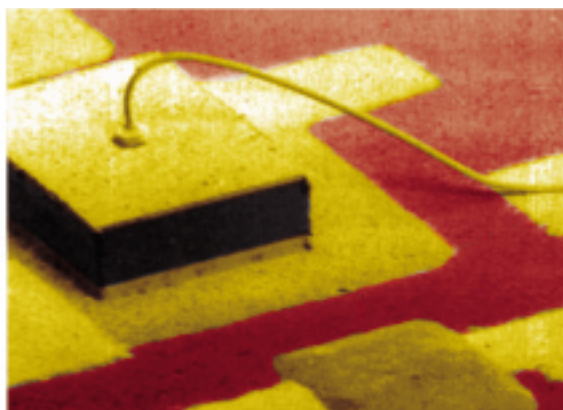
Silver Metalized BetaCHIP Thermistors:

An economical alternative to the gold leadless BetaCHIP thermistors is the **Silver** terminated leadless BetaCHIP thermistors. These elements are manufactured using the same high quality materials as our other thermistor products. The nominal dimensions remain the same for both gold and silver chips. Custom sizes are also manufactured for customer specific applications. Silver chip elements are supplied in vials, "gel" or "waffle" packs.

Silver metalized chips may be soldered or conductive epoxied to board termination points. The use of solder containing a small quantity of silver is recommended such as 62%Sn (tin), 36%Pb (lead) and 2%Ag (silver).

Silver Terminated Leadless BetaCHIP Thermistor Part Numbers and Specifications:

Part Number for +/- 5% @ 25 °C	Part Number for +/- 10% @ 25°C	Resistance @ 25 °C (ohms)	Alpha @ 25 °C	0/50 °C Beta Value	Curve #	Nominal Chip Dimensions (mm)			Nominal Chip Dimensions (in)		
						L	W	T	L	W	T
0.1K1C3	0.1K1C2	100	-3.50%	3108	1	1.397	1.397	0.305	0.055	0.055	0.012
0.3K1C3	0.3K1C2	300	-3.50%	3108	1	0.914	0.914	0.381	0.036	0.036	0.015
1K2C3	1K2C2	1000	-3.68%	3263	2	0.762	0.762	0.381	0.030	0.030	0.015
1K7C3	1K7C2	1000	-3.87%	3422	7	1.067	1.067	0.381	0.042	0.042	0.015
2.2K3C3	2.2K3C2	2252	-4.39%	3892	3	1.905	1.905	0.254	0.075	0.075	0.010
3K3C3	3K3C2	3000	-4.39%	3892	3	1.651	1.651	0.254	0.065	0.065	0.010
5K3C3	5K3C2	5000	-4.39%	3892	3	1.397	1.397	0.305	0.055	0.055	0.012
10K3C3	10K3C2	10000	-4.39%	3892	3	1.016	1.016	0.305	0.040	0.040	0.012
10K4C3	10K4C2	10000	-4.04%	3575	4	1.143	1.143	0.254	0.045	0.045	0.010
30K5C3	30K5C2	30000	-4.30%	3811	5	0.889	0.889	0.381	0.035	0.035	0.015
30K6C3	30K6C2	30000	-4.68%	4143	6	1.397	1.397	0.305	0.055	0.055	0.012
50K6C3	50K6C2	50000	-4.68%	4143	6	1.143	1.143	0.381	0.045	0.045	0.015
100K6C3	100K6C2	100000	-4.68%	4143	6	0.889	0.889	0.381	0.035	0.035	0.015
1M9C3	1M9C2	1000000	-5.20%	4582	9	0.889	0.889	0.254	0.035	0.035	0.010



SEM Photo 30x Hybrid Thermistor Chip

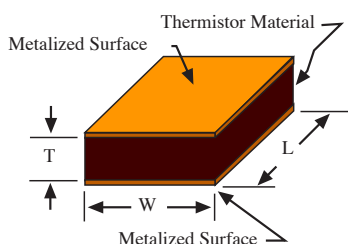
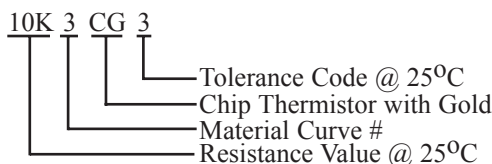


Figure # 1

Sample Part Number:Gold Termination BetaCHIP Thermistors:Applications

- WDM (Wavelength Division Multiplexing) for advanced frequency control in modern communications systems and wireless applications.
- Thermopile sensors for thermal radiation recognition and infrared sensing.
- Thermal protection of sensitive circuits.
- Hybrid circuit temperature compensation.
- Localized temperature sensing.

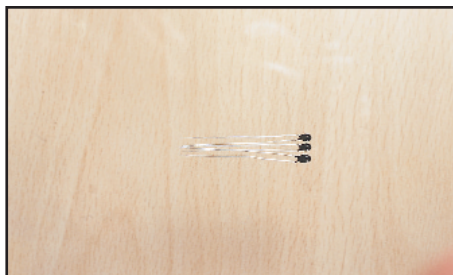
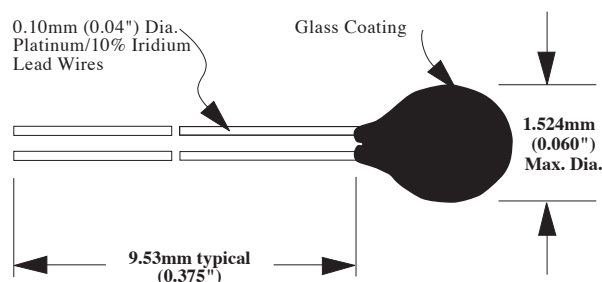
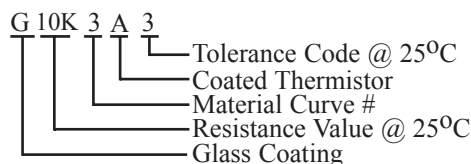
Features:

- Rapid Time Response (<1 second typical in liquids).
- Standards supplied with 5% and 10% tolerance.
- 1% and 2% available upon request.
- Surface Mount Capability.
- 1 mW/°C Dissipation Constant in air at 25°C.
- Uniformly Sized for Pick & Place Assembly.
- Higher precision tolerance available.
- Square and Rectangular Configurations.

BetaTHERM offer high reliability **Gold** terminated leadless BetaCHIP thermistors that meet today's hybrid microelectronics needs and are offered by BetaTHERM. With metalization on top and bottom surfaces, attachment to hybrid, IC or PC circuits is accomplished using industry standard die attach and wire bonding techniques. Chips may be soldered or conductive epoxied to board termination points where space is at a premium. Typical chip sizes (1mm x 1mm x 0.25mm thick) allow for accurate robotic placement. **Gold BetaCHIP** thermistors are supplied in "gel" or "waffle" packs.

Gold Metalized BetaCHIP Thermistor Part Numbers and Specifications:

Part Number for +/- 5% @ 25 °C	Part Number for +/- 10% @ 25°C	Resistance @ 25 °C (ohms)	Alpha @ 25 °C	0/50 °C Beta Value	Curve #	Nominal Chip Dimensions (mm)			Nominal Chip Dimensions (in)		
						L	W	T	L	W	T
0.1K1CG3	0.1K1CG2	100	-3.50%	3108	1	1.397	1.397	0.305	0.055	0.055	0.012
0.3K1CG3	0.3K1CG2	300	-3.50%	3108	1	0.914	0.914	0.381	0.036	0.036	0.015
1K2CG3	1K2CG2	1000	-3.68%	3263	2	0.762	0.762	0.381	0.030	0.030	0.015
1K7CG3	1K7CG2	1000	-3.87%	3422	7	1.067	1.067	0.381	0.042	0.042	0.015
2.2K3CG3	2.2K3CG2	2252	-4.39%	3892	3	1.905	1.905	0.254	0.075	0.075	0.010
3K3CG3	3K3CG2	3000	-4.39%	3892	3	1.651	1.651	0.254	0.065	0.065	0.010
5K3CG3	5K3CG2	5000	-4.39%	3892	3	1.397	1.397	0.305	0.055	0.055	0.012
10K3CG3	10K3CG2	10000	-4.39%	3892	3	1.016	1.016	0.305	0.040	0.040	0.012
10K4CG3	10K4CG2	10000	-4.04%	3575	4	1.143	1.143	0.254	0.045	0.045	0.010
30K5CG3	30K5CG2	30000	-4.30%	3811	5	0.889	0.889	0.381	0.035	0.035	0.015
30K6CG3	30K6CG2	30000	-4.68%	4143	6	1.397	1.397	0.305	0.055	0.055	0.012
50K6CG3	50K6CG2	50000	-4.68%	4143	6	1.143	1.143	0.381	0.045	0.045	0.015
100K6CG3	100K6CG2	100000	-4.68%	4143	6	0.889	0.889	0.381	0.035	0.035	0.015
1M9CG3	1M9CG2	1000000	-5.20%	4582	9	0.889	0.889	0.254	0.035	0.035	0.010

Glass Coated BetaCHIP Thermistor Series:Thermistor ConfigurationExample: Glass Coated BetaCHIP Series Part NumberApplications

- Over temperature protection for applications up to 300°C
- Coil heater sensors
- Photo copier ink sensors

Features

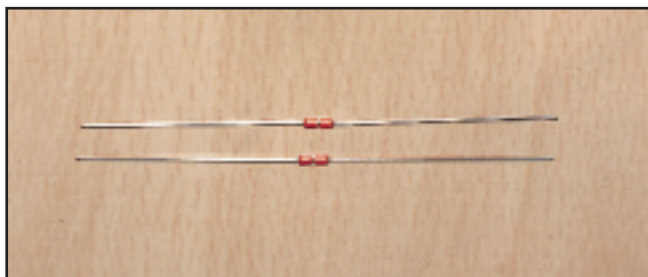
- Rapid Time Response (<1 second typical in liquids).
- DC (Dissipation Constant) = 0.40 mW/°C typical in still air at 25°C.
- Min./Max. Temperature Exposure = -80°C to 300°C.
- Available in custom probe assemblies.
- Excellent "long term" stability at high temperatures.
- Glass Hermetic Seal covering thermistor element.
- Weldable Pt/Ir lead wires.

The Glass coated *BetaCHIP Thermistors* are small glass coated devices with solid 0.1mm diameter Platinum/10%Iridium lead wires. The series offers a choice of +/- 5% and +/- 10% tolerance classifications as standard. Higher or tailored precision tolerances are available upon special request. Glass coated thermistors are generally selected for applications that exceed +150°C.

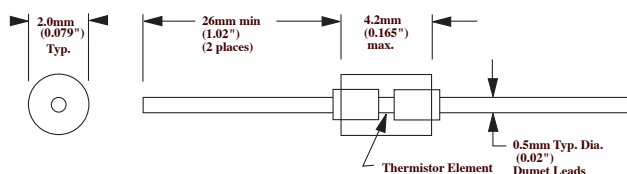
The Glass Coated *BetaCHIP Series* is produced with same high reliability chip thermistor materials as our *BetaCURVE Series*. The conductor materials (Platinum/Gold and Platinum/Iridium) used in conjunction with our thermistor materials raise the maximum temperature exposure rating to 300°C. Although glass coated thermistors will withstand temperatures to 300°C, it is recommend limiting the "long term" temperature usage range from -80°C to 225°C due to thermal aging characteristics. High temperature storage tests (2000 hrs. @ 150°C) have been documented showing superior stability (Avg delta R = 0.016%).

Standard Glass Coated Thermistor Part Numbers and Specifications:

Part Number for +/- 5% @ 25 °C	Part Number for +/- 10% @ 25 °C	Resistance @ 25 °C (Ohms)	Alpha @ 25 °C	0/50 °C Beta Value	Curve #
G10K3A3	G10K3A2	10000	-4.39%	3892	3
G20K3A3	G20K3A2	20000	-4.39%	3892	3
G50K6A3	G50K6A2	50000	-4.68%	4143	6
G100K6A3	G100K6A2	100000	-4.68%	4143	6
G200K6A3	G200K6A2	200000	-4.68%	4143	6
G500K6A3	G500K6A2	500000	-4.68%	4143	6



Thermistor Configuration



Sample Part Number



DO-35 Packaged Thermistors.

Applications:

- Low cost
- High temperature printer ink sensing.
- Consumer Electronics.
- High temperature-high speed tire manufacturing.
- Printed circuit board temperature sensing.

Features

- High temperature devices for applications to +200°C.
- P.C. board mounting.
- Hermetically sealed element. Glass to metal package.
- Axial leads
- Standard tin plated leads are solderable.
- Time Constant - 8 seconds in air.
- Dissipation Constant - 2.5mW/°C in air at 25°C.
- Available on tape and reel.

The rugged construction of the DO-35 package is ideally suited for applications which cover the temperature range from -60 °C to +200°C with leads that are suitable for welding or soldering. The glass package hermetically seals to the metal leads which protects the thermistor element from extreme environmental conditions. The axial leads make this device a perfect choice for P.C. board mounting and the leads are tin plated giving a temperature rating to +200°C. The standard devices are specified as +/- 5% and +/- 10% at 25°C although custom tolerances at various different temperatures are available upon request.

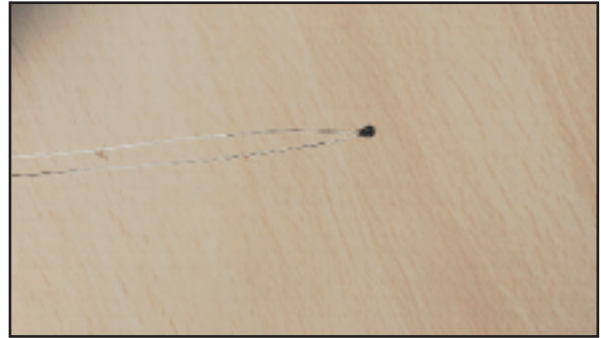
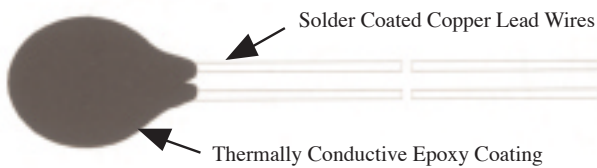
DO-35 Packaged BetaCHIP Thermistor Part Numbers and Specifications.

Part Number for +/- 5% @ 25°C	Resistance @ 25°C (ohms)	25/85°C Beta Value
5K3600DP3	5000	3600 +/-2%
10K3700DP3	10000	3700 +/-2%
10K3970DP3	10000	3970 +/-2%
15K3970DP3	15000	3970 +/-2%
30K3970DP3	30000	3970 +/-2%
50K3970DP3	50000	3970 +/-2%
100K3970DP3	100000	3970 +/-2%
100K4200DP3	100000	4200 +/-2%
200K4260DP3	200000	4260 +/-2%
1M4600DP3	1000000	4600 +/-2%

Discrete Temperature Sensors:

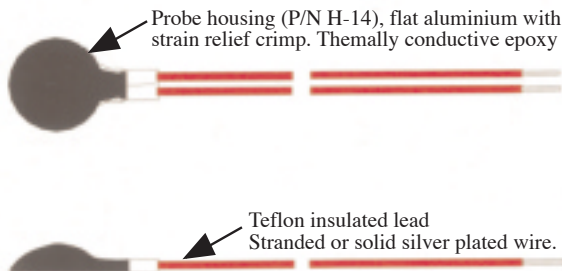
Epoxy encapsulated thermistor chip elements.

- Resistance from 1K ohm to 5K ohm @ 25°C.
- Tolerances +/-0.2°C from 0°C to 100°C.
- Operating Temperatures -55°C to 150°C.
- Manufactured to ESA/SCC 4006/013 Specification.
- ESA/SCC Qualification pending .

**Surface Mount Probe Assemblies:**

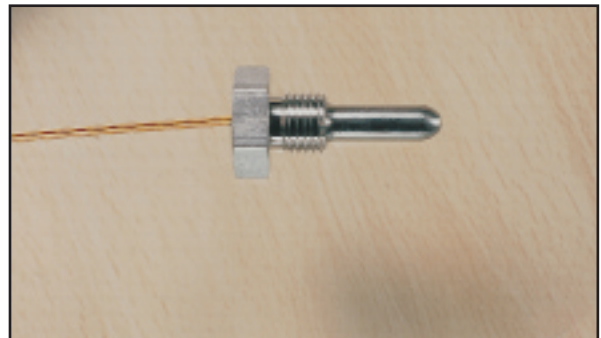
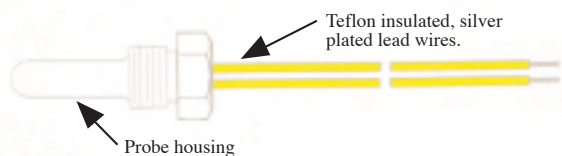
Matched glass coated thermistor beads mounted on an aluminum housing and encapsulated using a black epoxy encapsulant.

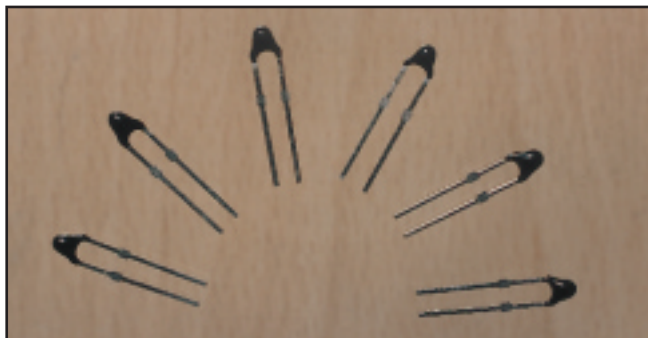
- Resistances from 2K ohm to 100K ohm at 25°C.
- Tolerances +/-0.35 from 0°C to 100°C.
- Operating Temperatures -40°C to +160°C.
- Manufactured to ESA/SCC 4006/014 Specifications.
- ESA/SCC Qualification pending.

**Customized Probes and Assemblies:**

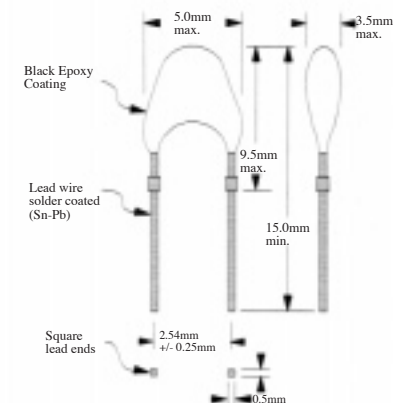
Extensive range of thermistor probes and assemblies offering a number of solutions to customer requirements.

- Components manufactured to ESA/SCC or Mil standards.
- Wide range of Resistance/Temperature characteristics and tolerances to meet specific customer needs.
- Lot Acceptance Levels 1, 2 & 3 testing.

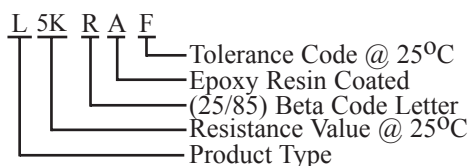




L Series Thermistor Configuration:



Part Number Code:



L Series Thermistor:

Applications:

- Disposable medical products.
- Energy management systems.
- Home appliances.
- Industrial equipment.
- Automotive applications.
- R&D testing and analysis.

Features:

- Compact size.
- Uniformed type for automatic assembly. (Control lead spacing).
- Economically priced.
- Available in tolerances of +/-1%, +/-2%, +/-3% and +/-5%.

The range of L Series NTC thermistors are designed for close tolerance resistance-temperature curve tracking over standard temperature ranges. They may be used in any general temperature measurement, control or compensation application where interchangeability and low cost are major considerations.

Resistance Tolerance Codes @ 25°C

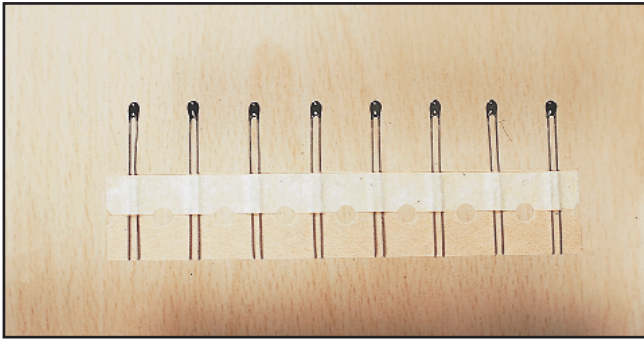
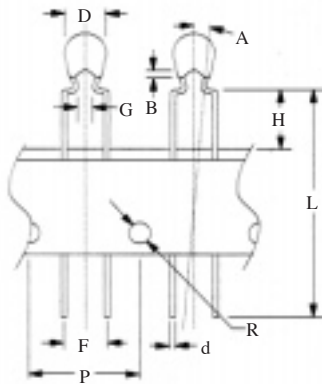
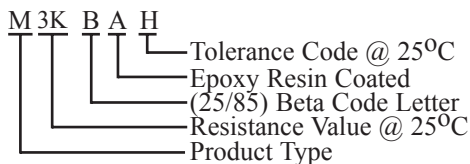
- F = +/-1%
- G = +/-2%
- H = +/-3%
- J = +/-5%

Thermal and Electrical Properties:

Dissipation Constant	Min. 1.5mW/ °C (25 °C to 75 °C in still air) Min. 8.0mW/ °C (25°C to 75 °C, in stirred oil)
Thermal Time Constant	Max. 16 sec. (75 °C to 25 °C, in still air) Max. 2 sec. (75 °C to 25 °C in stirred oil)
Maximum Power Rating	40mW
Operating Temperature Range	-30 to 125 °C

L Series Part Numbers and Specifications:

Part Number	Resistance @ 25 °C (ohms)	0/50 °C Beta Value	25/85 °C Beta Value	Beta Code Letter
L5KRAF	5000 +/-1%	3220	3325	R
L5KBAF	5000 +/-1%	3450	3600	B
L5KFAF	5000 +/-1%	3880	3970	F
L10KUAF	10000 +/-1%	3350	3450	U
L10KCAF	10000 +/-1%	3583	3720	C
L10KFAF	10000 +/-1%	3880	3970	F
L15KFAF	15000 +/-1%	3880	3970	F
L20KOAF	20000 +/-1%	3880	3970	O
L23KHAF	23000 +/-1%	4164	4354	H
L30KOAF	30000 +/-1%	3880	3970	O
L50KOAF	50000 +/-1%	3880	3970	O
L50KQAF	50000 +/-1%	3960	4087	Q
L100KGAF	100000 +/-1%	3988	4200	G
L200KIAF	200000 +/-1%	4185	4391	I

M Series Thermistor Configuration:Part Number Code:M Series NTC Thermistor:Applications:

- Temperature sensing and control.
- Temperature compensation.
- Temperature measurement.
- Automotive Applications.

Features:

- Low cost.
- High stability.
- Available on tape and reel or bulk.
- 25/85 Beta Value tolerance = $\pm 3\%$
- High dissipation Constant (min 4.5mW/°C).

The range of M Series Thermistors are commonly used as a temperature compensation device because of low cost. This high quality, stable thermistor can be employed for temperature control sensing between -30°C and 125°C . The complete series is available on tape and reel suitable for automatic assembly.

Resistance Tolerance Codes @ 25°C.

- H = $\pm 3\%$
- J = $\pm 5\%$
- K = $\pm 10\%$
- L = $\pm 15\%$

Thermal and Electrical Properties:

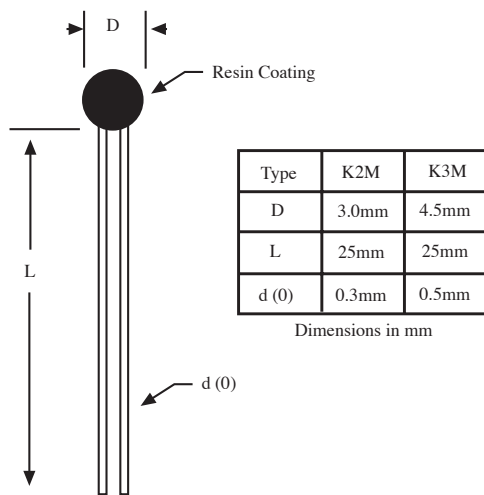
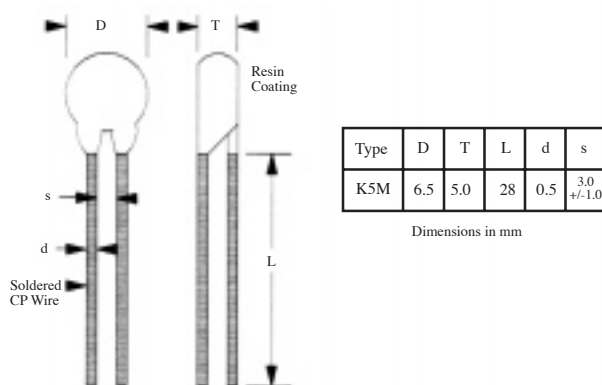
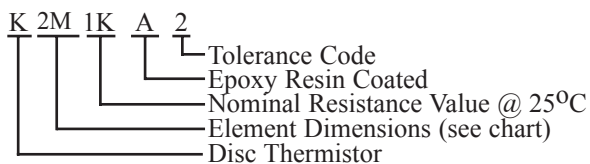
Dissipation Constant	Min. 4.5mW/°C (25 °C to 75 °C in still air)
Thermal Time Constant	Max. 50 sec. (75 °C to 25 °C in still air)
Maximum Power Rating	450mW
Operating Temperature Range	-30 to 125 °C

M Series Thermistor Part Numbers, Specifications and Dimensions:

Part Number	Resistance @ 25 °C (ohms)	25/85 °C Beta Value	Beta Code Letter	A (angle) max	B max	D max	d ± 0.1	F ± 0.3	G min	H min	L min	P ± 0.3	R ± 0.1
M3KBAH	3000 $\pm 3\%$	3600	B	10.0	1.5	3.5	0.5	2.5	NA	5.5	23.5	12.7	4.0
M5KFAH	5000 $\pm 3\%$	3970	F	10.0	1.5	3.5	0.5	2.5	NA	5.5	23.5	12.7	4.0
M10KFAH	10000 $\pm 3\%$	3970	F	10.0	1.5	3.5	0.5	2.5	NA	5.5	23.5	12.7	4.0
M10KUAH	10000 $\pm 3\%$	3450	U	10.0	1.5	3.5	0.5	2.5	NA	5.5	23.5	12.7	4.0
M20KOA H	20000 $\pm 3\%$	3970	O	10.0	1.5	3.5	0.5	2.5	NA	5.5	23.5	12.7	4.0
M30KOA H	30000 $\pm 3\%$	3970	O	10.0	1.5	3.5	0.5	2.5	NA	5.5	23.5	12.7	4.0
M50KOA H	50000 $\pm 3\%$	3970	O	10.0	1.5	3.5	0.5	2.5	NA	5.5	23.5	12.7	4.0
M100KGAH	100000 $\pm 3\%$	4200	G	10.0	1.5	3.5	0.5	2.5	NA	5.5	23.5	12.7	4.0
M150KIAH	150000 $\pm 3\%$	4391	I	10.0	1.5	3.5	0.5	2.5	NA	5.5	23.5	12.7	4.0
M1KCAH	1000 $\pm 3\%$	3720	C	10.0	2.0	5.5	0.5	2.5/5.0	1.2	5.5	23.5	12.7	4.0
M3KOA H	3000 $\pm 3\%$	3970	O	10.0	2.0	5.5	0.5	2.5/5.0	1.2	5.5	23.5	12.7	4.0
M5KQA H	5000 $\pm 3\%$	4087	Q	10.0	2.0	5.5	0.5	2.5/5.0	1.2	5.5	23.5	12.7	4.0
M10KGAH	10000 $\pm 3\%$	4200	G	10.0	2.0	5.5	0.5	2.5/5.0	1.2	5.5	23.5	12.7	4.0
M20KHAH	20000 $\pm 3\%$	4354	H	10.0	2.0	5.5	0.5	2.5/5.0	1.2	5.5	23.5	12.7	4.0
M30KIAH	30000 $\pm 3\%$	4391	I	10.0	2.0	5.5	0.5	2.5/5.0	1.2	5.5	23.5	12.7	4.0
M50KIAH	50000 $\pm 3\%$	4391	I	10.0	2.0	5.5	0.5	2.5/5.0	1.2	5.5	23.5	12.7	4.0
M100KLAH	100000 $\pm 3\%$	4814	L	10.0	2.0	5.5	0.5	2.5/5.0	1.2	5.5	23.5	12.7	4.0
M150KLAH	150000 $\pm 3\%$	4814	L	10.0	2.0	5.5	0.5	2.5/5.0	1.2	5.5	23.5	12.7	4.0

Standard Resistance Ratio - Temperature Chart for L-Series & M-Series Thermistors

	Beta Code Letter													
°C	A	B	C	F	G	H	I	L	O	Q	R	U	W	°C
-30	11.380	10.978	13.905	17.879	17.577	20.854	21.577	26.967	17.879	17.816	10.575	12.292	19.821	-30
-25	8.812	8.660	10.531	13.130	13.080	15.169	15.500	19.230	13.130	13.189	8.247	9.380	14.344	-25
-20	6.876	6.855	8.045	9.746	9.806	11.136	11.268	13.823	9.746	9.846	6.481	7.228	10.507	-20
-15	5.405	5.446	6.197	7.308	7.405	8.250	8.285	10.017	7.308	7.412	5.131	5.621	7.784	-15
-10	4.280	4.344	4.812	5.533	5.632	6.165	6.157	7.317	5.533	5.625	4.091	4.411	5.830	-10
-5	3.413	3.478	3.766	4.229	4.314	4.646	4.623	5.386	4.229	4.302	3.284	3.490	4.412	-5
0	2.739	2.796	2.968	3.260	3.327	3.530	3.505	3.995	3.260	3.315	2.653	2.784	3.371	0
5	2.213	2.258	2.357	2.535	2.583	2.703	2.689	2.986	2.535	2.573	2.158	2.237	2.600	5
10	1.798	1.830	1.884	1.987	2.019	2.086	2.078	2.248	1.987	2.012	1.765	1.811	2.023	10
15	1.471	1.490	1.516	1.569	1.587	1.621	1.617	1.704	1.569	1.583	1.453	1.476	1.587	15
20	1.209	1.218	1.227	1.248	1.256	1.269	1.268	1.301	1.248	1.254	1.202	1.211	1.255	20
25	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	1.000	25
30	0.8315	0.8231	0.8202	0.8066	0.8015	0.7943	0.7912	0.7739	0.8066	0.8022	0.8362	0.8317	0.8042	30
35	0.6948	0.6808	0.6762	0.6546	0.6457	0.6344	0.6296	0.6027	0.6546	0.6473	0.7025	0.6951	0.6504	35
40	0.5835	0.5658	0.5602	0.5343	0.5227	0.5095	0.5037	0.4722	0.5343	0.5254	0.5930	0.5837	0.5291	40
45	0.4922	0.4724	0.4663	0.4386	0.4253	0.4113	0.4051	0.3722	0.4386	0.4287	0.5028	0.4925	0.4326	45
50	0.4171	0.3962	0.3899	0.3620	0.3476	0.3338	0.3275	0.2950	0.3620	0.3517	0.4281	0.4174	0.3557	50
55	0.3550	0.3343	0.3271	0.3001	0.2851	0.2718	0.2664	0.2354	0.3001	0.2900	0.3658	0.3547	0.2931	55
60	0.3034	0.2834	0.2755	0.2500	0.2348	0.2223	0.2177	0.1888	0.2500	0.2403	0.3138	0.3025	0.2426	60
65	0.2602	0.2414	0.2330	0.2093	0.1942	0.1826	0.1787	0.1520	0.2093	0.2001	0.2703	0.2589	0.2017	65
70	0.2241	0.2064	0.1978	0.1760	0.1612	0.1506	0.1474	0.1230	0.1760	0.1674	0.2337	0.2224	0.1683	70
75	0.1936	0.1773	0.1685	0.1487	0.1344	0.1247	0.1221	0.09997	0.1487	0.1407	0.2029	0.1917	0.1410	75
80	0.1679	0.1529	0.1441	0.1261	0.1124	0.1037	0.1015	0.08158	0.1261	0.1187	0.1767	0.1658	0.1186	80
85	0.1461	0.1323	0.1236	0.1075	0.09441	0.08661	0.08481	0.06686	0.1075	0.1006	0.1544	0.1439	0.1001	85
90	0.1275	0.1150	0.1065	0.09193	0.07957	0.07259	0.07109	0.05492	0.09193	0.08559	0.1355	0.1253	0.08484	90
95	0.1116	0.1002	0.09196	0.07896	0.06731	0.06107	0.05981	0.04528	0.07896	0.07310	0.1192	0.1094	0.07215	95
100	0.09798	0.08769	0.07969	0.06808	0.05713	0.05157	0.05051	0.03747	0.06808	0.06267	0.1053	0.09578	0.06157	100
105	0.08628	0.07697	0.06928	0.05891	0.04866	0.04370	0.04281	0.03112	0.05891	0.05393	0.09327	0.08412	0.05271	105
110	0.07618	0.06777	0.06041	0.05116	0.04158	0.03716	0.03641	0.02593	0.05116	0.04656	0.08285	0.07409	0.04528	110
115	0.06746	0.05986	0.05283	0.04457	0.03564	0.03170	0.03108	0.02168	0.04457	0.04034	0.07381	0.06544	0.03902	115
120	0.05989	0.05303	0.04633	0.03896	0.03065	0.02714	0.02661	0.01819	0.03896	0.03507	0.06594	0.05795	0.03373	120
125	0.05331	0.04712	0.04075	0.03417	0.02644	0.02330	0.02286	0.01531	0.03417	0.03058	0.05907	0.05145	0.02925	125
130	0.04757	0.04198	0.03594	0.03005	0.02287	0.02007	0.01970	0.01293	0.03005	0.02675	0.05304	0.04579	0.02544	130
135	0.04256	0.03750	0.03177	0.02651	0.01984	0.01735	0.01703	0.01096	0.02651	0.02347	0.04775	0.04086	0.02218	135
140	0.03816	0.03358	0.02817	0.02346	0.01727	0.01503	0.01476	0.009311	0.02346	0.02065	0.04309	0.03654	0.01940	140
145	0.03429	0.03015	0.02503	0.02081	0.01506	0.01306	0.01284	0.007937	0.02081	0.01822	0.03898	0.03276	0.01701	145
150	0.03089	0.02714	0.02230	0.01851	0.01318	0.01139	0.01119	0.006785	0.01851	0.01612	0.03533	0.02943	0.01496	150
155	0.02788	0.02448	0.01991	0.01651	0.01156	0.009950	0.009786	0.005817	0.01651	0.01430	0.03210	0.02650	0.01319	155
°C	BETA CHART													°C
25/85	3423	3599	3720	3970	4200	4354	4391	4814	3970	4087	3325	3450	4096	25/85
25/125	3480	3627	3799	4008	4313	4462	4485	4961	4008	4140	3358	3522	4193	25/125

**K2M and K3M Configuration****K5M Configuration****Sample Part Number:****NTC Disc Thermistors:****Applications**

- Temperature Compensation for transistor and various electronic circuits.
- Detection and control of temperatures for air conditioning equipment.
- Delay circuit such as relay.
- Automotive Electronics.

Features

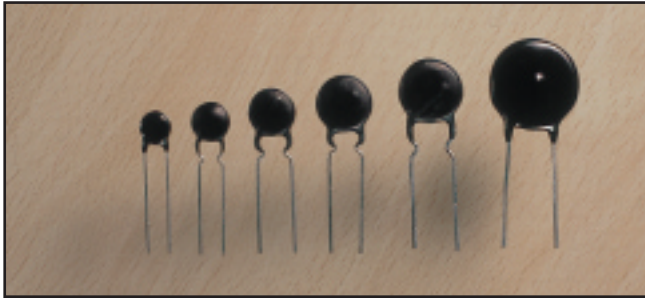
- Economically priced
- Available in tape and reel format.
- Max temperature exposure = +130°C.
- High D.C. (Dissipation Constant) from 2.0mW/°C to 7.5mW/°C.
- Available in tolerances of +/-3%, +/-5% and +/-10%.
- Custom resistance values and tolerances available upon request.

NTC Disc Part Numbers and Specifications:

Part Number	Resistance @ 25°C Ohms	25/85°C Beta Value K	Resistance Tolerance @ 25°C
K2M1KA2	1000	3520	+/-10%
K2M3KA2	3000	3810	+/-10%
K2M5KA2	5000	3910	+/-10%
K2M10KA2	10000	4050	+/-10%
K2M30KA2	30000	4270	+/-10%
K2M50KA2	50000	4330	+/-10%
K3M.5KA2	500	3430	+/-10%
K3M1KA2	1000	3620	+/-10%
K3M3KA2	3000	3880	+/-10%
K3M5KA2	5000	3950	+/-10%
K3M10KA2	10000	4130	+/-10%
K3M30KA2	30000	4240	+/-10%
K5M.05KA2	50	3200	+/-10%
K5M.1KA2	100	3350	+/-10%
K5M.2KA2	200	3500	+/-10%
K5M.3KA2	300	3550	+/-10%
K5M.5KA2	500	3650	+/-10%
K5M1KA2	1000	3800	+/-10%
K5M2KA2	2000	3900	+/-10%
K5M5KA2	5000	4150	+/-10%
K5M10KA2	10000	4200	+/-10%
K5M20KA2	20000	4300	+/-10%
K5M50KA2	50000	4650	+/-10%
K5M150KA2	150000	4900	+/-10%

25/85 Beta tolerance = +/-5%

Type	Rated Power @ 25 °C	Dissipation Constant	Time Constant	Max Operating Temperature °C
K2M	100mW	2.0mw/ °C	10 seconds	130 °C
K3M	250mW	3.0mw/ °C	15 seconds	130 °C
K5M	500mW	7.5mw/ °C	20 seconds	130 °C



Inrush Current Limiter:

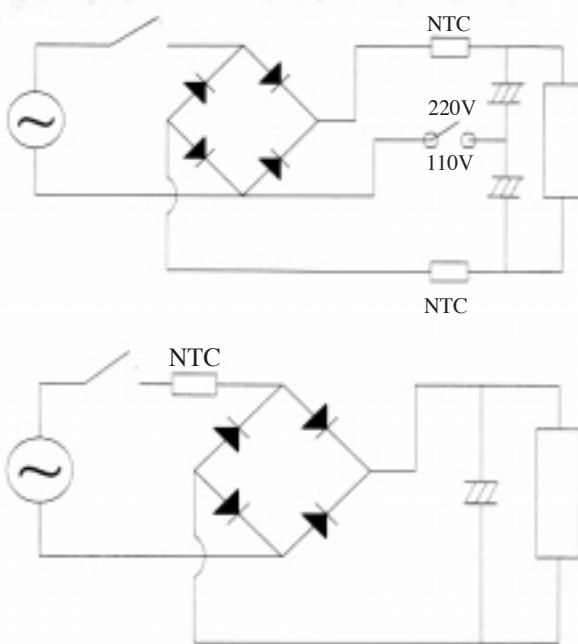
Applications:

- Suppressing capacitor induced inrush current.
- Surge current to filament bulbs.
- Switching mode power supplies.
- Inverter for fluorescent lamp.
- Heater and control fan motor speed of cooler for electric circuits.

Features:

- Economically priced.
- Available in tape and reel format
- High quality and high reliability due to superior manufacturing technology.
- Operating temperature range: -40°C to 180°C.
- Resistance tolerance at 25°C: +/-20%
- 25/85 Beta Value range: 2900 to 3800 (+/-10%).

Application Circuits:

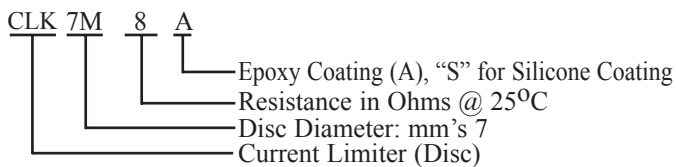


These NTC Thermistor devices are designed for suppressing inrush current to electronic circuits. Circuits that contain components with PTC characteristics (such as incandescent bulbs or coils) can experience inrush current more than 100 times the normal current on "power-up" when the circuit components are cold. The Power thermistor prevents electronic equipment from being damaged by limiting the inrush current to the circuit.

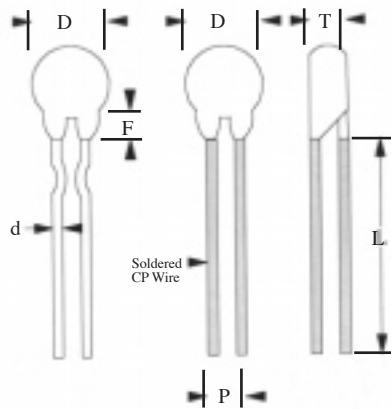
Resistance selection formula (25°C).

$$R_t \geq \frac{2E}{I_s}$$

Part Number Code:



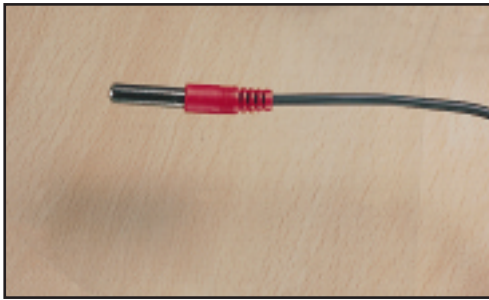
R_t : Resistance at 25°C.
E : Line voltage.
I_s : Inrush current.

I.C.L. ConfigurationInrush Current Limiter (I.C.L.) Dimensions:

Disc Code	Disc Element Diameter	D (mm)	T (mm)	L (mm)	P	F (mm)	d (dia)
CLK7M	7mm	9.5 max	5 max	25 min	5 +/-1mm	6 max	0.6mm
CLK9M	9mm	10.5 max	5 max	25 min	5 +/-1mm	6 max	0.6mm
CLK11M	11mm	12.5 max	5 max	25 min	7.5 +/-1mm	6 max	0.8mm
CLK13M	13mm	14.5 max	5 max	25 min	7.5 +/-1mm	6 max	0.8mm
CLK15M	15mm	16.5 max	6 max	25 min	10 +/-1mm	6 max	1.0mm
CLK22M	22mm	24.0 max	7 max	25 min	10 +/-1mm	6 max	1.0mm

Inrush Current Limiter Part Numbers and Specifications:

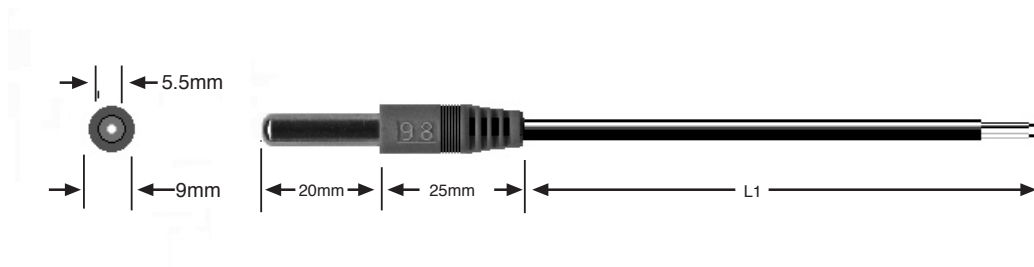
Part Number	Resistance at 25 °C (ohms)	Max Steady Current (amps)	Dissipation Constant (mW/ °C)	Time Constant (Sec.)	25/85 Beta Value K	Part Number	Resistance at 25 °C (ohms)	Max Steady Current (amps)	Dissipation Constant (mW/ °C)	Time Constant (Sec.)	25/85 Beta Value K
CLK7M5A	5 +/-20%	3.0	9	35	3000	CLK13M3A	3 +/-20%	5.0	14	45	3000
CLK7M8A	8 +/-20%	3.0	9	35	2950	CLK13M5A	5 +/-20%	5.0	15	70	3000
CLK7M10A	10 +/-20%	2.3	9	30	3000	CLK13M8A	8 +/-20%	4.0	16	65	3050
CLK7M15A	15 +/-20%	2.0	12	30	3050	CLK13M10A	10 +/-20%	4.0	17	60	2950
CLK7M16A	16 +/-20%	2.0	12	30	3050	CLK13M16A	16 +/-20%	3.0	19	55	3200
CLK7M22A	22 +/-20%	1.5	10	32	3000	CLK13M50A	50 +/-20%	2.0	15	75	3400
CLK7M50A	50 +/-20%	1.5	8	28	3100						
CLK9M3A	3 +/-20%	4.0	11	42	2950	CLK15M2.5A	2.5 +/-20%	6.5	20	65	2900
CLK9M5A	5 +/-20%	3.8	11	42	2900	CLK15M3A	3 +/-20%	6.5	20	70	2900
CLK9M8A	8 +/-20%	3.5	12	43	3000	CLK15M5A	5 +/-20%	6.0	20	75	2900
CLK9M10A	10 +/-20%	3.0	12	50	2950	CLK15M8A	8 +/-20%	5.0	20	75	3000
CLK9M12A	12 +/-20%	3.0	12	40	3000	CLK15M10A	10 +/-20%	4.8	19	80	3100
CLK9M16A	16 +/-20%	2.5	11	44	3150	CLK15M16A	16 +/-20%	4.0	17	85	3200
CLK9M18A	18 +/-20%	2.0	10	46	3150	CLK15M20A	20 +/-20%	3.0	15	90	3250
CLK9M22A	22 +/-20%	2.0	10	46	3200	CLK15M25A	25 +/-20%	2.8	15	90	3250
CLK9M50A	50 +/-20%	1.5	10	47	3200	CLK15M30A	30 +/-20%	2.5	16	95	3300
CLK9M400A	400 +/-20%	1.5	9	25	3800						
CLK11M3A	3 +/-20%	5.0	12	45	2900	CLK22M2.5A	2.5 +/-20%	7.0	24	100	3000
CLK11M5A	5 +/-20%	4.0	13	45	2950	CLK22M3A	3 +/-20%	7.0	24	100	3100
CLK11M8A	8 +/-20%	3.5	14	45	3000	CLK22M5A	5 +/-20%	6.6	25	85	3150
CLK11M10A	10 +/-20%	3.0	14	45	3000						
CLK11M12A	12 +/-20%	3.0	14	48	3100						
CLK11M16A	16 +/-20%	2.8	14	50	3150						
CLK11M25A	25 +/-20%	2.5	13	53	3200						

Style: H471**Standard Refrigeration and Air Conditioning Probe:****Applications:**

- Refrigeration and Air Conditioning.
- High Humidity Environments.

Features:

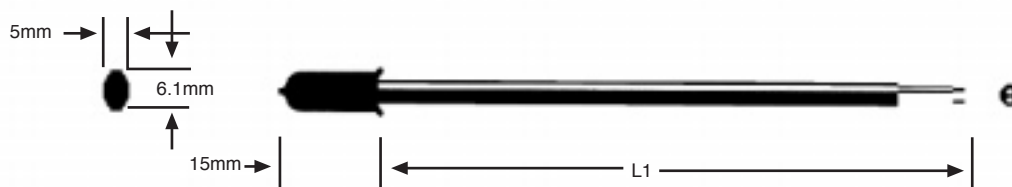
- Low cost.
- Rugged multi use design.
- Available with most NTC and RTD devices.
- High speed reaction times for use in controls.
- Available in a range of cable lengths and types.
- IP 68 Rating.
- Pipe mounting clip available from 12mm to 18mm.

**Style: H472****Air Conditioning Temperature Probe:****Applications:**

- Vehicle and Commercial Applications.
- Air Conditioning.

Features:

- Small, light weight and versatile design.
- Fully overmoulded for maximum protection.
- A cost effective solution for mass production products.
- IP 68 Rating.

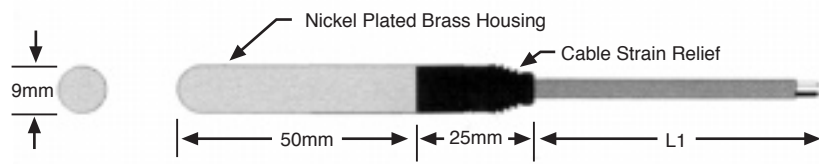
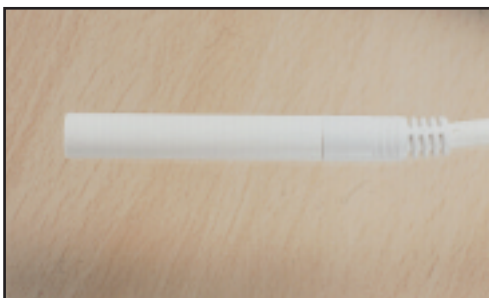


Style: H475**Spherical Ended Nickel Plated Brass Probe:****Applications:**

- General purpose HVAC probe.
- Refrigeration Cabinets.
- Immersion probe for use in liquids.
- Agricultural temperature monitoring.

Features:

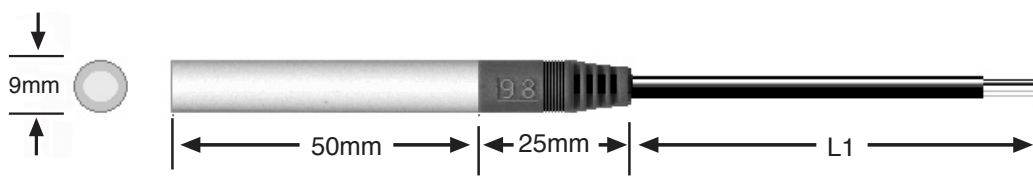
- Mechanical design protects thermistor from external environmental conditions.
- Suitable for high humidity.
- Strain relief protects probe assembly from cable damage long-term.
- Brass housing material has excellent thermal transfer characteristics.

**Style: H476****Overmolded Plastic Probe:****Applications:**

- General purpose HVAC probe.
- Refrigeration Cabinets.
- Medical Cabinets for product storage.

Features:

- Suitable for high humidity.
- Strain relief protects probe assembly from cable damage long-term.
- Lightweight.

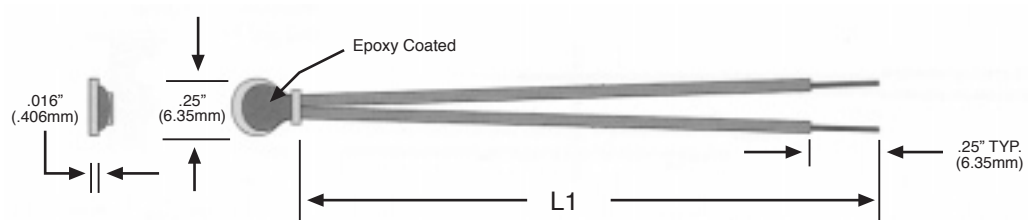
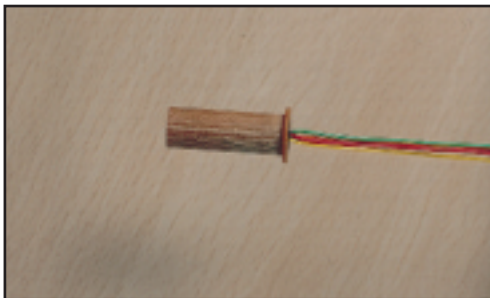


Style: H014Aluminum Surface Sensor:**Applications:**

- Electronic equipment heat sink temperature sensing.
- HVAC surface temperature sensing.
- Oven and platen surface sensing.
- Aerospace - panel temperature sensing.

Features:

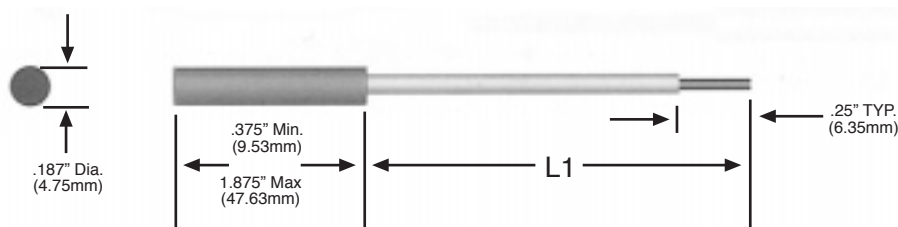
- Smaller size than H010 surface probe.
- Low profile aluminum housing has high thermal transfer properties.
- Housing has built-in strain relief crimp for lead wires.

Style: H028Flat Ended Nylon (Delrin) Probe:**Applications:**

- Applications where metal housings are not suitable.
- Building management applications for energy efficient HVAC systems.

Features:

- Nylon material allows the Time Constant to be extended. Rugged design protects thermistor element from damage.



Custom HVAC Probes and Assemblies

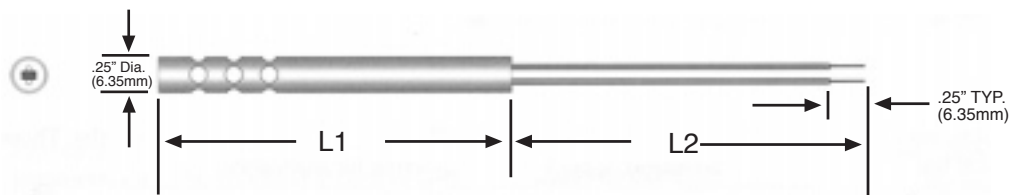


Style: H042**Stainless Steel Air/Gas Probe:****Applications:**

- Oven chamber temperature control and or monitoring.
- Ambient room temperature air sensing applications.
- Cabin temperatures on ships.
- HVAC applications.

Features:

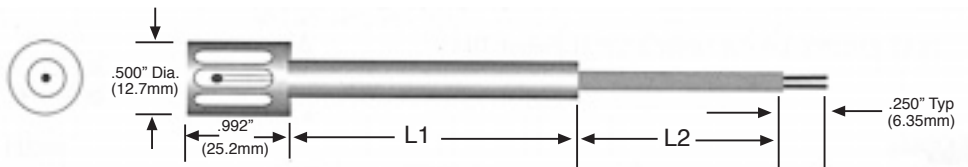
- Sensor is exposed to ambient conditions while housing protects device from mechanical shock.
- Probe can be made to any length.

**Style: H069****Stainless Steel Air/Gas Sensing Probe:****Applications:**

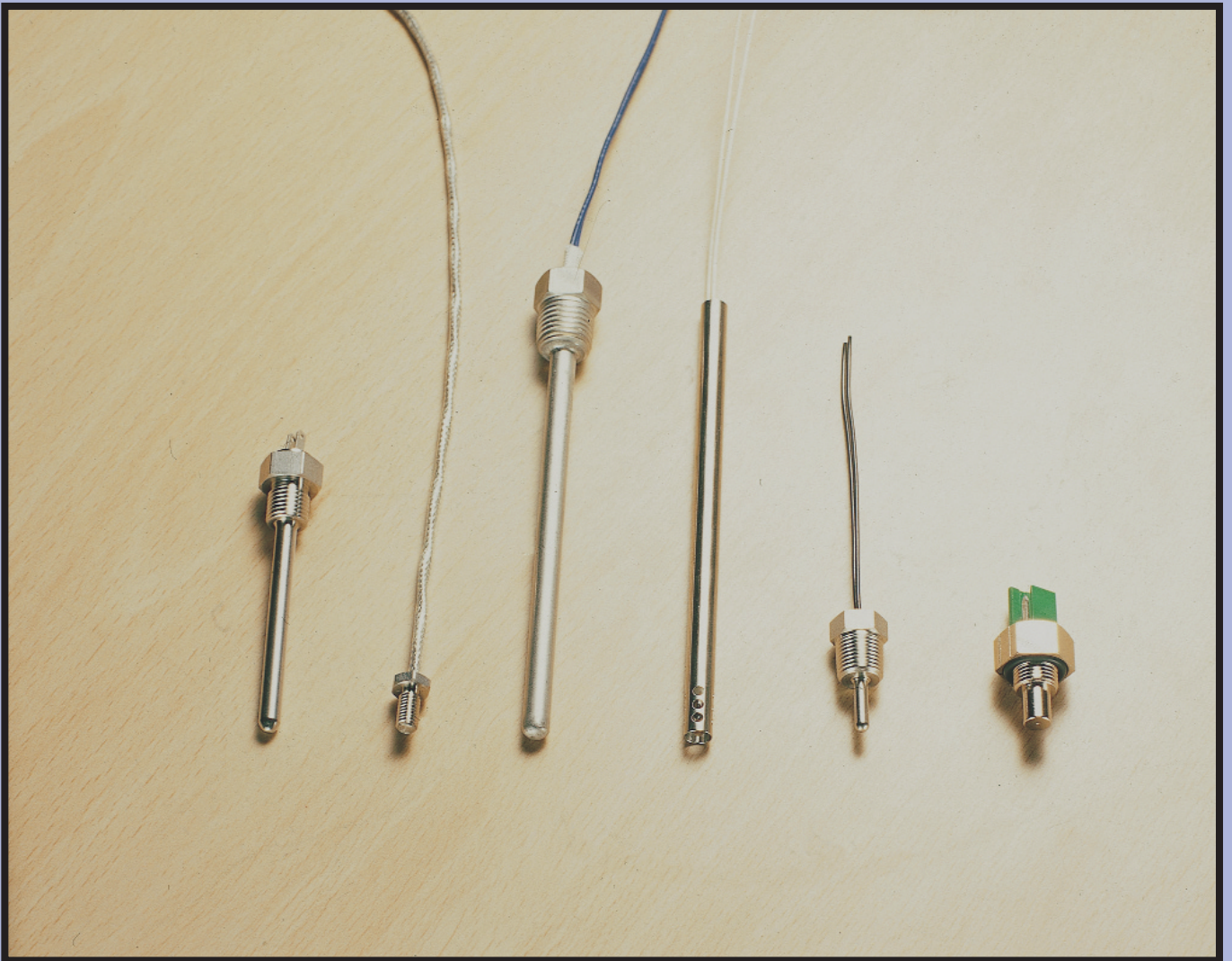
- Wall mounting in ovens or chambers.
- Control of cabin temperatures in submarines.
- Clean room temperature control.

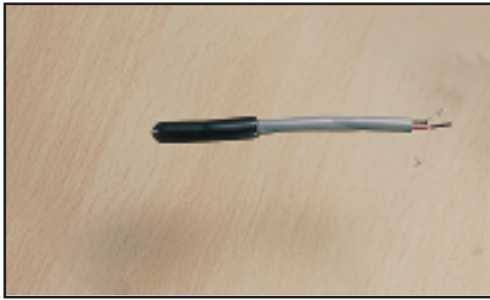
Features:

- Cage style housing allows excellent air/gas exposure to thermistor element while mechanically protecting the device.



Custom HVAC Probes and Assemblies

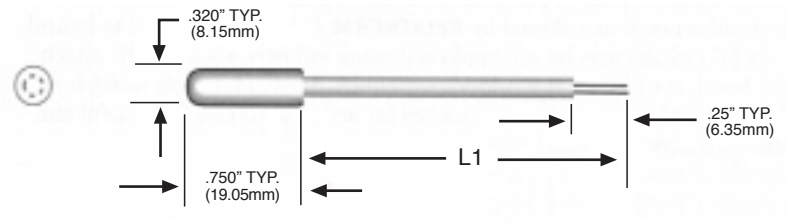
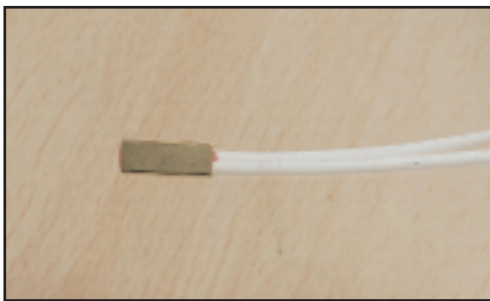


Style: H105Economical Round End Vinyl Probe:**Applications:**

- Oceanography research to monitor temperatures at various depths.
- Outdoor ambient temperature sensing and monitoring.

Features:

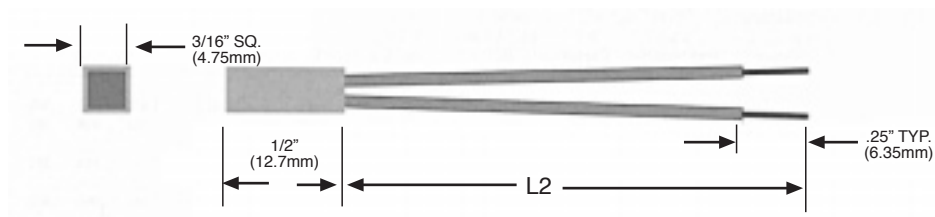
- Vinyl material, housing and cable are sealed from moisture.
- Probe cable (PVC insulated) is 22 AWG. A robust design for easy handling.
- Relative cost is economical compared to metal probes.

Style: H142Square Shape Brass Probe:**Applications:**

- Temperature monitoring surfaces of liquid piping systems.

Features:

- Brass housing material has excellent thermal transfer characteristics.
- Square shaped housing works well as surface sensor.
- Large lead wires (22 AWG) can be used in assembly.

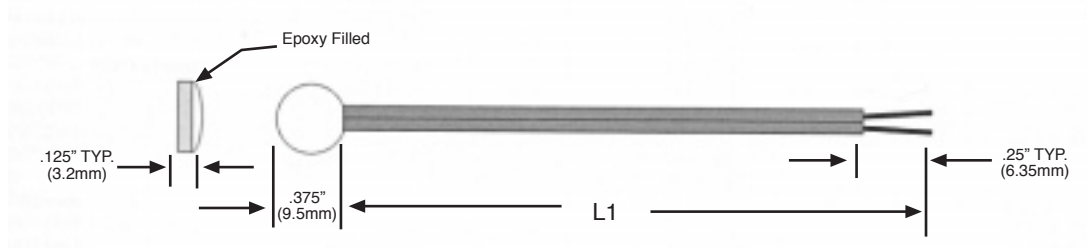
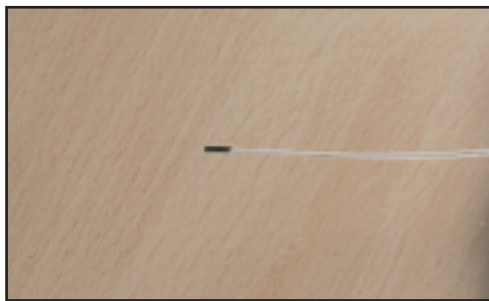


Style: H010**Stainless Steel Surface (Skin) Sensor:****Applications:**

- Skin sensor for reusable applications.
- Surface temperature sensor for ovens and platens.

Features:

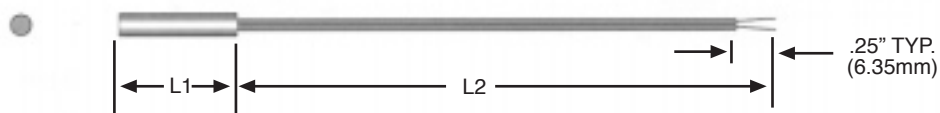
- The thin (0.010" thick) stainless steel "cup" shaped housing is ideally suited for skin sensing.
- Available with highly flexible cable wires designed for Medical use.
- Low profile design enhances thermal transfer to sensor.
- Available with cables and connectors or other requirements per customer specifications.

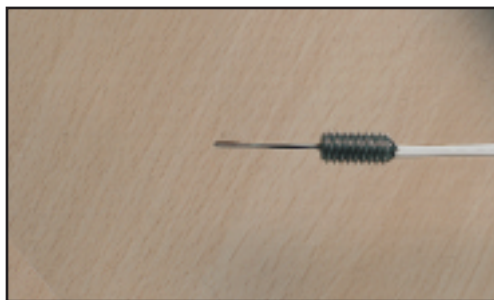
**Style: H020****Epoxy Filled Polyimide microtube Probe:****Applications:**

- Air temperature sensor for blood analysing equipment.
- Air/gas flow measurement equipment.
- Breathalyzer and nasal temperature sensing.
- Semiconductor processing equipment.

Features:

- Polyimide tubing provides superior insulation resistance.
- Thin walled (0.001" to 0.002" thick) allows rapid thermal transfer characteristics.
- Available polyimide sizes from 0.017" to 0.40" dia.
- Can be used or adapted for many probe applications.

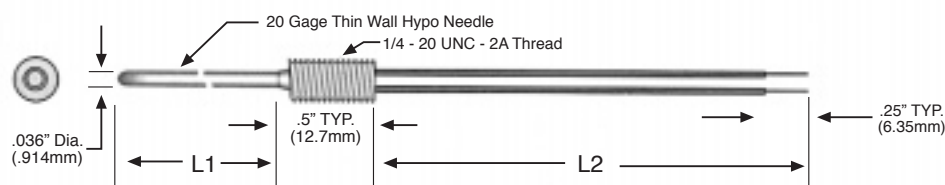


Style: H051**Screw Mountable micro-Probe:****Applications:**

- Blood analysing equipment.
- Scientific and animal research laboratories.

Features:

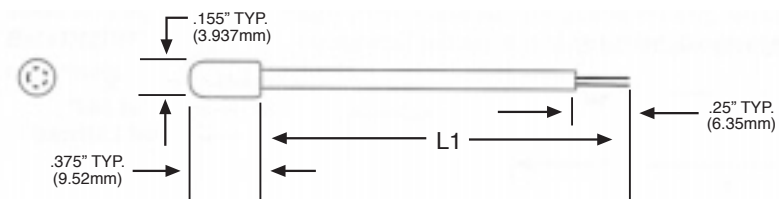
- Extremely small size allows rapid Time Constant sensing.
- The design is rugged for continuous handling.
- Time Constant is typically less than 0.30 seconds in liquids.
- The micro-BetaCHIP devices are designed to fit the H051 probe.

**Style: H064****Round ended Vinyl Probe:****Applications:**

- Medical probe for core temperatures.
- Common temperature sensing applications for indoor or outdoor use.
- Portable handheld temperature measurement instruments.

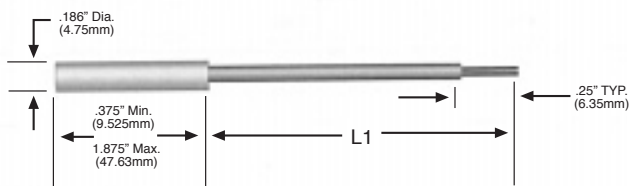
Features:

- Vinyl probe protects thermistor element from high humidity.
- Vinyl probe housing sealed to cable.
- Cable available in grey or white colors.
- Vinyl housing (end) available in white or red.



Custom Medical Probes & Assemblies



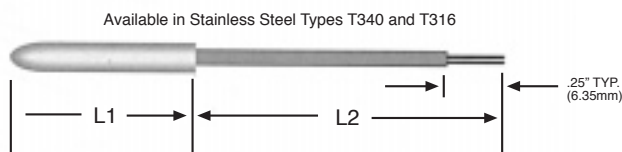
Style: H005**Flat Ended Aluminum Probe:****Applications:**

- Oven sensor (sheathed for mechanical protection).
- Bearing surface temperature sensing.
- Heating and air conditioning systems (internal wall mounting).
- Heater block (platen) temperature sensing.
- Air and Gas sensing.

Features:

- Aluminum probe material allows for fast thermal transfer compared to stainless steel.
- Housing provides for excellent mechanical protection.
- Housing may be combined with all BetaCURVE Thermistors.
- Extension wires or cable to 0.125\"/>
- Provides excellent protection from mechanical damage due to excessive handling or mounting operations.

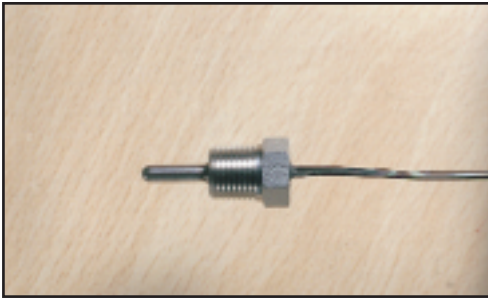
Assembly is recommended for use in equipment and building construction where relative humidity is low.

Style: H008**Spherical Ended Stainless Steel Probe:****Applications:**

- Immersion probe for use in most liquids.
- Geological research (soil temperatures).
- Control and monitoring of liquid bath temperatures.
- Agricultural temperature monitoring during growth period, harvesting and transport of produce.
- Refrigerated transport vehicles.
- Oven temperature monitoring.

Features:

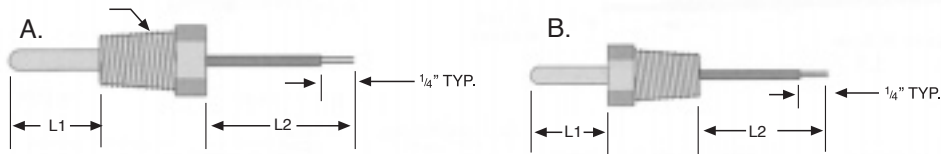
- Spherical, welded, sealed end of probe protects thermistor from external environmental conditions.
- Stainless steel offers excellent mechanical strength.
- Available in Stainless Steel Types 304 and 316. Standard Diameters in hypodermic gage sizes from 6.5 to 20 and fractional sizes from 1/16\"/>
- Probes may be made in lengths from 0.5 inches long to 100 inches long.

Style: H025National Pipe Thread (NPT) Probes:**Applications:**

- Dialysis equipment liquid sensor.
- Hydraulic oil temperature sensing.
- Industrial liquid processing equipment for dairy and food industry.
- Automotive transmission oil temperature sensing.
- Chemical processing and analysis equipment.

Features:

- Standard National Pipe Thread (NPT) sizes available - (1/8, 1/4, 3/8, and 1/2).
- Standard probe dia. 1/8", 3/16", and 1/4".
- Available in three standard configurations. Note, styles A and B.
- Pipe threaded probes provide excellent seal in closed loop pressurized systems.
- Probes are made with 304 or 316 stainless steel.

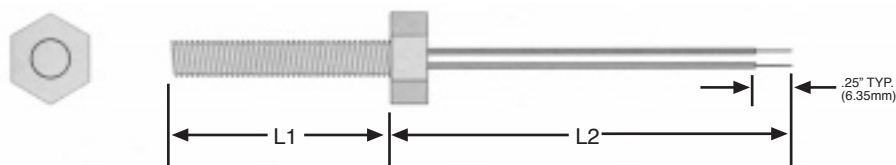
Style: H032Stainless Steel or Brass Hex Head Bolt Probe:**Applications:**

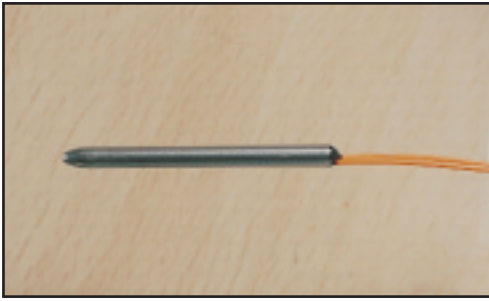
- Motor or heater block core temperature sensing.
- Platen temperature control or monitoring.

Features:

- Easy mounting and positioning with screw threads.
- Available in Imperial or Metric sizes.

Imperial	Metric
10-32	M5x1.0g
1/4-20	M6x1.0g
3/8-16	M10x1.0g

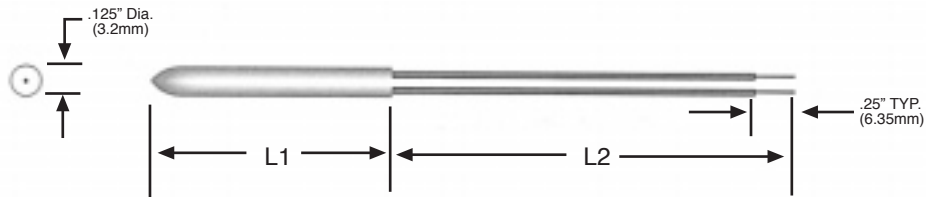


Style: H043**Conical End Stainless Steel Probe:****Applications:**

- Soil analysis and temperature tests.
- Rubber tire processing equipment.
- Frozen meat processing and monitoring.

Features:

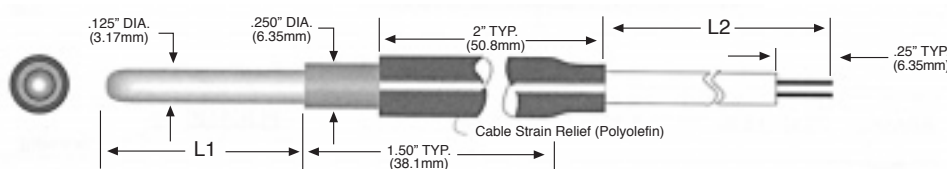
- Conical end of probe allows penetration into semi-solid materials.

**Style: H078****Stainless Steel Immersion Probe:****Applications:**

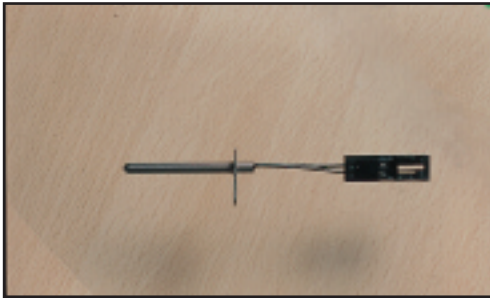
- Precision temperature monitoring of calibration bath temperatures.
- Liquid chemical processing equipment.
- Food and beverage processing equipment.

Features:

- Probe design protects thermistor from moisture and mechanical shock.
- Available in 304 or 316 stainless steel.
- Strain relief protects cable from long term damage.
- Cables of PVC or Teflon may be chosen.



Style: H083



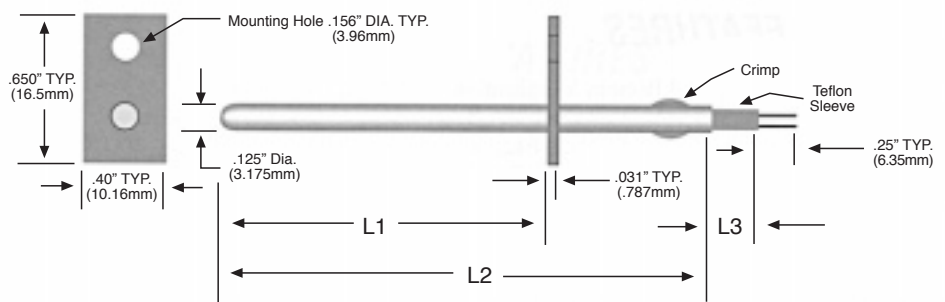
Flange Mount Stainless Steel Probe:

Applications:

- Fixed depth immersion probes for liquids.
- Oven or chamber temperature control and monitoring.

Features:

- Flexible design dimensions to accommodate customer requirements.
- Standard flange design for easy mounting with #8 screw.



Style: H150



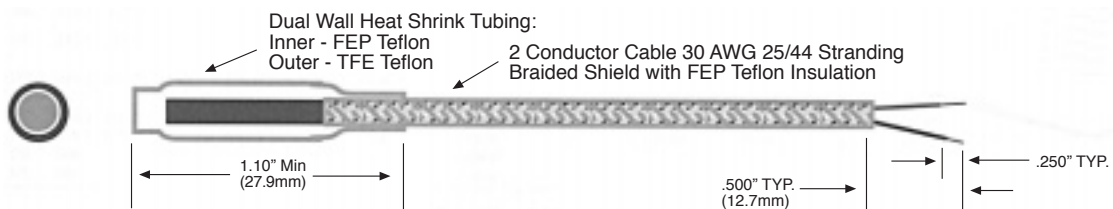
Teflon Probe:

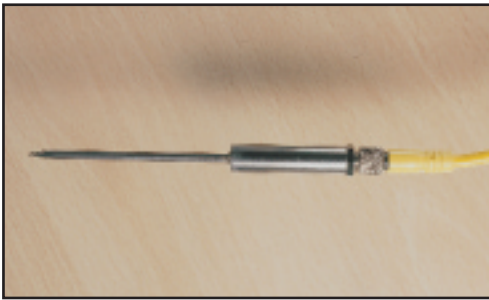
Applications:

- Pharmaceutical liquid mixing systems.
- PH specimen temperature sensor (built into PH probes).
- Immersion sensor in most liquids.

Features:

- Teflon material is impervious to most liquids.
- Unique design offers liquid seal of probe end to cable.
- Relatively small design for good thermal response with non-metallic housing material.

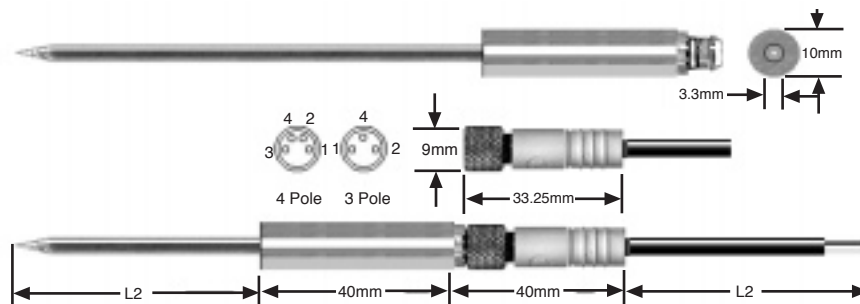


Style: H473**Piercing range of Temperature Probes:****Applications:**

- Insertion into dense materials (food, earth, etc.)
- Long-term research of dense materials.
- Frozen meat defrosting analysis.

Features:

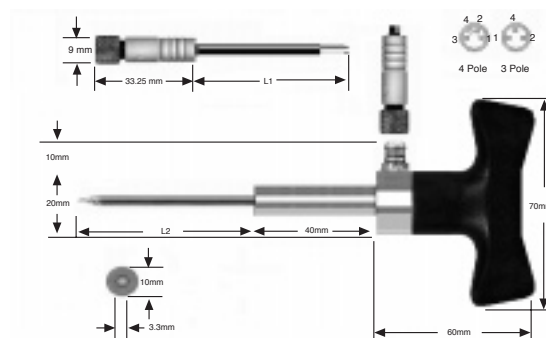
- Strong stainless steel construction.
- High specification industrial gold plated connectors.
- Durability to long exposure to harsh environments.
- Keyed three and four pole connectors for NTC and digital devices.

**Style: H474****Piercing probe with handle:****Applications:**

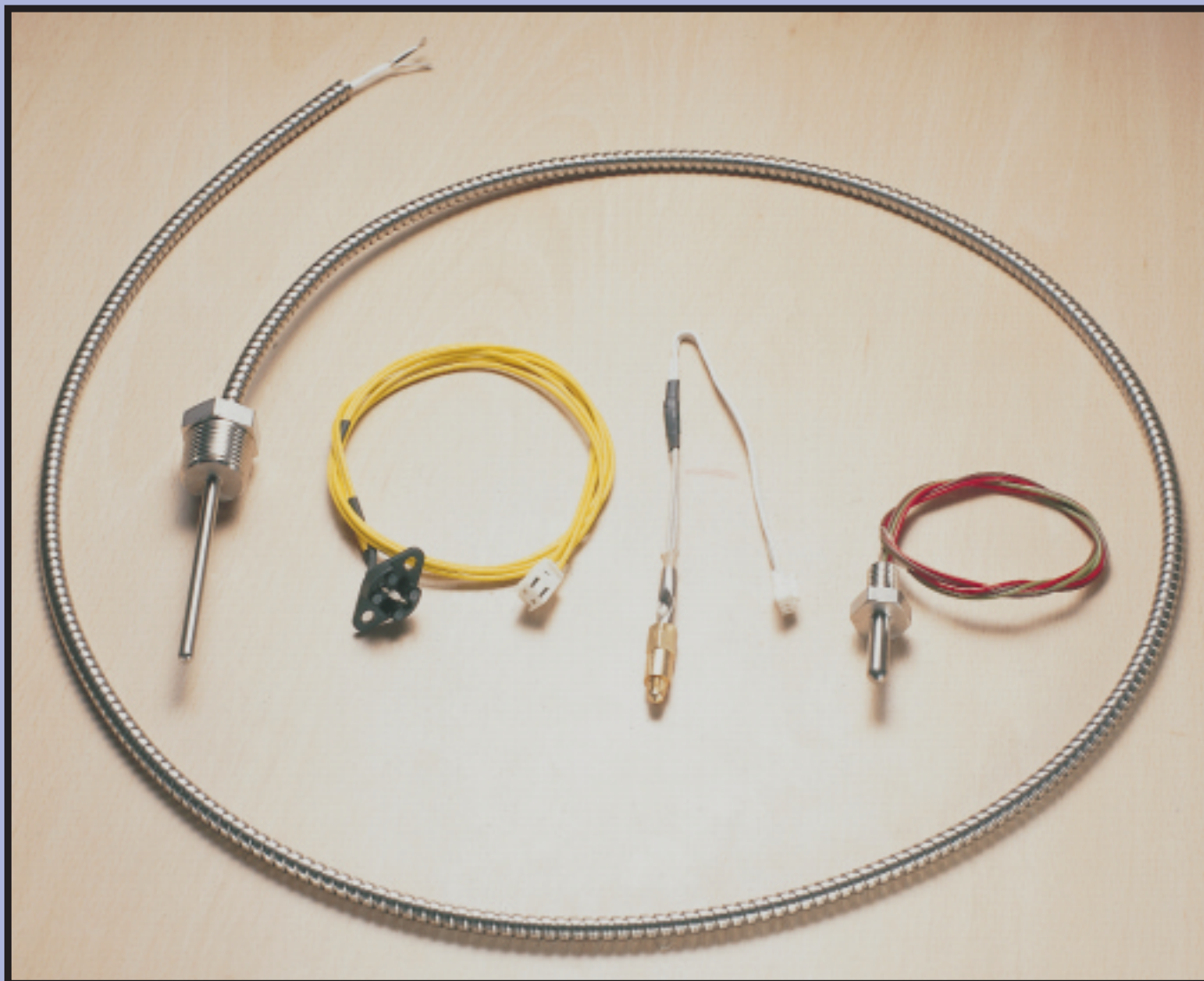
- Food processing applications (frozen, raw, fresh and cooked products).
- Temperature analysis of dense materials.

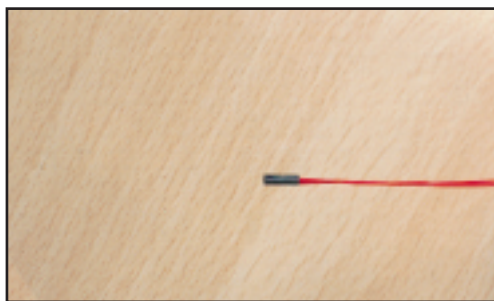
Features:

- Easy to use and clean.
- Simple action to remove from frozen products.
- Strong Stainless steel construction.
- High specification industrial gold plated connectors.
- Keyed three and four pole connectors for NTC and digital devices.
- Detachable cable design.



High Temperature (+ 300^oC) Custom Probes & Assemblies

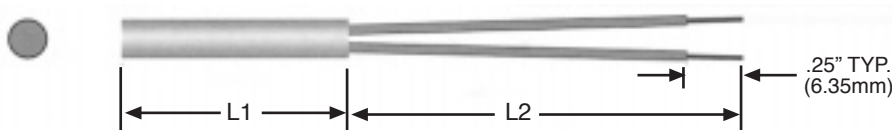
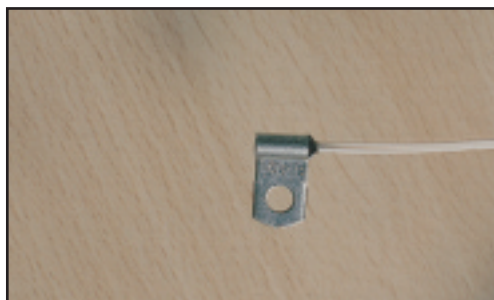


Style: H019Epoxy Filled Mylar Tube Probe:**Applications:**

- Color print copy machine ink sensor.
- Air temperature sensor in electronic equipment.
- Imbedded platen temperature.

Features:

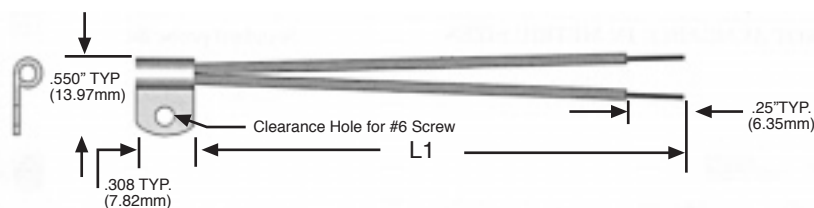
- Mylar is a non-shrink insulating tube material.
- Mylar insulation can withstand 1500 volts/0.001".
- Mylar has a continuous temperature rating of 150°C.
- Mylar is a relatively inexpensive housing material.
- Mylar package available in a variety of sizes ranging from 0.043" dia. to 0.150" dia. allowing a wide choice of lead wires or cables to be used in the assembly.

Style: H066Economical Tinned Copper Surface Mounting ("Flag Terminal") Probe:**Applications:**

- Semiconductor manufacturing equipment.
- Heatsink temperature monitoring in power supplies or other related equipment and instruments.
- Oven surface temperature control and monitoring.

Features:

- High thermal transfer properties of copper housing.
- Low profile housing locates thermistor close to surfaces being monitored.
- Standard mounting hole for #6 screw.
- Housing temperature rating to 220°C.

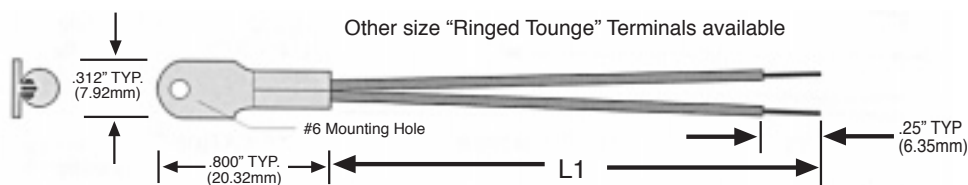


Style: H080Economical Tinned Copper Surface Mount ("Ring Tongue") Terminal Probe:**Applications:**

- Instrumentation heatsink temperatures.
- Over-temperature protection in power supplies and other heat sensitive equipment and instruments.

Features:

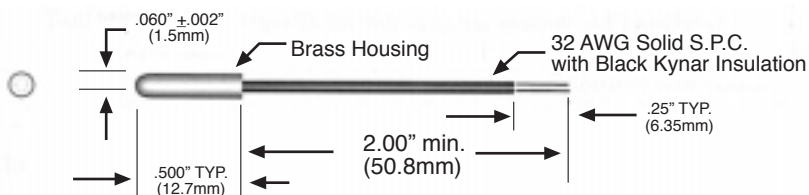
- Copper housing material has excellent thermal transfer characteristics.
- "Ring tongue" terminals are available in several sizes allowing a wide choice of extension wire and cables to be used in the assembly.
- Housing cost is very economical.

Style: H207Fast Time Response Brass Probe:**Applications:**

- Air temperature sensor for automotive applications.
- Gas flow sensor.
- Laboratory analysis.

Features:

- Brass housing material and small size results in fast Time Constant in liquids of 300 milliseconds.
- BetaTHERM's mini-Beta Probe series is designed to fit the H207 probe.



Notes

This image shows a single sheet of white paper with horizontal ruling lines. The lines are evenly spaced and run across the width of the page. There are no margins, text, or other markings on the paper.