Thermistors

Introduction

A thermistor is a specialized resistor, intentionally designed to be thermally sensitive and its primary characteristic is its ability to alter its electrical resistance in response to changes in case temperature. It can be used to measure temperature, or to sense temperature changes and compensate for the temperature changes. Thermistor resistance is a function of its absolute temperature. Thermistors are normally available with accuracy up to $\pm 1^{o}$C, however, higher accuracy devices are available, but are substantially more expensive. A time constant characteristic is also specified to signify the response rate to a temperature change (i.e., speed of the thermistor) and is usually expressed in seconds, defined as the time required to change 63.2% of the total difference between initial and final body temperature, when subjected to a step function change in temperature, under zero-power conditions. The generic relationship between thermistor resistance and temperature is expressed in the equation*:

$$\frac{R(T)}{R(T_o)} = e^{-\beta\left[\frac{1}{T}-\frac{1}{T_o}\right]}$$

where:

$R(T)$ = Resistance at some temperature (in ^{o}K);

$R(T_o)$ = Resistance at an initial measurement (reference) temperature, T (in ^{o}K);

β = Dissipation or thermistor material constant (usually expressed in mW/^{o}C or the amount of power required to induce a temperature rise of 1^{o}C).

**Note: Some thermistors will exhibit more complex resistance-temperature characteristics, and it will be necessary to use a more complex form of the above equation (usually a polynomial) to derive accurate temperature measurements. These formulas are available from the thermistor vendor. No thermistor exhibits linear resistance-temperature properties and in fact, most are extremely non-linear, but it is possible to assume linearity if measurements are made over a sufficiently small temperature range.*

Packaging

Thermistors are available in several package types. The most common package is a disk, although they are also available with axial leads and can be purchased as chip or Metal Electrode Leadless Faces (MELF) components for surface mount applications. Selection of packaging style depends on the application and where the temperature measurement needs to be made. Surface mounted chip thermistors will only be able to measure the temperature very close to the board, while disk styles can be mounted at a substantial distance above the board if the airflow needs to be sampled. Thermistors are also available as temperature probes for specialized applications.

Failure Mechanisms and Anomalies

The most common failure mode of a thermistor is an open circuit, as shown in Table 1. The cause of such failures are usually due to mechanical separation between the resistor element and the lead material, caused by handling damage, excessive heat, thermal mismatch, etc. The second most common failure mode is drift in resistance value as the thermistor ages, or parameter change. This results in inaccurate temperature measurements, thereby causing the thermistor circuit to provide incorrect thermal compensation as it ages. A short circuit is the least common failure mode, but it is important to note that a thermistor is much more likely to fail in the short circuit mode than a normal, fixed value resistor (by about a factor of 3).

Table 1. Normalized Failure Mode Distributions for Thermistors[1][1]

Failure Mode	Relative Probability
Open	63%
Parameter Change	22%
Short	15%

The unfortunate consequence of thermistor failures is they often cause substantial secondary damage to other circuit elements when they fail. This occurs because thermistors are often used as protection devices against excessive heat. In addition, failure of a thermistor often goes undiagnosed due to this secondary damage, particularly if the thermistor fails in the parameter drift mode. For example, one common thermistor application is to provide protection against excessive heat in a power supply. If the thermistor performs incorrectly, the power supply may run warmer than expected and eventually fail. Failure is then blamed on whatever part failed in the power supply rather than the thermistor. The reverse can also occur, where a protection circuit incorrectly provides protection when it is not needed. This results in premature shutdown.

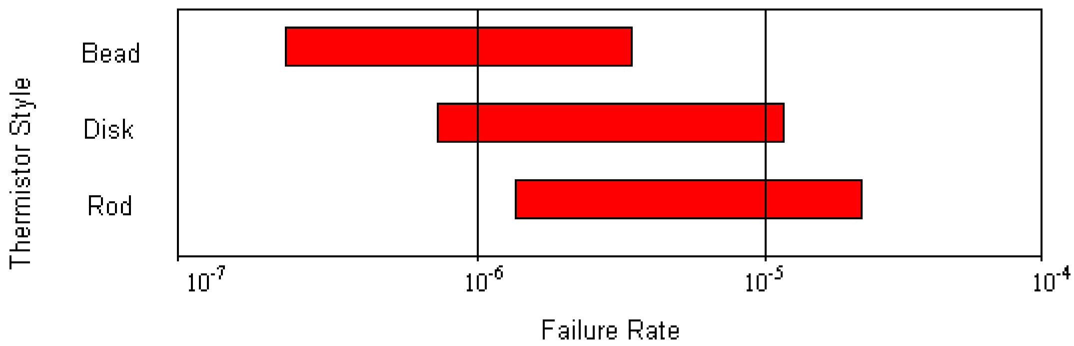

Figure1. Relative Failure Rates for Thermistors

Reliability

The reliability of thermistors is comparable to wirewound resistor styles, but failure rates vary substantially with style. Figure 1 shows the relative difference between failure rates of the three principle forms. As shown, bead-forms are generally the most reliable and rod-forms the least.

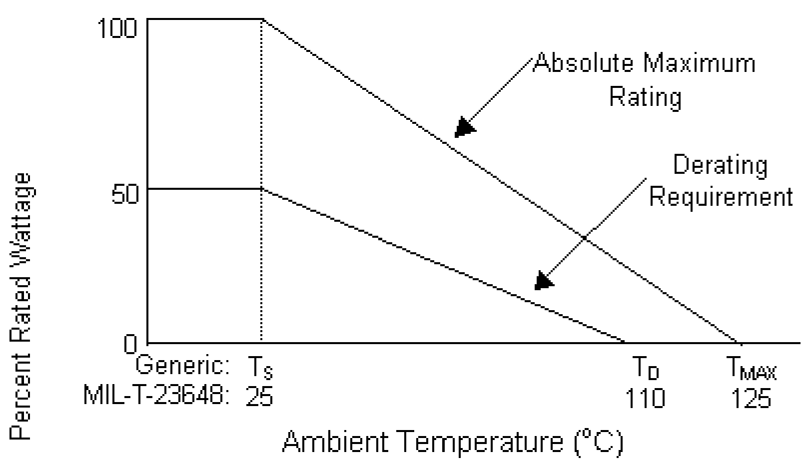

Figure 2. Derating Requirements for Thermistors

For thermistors with negative temperature coefficients, care must be taken to avoid thermal runaway due to self-heating effects because it can produce permanent changes to thermistor properties. Current limiting resistors can help prevent thermal runaway conditions.

Derating

Derate power to 50% of maximum full rated power below T_S. Above T_S, linearly derate to T_D, as shown in Figure 2, where $T_D = T_{MAX} - 15^o C$. The temperatures given in Figure 2 are for thermistors conforming to the requirements of MIL-T-23648 (Style RTH).

Design & Material

A thermistor is a mixture of metal oxides fused at high temperature to a sintered ceramic-like semiconductor material. As previously discussed in Technologies section, thermistors are available in four principle forms: disk, bead, rod, and chip. The chip styles are the only ones available with silver or gold plated terminations.

Facility Assessment & Quality

The quality control provisions for military thermistor types are covered through MIL-T-23648, “Thermistor (Thermally Sensitive Resistor) Insulated, General Specification for.” Thermistors conforming to MIL-T-23648 are required to undergo the qualification inspections/tests given in Table 2.

Sampling

Every thermistor vendor imposes some type of sampling plan to control the quality and uniformity of the product, but the type of sampling will vary between vendors. Thermistors conforming to MIL-T-23648 require sampling at specific lot sizes and are considered nonconforming if the number of defects exceeds a given value. Consult MIL-T-23648 to find specific sample lot sizes and the number of allowable defects, as they are dependent on type of test given in Table 2.

Table 2. List of Required Qualification Tests for Thermistors Conforming to MIL-T-23648

Visual and Mechanical Inspection	Dissipating Constant
Zero-Power Resistance	Thermal Time Constant
Resistance Ratio	Terminal Strength
Solderability	Resistance to Temperature Characteristics
Resistance to Solvents	Thermal Shock
Short Time Overload	Resistance to Soldering Heat
Insulation Resistance	Moisture Resistance
Dielectric Withstanding Voltage	Load Life
Low Temperature Storage	High Temperature Exposure
High Temperature Storage	Vibration, High Frequency
Immersion	Shock

Process Controls

The process controls of Military grade thermistors are controlled though the requirements of MIL-T-23648. Process controls for industrial and commercial grade thermistors will vary.

Part Assessment

Additional qualification testing or screening by the user is not typically performed. Additional qualification testing or screening by the user should be left up to the discretion of the user and is dependent on the specific application. Qualification testing by the user is not typically performed, although testing can be done to determine the initial measurement reference temperature ($R(T_o)$).

Handling & Storage Precautions

Thermistor construction is very rugged, especially for the bead-forms. Thermistors are not considered to be ESD sensitive.

Closing Comments

Surface mounted chip thermistors are intended to measure temperature very close to the board. If temperature needs to be measured at a substantial distance above the board or if the airflow needs to be sampled, disk packages are a better choice. The designer has the choice of three different types of devices available to measure temperature: the resistance temperature detector (RTD), thermocouple, and the thermistor. This section is only applicable to the thermistor, however, to aid the designer in choosing the best device for a given application, the following descriptions and characteristic curves (Figure 3) are offered:

a. *The RTD* is constructed similar to an accurate wire wound resistor. It is most accurate of the three types of temperature sensing devices because it has the best stability and the best linear response. Its main disadvantages are a slow response time, small resistance change, and it is sensitive to self-heating effects.

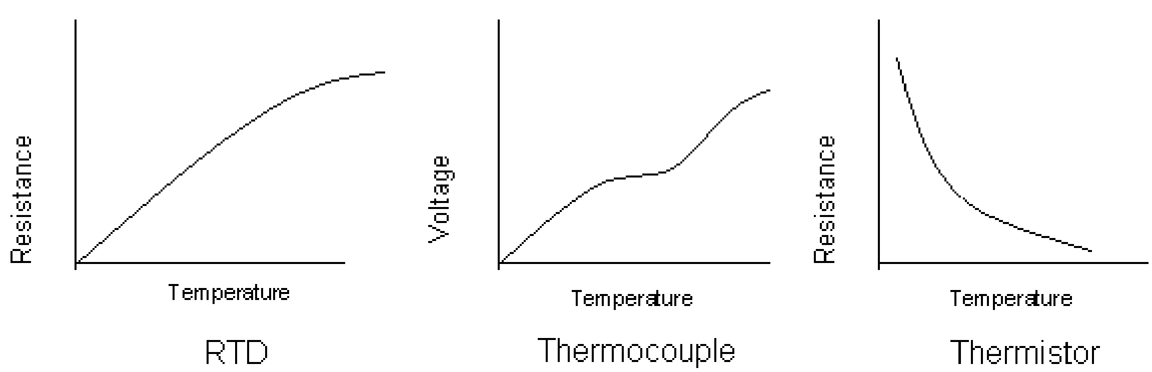

Figure 3. Comparison of Output Characteristics of Three Temperature Sensor Technologies

b. *The thermocouple* is constructed with two dis-similar metals joined together and takes advantage of the thermoelectric potential property of dissimilar metal junctions. The main advantages of a thermocouple are that a current source is not necessary and it has the largest temperature range of the three types of temperature sensors. The primary disadvantages are a low voltage (mV) output, a reference (cold junction) temperature is needed, and it has the lowest sensitivity of the three types.

c. *The thermistor* has much higher resistance values and exhibits a larger change in resistance with respect to temperature, but its temperature range is very limited in comparison to the other two types of temperature sensors.

[1]Failure Mode data for Table 1 was taken from a combination of MIL-HDBK-978, "NASA Parts Application Handbook," 1991; MIL-HDBK-338, "Electronic Reliability Design Handbook," 1994; Reliability Toolkit: Commercial Practices Edition," Reliability Analysis Center (RAC), 1998; and "Failure Mode, Effects and Criticality Analysis (FMECA)," RAC, 1993.