

# PTC THERMISTORS

Commercial PTC thermistors fall into two major categories. The first category consists of thermally sensitive silicon resistors, sometimes referred to as “silistors”. These devices exhibit a fairly uniform positive temperature coefficient (about  $+0.77\%/^{\circ}\text{C}$ ) through most of their operational range, but can also exhibit a negative temperature coefficient region at temperatures in excess of  $150^{\circ}\text{C}$ . These devices are most often used for temperature compensation of silicon semiconducting devices in the range of  $-60^{\circ}\text{C}$  to  $+150^{\circ}\text{C}$ .

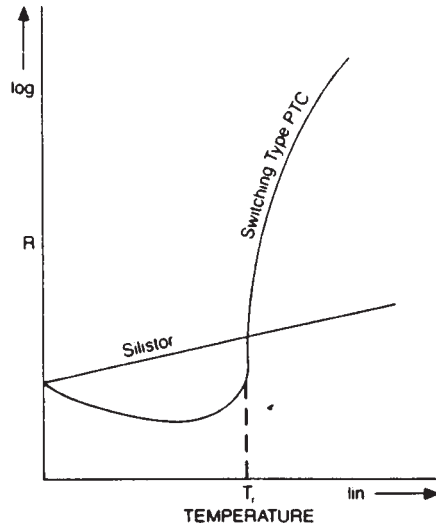


Figure 22: R-T Characteristics of PTC Thermistors.

The other major category, and the one that we shall concentrate on in this section, are referred to as switching PTC thermistors. These devices are polycrystalline ceramic materials that are normally highly resistive but are made semiconductive by the addition of dopants. They are most often manufactured using compositions of barium, lead and strontium titanates with additives such as yttrium, manganese, tantalum and silica.

These devices have a resistance-temperature characteristic that exhibits a very small negative temperature coefficient until the device reaches a critical temperature, that is referred to as its “Curie”, switch or transition temperature. As this critical temperature is approached, the devices begin to exhibit a rising, positive temperature coefficient of resistance as well as a large increase in resistance. The resistance change can be as much as several orders of magnitude within a temperature span of a few degrees.

Figure<22> illustrates the differences between silistor and switching PTC thermistors.

## Types of Switching PTC Thermistors

Commercial switching PTC thermistors are manufactured much like the NTC disk and chip type thermistors with metallized surface contacts. Connection into an electrical circuit is accomplished by means of a spring contact system or through lead wires soldered to the device. The most common body style is the disk, however, recent innovations have led to chip, lozenge and surface mount packages for these devices.

## Fabrication of Switching PTC Thermistors

The material composition is blended, milled, dried and then crushed into a powder. Following this, the material is calcined and then milled again with suitable binders. Next, binders are blended into the mix and the material is spray dried in towers. A mixture of particles with an outer coating of binders is thus formed into a fine powder with carefully controlled particle sizes. This powder is then compacted to form the desired geometry in a die using very high pressures.

The PTC thermistors must then be sintered to form the ceramic body. Metallized contacts are applied to the surface of the device by painting, dipping, sputtering or flame spraying.

The processing of PTC thermistors requires very careful control of materials and particle size in order to produce a device with the proper switching characteristics and voltage ratings. Contaminations on the order of a few parts per million will cause major changes in the thermal and electrical properties of the PTC thermistor.

Most PTC thermistors are designed to operate with a transition temperature somewhere between  $60^{\circ}\text{C}$  and  $120^{\circ}\text{C}$ , however, devices can be manufactured that can switch as low as  $0^{\circ}\text{C}$  or as high as  $200^{\circ}\text{C}$ .

The majority of switching PTC thermistors are intended to operate without an insulation coating. The devices are available, however, with insulation coatings when required. Also, small PTC disks / pellets can be sealed into glass envelopes for operation as fluid level detectors.

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Surface mount devices represent a recent technological advance in the manufacture of PTC devices. Both power and sensing devices are available in surface mount styles.

## PROPERTIES OF PTC THERMISTORS

As with the NTC devices, the PTC thermistors have specific thermal and electrical properties which are important considerations in each application. These properties are also a function of the geometry of the thermistor and of the particular "material system" that is being used.

### Thermal Properties

The thermal characteristics of PTC devices are similar to those of the NTC devices. Those characteristics can be described by the following terms:

- Heat Capacity
- Dissipation Constant
- Thermal Time Constant

### Heat Capacity

The product of the specific heat and mass of the thermistor, it is the amount of heat required to produce a change in the body temperature of the thermistor by 1°C.

### Dissipation Constant

The ratio of the change in the power applied to the thermistor to the resulting change in body temperature due to self-heating. The factors that affect the dissipation constant will include such things as: leadwire materials, method of mounting, ambient temperature, conduction or convection paths between the device and its surroundings, and even the shape of the device itself.

### Thermal Time Constant

The amount of time required for the thermistor to change 63.2% of the difference between the self-heated temperature and the ambient after power is disconnected. The thermal time constant is also influenced by the same environmental factors as those that affect the dissipation constant.

The discussions of the thermal properties of PTC thermistors are based upon simple device structures. The thermal time constant and dissipation constant data which is given in thermistor product literature is only valid for the test methods and mounting methods employed. For information on test methods contact Thermometrics Engineering.

## Electrical Properties

The electrical characteristics used to describe PTC devices are the following:

- Current-Time Characteristic
- Resistance-Temperature Characteristic
- Power and Minimum Resistance
- Minimum Resistor
- Temperature Coefficient of Resistance
- Transition Temperature
- Voltage Dependence
- Voltage Rating
- Voltage-Current Characteristic

### Current-Time Characteristic

Any change in the amount of power applied to the PTC thermistor will result in a change of its body temperature. The time that it takes for the device to either heat-up or cool-down is an important consideration in applications that involve resettable fusing, time delay, motor start and degaussing.

### Resistance-Temperature Characteristic

Although PTC thermistors can be used for temperature measurement and control applications in a zero-power mode, they are not usually operated that way. Data is not usually presented in the form of R-T tables or interpolation equations. However, there are some important resistance-temperature characteristic terms that require understanding by the designer / user of the devices.

### Power and Minimum Resistance

The zero-power resistance of the PTC thermistor is usually specified at a standard reference temperature (normally 25°C).

### Minimum Resistance

The minimum resistance of the PTC device is the lowest value of the R-T curve that the thermistor can achieve. It is the point just below the transition temperature where the slope of the R-T characteristic goes to zero as the device changes from the slight negative value for the temperature coefficient of resistance to a large positive value.

### Temperature Coefficient of Resistance

The slope of the R-T characteristic changes from a slight negative value at temperatures below the transition point to a positive value above the transition point. The maximum positive value for the temperature coefficient of resistance (maximum rate of change) occurs within a few degrees above the transition point. As the device gets hotter, the change in the positive value of the coefficient begins

to decrease gradually. Eventually the value can go negative again, however, this usually occurs at an extremely high temperature beyond the normal operating range for which the device has been designed or specified.

### Transition Temperature

The transition temperature is the point at which the resistance-temperature characteristic begins to increase sharply. This corresponds roughly with the Curie point of the material, however, it is difficult to assign an exact value to this temperature. PTC manufacturers will define this temperature as the point where a specified ratio exists between the minimum resistance (or the 25°C zero-power resistance) and the transition temperature resistance. For example, Thermometrics specifies the point where the resistance is twice (2x) the minimum value. Whereas other manufacturers might use a figure of ten (10x).

Figure 24: Voltage Dependence of PTC's.

### Voltage Rating

The voltage rating of a PTC thermistor is the maximum normal steady state voltage that guarantees long-term stability and service life for the device. This value is determined by the properties of the basic PTC ceramic structure.

Exceeding the maximum voltage rating of a device can lead to catastrophic failure. The device can self-heat to the point beyond the maximum resistance value shown in the R-T characteristic where the slope of the temperature coefficient goes into a negative region. At this point the device will go into a thermal runaway condition until the self-heating causes physical destruction of the device.

Figure 23: R-T Characteristic

### Voltage Dependence

Voltage dependence of PTC thermistors must be considered in any discussion of the resistance-temperature characteristic. Figure <24> shows that for a PTC maintained at a constant temperature, the resistance decreases as the voltage across the device is increased. Thus, any measurements of the resistance-temperature characteristic must specify the voltage applied during test in order to be meaningful.

## Voltage-Current Characteristic

The volt-amp (V/I) curve defines the relationship between current and voltage at any point of thermal equilibrium. It is clear from Figure 25 that the temperature and the resistance of the PTC are affected by both power dissipation (self-heating) and ambient conditions. Any factor that changes the dissipation constant also changes the shape of the V/I curve.

Figure 25: Voltage-Current Characteristic.

Figure 26: Voltage-Current Characteristic.

Figures <25> and <26> illustrate the two types of voltage-current characteristic plots used in PTC thermistor design applications.

The voltage-current characteristic for most PTC thermistors is usually not plotted from exact data. Rather, the manufacturer provides certain key data

and specifications that permit the designer or user to create an ideal model of the device. This greatly simplifies the design process, and is adequate for most applications involving self-heated PTC thermistors.

The ideal model of a PTC thermistor assumes the following conditions:

- The resistance of the device is equal to the minimum resistance for all temperatures below the transition temperature.
- The resistance of the device is infinite at all temperatures above the transition temperature.
- The dissipation constant does not change over the temperature range of interest.
- The voltage dependency of the device is not considered.

Similar to NTC devices, the steady state voltage-current characteristic of PTC devices will be affected by changes in the ambient temperature, radiation, dissipation constant and electrical parameters in the circuit.

## Applications for PTC Thermistors

There are very few commercial applications involving PTC thermistors that are based upon the resistance-temperature characteristic. Most PTC thermistor applications are based upon either the steady state self-heated condition (voltage-current characteristic) or upon the dynamic self-heated condition (current-time characteristic) or a combination of both. We shall now list some of the most popular uses for PTC thermistors.

## Resettable Fuses

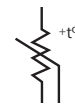
The dramatic rise in resistance of a PTC at and above the transition temperature makes it ideal for over current protection. A circuit is designed such that for all currents below the desired limiting current, the power dissipated in the thermistor is not sufficient to self-heat the device to its transition temperature. However, should an over-current condition occur, the thermistor will self-heat beyond the transition temperature and its resistance rises dramatically. This causes the current in the overall circuit to be reduced.

## Time Delay, Motor Starting, Degaussing

These three applications are somewhat similar in that they all rely on the dynamic operation (Current-Time Characteristic) of a self-heated PTC thermistor. In each case, current is allowed to pass through a series circuit for a prescribed amount of time before the thermistor self-heats into a high resistance condition.



Time Delay



Motor Starting



Degaussing

Figure 27: Resettable Fuse.

Figure <27> illustrates the principle of operation behind a PTC thermistor designed to operate as a resettable fuse. The region indicated as "A" in the figure represents the normal range of current operation. When current exceeds the value of  $I_{MAX}$ , the device will self-heat, increase its resistance and cause the circuit to operate now in the region indicated as "B".

The position of the load line for the circuit can be designed such that the over-current protection is either automatically reset, or requires a manual reset. In the automatic reset mode, the load line intercepts the V-I characteristic at the point labeled "F". Stable operation can only occur at this point for normal loads.

In the manual reset mode, the load line intercepts the V-I characteristic at three points in the figure; "C", "D" and "E". Point "D" is in an unstable region of the curve and so, in practice, steady stable operation will only occur at points "C" and "E".

Figure 28: Time Delay, Motor Start, Degaussing.

In the time delay circuit of Figure <28>, as the thermistor self-heats and increases its resistance, the voltage drop on the fixed resistor decreases to a minimum.

In the motor start circuit of Figure <28> the PTC has a low resistance at turn-on so that a significant amount of current is permitted to flow in the starting winding of the motor. After the thermistor has

self-heated into a high resistance state, the current through the starting winding becomes negligible.

In the degaussing circuit of Figure <28>, the current through the demagnetizing coil is initially large and decreases to a negligible value as the thermistor self-heats.

In all of these cases, the length of time required for the switching action to occur depends upon the amount of power applied to the PTC and its thermal characteristics.

### Heaters and Thermostats

The PTC thermistor can provide a combination of heater and thermostat in one device. As depicted in Figure <29>, the voltage-current characteristic curve is very nearly a constant power locus. Voltage fluctuations are compensated for by a corresponding change in current. As the ambient temperature increases, the PTC resistance also rises so that the effect is a power reduction to the circuit.

Figure 29: Heater / Thermostat.

### Liquid Level and Flow Sensing

These applications rely upon a change in the dissipation constant and the result it has upon the steady state V-I Characteristic. Operation is similar to that of the NTC thermistors previously described. An increase in the dissipation constant, such as placing the device into a liquid or an air flow condition, will lower the PTC operating temperature and increase the amount of power needed to maintain a given body temperature.

Figure <30> shows the V-I plots for two modes of operating PTC thermistors as a liquid level or flow sensors. In the top figure, the load line represents a series resistor with a fairly high value. This causes the thermistor to cool below its transition temperature in the high dissipation medium. The lower figure shows the effect of a low value of series resistor.

Figure 30: Flow Sensor / Liquid Level.