SMT POWER THERMISTORS

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ABSTRACT

This article focuses on the construction and application of SMT power negative temperature coefficient (NTC) and positive temperature coefficient (PTC) thermistors and the problems overcome in the conversion to SMT. The application specific requirements of power thermistors have made the conversion to SMT difficult. Thus the performance of the device is dependent upon the part size along with carefully controlled thermal impedances from the thermistor to the ambient.

The scope of the article will be on ceramic NTC and PTC power thermistors. Special emphasis will be on the end applications of current limiting for the NTC thermistors and over-current protection for PTC thermistors. A comparison to other type of non-power SMT thermistors will be made to enhance the understanding of the reader of the SMT technologies used in the ceramic based thermistor industry.

The manufacturing method employed in construction will be presented. Also included will be current limitations and a comparison to leaded devices.

NON-POWER SMT TYPES

Thermistor temperature compensation and temperature measurement applications are served by several SMT technologies. The most common are listed below:

- MELF construction encapsulated in glass (Figure 1)

Figure 1 - MELF Thermistors

- 1206 , 0805, 0603 and 0402 construction with Pd/Ag or Ni barrier contacts (Figure 2)

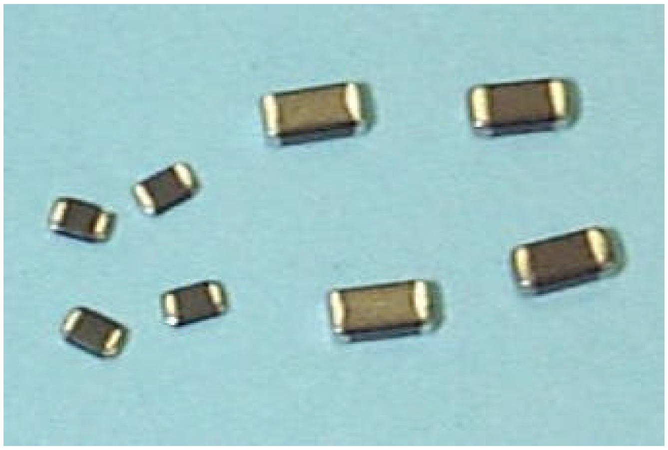

Figure 2 - 0805 and 1206 SMD Thermistors

Package size and construction for these components have been patterned after SMT resistors, capacitors, diodes and other two terminal SMT components available in the market.

REQUIREMENTS FOR INRUSH CURRENT LIMITERS

The primary application for inrush current limiting comes from the high capacitance found in the input circuitry of switching power supplies. Without a series limiting resistor the inrush current can weld switch contacts or blow fuses. The ideal inrush limiter would have a controlled initial resistance that would decrease to zero after the inrush has subsided and the capacitors are charged. The choice of techniques for inrush limiting is normally governed by the cost to accomplish the function.

Some of the primary methods of current limiting along with their advantages and disadvantages are as follows:

- NTC thermistor - low cost, simple but consumes moderate power and will not instantly reset.
- Resistor and a relay - low power consumption but costly and failure could result in the resistor burning out
- PTC thermistor and a relay - same as the resistor relay but provides protection from burning out

The equations that govern the operation of the NTC as an inrush limiter are the following:

1) Ln[R] ={ Bo+B1/T+B2/T^2+B3/T^3 }
2) P = D.C. *{T-Ta}
3) P*dt = H*d T +(T-Ta)*D.C.*dt

With the terms identified as follows:

- R is resistance measured in ohms
- Bo, B1,B2 and B3 are thermistor material constants
- P is power expressed in watts
- D.C. is the dissipation constant of the thermisor with units of watts/degree K
- H is the heat capacity of the NTC in joules/degree K
- T is temperature in Kelvin’s
- Ta is the ambient temperature in Kelvin’s
- dt is the differential of time
- dT is the differential of temperature

By solving equations 1), 2) and 3) with the thermistor in an actual circuit both the transient and steady state response can be calculated. In practice these equations are not solved generally but numerically with a computer or closely approximated with lookup tables.

In the specification of an inrush current limiter the most important parameters to the user are the following:

- Cold resistance - this resistance determines the degree of protection for the series components
- Maximum steady state current - this is determined by the amount of heat that the part can dissipate to theambient air and the resistance value of the thermistor at the maximum rated temperature as can be seen from equation 2). Thermistors with higher dissipation constants (D.C.) have higher steady state current ratings than parts with lower dissipation constants.
- Hot resistance - in general the lower the better
- Steady state power consumption - like hot resistance this ideally should be as close to zero as possible
- Short term energy rating - this determines the maximum value of input capacitor and is equal to the peak energy stored in the capacitor. In general the energy rating of the part is a function of the volume of ceramic material contained in the component. This normally is proportional to H in equation 3). Larger parts normally have greater energy ratings than smaller parts. This rating is also a function of the homogeneity of the part and electrode configuration.

Consider the following example to illustrate how these relationships apply:

R@ 25 C = 100 ohms
Bo = -8.0666
B1 = 4094.2
B2 = 75976
B3 = 540240
Ta = 25 C (298.15 K)
Tmax = 200 C (473.15 K)
D.C.=.030 W/K

By substituting the values for Bo, B1, B2 and B3 in equation 1) the resulting resistance value at 200 C becomes 1.22 ohms. Then from equation 3) the maximum power and current can be calculated, which are 5.25 watts and 2.1 amperes respectively.

PTC CURRENT LIMITER SPECIFICATIONS

The primary use for PTCs as current limiter is in circuits that normally have relatively low steady state currents that may be subject to faults. These faults can result in current levels that may damage or destroy other circuit components. The ideal PTC current limiter would have a very low resistance prior to a fault occurring and go to a very high resistance quickly after a fault occurs. Like the NTC used for inrush limiting there are several choices for preventing damage caused by faults. Some of the common methods of current limiting along with their advantages and disadvantages are as follows:

- Fuses - proven technology but require replacement after a fault
- Circuit breakers - proven technology but require a manual reset
- PTC thermistors - solid state, long life, will reset when the power is removed. but have a long reset time

The equations for modeling the performance of a PTC are somewhat different than those used for an NTC. In general equations to model the resistance temperature characteristic of PTCs are not widely published. In place of the resistance temperature equation the performance is approximated as a constant resistance below the switch or transition temperature, changing to an infinite resistance at the transitions temperature. A summary of the equations used to model PTCs as current limiters is as follows:

4) P = D.C. *{T-Ta}
5) P*dt = H*d T +(T-Ta)*D.C.*dt
6) R = R@25 C for T<Ttr
7) R = infinity for T>Ttr
8) t = H/D.C.*Ln{Po/(Po-(Ttr-Ta)*D.C.)}
9) t = H/Po*(Ttr-Ta)

Where equation 9) is an approximation of equation 8) arrived at by assuming that the heat dissipated is small compared to the heat stored while the PTC is heating from Ta to Ttr. This assumption means that the dissipation constant in equation 8) will approach zero. With a dissipation constant of zero it is necessary to apply L’Hospitals rule to equation 8) which results in equation 9)

Where equation 9) is a suitable estimate for switching times where Po>>D.C.*(Ttr-Ta).

The terms used in equations 4) through 8) are defined as follows:

- R is resistance measured in ohms
- P is power expressed in watts
- Po is the power applied to the PTC below Ttr
- D.C. is the dissipation constant of the thermistor with units of watts/degree K
- H is the heat capacity of the NTC in joules/degree K
- T is temperature in Kelvin's
- Ta is the ambient temperature in Kelvin's
- t is time in seconds
- Ttr is the PTC transition temperature (in Kelvin's) or that temperature where the PTC begins to increase rapidly in resistance

The two most important equations for the circuit designer are 8) and 4). By solving equation 8) the designer can calculate the length of time it takes the PTC to switch from the low resistance state to the high resistance state. This will provide the margin of safety in the design. The solution of equation 4) yields the steady state power generated in the PTC and the steady state current.

In the specification of a PTC current limiter the most important parameters to the user are the following:

- Cold resistance - this determines the voltage drop in the circuit under normal conditions
- Hot resistance - in general the higher the better
- Steady state power consumption - this ideally should be as close to zero as possible
- Heat capacity - this determines the length of time for the PTC to heat to the transition temperature and also the cool down time

The following example will illustrate the principle of operation of a PTC over-current protector:

R@25 C= 10 ohms
Ttr= 120C
H= 1.5 J/C
Ifault= 2 amperes
D.C.=.010 watts/K
Source voltage of 100 volts

By substituting these values into equation 8) the time for the PTC to switch from 25 C to its high resistance state at 120 C can be calculated to be .36 second. By using equation 4) along with the source voltage of 100 volts the current draw of the PTC under fault conditions can be calculated as .0095 amperes. It should be noted that the PTC switching time will be longer for less severe faults and the steady state current after a fault will be greater for lower supply voltages. Therefore the most damaging faults may not be from the highest fault voltage being applied to the circuit but from faults slightly over the rating of the components being protected. Since this will result in significantly longer switch times as should be evident from an examination of equation 8) or 9).

TIME RESPONSE CONSIDERATIONS

Power thermistors operate by increasing in temperature due to the heating resulting from current flow through the part. Thus the time required for the operation of either an NTC inrush current limiter or PTC current limiter is dependent on the current flow through the part. In addition, the operating time is also influenced by the thermal impedance of the part to the ambient and the heat capacity of the unit.

The time required for the power thermistor to return to the original cold state is a function of the mass of the part and thermal impedance from the part to the ambient. The following equation is an approximate relationship governing the cooling time:

10) H=D.C.*T.C.

With the terms identified as follows:

- H is the heat capacity of the NTC in joules/degree K
- D.C. is the dissipation constant of the thermistor with units of watts/degree K
- T.C. is the time constant in seconds

The following PTC example will illustrate this concept and demonstrate the interaction between cooling time and power dissipation:

Ttr = 120C
H = 1.5 J/K
D.C. = .010 watts/K

From equation 10) we can calculate the time constant to be 1.5 J/K/.010 watts/K=150 seconds. This is the time required for the part to cool to 63.2% of the temperature difference between 120 C and 25 C. The steady state power consumption from equation 4) becomes .010*(120-25)=.95 watts . If the dissipation constant were doubled, the power consumption would rise to 1.9 watts and the time constant would decrease to 75 seconds.

THE CONVERSION TO SMT

Prior to conversion to SMT, power thermistors were typically supplied as discs with radial leads attached. The photograph in Figure 3 illustrates a power thermistor. Normally these components range from 5mm in diameter to 25 mm in diameter. Thickness of the ceramic element ranges from approximately 1 mm to 3 mm. However, both larger and smaller devices are available

The SMT version of this power thermistor is illustrated in Figure 4. The component on the left depicts the thermistor as it would be viewed from the top of the circuit board. The component on the right shows a bottom view of the power thermistor as it would be mounted to the circuit board.

Figure 3 - Radial Lead Power Thermistor

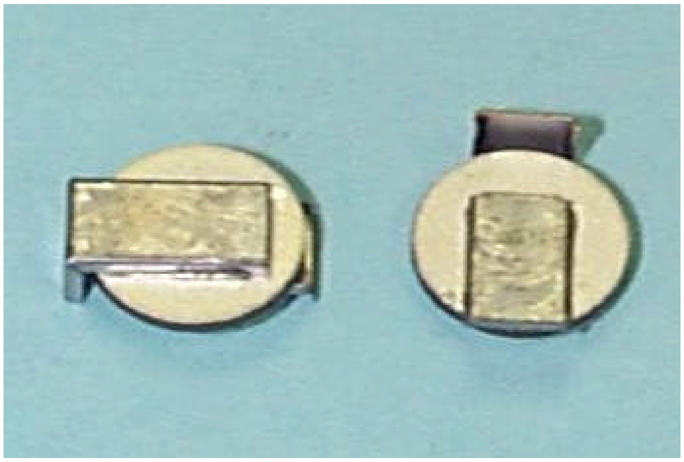

Figure 4 - SMT Power Thermistors

THE CERAMIC ELEMENT REMAINS THE SAME

The ceramic thermistor element remains virtually unchanged regardless of whether the part is leaded or SMT. By keeping a common ceramic the device parameters such as cold resistance, voltage rating, transition temperature, and curve shape are unchanged from the wired version..

Careful control of the mass and thermal conductivity of the lead frame mounting system results in an SMT part that has essentially the same thermal characteristics as the leaded part. In the case of both the NTC and the PTC, the dissipation constant is nearly identical to the leaded version. This results in virtually no effect upon switching current, effective heat capacity, and maximum steady state current for NTC thermistors used as inrush current limiters. Similarly for SMT PTC thermistors used as overcurrent protectors switch time and steady state current are very much like the leaded versions of the same device.

POWER SMD THERMISTORS GET HOT

By the very nature of how power thermistors operate they do get hot. For NTC inrush current limiters operated at full rating this could be over 200 C and typically develop up to 4 watts. PTC thermistors normally operate at approximately 40 C above the transition temperature. For a PTC with a 120 C (which is the most common) transition temperature, this would result in an operating temperature of approximately 160 C and typically develop 2 watts. Like any other SMT power device, power thermistors require careful attention to detail in the location of other temperature sensitive components. Under normal conditions the NTC operates hot and the PTC cold.

Cooling considerations are normally based upon the wattage developed by a component in the static state. For power thermistors this approach needs modification. Additional cooling will actually increase the steady state power consumption of either the power NTC or PTC.

SMD POWER THERMISTORS ARE BIG

To obtain the desired ratings and performance the parts need to be large. For some power thermistors this can be as large as 25 mm in diameter. This is necessary to obtain adequate capacitance ratings for NTCs or to obtain the desired resistance and voltage rating for PTCs. Careful planning of the board real estate is essential. This should be the first component planned for inclusion in a surface mount circuit and not the last.

TRANSIENT WITHSTAND

Transient withstand is a strong point of power thermistors. The typically static discharge or low energy voltage spike, that will destroy an IC, will not cause any problems with a power thermistor. In fact most low energy transients will not cause any harm to power thermistors. This degree of protection afforded by power thermistors is the result of the device not having a junction to punch through like an IC. However, PTC thermistors can be damaged by exceeding the voltage or instantaneous current rating of the device. Conversely, power NTC thermistors can be damaged by exceeding either the capacitance rating or the steady state current rating of the part.

HOW ARE POWER THERMISTORS MADE

The flow chart in Figure 5 illustrates the steps used to manufacture a leaded power thermistor.

In Figure 6 the process flow diagram is shown for SMT power thermistors. The main processing differences between the leaded version and the SMT version of the power thermistor are in lead attachment and packaging. The leaded power thermistor has leads attached by dip soldering. An alternate method used is melting a solder wire onto the face of the part either with a soldering iron or heating by hot air.

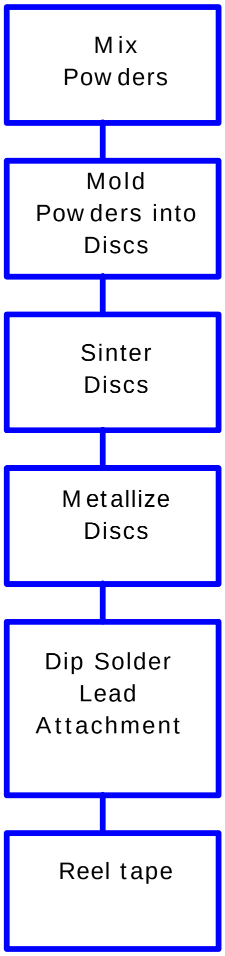

Figure 5 - Process Flow for Leaded Power Thermistors

The other major difference between SMT and leaded versions of power thermistors is in the packaging. The SMT version is almost always pocket taped and the leaded part is either reel taped on bulk packed.

CONQUERING EXPANSION PROBLEMS

The challenges in producing an SMT power thermistor are rooted in the size of the device and the power surge capability required for most common applications. The leadframe approach addresses both issues adequately.

Ceramic power thermistors have many of the same characteristics as most other ceramics. They are strong in compression, but relatively weak in tension. This weakness in tension necessitates a connection system that will absorb the relative movement between the power thermistor and the mounting substrate without placing too much stress on the ceramic element.

Both the NTC inrush current limiter and PTC current limiter operate hot. Actual body temperatures of the power thermistor can be as high as 200 C. This added to a substrate with a worst case ambient temperature of -55 C means that the temperature of the power thermistor may differ from the substrate from no difference to a maximum difference of 255 C. This temperature differential, along with the differences in expansion coefficients of the mounting substrate and the power thermistor's brittle nature, necessitate a mounting system with some flexibility. Thus the leadframe packaging with a long metal top member was chosen. The leadframe addresses the problems created by the mismatch of expansion coefficients over the extreme temperature differentials possible. This packaging allows relative movement between the power thermistor and the substrate on which it is mounted. The leadframe is designed to be a bendable link between the power thermistor and the mounting substrate. Thus the leadframe bends during the thermal excursions of the thermistor and substrate.

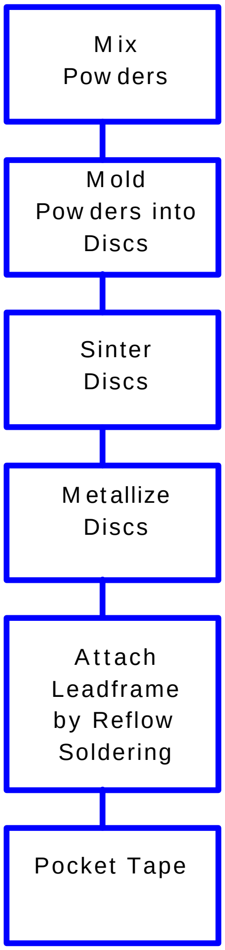

Figure 6 - SMD Power Thermistor Processing

CONTROLLED THERMAL PATH

The precise stamped dimensions of the leadframe create a controlled thermal path for heat dissipated from the power thermistor. By choosing the appropriate material for the leadframe the degree of isolation between the power thermistor and the substrate can be well controlled. Steel alloy leadframes have low thermal conductivity and give the power thermistor a high degree of isolation from the substrate. Copper leadframes provide high thermal conductivity and greater power dissipating properties. The table shown in Figure 11) illustrates some of the trade-offs between a leadframe with high thermal conductivity versus one with low thermal conductivity for a PTC with the following characteristic in a current limiter circuit:

R@25 C= 10 ohms
Ttr= 120C
H= 1.5 J/C
Ifault= 2 amperes
D.C.=.010 watts/K
Source voltage of 100 volts

LEADFRAME THERMAL CONDUCTION	LOW	HIGH
DISSIPATION CONSTANT	.010 W/K	.020 W/K
TIME CONSTANT	150 SECONDS	75 SECONDS
MAXIMUM NO TRIP CURRENT	.300 AMPERES	.435 AMPERES
STEADY STATE POWER	.95 WATTS	1.9 WATTS
STEADY STATE CURRENT	9.5 MA	19 MA

Figure 11 - The effects of different leadframe materials on PTC current limiter performance

LEADFRAME THERMAL CONDUCTION	LOW	HIGH
DISSIPATION CONSTANT	.015 W/K	.030 W/K
TIME CONSTANT	150 SECONDS	75 SECONDS
STEADY STATE POWER	2.62 WATTS	5.25 WATTS
STEADY STATE CURRENT	1.47 AMPERES	2.10 AMPERES

Figure 12 - The effects of leadframe material on NTC inrush current limiter performance

The effects of leadframe material on performance of an NTC used as an inrush current limiter are illustrated in Figure 12 for the following NTC characteristics used in an inrush current limiter circuit:

Bo= -8.0666
B1= 4094.2
B2= 75976
B3= 540240
Ta= 25 C (298.15 K)
Tmax= 200 C (473.15 K)
D.C.=.030 W/K
H= 1.5 J/K

The tables in Figures 11) and 12) make it apparent that the mounting conditions affect both the performance of the power thermsitors in the intended application as well as the power rating of the device.

SUMMARY

The proper use and selection of SMT power thermistors requires a knowledge of electrical as well as thermal properties of the power thermistor. The SMT designers needs to make allowances in their design to accommodate a part that may operate as hot as 200 C and have a temperature difference from the circuit board of over 250 C.

By the nature of the power thermistor operations, time is required for the component to perform the desired function of NTC inrush current limiting or PTC current limiting. Also time is required for the part to cool before the power thermistor can be operated at full rating. Cool down times can be accelerated at the expense of increased power dissipation and additional heat sinking into the circuit board.

Power thermistors are large and require a significant amount of circuit board real estate. It is not uncommon to have power thermistors as large as 25 mm.

Not all power thermistors are readily available in SMT packages. The first parts to be converted to the leadframe SMT package have been discs with a diameter of 8 mm or less.

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