NTC Thermistors
General Information

INTRODUCTION

Thermistors are thermally sensitive resistors suitable for many applications, including temperature measurement, control and compensation, current surge suppression, power measurement, amplitude control, trigger circuits, measurement of velocity of liquids or gases, etc.

Bead thermistors, directly and indirectly heated, are small devices suitable for low power applications.

Disc types are suitable for use at higher power levels and are all directly heated.

Rod types (Brimistors) are broad tolerance thermistors, particularly suitable for surge suppression and compensation for resistance variation of other components in radio, television, telecommunication and projection equipment.

CHARACTERISTICS

Negative temperature coefficient thermistors have a temperature coefficient $\left(-\frac{B}{T^2}\right)$ of resistance at 20°C of approximately ten times that of copper. The resistance (R_{T1}) of a thermistor at a temperature T1(°K) can be related to the resistance (R_{T2}) at any other temperature T2(°K) by the following equation:

$$R_{T1} = R_{T2} e^{\left(\frac{B}{T1} - \frac{B}{T2}\right)}$$

where B is the characteristic temperature of the thermistor expressed in °K.

SELF HEATING

When electrical power is dissipated within a thermistor it is said to be self-heated and its temperature can be considered to increase by an amount proportional to its dissipation constant.

The dissipation constant is defined as the power required to raise the temperature of the thermistor element by 1°C.

When using thermistors for temperature detection it is important to minimise self heating in order to prevent excessive temperature errors being introduced. The electrical power dissipated within the thermistor should be such as to produce a temperature rise of less than half the required resolution of temperature measurement. This statement assumes that there are no circuit or calibration tolerances for which allowances must be made.

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In practice the acceptable level of power dissipation depends upon all the various tolerances so that the total temperature error is less than half the required resolution of measurement.

In some applications where the thermistor will always be situated in the same stable environment it is possible to offset calibration in order to allow for the temperature rise due to self heating. In this way quite high power levels can be tolerated. It should be remembered that the greater the temperature rise the lower the sensitivity to an external temperature change and the higher the sensitivity to changes in thermal conductivity of its immediate surroundings.

The thermistor's sensitivity to electrical power input leads to its use for such applications as surge suppression, time delay, amplitude control, power measurement and voltage stabilization, also its sensitivity to changes in thermal conductivity permits its use in applications such as anemometry, katharometry, manometry and liquid level detection. For these applications the level of power dissipation is limited to the maximum ratings quoted in these data.

Thermistor types which are designed to be self heated are not, in general, suitable for applications where they are required to sense variations of temperature.

VOLTAGE CURRENT CHARACTERISTICS

Conduction in a thermistor is purely electronic as opposed to ionic and provided the temperature of the thermistor does not vary in sympathy with an applied signal, Ohm's law is obeyed. However, under self heating conditions, non-linearities will occur when the signal has a frequency comparable with, or less than, the inverse of the thermistor time constant.

As the current through a thermistor is increased, the voltage at first rises rapidly and soon obtains a maximum value, Emax. Thereafter the thermistor behaves as a negative slope resistance and there is a decrease in potential with further increase in current.

$$E_{MAX} \propto \sqrt{\frac{R_o K}{B}}$$

Where R_o = resistance at ambient temp. (Ohms).
K = dissipation constant (mW/°C).
B = characteristic temp. (°K).

It should be noted that the E_{MAX} value decreases with increasing temperature.

In the case of an indirectly heated thermistor the effect of heater power input on the voltage v. current characteristic of the bead element is similar to that of temperature on a directly heated element.

TIME RESPONSE

When heating power is removed from, or applied to a thermistor, an immediate resistance change will occur at a rate dependent upon the thermal mass and the surroundings of the device. In order to compare the rates at which different types of thermistor will respond, the time constant of the device is measured.

The time constant is defined as the time taken for the temperature of the thermistor element to change by a factor $\frac{e-1}{e}$ (i.e. c.a. 63 per cent) of the total temperature difference and is normally determined by suddenly removing heating power. For certain types of thermistor the time constant is different under self-heated and externally heated conditions. When this is the case, values for both time constants are quoted.

It is not possible to quote a time constant for the self-heating of a thermistor because the rate of heating is dependent on the circuit in which the thermistor is used. A device may change its resistance by a specified amount in one second in a low impedance circuit but may take as long as one minute when heated from a high impedance source.

In some applications it is not necessary for a thermistor to respond completely to a temperature change since a useful resistance change can occur in a fraction of the time constant. The initial rate of temperature change from the time a temperature stress is applied to a thermistor can be calculated as the total temperature difference divided by the time constant.

RESISTANCE v. TEMPERATURE TOLERANCES

The standard resistance tolerance of a thermistor at its selection temperature (normally 20°C or 25°C) is ± 20 per cent. In addition there is a tolerance on B value (normally ± 5 per cent) which causes an increasing resistance spread as the temperature deviates from the selection temperature.

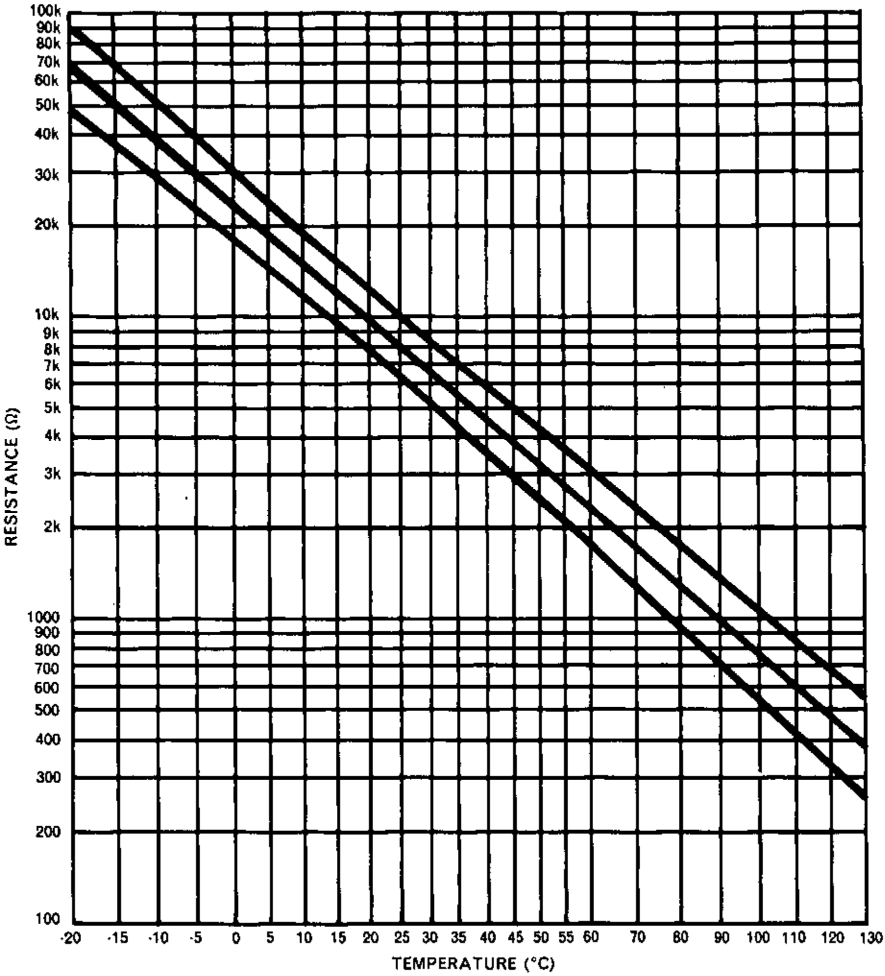
Fig. 1 shows the possible resistance spread of a thermistor having a nominal resistance at 20°C of 10K ohms with a tolerance of ± 20 per cent and a nominal B value of 3,500 with a tolerance of ± 5 per cent.

Fig. 1 has a log reciprocal scale which enables the thermistor characteristic to be drawn as a straight line. The B value is the slope, $\frac{\Delta \log_e R}{\Delta \frac{1}{T}}$.

This type of graph sheet is used for resistance/temperature characteristics in the N.T.C. thermistor component data.

Fig. 1.—Resistance v. Temperature Characteristic Spread

Thermistor resistance, 10K ± 20% at 20°C
B value, 3500 ± 5%



MODIFYING THERMISTOR CHARACTERISTICS

For some applications it may be necessary to modify the characteristics of thermistors and it may not always be possible to do this by chemical and/or physical changes in the semi-conductor material from which the thermistor is made. Modifications to characteristics can often be made by combining an existing thermistor with one or more ordinary resistors or with other thermistors. On account of the great diversity of characteristics which may be obtained it is impracticable to mention them all, but the following example will serve an as illustration.

By shunting a thermistor with a suitable fixed resistor, it is possible to obtain very nearly linear characteristics over a limited temperature range. Fig. 2 shows a typical resistance v. temperature characteristic for a type F thermistor having a resistance at 20°C of 2000 ohms (Curve A). Curve B shows the effect of shunting this thermistor with a resistor of negligible temperature coefficient having a resistance value equal to that of the thermistor at 20°C.

It will be seen that the characteristic of the combination is substantially linear over the range 0° to 50°C and very linear from 0° to 30°C.

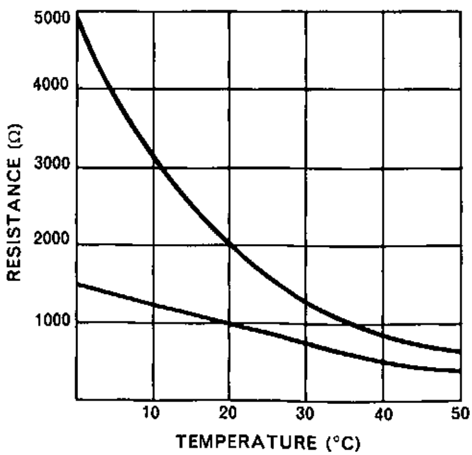
The linear portion obeys the expression:

$R_t = R_T (1 - \alpha t)$ where R_T = known resistance of the combination at known temperature T.

R_t = resistance at t°C.

α = temperature coefficient.

Fig. 2.—Thermistor characteristics modified by use of shunt resistor.



When the thermistor has the same resistance as its shunt, their parallel sum is roughly the midpoint of the linear part of the resistance v. temperature characteristic of the combination.

A simple rule for determining the temperature coefficient of a thermistor/shunt combination is as follows: when the thermistor has the same resistance as its shunt, the temperature coefficient of the combination is half that of the thermistor alone.

It will be evident from the above that this facility of changing the slope of a thermistor has considerable importance in temperature compensation problems.

THERMISTOR APPLICATION SELECTION CHART

PRIMARY APPLICATION	THERMISTOR TYPE												
	A	B	C/ CZ	D	E	F/ FS	G/ GL/ GT	KB/ KR/ KT/ KU	L	M	P	R	U
Temp. Measurement				*		*	*	*		*			*
Temp. Control				*		*	*	*		*			*
Temp. Compensation							*	*					*
Fire Detection							*	*		*			
Temp. Diff. Meas.						*	*			*			*
Surge Suppression	*		*										
Time Delay	*	*	*				*	*	*		*		
Amplitude Control	*	*		*	*		*		*			*	*
Power Measurement	*	*			*								*
Voltage Stabilisation	*	*	*										
Voltage Switch	*	*							*				
Colour T.V. Degaussing			*					*					
Liquid Flow							*				*		
Liquid Level							*						
Gas Flow							*				*		*
Wind Speed											*		*
Gas Chromatography											*		*
Gas Pressure							*				*		*

Description of Standard Bead and Disc Types

Type	Description	Standard physical variations
A	Bead in gas-filled glass envelope	—
AT	As type A but mounted in cartridge-type fuse holder	—
B	Indirectly heated bead in evacuated glass envelope	—
C	Rod type thermistor (Brimistor) without connecting wires	—
CZ & CZA	Rod types (Brimistors) with connecting wires	—
D	Bead in end of glass probe	—
E	Bead in gas-filled glass envelope	—
F	Bead sealed in 'pip' at end of glass probe	—
FS	Bead in end of glass probe	Two lengths of probe
G	Bead in solid glass pellet	Three diameters of pellet
GL	Bead in solid glass pellet	—
GT	As type G but mounted and potted inside nickel-plated case	Two sizes of case
KB	Disc mounted on metal plate	—
KR	Painted disc with radial lead wires	—
KT	Unpainted disc with radial lead wires	—
KU	Unpainted disc without leads	—
L	Indirectly heated bead in gas-filled glass envelope	—
M	Glazed bead mounted on nickel-iron alloy disc	—
P	Glazed bead suspended beyond end of glass probe	—
R	Bead in evacuated glass envelope	—
U	Unmounted glazed bead with platinum-ruthenium alloy leads	Single or double-ended lead arrangement

Matched pairs of thermistors.

Thermistors are available to order in matched pairs of the following types: D, F, FS, G, M, P, and U.

The resistance of each resistor is matched to within 1 per cent at 20°C, both thermistors being within the ±20 per cent tolerance of nominal resistance.

BRIMISTORS

Rod Type Thermistors

CHARACTERISTICS AND OPERATION OF BRIMISTORS

Brimistors are unpolarised resistive elements of thermistor material, and are peculiarly suitable for surge suppression and resistance variation compensation of other components in radio, television, telecommunication and projection equipment. The resistance of a Brimistor decreases with rising temperature, and so does its temperature coefficient. Thus a rise of about 20°C above room temperature will halve its resistance, but at 250°C an increase of 50°C is necessary to halve the resistance value.

OTHER CHARACTERISTICS

Voltage-Current

The current through a Brimistor increases with the voltage across it until that voltage reaches a certain maximum (E_{max}). Thereafter the Brimistor displays a negative voltage characteristic, current increasing rapidly with a decrease of voltage across the Brimistor.

The value of E_{max}, which depends upon the ambient temperature and the type of Brimistor, is given approximately by:

$$E_{max} = \frac{\sqrt{R_T}}{k}$$

where R_T = resistance of Brimistor at zero input and ambient temperature.
k = maximum voltage factor for the type of Brimistor concerned.

Initial Resistance

The resistance at zero power input of any type of Brimistor is entirely dependent, within normal manufacturing tolerances, upon the ambient temperature, as is shown in Table 1.

Thermal Characteristics

The rate of heating and consequent change of resistance of a Brimistor depends upon its mass, how it is mounted, and the circuit conditions in which it is employed; and the rate of cooling upon its mass and the difference between operating and ambient temperatures.

To choose the most suitable type of Brimistor for a specific application, consider the characteristics and ratings of the various types.

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COMPONENTS GROUP

STC

Type CZ

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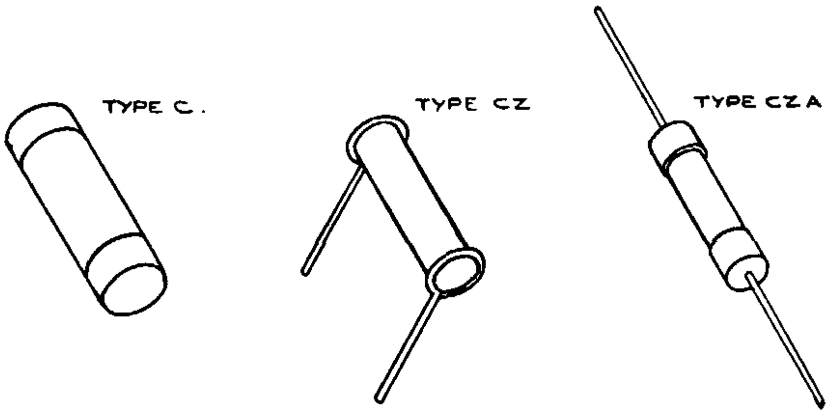

TYPICAL BRIMISTOR APPLICATIONS

Surge Suppression in A.C./D.C. Receivers (see Table II).

Time Delay of Relays (Type of Brimistor determined by delay required and voltage).

Efficient Operation of Dial Lamps (see Table III).

Protection of Rectifier Valves and Reservoir Condensers (see Table IV).

Delay of H.T. Voltage from Directly Heated Rectifiers (Type of Brimistors determined by R.M.S. value of current in centre tap of transformer).

Compensation for Increase in Resistance of Focus Coils (Normally CZ2 or CZ3).

Protection from Switch-on Surges in Mains Transformers (Type CZ9A, with shunt if required).

Protection against Filament Burn-out in Mains/Battery Receivers (CZ10 (in parallel) for 25 or 50mA chains).

Protection of Projector Lamps (see Table V).

Type CZ

CONTINUED

TABLE I

SUMMARY OF CHARACTERISTICS

Type	Dimensions (inches)	Initial Resistance Ohms			Max. Voltage Factor "k"	E_{max} Volts 20°C	Max. Operating Current Amp.	Resistance* at Max. Operating Current Ohms	Max. Instantaneous Current Amp.
		0°C	20°C	50°C					
CZ1 CZ1A	$1\frac{1}{4} \times \frac{5}{16}$	8 300	3 800	1 400	2.36	25	0.3	44	0.6
CZ2	$\frac{7}{8} \times \frac{1}{4}$	12 500	5 500	1 850	2.47	30	0.3	38	0.4
CZ3	$\frac{5}{16} \times \frac{3}{16}$	3 500	1 500	560	2.9	13.5	0.2	35	0.3
CZ4 C4 CZ4A	$1\frac{1}{2} \times \frac{7}{16}$	1 700	800	320	1.92	14.7	1.25	5.5	2.0
CZ6	$1\frac{1}{4} \times \frac{3}{8}$	6 000	3 000	1 120	2.4	23	0.45	27	0.7
CZ8A	$\frac{3}{4} \times \frac{5}{16}$	3 700	1 600	620	2.48	15.6	0.3	30	0.6
CZ9A	$\frac{3}{4} \times \frac{5}{16}$	800	350	130	2.53	7.8	1.0	3.7	1.3
CZ10	$\frac{5}{16} \times \frac{3}{32}$	26 000	11 000	4 000	5.4	19.5	0.075	148	0.150
CZ11	$1\frac{1}{4} \times \frac{3}{8}$	280	140	65	2.04	5.8	1.5	2.5	2.5
CZ12 CZ12A	$1\frac{1}{2} \times \frac{7}{16}$	240	120	53	1.71	6.4	2.5	1.5	4.0

* In an ambient of 20°C. At higher ambients, this figure will be somewhat lower.

Type CZ

CONTINUED

TABLE II

BRIMISTORS FOR VALVE FILAMENT CHAINS

Typical Chain	Current Amps.	Supply Voltage	Recommended Brimistor
4 + 1	0.3	200–240	CZ1 or CZ1A
4 + 1	0.15	200–240	CZ2
4 + 1	0.3	110	CZ1 or CZ1A
4 + 1	0.15	110	CZ1 or CZ1A
4 + 1	0.2	200–240	CZ1 or CZ2
4 + 1	0.1	200–240	CZ1 or CZ1A
* TV Receiver	0.3	200–240	CZ1A or CZ1 shunted or CZ4 or CZ6

* CZ1 limits the surge to 0.60A
CZ6 ,, ,, ,, ,, 0.45A
CZ4 ,, ,, ,, ,, 0.38A

TABLE III

BRIMISTORS FOR DIAL LAMP SHUNTS

Heater chains up to 0.2A	CZ3
Heater chains 0.2A to 0.3A	CZ8

TABLE IV

BRIMISTORS TO PROTECT RECTIFIERS

Direct Current up to 75mA	CZ10
,, ,, ,, ,, 100mA	CZ1 or CZ1A
,, ,, of 100 to 200mA	CZ6
,, ,, over 200mA	CZ4

Type CZ

CONTINUED

TABLE V

BRIMISTORS TO PROTECT PROJECTION LAMPS

Lamp Wattage	Supply Voltage	Cooling* Time	Suitable Brimistor
500	200–250	12 mins.	CZ12
250	105–125	12 ,,	CZ12
300	200–250	10 ,,	CZ11
150	105–125	10 ,,	CZ11
150	200–250	6 ,,	CZ9A
75 and below	105–125	6 ,,	CZ9A

* This is the time necessary to allow the Brimistor to cool sufficiently to give adequate protection. It will not in this time cool to room temperature or maximum resistance.

PRECAUTIONS IN USE

REFER TO TABLE I FOR MAXIMUM RATINGS

Current rating

The maximum *operating* current is a design centre rating which allows for normal supply voltage variation and an ambient temperature of 50°C.

The maximum *instantaneous* current cannot be exceeded without risking destruction of the Brimistor. Should a surge of this magnitude be likely (e.g. on switching on certain valve heater circuits) a suitable resistor must be shunted across the Brimistor to ensure a slower, steady rate of current rise during the warm-up period.

Voltage rating

The voltage applied to a Brimistor must not exceed E_{max} when its source resistance is less than 1/80 of the Brimistor's cold resistance. Even when this condition is fulfilled, care must still be taken that the maximum instantaneous current rating is not exceeded.

Type CZ

CONTINUED

Installation

In mounting, half an inch of wire must be left free for soldering "CZ" type Brimistors. Type "C" Brimistors have silvered ends for insertion in clips, and "CZ–A" have axial wires and end caps.

In positioning a Brimistor, remember that its body temperature may reach 250°C and thus affect other components. Similarly a Brimistor operating in a confined or thermally insulated space may cause damage to itself, and forced air cooling is not advisable, as cracking may occur owing to a thermal gradient being set up within the Brimistor.

Use of Shunts

In circuits of low total resistance, it may be necessary to increase the heating time of the Brimistor by shunting some of the current through a resistor. Constant current during the warm-up period may be obtained by choice of a suitable shunt resistor, but its value must not be such as to prevent E_{max} being reached owing to insufficient voltage being developed initially across the Brimistor.

Not to be used in parallel

Brimistors may not be used in parallel because differences in cold resistance, within manufacturing tolerance, result in unequal current flow which, being cumulative, will end by destroying one unit. They may in certain circumstances be connected in series.

Humidity

Brimistors are not specially sealed against moisture, and on first use after prolonged storage in high humidity there may be some increase of initial resistance, but once used, the Brimistor will return to its original cold resistance value.

Mechanical shock

The material of which Brimistors are made may fracture under excessive mechanical stress or shock.

Tolerance

It must be realised that Brimistors are manufactured to normal mass-production tolerances and are not suitable for use in precision measurements.