ELECTRONIC FUSES

Bourns Electronics has for some time marketed a series of circuit breakers that, in a number of applications, form good alternatives to the usual glass fuses. Known as MultiFuse, the devices are similar in their basic characteristics to positive temperature coefficient (PTC) resistors made from doped barium titanate ceramics, but are of a totally different construction based on conductive polymer composite materials. An important advantage of the MultiFuse is that after it has been tripped by an overload it needs only a short period after the overload has been removed to regain its normal operational characteristics.

Automatic circuit breakers are, of course, not new. Many electric coffee-makers and deep fryers have a thermal trip device that switches off the mains when the appliance gets too hot. After the heating element has had time to cool off, the trip element returns to its original position and the appliance operates normally again.

The MultiFuse has a similar function. As soon as the current through it exceeds a certain value, its resistance increases significantly. This reduces the current to a safe value so that the load does not get damaged.

However, in contrast to the usual electro-mechanical circuit breaker, the MultiFuse is an electronic component that has no moving (mechanical) parts. The advantages of this are clear: a mechanical circuit breaker is sensitive to vibrations, produces sparks when it is operated, and, after a time, presents an increasing resistance owing to corrosion of the contacts.

Ceramic positive temperature coefficient (PTC) resistors that occasionally are used in protection circuits operate in a manner similar to that of the MultiFuse. They have the serious drawback, however, of a much longer switching time. Another snag is that their resistance may decrease significantly, even to the point of a short circuit, when the voltage across them is too high.

Principle of operation

Although the basic characteristics of the MultiFuse are similar to those of a PTC, the construction of the two devices is quite different. Whereas a PTC is made from doped barium titanate ceramics, the MultiFuse is made from conductive polymer. In the past two decades substantial progress has been made in research on conductive polymer materials. In these materials, conductive particles—carbon black in the case of MultiFuse—are dispersed in a polymeric matrix of a suitable plastic material.

The properties of the conductive polymer composites used in MultiFuse lead to improvements in device characteristics that are not obtainable with conventional PTC resistor technologies. In the low resistance state, resistances as low as a few milliohms can be obtained. The PTC effect, which is the basis of the current-limiting function, can increase resistance by typically 5–7 decades. This PTC characteristic is maintained over and beyond the operating range of MultiFuse. Ceramic PTC resistors on the other hand can exhibit a negative temperature characteristic under overvoltage when their temperature rises beyond the anomaly temperature.

Properties of conductive polymers

To better understand some of the characteristics of MultiFuse devices, it is necessary to look at the underlying properties of conductive polymers.

The conductive poymer materials used to produce MultiFuse devices are filled with carbon black. The carbon black particles form themselves into chains instead of randomly dispersed particles. The resulting electrical conductivity of the polymer composition is of the order of 0.01 S ($=1\ \Omega^{-1}\ \text{cm}^{-1}$).

The type of carbon black and the volume ratio of carbon black to polymer determine the value of electrical resistivity. Changes in the volume ratio will cause changes in resistivity. A lower ratio of carbon black to polymer means a decreased number of conductive chains and therefore an increase in resistivity.

For MultiFuse devices a crystalline polymer is used. The crystalline structure of this material disappears in the region of 125 °C. The resulting increase in polymer volume reduces the ratio of carbon black to polymer and a very large resistance increase results within a very narrow temperature band. This anomalous positive temperature coefficient of resistance explains the "switching" characteristic of MultiFuse devices.

Figure 1 shows the link between volume and resistance. An increase in resistance of six orders of magnitude over a few tenths of a degree Celsius is typical. The figure also shows that the PTC characteristic is persistent far beyond the anomaly temperature.

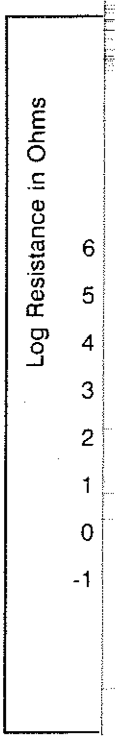
With cooling of the device below the anomaly temperature the polymer starts to recrystallize and more and more of the opened carbon black chains are re-established. Although most of the carbon black chains are closed again after minutes, the further crystallization process takes time. This fact leads to the slight increase in resistance after trip: after a cooling period of 1 hour, the value of the resistance is still up to 20% higher than original. However, the resistance value will return within 24 hours to within the tolerances specified by the makers.

MultiFuse devices are manufactured to yield a basic resistance close to its minimum specified value. When they are delivered, they have never been tripped and their volumetric ratio of carbon black to polymer is at a maximum.

Designing in a MultiFuse

The questions you need to answer when designing with MultiFuse devices include:

1. What is the maximum normal current that can pass throught the circuit at the maximum ambient temperature without tripping the device?



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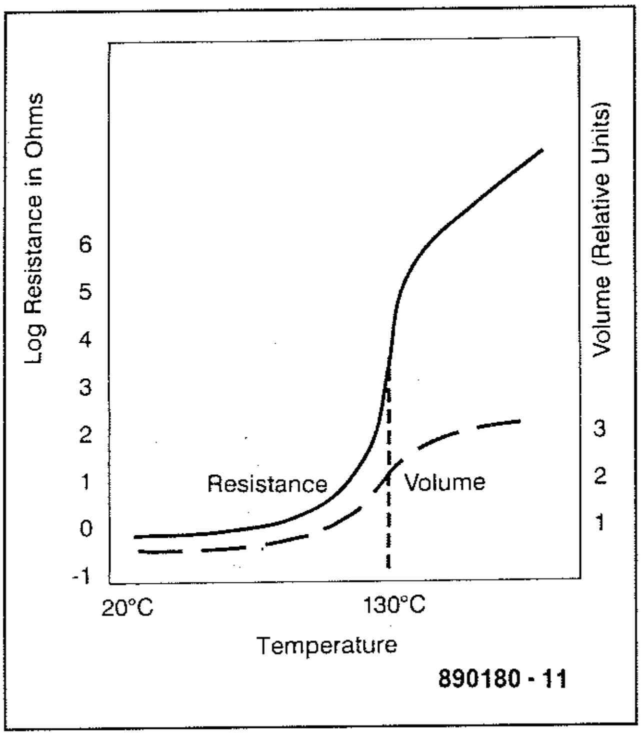

Fig. 1. Resistance and volume as a function of temperature.

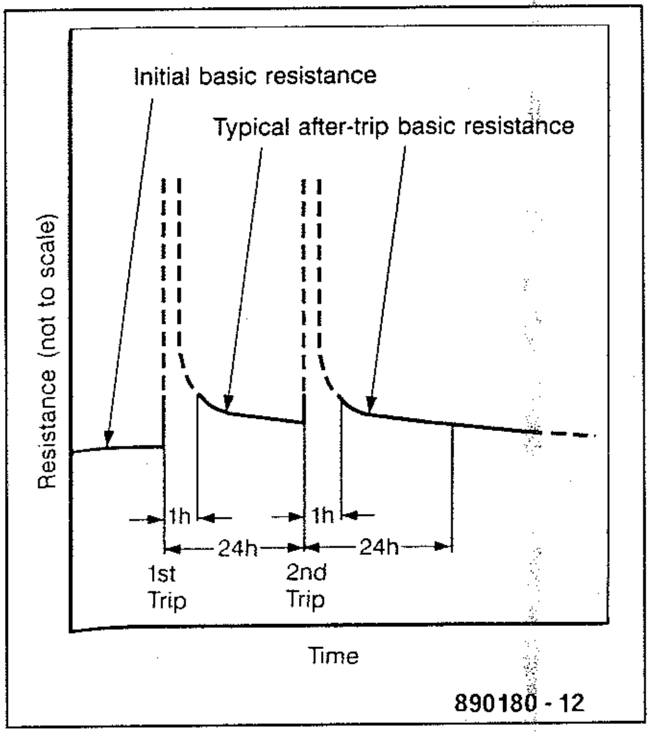

Fig. 2. Recovery of basic resistance after trip.

Part Number	V max V rms	I HOLD A rms	R min Ohms	R nom Ohms	R max Ohms	I trip A rms	P d W	I max A rms
MF-R020	50	0.20	1.83	2.67	4.50	0.30	0.40	40
MF-R025		0.25	1.25	1.83	3.10	0.38	0.45	
MF-R030		0.30	0.87	1.27	2.20	0.45	0.50	
MF-R040		0.40	0.55	0.81	1.33	0.60	0.55	
MF-R050		0.50	0.49	0.75	1.20	0.75	0.75	
MF-R065		0.65	0.30	0.46	0.75	0.98	0.90	
MF-R075		0.75	0.25	0.39	0.62	1.13	0.90	
MF-R090		0.90	0.19	0.34	0.48	1.35	1.00	
MF-R110	30	1.10	0.08	0.13	0.23	1.87	1.00	40
MF-R135		1.35	0.06	0.10	0.17	2.30	1.10	
MF-R160		1.60	0.05	0.08	0.14	2.72	1.20	
MF-R185		1.85	0.04	0.06	0.11	3.15	1.30	
MF-R230		2.30	0.03	0.05	0.09	3.91	1.40	
MF-R250		2.50	0.02	0.04	0.08	4.25	1.50	
MF-R300		3.00	0.02	0.03	0.06	5.10	2.00	
MF-R400		4.00	0.01	0.02	0.04	6.80	2.50	
MF-R600		6.00	0.005	0.01	0.03	10.2	3.50	
MF-R800		8.00	0.005	0.01	0.02	13.6	4.00	
MF-S200	15	2.00	0.03	0.04	0.08	3.00	*	100
MF-S350		3.50	0.02	0.03	0.04	5.25	*	
MF-T110	250	0.11	13	17	26.0	0.17	1.00	3
MF-T145		0.145	7	8.5	13.0	0.22	1.00	

Electrical specifications of a number of types of MultiFuse at an ambient temperature of 20 °C.

2. What is the maximum current that can pass through the circuit at the minimum ambient temperature without causing damage to circuit components?
3. What is the maximum fault current and voltage to which the device will be exposed?

A practical example

Suppose that a resistive load of 33 Ω, for instance, a motor, transformer or heating element, is to be protected against overcurrent with the aid of a MultiFuse.

In normal circumstances, the highest current is 150 mA, the highest ambient temperature is 70 °C and the maximum voltage is 30 V.

On the basis of these data, the most suitable type of MultiFuse is chosen from the table: in this case, the MF-R030. This has a hold current of 160 mA at a temperature of 70 °C and will, therefore, not trip in normal circumstances. Also, it can stand a voltage of 60 V, which is more than adequate for the requirement. At room temperature, the MF-R030 has a minimum resistance of 0.87 Ω, so that if a short-circuit occurs, the maximum current through the device is 34.8 A. This is lower than the maximum allowable current of 40 A. This example makes it clear that the device will not trip spontaneously and will survive the short circuit condition in this application.

Then there is the question whether the device will trip fast enough to protect the load. The relevant datasheet of the makers gives a typical response time at a specified current value at 20 °C: 0.4 s at a current of 2 A, that is an I^2t of 1.6. Therefore, energy equivalent to 52.8 joules ($(I^2t \times R_L)$ may be deposited into the load before the MultiFuse trips. If data on the load indicates that the load can withstand more energy than that amount before it fails, this particular MultiFuse device may be the right one for the application.

To confirm your choice, measure the I^2t failure curve for R_L and compare it with the I^2t trip curve for the MultiFuse device. If the curve for the MultiFuse device is below that for the load, the load will be protected. ■

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