Fundamentals of Resettable Functionality in PPTC Devices

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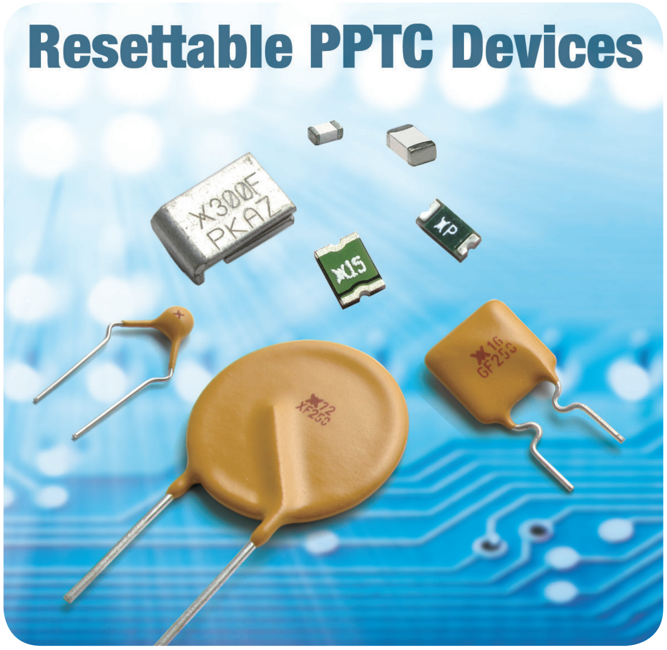

Protecting an electronic circuit from damage due to excessive current or heat is the primary function of many circuit protection technologies. In the past, this protection took the form of a fuse or fusible link, but in many of today's applications resettable devices such as Polymeric Positive Temperature Coefficient (PPTC) devices, ceramic PTC devices, bimetal breakers, and thermostats are the preferred solution. These devices do not require replacement after a fault event, and allow the circuit to return to the normal operating condition after the power has been removed and/or the overcurrent condition is eliminated. This resettable functionality can help manufacturers reduce warranty, service, and repair costs; however, proper application requires an understanding of how the device resets and the circuit conditions that must be met before reset will occur.

Although "resettable fuse" is a term sometimes used in describing PPTC devices, they are in fact, not fuses, but non-linear thermistors that limit current. Because all PPTC devices go into a high-resistance state under a fault condition, normal operation can still result in hazardous voltage being present in parts of the circuit. It is important that the circuit designer recognize critical differences between a fuse and the PPTC device.

Fuses are current interruption devices, and once a fuse "activates", the electrical circuit is broken, and there is no longer current present in the circuit. This electrical interruption (or open circuit) is a permanent condition. However, once a PPTC device trips into a high resistance state, a small amount of current continues to flow through the device. PPTC devices require a low joule heating leakage current or external heat source in order to maintain their tripped condition. Once the fault condition is removed and the power is cycled, this heat source is eliminated. The device can then return to a low-resistance status and the circuit is restored to a normal operating condition.

To Fuse or Not to Fuse

Despite the inherent and obvious advantages of resettable devices, there are circumstances where a fuse may be the preferred form of circuit protection. Under conditions where restoration of normal operation poses a potential safety hazard and/or where service on the equipment should be performed after a fault condition has occurred, a fuse or circuit breaker is appropriate. For example, a fuse is recommended on a garbage disposal because the blades could cause serious harm if the motor were to suddenly resume operation. On the other hand, the resettable PPTC device is a logical solution to protecting loudspeaker coils that might be damaged by excessive power during sustained high-volumes.

A failure to understand the precise nature of the device's resettable functionality may lead to improper use of a PPTC device in a circuit. Further confusion may result if the designer is comparing a PPTC device to other resettable devices, such as ceramic PTC devices, bimetal thermostats, and push-button breakers. The following table (Figure 1) describes the reset behaviors of these overcurrent protection devices. When selecting an overcurrent protection device, designers must also consider reset conditions, restoration time, and ambient conditions that can affect the performance of the device.

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Device Type	Can provide OT/OC(1) in same device?	Resettable functionality?	Reset type	Tripped state leakage current?	Will cycle?	Latches once tripped?
Current fuse	NO	NO	Replace	NO	NO	YES
Thermal fuse	SOMETIMES(2)	NO	Replace	NO	NO	YES
Bimetal	YES	YES	Self reset(3)	NO	YES	NO
Push-button breaker	NO	YES	Manual reset	NO	NO	YES
CPTC device	YES	YES	Self reset(4)	YES	NO	YES
PPTC device	YES	YES	Self reset(4)	YES	NO	YES

(1) Overtemperature and overcurrent protection.
(2) Thermal fuses are not designed for overcurrent protection, and generally require large currents to trip.
(3) Periodically attempts to reset until fault and/or power is removed, or resets to low resistance state when bimetal cools.
(4) Automatically resets to low-resistance state once the fault is cleared and power is removed.

Figure 1. Comparison of reset functionality and circuit conditions in fuses and resettable circuit protection devices.

PPTC Principle of Operation

PPTC circuit protection devices are made from a composite of semi-crystalline polymer and conductive particles. At normal temperature, the conductive particles form low-resistance networks in the polymer (Figure 2). However, if the temperature rises above the device's switching temperature (T_{SW}), either from high current through the device or from an increase in ambient temperature, the crystallites in the polymer melt and become amorphous. The increase in volume during melting of the crystalline phase causes separation of the conductive particles and results in a large non-linear increase in the resistance of the device.

The resistance typically increases by three or more orders of magnitude, as shown in Figure 3, i.e. the device "trips". This increased resistance protects the equipment in the circuit by reducing the amount of current that can flow under the fault condition to a low, steady-state level. The device will remain in its latched (high-resistance) position until the fault is cleared and power to the circuit is removed – at which time the conductive composite cools and re-crystallizes, restoring the PPTC to a low-resistance state and the circuit and the affected equipment to normal operating conditions.

Ultimately, designers must decide what level of protection is required for their applications, and only a system test can determine whether or not a specific protection device is appropriate. Recommendations from device manufacturers are useful in narrowing the options and benchmarking other protection schemes may be helpful, but actual system testing remains the decisive indicator as to whether or not the right protection solution has been selected.

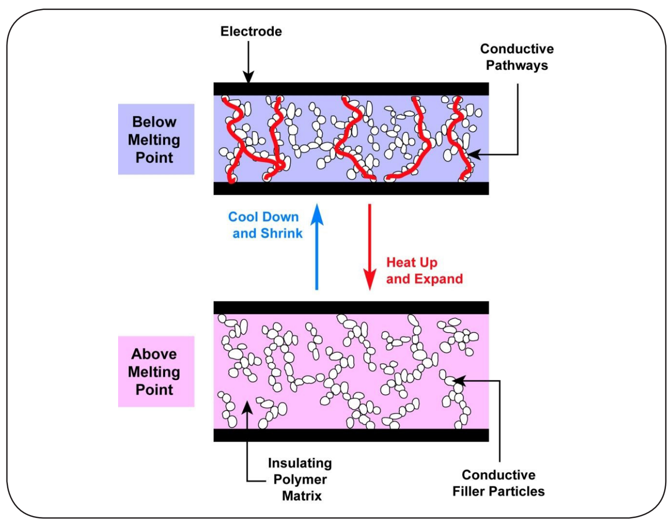

Figure 2. PPTC devices protect the circuit by going from a low-resistance state to a high-resistance state in response to an overcurrent or overtemperature condition.

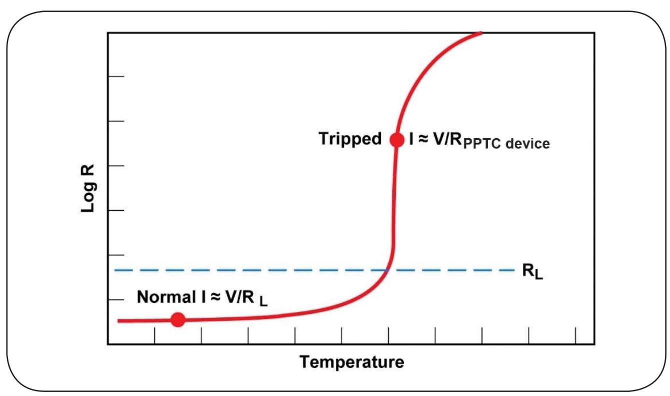

Figure 3. Typical operating curve for a PPTC device.

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Design Considerations for PPTC Devices

Some of the critical parameters to consider when designing PPTC devices into a circuit include device hold- and trip-current, the effect of ambient conditions on device performance, device reset time, leakage current in the tripped state, and automatic or manual reset conditions.

Hold- and Trip-Current:

Figure 4 illustrates the hold- and trip-current behavior of PPTC devices as a function of temperature. Region A describes the combinations of current and temperature at which the PPTC device will trip and protect the circuit. Region B describes the combinations of current and temperature in which the device will allow for normal operation of the circuit. In region C, it is possible for the device to either trip or remain in the low-resistance state, depending on the individual device resistance and its environment.

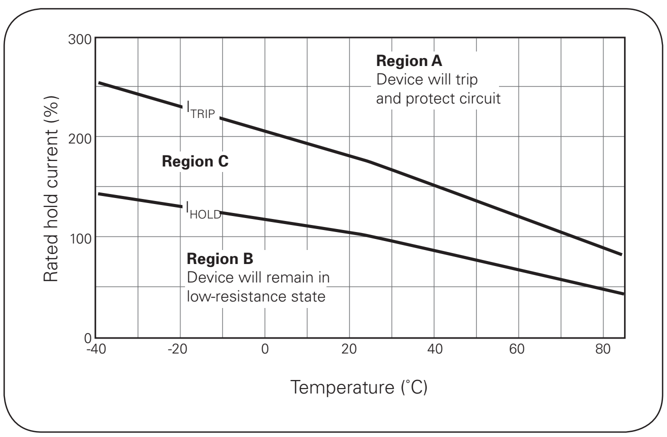

Figure 4. Example of hold- and trip-current as a function of temperature.

Since PPTC devices can be thermally activated, any change in the temperature around the device will impact the performance of the device. As the temperature around the device increases, less energy is required to trip the device and, therefore, hold-current (I_{HOLD}) decreases. Ceramic PTC as well as PPTC device manufacturers provide thermal derating curves and I_{HOLD} versus temperature tables to help the designer select the appropriate device.

Effect of Ambient Conditions on Device Performance:

The heat transfer environment of the device can significantly impact device performance. In general, by increasing the heat transfer of the device there will be a corresponding increase in power dissipation, time-to-trip, and hold-current. The opposite will occur if the heat transfer from the device is decreased. Furthermore, changing the thermal mass around the device will change the time-to-trip of the device.

The time-to-trip of a PPTC device is defined as the time needed, from the onset of a fault current, to trip the device. Trip time depends upon the size of the fault current and the ambient temperature. A trip event is caused when the rate of heat lost to the environment is less than the rate of heat generated. If the heat generated is greater than the heat lost, the device will increase in temperature. The rate of temperature rise and the total energy required to make the device trip depend on the fault current and heat transfer environment. Under normal operating conditions, the heat generated by the device and the heat lost by the device to the environment are in balance.

$$I^2R = U(T-T_A)$$

Where:

- I = current flowing through the device
- R = resistance of the device
- U = overall heat-transfer coefficient
- T = temperature of the device
- T_A = ambient temperature

Increases in either current, ambient temperature, or both will cause the device to reach a temperature where the resistance rapidly increases. This large change in resistance causes a corresponding decrease in the current flowing in the circuit, protecting the circuit from damage.

The hold-current is the highest steady-state current that a device will hold for an indefinite period of time without transitioning from the low-resistance to a high-resistance state. Hold-current can be fairly accurately defined by the heat transfer environment and can be impacted by a multitude of design choices, such as:

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- Placing the device in proximity to a heat-generating source such as a power FET, resistor, or transformer, resulting in reduced hold-current, power dissipation and time-to-trip.
- Increasing the size of the traces or leads that are in electrical contact with the device, resulting in increased heat transfer and larger hold-current, slower time-to-trip, and higher power dissipation.
- Attaching the device to a long pair of wires before connecting to the circuit board, increasing the lead length of the device and resulting in a reduction of the heat transfer and lowering of the device's hold-current, power dissipation, and time-to-trip.

Device Reset Time:

Figure 5 illustrates how, after a trip event, the resistance recovery to a stable value can be very rapid, with most of the recovery occurring within the first several seconds. As with other electrical properties, the resistance recovery time will depend on both the design of the device and the thermal environment. Since resistance recovery is related to the cooling of the device, the greater the heat transfer, the more rapid the recovery.

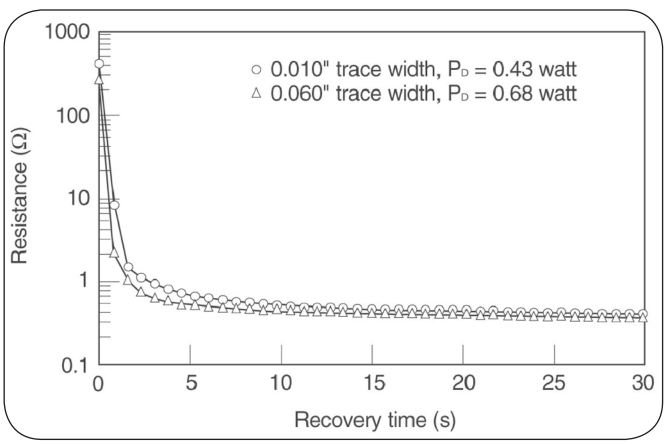

Figure 5. Typical resistance vs. time for varying trace widths for a surface-mount device.

Leakage Current in the Tripped State:

When the PPTC device is latched in its high-resistance state, the amount of current allowed to pass through the device is a fraction of the fault current. The current can be calculated by using the following equation:

$$I = P_D/V_{PS}$$

Where:

I = leakage current of the device in the tripped state

P_D = power dissipated by the PPTC device

V_{PS} = voltage across the PPTC device

Automatic Reset Conditions:

In most applications, power must be removed and the fault condition cleared in order to reset the PPTC device and restore the circuit to normal operation. However, under certain conditions, a PPTC device may automatically reset. Generally, automatic reset can be designed into applications if the voltage can be varied during operation.

An example of this is the loudspeaker overdrive-protection solution mentioned earlier. High-powered amplifiers used with low-powered speakers may overdrive loudspeaker coils with excessive power during sustained high volumes.

Fuses can be used to protect the speaker, but a "blown" fuse will be a source of frustration for the user and may result in warranty repair. Circuit breakers are an alternative solution, but they can arc as they open and create disturbing noises.

PPTC devices are often used in this application because they provide "soft switching" into a high-resistance tripped state and automatically reset to a low-resistance state when the source voltage is reduced. A typical circuit protection method is to place a PPTC device in series with the speaker. The PPTC device must be sized so that its time-to-trip at any particular current is less than the time required to damage the speaker at that current (Figure 6). As the source voltage is increased, current through the PPTC device increases, eventually causing it to trip and limit the power the speaker experiences. As the source voltage is decreased to normal levels, the voltage drop across the PPTC decreases. If the voltage drops to a sufficiently low level, the PPTC device will return to a low-resistance state and will automatically reset.

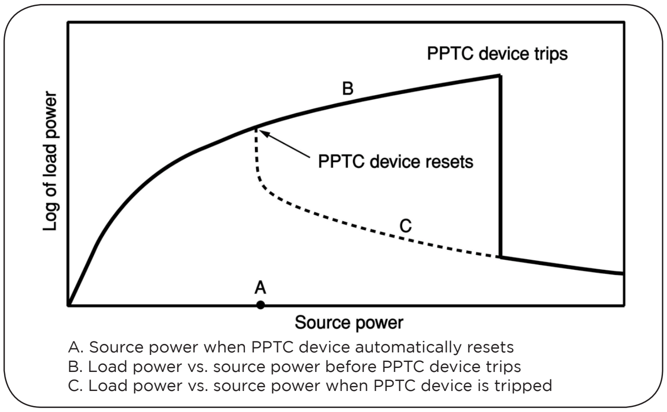

Figure 6. PPTC device effect on load power.

When the following condition is met the device will automatically reset:

$$\frac{V^2}{4R_L} < P_D$$

Where:

V = operating voltage of the circuit

R_L = load resistance

P_D = power dissipated by the PPTC device

Manual Reset Conditions:

In many applications it is preferred that the PPTC device be reset via user-intervention and some indicating method may be used to prompt this action. In a cellular phone charging application, for instance, an LED may indicate if the proper connection has or has not been made, prompting the user to replace the handset in the charging cradle. In a computer or multimedia application, an improper connection may freeze the computer, forcing the user to reboot the machine. In a battery-operated toy, simply cycling the on/off switch may be the only requirement for resetting the PPTC device. In each of these cases, the faults are temporary in nature and the reset function is transparent to the user.

In certain applications, failure to provide an indication of a fault condition to the user may result in eventual equipment damage. An example of this is an overcurrent protection scheme on the secondary side of an Uninterruptible Power Supply (UPS) used to provide back-up power to computers and other mission-critical equipment. In the case of an overcurrent fault, the PPTC device trips to protect the charger, but because the battery is still supplying power, the equipment continues to operate normally and the user may not realize that the charger has experienced a fault.

Until power is removed from the UPS, the PPTC device will remain latched, so that only a small amount of current trickles from the charger to the battery. Due to the fact that it is not receiving sufficient replenishing current, the battery will run down and may eventually lose its capacity from repeated deep discharging. This situation can be avoided by including a fault indicator that prompts the user to investigate the fault, remove power to the UPS by unplugging it, and restore the charging circuit.

Summary

PPTC circuit protection devices are used to protect against damage from harmful overcurrent surges, and overtemperature faults. Like traditional fuses, PPTC devices limit the flow of dangerously high current during fault conditions. The PPTC device, however, automatically resets after the fault is cleared and the power is cycled. Understanding the precise nature of these devices can help designers develop more reliable equipment and reduce warranty, service, and repair costs.

Selecting a PPTC Device

1. Choose the appropriate form factor

Select from radial-leaded, surface-mount, axial-leaded or chip parts. For mounting on circuit boards, radial-leaded or surface-mount is preferred. Radial-leaded parts are typically wave-soldered to the board. Surface-mount parts are typically reflow-soldered to the board. Chip parts are held in clips, usually in an electric motor, and are often custom designed for specific applications.

2. Choose a voltage rating

A PPTC device should be chosen with a voltage rating that equals or exceeds the source voltage in a particular circuit. Also, the expected fault voltage should not be greater than the PPTC device's voltage rating. When a PPTC device trips, the majority of the circuit voltage will appear across the device since it will be the highest resistance element in the circuit.

3. Choose a hold current rating (at the proper ambient operating temperature)

Hold current is defined as the steady-state current measured at room temperature that the PPTC device can carry without tripping into a high-resistance state. Because it is a thermal device, the hold current for a PPTC device decreases with increasing temperature. The actual value of the hold current for a given device and temperature may be obtained from the PPTC device manufacturer. The designer should review the device's thermal derating and select a device that can hold the expected current at its maximum expected operating temperature in the intended application.

4. Check trip time

PPTC device manufacturers can provide typical time-to-trip curves illustrating how quickly the PPTC device trips at various currents. The designer should determine what fault currents may occur, and how quickly the most sensitive system components may be damaged at these currents, and select a PPTC device that trips before these components are damaged. In many applications, there is a start-up surge current from a capacitance or motor. Normally this in-rush current does not contain enough energy to trip the PPTC device, but designers should confirm performance over the full range of expected ambient conditions.

5. Check maximum interrupt current

The PPTC device has a maximum interrupt current rating, i.e., the maximum fault current that the device consistently interrupts while remaining functional. The designer must ensure that the expected faults are below the device's maximum interrupt current rating.

6. Consider the PPTC device's tripped state power dissipation

This value will give an indication of the device's propensity for heating the surrounding area, as well as the magnitude of its leakage current ($I = P_D/V_{PS}$).