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The use of Zetex current monitors with PolySwitch™ overcurrent device

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Introduction

Zetex current monitors work by measuring the small voltage across a low value sense resistor. This signal is translated to either a voltage or current output and then used in many applications to measure, control or protect the system. The sense device is normally a precision low ohm resistor. It is possible to make use of the small finite value resistance of a PolySwitch™ device as the sense element.

PolySwitch devices are used where resettable over-current protection is required and can be used as a more practical solution than fuses. They are thermally operated devices with a finite trip time. The PolySwitch has a low ohmic resistance in its normal conduction condition that is ideal for use with a Zetex current monitor over a wide range of currents from hundreds of mA to tens of amps.

This application note discusses the applications, considerations and limitations of using a PolySwitch device in conjunction with Zetex current monitor IC's to monitor current and give a pre-warning of an over-current trip event.

Applications

The advantages of a PolySwitch device include the ability to reset automatically. Once a fault condition is removed and the device temperature drops (the I^2R loss related to fault current is no longer present), the device will return to a low resistance value to allow normal operation. Nuisance trips can also be avoided as the operation of the PolySwitch device is based around the temperature of the device. If a short duration event occurs, eg the inrush current for an inductive load, the PolySwitch device will not trip.

Applications where overcurrent protection is a critical feature include battery packs, motor control and lighting applications. (see Figure 1).

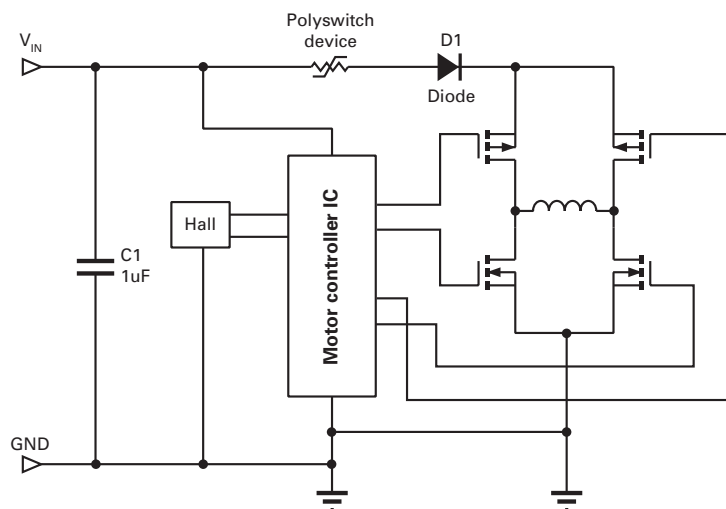


Figure 1 Typical application circuit utilizing a PolySwitch device

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Current measurement utilizing a PolySwitch device

Figure 2 illustrates a typical PolySwitch device inserted between the V_{SENSE+} and V_{SENSE-} terminals of a ZXCT1021 current monitor. The PolySwitch device provides a path for the current to flow into and protect if excessive current is drawn from the load.

The resistance of the PolySwitch is 'flat' in its hold current (I_H) range. I_H is the maximum current the device will pass without interruption at 20°C in still air conditions.

As the device reaches its trip current (I_T) the device will change from a low resistance state to a high resistance state.

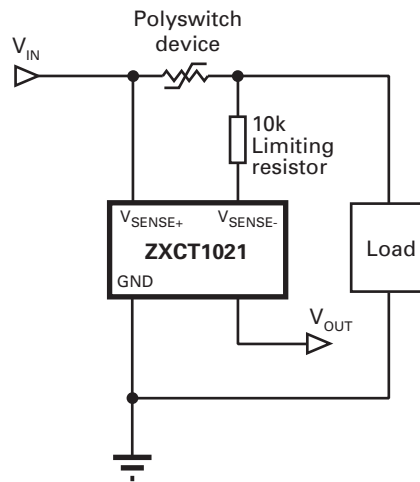


Figure 2 The use of a PolySwitch device with a current monitor device

The increase in resistance of the PolySwitch device can be orders of magnitude, dependent upon the device selected and the supply voltage. Figure 3 shows a typical change in resistance for a given load current.

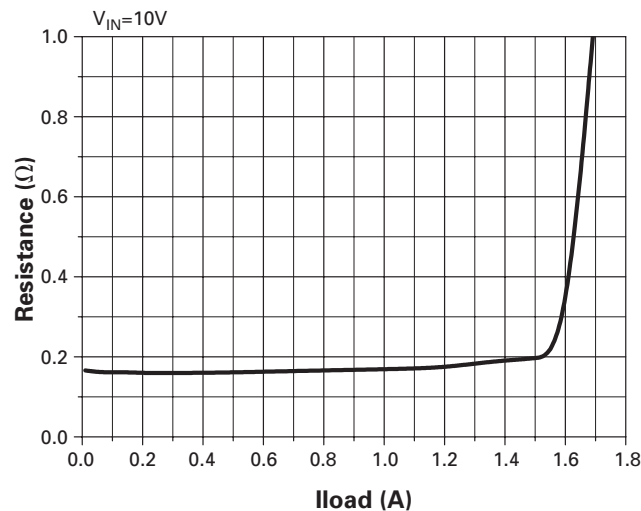


Figure 3 Typical resistance change of RUE120 with a change in load current

The resistance of the PolySwitch device is relatively constant up to the device's maximum hold current I_H . Prior to I_H being reached, the voltage developed across the device rises 'linearly' as load current increases, providing the device ambient temperature is constant.

The PolySwitch device will remain in a high impedance state until either the power is removed or the load current (I_{LOAD}) is reduced such that $I_{LOAD} \times V_{IN} < P_D$, where P_D is the power dissipated by the selected PolySwitch device in its tripped state (as defined in the Raychem PolySwitch data for each device).

Current measurement accuracy using a PolySwitch is not assured. The PolySwitch device impedance tolerance is much wider and will swamp the current monitors accuracy tolerance. Use with a comparator as a pre-warning of an impending trip event is more appropriate.

For more detailed information on the operation of PolySwitch device please refer to Glossary.

Limiting resistor

Consider the circuit in Figure 1. If the PolySwitch device trips and changes to a high impedance state, the supply voltage will develop across the PolySwitch device. If the maximum V_{SENSE} voltage is to be exceeded, a 10k resistor should be placed in series with the V_{SENSE-} input. This is because when the PolySwitch trips the differential voltage across the V_{SENSE} pins of current monitor could exceed the device ratings and damage the ZXCT device.

Early warning overload/overcurrent

In applications where overcurrent or fault conditions occur, it is possible, utilizing a PolySwitch device and a current monitor, to provide a pre-warning signal that a trip is about to occur.

Figure 4 shows how a PolySwitch device can be used in conjunction with a ZXCT1030 to provide an early warning flag that either an overload current or current surge is occurring.

The PolySwitch device is placed in series with the supply rail and load. It is selected to remain in a low impedance state for a required amount of current flow for the load. The hold current (I_H) is the critical parameter to ensure this.

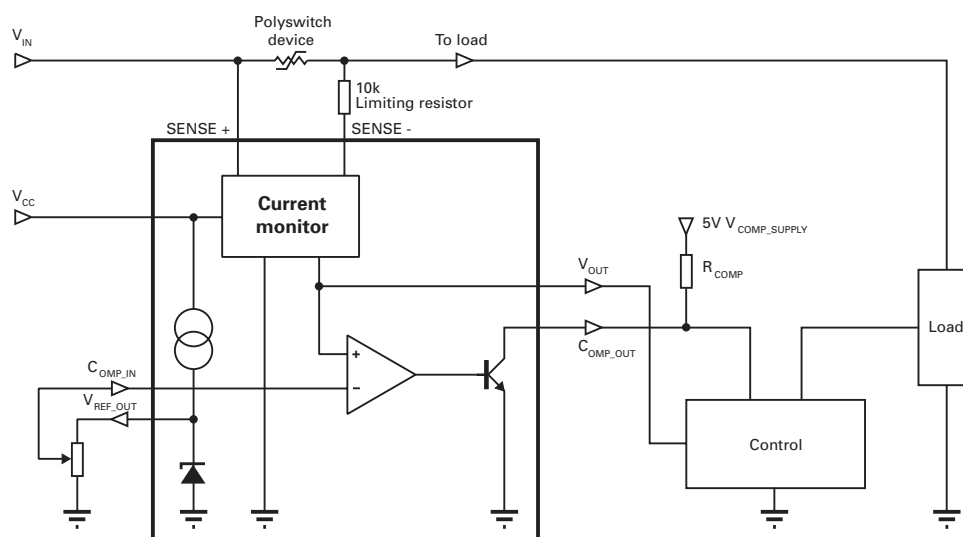


Figure 4 Typical application circuit for early warning flag

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Once a fault condition occurs, the current flow through the device activates a change in impedance. This increase in the temperature initiates the resistance change. The rapid change of resistance can be seen in Figure 3. The rate of change of resistance is determined by the magnitude of the current.

The maximum operating (non-trip state) resistance value (measured 1 hour after a trip event for through-hole devices or 1 hour after re-flow for surface-mount devices, unless otherwise stated on the device datasheet) of a PolySwitch device is R_{1MAX} . This means that at 20°C the value will never be higher than the stated value unless the device has tripped or load current is beyond maximum hold current I_H .

Using R_{1MAX} and the maximum hold current I_H of a PolySwitch, a maximum V_{SENSE} trip level (start of trip process) can be calculated (for ambient at 20°C).

Note:

Hold current (I_H) gives the maximum current level where the device will hold in a normal operating state at ambient 20°C.

Definite trip current (I_T) gives current level above which a device will definitely trip at ambient 20°C.

In between I_H and I_T the device is in transition period with increased impedance and device may reach tripped state.

For indication of start of an overcurrent condition (I_H) and R_{1MAX} can be used to calculate V_{SENSE} (trip start):

$$V_{SENSE} \text{ (trip start)} = R_{1MAX} \times I_H$$

For the overcurrent tripped condition (I_T) and R_{1MAX} can be used to approximate V_{SENSE} (trip):

$$V_{SENSE} \text{ (trip)} = R_{1MAX} \times I_T$$

Choice of V_{SENSE} depends upon the application.

As the PolySwitch device impedance increases with the temperature, the temperature effect needs to be taken into account to obtain the R_{1MAX} for the maximum normal operating ambient temperature in the above equations. Also, the impedance tolerance of the PolySwitch device needs to be considered.

Please refer to the glossary section 'Resistance of PolySwitch devices' and 'Tyco Electronics Raychem Circuit Protection' web sites for PolySwitch device impedance changes and tolerances. The PolySwitch datasheets and handbook give the R_{MIN} , R_{MAX} and R_{1MAX} and thermal derating curves for hold and trip currents for the purpose. (R_{MIN} is the minimum resistance of the device as supplied at 20°C, unless otherwise specified. R_{MAX} is the maximum resistance of the device as supplied at 20°C, unless otherwise specified):

The output voltage V_{OUT} of the ZXCT1030 will be $V_{SENSE}(\text{trip}) \times 10$.

The ZXCT1030 current monitor IC has an on-board comparator and voltage reference. A reference level can be set on the non-inverting input of the comparator to set a trigger level to switch the comparator output. V_{OUT} is connected to the inverting input of the comparator. Once V_{OUT} exceeds the desired threshold set via `comp_in`, the comparator output is pulled low. The comparator output stage is an open collector output. This can be connected to the supply rail via a pull-up resistor, typically 10kΩ.

The output signal from the comparator can be the input to a microcontroller to inform the system excessive current is flowing into the load. This allows the system to make an intelligent decision on a required action, eg save data into non-volatile memory.

The choice of PolySwitch device depends on the application and the maximum current the device is required to pass without interruption at ambient temperature conditions. This suggests at higher ambient temperatures, hold current (I_H) stated at 20°C needs to be temperature de-rated. The derating information is provided in the Raychem PolySwitch databook. As an example, a single USB current can be up to 500mA for 0°C to 70°C (for commercial temperature range). Based on this, the hold current for a single-port USB has to be 500mA at 70°C. From Raychem PolySwitch data, one of the choices of PolySwitch can be nanoSMDC075.

Conclusion

The use of PolySwitch overcurrent devices alongside current monitor ICs allows current to be measured giving an indication of the level of current flow into a load. The limitations of this are based around the thermal activation process of the PolySwitch device and the impedance tolerance.

Combining a ZXCT1030 and a PolySwitch together provides a circuit solution, which gives early warning to a system that an overload condition is occurring or has already occurred. This allows a system to react before the current is restricted into the load. A system that shuts down with no early warning can result in loss or corrupted data. A typical application area for this is USB port protection, where a device such as the nanoSMDC075F or nanoSMDC150F will provide single or dual-port protection whilst the Zetex ZXCT1030 will provide an error flag to denote that an overcurrent event has occurred.

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Glossary

PolySwitch overcurrent device

PolySwitch PPTC (Polymeric Positive temperature Coefficient) devices are protection devices for circuits, often called resettable fuses. They are placed in circuit as a series element; allowing current to flow into a circuit under normal operation and protect a circuit if an over-temperature or over current condition occurs.

When an overcurrent condition occurs in circuit, the PolySwitch device changes from a low resistance state to a high resistance state, restricting the amount of a current flow into a load. A PolySwitch device is a non-linear thermistor. The device's resistance increases either due to its internal I^2R heating effect or an increase in the ambient temperature, providing a mechanism for circuits to be protected from overload currents, overtemperature events and short circuits.

Once the current increases above I_H towards definite trip current I_T , the resistance is non linear. For a given device (with fixed heat transfer coefficient, operating temperature and a constant ambient temperature) the device operates in a constant power state and its resistance is proportional to the square of the voltage across the device. Therefore the sense voltage will be of a non-linear value. Beyond I_T the device is in a fully tripped state and remains in 'relatively constant' high impedance. The output of the current monitor will give a voltage gain of ten times the sense voltage, but this will no longer be directly proportional to the load current:

$$V_{OUT} = V_{SENSE} \times 10$$

Resistance of PolySwitch devices

The activation process of a PolySwitch device is temperature. Figure 5 shows the operating curve for a PTC device. This gives inherent limitations if the device is to be utilized as a current measurement device. As current passes through the device it will begin to heat due to the I^2R losses.

The energy balance of polymeric PTC PolySwitch device is described by the equation below (ref: Tyco Electronics Raychem Circuit Protection web pages):

$$mC_p(\Delta T/\Delta t) = I^2R - U (T - T_0)$$

Where:	m	=	Mass of the PolySwitch device
	C _p	=	Heat capacity of the PolySwitch device
	Δt	=	Change in time
	ΔT	=	Change in the PolySwitch device temperature
	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

The I^2R generated heat is lost to the environment at the rate $U (T - T_0)$. Any heat not dissipated to the environment raises the PolySwitch device temperature. If heat generated and heat lost to environment by the PolySwitch device is in balance the above equation simplifies to:

$$I^2R = U (T - T_0)$$

This describes the energy balance during normal operations points A to C in Figure 5. Between points A and C the resistance of the device can change by either current change, environment temperature change, or both. Within these points the resistance of the device is able to stabilize if there is no further increase in current or temperature.

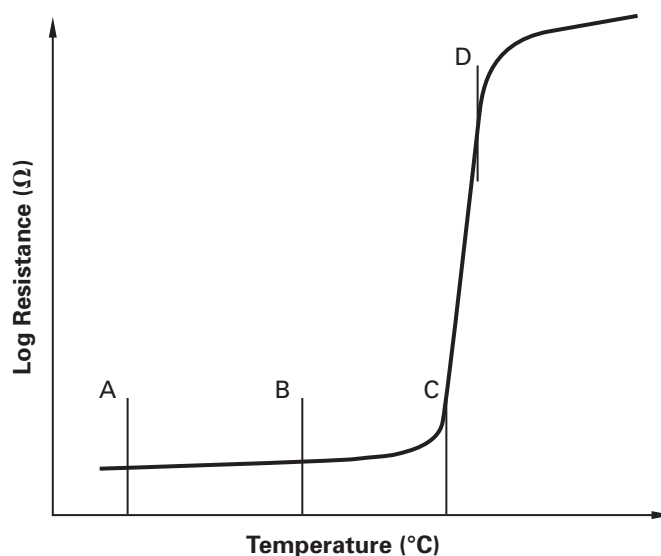


Figure 5 Temperature versus log resistance of PolySwitch device

At point C, a further increase in current temperature, ambient temperature, or both will cause the device to reach a temperature whereby its resistance rapidly increases. For increased current beyond I_H , the rate of I^2R heat generated is greater than the rate of heat loss from PolySwitch device heating it up rapidly. (Points C to D in Figure 5), thus resulting in a large increase in PolySwitch device impedance. Temperature change between point 3 and 4 is small and can therefore assume $(T-T_0)$ to be constant resulting in PolySwitch device constant power state:

$$I^2R = V^2/R = U (T-T_0)$$

Where U and $(T-T_0)$ are considered constant for operation between points C and D.

It is for this reason the thermal derating curve will need to be considered alongside the hold current and the trip current.

The change in impedance of the PolySwitch device for change in ambient temperature while allowing constant current can be obtained using the above equations along with thermal derating curves for I_H and I_T , PolySwitch device impedance at 20°C.

Reference:

Circuit Protection Databook: **Tyco Electronics Raychem Circuit Protection, 2004**

Tyco Electronic Circuit protection web site: www.circuitprotection.com

Note:

The content of this application note was first produced in Power Electronics Magazine, April 2006

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