How to protect control systems from thermal damage

Introduction

In many control systems, the operating temperature is one of many key factors that can affect the system's performance, reliability, and safety. Understanding the temperature effects on control systems can help system designers anticipate and prevent thermal damage.

Typically, control systems are specified to operate within a limited operating temperature range and its behavior is well understood. In contrast, whenever the system operates beyond its specified temperature range, the behavior is less predictable. When operating at high temperatures, the control system typically experiences a decrease in efficiency, an increase in heat dissipation, and accelerated aging. On the other hand, low temperatures can also have a negative impact on the system's safety and function as the operating condition reaches critical points such as condensation. The combination of these effects may lead to costly failures.

Thermal Protection Solutions

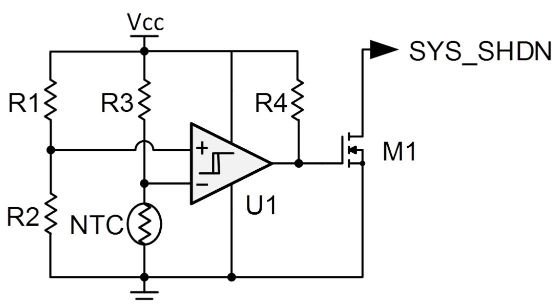

Figure 1. Example Discrete Implementation of a Temperature Switch

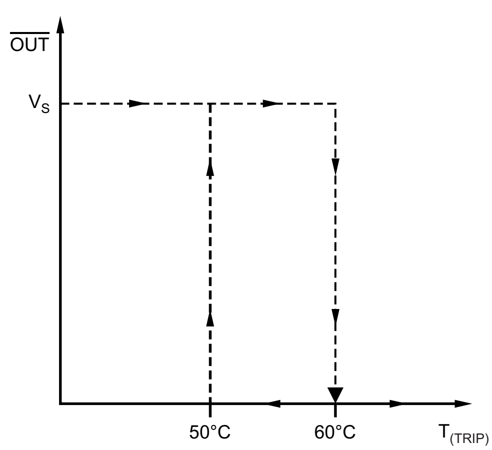

Figure 2. Example Temperature Switch Trip Behavior With Hysteresis

There are a number of preventive solutions available to protect control systems from thermal damage. The solutions can either be discrete or integrated. Generally, these solutions consist of a temperature sensor, a comparator and a voltage reference (see Figure 1). This approach provides real-time thermal protection without interrupting the control processing system. The ideal temperature switch behavior is shown in Figure 2. In this example, the trip point is set to 60°C with a 10°C hysteresis. In some cases, both thermal protection and monitor functions are required and thus an ADC is also needed (see Figure 3). The specific implementation depends on specific application requirements:

- Features
- Cost
- Footprint
- Power
- Accuracy

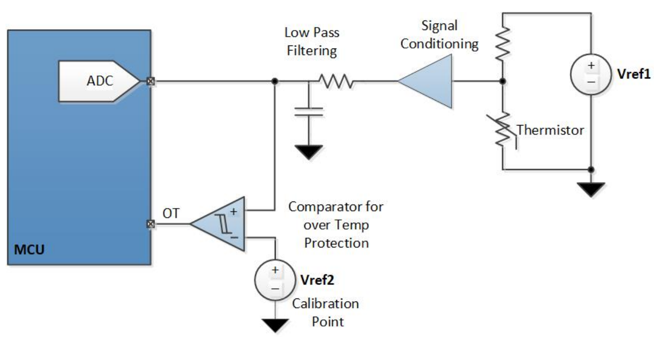

Figure 3. Example Discrete Implementation of a Temperature Monitor and Switch

Some of the key features that customers typically look for are hysteresis, trip point programmability, trip test, qualifications (like automotive and UL, for example), output type, channel count, and supply voltage range.

Discrete Solutions

It is quite common to see a discrete implementation of a temperature switch using an NTC thermistor because the utility of these devices are well established. In addition, thermistor solutions are often considered low-cost. However, due to the demanding requirements of thermal protection like guaranteed performance, discrete solutions often prove to be challenging and costly. Some of the key challenges when designing a discrete thermal protection solution are accuracy, reliability, and efficiency.

Due to the non-linear nature of NTC thermistors, maintaining a high accuracy trip point at high or low temperatures is difficult without using precision components that can increase system cost. Note that calibration is not practical in these hardware-based switching applications. In addition, a discrete implementation requires multiple components working together, and thus can decrease system reliability. Lastly, NTC discrete solutions dissipate a significant amount of power when hot because the NTC resistance significantly decreases at high temperatures.

IC Solutions: Temperature Switch/thermostats

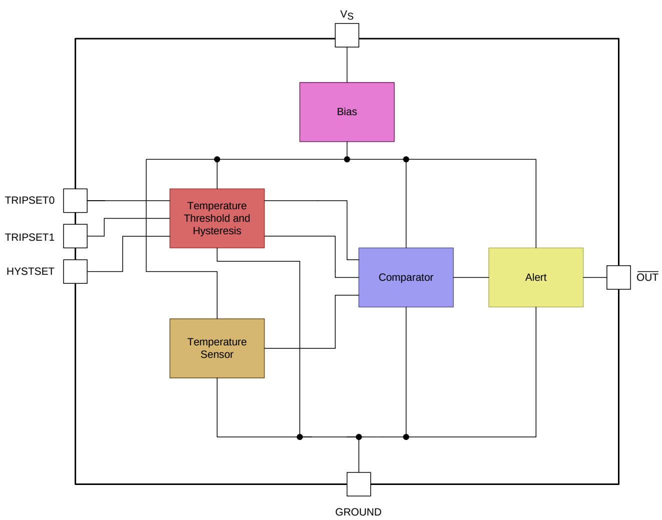

Figure 4. Example Block Diagram of a Pin-Programmable IC Temperature Switch

Another thermal protection solution that is popular with control systems is the integrated temperature switch/thermostat. Typically, these devices have a temperature sensor, comparator, and voltage reference fully integrated in a single chip. These temperature switches are smart sensors that autonomously make decisions to provide real-time thermal protection without interrupting the control processing system. The key advantages of these sensors are:

- Autonomously enable thermal protection independent of control unit
- Zero software
- Guaranteed temperature accuracy for trip point with hysteresis
- Simple & cost effective over / under temperature detection
- Various threshold programming options (resistor, pin programmable, factory preset)
- Some parts also offer analog output

The highly integrated sensor lowers the solution cost, which enables redundancy in safety applications.

TI provides a broad portfolio of temperature switch/thermostats such as the TMP302. The block diagram of the TMP302 device is shown in Figure 4. The TMP302 is available in a small SOT-563 package (1.6 mm × 1.2 mm). The device offers low power (15 μA maximum) and ease-of-use through pin-selectable trip points and hysteresis. The TMP302 is guaranteed to achieve a trip point accuracy of ±2°C from –40°C to 125°C without any calibration.

Design Tips

The majority of the temperature that the TMP302 measures is the temperature of the device leads. Careful PCB layout considerations are essential to accurately measure ambient or board temperature.

As with any physical board design, environmental factors can have a significant impact on the performance of the system. To avoid leakage and corrosion, the system must be kept insulated and dry. This is especially true if the system operates in cold temperatures where condensation can occur. Printed-circuit coatings are often used to ensure that moisture cannot corrode the sensor or its connections.

Table 1. Alternative Device Recommendations

Device	Optimized Parameters	Performance Trade-Off
TMP708	Resistor programmable	Reduced accuracy
TMP303	Window comparator	Limited factory programmed trip points available
TMP390	Resistor programmable with two outputs for over and under-temp	Additional components required
LM56	Two internal comparators with two over-temp outputs and one analog output	Increased power consumption
LM26	Over-temp and analog outputs, UL recognized	Reduced accuracy

Table 2. Related Documentation

Literature Number	Title
SNOA967	Temperature Sensors: PCB Guidelines for Surface Mount Devices
SNOA966	TMP116 Ambient Air Temperature Measurement

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