Application Note

Temperature Slew Rate Warning Overview

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Abstract

System designs continue to push the boundaries of performance in every aspect including high temperature operation. It is important not only to know the current temperature but also be able to predict the temperature based on sudden load or performance changes. The Temperature Slew Rate Warning gives system designers a new tool to prevent thermal stress and degradation by allowing for predictive temperature control.

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1 Introduction

Temperature control traditionally uses min or max temperature thresholds to take corrective action using the system's thermal cooling system or shut-down devices. This process does not address over temperature conditions that occur between temperature conversion samples, or allow systems to predict thermal issues before they occur. Additionally, as system designs become more compact and higher power, thermal limit excursions can occur quicker leading to system damage.

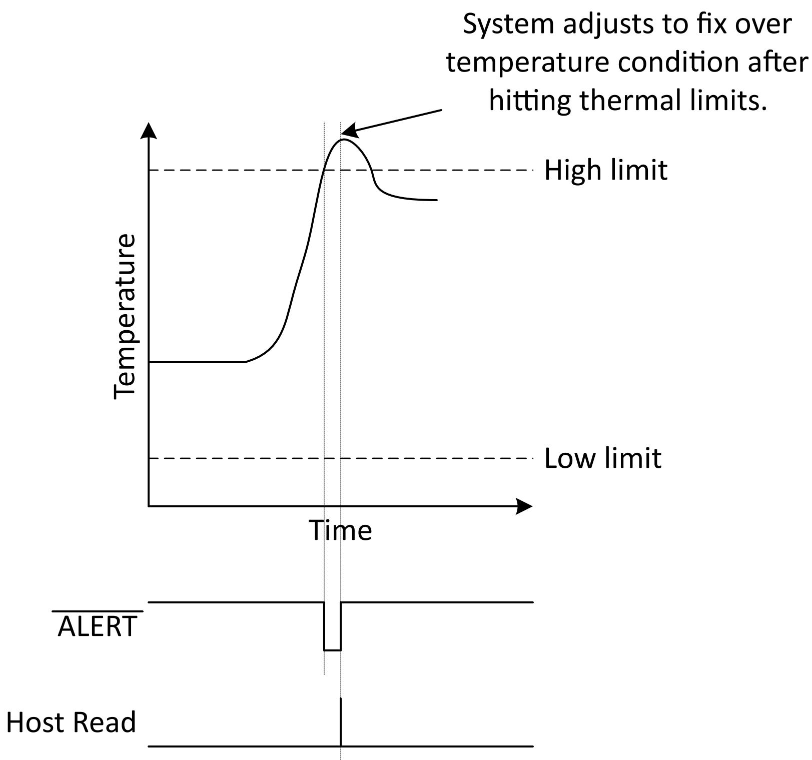

Figure 1-1. Traditional Threshold Alert

2 Concept

The Temperature Slew Rate Warning continuously monitors temperature change over time and calculates the slew rate to alert the system of a rapid temperature rise. This process enables systems to take corrective action before the operating temperature exceeds its intended range. Figure 2-1 shows a visual representation of the slew rate warning $\overline{\text{ALERT}}$ response to a rapid temperature rise.

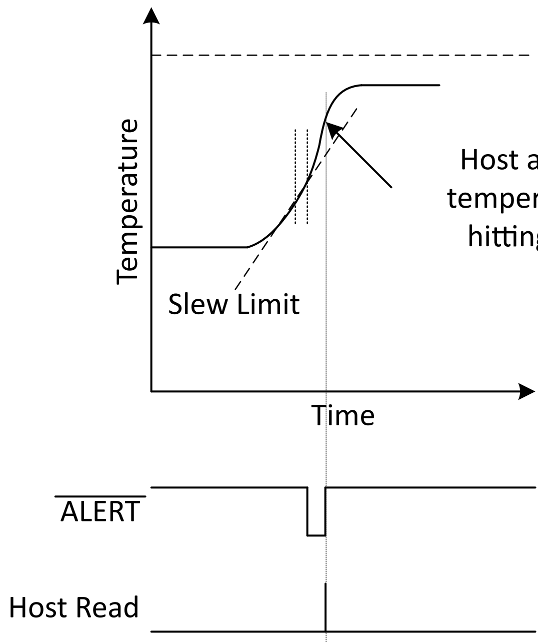

Figure 2-1. Slew Rate Warning

3 Design Considerations

The slew rate warning feature has two parameters which can impact how the feature performs. This section discusses how device operation can impact the feature functionality.

3.1 Conversion Period Impact

The slew rate warning will compare the most recent temperature conversion result with the previous temperature conversion result. Figure 3-1 shows how the slew rate feature responds to rapid temperature change with a 1 second conversion rate. When designing with the slew rate feature, it is important to consider that the temperature sensor measuring the slew rate can only respond as fast as the conversion period. In this example the sensor reports a peak slew rate of 7.5°C/s.

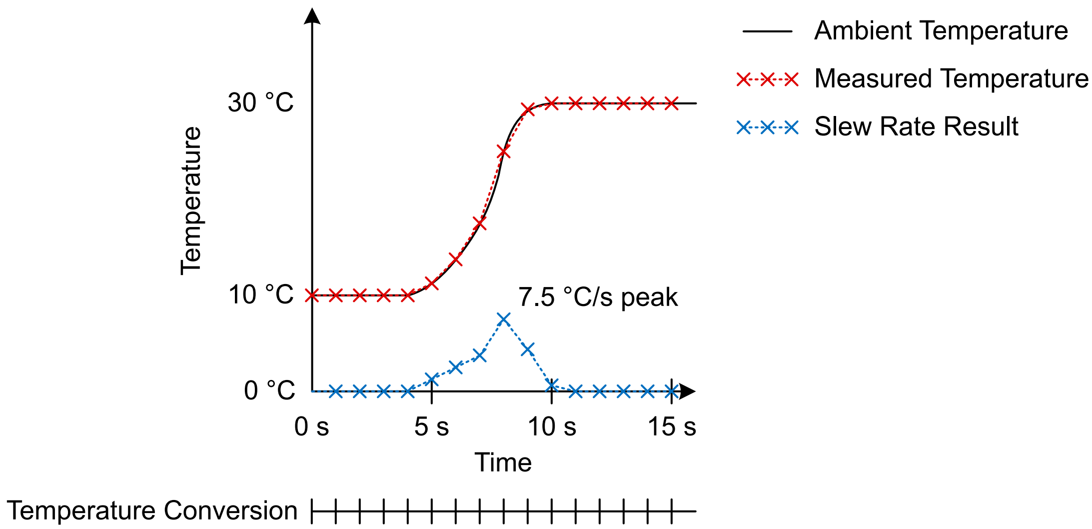

Figure 3-1. Slew_Rate with 1 Second Conversion Period

With the same ambient temperature profile and a faster conversion period, the slew rate warning can yield more accurate and granular results of the ambient temperature slew profile. Figure 3-2 depicts the resulting waveform if the conversion period is adjusted to 0.5 seconds instead of 1 second. With this setting the device reports a peak of 10°C/s with the same temperature profile.

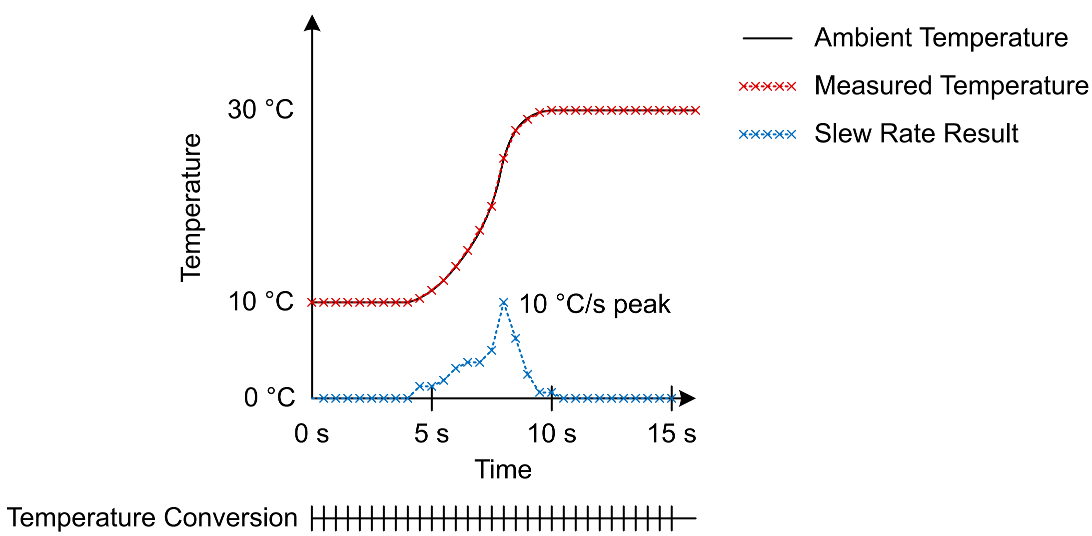

Figure 3-2. Slew_Rate with 0.5 Second Conversion Period

3.2 Impact of Conversion Period Error

The slew rate warning feature utilizes the known conversion period for the calculation of the slew rate based on the device setting. If there is an error of the conversion period (t_{CONV_PERIOD}) due to a non-ideal oscillator, the actual conversion period may be slightly longer or shorter, resulting in error of the slew rate calculation. Equation 1 shows the equation for calculating the slew rate with t_{CONV_PERIOD} as the time period over which the calculation takes place. If t_{CONV_PERIOD} is 90% of the expected value, the slew rate calculation will be 11% faster than the real value, calculated with Equation 2. This can be accounted for in a similar manner to temperature accuracy with proper guardbanding, as shown in the Design Example.

$$SlewRate = \frac{(T_{RECENT} - T_{RECENT-1})}{t_{CONV\_PERIOD}} \tag{1}$$

$$SlewRate_{Adjusted} = \frac{(T_{RECENT} - T_{RECENT-1})}{t_{CONV\_PERIOD} * (1 \pm timing\ error)} \tag{2}$$

4 Design Example

This section will give an example implementation of the slew rate warning feature.

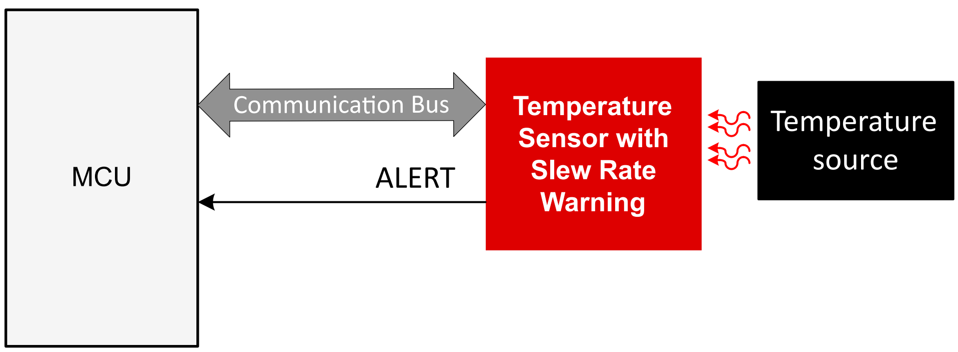

Figure 4-1. Design Example

4.1 Design Requirements

In this example a power FET driving a brushless DC motor cannot operate above 125 °C, and it is known that there is a potential issue with the FET if the temperature rises faster than 20 °C/s. This rapid change in temperature will lead to a runaway thermal condition unless the current is reduced.

The accuracy of the temperature sensor should remain within 1 °C throughout its temperature range. And the temperature sensor has a conversion period error of 15 %. A timing error of 15 % would indicate that for a given conversion period setting, the conversion period can be ±15 % of the setting.

4.2 Detailed Design Procedure

With a desired system limit of 20 °C/s and a conversion period timing error of 15 %, the Slew Rate Limit setting can be calculated as shown in the following equations. To ensure the warning triggers by 20 °C/s, the ±15 % timing error must be factored into the calculation. Using the below equations we get a Slew Rate Limit of 17.4 °C/s.

$$SlewRate = \frac{(T_{RECENT} - T_{RECENT-1})}{t_{CONV\_PERIOD}} = 20$$
$$SlewRate_{Adjusted} = \frac{(T_{RECENT} - T_{RECENT-1})}{t_{CONV\_PERIOD} * (1 + timing\ error)} = \frac{(T_{RECENT} - T_{RECENT-1})}{t_{CONV\_PERIOD} * (1 + 0.15)} = \frac{(T_{RECENT} - T_{RECENT-1})}{t_{CONV\_PERIOD}} * \frac{1}{(1 + 0.15)}$$
$$SlewRate_{Adjusted} = 20 * \frac{1}{(1 + 0.15)} = 17.4 \tag{3}$$

With a Slew Rate Limit setting of 17.4 °C/s , minimum and maximum slew rates that will trigger an alert can be determined by Equation 4. A setting of 17.4 °C/s will trigger an alert at a minimum slew rate of 14.79 °C/s, a typical slew rate of 17.4 °C/s, and a maximum slew rate of 20 °C/s. This ensures that the warning will always trigger before reaching the 20 °C/s design requirement.

$$SlewRate_{Min} = \frac{(T_{RECENT} - T_{RECENT-1})}{t_{CONV\_PERIOD} * (1 - timing\ error)} = 20 * \frac{1}{(1 - 0.15)} = 14.79\ °C/s$$
$$SlewRate_{Max} = \frac{(T_{RECENT} - T_{RECENT-1})}{t_{CONV\_PERIOD} * (1 - timing\ error)} = 20 * \frac{1}{(1 + 0.15)} = 20\ °C/s \tag{4}$$

The second outlined requirement is the system must react within 200 ms to the temperature spike occuring. The list of possible conversion period settings are shown in Table 4-1. From this table it is acceptable to choose between options 31.25 ms (1h), 62.5 m (2h), or 125 ms (3h). This would allow the device to detect and alert the system faster than 200 ms. Setting 0h cannot be chosen as the slew rate warning requires a time delay between temperature conversions.

Table 4-1. Example Conversion Period Settings

Setting	Conversion Period
0h (No delay between conversion)	5.5 ms
1h	31.25 ms / 32 Hz
2h	62.5 ms / 16 Hz
3h	125 ms / 8 Hs
4h	250 ms / 4 Hz
5h	500 ms / 2 Hz
6h	1 s / 1 Hz
7h	2 s / 0.5 Hz

The device settings for this design example are shown in Table 4-2.

Table 4-2. Device Settings

Setting	Conversion Period
Slew Rate Limit	17.4 °C/s
Conversion Period	125 ms

5 Summary

The Temperature Slew Rate Warning is an effective tool to detect runaway thermal conditions and alert system controllers to moderate thermal performance. By utlitizing the steps outlined previously the feature can be tailored to fit multiple use cases.

6 Temperature Slew Rate Warning Device List

Table 6-1 shows the TI temperature sensors with the Temperature Slew Rate Warning feature.

Table 6-1. Slew Rate Warning Devices

Part Number	Device Type	Interface	Alert pin included	Temperature Accuracy (Max)
TMP126	Local	SPI	Yes	0.3 °C
TMP126-Q1	Local	SPI	Yes	0.3 °C
TMP114	Local	I^2C	No	0.3 °C