AN10137

Temperature sensing using TrenchPLUS devices

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Document information

Info	Content
Keywords	Accurate temperature sensing, temperature control, sensor theoretical accuracy, forward voltage, temperature coefficient, trip temperature, trip temperature error
Abstract	As the automotive industry moves towards driving higher powered motors in Electronic Power-Assisted Steering (EPAS) and Integrated Starter Alternator (ISA) applications, the need for accurate sensing of temperature and current becomes paramount. This document considers some of the protection strategies available using NXP TrenchPLUS temperature sensing devices.

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Revision history

Rev	Date	Description
01	20090608	Updated to meet NXP Semiconductors house style and rewritten.

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1. Introduction

The market-leader in the field of temperature sensing devices is the BUK9107-40ATC. An N-channel power MOSFET with monolithically-integrated temperature sensing and clamping diodes that internally monitor the temperature of the MOSFET chip. Designed for high current applications, the device has a typical $R_{DS(ON)}$ of 5.8 mΩ at 25 °C with a gate drive of 5 V.

It is relatively simple to incorporate temperature sensing into your temperature protection strategy. Traditionally, a system can be protected against overtemperature using a comparator and a few passive components which directly measure the chip temperature. This application note demonstrates that a more accurate method of temperature control can be achieved using a suitable microcontroller.

2. Example of a temperature sensing device application

A typical temperature sensing circuit is shown in Figure 1 which shows the MOSFET controlled by a microcontroller. The output from the MOSFET temperature sensor is connected to the analog-to-digital input of the microcontroller. The resistor values of R_A and R_G define the current in the sense diode and hence its forward voltage (V_F) and gate switching time.

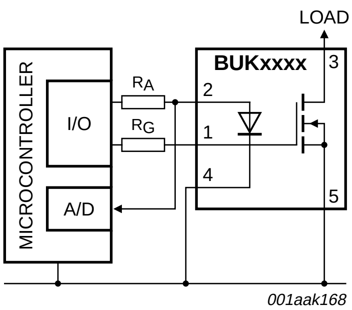


Fig 1. Typical temperature sensing circuit

During normal operation, the V_F of the diode is monitored and a reference level ($V_{F(ref)}$) is chosen, below which the device switches off. The value that is chosen for $V_{F(ref)}$ depends on the V_F temperature coefficient (S_F) and the temperature at which the MOSFET should be switched off.

The V_F characteristic is linear over the full temperature range, which enables numerous overtemperature protection strategies to be implemented; see Figure 2. By continually monitoring V_F, the microcontroller can provide an early warning of overtemperature conditions, and can also determine the rate-of-change of temperature.

Depending on the microcontroller used, there are various possible ways to respond to the information provided by the temperature sensor. The information could be used to trigger a latched shutdown, shutdown and cyclic retries, or simply used as a diagnostic tool for the application.

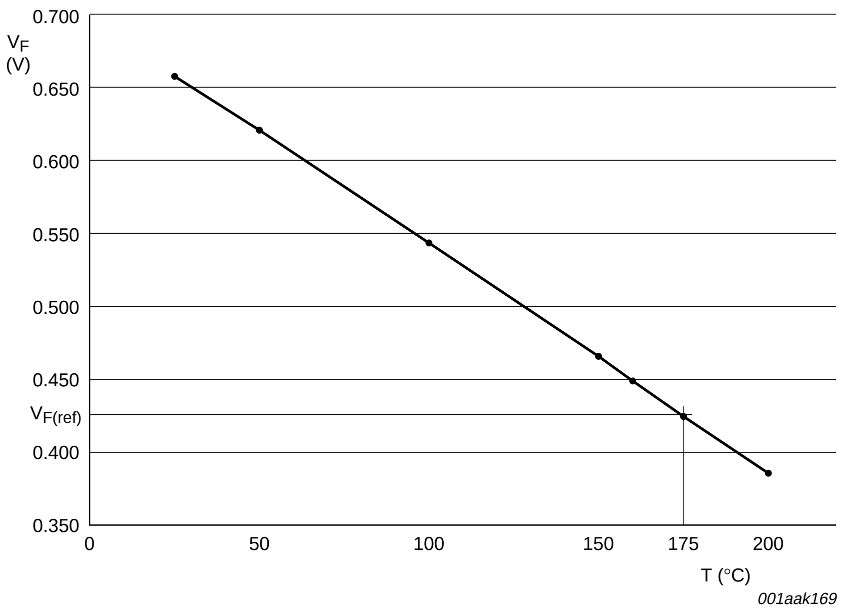


Fig 2. Temperature sense diode forward voltage as a function of temperature

2.1 Theoretical estimation of temperature sensor accuracy

The theoretical accuracy of the temperature sensor depends on three factors:

- Uncertainty of V_F
- Uncertainty of S_F
- Chosen value of $V_{F(ref)}$

The effect of the above factors is shown more clearly in Figure 3. Any inherent variability in V_F adds a fixed offset to the trip temperature (T_{trip}). Any variation in S_F is shown by a change in the gradient. A lower value of S_F causes the device to trip at a higher temperature $T_{trip(u)}$. Depending on the value of T_{trip} this may lead to devices operating above their maximum operating temperature which may reduce their life expectancy. Conversely, a higher value of S_F causes erroneous nuisance tripping below the desired set point. Both these factors have implications for the overtemperature protection strategy employed.

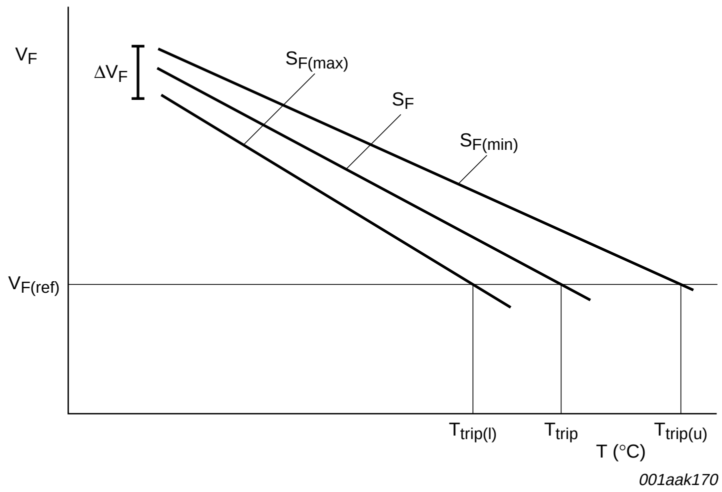


Fig 3. Variation of T_{trip} with changes in V_F and S_F

The total error in temperature sensor accuracy is the sum of all contributions from the uncertainty of both V_F and S_F.

The values for V_F and S_F of the temperature sensing diode given in the data sheet for the BUK9107-40ATC are shown in Table 1.

Table 1. Temperature sense diode characteristics for BUK9107-40ATC

Symbol	Parameter	Min	Typ	Max	Unit
V_F	forward voltage	648	658	668	mV
S_F	temperature coefficient	–1.4	–1.54	–1.68	mV/K

The BUK9107-40ATC has a very tight V_F tolerance of 10 mV, and the variation in S_F is also correspondingly tight. However, if the device is used in the circuit shown in Figure 1 without calibration, then the total error in T_{trip} due to errors in both V_F and S_F becomes significant. The maximum error will occur if the V_F, at T_j = 25 °C, is at its highest value and S_F is at its lowest value.

If T_{trip} is set to 150 °C and V_F and S_F are not measured, then the T_{trip} error is given by Equation 1:

$$T_{trip} = \frac{(V_F - \overline{V_{F(ref)}})}{S_F} - (T_{trip} - 25) \quad (1)$$

where the average reference forward voltage $\overline{V_{F(ref)}}$ is given by Equation 2:

$$\overline{V_{F(ref)}} = \overline{V_F} - (T_{trip} - 25) \times \overline{S_F} = 465mV \quad (2)$$

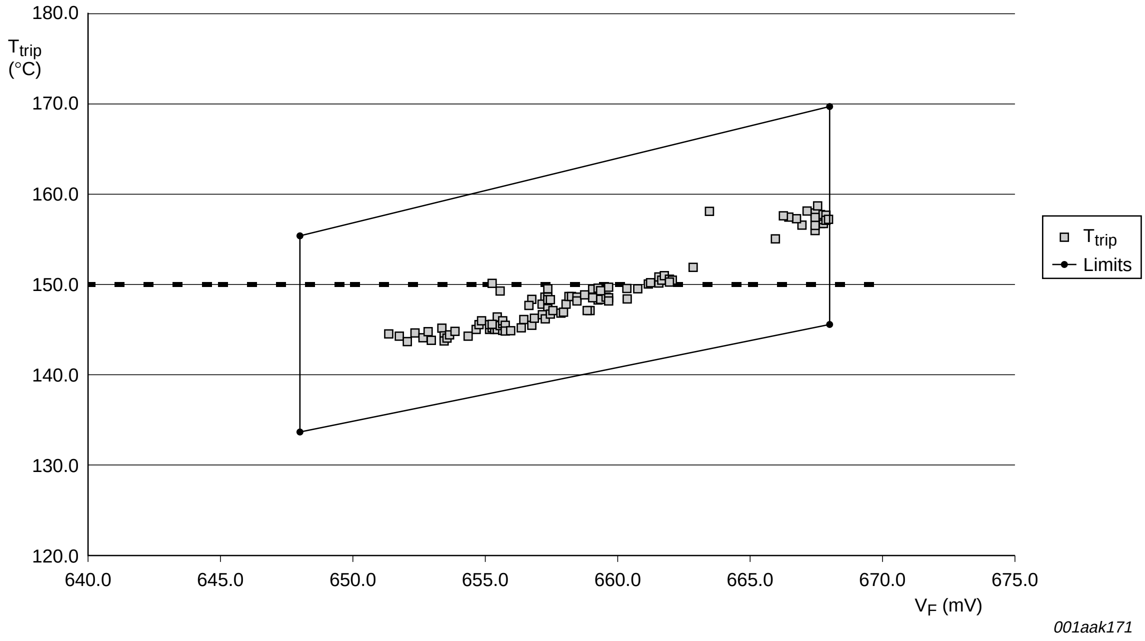
Substituting the values given in the data sheet into Equation 2 gives the following results:

$$T_{trip(u)} = 150 + 19.6\ °C$$

$$T_{trip(l)} = 150 - 16.4\ °C$$

In practice, the results are much better than that shown.

Figure 4 shows T_{trip} as a function of V_F for where a number of devices have been measured across the temperature range, and the actual T_{trip} value has been determined for each using a reference voltage of 465.5 mV.



T_j = 25 °C

Fig 4. **T_{trip} as a function of V_F without error correction**

The box in Figure 4 defines the theoretical limits of T_{trip}. The data clearly lies within ±10 °C of the target temperature.

2.2 Improving accuracy

The accuracy of the device can be vastly improved if its V_F is measured at room temperature. Using this value, $V_{F(ref)}$ can be reset to eliminate the error in V_F. This situation is shown in Figure 5.

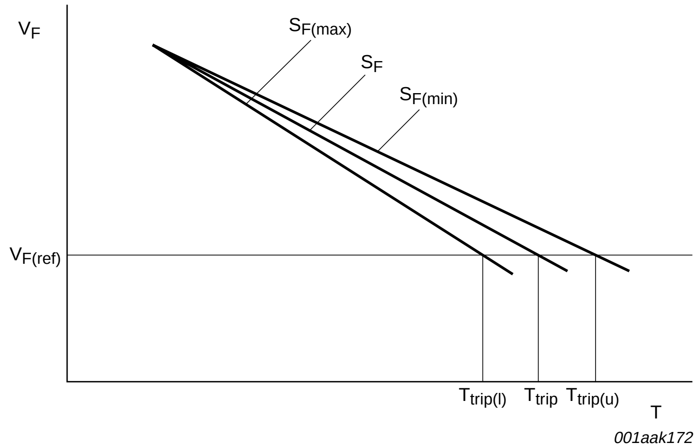


Fig 5. T_{trip} error decreases when the value of V_F at room temperature is known

In this case there is still an error associated with S_F shown by the variation in gradient. As before, the upper values of S_F are taken from the maximum values given in the data sheet shown in Table 1.

The total error at T_{trip} is now given by Equation 3:

$$d(\Delta T) = -\Delta V_F \frac{dS_F}{(S_F)^2} + \frac{1}{S_F} d(\Delta V_F) \quad (3)$$

where ΔV_F is the voltage drop required to trip at 150 °C from 25 °C, and dS_F is the variation in S_F given in the data sheet (1.68 – 1.54 = 0.14). By adjusting $V_{F(ref)}$, the term on the right-hand side of Equation 3 becomes zero. Substituting the remaining values gives the following results:

$$T_{trip} = 150 \pm 11 °C$$

Again, in practice, the results are better than this.

Figure 6 shows the effect when an estimate of T_{trip} is made for the same device using a corrected $V_{F(ref)}$.

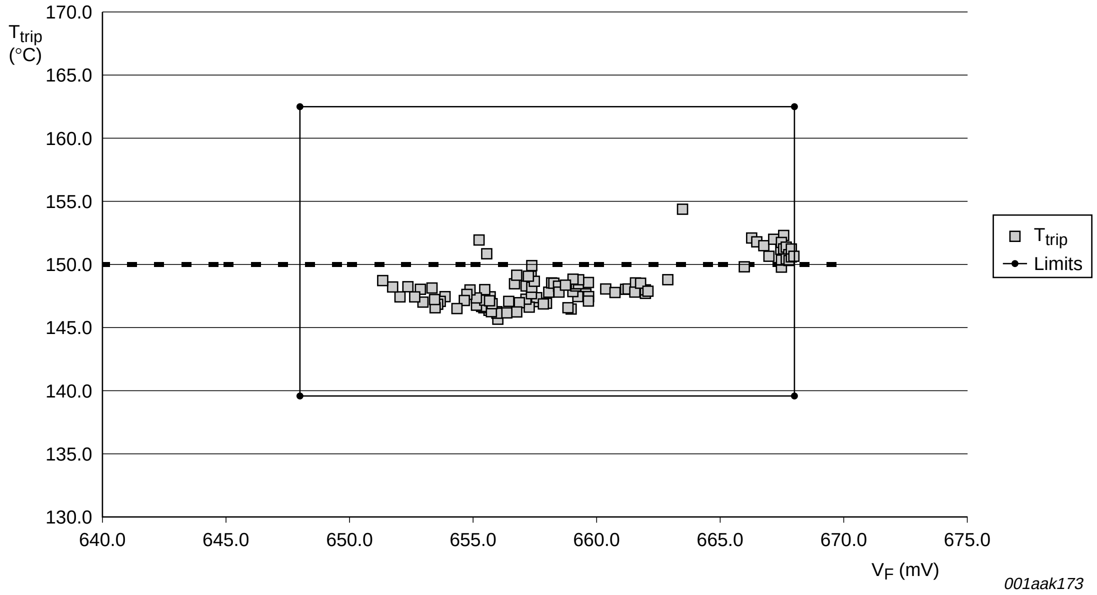


Fig 6. T_{trip} as a function of V_F with $V_{F(ref)}$ corrected

As in Figure 4, the outer box defines the theoretical limit which now gives the following results: $T_{trip} = 150 \pm 11°C$

The measured values now lie within ±5 °C of the target. It is clear that significant improvements in accuracy are possible by measuring the value of V_F at room temperature.

A further theoretical improvement can be made because a relationship exists between S_F and V_F measured at 25 °C. The accuracy will be increased if V_F (at 25 °C) is measured, and S_F is calculated using the expression given in Equation 4.

Using the graph, if V_F (at 25 °C) is measured, the value of S_F will lie in the range given in Equation 4:

$$S_{F(calc)} = \{[-0.0041 \times V_F(25°C)] + 4.2387\} \pm 0.099 \quad (4)$$

The error in S_F of 0.099 represents 5 standard deviations from the mean. If we again assume that T_{trip} is set to 150 °C, the accuracy now becomes: $T_{trip} = 150 \pm 8°C$.

The greatest accuracy can be achieved if both V_F and S_F are measured for every device. In this case, V_F (at 25 °C) and V_F (at 150 °C) are measured, and S_F is calculated and stored using Equation 5.

$$S_F = \frac{V_{F(25)} - V_{F(150)}}{150 - 25} \quad (5)$$

Again, $V_{F(ref)}$ must be redefined as in Equation 3. In this way, T_{trip} will be limited only by the accuracy of the voltmeter used, and an accuracy of ±1 °C can be readily achieved. This could be integrated into the module build to provide excellent temperature control in your system.

3. Summary

There are four methods of using the temperature sensing diode with increasing theoretical accuracy for each subsequent method. The two simplest methods have been measured and compared with theory. A summary of all the results is given in Table 2.

Table 2. Summary of results

Accuracy method	Result	
	Theory	Experiment
V_F not measured	$T_{trip} = 150 \pm 19\ °C$	$T_{trip} = 150 \pm 10\ °C$
V_F measured (at 25 °C) and use S_F = 1.40 – 1.68	$T_{trip} = 150 \pm 11\ °C$	$T_{trip} = 150 \pm 5\ °C$
V_F measured (at 25 °C) and calculate S_F	$T_{trip} = 150 \pm 8\ °C$	
Measure V_F and S_F	$T_{trip} = 150 \pm 1\ °C$	

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5. Tables

6. Figures

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