Application Report

Enabling Smarter, Integrated Protection for 4-20mA Current Loops with eFuses

TEXAS INSTRUMENTS

ABSTRACT

Industrial equipment such as Programmable Logic Controller (PLC) have current loop for measurement of sensor outputs (like Pressure, Temperature, and so on). The current output of sensor is measured by converting it into a voltage using a burden resistor. Due to miswiring and transients (such as Surge) in industrial environment, the power rating and size of burden resistor have to be increased. The accuracy of current measurement reduces due to leakage current of protection components (such as Zener Diodes). This application report describes the use-case of TPS2661x devices for protection of current inputs with improved accuracy and with reduced size of burden resistor.

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1 Introduction

The Programmable Logic Controllers (PLC) are widely used for automation in industries. The PLC collects data from sensors, analyze this data, and controls the industrial process through actuators. One way of collecting data from different sensors is through current loops. The sensor transmitters convert the measured parameter in to a current output and the current is transmitted over a cable to analog input module for measurement. The analog input module converts the analog current value in to a digital value by measuring the voltage drop across burden resistor. Figure 1-1 illustrates an analog input module with current inputs.

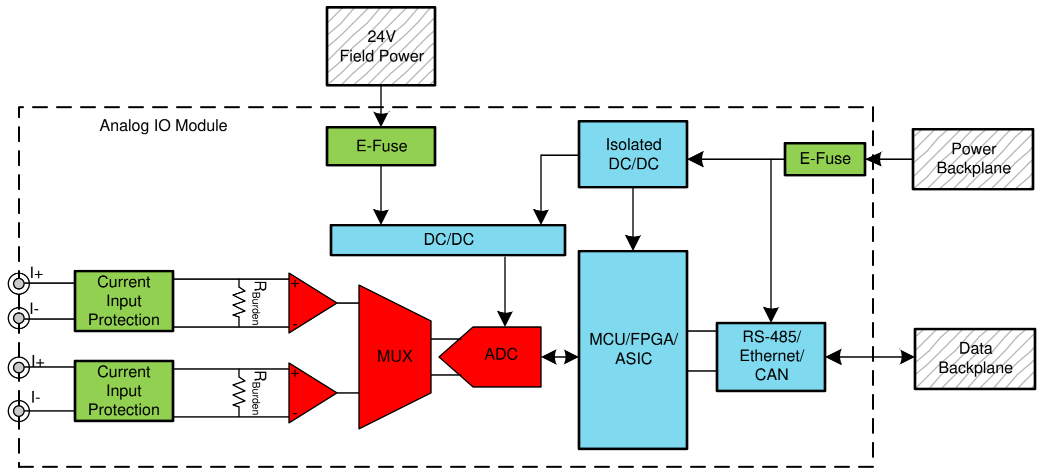


Figure 1-1. Current input protection in Analog Input modules

The Digital values of sensor outputs are transmitted to PLC CPU through the backplane. Due to miswiring and transients on current input, the analog input module needs protection components on current inputs. Section 2 describes the protection required for current inputs in analog input modules

2 Protection Required for Current Inputs in Analog Input Modules

2.1 Over-Current Protection from Miswiring to Field Power Supplies

In the factory environment, a voltage source for example, 24 V power supply, can be miswired to a current input. The voltage source will lead to excessive current flow through the burden resistor and may burn the burden resistor. An over-current protection device with bi-directional current limiting (similar to PTC) is used traditionally to limit the current in the burden resistor.

2.2 Over-Voltage Protection from Miswiring to Field Power Supplies

During miswiring to field power source, a large voltage can appear across the ADC inputs, burden resistor or current limiting element. An over-voltage protection device with cut-off or voltage clamping is required to protect the ADC inputs from high voltage. Over-voltage protection for Burden resistor and current limiting element is also required to limit the power dissipation in burden resistor and reduce heating of entire module.

3 Typical Discrete Circuit for Protection of Current Input

A discrete circuit consisting of TVS diode, Zener diodes and PTC is typically used for protection input. TVS diode provides protection from surge pulses, Zener diodes provide protection from over-voltage and PTC provides over-current protection.

Figure 3-1 illustrates an example of a discrete circuit for protection of current inputs in analog input modules. A PTC is required for required for over-current protection while Back-to-Back Zener diodes are required for over-voltage protection and limiting the power dissipation in Burden Resistor in case of miswiring to field supplies. Multiple burden resistors or a MELF resistors (MMB) are required in parallel to dissipate the power in case of miswiring events. A TVS diode is required to protect from surge transients.

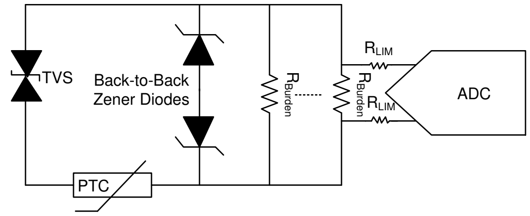


Figure 3-1. Discrete Circuit for Current Input Protection

3.1 Protection Provided by Discrete Circuit

3.1.1 Over-Current Protection with Discrete Circuit

During miswiring to field power source, a current continuously flows through the burden resistor. PTCs allow a continuous current up-to I_{HOLD} without tripping. As the current increases above I_{TRIP} and PTCs temperature go above switch temperature or Curie point, PTCs increase resistance and add drop to loop in normal operation. I_{TRIP} and I_{HOLD} vary significantly (~50%) with the ambient temperature. Figure 3-2 provides the variation of I_{TRIP} and I_{HOLD} with temperature of a typical PTC with I_{HOLD} = 55mA at 25°C.

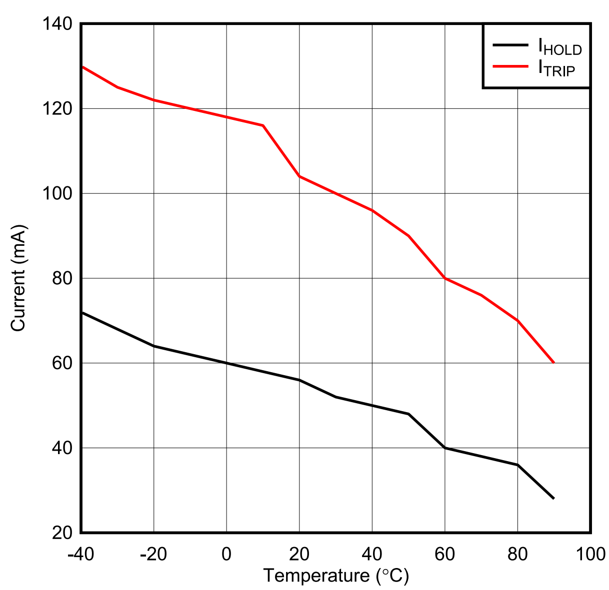


Figure 3-2. Hold and Trip Current of PTC

To operate with current inputs up-to 24mA, The PTC needs to be selected such that I_{HOLD} is more than 24mA over operating temperature range. With PTC having I_{HOLD} more than 24mA across operating range, I_{TRIP} is typically more than 100mA at 25°C.

PTCs have an operating time in order of few seconds to bring down the current to the residual leakage current. Figure 3-3 provides the typical operating time of a PTC with I_{HOLD} = 55mA.

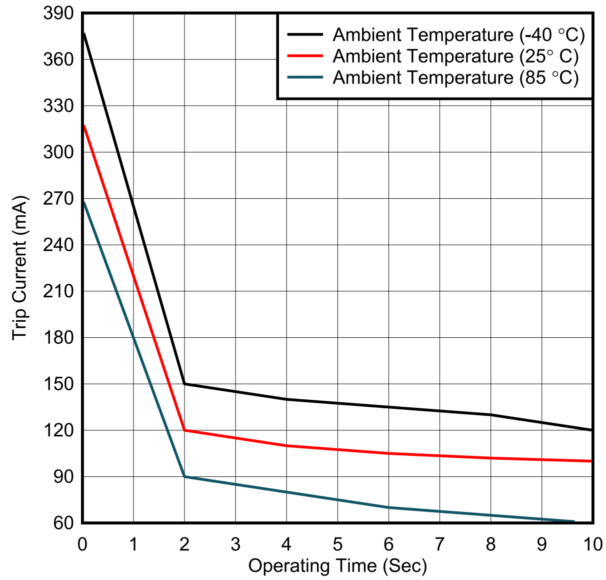


Figure 3-3. Operating Time of PTC

With an operating time of few seconds, a significant amount is power dissipated in burden resistor and Zener Diode. Figure 3-4 provides the power dissipated in Burden resistor and Zener Diode during miswiring to Field Supply.

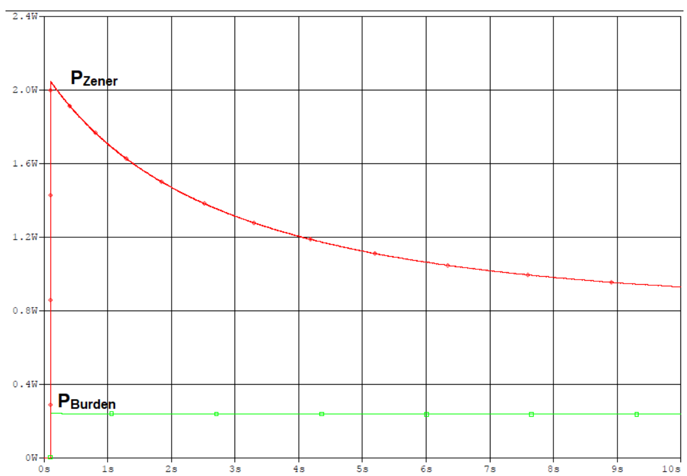


Figure 3-4. Power Dissipation in Zener and Burden Resistor During Miswiring Faults

Due to the increased power dissipation in Zener and Burden resistor, the power rating of Zener has to be increased more than 2W and power rating of burden resistor has to be increased more than 300 mW for a 50-Ω burden resistor.

With increased power rating of Zener Diodes and Burden resistor, a Zener diode with larger package has to be used and multiple resistors in parallel are required for R_{Burden} to dissipate the power during miswiring event.

Figure 3-5 shows a typical PCB layout with an estimated area of 142 mm^2 for current input circuit with PTC, Zener and multiple 0805 (125 mW) burden resistors. Figure 3-6 shows a typical PCB layout with an estimated area of 102 mm^2 for current input circuit with PTC, Zener and a 1W MELF resistor.

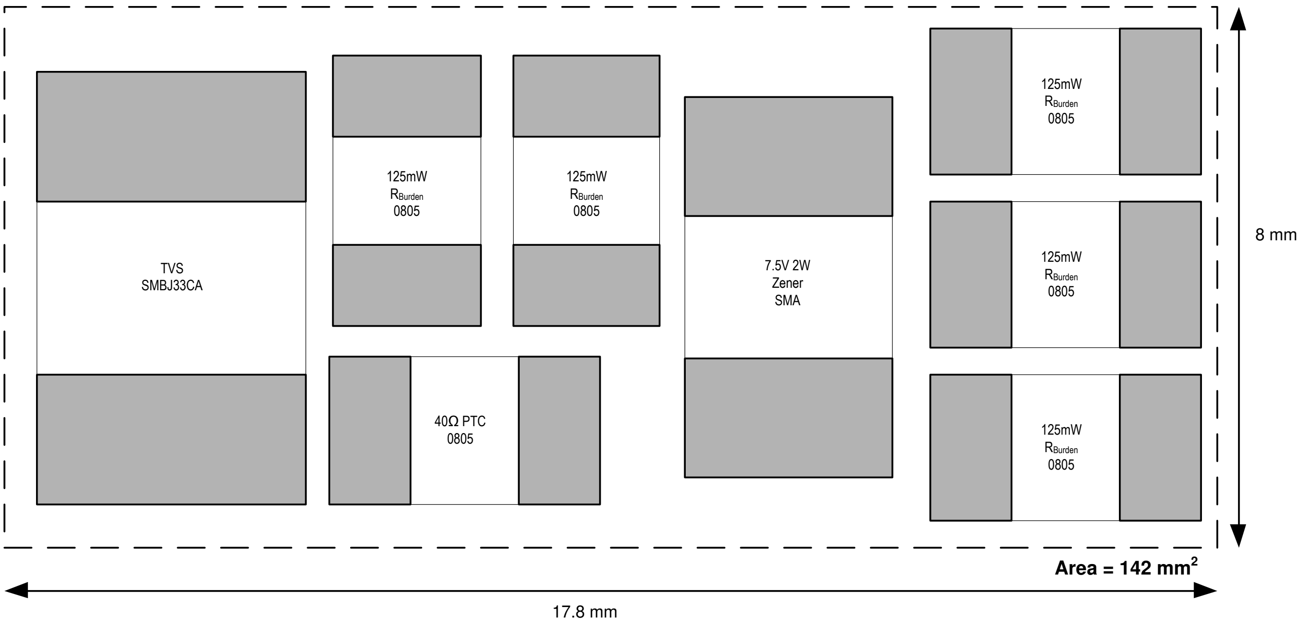


Figure 3-5. PCB Size with Multiple Burden Resistors

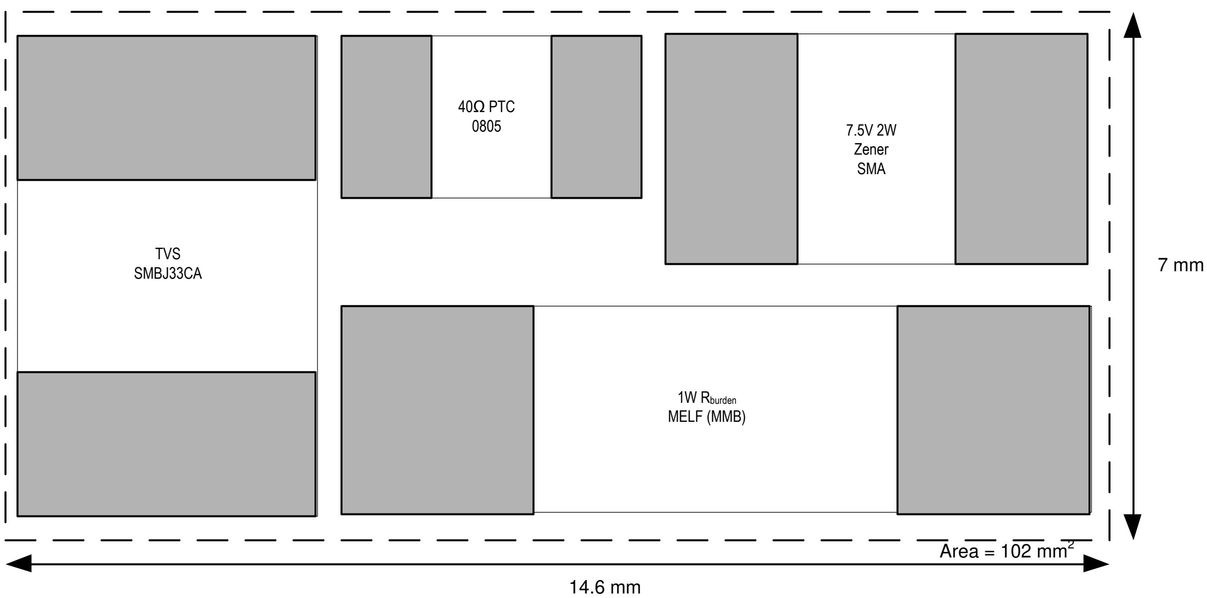


Figure 3-6. PCB Size with MELF Resistor

3.1.2 Over-voltage Protection with Discrete Circuit

During miswiring to field power source, a large voltage can appear across the ADC inputs and burden resistor. Back to Back Zener diodes are used to protect the ADC inputs from high voltage. The Zener diode also limits the current through the burden resistor and limits the power dissipation in burden resistor in case of miswiring to field power supply. With Zeners, no overvoltage cut-off is provided and the voltage is clamped across the burden resistor. Due to this, there is still power dissipation in the PTC and burden resistor. This causes heating of the entire PLC module.

3.2 Heating and Temperature Rise with Discrete Circuit

As the PTC and Zener diode don't provide the cut-off protection during miswiring faults, there is a continuous flow of current through the burden resistor, PTC, and Zener diodes. This current flow leads to power dissipation in these components and heating of the entire module. Figure 3-7 provides the temperature rise in PTC during miswiring faults. The temperature of PTC rises ~95°C above ambient temperature during miswiring faults

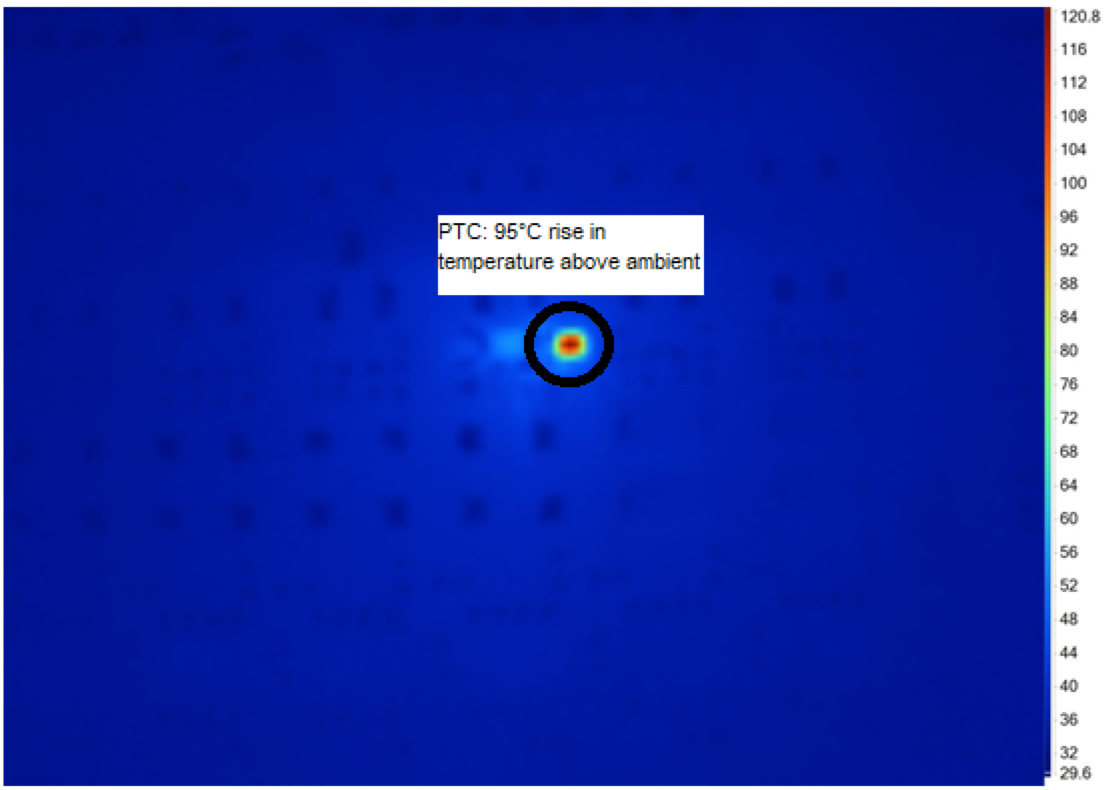


Figure 3-7. Temperature rise with Discrete Circuit

3.3 Reverse Leakage Current of Zener Diodes and Current Measurement Accuracy

As described in Section 3.1.1, a Zener diode with power rating more than 2W is required for protection in current input. Zener diode with a higher power rating has higher reverse leakage currents. Reverse leakage current of Zener diode cause an error in current measurements, Figure 3-8 illustrates the reverse leakage current in a 7.5 V and 2W Zener diode and the corresponding error in 20mA current measurement. As the ambient temperature goes above 60°C, the error contributed by reverse leakage current is more than 0.1% and this starts degrading the overall current measurement accuracy. A higher value of R_{Burden} is usually preferred for lower noise in current measurements. The reverse leakage current increases with voltage drop across R_{Burden} and it becomes difficult to achieve accuracy better than 0.25% with higher value of burden resistors.

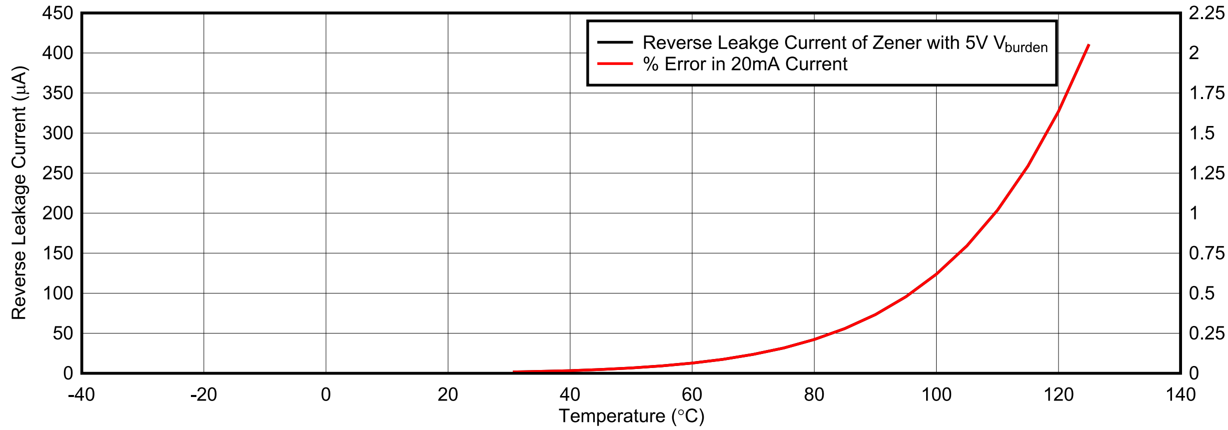


Figure 3-8. Reverse Leakage Current in a 7.5 V and 2W Zener Diode

4 TPS26610 for Analog Current Loop Protection

4.1 Current Input Protection with TPS26610

TPS26610 device integrates accurate current limiting (±30mA) and over-voltage cut-off protection for protection of Burden resistor from miswiring events. Additional Zener diodes and PTC are not required with TPS26610 for protection of burden resistor. A TVS is required for clamping of signal line surge transients (IEC61000-4-5). Figure 4-1illustrates the application circuit with TPS26610 for current input protection.

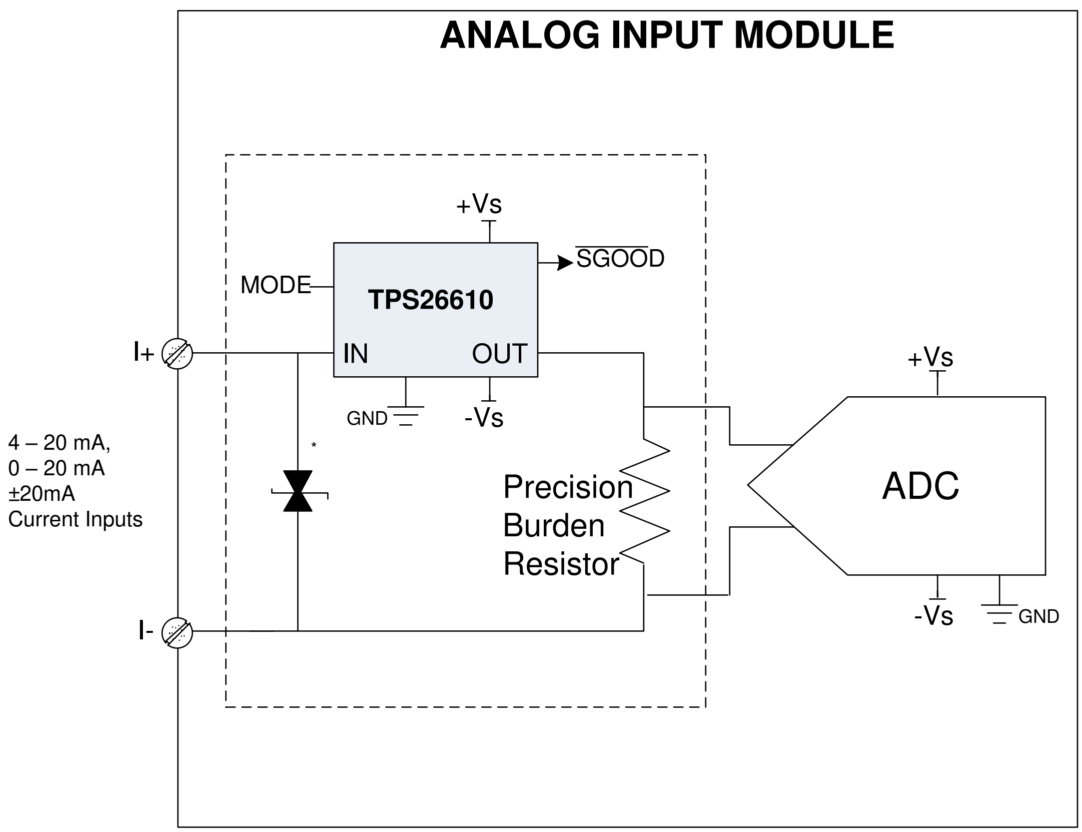


Figure 4-1. Current input protection with TPS26610

4.2 Accurate Current Limiting with TPS26610

TPS26610 has an accurate limiting for protection with 249Ω burden resistor from mis-wiring faults to field supplies with voltage up-to Vs supply of the device.

Figure 4-2 provides the variation of current limit of TPS26610 with temperature.

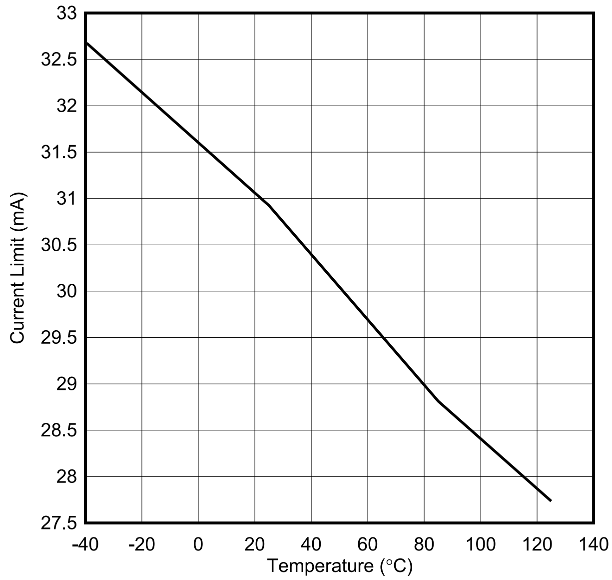


Figure 4-2. Current Limit with TPS26610

With accurate current limiting, the power dissipation in burden is reduced and numbers of burden resistors are reduced. Table 4-1 summarizes the number of 0805 (125 mW) burden resistors for different values of R_{Burden}.

Table 4-1. Reduced Power Dissipation in Burden Resistor with TPS26610

I_{LIM}(max)	R_{Burden} (Ω)	Power Dissipated in R_{Burden} (mW)	Number of 0805 (125mW) burden resistors required in Parallel
35 mA	249	305	3
35 mA	100	122.5	1
35 mA	49	61.25	1

4.3 Leakage Current of TPS26610 and Current Measurement Accuracy

TPS26610 device only takes a total leakage current less than 20nA from IN and OUT pins and this contributes to an error less than 0.0001% in current measurements of 20mA.Figure 4-3 provides the sum of leakage current from IN and OUT pins of TPS26610 with a voltage of 5V across burden resistor. With TPS26610, it is possible to use a burden resistor of resistance 50 to 249Ω and achieve higher ENOB and lower noise for current measurements.

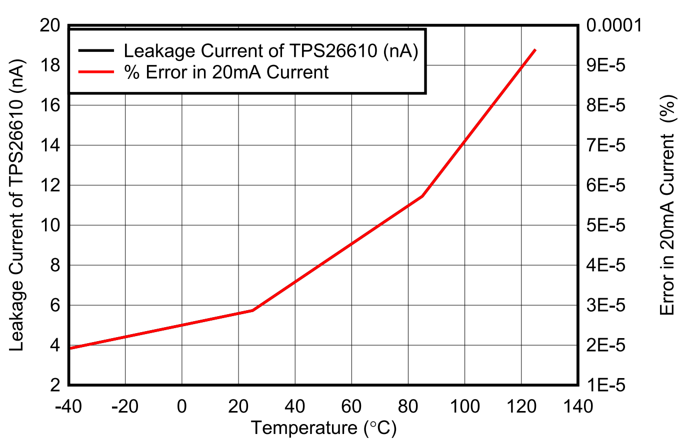


Figure 4-3. Leakage Current of TPS26610

4.4 Protection from Mis-wiring to Field Power Supplies

TPS26610 Device has integrated over-voltage and under voltage cut-off on OUT pin when voltage on OUT pin is more than ±Vs supplies. During a miswiring fault to field supply more than ±Vs supplies, TPS26610 turns off the internal FETs within 5µs and prevents power dissipation in burden resistor.Figure 4-4 illustrates the protection provided by TPS26610 during miswiring fault to field supply more than Vs supply

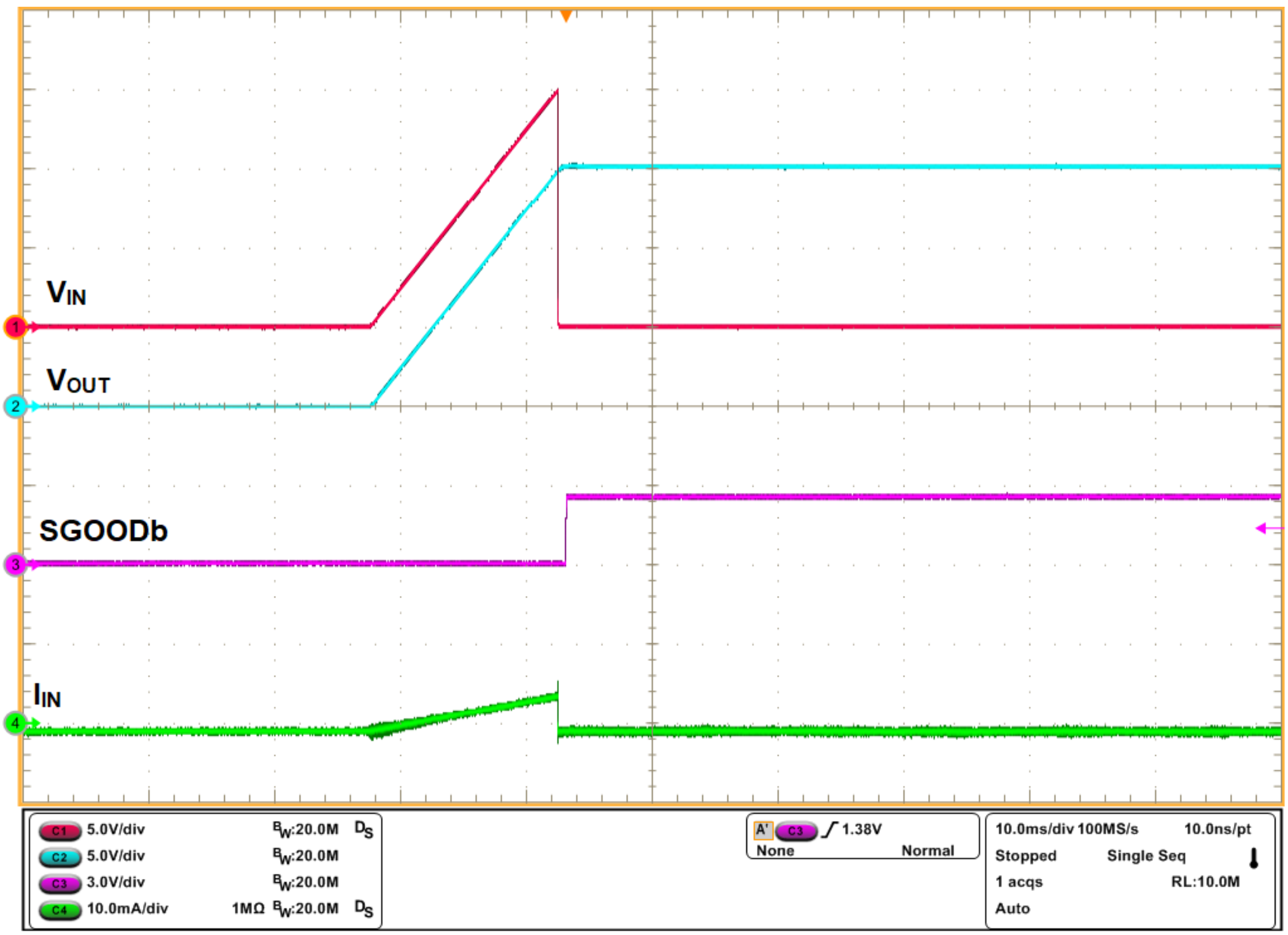


Figure 4-4. Over-voltage Cut-off with TPS26610

4.5 Heating and Temperature Rise with TPS26610

As the TPS26610 device provides cut-off protection during miswiring faults, there is no heating and subsequent temperature rise in components during miswiring faults Figure 4-5 provides the temperature rise with TPS26610 during miswiring faults. The temperature of TPS26610 rises ~15°C above ambient temperature during miswiring faults.

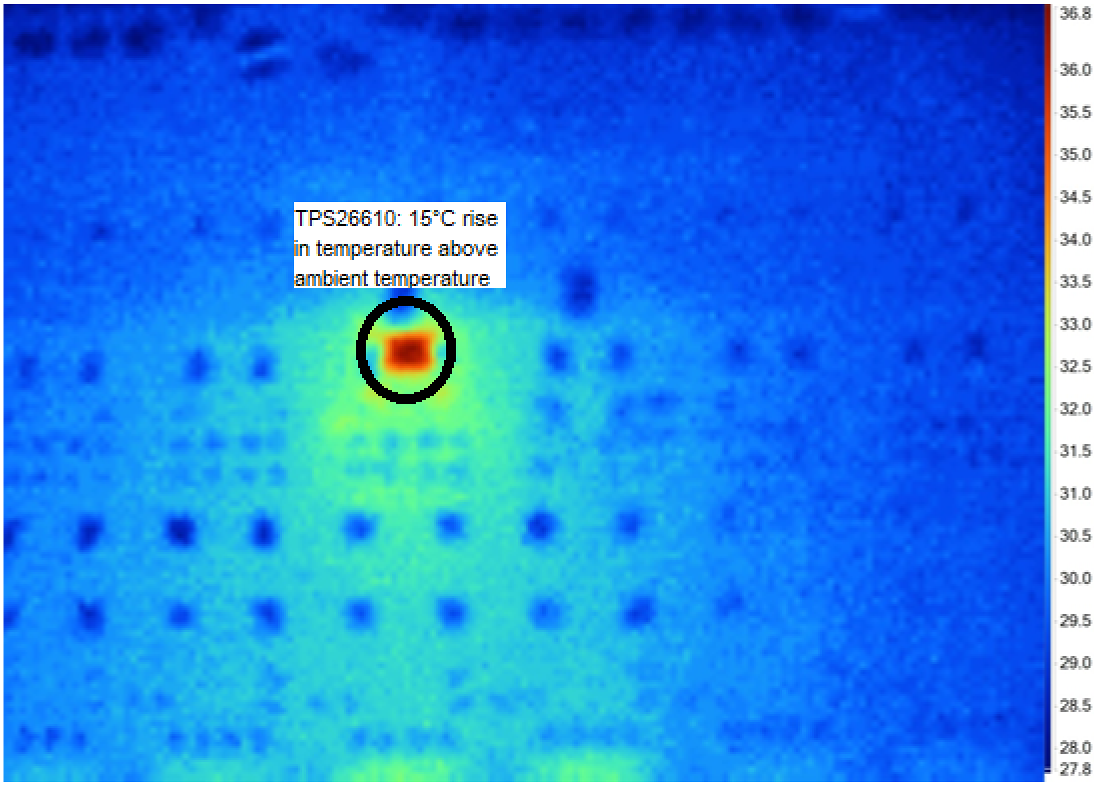
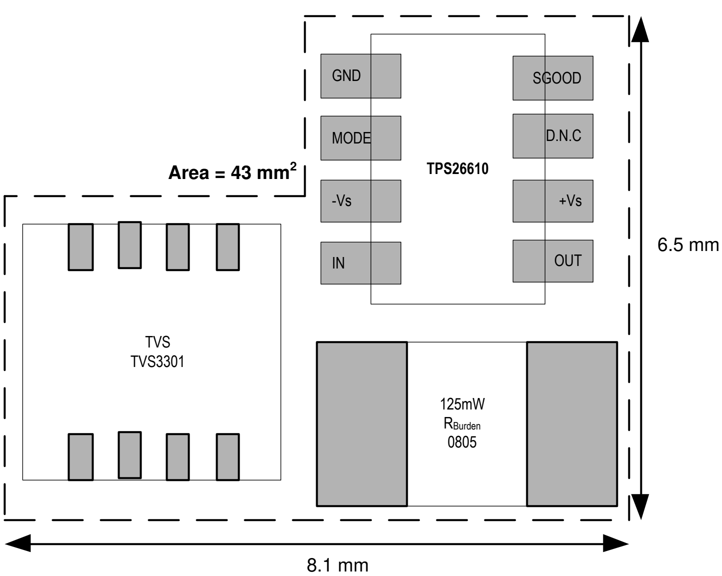


Figure 4-5. Temperature rise with TPS26610

4.6 Reduction in PCB Size with TPS26610 for Current Input Protection

As the number of burden resistor is reduced, TPS26610 provides a compact solution for current input protection. Figure 4-6 illustrates an example PCB layout with TPS26610 using a single 0805 burden resistor with estimated area of 43 mm^2.

Figure 4-6. PCB Size with TPS26610 for Current Input Protection



5 Conclusion

With accurate current limiting, low leakage currents, over-voltage and under-voltage protections, TPS26610 device offers a more compact and accurate solution for current input protection in analog input modules. Table 5-1 summarizes the comparison between current input protection with TPS26610 and with discrete circuit.

Table 5-1. Comparison of TPS26610 with Discrete Circuit for Current Input Protection

	Current Input Protection with TPS26610	Current Input Protection with Discrete Circuit
Error due to leakage currents (-40 to 125°C)	0.0005%	1.6%
Current Limit Accuracy (-40 to 125°C)	±17%	±50%
Over-voltage and under-voltage Cut-off protection for miswiring faults	Yes	No
Estimated PCB Area	43 mm^2	102 to 142 mm^2
Lower Noise and Higher ENOB with 249Ω Burden Resistor without increase in leakage currents	Yes	No
Temperature Rise in miswiring faults (Above Ambient Temperature)	15°C	95°C
Voltage Drop in Loop	150 mV	800 mV (with 40Ω PTC)