Application Note

Design Considerations for Heat Sink Monitoring With Ring Lug Thermistors

Jalen Tate

Temperature and Humidity Sensing

ABSTRACT

This application note reviews data and provides recommendations for using Negative Temperature Coefficient (NTC) ring lug thermistors to monitor the temperature of a heat sink. The accuracy of an NTC-style ring lug and TMP6-style ring lug are compared with a Fluke® TiS60+ thermal imager. The findings discussed throughout this application note are summarized into a systems perspective for designers, providing design tradeoffs for ring lug thermistor applications.

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1 Heat Sink Temperature Sensor Monitoring

A common method of tracking critical component temperature is to capture the temperature of a heat sink contacting the device of interest, as shown in Figure 1-1. Mechanically, the sensors in these applications can either be attached to the heat sink with epoxy, a clip, or a bolt if the package permits. The equivalent thermal circuit for this method is shown in Figure 1-1, where the $R_{\theta JC(IGBT)}$ is the thermal resistance from the junction of the insulated-gate bipolar transistor (IGBT) module to the top of the module package.

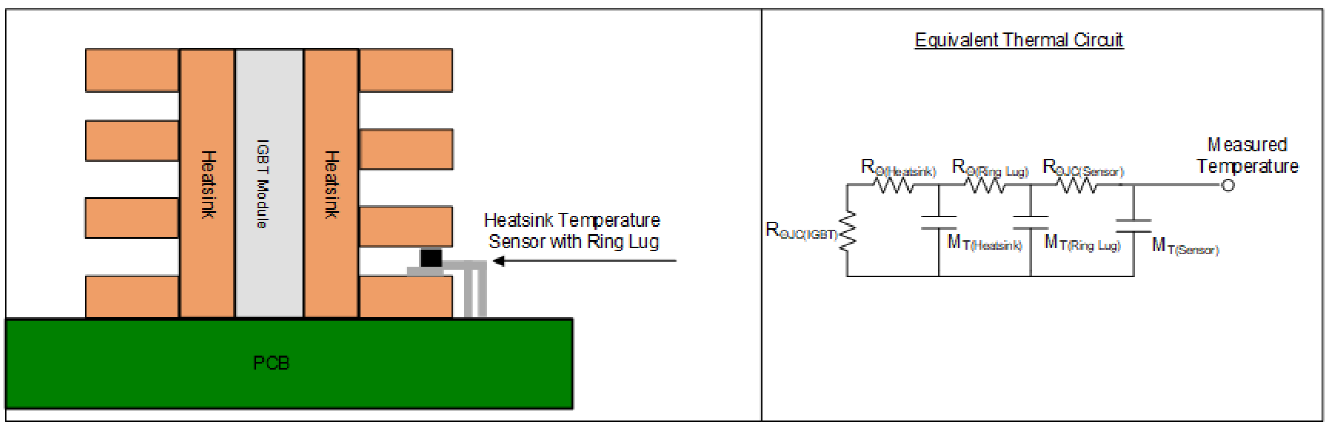


Figure 1-1. Equivalent Thermal Circuit for Heat Sink Temperature Sensing

When using this method of temperature monitoring, the measured temperature at the sensor depends on a few key considerations: the thermistor, epoxy, and the mounting stud used for contact. The following sections of this application note explore tradeoffs and considerations when using ring lug thermistors to measure heat sink temperature.

2 Test Overview

The testing performed in this application note uses the TIDA-020030 reference design. The TIDA-020030 is an IGBT or SiC isolated gate driver power stage that drives an insulated-gate bipolar transistor (IGBT) module with advanced protection features. This reference design drives a traction inverter system. The reference design performs testing with the following subsystems: high-side and low-side isolated gate drivers, gate drive pulse width modulation (PWM) monitoring, isolated power supplies, and an IGBT module.

2.1 Hardware

Figure 2-1 shows the TIDA-020030 hardware and the IGBT module with double-sided cooling. The position of the isolated gate driver, UCC21732-Q1, is also shown. The heat sinks are symmetrically attached to the top and bottom side of the IGBT module for maximum cooling. The isolated barrier on the drive board is outlined by the PCB silkscreen.

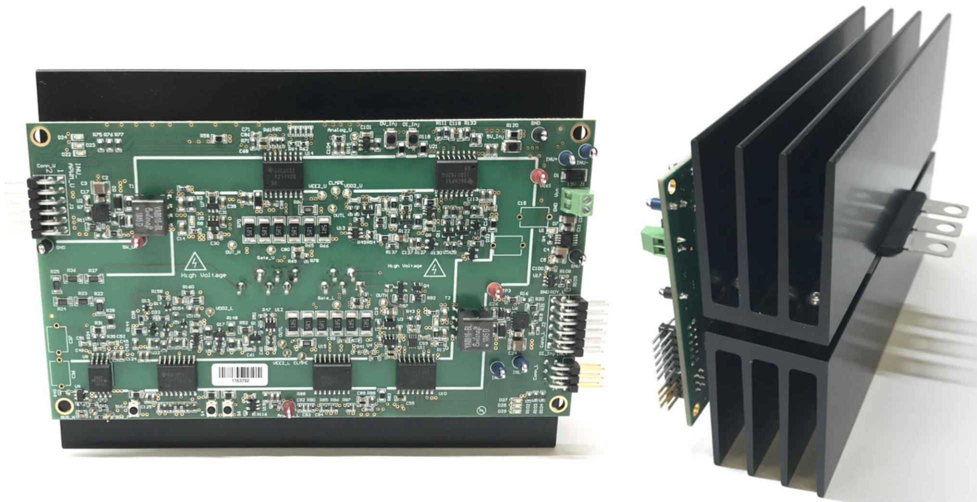


Figure 2-1. TIDA-020030 Hardware

Additionally, the following laboratory test equipment is used:

- DC supplies
- Programmable DC electronic load
- Oscilloscope

2.1.1 Keysight E3631A Power Supply

The Keysight™ E3631A (Agilent) power supply is designed for general purpose applications. Output ratings are 0 to 25 V and 0 to 1 A for the power supply channel used in this test. The power supply is configured as a 15-V DC supply and is used to apply DC power to the signal board.

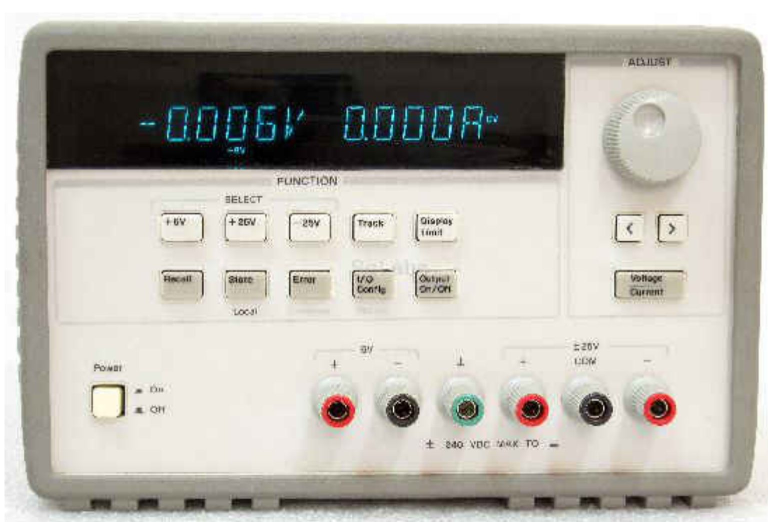


Figure 2-2. Keysight E3631A Power Supply

2.1.2 Sorensen™ DCS 40-25E Programmable DC Power Supply

The Sorensen™ DCS 40-25E programmable DC power supply is designed for a wide range of applications requiring DC power in a small form factor with high-frequency switching technology. The output of this supply is 0 V to 40 V and 0 A to 25 A with an output power of 1.0 kW. This DC power supply provides 15 V DC and 20 A to the IGBT Module.

Figure 2-3. Sorensen DCS 40-25E Programmable DC Power Supply

2.1.3 B&K Precision™ 8500 DC Electronic Load

The B&K Precision™ 8500 DC Electronic Load can be used for testing and evaluating a variety of DC power sources. The electronic loads can operate in constant current (CC), constant voltage (CV), constant resistance (CR), or constant power (CP) mode while voltage and current or resistance and power values are measured and displayed in real time. The 8500 model provides an output power up to 300 W with an operating voltage of 0.1 V to 120 V and rated current of 30 A. The B&K Precision Electronic Load is configured as a 15-V and 20-A source for the IGBT module power supply.

Figure 2-4. B&K Precision 8500 DC Electronic Load

2.1.4 TDS3014B Tektronix® Digital Oscilloscope

The TDS3014B is a 100-MHz, 4-channel digital oscilloscope from Tektronix®. The oscilloscope measures voltage or current signals over time in an electronic circuit or component to display amplitude, frequency and rise times, and so forth. Applications include troubleshooting, production test, and design. The digital oscilloscope is used to confirm operation and functionality of the isolated gate driver inputs and outputs as well as IGBT module.

Figure 2-5. TDS3014B Tektronix Digital Oscilloscope

2.1.5 Fluke® TiS60+ Thermal Imager

The Fluke® TiS60+ Thermal Imager is a thermal camera that can measure up to 400°C and capture temperature distances. The thermal imager allows for configurable emissivity settings and export control of images. The camera also uses IR fusion technology to combine visible light and infared images into an image, providing improved clarity. The Fluke TiS60+ Thermal Imager camera is used as a second reference to temperature measurements obtained throughout testing.

Figure 2-6. Fluke TiS60+ Thermal Imager

2.1.6 MSP430F5529LP LaunchPad™

The MSP430F5529LP LaunchPad™ microcontroller is an inexpensive and simple development kit for the MSP430F5529 USB Microcontroller. The development kit offers an easy method to start developing on the MSP430™ MCU, with onboard emulation for programming and debugging as well as buttons and LEDs for a simple user interface. The MSP430 LaunchPad™ development kit provides a PWM signal to the IGBT gate driver and for data collection of thermistors on the analog inputs of the microcontroller.

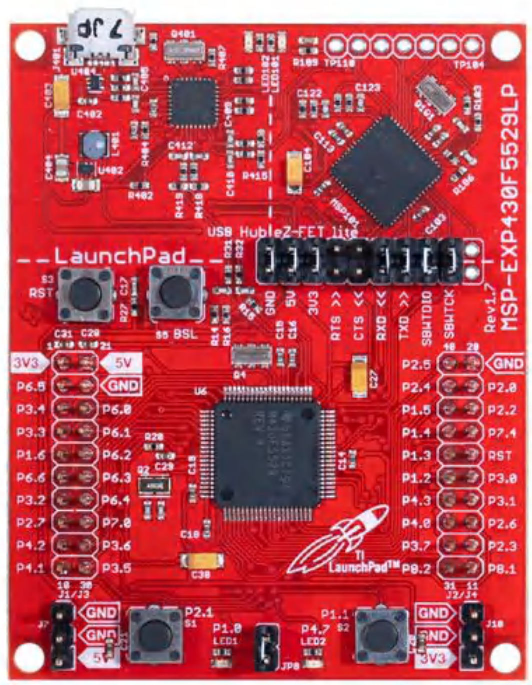


Figure 2-7. MSP430F5529LP LaunchPad™ Microcontroller

2.2 Isolated Gate Driver

The TIDA-020030 reference design has two UCC21732-Q1 galvanic isolated single-channel gate drivers designed for up to 1700-V SiC MOSFETs and IGBTs with advanced protection features. The UCC21732-Q1 gate drivers have up to ±10-A drive strength, support up to 1.5-kV_{RMS} working voltage, and 12.8-kV_{PK} surge immunity with longer than 40 years of isolation barrier life. The UCC21732-Q1 gate drivers are used to drive the high and low side of the IGBT module, although this test uses only the high-side driver.

2.3 IGBT Module

The Infineon FF400R07A01E3_S6 IGBT half-bridge module is a compact half-bridge module for hybrid and electric vehicle applications. The FF400R07A01E3_S6 module is designed for Double Sided Cooling (DSC). The FF400R07A01E3_S6 operates up to 150°C with limited operation up to 175°C. The module is rated for up to 700 V and 400 A with a maximum power dissipation of 1500 W. The gate thresholds have a typical value of 5.80 V.

2.4 NTC Ring Lug

The NTCALUG01A series resistors from Vishay® are ring lug style NTC thermistors. An NTC thermistor chip is soldered to 24-gauge stranded silver-plated copper leads with PTFE (polytetrafluoroethylene) insulation and insulated with epoxy coating. The insulated sensor is attached to a tin-plated copper ring lug. The lead wires are stripped, twisted and dipped in a tin-silver solder alloy. The NTCALUG01A103FLA specifically selected for this test has the following specs: Automotive AEC Q-200 qualified, 10-kΩ nominal resistance, 1% resistor tolerance, 1% B tolerance, and –40°C to 150°C operating range.

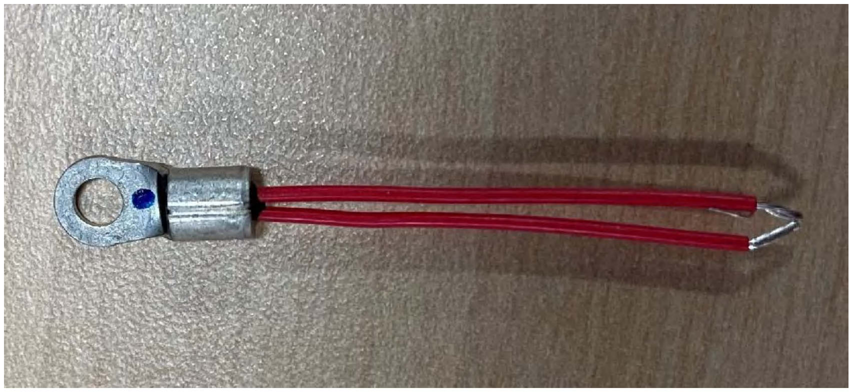


Figure 2-8. NTCALUG01A NTC Ring Lug

2.5 TMP6 Ring Lug

The TMP61-Q1 is a silicon-based linear thermistor, offering linearity and consistent sensitivity across temperature to enable simple and accurate methods for temperature conversion. The LPG package is a 2-pin through-hole TO-92S package. This package is fit into a JST5.5-S3 ring lug terminal. The LPG packaged TMP61-Q1 is covered with epoxy (MG Chemicals Thermal Epoxy 8329TCM) and wires. Heat-shrink tubing is added to the leads of the device. The specifications of the TMP61-Q1 are as follows: Automotive Q-200 tested, 10 kΩ nominal resistance, 1% resistor tolerance, and –40°C to 170°C operating range.

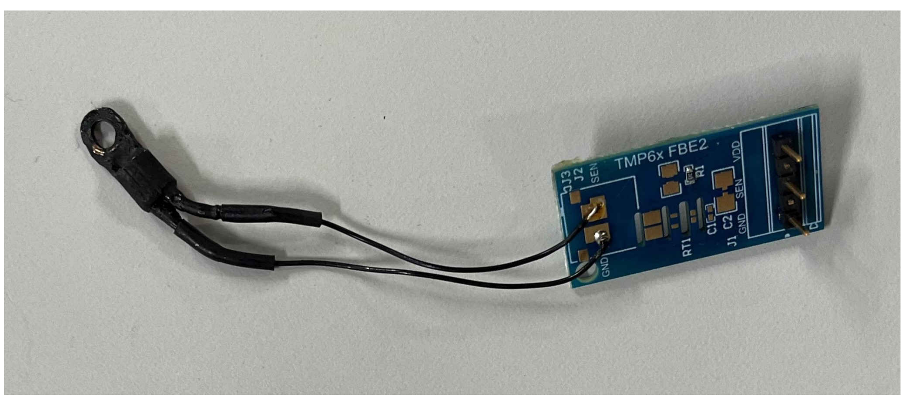


Figure 2-9. TMP6 Ring Lug With Added Epoxy and Heat-shrink Tubing

All of the ring lug style thermistors used in this testing are connected to PCB boards that included bias resistors and pins for powering the thermistor as well as measuring the thermistor voltage. The ring lugs are also sprayed with a matte black paint for the purpose of measuring an accurate temperature when using the Fluke TiS60+ Thermal Imager, as shown in Figure 2-10.

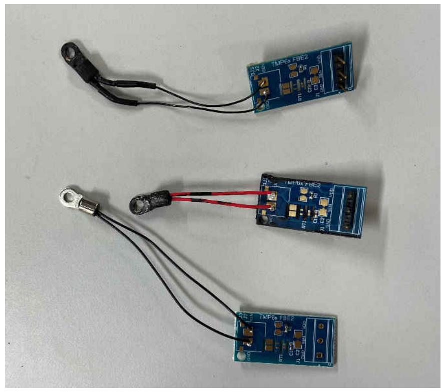


Figure 2-10. Ring Lug Thermistor PCBs

2.6 Schematic

The Figure 2-11 shows the portion of the TIDA-020030 reference design schematic used in this application note. The highlighted portion of the schematic is shown in Figure 2-12 is the primary focus of the test in this application note.

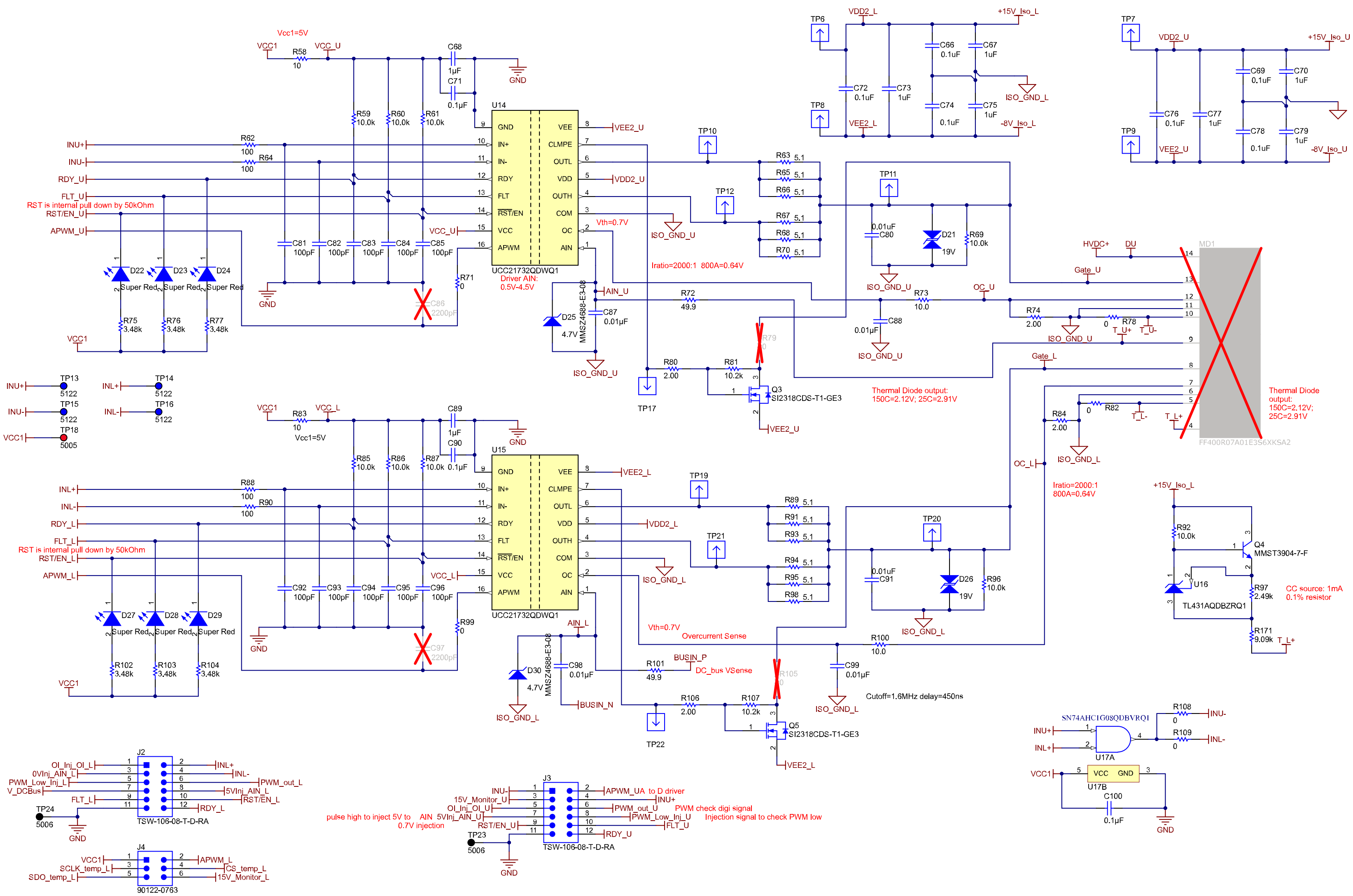


Figure 2-11. Full Schematic

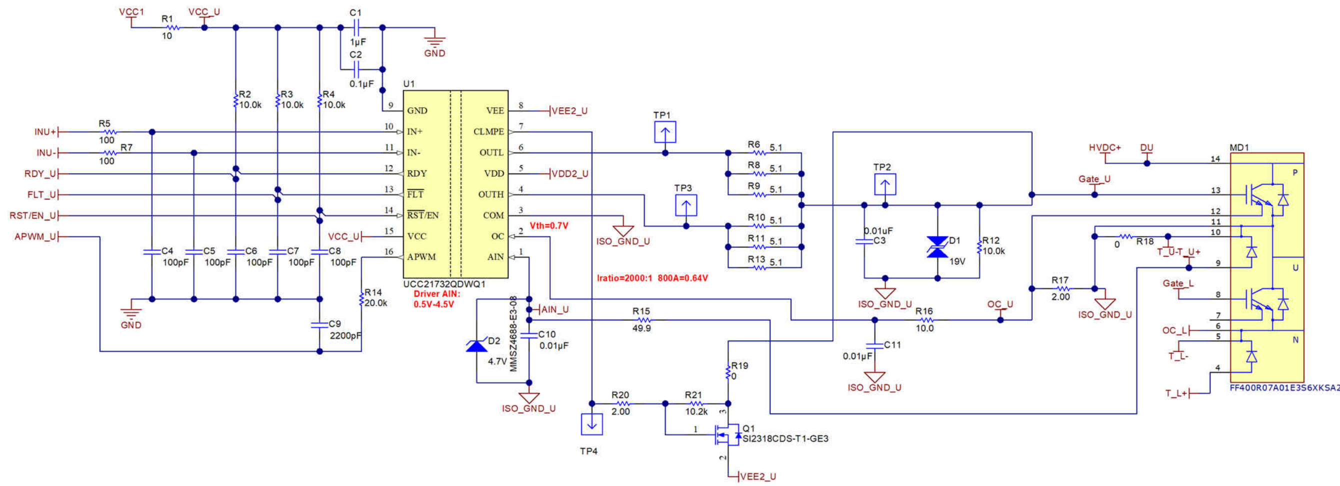


Figure 2-12. Isolated Gate Driver Circuit

Note that J3 in Figure 2-11 is used to apply the inputs to the isolated gate driver as described in the following.

The UCC21732-Q1 isolated gate driver circuit (U1) drives the high side of the IGBT module (MD1). The output pins OUTH (pin 4) and OUTL (pin6) drive the drain of the MOSFET through Gate_U (Pin 13). The isolated gate driver outputs are verified through test points TP1 and TP3. An analog PWM signal from a host MCU is driven to IN+ (pin 10) of the isolated gate driver. This PWM signal is set to an 80% duty cycle at 15 kHz. IN– (pin 11) of the isolated gate driver is connected to GND. An external voltage is applied to HVDC+ (pin 14) of the IGBT module, with pin N grounded, and the switching monitored on pin U.

3 Test Implementation

A DC power of 15 V is applied to the signal conditioning board.

An analog PWM signal set to an 80% duty cycle at 15 kHz is applied to the IN+ pin of the UCC21732-Q1. The input waveform is shown in Figure 3-1. The isolated gate driver boosts the input to a 15-V output on OUTA to drive the IGBT Module MOSFETs through pin 13.

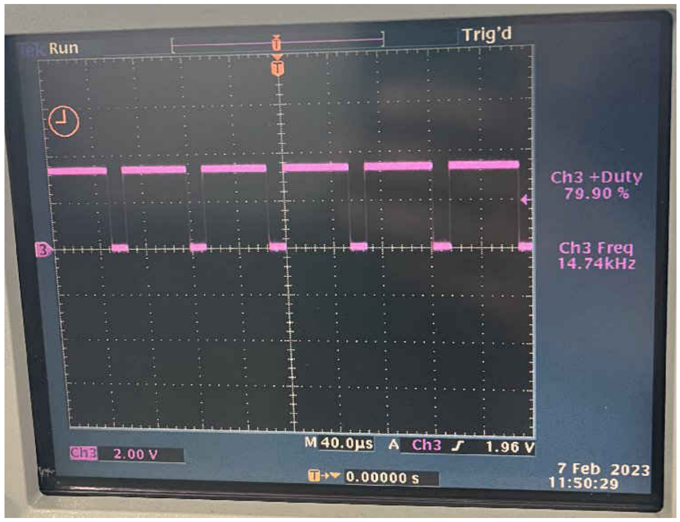


Figure 3-1. Input PWM Signal

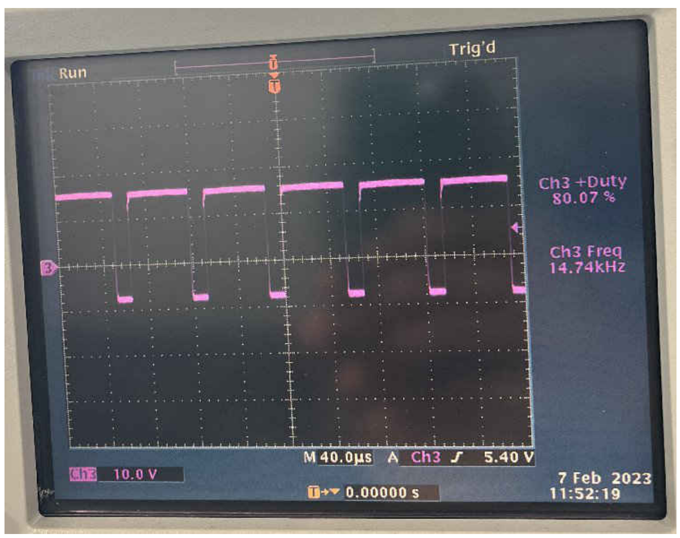


Figure 3-2. Output PWM Driver Signal

The analog inputs from the thermistors are measured to confirm that the correct temperature is reported. The software on the MSP430 converts the analog voltage to a temperature value for both the TMP6 and NTC ring lug thermistors. The temperature is output to the serial monitor, as shown in Figure 3-3.

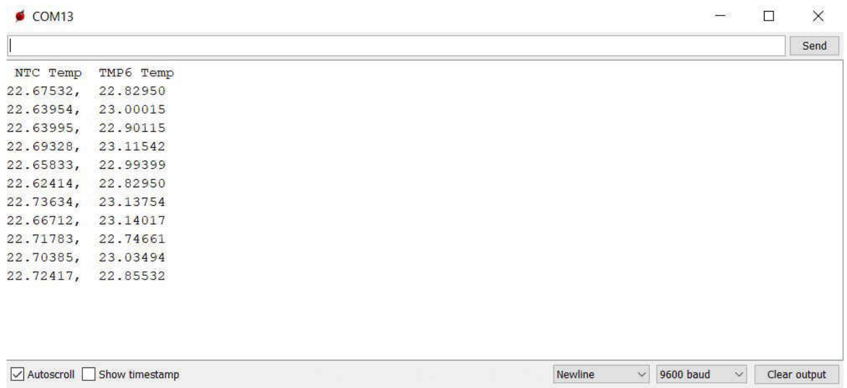


Figure 3-3. Thermistor Serial Data

After the initial measurements are confirmed, power is applied to the IGBT module. The IGBT module receives 15 V DC and 20 A.

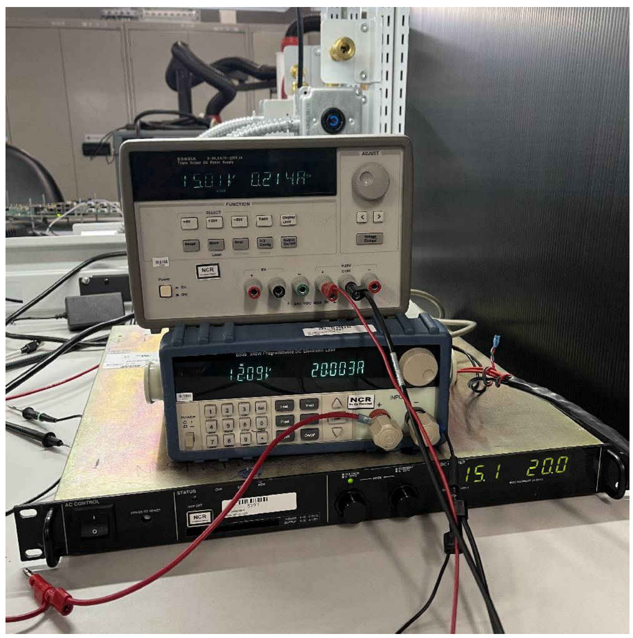


Figure 3-4. Load and DC Supplies

The oscilloscope measures the switching of the IGBT module and the temperature of the system, particularly the heat sink, which is monitored to make sure changes are occurring. The heat sink temperature steadily increases, increasing the temperature measurements from the ring lug thermistors.

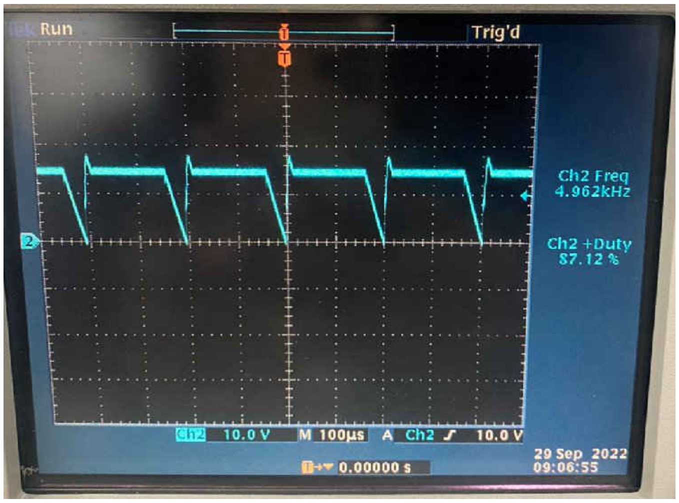


Figure 3-5. IGBT Module Output

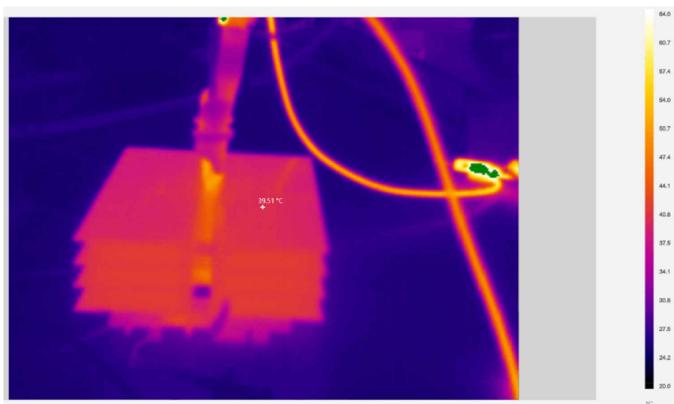


Figure 3-6. Heat Sink Temperature

The system is allowed to run and the heat sink temperature is monitored as the system begins to rise in temperature. Signal measurements are taken from both ring lug thermistors as well as thermal images of the ring lugs and heat sink.

3.1 Data Collected

After allowing the heat sink to run for 20 minutes, the temperature of the top of the heat sink, TMP6 ring lug, and NTC ring lug are collected using the FLIR thermal camera. As shown in Figure 3-7, the top of the heat sink measured 60.3°C. Figure 3-8 and Figure 3-9 show the TMP6 and NTC ring lug temperatures as 58.3°C and 58.8°C respectively. All temperatures corresponded well with each other.

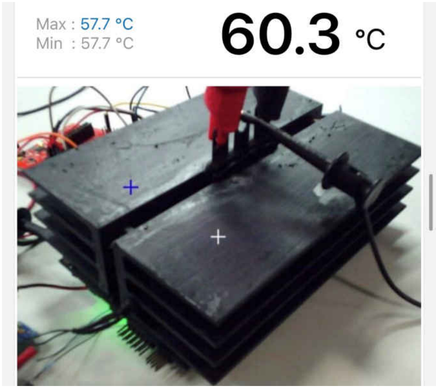


Figure 3-7. Heat Sink Final Temperature

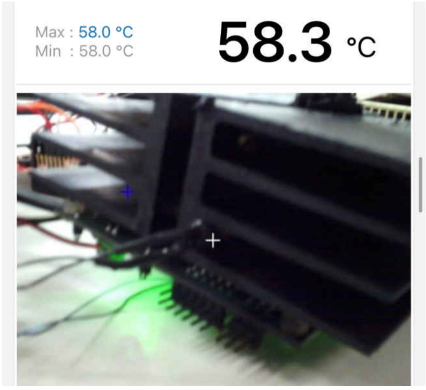


Figure 3-8. TMP6 Ring Lug Final Temperature

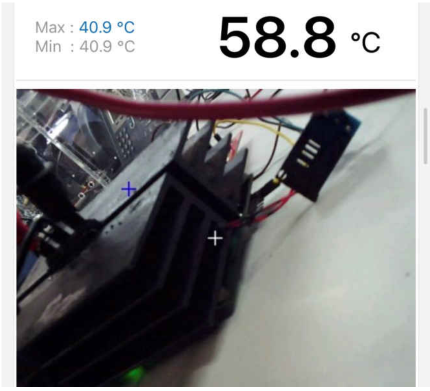


Figure 3-9. NTC Ring Lug Final Temperature

Table 3-1 shows the final temperatures recorded.

Table 3-1. Temperature Data

FLIR Thermal Image Data			Thermistor Voltage Feedback	
Heat Sink Temperature	TMP61 Ring Lug Temperature	NTC Ring Lug Temperature	TMP6 Reported Temperature	NTC Reported Temperature
60.3°C	58.3°C	58.8°C	53.5°C	46.3°C

3.2 Test Results

The data from Table 3-1 shows that although the temperature measured from the heat sink and ring lugs are quite similar (agree within 1°C to 2°C), the temperature information from the thermistors is not accurate to the same level. The temperature measurement of the TMP6 is approximately 5°C error from the measured ring lug temperature and ultimately 7°C error from the temperature measurement of the heat sink. The NTC reported temperature is less accurate, with 12°C error from the ring lug temperature and 14°C error from the temperature measurement of the heat sink. When comparing the reported temperature information from both the TMP6 and NTC, the TMP6 is 7°C more accurate than the NTC.

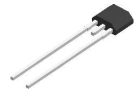
Although both the TMP6 and NTCALUG01A103FLA are specified as 1% tolerant thermistors, there can be a few reasons for the differences in temperature accuracy. The two main factors for temperature accuracy when using a ring lug configured thermistor are the ring lug itself and thermal epoxy used within the ring lug to conduct heat to the thermistor sensor. To control the test conditions and have a similar condition for both ring lug style thermistors, the same ring lug is used for both the NTC and TMP6. The only significant difference between the two ring lug style thermistors is the thermally conductive epoxy used. The thermally conductive epoxy is considered to be the biggest factor for differences in temperature accuracy.

4 Design Recommendations

Considering the two main factors for temperature accuracy are the ring lug itself and thermal epoxy, this section offers recommendations as well as considerations of the TMP6 when deciding on ring lugs to create a ring lug style thermistor.

4.1 Ring Lugs for the TMP6

Choosing a ring lug to create a ring lug style type thermistor requires evaluating several dimensions. This document covers the dimensions of the TMP6 LPG (TO92-S) package. Key dimensions of the TMP61 LPG package are a width of 3.9 mm – 4.1 mm across the package, a length of 1.42 mm – 1.62 mm from front to back of the package, and a distance of 2.44 mm to 2.64 mm between leads. The dominant dimensions are the width of 3.9 mm – 4.1 mm and the length of 1.42 mm – 1.62 mm. These dimensions determine which ring lugs are available for a given application.

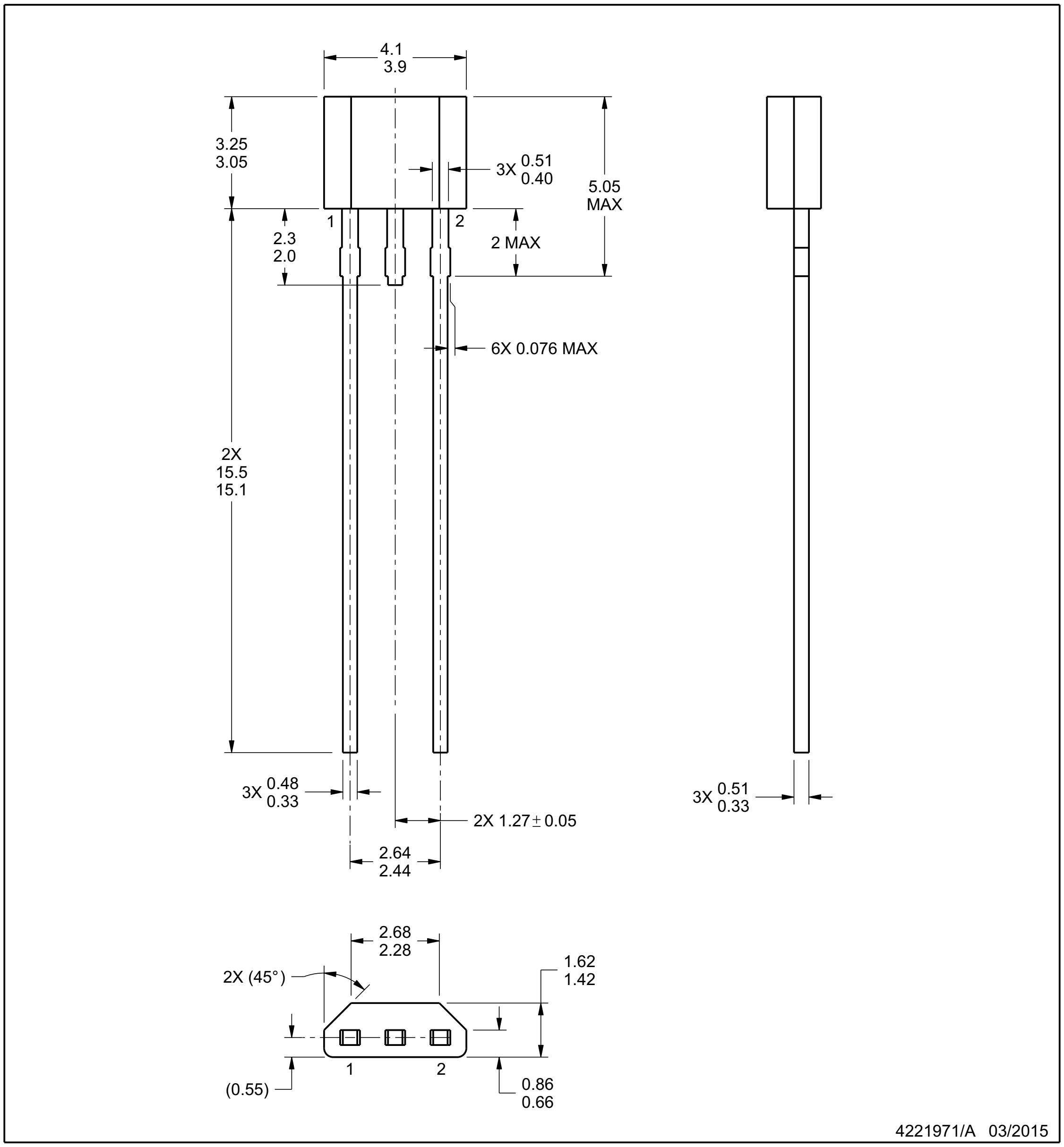


PACKAGE OUTLINE

LPG0002A

TO-92 - 5.05 mm max height

TO-92



NOTES:

1. All linear dimensions are in millimeters. Any dimensions in parenthesis are for reference only. Dimensioning and tolerancing per ASME Y14.5M.
2. This drawing is subject to change without notice.

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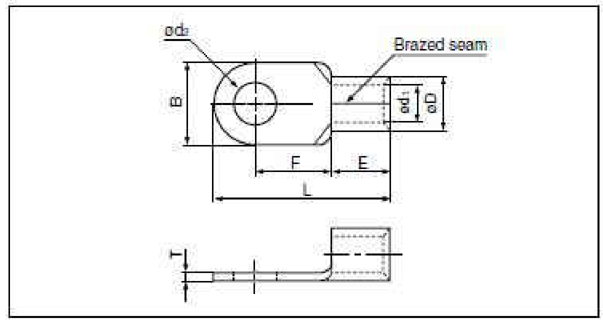
Figure 4-1. LPG (TO-92S) Package Outline

Solderless terminals

RING TONGUE (R type) *Non-Insulated*



Applicable Wire AWG# (mm²)	Stud size		Part No.		Standard	Dimensions mm (in.)								Tool No.	Qty/box
	American	Metric	JST	JIS		ød2	B	L	F	E	øD	ød1	T		
8 (6.64 to 10.52)	8	4	8-NK4		UL CSA	4.3 (.169)	9.0 (.354)	16.5 (.650)	5.8 (.228)	6.2 (.244)	7.1 (.280)	4.5 (.177)	1.2 (.047)	YHT-8S YA-4 YPT-60N YF-1 YET-60-1 E-4 (Note 2)	500
	8	4	8-4NS		UL CSA	4.3 (.169)	8.0 (.315)	21.8 (.858)	9.3 (.366)	8.5 (.335)				YHT-8S YA-4, YA-5 YPT-60N YPT-150-1 BCT-0514 BCT-860N BCT-8150 YF-1 YET-60-1 E-4 YET-150-1	1,000
	8	4	8-4		UL CSA	4.3 (.169)	12.0 (.472)	23.8 (.937)	9.3 (.366)	8.5 (.335)					500
	10	5	8-NK5		UL CSA	5.3 (.209)	9.0 (.354)	16.5 (.650)	5.8 (.228)	6.2 (.244)				YHT-8S YA-4 YPT-60N YF-1 YET-60-1 E-4 (Note 2)	
	10	5	8-5NS		UL CSA	5.3 (.209)	9.0 (.354)	22.3 (.878)	9.3 (.366)						1,000
	10	5	8-5	*R8-5	UL CSA JIS	5.3 (.209)	12.0 (.472)	23.8 (.937)	9.3 (.366)						500

Figure 4-2. JST 8-4

The data sheet for JST solderless non-insulated ring tongue terminals, provides many dimensions to consider for your design. The stud size is important depending on where you want to mount the ring lug terminal. Depending on the screw in use, the dimension d2 can also be helpful. Concerning the width of the TMP6 thermistor, verify that the width inside the ring tongue allows for the thermistor to fit inside (dimension d1).

From Figure 4-2, a good recommendation for a non-insulated ring tongue is the JST8-XX family. The JST8-4 can be a good fit because this ring tongue has an inside width of 4.5 mm that the TMP6 can fit within the ring tongue and leaves room for adding a thermal epoxy. The JST8-4 is also a size M4 stud size which allows enough room for mounting to heat sinks in your application.

4.2 Thermal Epoxy

A thermal adhesive inside the ring lug terminal is critical to maintain thermal conduction between the ring lug itself and the fit of the temperature sensor within. The thermal adhesive needs to have a high thermal conductivity; strong electrical insulation; resistivity to humidity, salt water, and mild bases; and an adhesive that bonds well to substances. MG Chemicals 8329TCM is recommended as a 2-part thermally conductive epoxy adhesive. This adhesive is often used as a heat sink glue or with other heat generating electronics components. If looking for an adhesive with lower viscosity, 8349TFM is sufficient.

5 Summary

In summary, TIDA-020030 is a reference design used to drive traction inverters which is employed to heat up a heat sink. The temperature of the heat sink is measured by both an NTC and TMP6 ring lug style thermistor. In the test implementation, an IGBT Module is driven by the PWM output drive signal from an isolated gate driver. The IGBT module heated up, resulting in an increase of heat sink temperature. The temperature of the heat sink is captured on a FLIR thermal camera and the temperature data of the ring lug style thermistors is recorded.

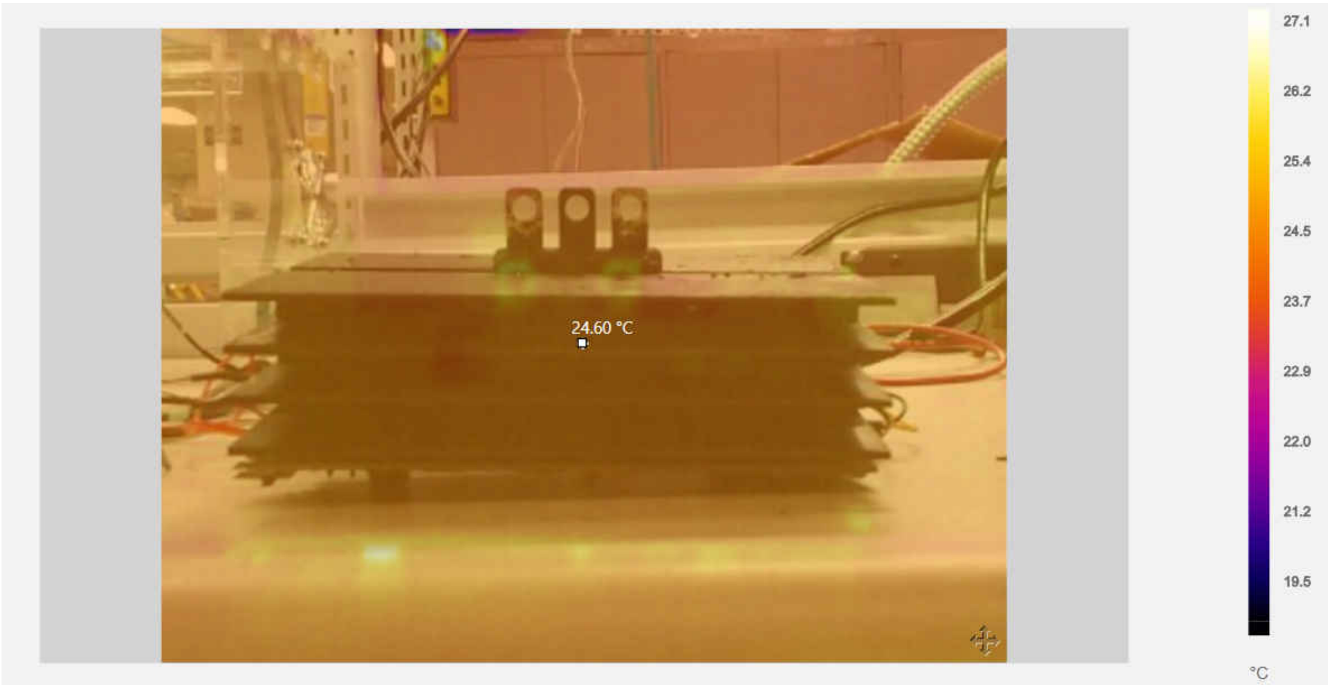


Figure 5-1. Test Hardware at Room Temperature

Figure 5-1 shows that initially, while at rest, the heat sink and ring lug style thermistors are at the same temperatures.

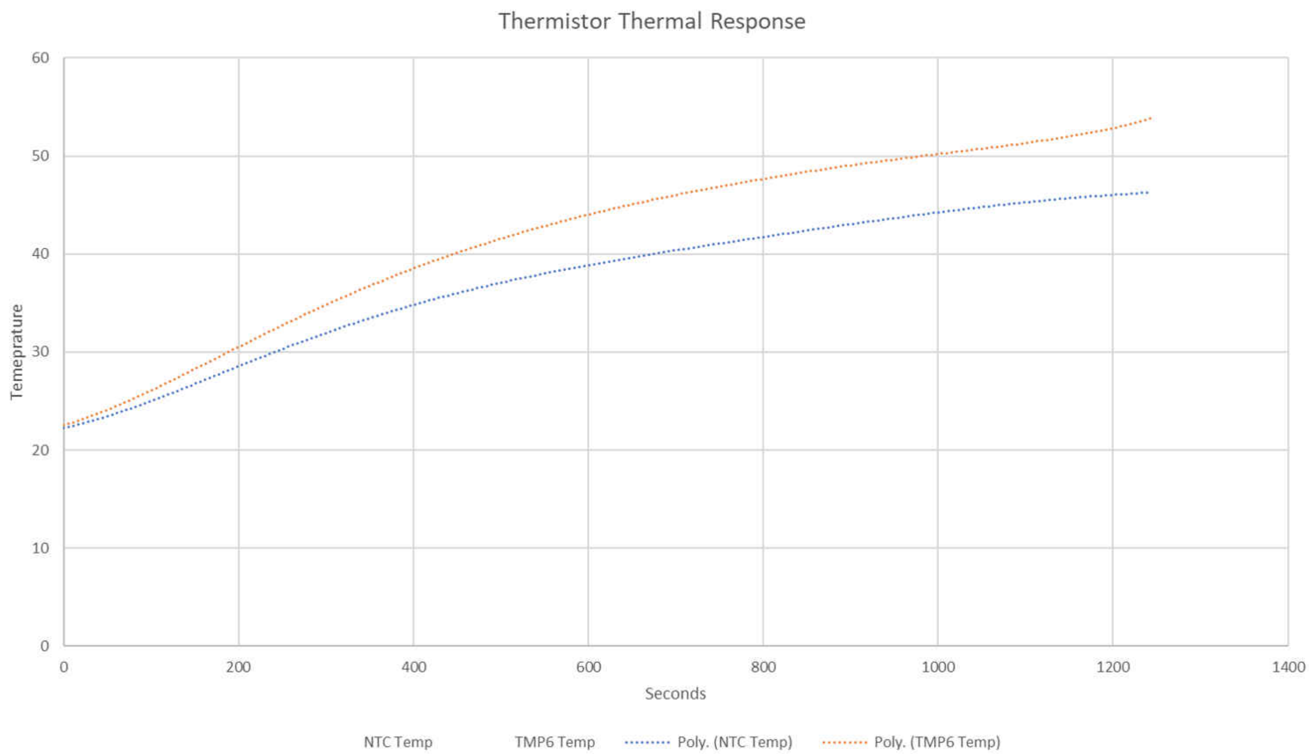


Figure 5-2. Thermistor Temperature Response

The temperature response of both thermistors is shown in Figure 5-2. The TMP6 and NTC temperatures diverged over time. At the start, the temperature sensors read the same initial value of approximately 22°C, but there is about a 5°C delta around 10 minutes where the TMP6 reads approximately 43°C and the NTC reads approximately 38°C. At the end of the test, the TMP6 thermistor reads 53.5°C while the NTC reads 46°C. With the heat sink measuring 60°C, the TMP6 provides a more accurate result by 7°C. The response plot shows that throughout the time period the TMP6 consistently provided a more accurate result.

6 References

1. Texas Instruments, *Reduce Bridge Measurement Offset and Drift Using the AC Excitation Mode in the ADS1235 and ADS1261* application brief

Mailing Address: Texas Instruments, Post Office Box 655303, Dallas, Texas 75265