Application Note

Temperature Monitor for Power Modules and Power Electronic Parts in CT MRI and Indutrial system

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ABSTRACT

Power modules and power parts such as IGBT, SIC-MOSFET, GaN-MOSFET, MOSFET are widely used in the medical system, the industry system, and the electric car system to generate a high voltage power supply to drive x-ray tubes, or drive large capacitance motors in electric car, and inverting a DC voltage from solar panel to AC voltage and then feed to a power grid. In all these systems, one issue is to monitor the temperature of power modules to keep the system running safely and reliably. In these systems, the temperature sensor must be close to a power module or heatsinks to obtain the precise temperature of power modules. However, power modules of these system generally run under a high voltage power supply and heatsink potential shorted with high voltage from a high voltage bus. This potential risk ask temperature monitor system isolated with power modules for protection control system safety. Another issue is that the temperature sensors must mount simply with heatsink or power modules. The third issue is low cost and compact size. This application note introduces several temperature monitor methods to meet power module temperature monitor requirements.

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1 Introduction

Power modules such as IGBT, SIC-MOSFET, GaN-MOSFET, MOSFET are widely used in medical, industry, electrical car systems. In an x-ray, CT, or MRI system, designers use IGBT or SIC-MOSFET to generate a large capacitance high voltage power supply to drive x-ray tubes or a power gradient amplifier. In power grid systems, engineers use IGBT or SIC-MOSFET to inverter DC voltage from solar panel to AC voltage and then feed to power grid. In electrical car systems, engineers use SIC-MOSFET or IGBT to drive motors. In all these systems, power modules generate a lot of thermal energy and this potentially increases fail rate and reduces system reliability if the designer has not properly sprayed the thermal. To keep power electronic systems running safety, designers generally must monitor the temperature of power modules to protect the power modules from failure and then improve system reliability.

1.1 Temperature Monitor for Power Modules and Power Electronic Parts

Many modern power modules have one to three integrated NTC internal thermistors for monitoring internal temperature of IGBT or SIC-MOSFET with precision. See Figure 1-1 and Figure 1-2. However, most discrete power electronic parts do not have an integrated temperature sensor. In the actual design, engineers are required to monitor the temperature of the heatsink or surface temperature of power parts to deduce the temperature of the junction of an IGBT or MOSFET. In general, the heatsink is mounted with a thermal pad of power electronic parts and which potentially shortened with a high voltage bus. This potential need to keep the temperature monitor circuit keeps the control system safe since the temperature sensor potential is mounted with a heatsink or power electronic parts.

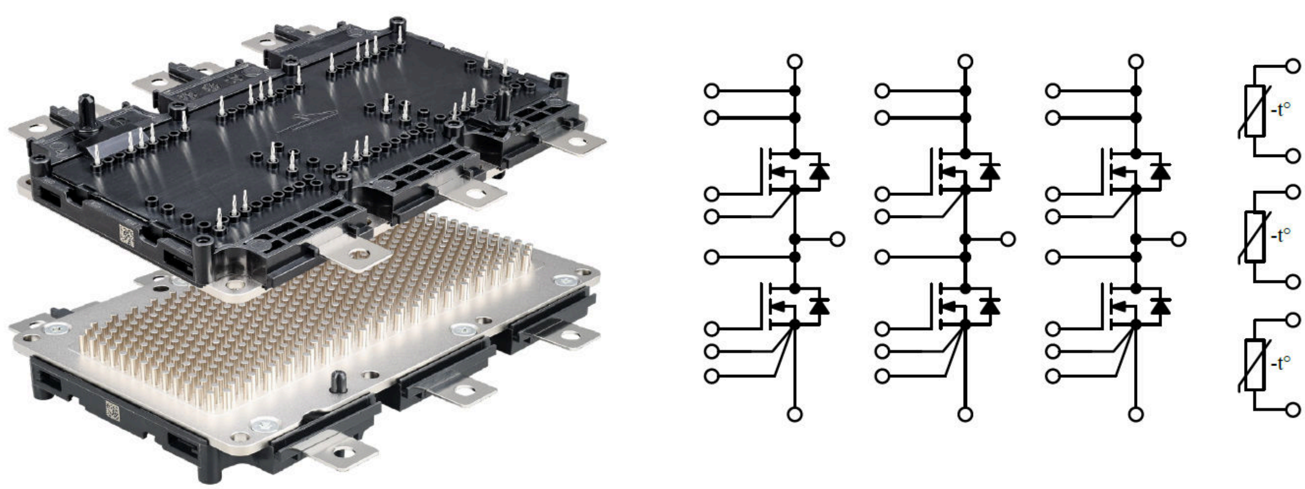

Figure 1-1. Wolfspeed SIC-MOSFET ECB2R1M12YM3

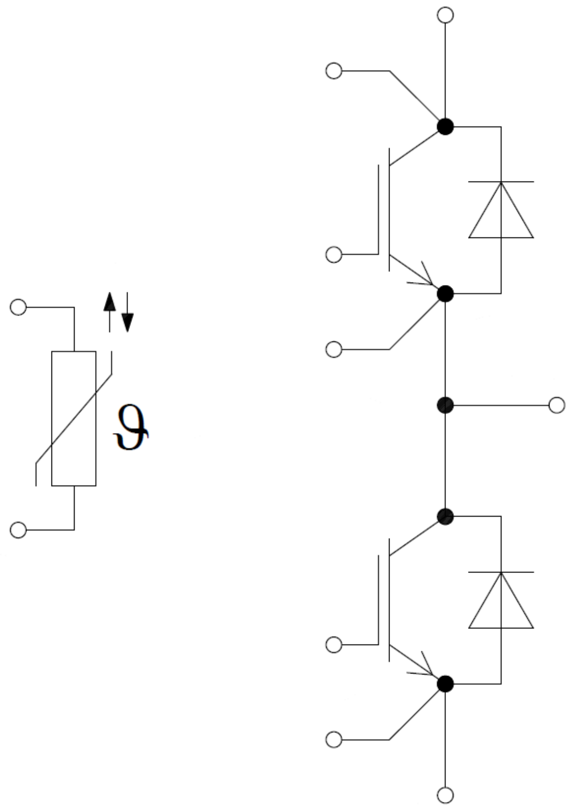

Figure 1-2. Infineon IGBT FF300R12ME7_B11

1.2 Key Factors to Consider to Monitor Temperature of Power Parts

For monitor temperature of power electronic parts, the designer must consider safety first since the sensor can potentially short with high bus voltage. The second factor is to select a temperature sensor for a simple mount with heatsink or power parts. There are many temperature sensors on the market, but many of these temperature sensors are surface mount sensors and not simple to mount with heatsink or power parts. The third factor is proper precision, simple circuit, and so on.

2 Methods to Monitor Power Module Temperature

TI has many temperature sensors and signal conditional circuits that can meet power module temperature monitor requirements. Because of these miscellaneous packages for these temperature sensors, designers can select through hole package for a simple mount with heatsink or power parts. The following section of this application shows three methods to monitor temperature of heatsink or power parts under safety and simple mounting constrain conditions.

2.1 Temperature Monitor with Through Hole Digital Temperature Sensor

The first method to monitor temperature of heatsink or power parts is using a digital temperature sensor with a digital isolator. LMT01 is a high-accuracy, 2-pin through hole or surface mounting temperature sensor with a pulse count current loop interface, which makes the sensor designed for heatsink or power parts temperature monitor. LMT01 digital pulse counts output and high accuracy over a wide temperature range, which allows for pairing with any MCU or FPGA without concern for integrated ADC quality or availability, while minimizing software overhead. TI's LMT01 device achieves a maximum ±0.5°C accuracy with very fine resolution (0.0625°C) over a temperature range of –20°C to +90°C without system calibration or hardware and software compensation.

The LMT01 temperature output is transmitted over a single wire using a train of current pulses that typically change from 34µA(0) to 125µA(1). A simple resistor can then be used to convert the current pulses to a voltage. With a 10kΩ resistor, the output voltage levels range from 340mV to 1.25V, typically. A simple microcontroller comparator or external transistor can be used convert this signal to valid logic levels which the MCU or FPGA can process properly through a GPIO pin. For monitor power parts temperature with a safety constrain, a digital isolator must be used between MCU/FPGA and the heatsink or power parts. The proposed system solutions as shown in Figure 2-1. The ISOW7821 digital isolator is selected for this example. ISOW7821 integrated an isolated high efficiency power supply that can source 75mA current at 3.3V power supply and enough to power LMT01.

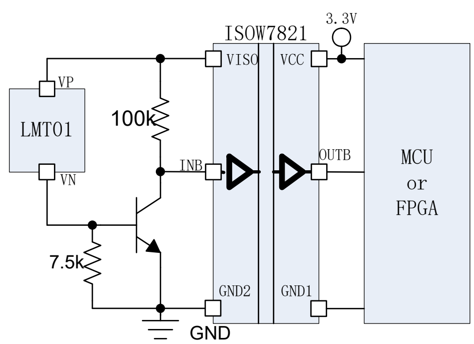

Figure 2-1. Use LMT01 to Monitor Temperature of Power Electronic Modules

The designer can use two different methods to obtain the temperature from LMT01. The first method is the least accurate and uses a first order equation, and the second method is the most accurate and uses linear interpolation of the values found in the look-up table (LUT). For power parts temperature monitor, the precise of first order equation is accepted and sufficient. If designer requires less than ±0.4C precise, the look up table method must be used. The output transfer function is linear and can be approximated with Equation 1

$$Temp = \left(\frac{PC}{4096} \times 256^{o}C\right) - 50^{o}C \quad (1)$$

Where: PC is the Pulse Count and Temp is the temperature reading.

The total time for LMT01 to implement temperature to digital conversion and the pulse train time interval is 104ms (maximum). If power is continuously applied, the pulse train output repeats every 104ms (maximum). This is sufficient for a temperature monitor since temperature variation is slow in general.

2.2 Temperature Monitor with Analog Temperature Sensor and Isolated Amplifier

The second method that a designer can use is an analog temperature sensor with isolated amplifier to measure the temperature of heatsink or power parts. LM35 is a precision integrated-circuit temperature sensor with an output voltage linearly proportional to the Centigrade temperature. The LM35 device has an advantage over linear temperature sensors calibrated in Kelvin, as the user is not required to subtract a large constant voltage from the output to obtain convenient Centigrade scaling. LM35 does not require any external calibration or trimming to provide typical accuracies of ±0.25°C at room temperature and ±0.75°C over a full −55°C to +150°C temperature range. The function between output voltage and ambient temperature of LM35 as Equation 2 shows.

$$V_{out} = 10mV/^{o}\text{C} \quad \times T \tag{2}$$

Where: V_{OUT} is the LM35 output voltage and T is the temperature in °C. The features of the LM35 are designed for many general temperature sensing applications and remote temperature sensing applications. Multiple package options expand on flexibility. For sensing temperature of heatsink or power parts, select the TO92 or TO220 package for simple mounting.

Power parts often are running in high voltage system. Isolation between high voltage and control system is adopted for the safety monitor temperature of power parts. AMC1350 is a precision isolated amplifier with an output separated from the input circuitry by an isolation barrier that is highly resistant to magnetic interference. A ±5V input range can help AMC1350 match with most analog temperature sensors. AMC1350 is a device designed for this application. To power supply the input side of AMC1350 and LM35, the UCC33420 isolated power module was proposed for this example. The proposed is designed based LM35, AMC1350, and UCC33420 as Figure 2-2 shows. TLA2022 is a12 bit differential input SAR ADC with IIC interface.

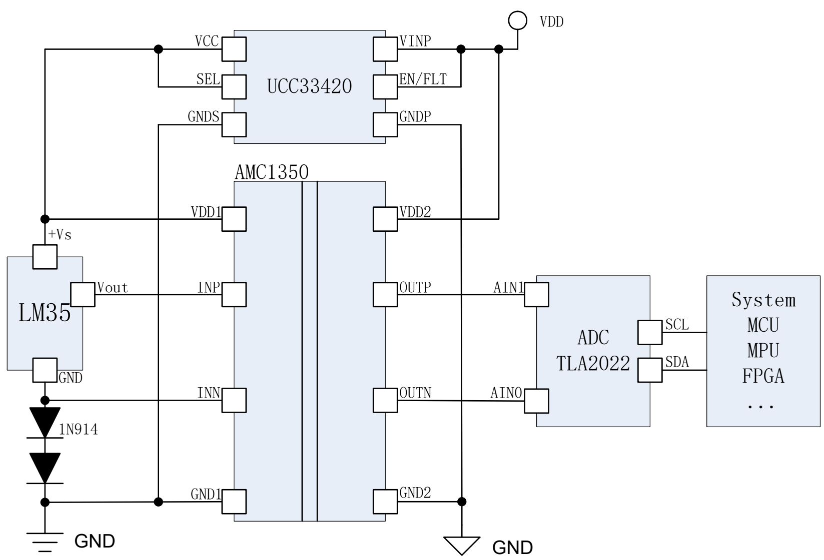

Figure 2-2. Sensing Temperature of Power Electronic Parts with LM35 Analog Temperature Sensor

2.3 Temperature Monitor with NTC Thermistor

In a lot of large capacity power electronic equipment, power parts have integrated one or three NTCs to monitor power parts' temperature and improve system reliability. Then temperature sensors are not required, but an external signal condition circuit is required. A traditional signal condition circuit for measuring NTC resistance is a resistor divider or bridge circuit. See Figure 2-3 and Figure 2-4. Both circuits require an external precise voltage reference which results in increased cost and large package size. The second issue is non-linear between reference voltage and output. For resistor dividers, a large amount of common voltage is another issue and this causes less resolution. For bridge circuits, an external instrument amplifier is required, which also increases cost.

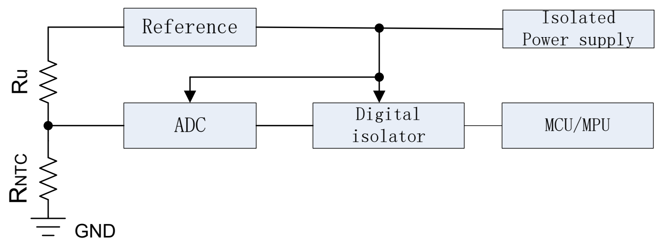

Figure 2-3. Block Figure of Resistor Divider to Monitor Temperature of Power Electronic Parts with Internal NTC Resistor

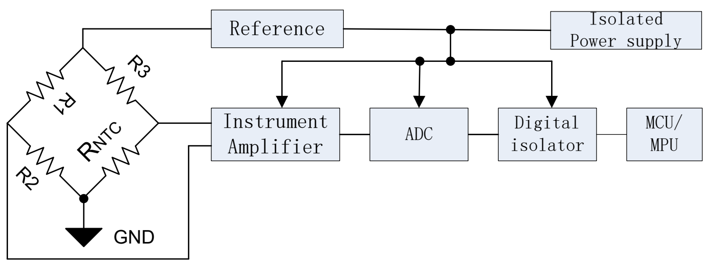

Figure 2-4. Block Figure of Bridge to Monitor Temperature of Power Electronic Parts with Internal NTC Resistor

ADS124S08 is a 12-channel input ADC with 24 bit resolution and integrates two adjustable constant current sources for excite NTC and compensation wire resistance. ADS124S08 can interface with 3 NTCs directly. At any time, just one NTC permits to be tested. And for the remain NTCs that is not testing, the internal MUX of corresponding channels must be switched off. See Figure 2-5 for system designs. ISOW7741 is a digital isolator with integrated power supply modules and can be used to power supply ADS124S08. The second function of ISOW7741 cooperates with the ISO7720 digital isolator to interface with an ADS124S08 SPI interface.

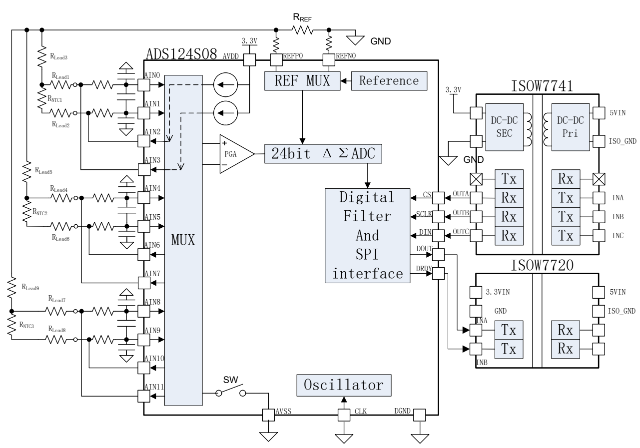

Figure 2-5. ADS124S08 Interfaces with Three Internal NTCs of Power Electronic Parts

See the ADS124S08 data sheet. The function between the reference resistor and the NTC resistance is shown in Equation 3

$$D = \frac{V_{NTC}}{V_{REF}} \times 2^{24} = \frac{I_{Excite} \times R_{NTC}}{2 \times I_{Excite} \times R_{REF}} \times 2^{24} = \frac{R_{NTC}}{R_{REF}} \times 2^{23} \quad (3)$$

so:

$$R_{NTC} = \frac{D}{2^{23}} \times R_{REF} \quad (4)$$

If power modules have only integrated one NTC for temperature monitor, ADS122C04 is a preferred design. This device is similar to ADS124S08 but with 4-channels input, and integrated two constant current sources to excite NTC and IIC to interface with MCU or FPGAs. ISO1642 is a preferred digital isolator for safety operating ADS122C04. The function for obtaining the resistance of the NTC is exactly the same as ADS124S08. See the ADS122C04 data sheet for more information. Figure 2-6 shows a system design for monitor temperature of half bridge IGBTs.

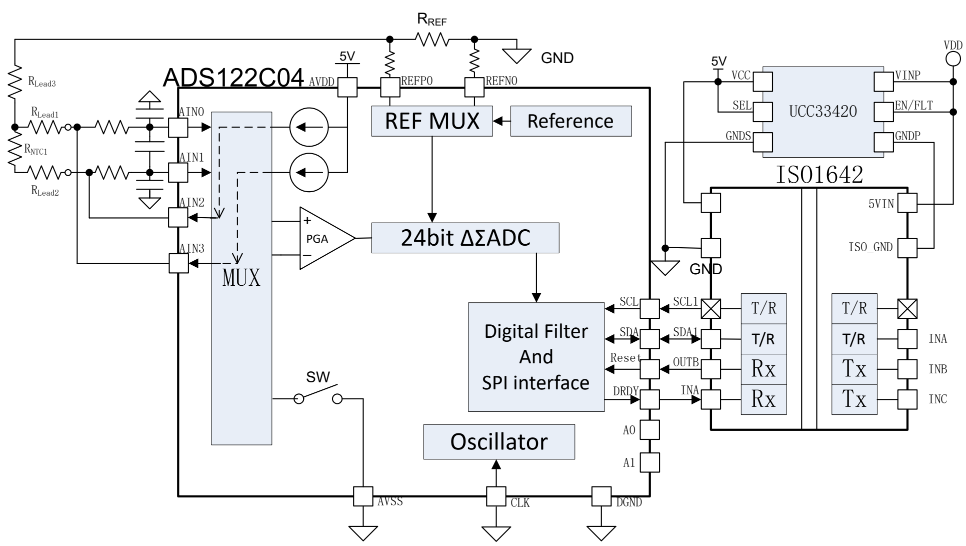

Figure 2-6. ADS122C04 Interfaces with Internal NTCs of Power Electronic Parts

3 Summary

Power modules and a power parts temperature monitor are important for keeping power electronic systems running safely especially for large capacity power electronic system. For power parts without an integrated temperature sensor, LMT01 and LM35 is a preferred temperature sensor for high precise, simple mounting with heatsink or power parts. For power modules that have integrated NTCs, ADS124S08 and ADS122C04 are a preferred signal condition circuit for better linear, better precision, wire compensation, integrated excite constant current source and then small package. Consult associated data sheet for more detailed information. TI has a series of ADCs similar to ADS124S08 but with different resolutions, input channel, and interface to meet customer miscellaneous requirements. Consult an FAE or visit for more detailed information.

4 References

1. Texas Instruments, *A Basic Guide to RTD Measurements*, application note.
2. Texas Instruments, *Designing Temperature Monitoring Systems with NTC and RTD*, application note.
3. Texas Instruments, *LMT01 0.5°C Accurate 2-Pin Digital Output Temperature Sensor with Pulse Count Interface*, data sheet.
4. Texas Instruments, *ISOW7821 High-Performance, 5000 VRMS Reinforced Dual-Channel Digital Isolator with Integrated High-Efficiency, Low-Emissions DC-DC Converter*, data sheet.
5. Texas Instruments, *LM35 Precision Centrigrade Temperature Sensors*, data sheet
6. Texas Instruments, UCC33420 Ultra-Small, 1.5W, 5.0V, 3kVRMS Isolation, Industrial DC/DC Module, data sheet.
7. Texas Instruments, *AMC1350 Precision ±5V Input, Reinforced Isolated Amplifier*, data sheet
8. Texas Instruments, *ADS124S0x Low-Power, Low-Noise, Highly Integrated 6- and 12-Channel, 4-kSPS, 24-Bit, Delta-Sigma ADC with PGA and Voltage Reference*, data sheet.
9. Texas Instruments, *ISOW774x Quad-Channel Digital Isolator with Integrated Low-Emissions, Low-Noise DC-DC Converter*, data sheet
10. Texas Instruments, *ISO772x High-Speed, Robust EMC, Reinforced and Basic Dual-Channel Digital Isolator*, data sheet.
11. Texas Instruments, *ADS122C04 24-Bit, 4-Channel, 2-kSPS, Delta-Sigma ADC with I2C Interface*
12. Texas Instruments, *ISO164x Hot-Swappable Bidrectional I2C Isolators with Enhanced EMC and GPIOs*, data sheet.
13. Texas Instruments, *TLA202x Cost-Optimized Ultra-Small, 12-Bit, System-Monitoring ADCs*, data sheet.

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