Using Thermistors to Optimize the Thermal Performance of IGBT Modules

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Introduction

The Insulated Gate Bipolar Transistor (IGBT) is a device widely used in switched-mode power supplies and traction motor systems. IGBTs play a critical role in application spaces such as electric vehicles, renewable energy, airplanes, naval ships, CT and MRI scanners, and building automation.

IGBTs typically operate in applications that have switching frequencies of less than 100 kHz, power consumption greater than 5 kW, and operating temperatures exceeding 125°C. Thus, IGBTs require thermal monitoring and protection to ensure the safety and reliability of the system. Thermistors have been widely used as thermal management solutions due to their low cost and reliable performance.

Thermal Safety With IGBTs

An IGBT uses the input voltage controlled feature of a MOSFET, but has the output switching and conduction characteristics of a BJT. Multiple IGBT dies are often closely packaged together, which can increase the junction temperature. By using thermistors to monitor the temperature inside the module, the output can be safely managed and optimized.

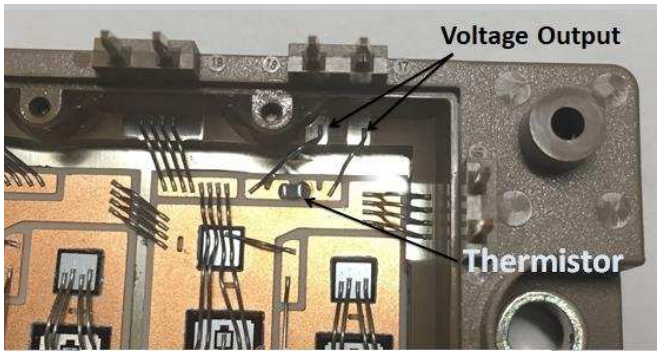

Figure 1. Thermistor in an IGBT Module

High temperatures in IGBTs can indicate overloads or faults, such as phase-to-phase short circuits, phase-to-earth short circuits, or shoot-through effects. Typically, a thermistor is integrated on its own island in the module for electrical isolation. Use Figure 1 as an example.

Failure to properly monitor the temperature can increase safety hazards and reduce the operational lifetime of the IGBT module system.

Thermistors for Temperature Monitoring

Thermistors are passive components that change resistance with a change in temperature. Typically, thermistors are either placed on the bottom of the voltage divider or biased by a constant current source as shown in Figure 2.

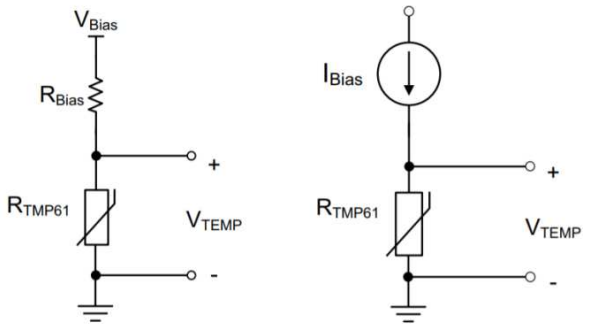

Figure 2. Thermistor Current and Voltage Biasing Circuits

There are two types of thermistors that can be used for this application: Negative Temperature Coefficient (NTC) and Positive Temperature Coefficient (PTC). NTCs are inherently nonlinear, making it difficult to achieve high accuracy over the whole temperature range. At high temperatures, the ratio of volts per degree diminishes, and the resolution is coarse due to noise and errors. Such effects of non-linearity are often managed through the use of hardware and software-based linearization methods. Unlike NTCs, silicon-based PTCs have a positive linear shift in resistance with an increase in temperature.

As a result of its lower resistance at high temperatures, an NTC draws more current from the constant biasing voltage. This leads to a higher self-heating error compared to PTCs. These characteristics are shown in Figure 3, which compares the linearity of the PTC versus the NTC.

When designing a temperature-monitoring circuit, the system must account for errors like the tolerance of the components, system complexity, and the analog-to-digital converter (ADC) resolution. These errors can greatly influence the thermistor output and compromise the safety of the system.

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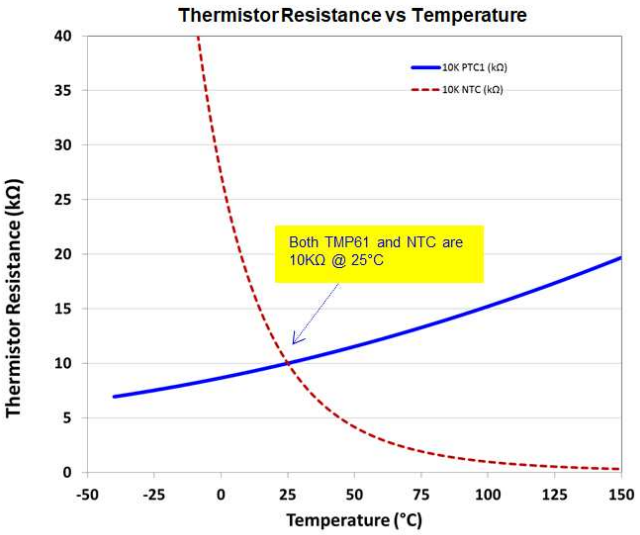

Figure 3. Resistance vs Temperature of PTC vs NTC

At higher temperatures, NTCs are more susceptible to these errors due to their lower voltage per degree than PTCs as shown in Figure 4.

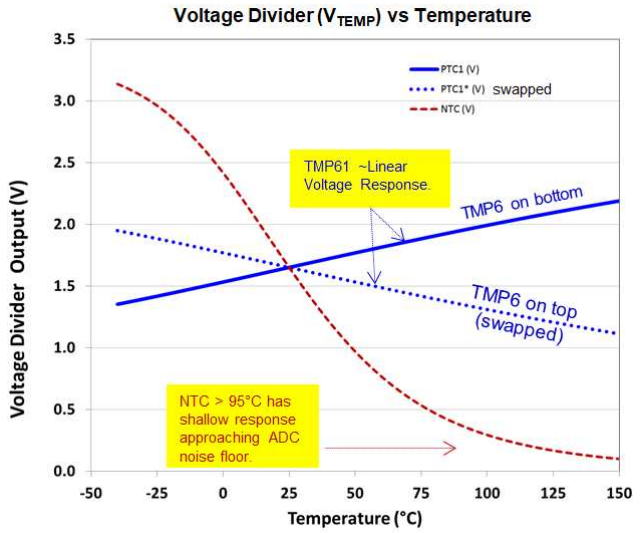

Figure 4. Voltage Biased Output of PTC vs NTC

In some applications, the PTC can be placed on the high side of the voltage divider circuit if a negative slope characteristic is preferred. This outputs a linear inverse slope that requires less calibration than the nonlinear NTC (see Figure 4).

Furthermore, if an NTC is disconnected from the system due to poor layout or other mechanical stresses, the microcontroller (MCU) or microprocessor (MPU) will read a low temperature due to the open circuit (high resistance) (see Figure 3).

If a PTC is disconnected from the system, however, the MCU/MPU will read a high temperature and take necessary actions for protection, increasing the overall reliability and safety of the module.

Conditioning Circuit

There are many factors used to calculate the system accuracy. A thermal monitoring system error includes thermistor tolerance and nonlinearity, bias resistor temperature drift, ADC quantization errors, and reference voltage fluctuations. Due to the PTC linearity across the wide operating range, the linearization error is much lower than that of NTCs. NTCs also require an extensive lookup table or a high-order polyfit to accurately convert the system ADC output values to a human readable temperature. In contrast, silicon-based PTCs have much smaller lookup tables that use less memory on the MCU/MPU. By using PTCs, errors and overall system costs are minimized. Figure 5 shows the typical block diagram for a PTC-conditioning circuit in an IGBT module system. Using PTCs to reduce system errors can increase the performance and reliability of IGBT modules.

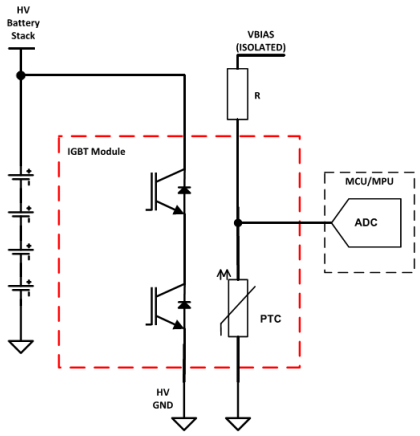

Figure 5. PTC-Conditioning Circuit

Device Recommendations

The TMP61 is a silicon-based PTC thermistor designed for temperature measurement, protection, compensation, and control systems. The TMP61 has a tolerance of ±1% between –0°C to 70°C, and a wide operating range of –65°C to 150°C. Compared to traditional NTCs, the TMP61 offers enhanced linearity and consistent sensitivity across the full temperature range.

Table 1. Related Documentation

COLLATERAL	DESCRIPTION
Data Sheet	*TMP61 Silicon-Based Linear Thermistors*
Tech Note	*Methods to Calibrate Temperature Monitoring Systems*
Application Report	*Methods to Reduce Thermistor Linearization Error, Memory, and Power Requirements Over Wide Operating Temperature Ranges*

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