Application Note

Meeting ASIL Requirements for LIDAR Systems Using Remote Temperature Sensors

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Temperature and Humidity Sensing

ABSTRACT

Functional safety is a key requirement in automotive systems, especially in advanced driver assistance systems. The automotive industry uses a safety rating system known as Automotive Safety Integrity Levels (ASILs), and light distance and ranging (LIDAR) systems often require the highest grade of ASIL-D. Because temperature sensors used in these applications are often single-function devices, these safety demands are typically met by using redundant and diverse temperature sensors, whose signals are then compared on a microcontroller. LIDAR systems make this challenge more complex because several components in the design require temperature monitoring. TI's automotive remote temperature sensors simplify this challenge of redundancy and diversity to achieve ASIL ratings by monitoring multiple temperatures with flexibility and ease. This application report discusses the importance of temperature monitoring in LIDAR systems, and provides design examples for meeting ASIL requirements using remote temperature sensors.

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1 Introduction

LIDAR systems contain several critical components such as the laser arrays, time-of-flight sensors, and an MCU or processor. Monitoring the temperature of these components is essential for proper operation of the system. For example, LIDAR designs typically have two or more laser arrays and at temperatures above 70°C, the performance of each laser array will vary and require compensation. The time-of-flight sensor relies on optics, which has a different focus as temperatures change, making temperature monitoring crucial. Lastly, processors often become temperature sensitive around 105°C or higher. At high temperatures, designers may choose to lower the clock rate of the processor or shut it down to prevent overheating. Monitoring the temperatures of these components enhances safety and reliability and helps meet the ASIL requirements of LIDAR systems.

ASILs are established in ISO 26262 and specify the applicable requirements and safety measures needed to avoid unreasonable residual risk. The four ASIL levels range from A to D, with A representing the least stringent level and D the most stringent level. Depending on the specific function of the system within the vehicle, LIDAR systems can require up to an ASIL-D grade. Because temperature sensors used in these applications are often single-function devices, these safety standards are met using redundant and diverse temperature sensors. Redundancy means there are at least two temperature sensors where monitoring is needed, and the devices at each location may also connect to separate communication buses. Diversity ensures that the temperature sensors are as different as possible for safety reasons, and it can be introduced into the design in many ways (for example, differences in fabrication, packaging, die, common mode faults, and so forth). TI offers several options to achieve various levels of diversity depending on the requirements of the design.

There are different methods for meeting these temperature monitoring challenges, two of which are discussed in this application report. Option 1 is to use two thermistors or analog temperature sensor ICs at each location where temperature monitoring is needed. Option 2 is to use remote temperature sensors, which incorporate a local temperature sensor and remote channels for monitoring the temperature of another location. As is discussed, option 2 optimizes this design by using TI’s automotive remote temperature sensors to monitor several temperatures with high accuracy and fewer components.

2 LIDAR Temperature Sensing Solution Using Thermistors or Analog Temperature Sensor ICs

Thermistors are commonly used to meet the temperature monitoring requirements of LIDAR systems. Designers can use two TI thermistors—for example, one TMP61-Q1 and one TMP63-Q1—at each location where temperature monitoring is needed to satisfy redundancy, as shown in Figure 2-1.

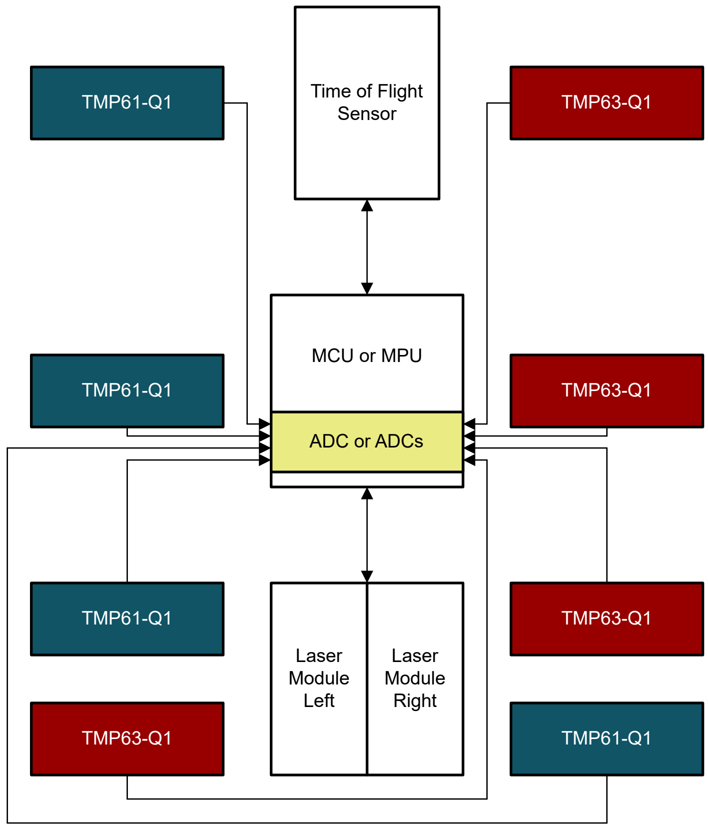

Figure 2-1. Simplified LIDAR Block Diagram With Temperature Monitoring Using TMP6 Linear Thermistors

Redundancy is achieved by having two temperature sensors monitoring the time-of-flight sensor, two monitoring the MCU or processor, and two monitoring the left and right laser modules. The sensors at each location connect to channels of the ADCs which are compared by the MCU or processor. Depending on system architecture, the thermistors may connect to the same ADC, separate ADCs, or both ADCs.

The TMP61-Q1 and the TMP63-Q1 are linear thermistors with different R_{25} values of 10 kΩ and 100 kΩ, respectively, which contribute to the diversity of the design. Using different package types of the TMP61-Q1 and the TMP63-Q1 can also add to the diversity of the sensors. The TMP61-Q1 Functional Safety FIT Rate and FMD application report shows the TMP61-Q1 has a FIT rate of 3 and failure mode of "open", which increases the safety of the system and makes it easier to detect failures.

Although a design using only thermistors is inexpensive, some disadvantages include the use of more external circuitry to bias the device and the inability to use any integrated thermal transistors that may be in the components of the LIDAR system. Additional work is also required to achieve high accuracy because thermistors are discrete devices and the total temperature sensing accuracy depends on the tolerances and PPM error of the other components in the circuit. However, if a designer still prefers a low-cost analog temperature sensing solution and wants more diversity, another option is to use one TMP61-Q1 and an integrated analog temperature sensor like TI's TMP235-Q1, as shown in Figure 2-2. Analog temperature ICs provide the reduction of external components, assuring accuracy to the data sheet specification without calibration, and an integrated output driver. Additional information is available in the TMP23x-Q1 Functional Safety FIT Rate and FMD application report.

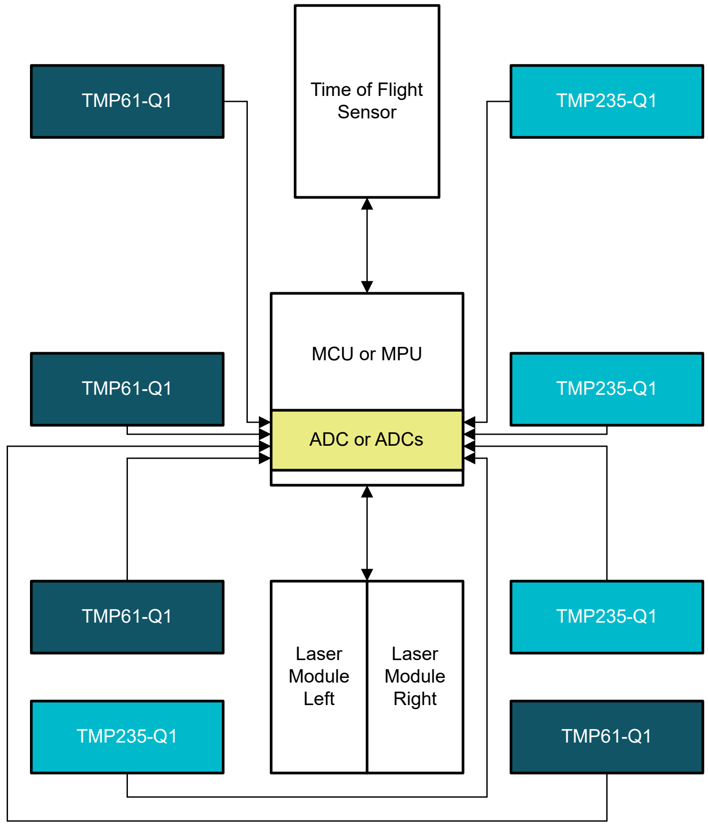

Figure 2-2. Simplified LIDAR Block Diagram With Temperature Monitoring Using the TMP61-Q1 and TMP235-Q1

3 LIDAR Temperature Sensing Solution Using Remote Temperature Sensors

TI's digital remote temperature sensors measure the local temperature of the device and sense the junction temperature of either an NPN or PNP bipolar junction transistor (BJT). The BJT can be an integrated transistor in an MCU, GPU, ASIC, FPGA, or a discrete transistor. Figure 3-1 shows a typical application of TI's TMP451-Q1 automotive remote temperature sensor.

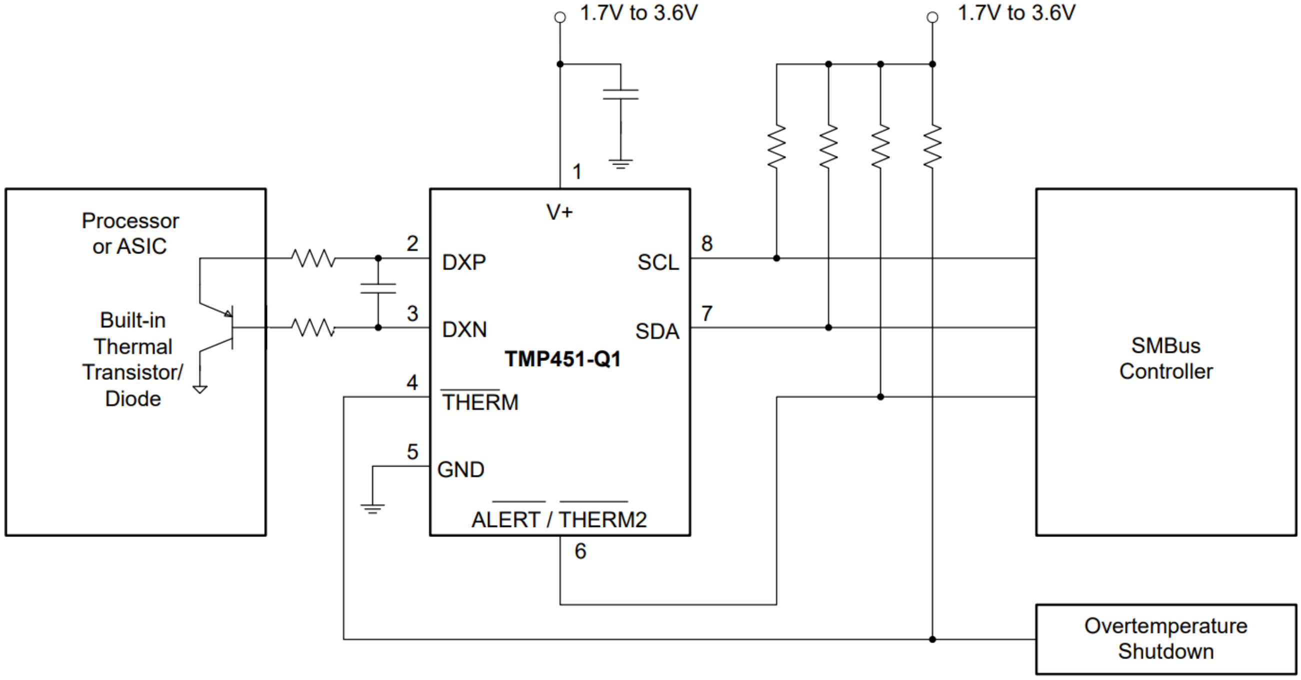

Figure 3-1. Typical Application of TMP451-Q1 Automotive Remote Temperature Sensor

This device and TI's other remote sensors are ideal for multi-location, high-accuracy temperature measurements. Using remote temperature sensors is particularly beneficial in LIDAR applications because the MCU or processor, time-of-flight sensor, and other components may have built-in thermal transistors or diodes that can be used to measure their temperature. Remote channels of the temperature sensors allow the use of these built-in transistors, which prevent the need for another external sensor and have a better response time because they measure the die temperature directly.

For components that do not have integrated thermal transistors, the local temperature sensor or the remote channel with a discrete thermal transistor can still be used for temperature monitoring. When using the remote channel of the temperature sensor with an integrated or discrete thermal transistor, it is important to ensure that the sensor is optimized for the most accurate temperature readings. For more information on optimizing remote temperature sensors, see the *Optimizing Remote Temperature Sensor Design* application report. Like the TMP61-Q1, TI also provides the *TMP451-Q1 Functional Safety FIT Rate and FMD* functional safety information to aid in system-level functional safety certification.

3.1 Example Block Diagrams

Consider the simplified LIDAR system block diagram shown in Figure 3-2, with the MCU or processor, the time-of-flight sensor, and the laser array. Each of these components requires redundant and diverse temperature monitoring to meet safety requirements. As a result, at least two temperature sensing elements are needed for each component, and each of those temperature sensing elements must be diverse.

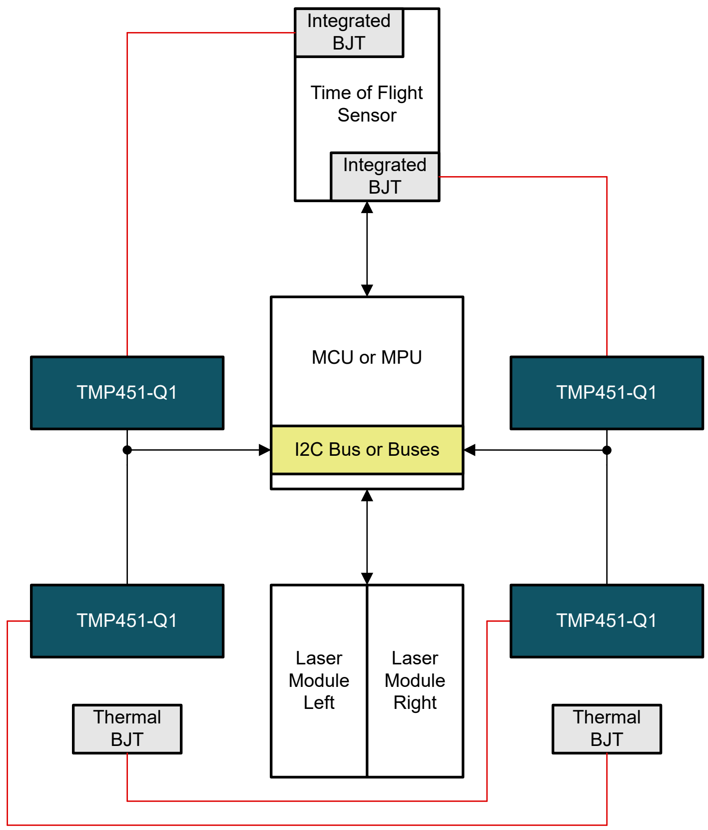

Figure 3-2. Simplified LIDAR Block Diagram With Temperature Monitoring Using TMP451-Q1 Remote Temperature Sensors

In this design, the MCU or processor temperature is monitored by two TMP451-Q1 remote temperature sensors, satisfying the redundancy requirements for monitoring the temperature of that component. The remote channels (shown in red) of those two sensors are connected to two different integrated thermal transistors inside the time-of-flight sensor, meeting the redundancy and diversity requirements for that device. As a result, no additional external components are needed to monitor the temperature of the time-of-flight sensor. Lastly, two TMP451-Q1 sensors monitor the temperature of the laser modules. The remote channels of each sensor are connected to discrete thermal transistors (PNP or NPN) on the opposite laser module, achieving redundancy and diversity in monitoring the temperature of the laser modules. Although the same temperature sensor is used throughout this design, using two different packages of the TMP451-Q1 can contribute to the diversity requirement. Also note that, in this example, it is assumed the time-of-flight sensor has an integrated thermal transistor. Depending on the design, other components, such as the MCU or processor, may also have integrated thermal transistors that can be read using channels of remote temperature sensors.

The remote temperature sensors connect to I2C buses on the MCU or processor, where temperature measurements are processed and compared. Depending on the architecture of the system, the temperature sensors may connect to the same I2C bus or separate I2C buses.

If more diversity is desired, another option is to use two different remote temperature sensors, such as one TMP451-Q1 and one TMP421-Q1, as shown in Figure 3-3.

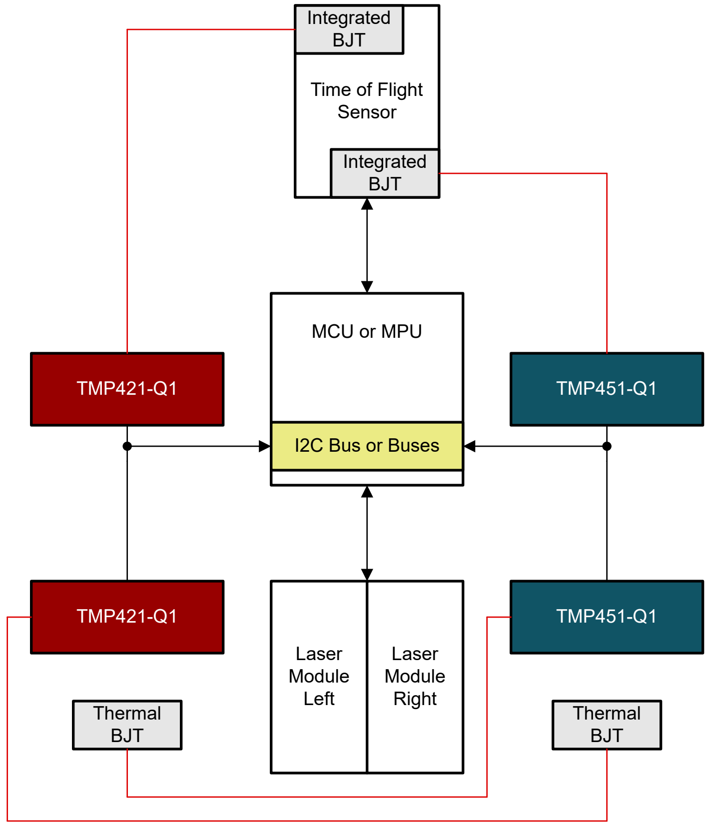

Figure 3-3. Simplified LIDAR Block Diagram With Temperature Monitoring Using TMP421-Q1 and TMP451-Q1

4 Summary

LIDAR systems need multiple temperature sensors in several locations due to redundancy and diversity requirements to achieve ASIL ratings. This temperature monitoring design challenge can be solved efficiently several ways using TI's automotive grade temperature sensors. The combination of two analog sensors, two of TI's TMP6 thermistors or a TMP6 thermistor and a TMP235-Q1 device, helps achieve a low-cost design. Using TI's automotive grade remote and local temperature sensors allows designers to take advantage of any built-in thermal transistors while also minimizing the number of external components.

Table 4-1 displays a comparison of the different options presented in this document.

Table 4-1. Comparison of Options

Option	Cost	Diversity	MCU, Processor, or Other Resources Needed	Ability to Utilize Integrated Thermal Transistors
TMP6x-Q1 thermistors	Lower	Different package options Difference devices	ADC or ADCs Biasing circuit	No
Automotive analog temperature sensor ICs	Middle	Different package options Different devices Different gain	ADC or ADCs	No
Automotive remote temperature sensors	Higher	Different package options Different transistors (NPN or PNP)	I2C bus or buses	Yes
	Higher	Different package options Different devices Different transistors (NPN or PNP)	I2C bus or buses	Yes

5 References

For related documentation, see the following:

- Texas Instruments, *TMP61-Q1 Automotive Grade, ±1% 10-kΩ Linear Thermistor With 0402 and 0603 Package Options* Data Sheet
- Texas Instruments, *TMP63-Q1 ±1% 100-kΩ Automotive Grade Linear Thermistor With 0402 and 0603 Package Options* Data Sheet
- Texas Instruments, *TMP23x-Q1 Automotive Grade, High-Accuracy Analog Output Temperature Sensors* Data Sheet
- Texas Instruments, *TMP451-Q1 ±1°C Remote and Local Temperature Sensor With η-Factor and Offset Correction, Series-Resistance Cancellation, and Programmable Digital Filter* Data Sheet
- Texas Instruments, *TMP42x-Q1 ±1°C Remote and Local Temperature Sensor* Data Sheet

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