Application Report

System Optimization Through Integrated Solutions for Temperature Threshold Detection

Andrew Yu

Temperature and Humidity Sensing

ABSTRACT

This document provides different solutions to thermal threshold detection and offers a comparison of the different methods. The key factors in each design solution are the size, cost, and power consumption of the design. Solutions utilizing discrete components are compared to solutions utilizing the TMP390 and TMP392 devices.

Table of Contents

List of Figures

List of Tables

Trademarks

All trademarks are the property of their respective owners.

1 Temperature Switch Introduction

The ability to detect and react to thermal events within a system is not only a paramount aspect of safety, but also a strong factor in being able to optimize system performance. There are many applications in which thermal management is important, including DC/AC inverters, DC/DC converters, temperature transmitters, environmental control systems (ECS), power tools, power banks, and wireless infrastructure. The simplest solution is to create a temperature switch that toggles based on certain thresholds that the user sets, and will alert the user should the temperature exceed the set thresholds. Figure 1-1 shows an example of the desired operation of a temperature switch.

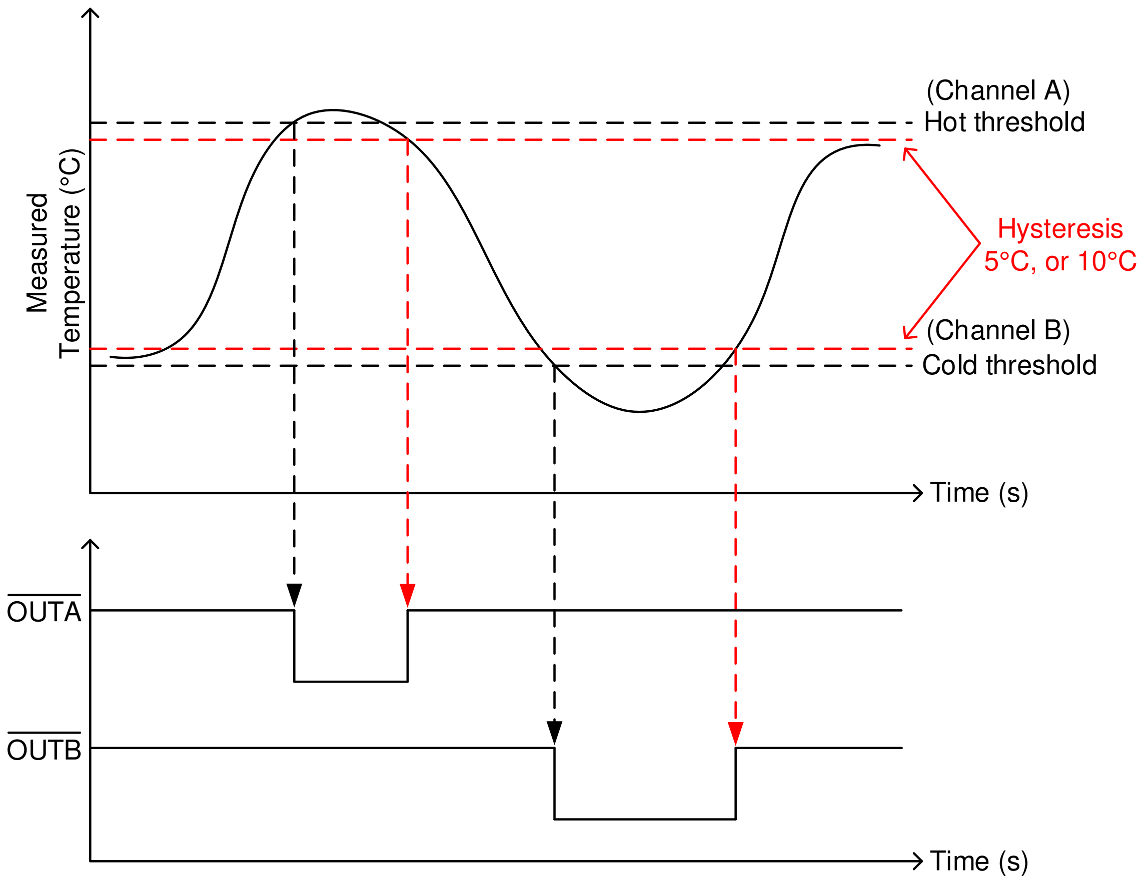


Figure 1-1. Temperature Switch Output With Hot or Cold Thresholds and Hysteresis

There are two outputs that both have active low logic. Each output corresponds to a channel and each channel corresponds to a threshold. In this example, Channel A corresponds to the hot threshold while channel B corresponds to the cold threshold, both of which can be specified by the user. In addition, there is an option of hysteresis of either 5°C or 10°C. This behavior is recreated with the three subsequent designs presented in this report.

1.1 Temperature Switch Design Using Discrete Components

There are many important factors to consider when designing a temperature switch, for example; size, cost, the range of operation (minimum and maximum temperatures), ease of use (threshold adjustments), and so forth. Figure 1-2 shows an example of a temperature switch design.

Note

For all of the following designs and calculations, the supply voltage is assumed to be 3.3 V and all resistors are E96 series (1% tolerance). The output logic is active low. All resistors and capacitors are sized at 0201, and all thermistors are sized at 0402.

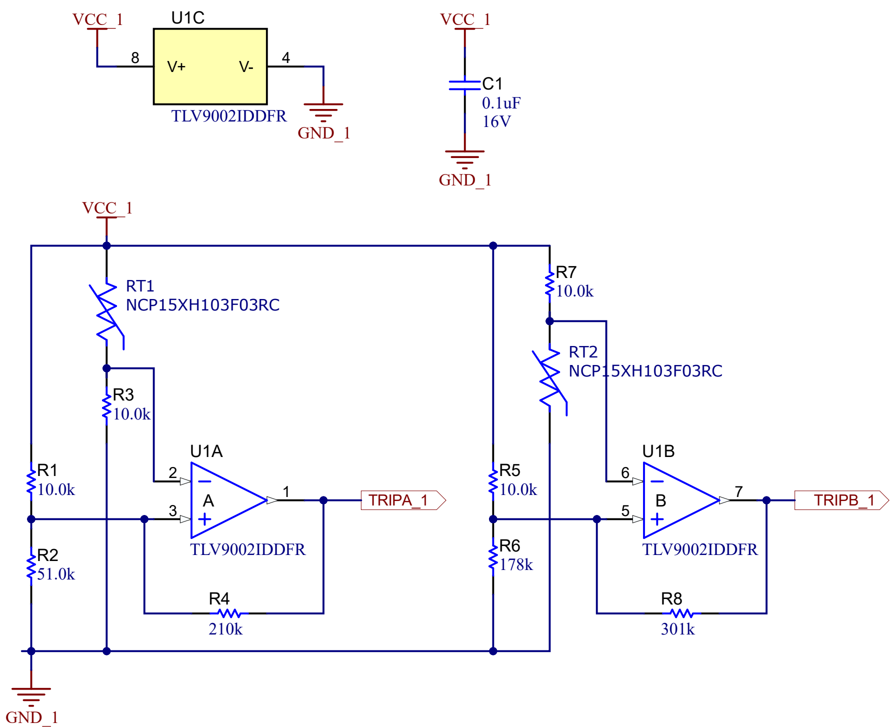
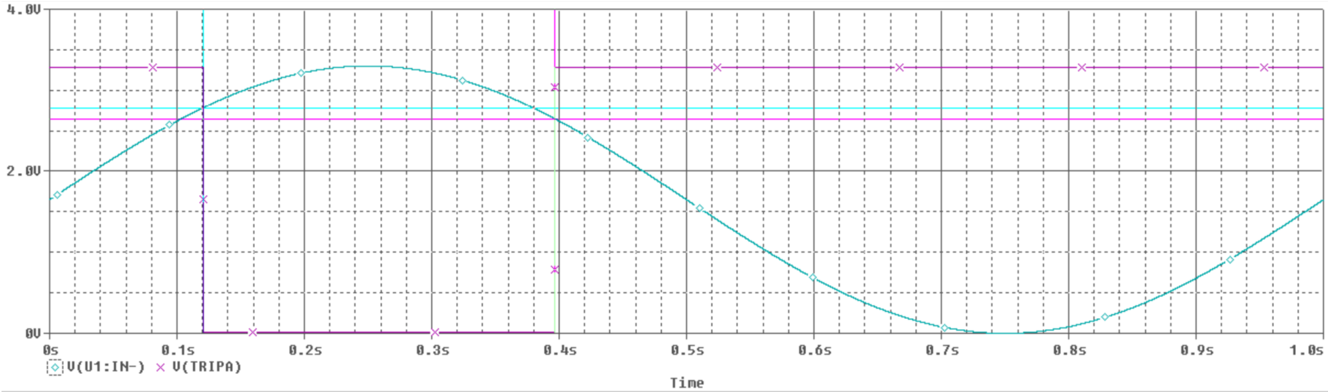


Figure 1-2. Temperature Switch Schematic

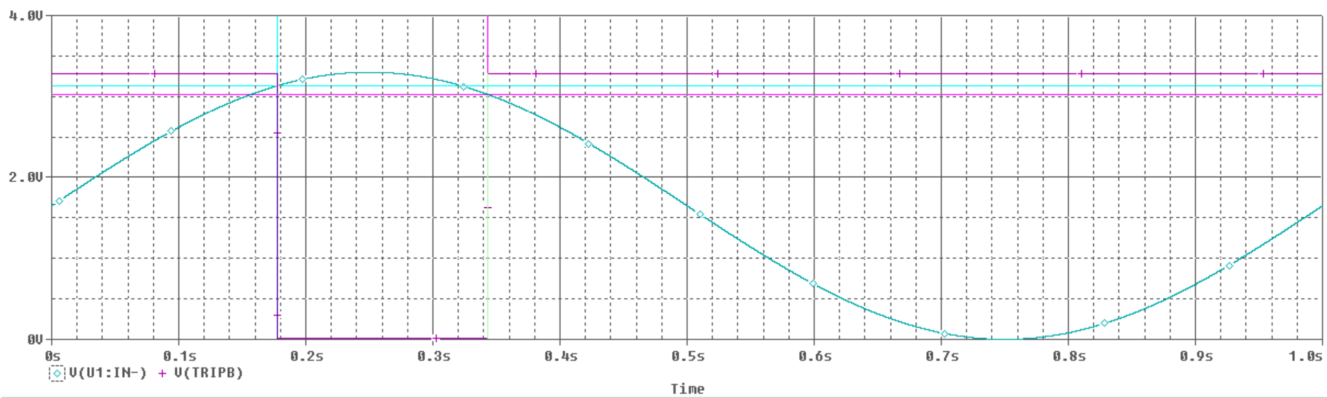
This design uses the TLV9002 dual-channel op amp (a comparator would work as well) and two negative temperature coefficient (NTC) thermistors. All other resistors either bias the circuit and set the reference points for the desired operation or create hysteresis. RT1 and R3 create a voltage divider that is fed into one of the inverting inputs of the op amp while R1 and R2 create a voltage divider that is fed into one of the noninverting inputs of the op amp, such that when the voltage generated between RT1 and R3 is greater than the voltage generated by R1 and R2, the output TRIPA_1 goes low. Inversely, when the voltage generated between RT1 and R3 is less than the voltage generated by R1 and R2, the output TRIPA_1 goes high. Since the output logic is active low and RT1 is an NTC thermistor, this would imply that the output TRIPA_1 represents a hot temperature threshold. Using the same logic with RT2 and R7 and R5 and R6, one can reasonably conclude that TRIPB_1 represents a cold temperature threshold. R4 and R8 function to create hysteresis for the hot and cold thresholds, respectively. The values of the components have been calculated to result in a hot threshold of 80°C with 10°C of hysteresis and a cold threshold of –40°C with 10°C of hysteresis.

A PSPICE simulation of the circuit in Figure 1-2 results in the waveforms seen in Figure 1-3 and Figure 1-4 of the TRIPA_1 output and the TRIPB_1 output, respectively. It should be noted that instead of the voltage dividers created by RT1 and R3 and RT2 and R7, a sinusoidal input was applied to mimic the behavior of the voltage divider, so the functionality of the circuit remains the same.



Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		136.169m		
	X Values	120.690m	396.553m	-275.863m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(U1:IN-)	2.7847	2.6485	136.169m		0.000	0.000	2.7847	2.6485	2.7166
	V(TRIPA)	18.520m	3.2821	-3.2635		-2.7662	633.519m	3.2821	18.520m	1.6503

Figure 1-3. PSPICE Simulation Result of TRIPA_1 Output



Trace Color	Trace Name	Y1	Y2	Y1 - Y2		Y1(Cursor1) - Y2(Cursor2)		106.508m		
	X Values	177.587m	343.104m	-165.517m		Y1 - Y1(Cursor1)	Y2 - Y2(Cursor2)	Max Y	Min Y	Avg Y
CURSOR 1,2	V(U1:IN-)	3.1321	3.0256	106.508m		0.000	0.000	3.1321	3.0256	3.0789
	V(TRIPB)	3.2821	3.2821	-22.000p		149.928m	256.436m	3.2821	3.2821	3.2821

Figure 1-4. PSPICE Simulation Result of TRIPB_1 Output

These waveforms are consistent to the desired behavior discussed about Figure 1-1. Furthermore, it can be observed that when the sinusoidal input reaches a certain voltage, the output goes low, then goes high again when the sinusoidal input voltage reaches another certain voltage. For example, in Figure 1-3, these voltages are 2.7847 V and 2.6485 V, highlighted by the light blue box. These values can be understood by analyzing the voltage divider created by RT1 and R3; at 80°C, the NTC thermistor has a resistance of 1.669 kΩ. Therefore, the inverting input of the op amp detects a voltage of 2.828 V. Since 80°C is the hot threshold, the output should go low at 2.828 V, in which it does at a voltage of 2.7847 V (the discrepancy between these two values can be attributed to non-ideal resistors and using standard resistor values). There is also a desired hysteresis of 10°C, so the output should go high at 70°C. At 70°C, the NTC thermistor has a resistance of 2.228 kΩ. Therefore, the inverting input of the op amp detects a voltage of 2.699 V, and the output should go high at an input voltage of 2.699 V, in which it does at a voltage of 2.6485 V (again, the discrepancy between these two values can be attributed to non-ideal resistors and using standard resistor values). Therefore, the measured voltages are consistent with the desired operation. In systems that require high accuracy switching, the voltage discrepancies may present an issue. In this case, the voltage discrepancies result in a maximum error in trip point of 4°C.

The design presented in Figure 1-2 results in the layout shown in Figure 1-5. Making the layout as compact and consolidated as possible, the minimum area obtained is 53.6 mm^2. At temperatures of 25°C, 85°C, and –10°C, this design results in approximate supply quiescent currents of 542 µA, 788 µA, and 337µA, respectively.

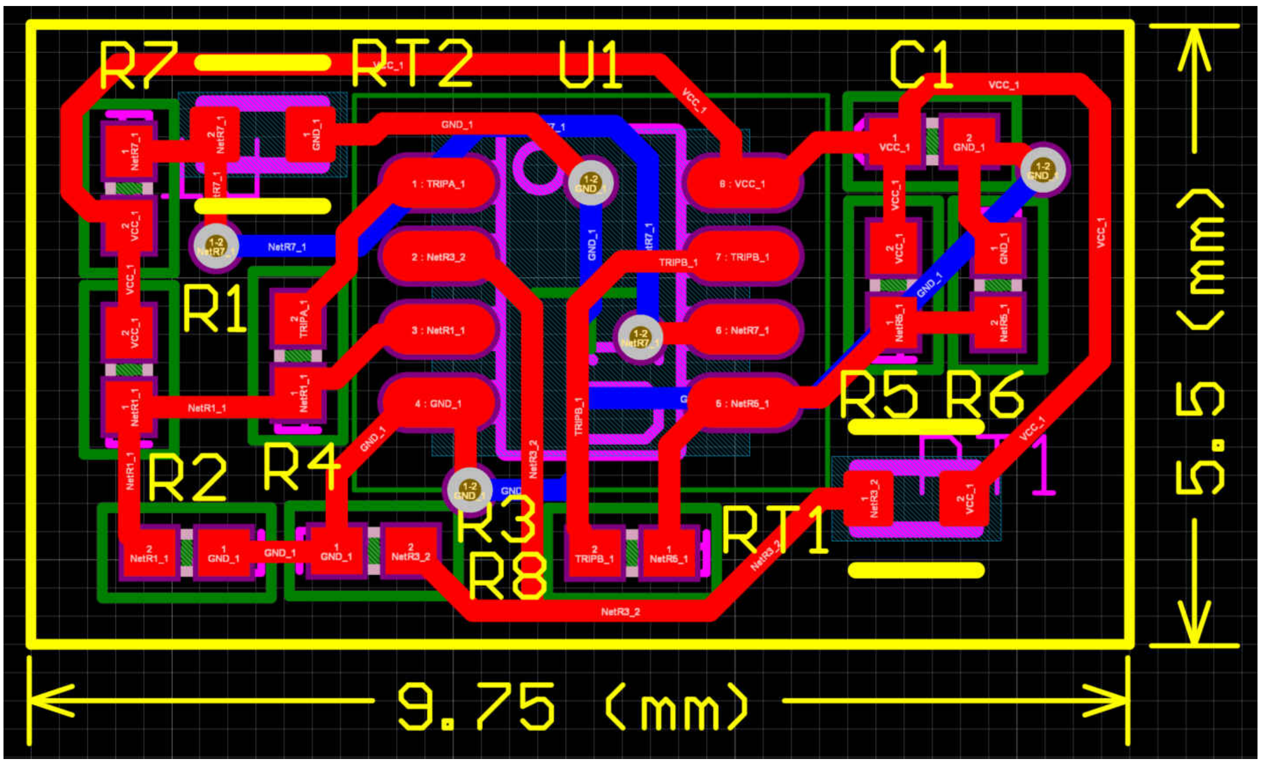


Figure 1-5. Temperature Switch Layout

The TMP61 is a linear thermistor that operates with a positive temperature coefficient and can offer better accuracy and a smaller design due to its linearity and low tolerance. Figure 1-6 shows the schematic of the temperature switch using the TMP61. This design is very similar to the previously-outlined design while providing the same specifications.

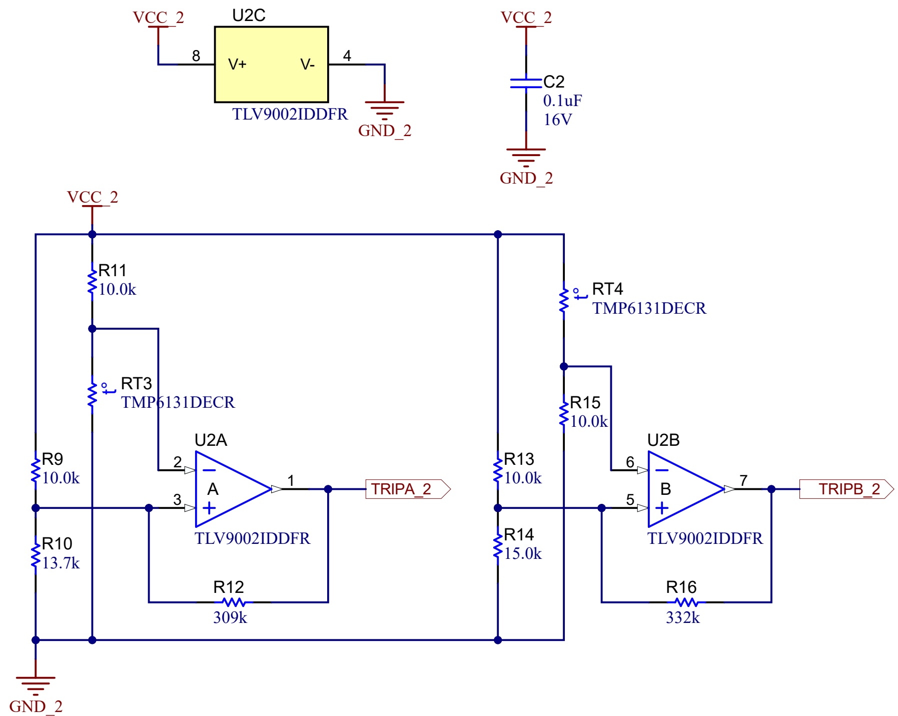


Figure 1-6. Temperature Switch Schematic Using the TMP61

This design results in the layout shown in Figure 1-7. Making the layout as compact and consolidated as possible, the minimum area obtained is 51.9 mm^2, which is smaller when compared to using an NTC thermistor. At temperatures of 25°C, 85°C, and –10°C, this design results in approximate supply quiescent currents of 728 µA, 673 µA, and 765 µA, respectively.

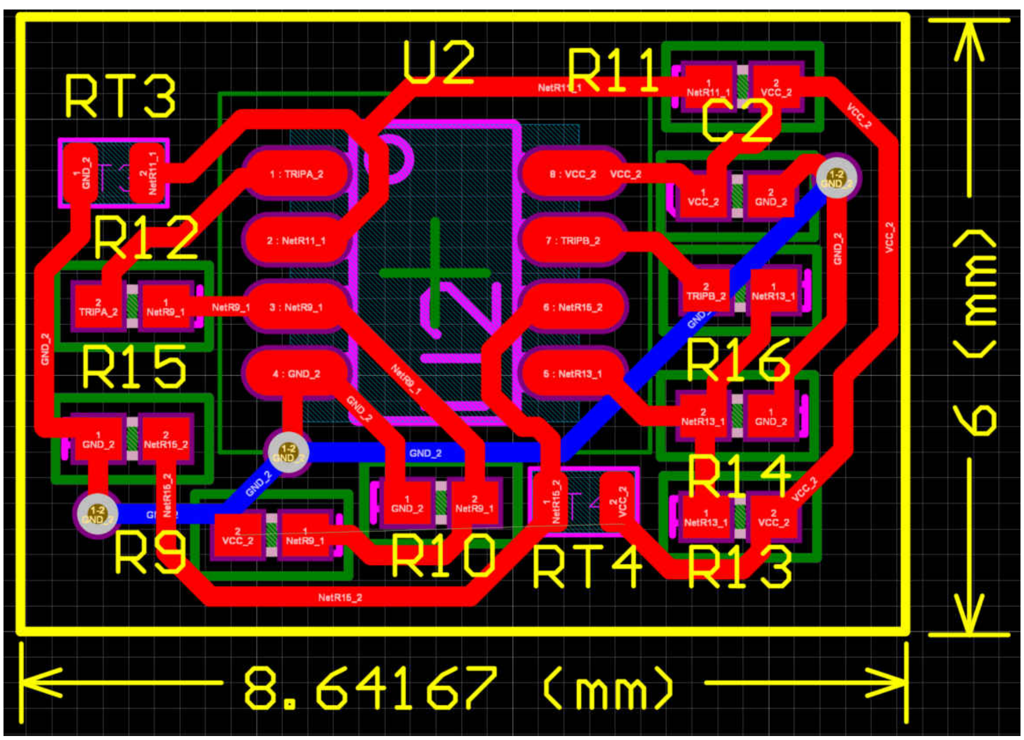


Figure 1-7. Temperature Switch Layout Using the TMP61

1.2 Replacing Discrete Solutions With TMP390

Although the aforementioned temperature switch designs are viable methods of implementing temperature threshold detection, the size and cost can be reduced, and accuracy can be improved. The TMP390 is an ultra-low power, dual-channel, resistor programmable temperature switch that is able to operate in temperatures ranging from –50°C to 130°C. This device functions identically to the previously-designed temperature switches, but comes in a smaller package and reduced cost, and also has improved accuracy for systems that require high accuracy. For example, Figure 1-8 shows the design of the circuit needed to provide temperature threshold detection when using the TMP390. All specifications are nearly identical as before: a hot threshold of 80°C with 10°C of hysteresis and now a cold threshold of –50°C with 10°C of hysteresis, which is a range of 10°C more than what is offered by the discrete solutions.

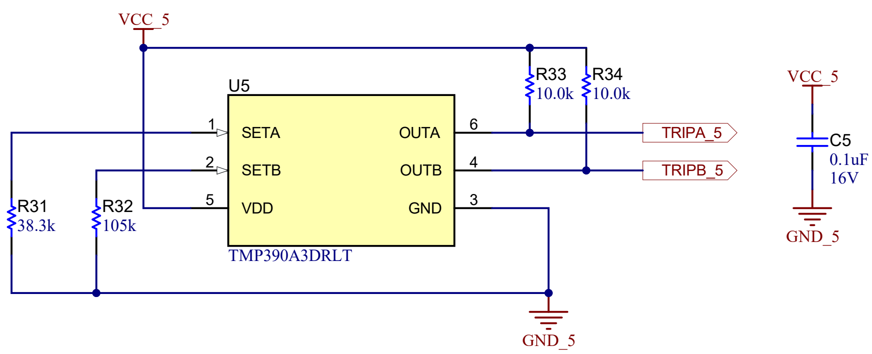


Figure 1-8. Temperature Switch Schematic Using the TMP390

Note that there are far fewer components when compared to the discrete solution; this results in a much smaller layout area of 26.2 mm^2, as shown in Figure 1-9. At temperatures of 25°C, 85°C, and –10°C, this design results in an approximate supply quiescent current of 0.5 µA, which is considerably lower than the currents of the discrete solutions.

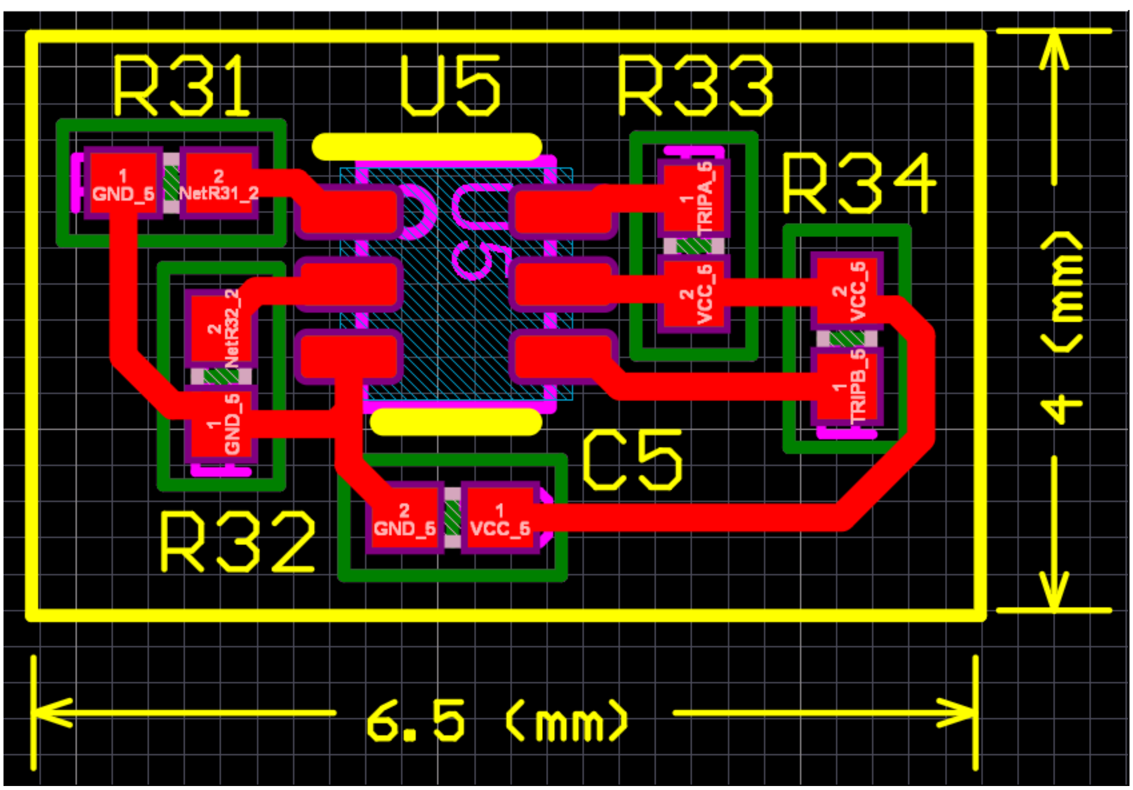


Figure 1-9. Temperature Switch Layout Using the TMP390

2 Alternative Applications

There may exist some applications in which rather than a hot or cold threshold detection, a hot or warm threshold is needed. Consider Figure 2-1 for an example of the desired operation.

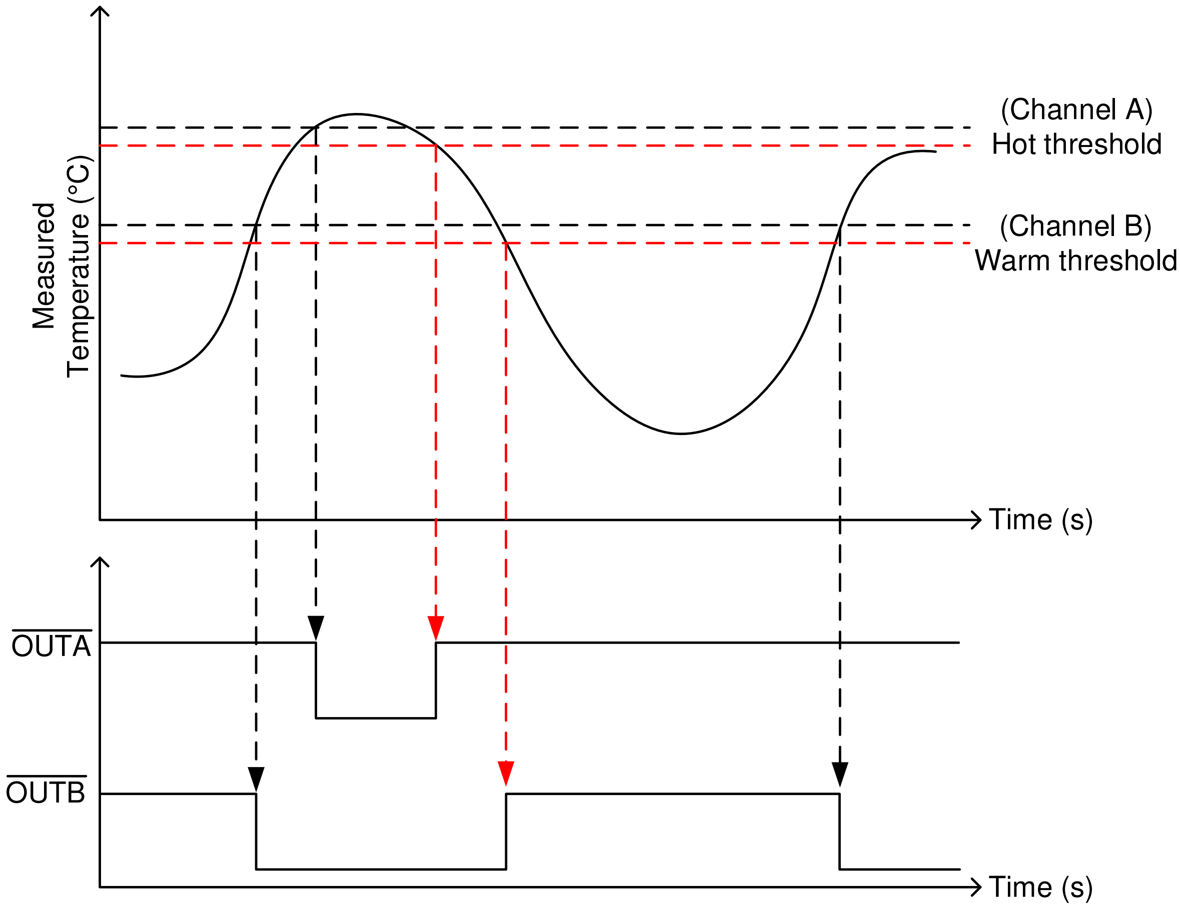


Figure 2-1. Temperature Switch Output With Hot or Warm Thresholds and Hysteresis

There are two outputs that both have active low logic. Each output corresponds to a channel and each channel corresponds to a threshold. In this example, Channel A corresponds to the hot threshold while channel B corresponds to the warm threshold, both of which can be specified by the user. In addition, there is an option of hysteresis. This behavior is recreated with the subsequent designs presented in this report. In terms of a discrete solution, this simplifies the designs outlined in Figure 1-2 and Figure 1-6 by removing a thermistor and resistor, effectively reducing the total required components by 2.

Figure 2-2 depicts a design that utilizes a single NTC thermistor and operates using the same concepts as discussed in Section 1.1.

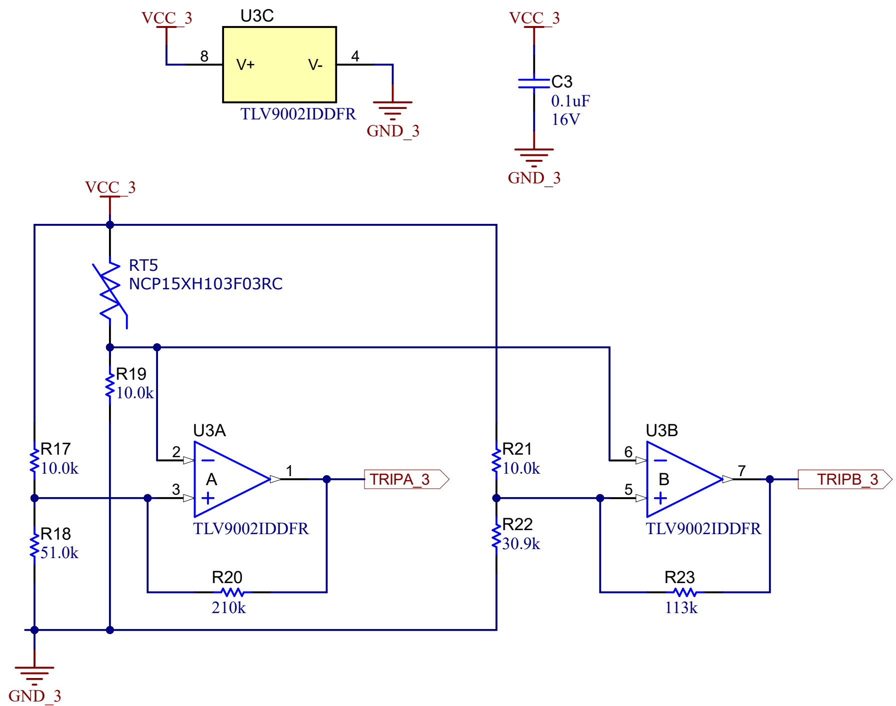


Figure 2-2. Temperature Switch Schematic

The resulting layout is shown in Figure 2-3. Making the layout as compact and consolidated as possible, the minimum area obtained is 49.0 mm^2. At temperatures of 25°C, 85°C, and –10°C, this design results in approximate supply quiescent currents of 611 µA, 857 µA, and 407 µA, respectively.

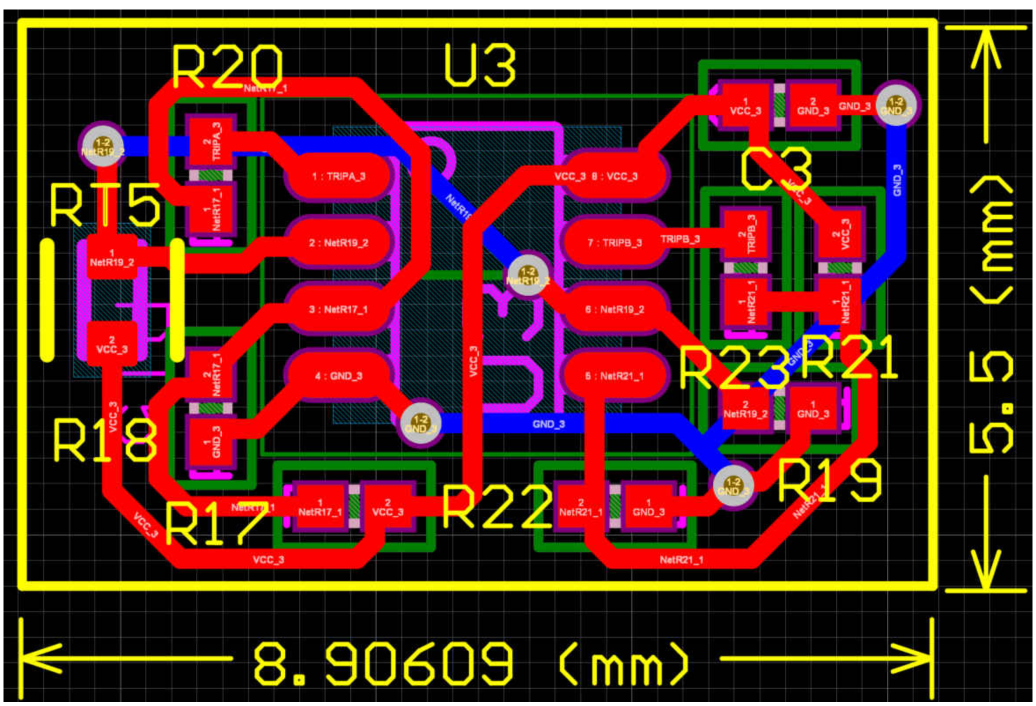


Figure 2-3. Temperature Switch Layout

Once again, a linear positive temperature coefficient thermistor can be used in place of an NTC thermistor. Using the TMP61 again, Figure 2-4 shows the schematic while Figure 2-5 shows the layout. Making the layout as compact and consolidated as possible, the minimum area obtained is 45.1 mm^2, which is smaller when compared to using an NTC thermistor. At temperatures of 25°C, 85°C, and –10°C, this design results in approximate supply quiescent currents of 746 μA, 691 μA, and 782 μA, respectively.

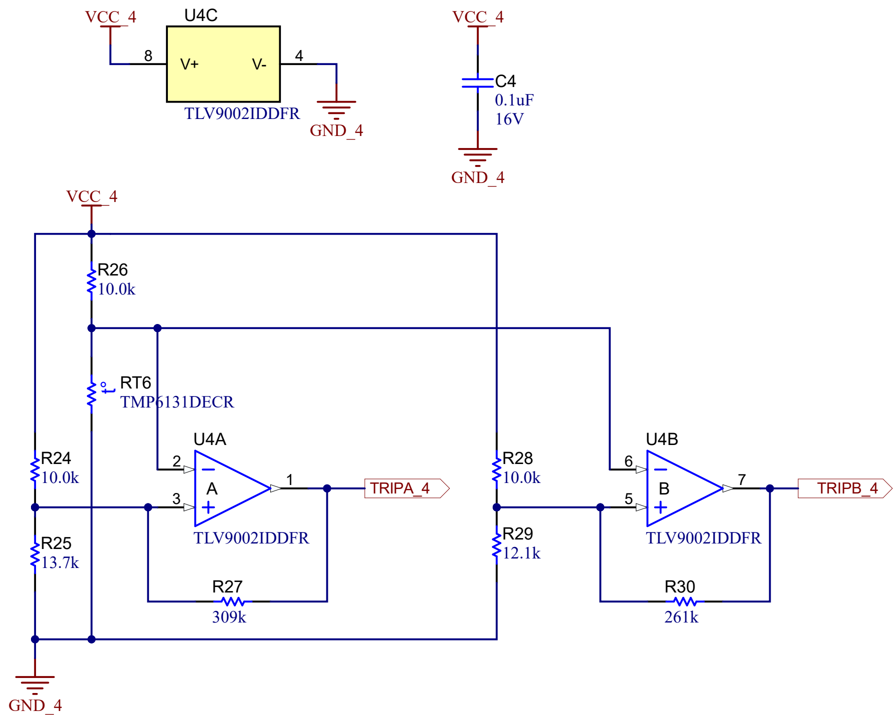


Figure 2-4. Temperature Switch Schematic Using the TMP61

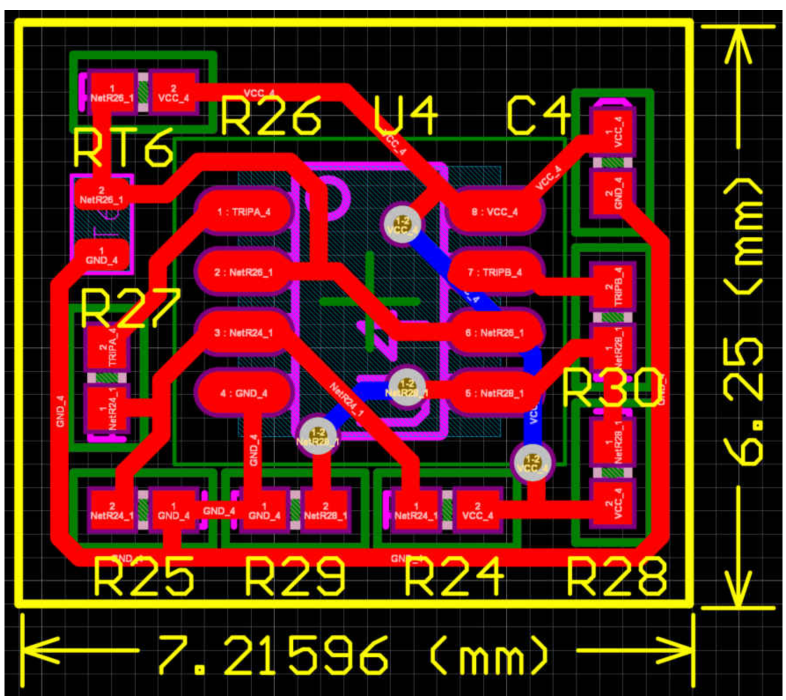


Figure 2-5. Temperature Switch Layout Using the TMP61

As before, the cost and size of this design can be reduced. The TMP392 is another ultra-low power, dual-channel, resistor programmable temperature switch that is able to operate in temperatures ranging from 30°C to 130°C. This device provides the same functionality as the two previous designs; since it shares the same size and implementation as the TMP390, Figure 1-8 and Figure 1-9 provide an accurate representation of the schematic and layout when using the TMP392. Therefore, when making the layout as compact and consolidated as possible, the minimum area obtained is also 26.2 mm^2. The supply quiescent currents are also the same as those of the design using the TMP390.

3 Conclusion

In many applications, designers need to be able to detect and react to thermal events, especially in thermally sensitive systems. One way to implement this is to use a temperature switch. This can be done using only discrete components or using the TMP390 or TMP392, as discussed within this report. Table 3-1 summarizes the differences in using only discrete components and using the TMP390 or TMP392.

Table 3-1. Discrete Solutions versus TMP390 and TMP392

	TMP390, TMP392	**Discrete Solutions**	**TMP390, TMP392 Benefits**
Smallest Circuit Area	6.55 mm × 4 mm (26.2 mm^2)	7.22 mm × 6.25 mm (45.1 mm^2)	42% smaller PCB area
Minimum Number of External Components	4 resistors + 1 cap	8 resistors (including thermistor) + 1 caps + 1 op amp	50% fewer components
Minimum Number of 1% Tolerance Resistors	4	7	43% direct cost saving for 1% resistors
PCB Consideration	No vias	Minimum of 3 vias	Improved PCB manufacturing costs
Trip Test	Yes	No	Supports production self-test
Circuit Flexibility	No re-design, simple swap of resistors	Circuit needs to be re-designed and tested	Faster time to market
Dual Trip Temp with Single Output	Open drain outputs; simple tie-off	Need additional circuit to connect output of 2 op amps	Flexible and simpler design layouts
Accuracy	Higher	Lower	Allows for better operation in thermally sensitive systems
Power Consumption	Very Low	Very High	Allows for use of a battery as a power supply and increases portability and flexibility of system
Overall Cost	Lower	Higher	Reduced manufacturing costs due to less components

After extensive comparisons have been made between discrete solutions and the TMP390 or TMP392, it is evident that to reduce size, cost, power consumption, and have high accuracy, the TMP390 or TMP392 offer the best solution. In addition to its low price and small size, it is easy to implement and integrate into a system, with high flexibility in controlling the desired thresholds by changing external resistors that can be chosen via a lookup table.

4 References

- Texas Instruments, *TMP390 Ultra-Small Dual-Channel 0.5-µA Resistor-Programmable Temperature Switch* data sheet
- Texas Instruments, *TMP392 Ultra-Small, Dual-Channel (Hot and Warm Trip), 0.5-µA, Resistor-Programmable Temperature Switch* data sheet
- Texas Instruments, *TMP61 ±1% 10-kΩ Linear Thermistor With 0402 and 0603 Package Options* data sheet
- Texas Instruments, *TLV900x Low-Power, RRIO, 1-MHz Operational Amplifier for Cost-Sensitive Systems* data sheet

IMPORTANT NOTICE AND DISCLAIMER