TIDA-00824 Human Skin Temperature Sensing for Wearable Applications Reference Design

Abstract

This TI Design report will show how to use the LMT70 temperature sensor to measure human skin temperature in a wearable device such as a smart watch or a fitness tracker (not as a diagnostic or therapeutic use). The wearable design covers both electrical and mechanical design to optimize performance of the LMT70 sensor's ability to accurately measure skin temperature. Test data such as accuracy and thermal response is also discussed in this document.

Document History

Version	Date	Author	Notes
1.0	September 2015	Michael Wong	First Release

Contents

1. OBJECTIVE 3
2. WEARABLE DESIGN 3
2.1. ELECTRICAL DESIGN 3
2.1.1. SIGNAL PATH 3
2.1.2. MAIN PCB 4
2.1.3. REMOTE PCB 5
2.1.4. LMT70 TEMPERATURE SENSOR 5
2.1.5. ADS1115 ANALOG-TO-DIGITAL CONVERTER 6
2.1.6. MSP430G2553 MICROCONTROLLER 7
2.2. MECHANICAL DESIGN 7
2.2.1. MOUNTING LMT70 TEMPERATURE SENSOR 7
2.2.2. HARDWARE IMPLEMENTATION 9
3. TEST DATA 12
3.1. SYSTEM ACCURACY 12
3.2. THERMAL RESPONSE 13
4. CONCLUSION 14
5. APPENDIX 17
5.1. PCB LAYOUT 17
5.2. SCHEMATIC 20
5.3. MECHANICAL DRAWING 21
5.4. SUPPORT DOCUMENTS AND RESOURCES 21

List of Figures

Figure 1: Signal Path 3
Figure 2: Main PCB 4
Figure 3: Remote PCB 5
Figure 4: LMT70 Block Diagram 6
Figure 5: ADC1115 Block Diagram 6
Figure 6: MSP430G2553 Block Diagram 7
Figure 7: Remote PCB Side Cutout View 8
Figure 8: Remote PCB Top View 8
Figure 9: Remote PCB Bottom View 9
Figure 10: Side View of Metal Cap with Mounted Remote PCB 9
Figure 11: Wearable Design Top View 10
Figure 12: Wearable Design with Cover Off 10
Figure 13: Wearable Design of Main PCB and Remote PCB Epoxied into Metal Cap 11
Figure 14: Wearable Design Back View 12
Figure 15: System Accuracy 13
Figure 16: Thermal Response 14
Figure 17: First Button Press Shows the Main Menu 15
Figure 18: After the Main Menu is the Skin Temperature Page 15
Figure 19: Press the Button Again for the Room Temperature Page 16
Figure 20: Pressing the Button Again for the Scale Change Menu 16
Figure 21: Holding the Button for Two Seconds Changes Temperature to Fahrenheit 17
Figure 22 Top Layer 17
Figure 23: Ground Layer 18
Figure 24: Power Layer 18
Figure 25: Bottom Layer 19
Figure 26: Schematic 20
Figure 27: Exploded View 21

1. Objective

The objective of the LMT70 Wearable Design is to show how to design and mount a small form factor electrical system that fits inside a smart watch or fitness tracker that measures both human skin and room temperatures with accuracy of 0.1°C in the human body temperature range of 20°C-42°C.

To achieve these objectives the LMT70 analog temperature sensor, ADS1115 analog-to-digital converter, and the MSP430G2553 microcontroller were implemented together as the signal path.

2. Wearable Design

The Wearable Design section includes an overview of the electrical and mechanical design of the LMT70 Wearable Design. Since temperatures are being measured, the mechanical aspects must be carefully designed to conduct as much heat that goes into the LMT70 as possible. The electrical design must fulfill the signal path system accuracy requirements while maintaining a small size form factor.

2.1. Electrical Design

The electrical design consists of two PCB's, the main PCB board which hosts the battery, LCD connector, the ADS1115, and the MSP430G2553 is responsible for converting the LMT70 data into an accurate temperature value. The remote PCB is a very small PCB with only the skin temperature sensing LMT70 and supporting thermal devices such as copper pads and thermal vias is used primarily to sense skin temperature. These two boards are connected with the J2 connector.

2.1.1. Signal Path

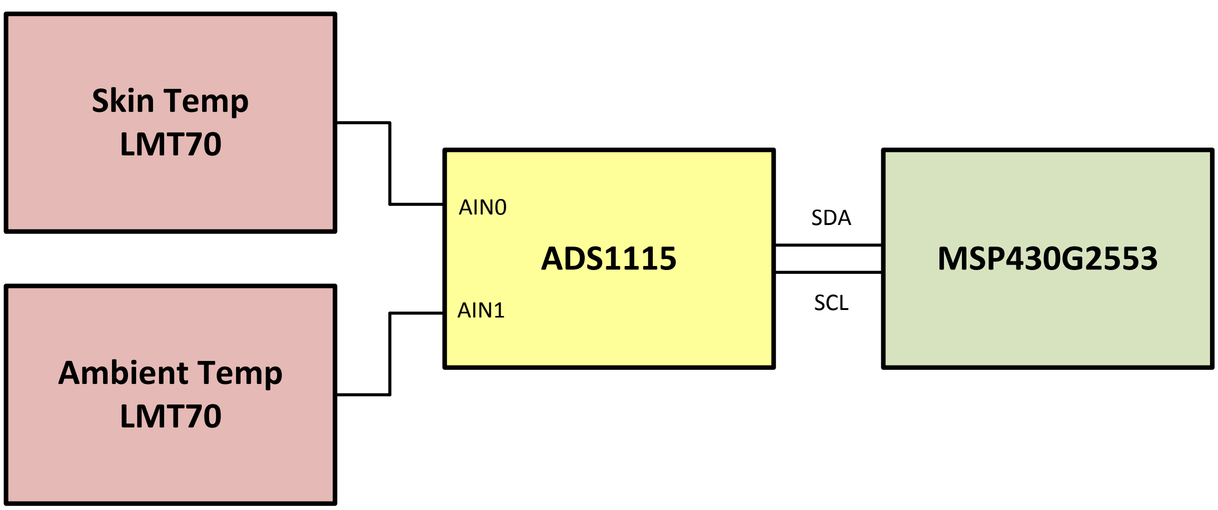

Figure 1: Signal Path

The signal path of the Wearable Design starts with two LMT70's, one for measuring the skin temperature and one measuring for the ambient/board temperature. Both devices are connected to two channels on the ADS1115. After the analog to digital conversion is complete, the data is sent through an I2C interface to the MSP430G2553 microcontroller for further processing.

The LMT70 used for measuring skin temperature is located on the remote PCB and epoxied to a metal cap for best thermal transfer (More details in the Mechanical Design section). The ambient temperature sensing LMT70 is located on the board itself and measures the ambient/board temperature.

One of the requirements for this TI Design is to have a system accuracy of at least 0.1°C. The LMT70 has a transfer function of 5.19mV/C so an ADC resolution that produces less than 0.1°C is needed. Error analysis with the ADS1115 is shown in Application Note SNIA022.

2.1.2. Main PCB

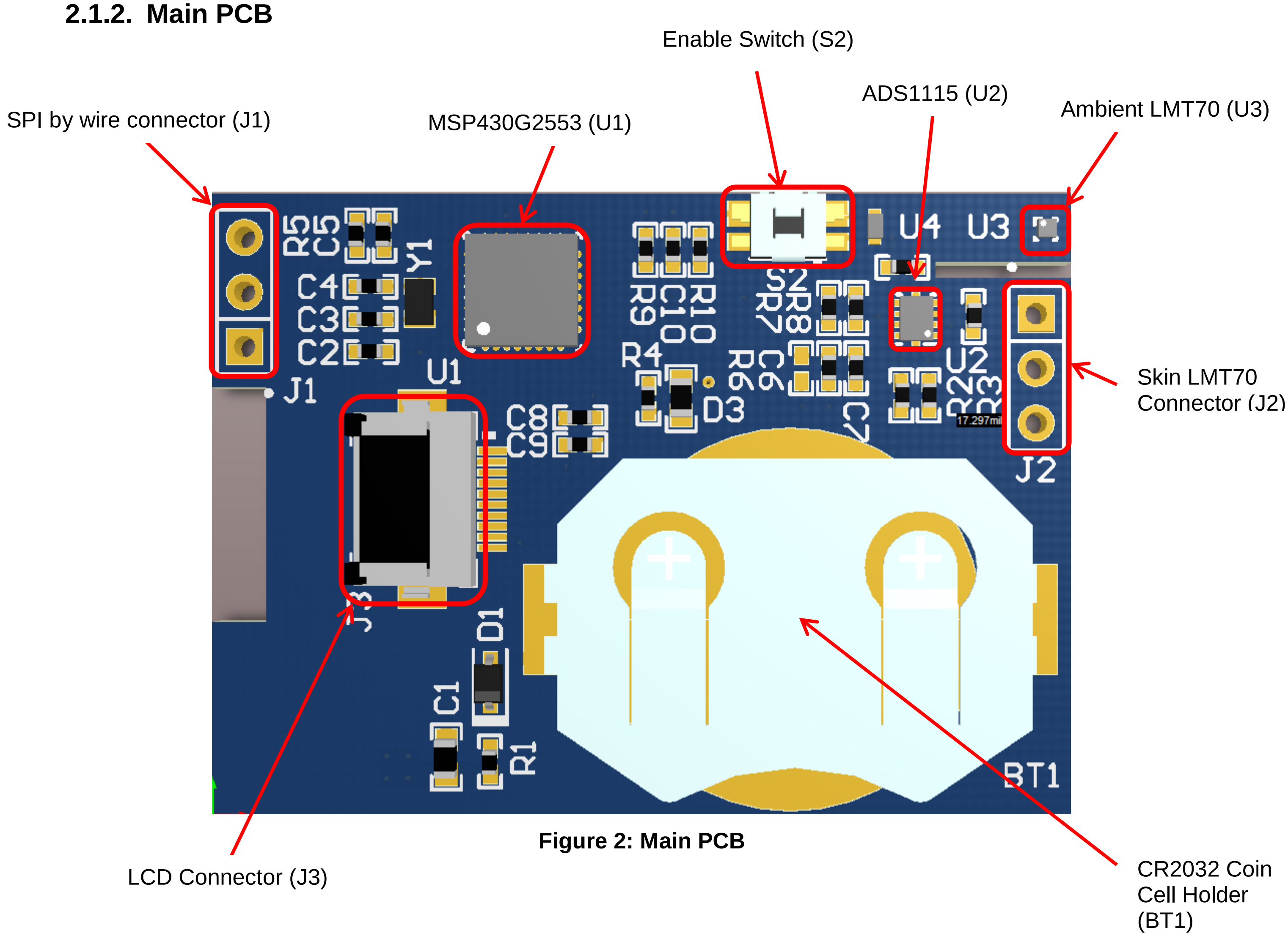

Figure 2: Main PCB

The main PCB is 4-layer board powered by a single CR2032 3V coin cell battery. The skin temperature sensing remote PCB is connected to the main PCB board via connector J2 (See Mechanical Design section) which is interfaced with one of the inputs of the ADS1115. The ambient temperature sensing LMT70 is located on the main PCB board and is connected a dedicated input of the ADS1115. After the analog-to-digital conversion is completed the ADS1115 transfers digital data over an I2C bus with the MSP430G2553 microcontroller. The microcontroller can be programmed by the SPI by wire connector (J1) for firmware modifications. The SPI by wire communication protocol was chosen for its low wire count and space saving connection. The temperature data is then sent to a LCD screen attached to the back of the PCB through the LCD connector (J3). The Enable Switch (S2), once pressed, applies power to all the devices, takes a temperature sample, transfers that data onto the LCD screen, and goes back to standby mode.

2.1.3. Remote PCB

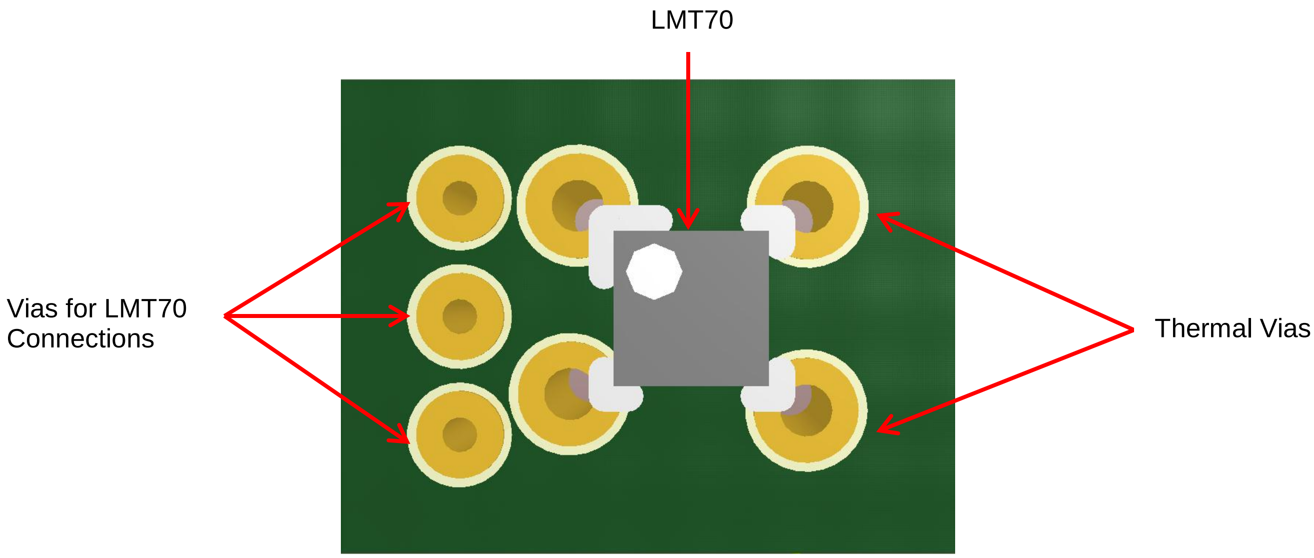

Figure 3: Remote PCB

An off board PCB called the remote PCB is used to measure the skin temperature. It is remote from the main board because the LMT70 temperature sensor detects temperature best by being as close as possible to the heat source (e.g. skin). This remote PCB is very small, measuring only 2.9mm x 2.16mm, which means it heats up quickly for a fast thermal response. This PCB also has thermal copper pads on the underside of the PCB which is used to conduct heat. This heat is then routed through thermal vias to the BGA balls of the LMT70. This directly heats the die on which the temperature sensor is located. More details of the remote PCB can found in the Mechanical Section of the report.

2.1.4. LMT70 Temperature Sensor

The LMT70 is an analog output temperature sensor that has 0.05°C typical accuracy within the human body temperature range (20°C-42°C) and 0.36°C max accuracy over the full temperature range of -55°C-150°C. The LMT70 comes in a tiny chip scale WLCSP package that measures just 0.88mm x 0.88mm which makes it ideal for space conscious designs. The part's wide voltage range of 2V-5.5V and low 12uA current consumption allows it to be paired with a variety of batteries common in portable electronics. With these specs, the LMT70 is TI's smallest, most accurate temperature sensor and is perfect for applications where high thermal accuracy is required and PCB board space is limited.

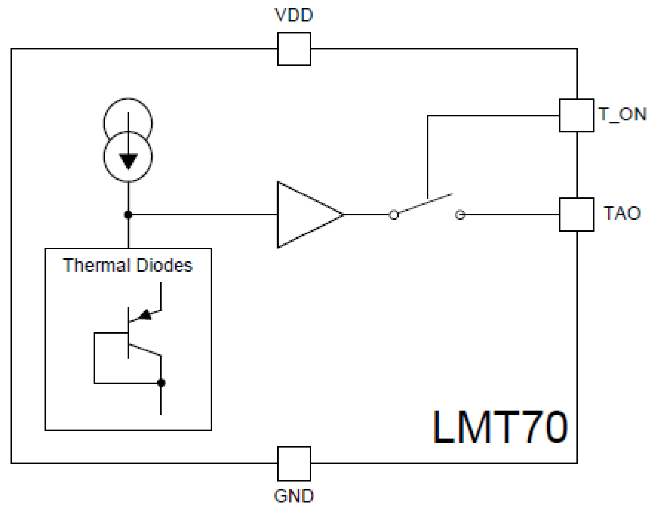

Figure 4: LMT70 Block Diagram

2.1.5. ADS1115 Analog-to-Digital Converter

The ADS1115 is a 16-bit sigma-delta, 4 single channel/2 differential channel, 860SPS analog-to-digital converter. This ADC features an internal voltage reference and oscillator that reduces the total footprint and total number of components on a board. There is an internal multiplexor to switch between the 4 channels and an internal PGA to increase the gain of the input voltage signal. The part communicates through an I2C interface and operates between 2V-5.5V.

While integrated ADC's exist in various MCU's, such as TI's MSP430 line of low power microcontrollers, their performance does not meet the requirements for accuracy. Errors such as INL, DNL, reference, gain, and offset are significantly more than the ADS1115's specs.

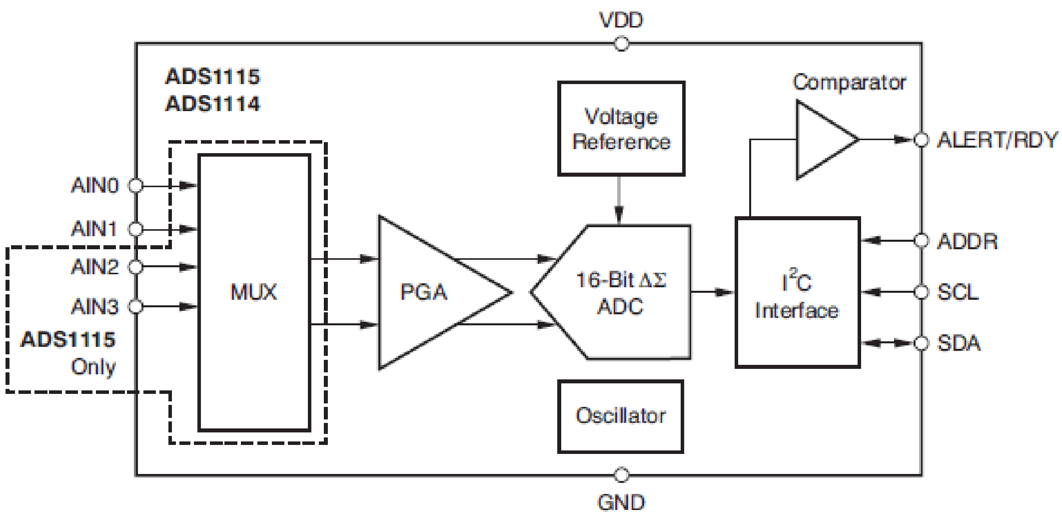

Figure 5: ADC1115 Block Diagram

2.1.6. MSP430G2553 Microcontroller

The MSP430G2553 microcontroller is part of TI's family of MSP430 ultra low power controllers. It operates between the voltage ranges of 1.8V-3.6V and consumes 230uA in active mode and 0.5uA in standby mode. The part features 24 GPIO pins, an integrated ADC, and supports a variety of digital communication interfaces. The MSP43G2553 microcontroller is used in this TI design to communicate with the ADS1115 and to present the skin and room temperatures on the LCD screen.

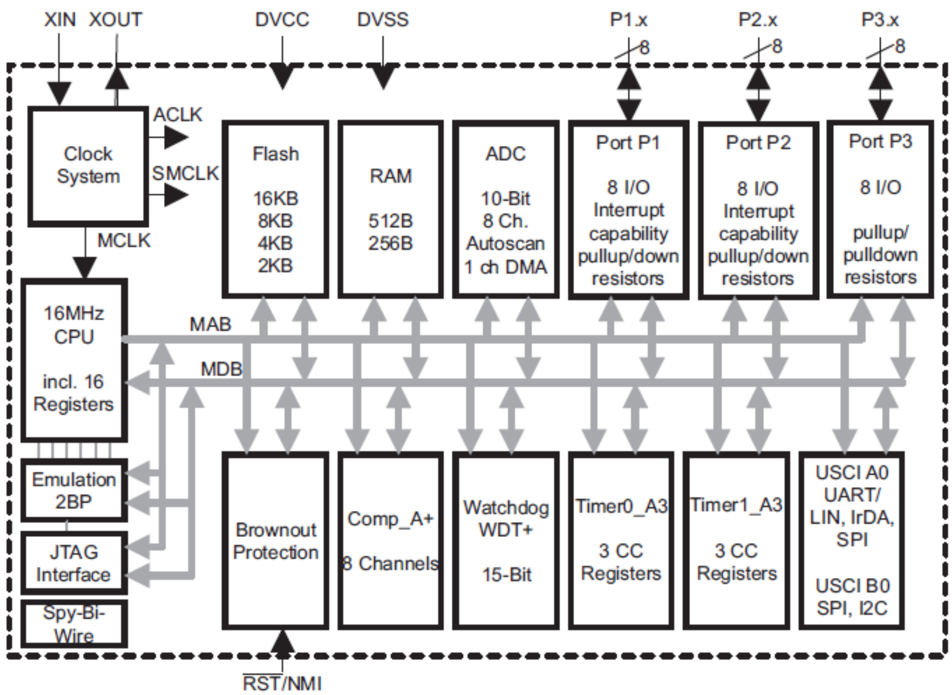

Figure 6: MSP430G2553 Block Diagram

2.2. Mechanical Design

The mechanical design portion of this TI Design involves how to mount the LMT70 skin temperature sensor to the remote PCB and how to mount the remote PCB to a metal cap for best thermal conduction.

2.2.1. Mounting LMT70 Temperature Sensor

The LMT70 Wearable Design detects skin temperature through a remote PCB. This PCB is specifically designed collect as much heat as possible on the copper pads by routing it through thermal vias which connect to the solder balls of the package. The solder balls heats up the die on which the temperature sensor is located.

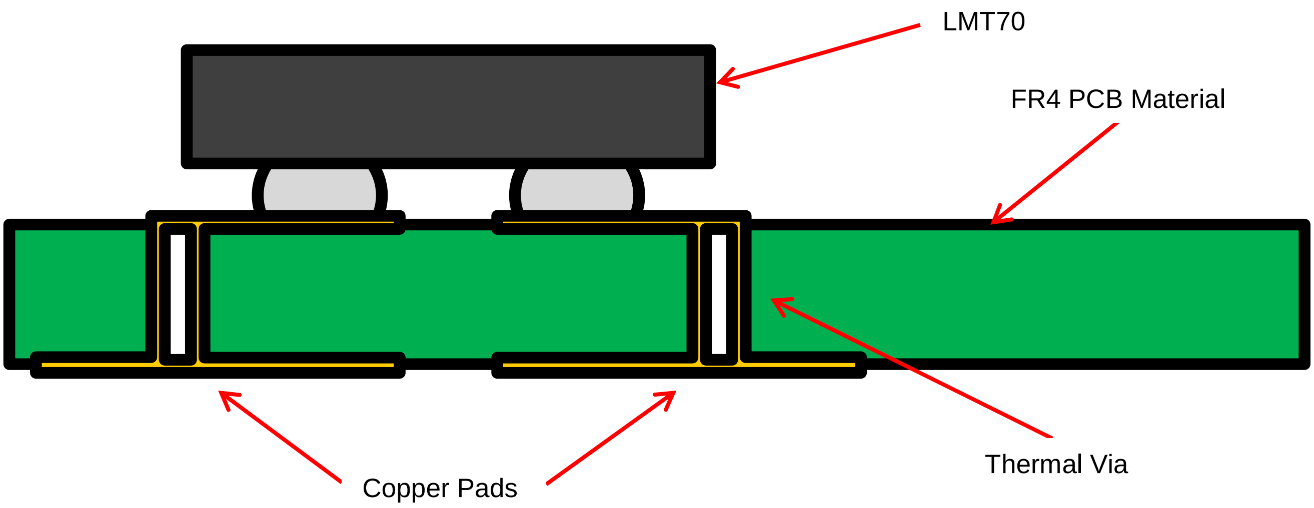

Figure 7: Remote PCB Side Cutout View

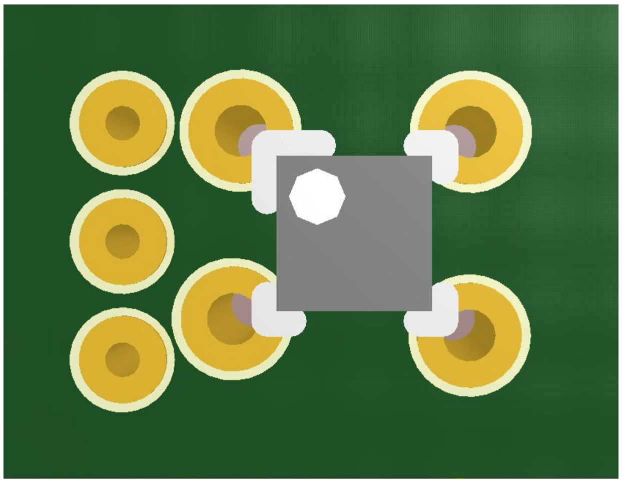

Figure 8: Remote PCB Top View

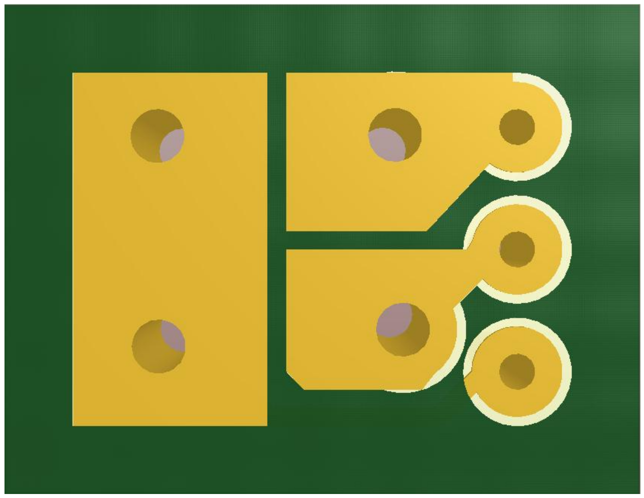

Figure 9: Remote PCB Bottom View

The remote LMT70 board is connected with 3 Nickel wires that are connected to the J2 connector on the main PCB board. Nickel wire is used for its thermal insulating properties. The board is then placed in a hollow metal cap that is filled with thermally conductive epoxy. The hollow metal cap we used was a TO can package shell used in amplifier IC's.

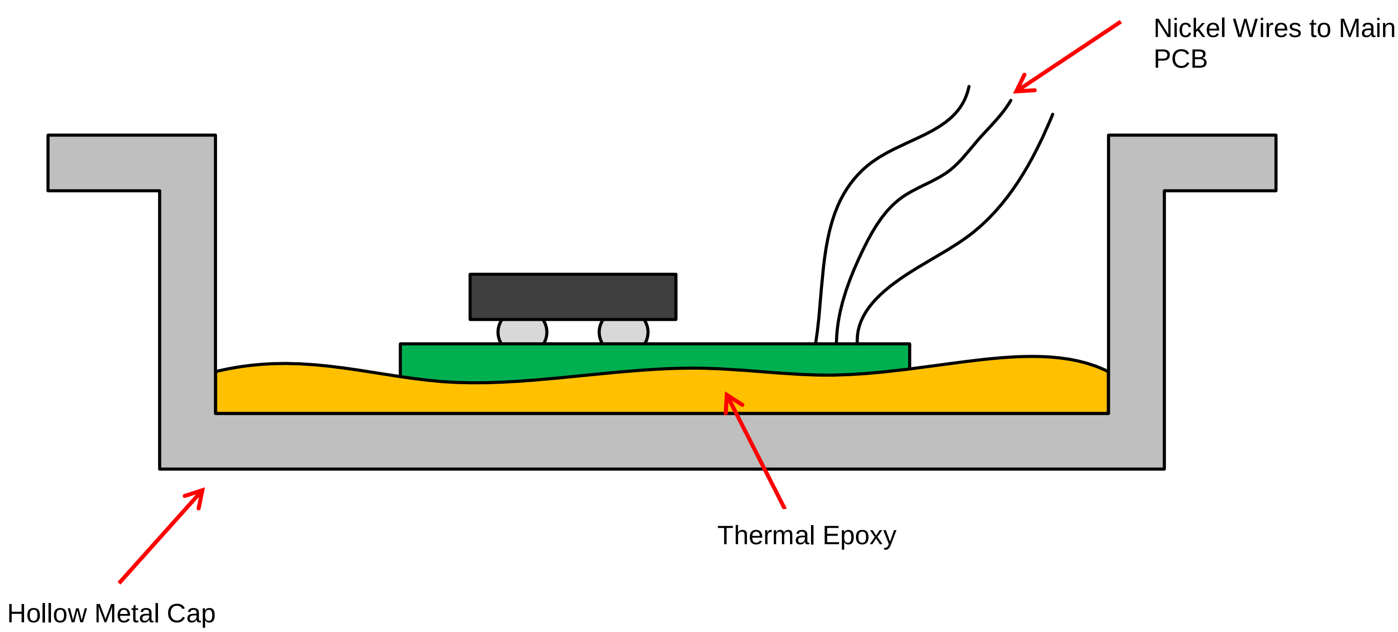

Figure 10: Side View of Metal Cap with Mounted Remote PCB

2.2.2. Hardware Implementation

The wearable design consists of a case to place all the components, a metal cap to conduct heat into the main temperature sensor, a LCD screen to display the temperature data, and a button to enabled the temperature conversion and display it onto the LCD screen.

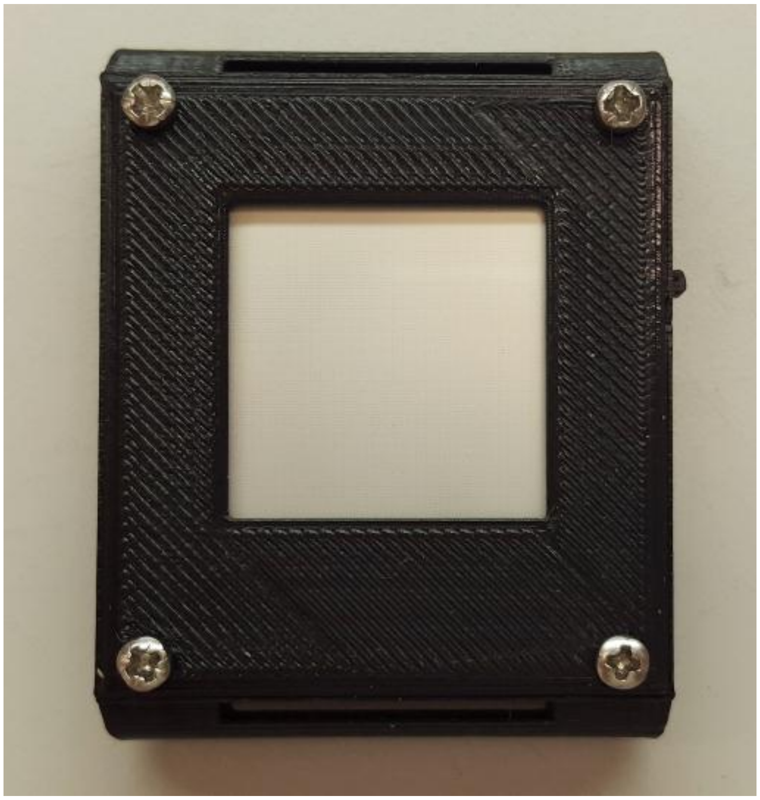

Figure 11: Wearable Design Top View

Figure 12: Wearable Design with Cover Off

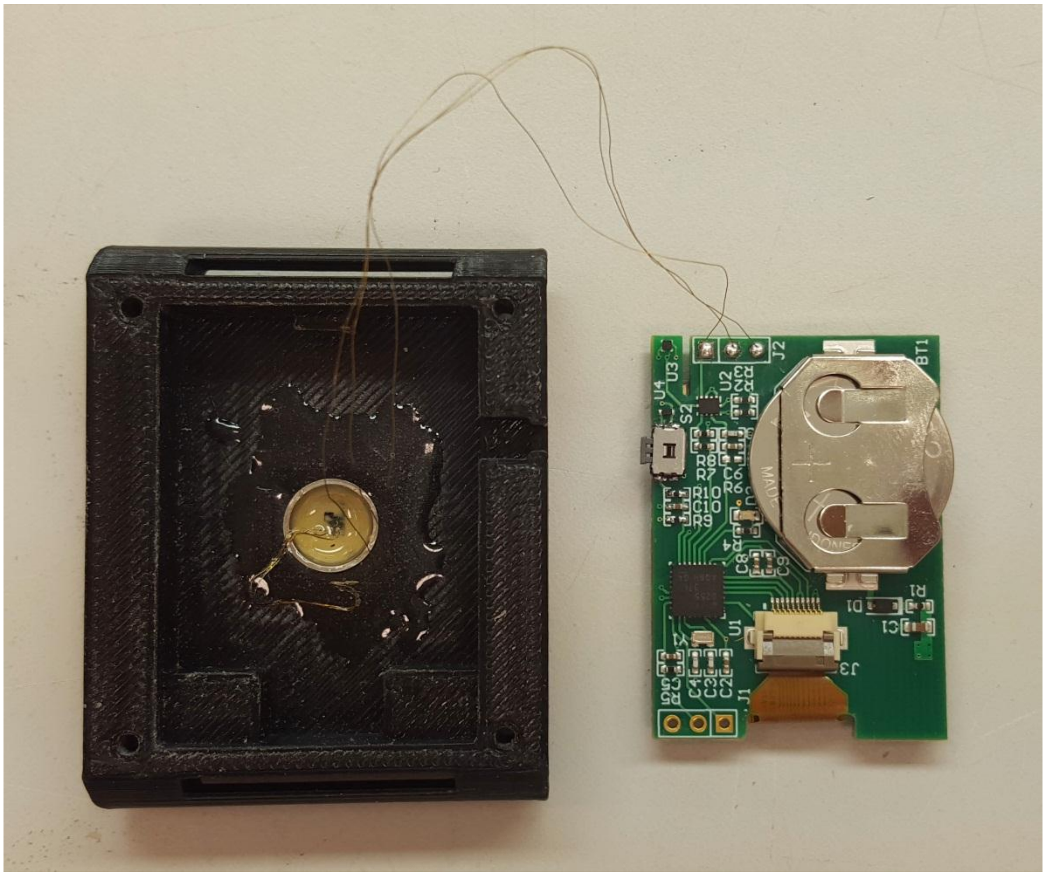

Figure 13: Wearable Design of Main PCB and Remote PCB Epoxied into Metal Cap

Figure 14: Wearable Design Back View

3. Test Data

Important metrics for measuring skin temperature is how accurate is the sensor when interfaced with an ADC and microcontroller signal chain and the thermal response of the LMT70 when placed inside the case for measuring human skin temperature.

3.1. System Accuracy

One of the requirements for this TI Design is to meet 0.1°C accuracy within the human body temperature range. The metal cap with the LMT70 sensor was placed inside a temperature controlled stirred oil bath. A temperature sweep was performed on the LMT70 module in the oil bath and the temperature was recorded and referenced to a high accuracy RTD thermometer. The LMT70 module fully meets our requirement with an average accuracy of 0.05°C across the full human body temperature range.

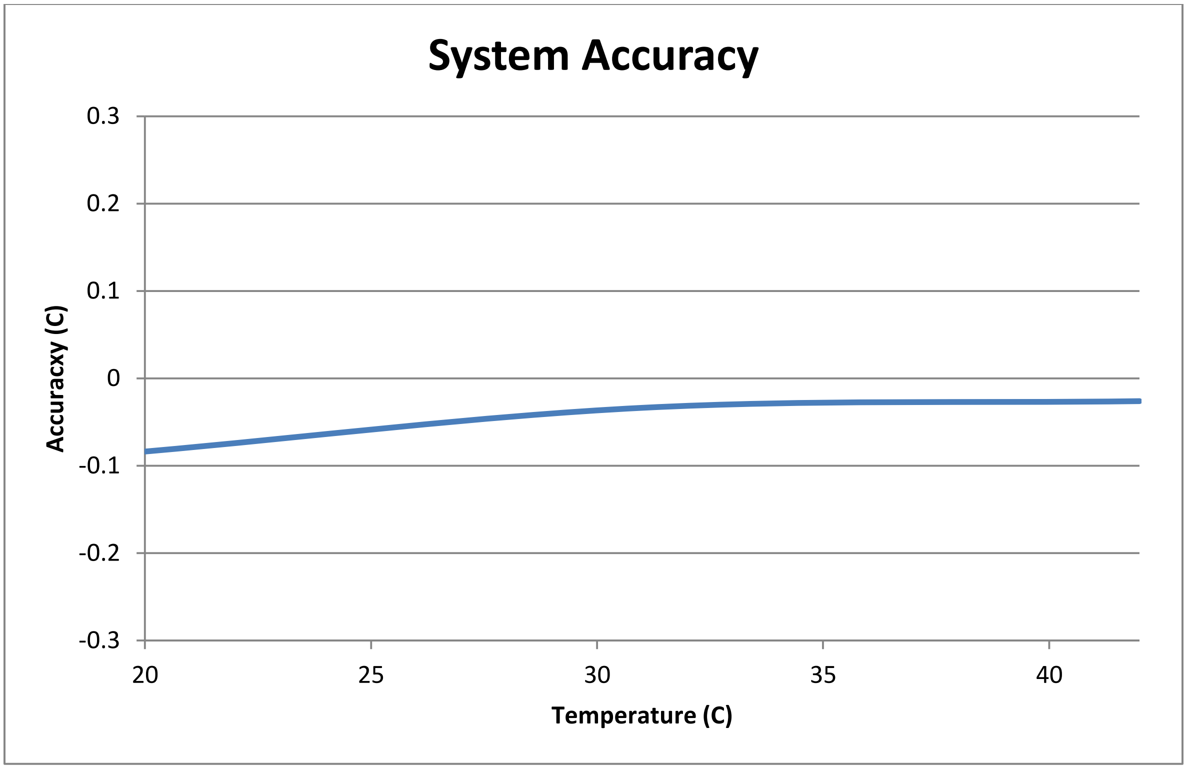

Figure 15: System Accuracy

3.2. Thermal Response

Thermal response is the time it takes for an object to reach final temperature from ambient. One of the difficulties of measuring human skin temperature is sensor placement. Different parts of the bodies exhibit different skin temperatures at locations such as the core or the extremities. A test was conducted by placing the wearable design on the wrist and in the armpit to determine the thermal response.

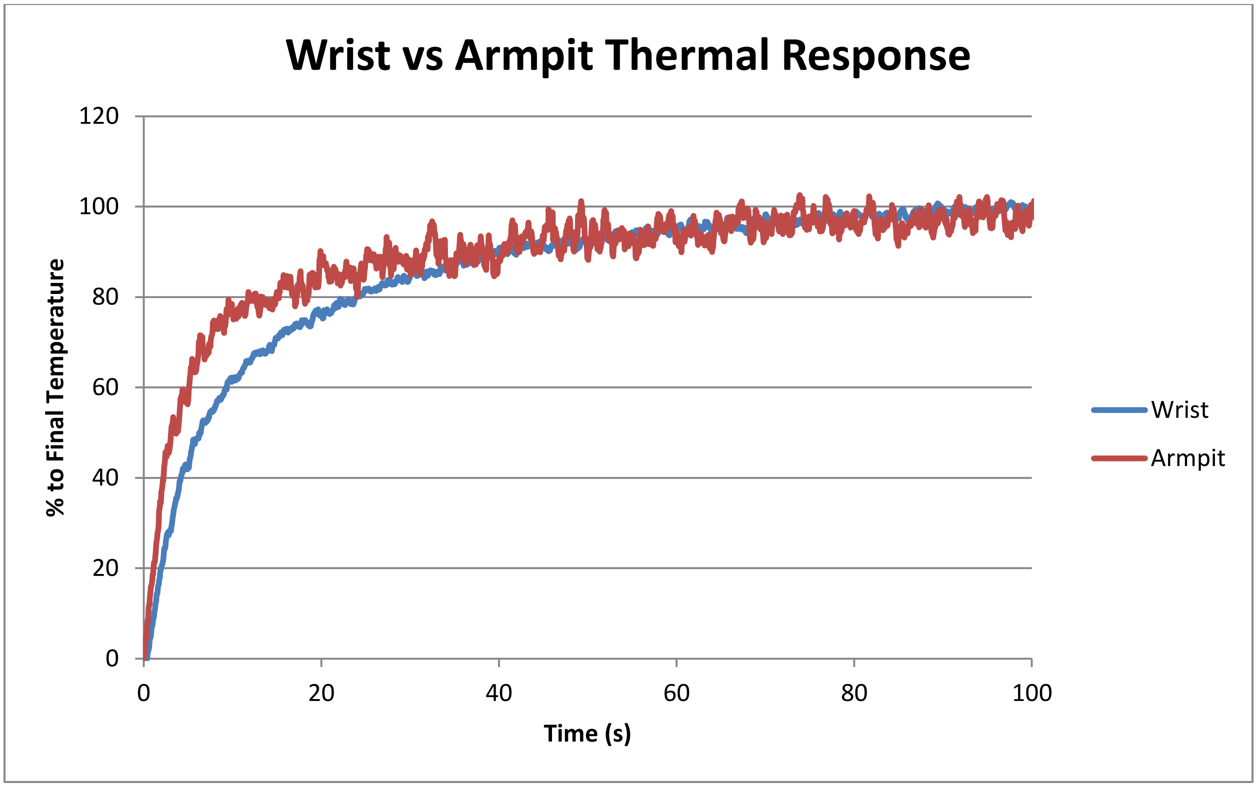

Figure 16: Thermal Response

The chart shows the thermal response when the wearable design is placed in the armpit is faster than the wrist. This is because the armpit is located closer to the core body compared to the wrist which is much further away. The “noise” of the armpit response is due to the consistency of pressure pressing against the sensor during inhale and exhale of the lungs.

4. Conclusion

An accurate wearable temperature sensor that detects skin temperature was made featuring TI’s most accurate temperature sensor, the LMT70. The total system accuracy with the LMT70 interfaced with the ADS1115 analog-to-digital converter yielded high accuracy of 0.08°C error in the human body temperature range. The thermal response time varies depending on where the sensor is placed on the body but should take no more than 100 seconds to settle to the final temperature. Using this TI Designs report as a guide should provide wearable designers to produce an accurate device for measuring human skin temperature.

Figure 17: First Button Press Shows the Main Menu

Figure 18: After the Main Menu is the Skin Temperature Page

Figure 19: Press the Button Again for the Room Temperature Page

Figure 20: Pressing the Button Again for the Scale Change Menu

Figure 21: Holding the Button for Two Seconds Changes Temperature to Fahrenheit

5. Appendix

5.1. PCB Layout

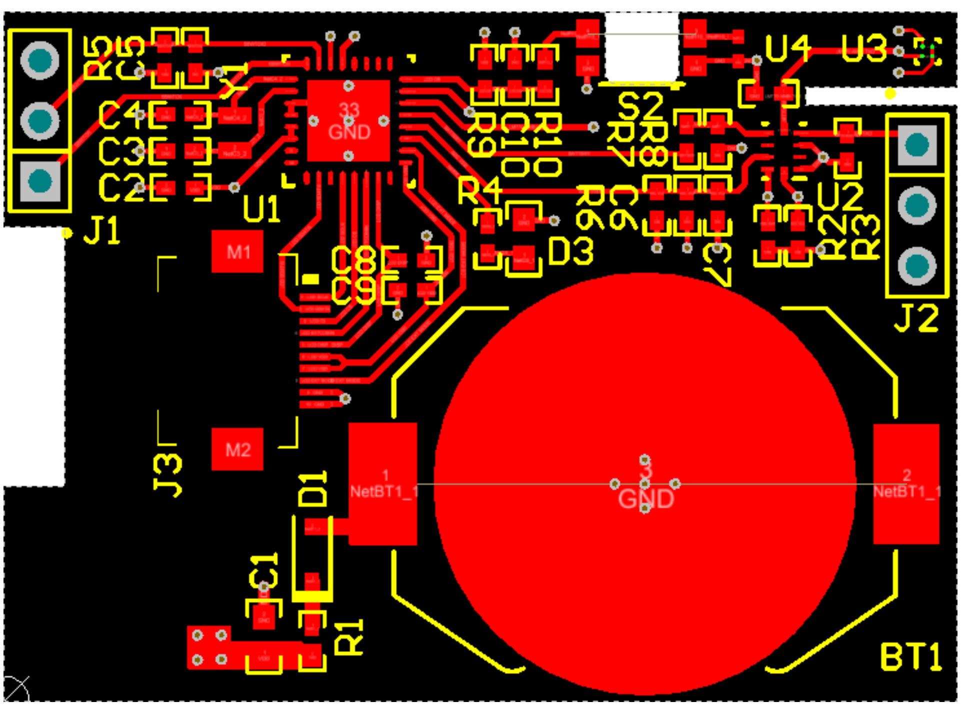

Figure 22 Top Layer

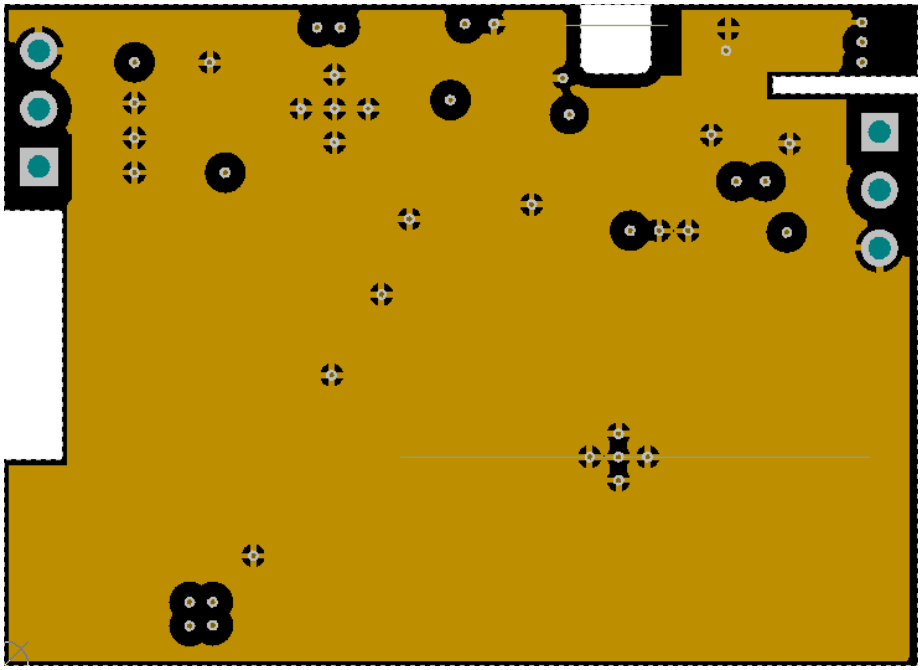

Figure 23: Ground Layer

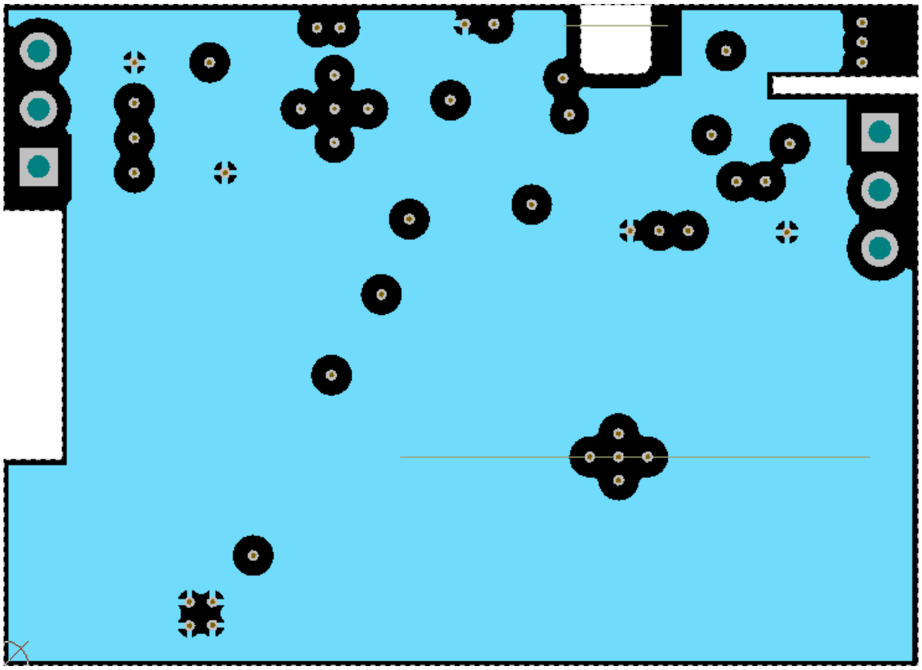

Figure 24: Power Layer

Figure 25: Bottom Layer

5.2. Schematic

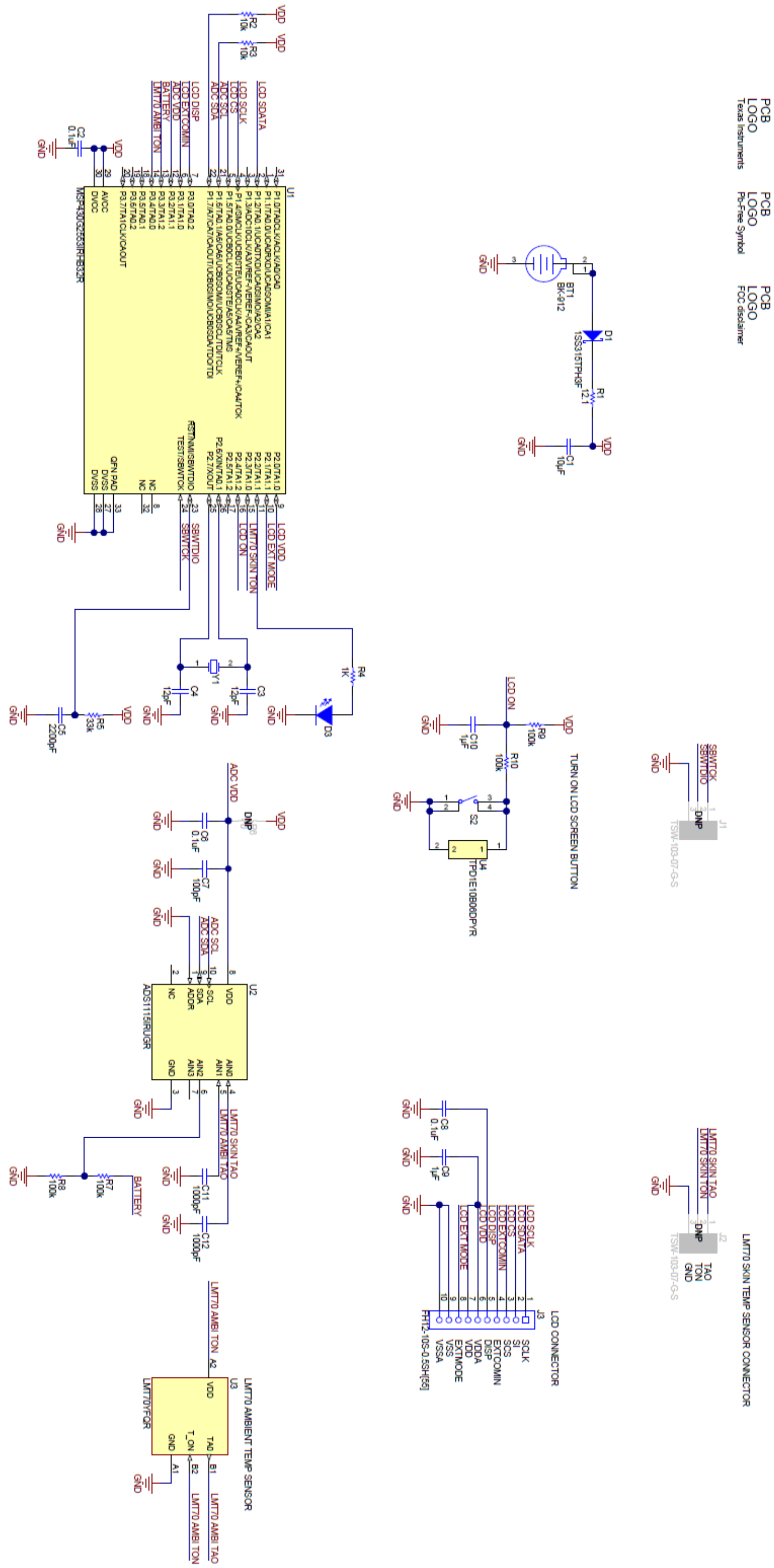

Figure 26: Schematic

5.3. Mechanical Drawing

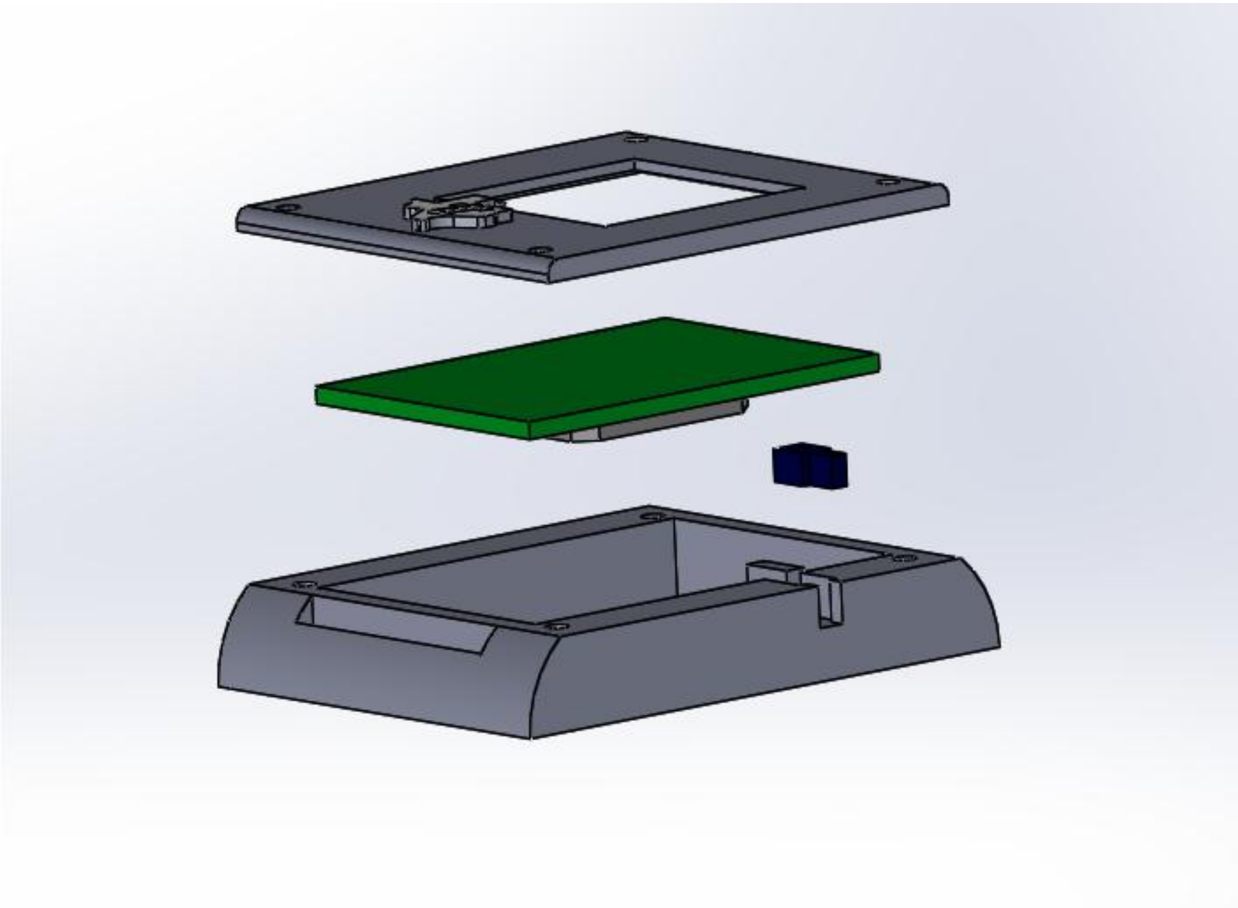

Figure 27: Exploded View

5.4. Support Documents and Resources

E2E Temperature Sensor Forum: https://e2e.ti.com/support/sensor/temperature_sensors/

LMT70 Datasheet: http://www.ti.com/lit/ds/symlink/lmt70.pdf

ADS1115 Datasheet: http://www.ti.com/lit/ds/symlink/ads1115.pdf

MSP430G2553 Datasheet: http://www.ti.com/lit/ds/symlink/ads1115.pdf

Wearable Temperature Sensing Layout Considerations
Optimized for Thermal Response Application Note: http://www.ti.com/lit/an/snia021/snia021.pdf

IMPORTANT NOTICE FOR TI REFERENCE DESIGNS

Texas Instruments Incorporated ("TI") reference designs are solely intended to assist designers (“Buyers”) who are developing systems that incorporate TI semiconductor products (also referred to herein as “components”). Buyer understands and agrees that Buyer remains responsible for using its independent analysis, evaluation and judgment in designing Buyer’s systems and products.

TI reference designs have been created using standard laboratory conditions and engineering practices. **TI has not conducted any testing other than that specifically described in the published documentation for a particular reference design.** TI may make corrections, enhancements, improvements and other changes to its reference designs.

Buyers are authorized to use TI reference designs with the TI component(s) identified in each particular reference design and to modify the reference design in the development of their end products. HOWEVER, NO OTHER LICENSE, EXPRESS OR IMPLIED, BY ESTOPPEL OR OTHERWISE TO ANY OTHER TI INTELLECTUAL PROPERTY RIGHT, AND NO LICENSE TO ANY THIRD PARTY TECHNOLOGY OR INTELLECTUAL PROPERTY RIGHT, IS GRANTED HEREIN, including but not limited to any patent right, copyright, mask work right, or other intellectual property right relating to any combination, machine, or process in which TI components or services are used. Information published by TI regarding third-party products or services does not constitute a license to use such products or services, or a warranty or endorsement thereof. Use of such information may require a license from a third party under the patents or other intellectual property of the third party, or a license from TI under the patents or other intellectual property of TI.

TI REFERENCE DESIGNS ARE PROVIDED "AS IS". TI MAKES NO WARRANTIES OR REPRESENTATIONS WITH REGARD TO THE REFERENCE DESIGNS OR USE OF THE REFERENCE DESIGNS, EXPRESS, IMPLIED OR STATUTORY, INCLUDING ACCURACY OR COMPLETENESS. TI DISCLAIMS ANY WARRANTY OF TITLE AND ANY IMPLIED WARRANTIES OF MERCHANTABILITY, FITNESS FOR A PARTICULAR PURPOSE, QUIET ENJOYMENT, QUIET POSSESSION, AND NON-INFRINGEMENT OF ANY THIRD PARTY INTELLECTUAL PROPERTY RIGHTS WITH REGARD TO TI REFERENCE DESIGNS OR USE THEREOF. TI SHALL NOT BE LIABLE FOR AND SHALL NOT DEFEND OR INDEMNIFY BUYERS AGAINST ANY THIRD PARTY INFRINGEMENT CLAIM THAT RELATES TO OR IS BASED ON A COMBINATION OF COMPONENTS PROVIDED IN A TI REFERENCE DESIGN. IN NO EVENT SHALL TI BE LIABLE FOR ANY ACTUAL, SPECIAL, INCIDENTAL, CONSEQUENTIAL OR INDIRECT DAMAGES, HOWEVER CAUSED, ON ANY THEORY OF LIABILITY AND WHETHER OR NOT TI HAS BEEN ADVISED OF THE POSSIBILITY OF SUCH DAMAGES, ARISING IN ANY WAY OUT OF TI REFERENCE DESIGNS OR BUYER’S USE OF TI REFERENCE DESIGNS.

TI reserves the right to make corrections, enhancements, improvements and other changes to its semiconductor products and services per JESD46, latest issue, and to discontinue any product or service per JESD48, latest issue. Buyers should obtain the latest relevant information before placing orders and should verify that such information is current and complete. All semiconductor products are sold subject to TI’s terms and conditions of sale supplied at the time of order acknowledgment.

TI warrants performance of its components to the specifications applicable at the time of sale, in accordance with the warranty in TI’s terms and conditions of sale of semiconductor products. Testing and other quality control techniques for TI components are used to the extent TI deems necessary to support this warranty. Except where mandated by applicable law, testing of all parameters of each component is not necessarily performed.

TI assumes no liability for applications assistance or the design of Buyers’ products. Buyers are responsible for their products and applications using TI components. To minimize the risks associated with Buyers’ products and applications, Buyers should provide adequate design and operating safeguards.

Reproduction of significant portions of TI information in TI data books, data sheets or reference designs is permissible only if reproduction is without alteration and is accompanied by all associated warranties, conditions, limitations, and notices. TI is not responsible or liable for such altered documentation. Information of third parties may be subject to additional restrictions.

Buyer acknowledges and agrees that it is solely responsible for compliance with all legal, regulatory and safety-related requirements concerning its products, and any use of TI components in its applications, notwithstanding any applications-related information or support that may be provided by TI. Buyer represents and agrees that it has all the necessary expertise to create and implement safeguards that anticipate dangerous failures, monitor failures and their consequences, lessen the likelihood of dangerous failures and take appropriate remedial actions. Buyer will fully indemnify TI and its representatives against any damages arising out of the use of any TI components in Buyer’s safety-critical applications.

In some cases, TI components may be promoted specifically to facilitate safety-related applications. With such components, TI’s goal is to help enable customers to design and create their own end-product solutions that meet applicable functional safety standards and requirements. Nonetheless, such components are subject to these terms.

No TI components are authorized for use in FDA Class III (or similar life-critical medical equipment) unless authorized officers of the parties have executed an agreement specifically governing such use.

Only those TI components that TI has specifically designated as military grade or “enhanced plastic” are designed and intended for use in military/aerospace applications or environments. Buyer acknowledges and agrees that any military or aerospace use of TI components that have ***not*** been so designated is solely at Buyer's risk, and Buyer is solely responsible for compliance with all legal and regulatory requirements in connection with such use.

TI has specifically designated certain components as meeting ISO/TS16949 requirements, mainly for automotive use. In any case of use of non-designated products, TI will not be responsible for any failure to meet ISO/TS16949.

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