LMT70 Thermal Response for Wearable Devices

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1. Introduction

The LMT70 is a highly accurate analog output temperature sensor with an output enable switch. This temperature sensor can be used to detect temperatures between -55°C to 150°C. At 30°C its accuracy is +/- 0.13°C which makes it ideal to use in medical and wearable applications such as body monitors or fitness watches.

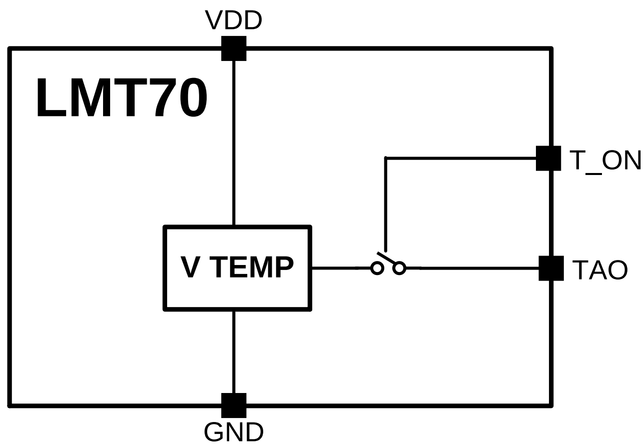

Figure 1: LMT70 Block Diagram

The purpose of this TI Design report is to show the thermal response of the LMT70 temperature sensor when mounted onto different substrates for wearable applications. The report will also go into offset, gain, and reference calibration of the integrated ADC in the MSP430 to achieve accurate temperature readings from the LMT70.

2. LMT70EVM

The LMT70EVM was used in this TI Design to measure and record the output voltage of the LMT70 on different substrates. For installation instructions of the LMT70EVM software and usage, please refer to the following link: http://www.ti.com/tool/lmt70evm.

The EVM features the LMT70 on a breakout tab on a USB form factor EVM board. The breakout tab can be removed so the user can solder wires or headers to the exposed copper pads for remote temperature measurements. The EVM also features a MSP430F5548 microcontroller which reads the output voltage of the LMT70 and with its integrated ADC.

Note: Do not break the breakouts with your hands. Doing so may damage the LMT70 device. It is recommended to use a saw or shears to break the breakouts.

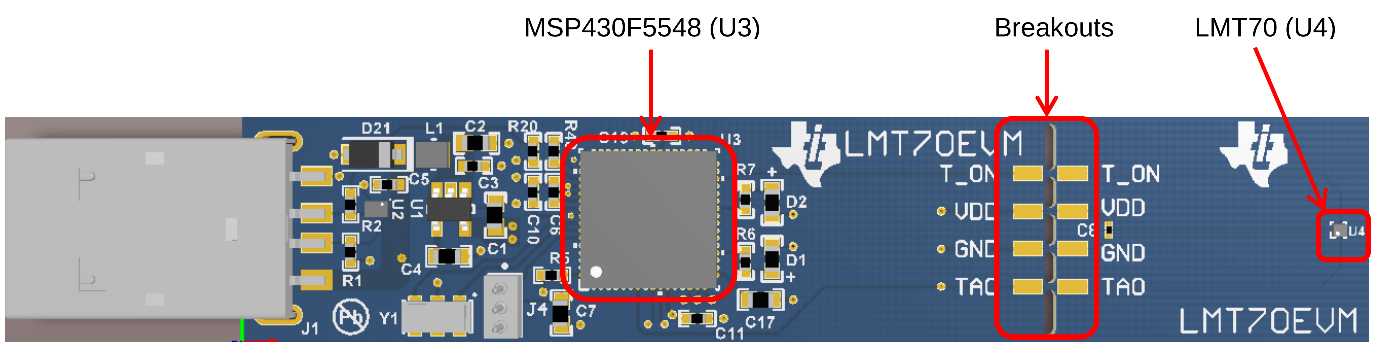

Figure 2: LMT70EVM Evaluation Board

3. MSP430 ADC Calibration

Calibration of the integrated ADC on the MSP430 is critical to achieve the correct ADC code when measuring highly accurate signals from the LMT70. The MSP430F5548 comes with a calibration table (Table 65 in the MSP430F5528 Datasheet) and a calibration guide (Section 1.12.5 in MSP430 x5xx User's Guide).

Short Name	Value	Description
LDTAG	01h	Legacy descriptor (1xx, 2xx, 4xx families)
PDTAG	02h	Peripheral discovery descriptor
Reserved	03h	Future usage
Reserved	04h	Future usage
BLANK	05h	Blank descriptor
Reserved	06h	Future usage
ADCCAL	11h	ADC calibration
REFCAL	12h	REF calibration
Reserved	13h - FDh	Future usage
TAGEXT	FEh	Tag extender

Table 1: Tag Length Value (TLV) Descriptors in MS430F5528

The calibration values are used in the following sections below:

Voltage Reference Calibration

The LMT70EVM uses a 1.5V internal voltage reference for the integrated SAR ADC

$$\mathrm{ADC(ref\_corrected)} = \mathrm{ADC(raw)} * \mathrm{CAL\_ADC\_15VREF\_FACTOR} * \frac{1}{2^{15}}$$

Offset and Gain Correction

The final ADC value with offset and gain can be corrected using the following steps:

$$\mathrm{ADC(gain\_corrected)} = \mathrm{ADC(ref\_corrected)} * \mathrm{CAL\_ADC\_GAIN\_FACTOR} * \frac{1}{2^{15}}$$

$$\mathrm{ADC(ref\_gain\_offset\_corrected)} = \mathrm{ADC(gain\_corrected)} + \mathrm{CAL\_ADC\_OFFSET}$$

Example Calculation

The ADC Raw Value is the uncalibrated, raw data from the integrated MSP430 ADC. The CAL_ADC_15VREF_FACTOR, CAL_ADC_GAIN_FACTOR, and CAL_ADC_OFFSET values are read from the MSP430 registers. Refer to the MSP430F5528 datasheet for more details.

ADC Raw Value = 2656
CAL_ADC_15VREF_FACTOR = 32646
CAL_ADC_GAIN_FACTOR = 32770
CAL_ADC_OFFSET = 0

$$\mathrm{ADC(ref\_corrected)} = \mathrm{ADC(raw)} * \mathrm{CAL\_ADC\_15VREF\_FACTOR} * \frac{1}{2^{15}}$$
$$\mathrm{ADC(ref\_corrected)} = 2656 * 32646 * \frac{1}{2^{15}} = 2646.11 = 2646$$

$$\mathrm{ADC(gain\_corrected)} = \mathrm{ADC(ref\_corrected)} * \mathrm{CAL\_ADC\_GAIN\_FACTOR} * \frac{1}{2^{15}}$$
$$\mathrm{ADC(gain\_corrected)} = 2646 * 32770 * \frac{1}{2^{15}} = 2646.11 = 2646$$

$$\mathrm{ADC(ref\_gain\_offset\_corrected)} = \mathrm{ADC(gain\_corrected)} + \mathrm{CAL\_ADC\_OFFSET}$$
$$\mathrm{ADC(ref\_gain\_offset\_corrected)} = 2646 + 0 = 2646$$

For more information on ADC calibration, please refer to the MSP430x5xx and MSP430x6xx Family User's Guides section 1.12.5 located at the following link: http://www.ti.com/lit/ug/slau208n/slau208n.pdf. A complete list and descriptions of the Tag Length Value (TLV) Descriptors can be found in Table 65 of the MSP430F5528 datasheet: http://www.ti.com/lit/ds/symlink/msp430f5528.pdf.

4. LMT70EVM's ADC Calibration on Temperature Measurements

High temperature accuracy is achieved by calibrating the voltage reference, gain, and offset constants in the MSP430 microcontroller. Below is a plot that demonstrates temperature accuracy with and without calibration with respect to a high accuracy temperature probe (Fluke 1502A). This test was performed in a controlled environment with an oil bath set at 23C. The calibrated ADC Temperature and uncalibrated ADC Temperature plots are shown below with a 256 point running average.

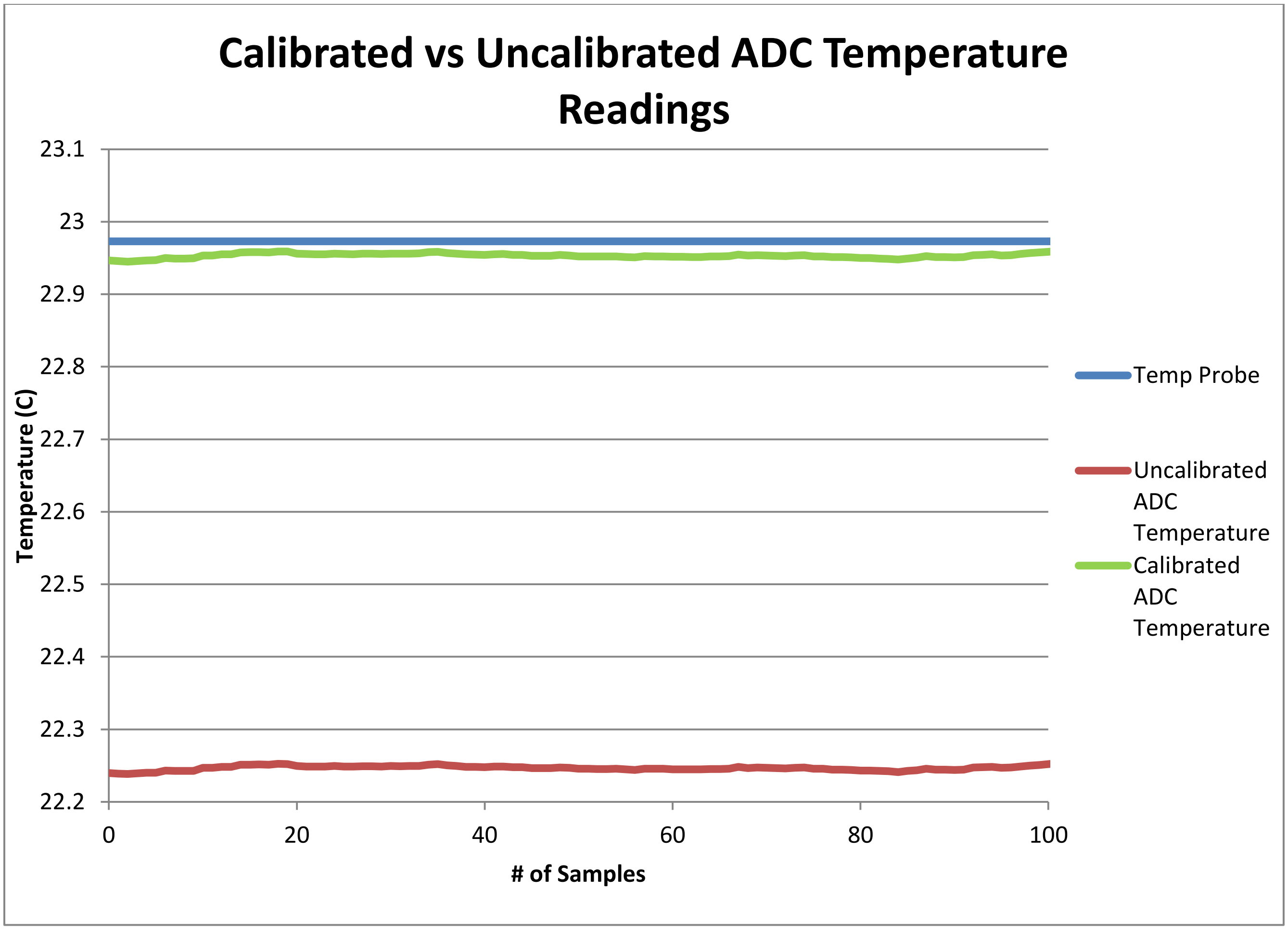

Figure 3: Temperature Measurements with ADC Calibration

Human body temperatures are mainly between the temperature ranges of 25°C to 45°C. It is also a temperature range in which the LMT70 with the calibrated MSP430 on the LMT70EVM is very accurate (less than 0.03°C accuracy). Below is a plot of this temperature range:

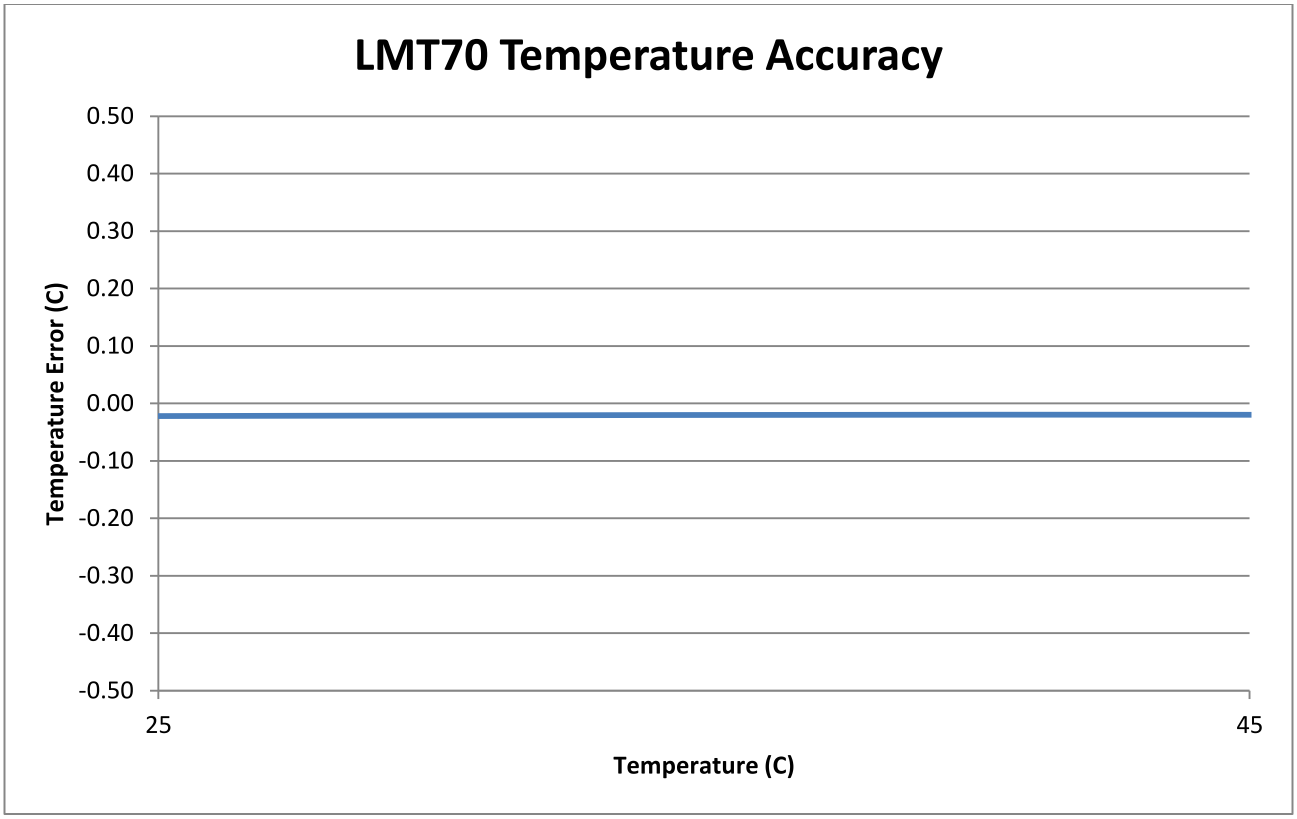

Figure 4: LMT70 Temperature Accuracy (25°C to 45°C)

5. Thermal Response Time Test Methodology

Response time is how fast the sensor settles to the object’s final temperature. This is important for applications where the user places the sensor on an object and wants to read the temperature within a reasonable amount of time. Note that despite having a highly accurate temperature sensor the response time is dependent on the industrial design around the sensor, physical placement of the sensor, and the substrate of the sensor is connected to. The LMT70 detects temperature best through its ground BGA with the substrate being a function of the thermal response time.

In the following tests, the response time of the LMT70 is measured with three different types of substrates: regular PCB, thin PCB, and a flex PCB. The three substrates were placed from ambient room temperature to the armpit of a human being and measured for 5 minutes.

Block Diagram

The test was conducted by breaking apart the LMT70EVM along the breakout tabs. The LMT70 was then soldered onto the test substrates and then connected to the exposed pads on the LMT70EVM. The exposed pads are labeled VDD, GND, T_ON, and TAO on the EVM and must correspond to the appropriate pins on the LMT70. A block diagram of the system setup is shown below:

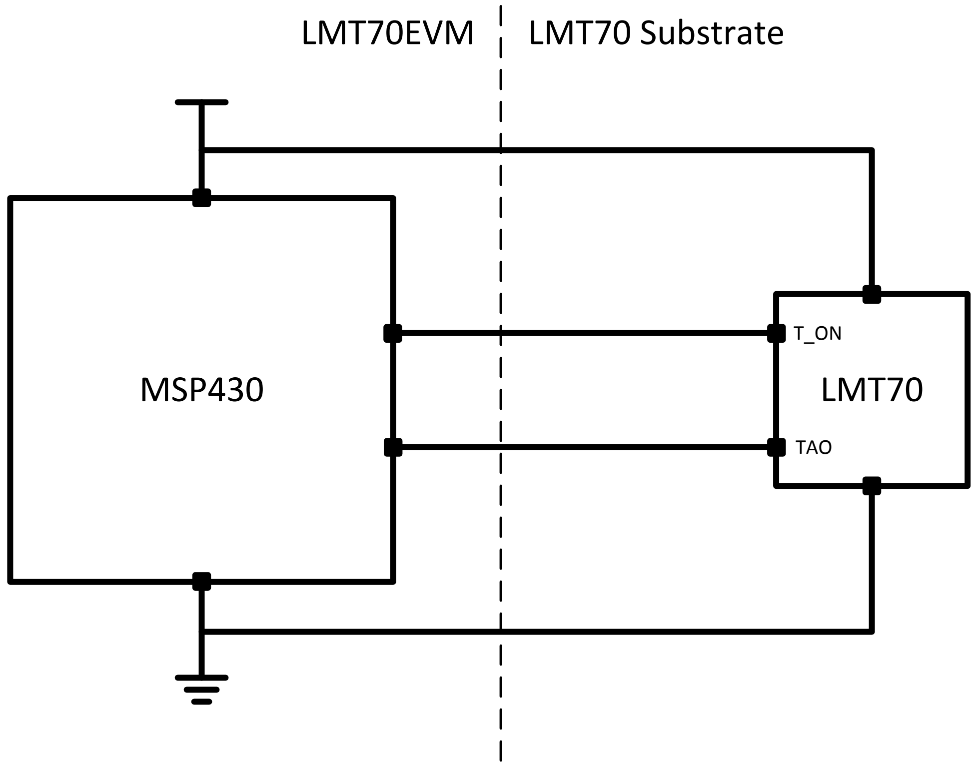

Figure 5: Block Diagram

The three substrates used in the thermal response test are described below:

Regular PCB
The regular PCB comes from the LMT70EVM where the sensor side was broken apart from the rest of the EVM. This PCB is a standard single layer FR4 board.

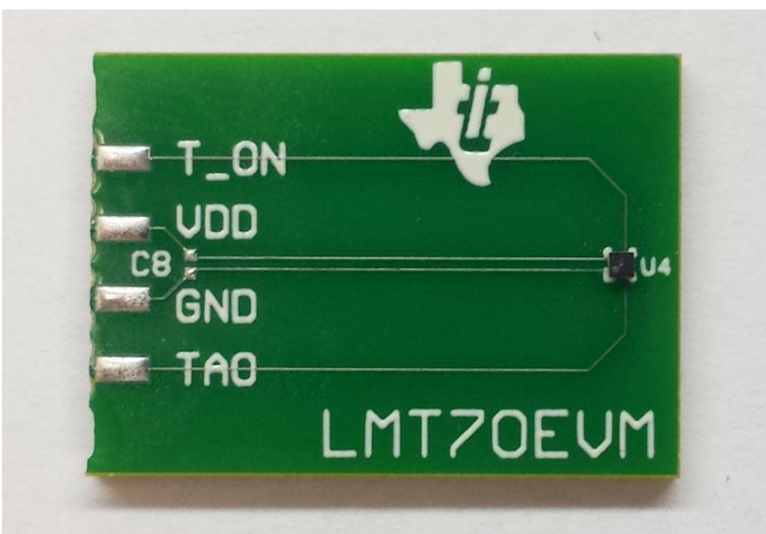

Figure 6: Regular PCB

Thin PCB

The think PCB is a 0.5mm thick and 2mm wide and has 0.102mm (4 mil) wide traces. This provides a “hard” PCB solution with reduced thermal mass.

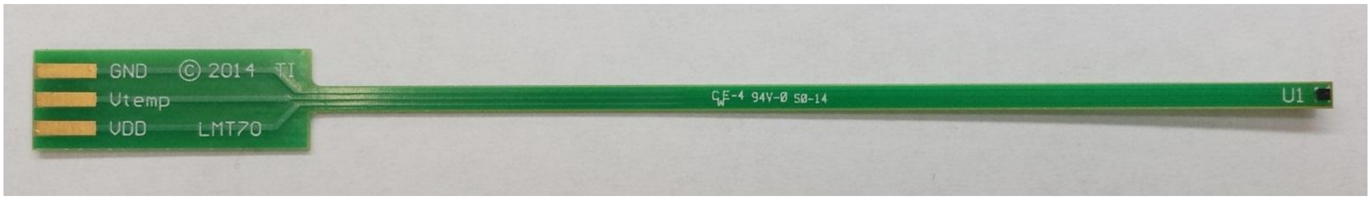

Figure 7: Thin PCB

Flex PCB

The Flex PCB is a standard flex PCB with the LMT70 footprint on one side and a plastic stiffener on the opposite side to provide mechanical rigidity. This PCB provides the ability to be mounted on curved surfaces or wrapped around an object. This PCB also has the least thermal mass of all three solutions.

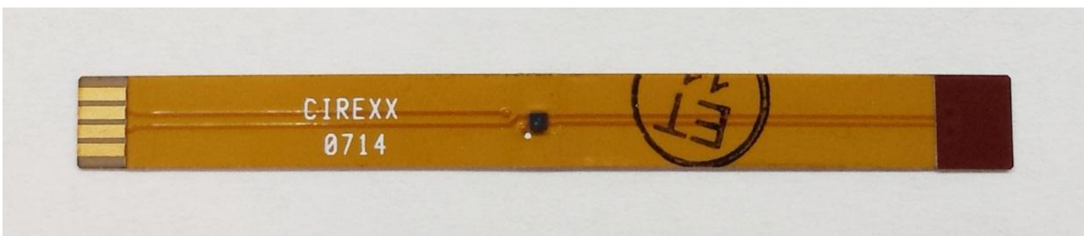

Figure 8: Flex PCB

6. Thermal Response Test Results

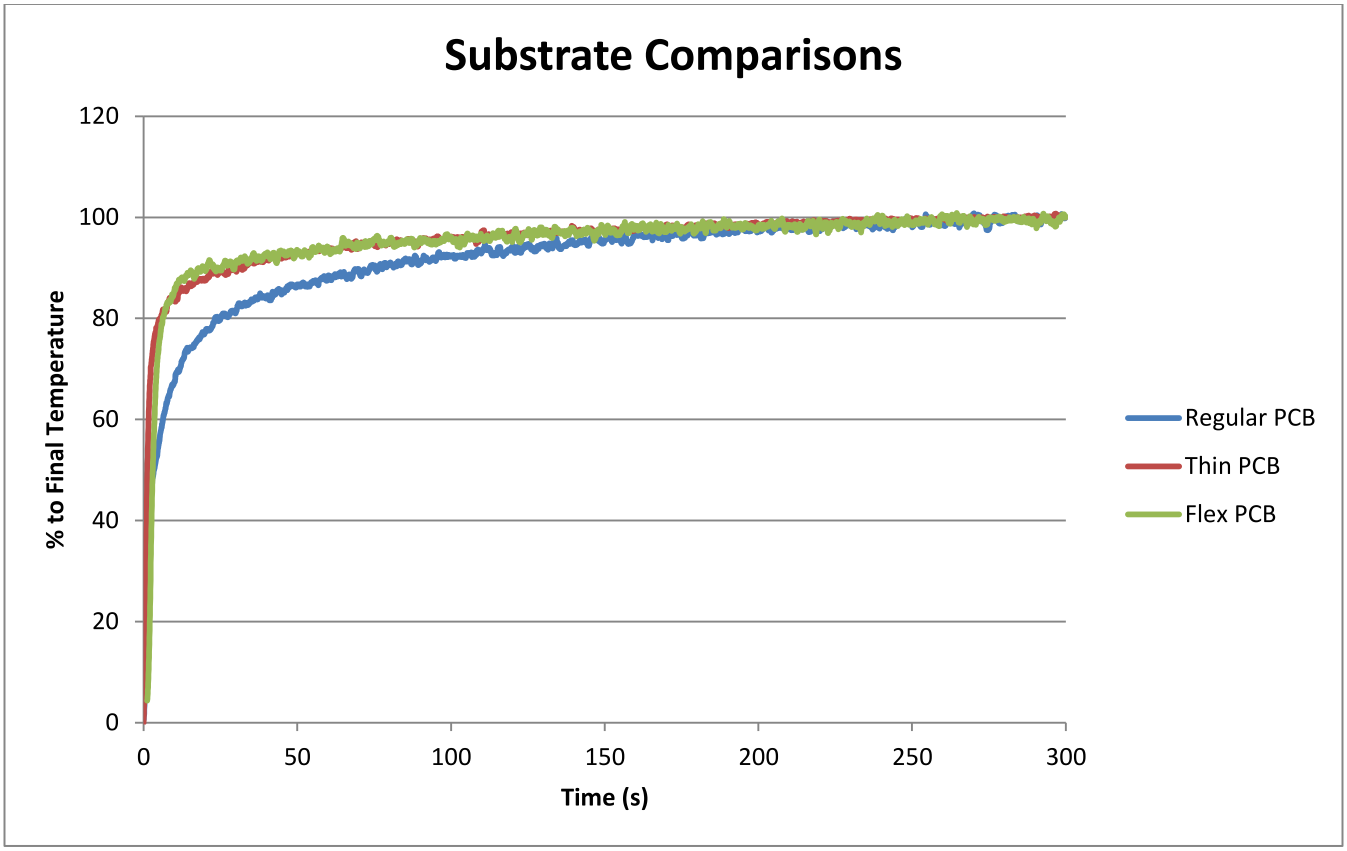

Figure 9: Overall Substrate Comparison

Observations and Conclusions

The thin and flex PCB substrates have the fastest thermal response due to its small thermal mass. It is not surprising as less mass takes less time to heat up and reach thermal equilibrium. The regular PCB takes the most time to heat up because of its larger area and thickness compared to the other two substrates. Notice the temperatures fluctuates and is not a constant straight line, and note that human temperature is not a controlled heat source and may change due to many factors.

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