

Wearable Temperature Sensing Layout Considerations Optimized for Thermal Response

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ABSTRACT

This application note covers thermal response considerations for sensors that come in a DSBGA package for measuring skin temperature for applications such as wearables such as fitness bands and medical devices. It will specifically focus on the LMT70, a 0.88mm x 0.88m 0.13°C max accuracy (0.05°C typ) temp sensor over the human body temperature range, but learning can be applied to other temperature sensors that come in a similar package, whether they be analog or digital sensors. Contact temperature sensors, such as the LMT70, need to be placed in close contact with the surface that needs to be measured. This can be quite challenging for the DSBGA package that is if fast thermal response is also necessary. Experimental results of different PCB layouts will be presented when measuring axillary.

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1 Introduction

The two major concerns for measuring body temperature in wearables are accuracy and speed. The LMT70 is a 4-pin analog temperature sensor that comes in a DSBGA package that is 0.88 mm x 0.88 mm. Its small size means small thermal mass thus quick response. The LMT70 also includes internal calibration making it one of the most accurate analog IC temperature sensors in the market. The LMT70's typical accuracy of 0.05°C from 25°C to 45°C makes it ideal for measuring body temperature. This application note will discuss the PCB layout considerations required to achieve good thermal conductivity as well as fast thermal response for the LMT70 as PCB layout can dramatically affect these parameters.

The LMT70 temperature sensing circuitry is based on the transistor base emitter diode junction thermal properties. The diode voltage is then amplified and buffered as shown in Figure 1. The sensing element of the LMT70 consists of stacked BJT base emitter junctions that are biased by a current source. The output of the sensing element is buffered by a precision amplifier whose class AB push-pull output stage can easily source and sink currents of up to 3 mA. The amplifier output connects to an output switch that is turned on and off by the digital control input T_ON (see Figure 1). This switch allows for the multiplexing of multiple sensors on one signal line.

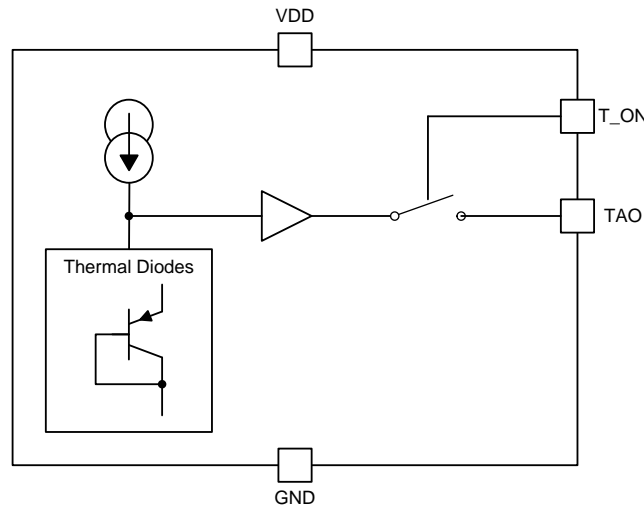


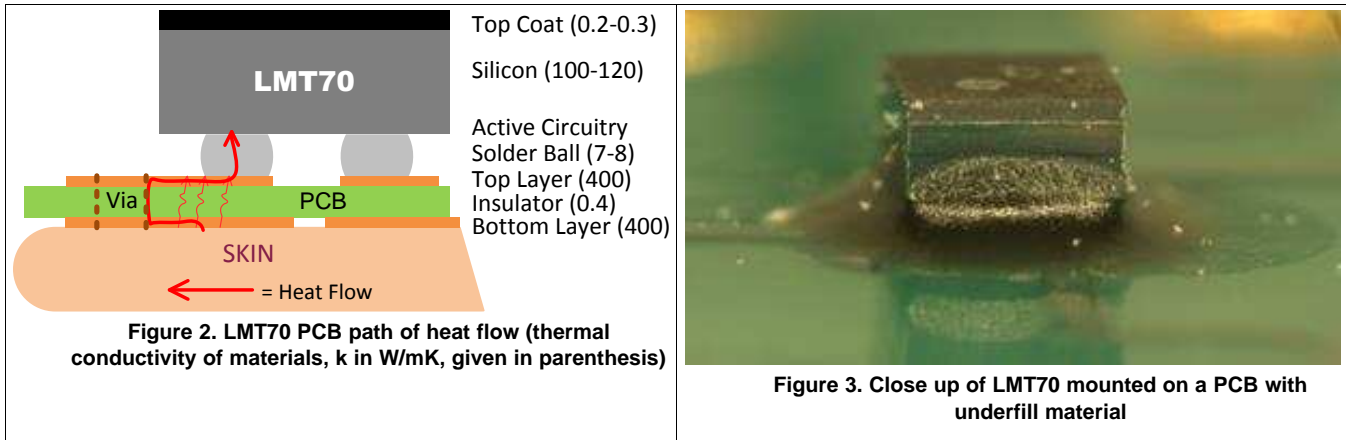
Figure 1. LMT70 Block Diagram

The LMT70 is a contact sensor, thus making good contact with the surface that is measured is of primary importance. There are several methods of heat transfer conduction, convection and radiation. For the LMT70 the main method is conduction. Thermal conductivity is the main parameter of a material that needs to be considered in addition to the contact area and the length material. Thermal conductivity (W/(mK)) of several materials that may be used in the production of a PCB are given in the table shown in Table 1.

Table 1. Thermal Conductivity of Different Materials

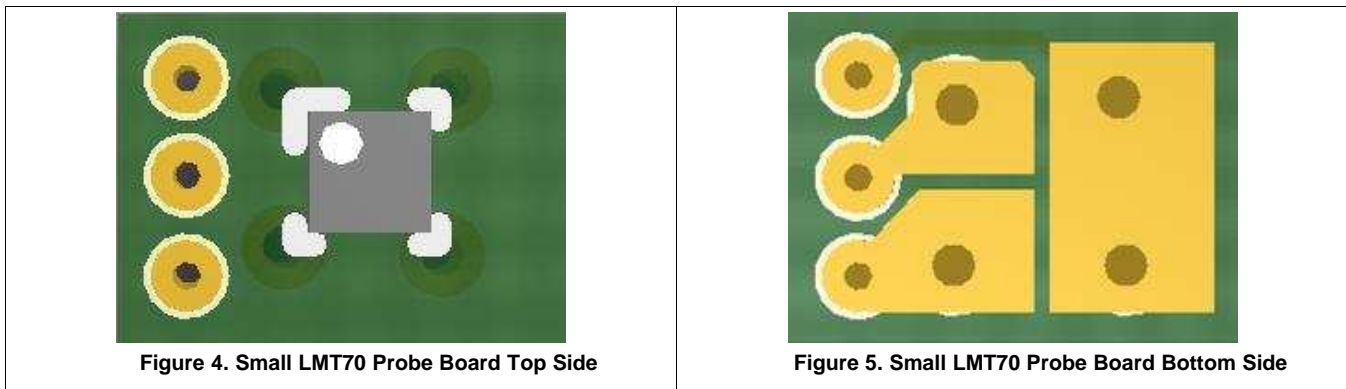
Material	Thermal Conductivity (k in W/mK)
Air	0.023 to 0.045
Wood	0.04 to 0.3
Epoxy coating on top of LMT70 die	0.2 to 0.3
FR4	0.4
Polyimide	0.5
Thermally Conductive Epoxy	1 to 7
LMT70 Solder Ball	7 to 8
Stainless Steel	16 to 24
Solder (63/67)	39
Nickle	91
Silicon	100 to 120
Aluminum	204 to 250
Gold	320
Copper	400
Silver	425
Diamond	900<

The higher the k factor the better the thermal conductivity thus the faster the response time. Maintaining a small thermal mass will improve the thermal response time of the circuit. This is where good thermal modeling software becomes a necessity. Shown in Figure 4 is a cross section of an LMT70 mounted on a PCB. As can be seen in the Thermal Conductivity of Different Thermal Materials table copper is a very good thermal conductor and so is solder. The red arrow shows the heat flow path from the back side of the PCB to the LMT70 active circuitry (cross hatched area) through metal portions of the PCB (the traces, pads, and solder balls). Since there is air surrounding the part and the solder balls in this example the thermal conductivity is compromised. Better results can be obtained if underfill is added surrounding the LMT70 die (package) as shown in Figure 3, thus improving the conductivity to the actual silicon which has very high thermal conductivity. FR4 and Polyimide insulators do not have very good thermal conductivity thus their thickness should be minimized.



2 Small LMT70 Probe Board Description

As mentioned previously size matters and so does the material you use. The following board was designed to optimize the thermal response time of the LMT70. The board was made very small approaching minimum sizes for PCB manufacturing. The back side of the board has large surface area with vias to the top side as shown in Figure 4 and Figure 5.



Probe Board Dimensions

- Width: 115mil (2.9mm)
- Height: 85mil (2.16mm)
- Thickness: 20mil with 1oz copper
- Via size: 12mil hole, 24mil diameter
- Wire pad: 8mil hole, 20mil diameter
- No bottom side solder mask

Boards are all assembled with LMT70 first with the panel intact. Then the LMT70s were epoxied to the board. Forty gauge nickel wire was soldered to the PCB connecting holes for connection purposes as shown in Figure 6. Nickel was chosen for the wire material as it has lower thermal conductivity than copper. The small diameter wire was chosen because of its small mass. This type of wire was used in order to minimize the thermal effects of the wires to the PCB response time. The wires attached to the PCB can act as a heat sink thus lower thermal mass and lower thermal conductivity would minimize the heat sink affect. Holes were used rather than pads in order to provide more mechanical strength to the wire assembly. Four mil copper traces and 40 AWG copper wire should affect the response time by a very small amount as the main benefits of this layout are the exposed copper bottom side pads and vias.

We are working on identifying thermally conductive but electrically isolating under-fill material (such as Henkel 3800 or 3810) that will work in helping with the thermal conductivity on the top side (see Figure 3). It will enable an automated production environment as the epoxy glue that was used for this experiment was hand applied. Comparison results will be published in a revision of this app note.

3 The Measurement System

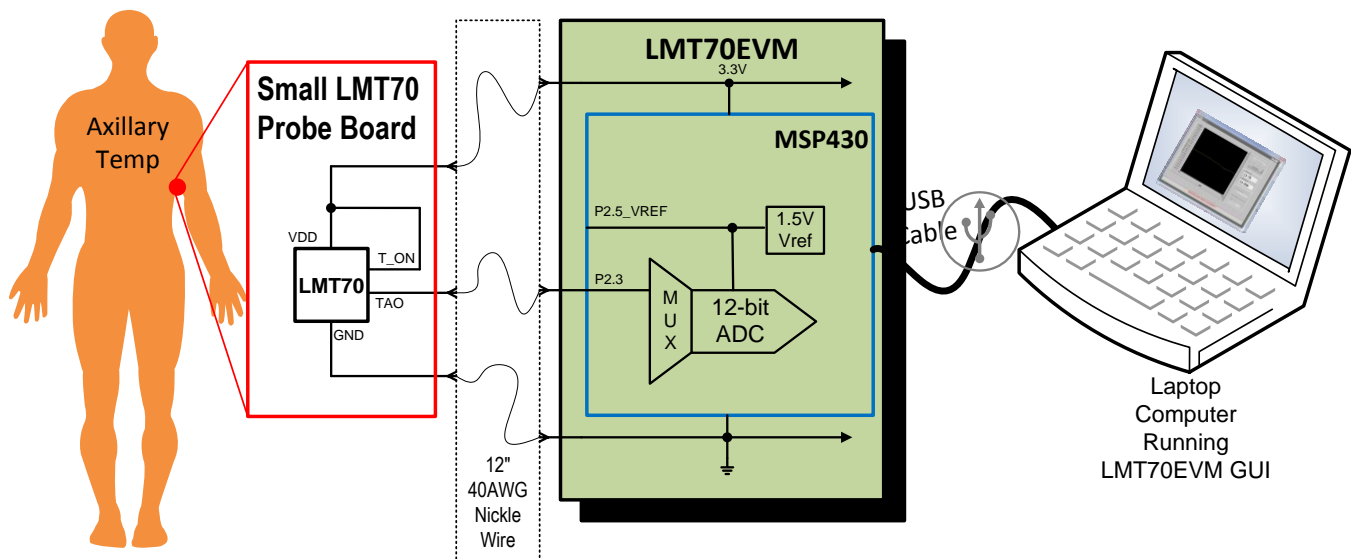


Figure 6. LMT70 Probe Board Thermal Response Measurement System

The LMT70 Probe board was connected to the LMT70EVM through 40AWG wires as shown in Figure 6. The LMT70 output temperature was recorded using the LMT70EVM GUI. The LMT70EVM is USB powered. See TI Design “Temperature Sensor for Wearable Devices Reference Design” ([TDA-00452](#)) and the LMT70EVM for more information on the GUI and firmware source code and performance of the system.

4 Probe Board Test Results

The curve in Figure 7 shows the percent of final value on the Y axis and time in seconds on the X axis. Initial temperature of about 22C is the initial 0% level as shown in the curve. The 100% level of course is the axillary skin temperature. It is common to normalize and the thermal response time of a temperature sensor in this manner. Usually thermal time constant is given to the 63% level, similar to RC time constant. This is a good way to compare the response time of different boards as it normalizes the starting temperature of the test and allows easy comparison. As can be seen in Figure 8, the **Small LMT70 Probe Board** (purple trace) improves upon the thermal response time performance when compared to several other types of PCBs by about 100 seconds to the 99% (black trace) of final value. The next best performing PCB is the flex PCB shown in green. More information on the **Thin PCB** (red), **Flex PCB** (green), and **Regular PCB** (blue) can be found in the TI Design “Temperature Sensor for Wearable Devices Reference Design” ([TIDA-00452](#)) and Section 5.

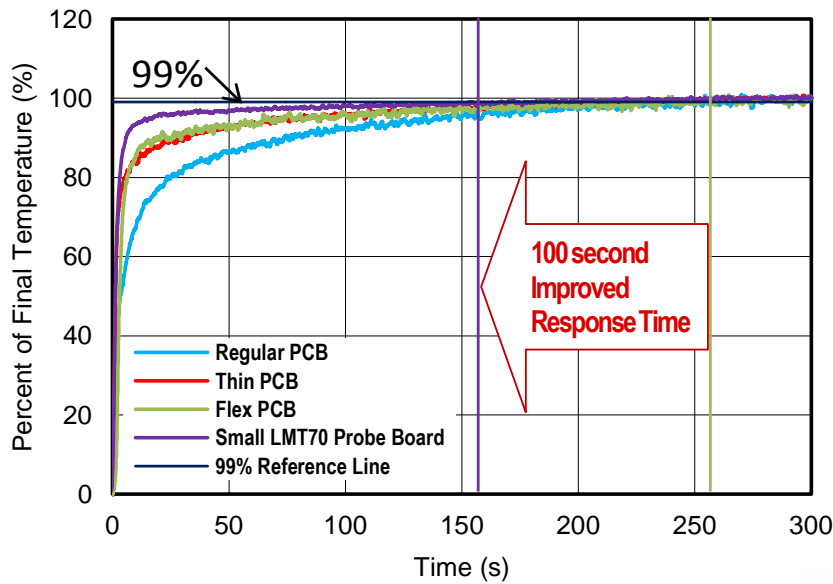


Figure 7. Comparison of the Small PCB to other types of substrates when measuring axillary body temperature.

5 Appendix

5.1 Other Board Descriptions

For quick review the additional LMT70 boards are described in this section briefly. These boards have a color coded boarder to match the traces as shown in Figure 7 for easy reference purposes. The red trace thin PCB is 2mm wide at the right, (8mm wide at left), and 0.5mm thick with 0.102mm (4 mil) traces. The LMT70 mounts at the far right. No thermal vias or pads are on the back side of the board.



Figure 8. Thin PCB

The green trace Flex PCB has the LMT70 mounted in the middle. It has a stiffener on the back side of the LMT70 in order to provide mechanical stability to the LMT70 mounting.



Figure 9. Flex PCB

The blue trace Regular PCB is the LMT70EVM which is standard 12 mil thickness but has very small 4 mil traces. The LMT70 is mounted on the far right. The size of the PCB is 850 mils or 21mm by 600 mils or 15mm with thickness of 1.5mm.

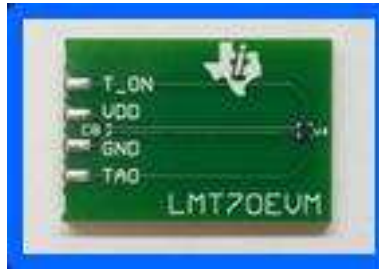


Figure 10. Regular PCB (from LMT70 Evaluation Module)

6 References

- *LMT70, LMT70A $\pm 0.1^{\circ}\text{C}$ Precision Analog Temperature Sensor, RTD and Precision NTC Thermistor IC Data Sheet* ([LMT70 Datasheet](#).)
- *LMT70 Evaluation Module Precise Analog Output Temperature Sensor with Output Enable* ([LMT70 EVM](#))
- *TI Design: Temperature Sensor for Wearable Devices Reference Design* ([LMT70 TI Design](#))

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