

Expanding Thermistor Temperature Measurements Using TSP™ Technology

APPLICATION NOTE



KEITHLEY
A Tektronix Company

Compatible Instruments

DAQ6510, DMM6500, and DMM7510

Introduction

A thermistor is a resistor whose value varies with temperature. The relationship is non-linear but well defined. These two-terminal devices are one of the most common and readily available temperature measurement devices. The semiconductor metal oxide makes them sensitive to small temperature changes. Thermistors work best in various temperatures and applications because they are durable and reliable.

There are two types of thermistors, negative temperature coefficient (NTC) and positive temperature coefficient (PTC) thermistors. NTCs display a negative resistance to temperature relationship. This means that the resistance of an NTC thermistor will decrease as temperature increases. Conversely, PTC thermistors have a positive resistance to temperature relationship, where resistance increases as temperature increases. This makes them useful for applications such as fuses. NTCs are the most common for measurements, and for this reason we will focus on them going forward.

NTC Thermistor Considerations

Thermistors can be characterized by two factors: the base resistance and the B value or beta value. The base resistance is the resistance of the thermistor at a standard temperature, usually 25°C. Common base resistances range from a couple kilo-ohms to 100 kilo-ohms. The current and voltage levels used in the circuit usually determine the base resistance needed.

The relationship between temperature and resistance of a thermistor is nonlinear, therefore it is necessary to characterize the relationship. The B value is a material dependent constant that describes the gradient of the resistance curve over a certain temperature range. This temperature range is typically indicated using the notation $B_{T1/T2}$, or the B value over a range of T1 to T2. The B value is calculated using a variation of an equation called the Steinhart-Hart equation:

$$1. B = \left(\frac{T2 * T1}{T2 - T1} \right) * \ln \left(\frac{R1}{R2} \right)$$

A more accurate model can be generated using the full Steinhart-Hart equation and three reference points to generate three coefficients for the model. The three reference points are either given on a lookup table or the resistance of the thermistor is measured at three different temperatures. The reference temperatures used depend on the valid temperature range for the thermistor. Before we continue, let's define a few of the described variables:

Variable	Additional name	Description
T1	T_{low}	Lowest temperature in the thermistor's given range
T2	T_{mid}	Middle temperature in the thermistor's given range
T3	T_{high}	Highest temperature in the thermistor's given range
R1	R_{low}	Resistance value at T_{low}
R2	R_{mid}	Resistance value at T_{mid}
R3	R_{high}	Resistance value at T_{high}

Table 1. Reference Variable Descriptions.

The first reference point is the lowest temperature in the thermistor's thermal range. Next, we pick a value close to the middle of the temperature range. For this, we usually pick 25°C, as the resistance at a standard temperature. However, there are more available options for the middle value. Finally, the third resistance value is measured at the highest temperature in our range. These three reference points are then used to determine the A, B, and C coefficients for this temperature range. A, B, and C are curve fitting coefficients that are fitted by the following equations:

$$2. \frac{1}{T_1} = A + B(\ln R_1) + C(\ln R_1)^3 \quad 3. \frac{1}{T_2} = A + B(\ln R_2) + C(\ln R_2)^3 \quad 4. \frac{1}{T_3} = A + B(\ln R_3) + C(\ln R_3)^3$$

A, B, and C can then be found using the equivalencies below (where: $y_n = \ln(R_n)$ and $x_n = 1/T_n$):

$$5. C = \frac{((x_3 * (y_1 - y_2)) - (x_1 * (y_1 - y_2)) + (y_1 * x_1) - (y_1 * x_2) - (y_3 * x_1) + (y_3 * x_2))}{(((y_3^3) * (y_1 - y_2)) - (y_1 * (y_2^3)) + (y_1^4) - ((y_1^3) * (y_1 - y_2)) + (y_3 * (y_2^3)) - (y_3 * (y_1^3)))}$$

$$6. B = \frac{(x_1 - x_2 + (C * (y_2^3)) - (C * (y_1^3)))}{(y_1 - y_2)}$$

$$7. A = x_2 - (B * y_2) - (C * (y_2^3))$$

The curve fitting coefficients can be used to calculate the temperature corresponding to any measured resistance using the full Steinhart-Hart equation:

$$8. \frac{1}{T} = A + B(\ln R) + C(\ln R)^3$$

This is the equation we will be using to solve for temperature (along with equations 5, 6, and 7).

Setting Up the Thermistor TSP App

While the equations listed above can be implemented in custom code, the Thermistor TSP app for the DMM6500, DAQ6510 and DMM7510 simplifies the process to take thermistor measurements with any thermistor type. Before you start using the app, note that it takes two-wire resistance measurements.

To set up for the Steinhart-Hart model, we must find three reference temperatures. First, find the temperature range of the desired thermistor and take note of it. Our first reference temperature will be the lowest temperature in the range. The second reference temperature is somewhere close to the middle of the range and is usually the standard temperature 25°C. The third reference temperature is the highest temperature in the thermistor's range. After noting these temperatures, we find their corresponding resistance values. These are either listed in the thermistor's datasheet, or we source a temperature and measure the thermistor's resistance at each of these points.

To prepare to use the Beta model, we must find the resistance at standard temperature, as well as the Beta value of the thermistor. These are typically always listed in the datasheet.

Using the Thermistor TSP App (Steinhart-Hart Model)

Once the three reference temperatures have been obtained, we can properly control the app. Download the .tspa file into the root directory of your USB drive. Insert the USB drive on the front panel and select the "APPS" button to go to the Apps Manager page. You will now see the app, which can be run directly from the USB or saved to the instrument. Touch "Run" to start the app.

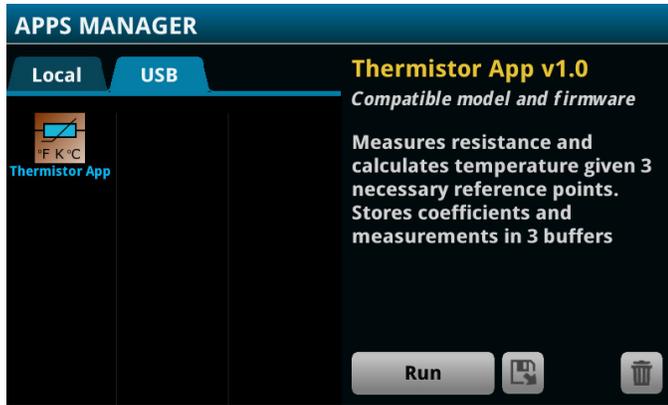


Figure 1. Apps Manager Page.

Once the app is opened, the user will be asked to select a model: select Steinhart-Hart.

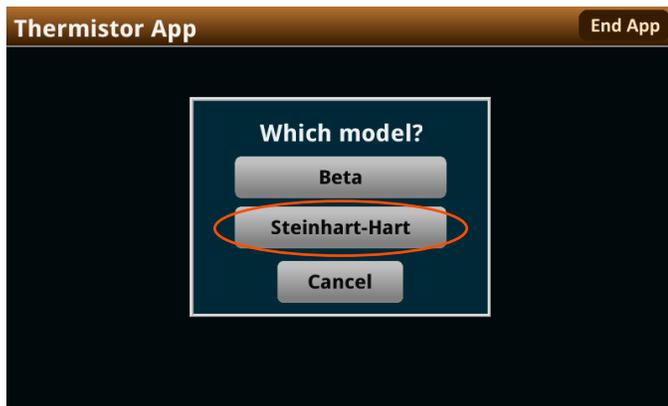


Figure 2. Model Select Prompt (Steinhart-Hart).

Next, the user will be notified of the current terminal setup. We will cover rear terminal operation later; but for now, let's use the front terminals for measurements. Please tap "OK" to acknowledge this selection.

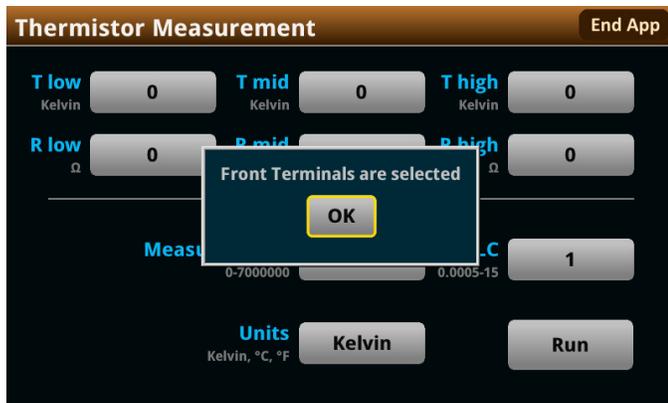


Figure 3. Front Terminals Acknowledgement Prompt.

At the home screen, reference point values can be entered at the top of the screen. Units can be selected at the bottom of the screen. This selects the value for entered temperatures AND temperatures calculated by the app. Resistance will always be entered and measured in ohms. Be sure to enter the desired number of measurements and sampling rate. To start your measurements, touch "Run."



Figure 4. Thermistor App Home Page.

The app will run for the designated number of samples and convert the resistance measurements to temperature values. A loading bar at the center of the screen will show the progress of the measurements, and an "Abort" button will replace the "Run" button. Touch "Abort" at any time to cancel the current run. When the measurements are complete, a prompt will appear to notify the user.

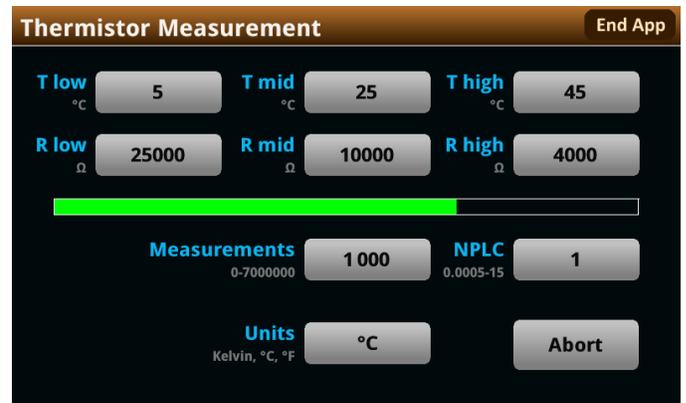


Figure 5. App Making Measurements.

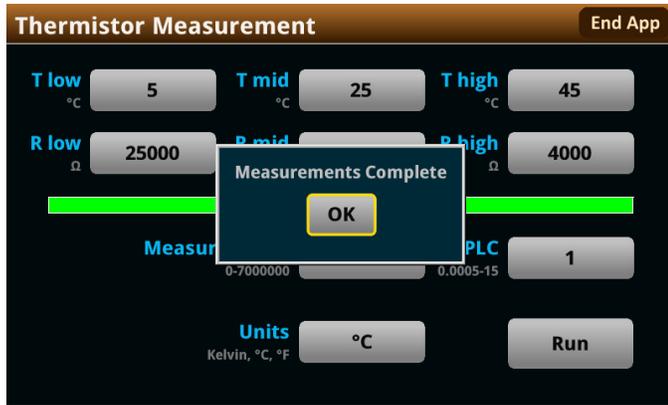


Figure 6. Measurements Complete Prompt.

The app will utilize 3 data buffers: defbuffer1, tempVals, and coefficientVals. These can be viewed and managed anytime by visiting the menu page, even when measurements are running. The app will automatically display the “READING TABLE” page once the instrument has finished taking measurements. For reference, resistance measurements will be stored in defbuffer1, temperature values in tempVals, and coefficients A, B, and C in coefficientVals (coefficients will be stored in that order). Note that the resistance is converted to temperature, and the buffers are updated with each measurement.

Index	Time	Reading	Channel
1	03/29 12:02:56.363864	+099.9262 Ω	Front
2	03/29 12:02:56.382061	+099.9263 Ω	Front
3	03/29 12:02:56.400357	+099.9263 Ω	Front
4	03/29 12:02:56.418594	+099.9263 Ω	Front
5	03/29 12:02:56.436778	+099.9260 Ω	Front
6	03/29 12:02:56.472755	+099.9260 Ω	Front
7	03/29 12:02:56.490970	+099.9264 Ω	Front
8	03/29 12:02:56.509196	+099.9262 Ω	Front
9	03/29 12:02:56.527436	+099.9259 Ω	Front
10	03/29 12:02:56.545687	+099.9263 Ω	Front

Figure 7. Resistance Values Buffer.

Index	Time	Reading	Channel
1	01/01 00:00:00.000000	+120.597440 °C	Rear
2	01/01 00:00:01.000000	+120.597420 °C	Rear
3	01/01 00:00:02.000000	+120.597424 °C	Rear
4	01/01 00:00:03.000000	+120.597414 °C	Rear
5	01/01 00:00:04.000000	+120.597472 °C	Rear
6	01/01 00:00:05.000000	+120.597470 °C	Rear
7	01/01 00:00:06.000000	+120.597402 °C	Rear
8	01/01 00:00:07.000000	+120.597442 °C	Rear
9	01/01 00:00:08.000000	+120.597491 °C	Rear
10	01/01 00:00:09.000000	+120.597425 °C	Rear

Figure 8. Temperature Values Buffer.

Index	Time	Reading	Channel
1	01/01 00:00:00.000000	+2.10850817 m	Rear
2	01/01 00:00:01.000000	+79.7920473 μ	Rear
3	01/01 00:00:02.000000	+653.507631 n	Rear

Figure 9. Coefficient Values Buffer.

Press the “MENU” button to visit the menu page. Here you can enter the table page and view the buffers (as shown above). The “Graph” and “Reading Buffers” pages allow you to visually display your data buffers, as well as manage and store them on a USB.



Figure 10. Thermistor App Menu Page.

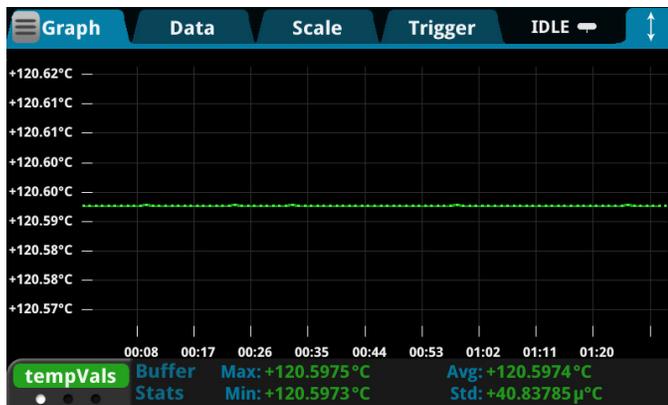


Figure 11. Thermistor App Graph Page.

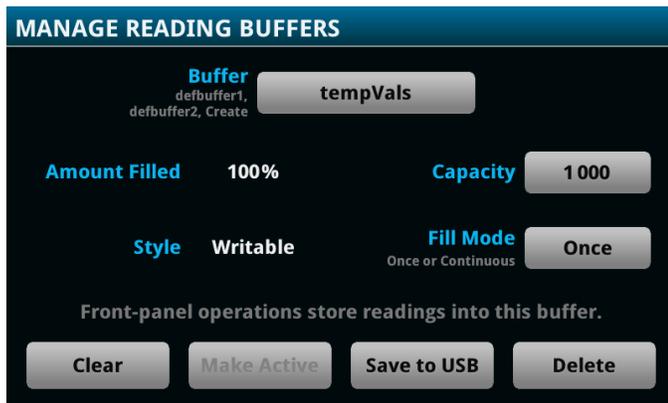


Figure 12. Thermistor App Reading Buffers Page.

Using the Thermistor TSP App (Beta Model)

The app also supports the Beta model. While the Beta model is only accurate over small temperature ranges, it is also fast and simple, making it easy-to-use. As previously mentioned, an initial prompt allows a user to choose between the 2 models: select “Beta” to use the Beta model.



Figure 13. Model Select Prompt (Beta).

Acknowledge the front/rear terminal prompt and select a channel (if using rear terminals). The previously-mentioned values must be entered in order to use the Beta model:

- Resistance of the thermistor at standard temperature (25°C).
- Beta value given in the thermistor’s datasheet.

Next, enter the desired number of measurements, NPLC, and units. Tap “Run” to start making measurements and storing data. For reference, resistance values will be stored in defbuffer1 and converted temperature values will be stored in tempVals. Unlike the Steinhart-Hart model, coefficient values are not needed to convert to temperature. The Beta value defines the relationship between resistance and temperature. Thus, the coefficientVals buffer is not generated when using the Beta model. All other app features mentioned in the Steinhart-Hart model are available during the Beta model measurements.

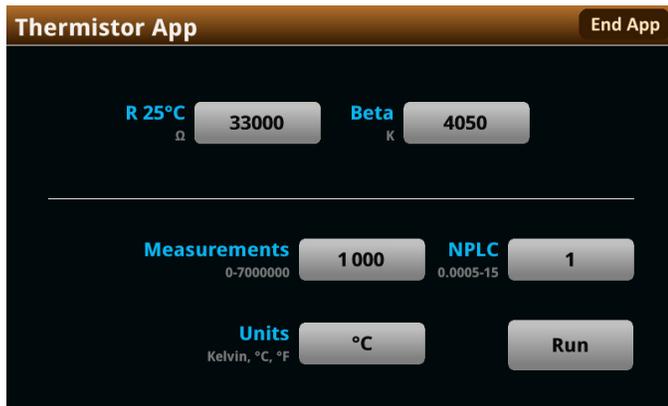


Figure 14. Beta Model Home Page.

Using the Thermistor TSP App with a Switch Card

If you would like to use a switch card with the app, please ensure that the manual terminal selection is set to “REAR.” When you start the app, a prompt will ask you to confirm the configuration and enter a channel to monitor. The channel number entered must follow standard channel identifier format e.g., 101, 102, 201. Once this initial prompt is complete, the user is free to take measurements on this channel. If a channel switch is necessary, the user must restart the app.

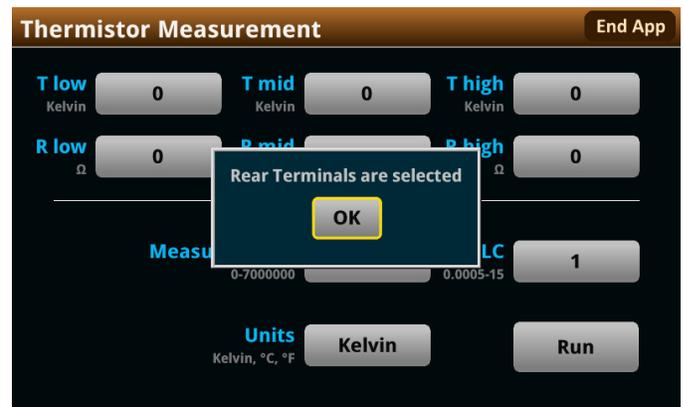


Figure 15. Rear Terminals Acknowledgement Prompt.

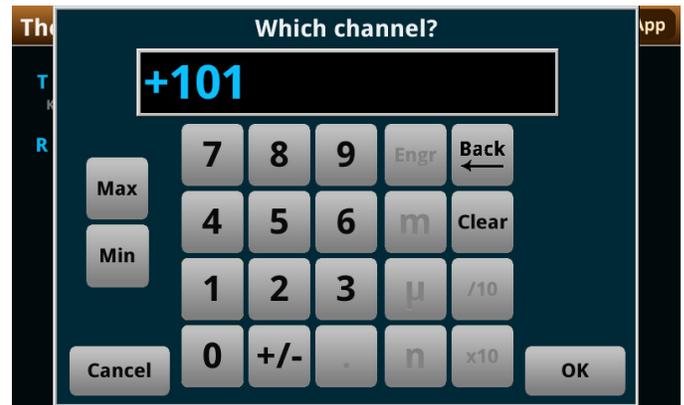


Figure 16. Channel Selection Prompt.

Please note that using rear terminals on the DMM7510 is not allowed, as there is no support for switch cards. However, if this configuration occurs, a prompt will appear to prevent the user from accidentally attempting to use this mode.

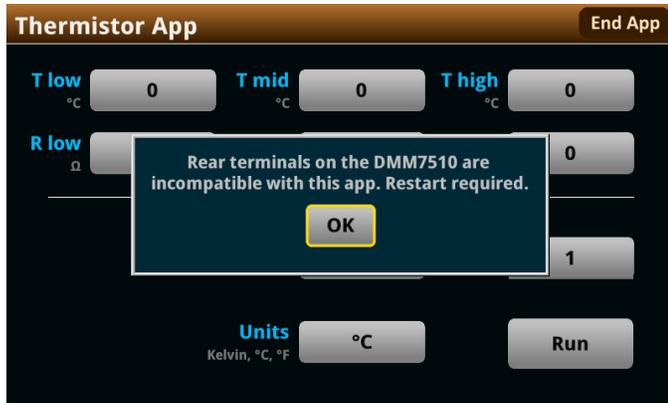


Figure 17. DMM7510 Terminal Prompt.

Conclusion

Thermistors are commonly used to measure temperature because of their wide range of functionality and their accuracy. The Thermistor TSP app for the DAQ6510, DMM6500, and DMM7510 expands available thermistor types, with built in functionality to calculate the curve fitting coefficients and convert the data to temperature units. Please visit tek.com for additional information and to download the app.

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Rev. 02.2022



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