Thermistor Implementation Plan

Currently, the thermistors the team has are NTC thermistors, which are also called *Negative Temperature Coefficient* thermistors. In other words, the thermistor's resistance decreases with increasing temperature of the cells to which the specific thermistor is connected to. The thermistor part numbers are **TH310J39G.** Using the datasheet for this thermistor**,** the constraints specific to the thermistor were calculated from below and these values of temperature tolerance or B value were used to calculate the resistance of the thermistor at 25 degrees Celsius.

$$B = 3853.9\ ln\left(\frac{R25}{R50}\right)$$

Equation 4.7.3 Equation used to calculate R_{25} of the thermistor given the values of B = 3933 and R_{50} = 10 kOhms from the datasheet in the Thermistor Usage document.

From the above equation and the list of datasheets found in the resistance-temperature pdf under the Thermistor Usage document, the Team was able to find the following resistance-temperature table and equations shown in Figure 4.7.3a below.

Temp Range (°C)	Ratio	Beta
0 to 50	9.08	3895
0 to 70	18.64	3917
25 to 50	2.78	3933
25 to 85	9.30	3969
25 to 100	14.64	3981
25 to 125	29.05	3999
37.8 to 104.4	9.67	4000

To calculate Rt/R25 at temperatures other than those listed in the table, use the following equation:
$Rt/R25 = \exp\{A + B/T + C/T^2 + D/T^3\}$
where T = temperature in K
where K = °C + 273.15

Figure 4.7.3a Resistance-temperature equations for the thermistor and the validation of matching the constraints of the thermistor with its datasheet.

30 thermistors needed to monitor all 60 ultracapacitors. No matter the plan implemented, each capacitor will be connected in series with a resistor of value such as 10 kOhms and one lead of this small connection will connect to the positive of one ultracapacitor and the other will be connected to the negative of the ultracapacitor next to the first connection. This is shown in Figure 4.7.3b below.

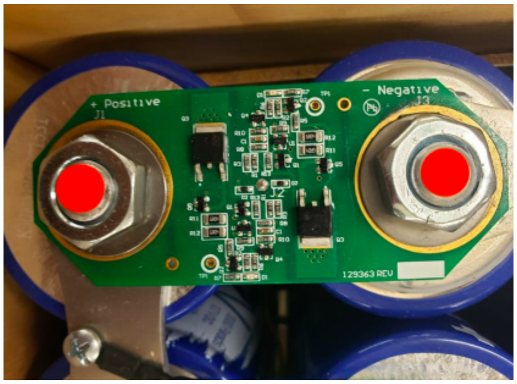

Figure 4.7.3b Shows the connection between a pair of ultracapacitors in which the thermistors would be connected.

The first plan is to connect this small connection directly to the ultracapacitors, as done in temperature monitoring of some Li-Ion batteries, by the use of epoxy for safety. The other option is to get 3 additional LTC6812 boards and connect the appropriate amount of thermistors in its pins. This can satisfy the temperature measurement of the ultracapacitors since each LTC6812 board is capable of monitoring the temperature of 9 cells. Since the Team currently has 4 or 36 temperatures monitored, the additional 3 boards can sustain the monitoring of the temperatures of the rest of the 24 cells currently not monitored. A mux can also be implemented in the connection with the thermistors to switch the values monitored for each cell temperature. Note that the resistance-temperature equations will be used through the measurement of the resistance of the thermistor using a voltage divider as shown in Figure 4.7.3c below.

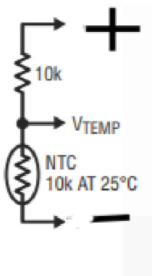

Figure 4.7.3.c Voltage divider for measuring resistance of a thermistor to determine its temperature.

Thermistor Specs (TH310J39GBSN(25/85)): TH310J39G

https://www.digikey.com/product-detail/en/amphenol-advanced-sensors/TH310J39GBSN-25-85/235-1546-ND/6165897

https://www.mouser.com/ProductDetail/Amphenol-Advanced-Sensors/TH310J39GBSN25-85?qs=sGAEpiMZZMuBd0%252BwiCVS23f3gU6QAoiogbxA%252BnEP%2FWcK9HgJc80Xsg%3D%3D https://www.mouser.com/datasheet/2/18/AAS-920-320E-Thermometrics-NTC-Diode-082317-web-1315825.pdf

Temperature Curve
https://www.mouser.com/ProductDetail/Amphenol-Advanced-Sensors/TH310J39GBSN25-85?qs=sGAEpiMZZMvI6uSdB0AenYuOB5Kvs0U%252B0BwW8WeAKCA%3D
(Under Documents and NTC Sensor Linearization) and (Under Documents and then Technical Resources, and click Reference Guide Sensor-Temperature Resistance Curves)

Negative Controlled Temperature Thermistor:
-As temperature Increases, resistance decreases;
-Temp decreases, resistance increases

Data Sheet Explanation of Part Number
Link above shows result for **TH310J39GBSN**
Page 7 under Data Sheets DKx, GE, MEL, TH Series Data Sheet of link above

TH : Diode type thermistor
310 : 10 x 10^3 Ohm resistor = 10KOhm
J : +-5% resistance tolerance
39 : B value range of 3900k to 3999k
G : B value tolerance +-5% according to data sheet but explanation of part number gives of +-2%
B : Standard temperature of 25 degrees Celsius
SN : (Lead wire type) Sn or Tin plated

The **B value** is a material constant which is determined by the ceramic material from which it is made. it describes the gradient of the resistive (R/T) curve over a particular temperature range between two temperature points

Type TH Specifications
https://www.mouser.com/Circuit-Protection/Thermistors/NTC-Thermistors/_/N-axfvt?Keyword=TH310J39GBSN&FS=True

https://www.mouser.com/datasheet/2/18/AAS-920-320E-Thermometrics-NTC-Diode-082317-web-1315825.pdf

Temperature guide can be found here, under "temperature resistance curves guide"

LTC6812-1 Specs (version states Rev A, Version used is Rev 0):
https://www.analog.com/media/en/technical-documentation/data-sheets/LTC6812-1.pdf

DC2350-A Schematic [Overall website with links]:
https://www.analog.com/media/en/technical-documentation/eval-board-schematic/DC2350A-4-SCH.PDF

Maxwell Capacitor Connection Documents:
https://www.maxwell.com/images/documents/Integration%20Kit_User%20Manual_1011158_6.pdf
https://www.maxwell.com/images/documents/Integration_Kit_Data_Sheet_1006286_9.pdf

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Usage:

- Continual measurement of Accumulator Voltage/Temperature via connections to LTC6812/AMS; prevention of AMS overheating

> "Accumulator Management System The AMS must monitor the temperature of the accumulator in 6 locations as well as the voltage of each individual cell. Temperatures about 65 degrees Celsius, voltages above 2.6V, and large voltage variations between cells will trigger a shutdown of the high voltage system by opening the shutdown relay and sending error data to the Motherboard. The AMS circuitry will be galvanically isolated from all low voltage system components. "
> -2019 Final Report

> - 65 degrees Celcius maximum means that thermistors must be adjusted so that above 65 Celcius, will allow for voltage flow to increase above 2.6V and/or trigger shutdown via overvoltage error

- Thermistors were not included from last year's project due to "packaging concerns"

> "Due to packaging concerns, the cell temperature monitoring thermistors were not included in this project. The accumulator containers, which serve to support the ultracapacitors as well as isolate them from the environment, need to be constructed before the thermistors can be appropriately packaged." - 2019 FR

> - They are now constructed

> "The thermistors can be integrated into the support structure between the cells, which will hold them in contact with the surface of the cells. Each thermistor will be in contact with two cells, allowing every individual cell to be in contact with a thermistor" - 2019 Final Report

> -30 thermistors needed for 60 cells, possibly within LTC6812-1 15-stack Daisy Chain: how to connect? Possible connections onto the maxwell Caps board?

Figure 1

$$V_{out} = V_{in} \times \left(\frac{R2}{R1+R2}\right)$$

In terms of the voltage divider in a thermistor circuit, the variables in the equation above are:

V_{out} : *Voltage between thermistor and known resistor*
V_{in} : V_{cc}, *i.e.* $5V$
$R1$: *Known resistor value*
$R2$: *Resistance of thermistor*

Basic thermistor circuit

Thermistor Spec Summary: TH310J39G

https://www.mouser.com/datasheet/2/18/AAS-920-320E-Thermometrics-NTC-Diode-082317-web-1315825.pdf (Used for images below)

Explanation of Part Number

TH	410	S	40	F	D	SN	-	T5
(1)	(2)	(3)	(4)	(5)	(6)	(7)		(8)

1	2	3 / 5	4	6	7	8
Type	Resistance R(25°C)	Resistance / B Value Tolerance	B Value Range	Standard Temperature	Lead Wire Type	Packing & Other Description
Diode Type Thermistor	225:25x10^2 = 2.5kΩ 310:10x103 =10kΩ 410:10x10^4 =100kΩ	F : ± 1% G : ± 2% H : ± 3% J : ± 5% K : ± 10% L : ± 15% M : ± 20% : : S : others S : ± 1.5%	33:3300k ~3399k 40:4000k ~4099k 42:4200k ~4299k	J : -18°C A : 0°C B : 25°C C : 50°C D : 75°C E : 85°C F : 100°C G : 150°C H : 200°C : : S : others	NR : CP wire NI : Ni plated Sn : Sn plated : : : : S : others	T5 : Taping (52mm, Ammo) --------------- R3 : Reel (52mm, 3KP) --------------- C11 : 11mm (Wire cutting) --------------- Other Special Shape or Dim

Part Number	Resistance (25 Ω)	ß Constant (25/50)	Recommended Maximum Operating Current at 77°F (25°C)	Maximum Permissible Current at 77°F (25°C)
TH310J39G	10.0 K	3933 K	0.14 mA	20.0 mA

Dissipation Factor (in still air)	Time Constant (in still air)	Operating Temperature Range	Rated Power at 77°F (25°C)
2.0 (mW/°C)	25 (seconds)	-40°F to 482°F (-40°C to 250°C)	25 mW

B = 3853.9 In (R25/R50)
R25 and R50 represent the thermistor resistance at 77°F and 122°F (25°C and 50°C) respectively

Resistance of 10kOhm at 25 degrees Celsius with B = 3933
B = 3853.9 ln(R25/R50) → 3.6kOhm at 50 degrees Celsius
(Evident from matching values from third column of Temp Range third columns of Ratio and Beta)

Material type GC3 on **page 12** of
https://www.mouser.com/ProductDetail/Amphenol-Advanced-Sensors/TH310J39GBSN25-85?qs=sGAEpiMZZMvI6uSdB0AenYuOB5Kvs0U%252B0BwW8WeAKCA%3D
(Under Documents and NTC Sensor Linearization) and (Under Documents and then Technical Resources, and click Reference Guide Sensor-Temperature Resistance Curves)

AMS triggers an overvoltage at 65 degrees Celsius
Type F on page 12 of temperature curve

Specifications

Product Attribute	Attribute Value	Search Similar
Manufacturer:	Amphenol	☐
Product Category:	NTC Thermistors	☑
Series:	TH	☐
B Parameter:	10000 K	☐
Resistance:	10 kOhms	☐
Power Rating:	25 mW	☐
Tolerance:	5 %	☐
Termination Style:	Axial	☐
Minimum Operating Temperature:	- 40 C	☐
Maximum Operating Temperature:	+ 250 C	☐
Package / Case:	DO-35	☐
Diameter:	2 mm	☐
Length:	56.2 mm	☐
Width:	2 mm	☐
Packaging:	Bulk	☐
Brand:	Amphenol Advanced Sensors	
B Tolerance:	2 %	
Beta Value:	B25/85	
Product Type:	NTC Thermistors	
Factory Pack Quantity:	3000	
Subcategory:	Thermistors	
Tradename:	THERMOMETRICS	
Part # Aliases:	DIF085H00-00D0	

We determined that the thermistors and the LTC board thermistors are not the same.

From LTC6812-1 Spec Sheets Page 84:

READING EXTERNAL TEMPERATURE PROBES

Figure 49 shows the typical biasing circuit for a negative temperature coefficient (NTC) thermistor. The 10k at 25°C is the most popular sensor value and the V_{REF2} output stage is designed to provide the current required to bias several of these probes. The biasing resistor is selected to correspond to the NTC value so the circuit will provide 1.5V at 25°C (V_{REF2} is 3V nominal). The overall circuit response is approximately –1%/°C in the range of typical cell temperatures, as shown in the chart of Figure 49.

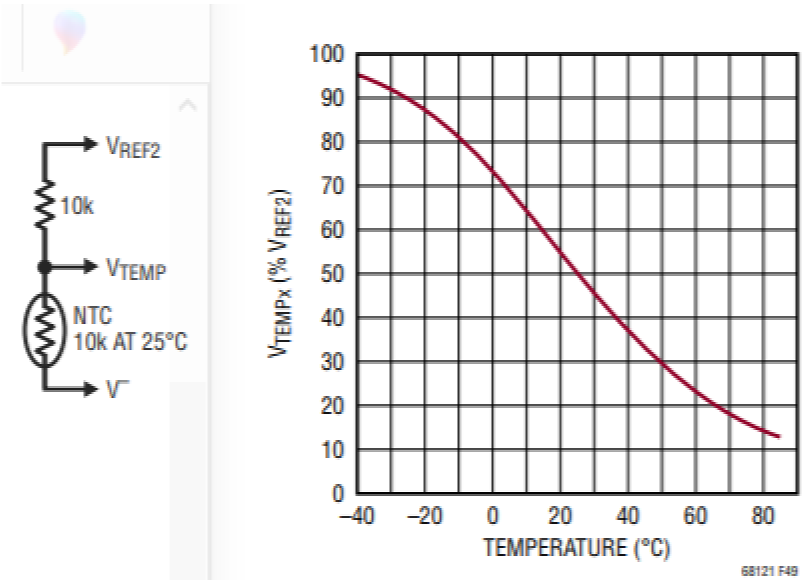


Figure 49. Typical Temperature Probe Circuit and Relative Output

- We want to limit temperature to 65 degrees Celsius
- From LTC6812-1 Spec Sheets, pg 68

PIN FUNCTIONS

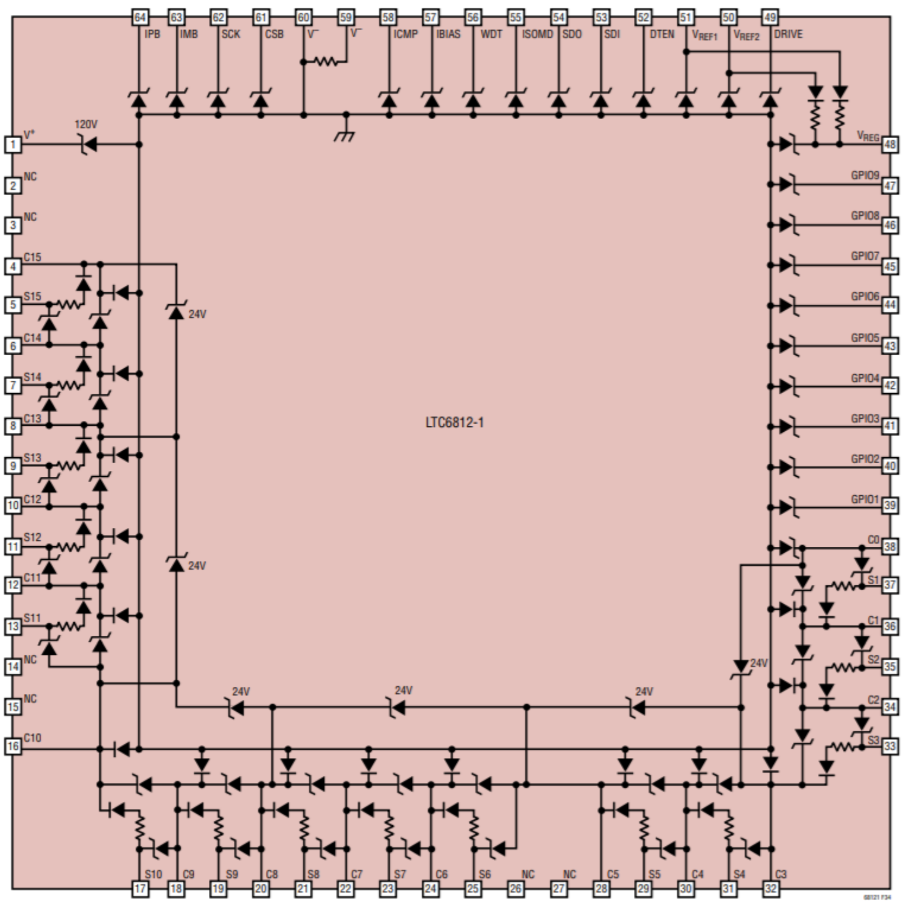
C0 to C15: Cell Inputs.

S1 to S15: Balance Inputs/Outputs. 15 internal N-MOSFETs are connected between S(n) and C(n–1) for discharging cells.

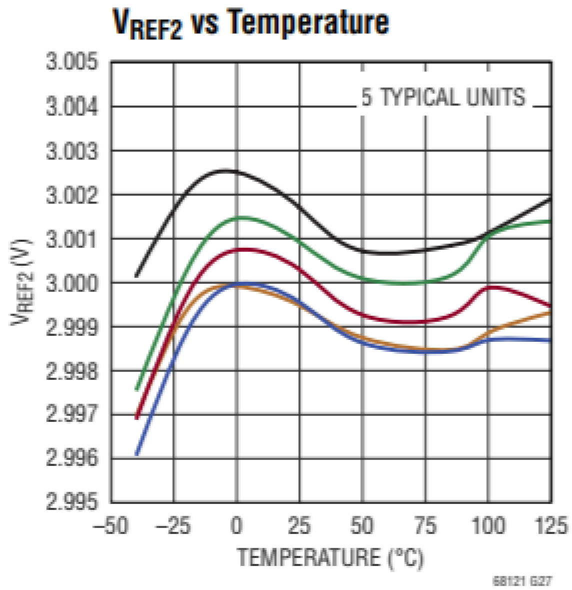
V^+: Positive Supply Pin.

V^-: Negative Supply Pins. The V^- pins must be shorted together, external to the IC.

V_{REF2}: Buffered 2nd Reference Voltage for Driving Multiple 10k Thermistors. Bypass with an external 1µF capacitor.

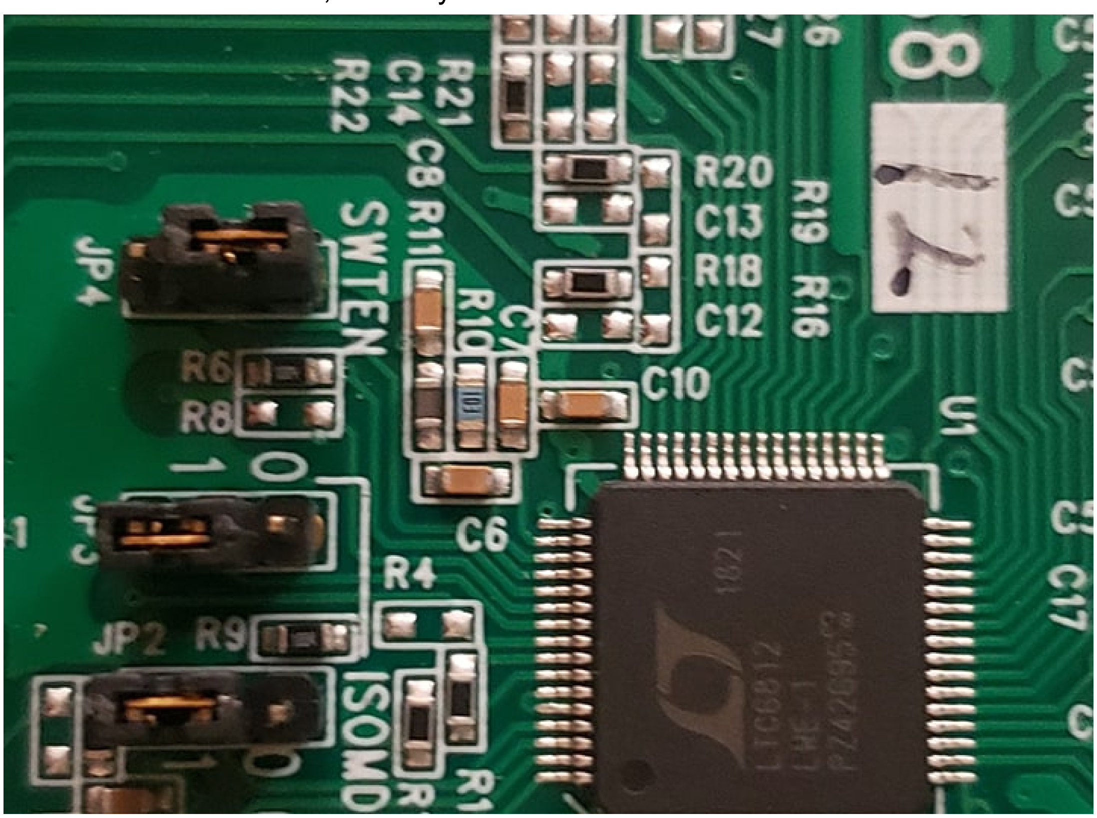


NOTE: ZENER VOLTAGE IS 8V UNLESS MARKED OTHERWISE.



- page 11 of LTC Spec Sheet

-See DC2350 schematic for more info:
Vref2 already in use with a thermistor in place
Vref2 is connected to R10, R11 via circuitry
R11 should be thermistor, currently is stable 10kohm resistor



Current Code Implementation:

Main.c

WritereadSPI Function: [See Functions Document here]

Getinfo: [See Functions Document here]

Possible breakdown of what it does:

Line 174: definition of thermistor max temp, currently 0; should be Sixty five degrees Celsius based on previous team's documentation along with spec sheets

Function: getinfo() line 767

Returns information regarding temperature and AMS systems

768: resets all time variables through a delay of 2300 ms
770: CS_ISOB [Chip select, ISO SPI (Boolean?)] = set to low, read temperature and write it out
771-774: reset CS_ISOB (delay 100 ms)
775: define next variable within SPI, set as sumall
776-778: reset CS_ISOB
779: Sum last bit of sumall and third byte of SPI
780-782: reset CS_ISOB
783: sets "temp" as fourth byte of SPI
784-785: resets CS_ISOB
786: see if error occurred based on line 783 variable "temp"
787: set CS_ISOB to low (part of reset)
788: define final temperature to be used for further error messages, comes from 5th byte

Ideas on Implementation of Thermistors into the AMS System
LTC6812-1
https://www.analog.com/en/products/ltc6812-1.html#product-overview

https://www.analog.com/media/en/technical-documentation/data-sheets/LTC6812-1.pdf

Idea on direct attachment to power source
https://www.ametherm.com/blog/thermistors/thermistors-ntc-thermistor-temperature-sensors-provide-li-ion-battery-safety/

https://www.electronicdesign.com/technologies/electromechanical/article/21750479/add-simple-temperature-monitoring-to-batterymanagement-systems

After having found the resistance-temperature curve for the set of thermistors and realizing that there doesn't seem to be any extra pins on the Maxwell boards for extra thermistors and even possibly considering placing multiple thermistors with the already given thermistor on each board, a conclusion is reached. The plan is to mount each thermistor on an ultracapacitor similar to mounting thermistors on each cell of Li-Ion batteries. This way, the thermistor may be more responsive to the temperature of the corresponding ultracapacitor due to direct contact. The way to attach each thermistor is to have each of its lead to connect from the positive of one ultracapacitor to the negative of a nearby ultracapacitor. This way, each thermistor can act as a temperature sensor between ultracapacitors.

With regards to reading the temperature of each thermistor, each thermistor may also be connected to a mux, through which one can choose the temperature of a specific thermistor in a cycle, making sure that the temperatures are within specs. An additional board may be needed in order to have ADC, which can feed into the controllers.

Uses for epoxy on the leads to reduce danger. Get the right epoxy.