TI Designs: TIDA-01528

Ultra-Low-Power Reference Design: Secondary Protection for Over/Undertemperature Conditions in ESS

Description

This ultra-low-power reference design implements a secondary thermal-monitoring solution for large-scale battery packs. Many industry guidelines require the secondary temperature system to remain powered and operational in the event that the primary power supply fails. This design is capable of continuing operation in a low-power state by utilizing low-power, factory-preset thermal trip points on a super-capacitor-powered backup rail. The solution ensures that any over- or undertemperature event can be captured and resolved, even when the power from the main system controller is unavailable, thereby increasing the safe operating window of the total system.

Resources

TIDA-01528	Design Folder
TMP303	Product Folder
bq25570	Product Folder
LM324A	Product Folder
MSP430FR5994	Product Folder

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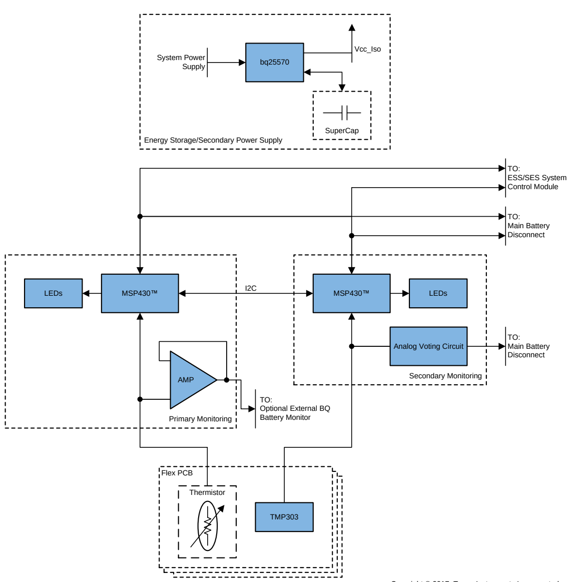
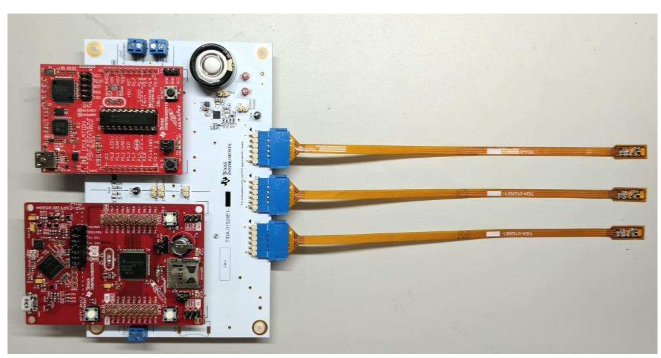
Features

- Ability to Provide Thermal Monitoring and Protection During Normal Operation or When Primary Circuit Loses Power
- Ultra-Low-Power TMP303 Uses Only 5 µA Max per Device
- Integrated Backup Power Source Through Supercap and Charger
- Satisfies Primary and Secondary Protection Requirements With Interface for TI Cell Supervisors for Charge Control
- Factory Programmable Over- and Undertemperature Trip Points With Hysteresis

Applications

- Stationary Energy Storage
- HEV/EV
- Light Rail





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1 System Description

At the time of this writing, the energy generation market is producing an increasing rate of electricity from renewable energy sources. Whether the demand for renewable energy comes from governments or individuals, the field is expanding. This paradigm shift in electricity generation is positive; however, it is not without challenges. Due to the variability in output, certain factors have created the need for energy storage devices, which help to regulate and sustain the grid when the sun goes behind a cloud or a steady wind dies down. During these transitions, there is often a gap of time between these sources lowering their energy output and more traditional generation techniques taking their place (such as the wind-up time on generators), as well as capturing excess energy produced to use later. This storage capacity enables energy to be captured and conserved to keep the power output stable, and produce the power as efficiently as possible without derating.

The design implements temperature sensing elements on the end of a flexible printed-circuit board (flex-PCB), which allows the installer to drop the elements in between individual battery cells. After placing the sensing elements, a thermal epoxy may be used to ensure good thermal conduction and prevent movement. The use of a flex-PCB allows the designer to establish a reliable connection between the sensing elements and the main board without having to manage a bundle of wires. Depending on the manufacturing technique and materials used, flex-PCBs can be made to withstand high temperatures for a variety of environments. Be sure to always check with the original equipment manufacturer for specific thermal capabilities.

Many industry guidelines require the secondary temperature system to remain powered and operational in the event that the primary power supply is lost. This design makes use of a power management integrated circuit (IC) with a boost charger and nanopower buck converter (bq25570). This device maintains a charge on a supercapacitor (supercap) when connected to a power source and maintains a constant output voltage to supply the components of the secondary system.The device is then able to use the supercap as an energy source when the main power supply is lost, therefore ensuring power delivery to the secondary protection circuit. This feature allows continued operation of the secondary side for a determined amount of time before failing safe. The advantage to using this system with a management IC and supercap is lower maintenance, as the lifetime of the capacitor is much longer than a similar Li-Ion coin cell, and supercaps typically do not require additional certification requirements for industry standards.

1.1 Key System Specifications

Table 1. Key System Specifications

PARAMETER	SPECIFICATIONS	DETAILS
Backup power run time	1 day	Table 5
Thermal trip-points	Configurable based on battery pack requirements	Section 2.3.2
Low current consumption	25 µA	Section 2.3.3

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2 System Overview

2.1 Block Diagram

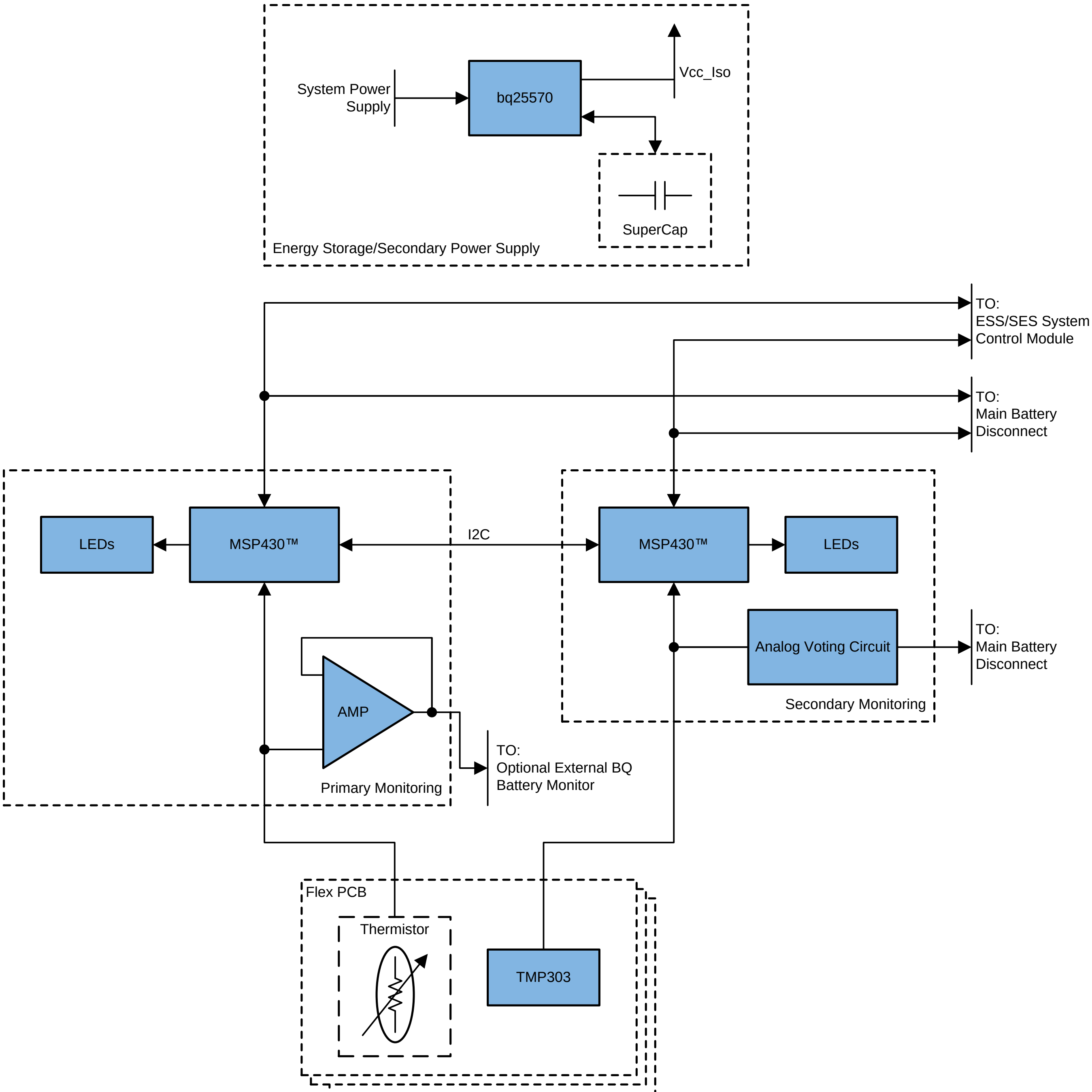

Figure 1. TIDA-01528 Block Diagram

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2.2 Highlighted Products

2.2.1 TMP303

The TMP303 family of devices are temperature range monitors that offer design flexibility through an extra-small footprint (SOT-563), low power (5 μA maximum), and low supply voltage capability (as low as 1.4 V). These devices require no additional components for operation; each device can function independent of microprocessors or microcontrollers.

- Low power: 5 µA (maximum)
- SOT-563 package: 1.60 × 1.60 × 0.6 mm
- Trip point accuracy:
  - ±0.2°C (typical)
  - Factory-programmed trip points
- Push-pull output
- Selectable hysteresis: 1/2/5/10°C
- Supply voltage range: 1.4 V to 3.6 V

Figure 2 shows the TMP303 functional block diagram.

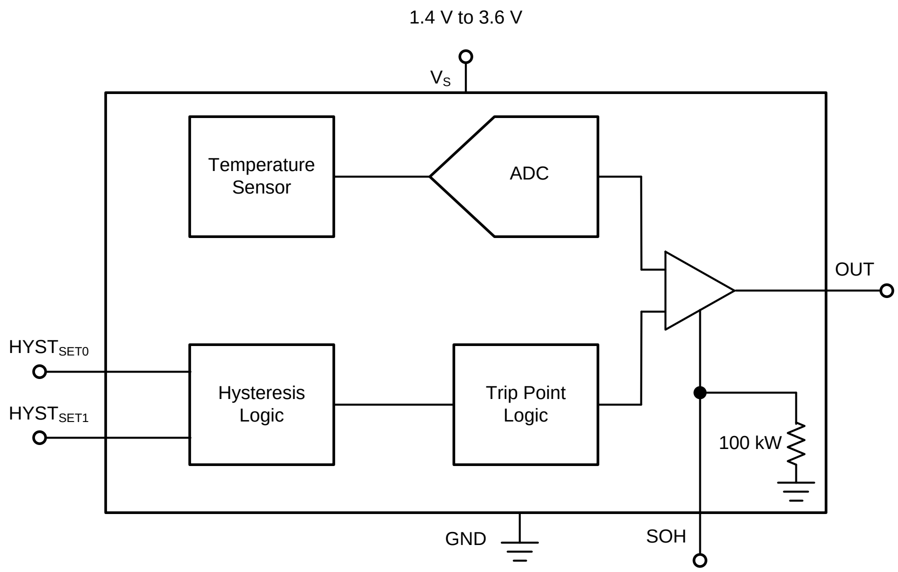

Figure 2. TMP303 Functional Block Diagram

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2.2.2 BQ25570

The bq25570 device is specifically designed to efficiently extract microwatts (µW) to milliwatts (mW) of power generated from a variety of high-output impedance DC sources like photovoltaic (solar) or thermal electric generators (TEG) without collapsing those sources. The battery management features ensure that a rechargeable battery is not overcharged by this extracted power, with voltage boosted, or depleted beyond safe limits by a system load. In addition to the highly-efficient boosting charger, the bq25570 integrates a highly-efficient, nano-power buck converter for providing a second power rail to systems such as wireless sensor networks (WSN), which have stringent power and operational demands. All the capabilities of the bq25570 are packed into a small-footprint, 20-lead, 3.5×3.5-mm QFN package (RGR).

- Ultra-low-power DC/DC boost charger
- Energy storage
- Battery charging and protection
- Battery good output flag
- Programmable step-down regulated output (buck)
- Programmable maximum power point tracking (MPPT)

Figure 3 shows the BQ25570 typical application schematic.

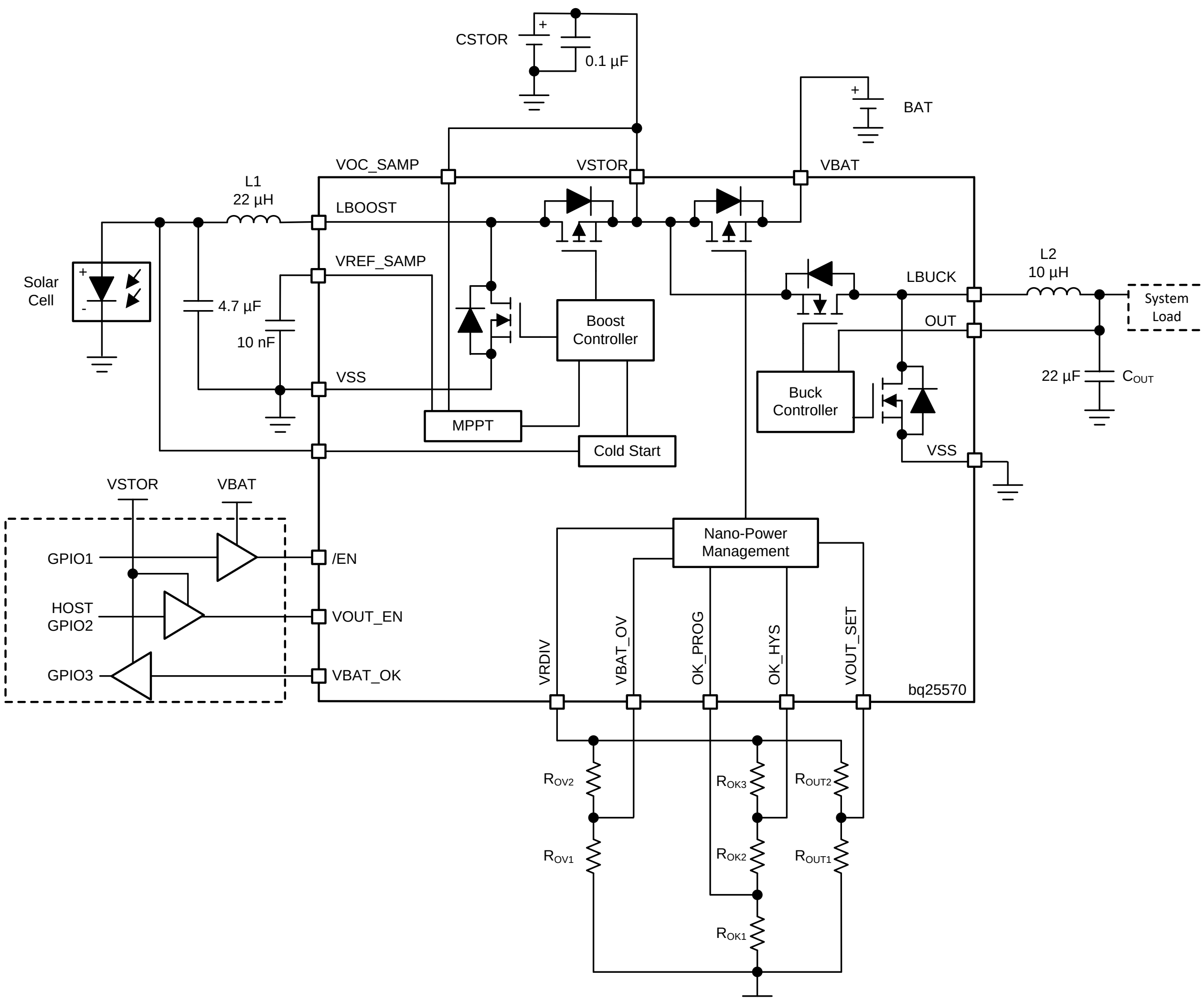

Figure 3. bq25570 Typical Application Schematic

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2.2.3 MSP430FR5994 ™ MCU

The MSP430™ ultra-low-power (ULP) FRAM platform combines uniquely-embedded FRAM and a holistic ultra-low-power system architecture, allowing innovators to increase performance at lower energy budgets. FRAM technology combines the speed, flexibility, and endurance of SRAM with the stability and reliability of flash at much lower power.

- Embedded microcontroller
- Optimized ultra-low-power modes
- Ultra-low-power ferroelectric RAM (FRAM)
- Intelligent digital peripherals
- High-performance analog
- Multifunction input and output ports
- Code security and encryption
- Enhanced serial communication
- Flexible clock system
- Development tools and software

Figure 4 shows the MSP430FR5994 functional block diagram.

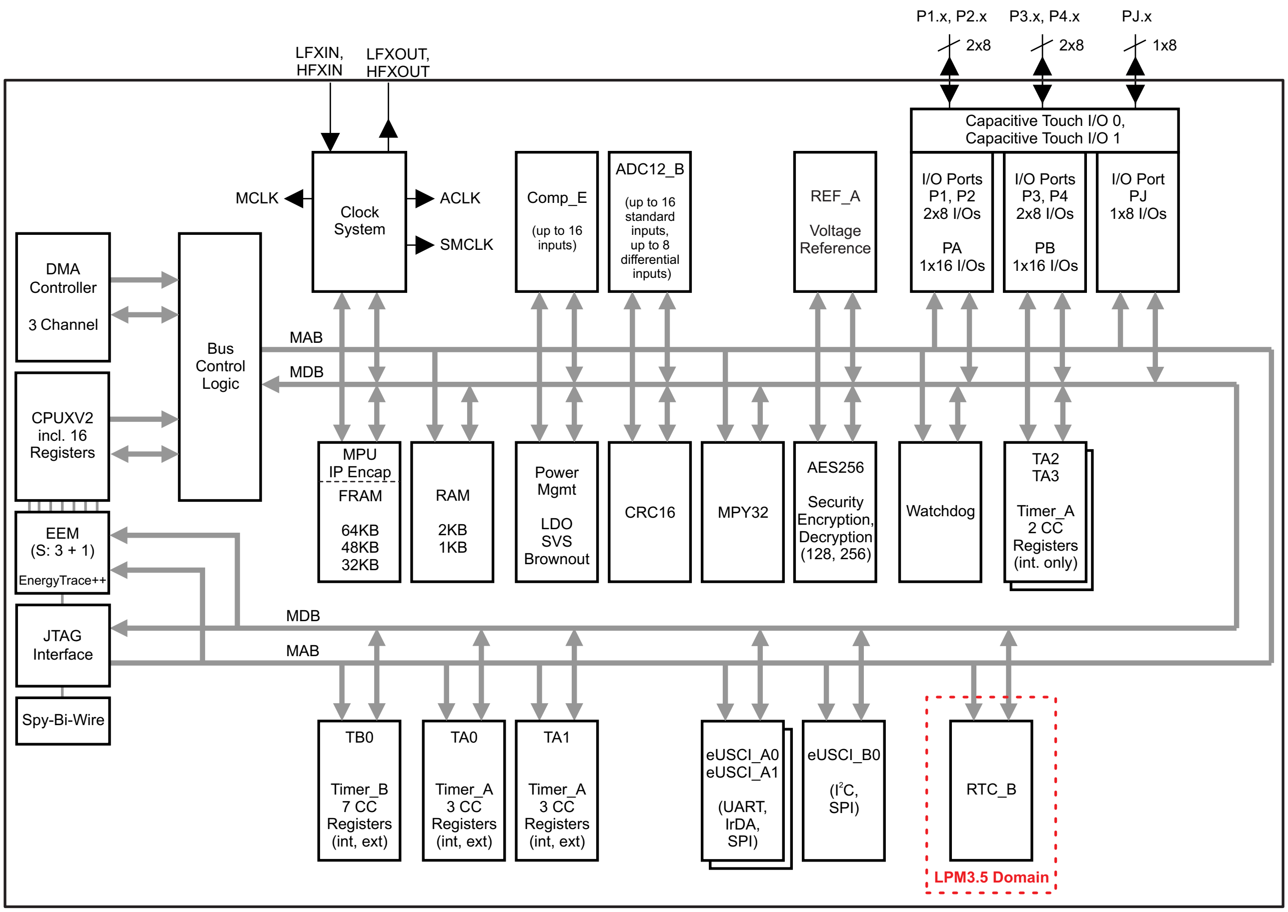

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Figure 4. MSP430FR5994 Functional Block Diagram

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2.2.4 LM324A Quadruple Operational Amplifier

These devices consist of four independent, high-gain frequency-compensated operational amplifiers that are designed specifically to operate from a single supply or split supply over a wide range of voltages.

- 2-kV ESD protection for:
  - LM224K, LM224KA
  - LM324K, LM324KA
  - LM2902K, LM2902KV, LM2902KAV
- Wide supply ranges
  - Single supply: 3 V to 32 V (26 V for LM2902)
  - Dual supplies: ±1.5 V to ±16 V (±13 V for LM2902)
- Low supply-current drain independent of supply voltage: 0.8 mA typical
- Common-mode input voltage range includes ground, allowing direct sensing near ground
- Low input bias and offset parameters
  - Input offset voltage: 3 mV typical
    A versions: 2 mV typical
  - Input offset current: 2 nA typical
  - Input bias current: 20 nA typical
    A versions: 15 nA typical
- Differential input voltage range equal to maximum-rated supply voltage: 32 V (26 V for LM2902)
- Open-loop differential voltage amplification: 100 V/mV typical
- Internal frequency compensation

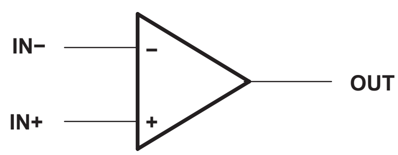

Figure 5. Symbol (Each Amplifier)

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2.3 System Design Theory

2.3.1 Thermal Sensing

The main component showcased in this design is the TMP303, a window temperature sensing device which has a single *Alert* output that is normally low when the temperature is between the over- and undertemperature threshold. When the device senses a temperature outside the thresholds, the Alert pin goes high and remains high until the sensed temperature of the device falls back to within the acceptable range. Additionally, a percentage of hysteresis is programmable through tying two pins high or low in combination.

Another advantage of the TMP303 is the ability to use the alert pin to directly feed into a disconnect device in a system. This task does not require calculating the temperature or external decision making because the TMP303 accounts for these values, which are programmed during manufacturing.

In addition to the TMP303 temperature switch, this design uses a standard negative temperature coefficient (NTC) thermistor, which is added to the sensing system for normal temperature profiling.

Figure 6 shows the schematic of the temperature-sensing flex daughter PCB.

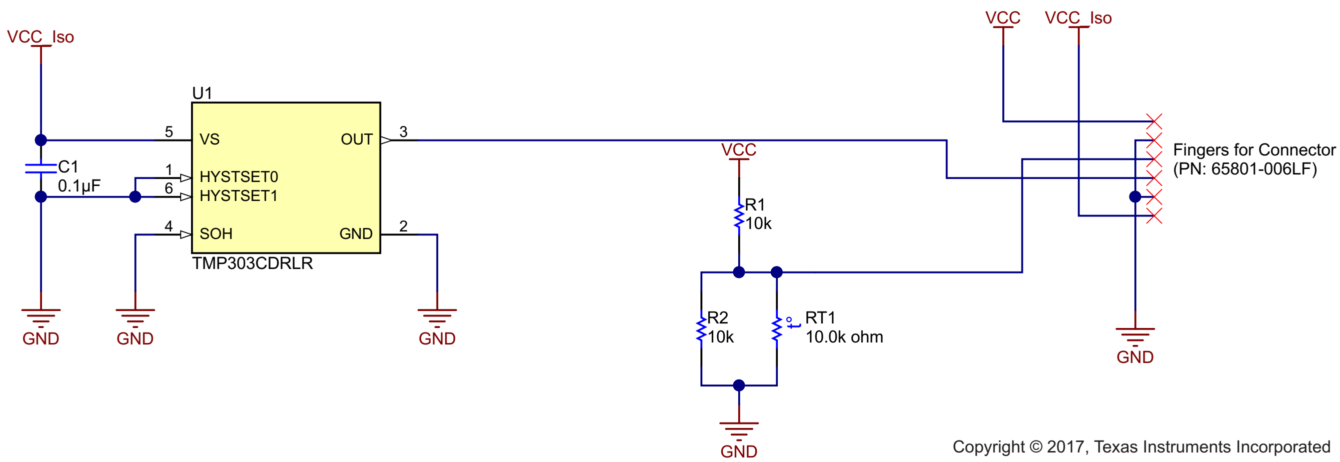

Figure 6. Temperature Sensing Flex Daughter PCB

Placing the temperature sensing elements on the end of flex PCBs accomplishes several tasks. First, the installation is simplified by allowing all power and signaling lines to be contained together within one strip. With the flex-PCB, an installer is able to route and then secure the probes with ease. The use of surface mount devices also increases the number of devices to choose from, especially if the designer wishes to use a digital temperature sensor on the primary side.

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2.3.2 Fault Signaling

To enable designer confidence in using the correct operation during monitoring, simplify the signaling, and reduce the number of points of failure, the TMP303 is device is preprogramed to make the decision as to whether a temperature reading is outside of the proper operating conditions. A list of available TMP303 devices and the associated trip points is available in Table 2. This configuration reduces or even eliminates the mistakes caused during temperature conversion by the variable of an external comparator or controller. With a simple high or low signal, precise analog-to-digital converters (ADCs) and compensation curves are not required and can feed directly into a disconnect switch.

Table 2. TMP303 Preprogramed Trip Point Options

DEVICE	TRIP POINTS (°C)
TMP303A	$T_L = 0$, $T_H = 60$
TMP303B	$T_L = 0$, $T_H = 55$
TMP303C	$T_L = –20$, $T_H = 60$
TMP303D	$T_L = –15$, $T_H = 125$
TMP303E	$T_L = 0$, $T_H = 70$
TMP303F	$T_L = 0$, $T_H = 80$
TMP303G	$T_L = 0$, $T_H = 90$

Through the implementation of a discrete ORing circuit, TMP303 signals can together control a normally high output to a disconnect circuit. This circuit enables any of the devices to cause a disconnect when abnormal temperatures are detected and cause the output to be pulled low in the event that the power supply of the secondary system is lost. This simple ORing arraignment enables simple control of an external element, such as a power relay or field-effect transistor (FET) that can cut power to the battery pack without requiring any influence by the host application processor.

2.3.3 Low-Power Operation

The system utilizes two MSP430™ LaunchPad™ Development Kits, which showcase TI's ultra-low power MCUs. Through the use of these devices, both on the primary and secondary side, the task of supervising the power supply and temperature measurements is easy to complete. The other advantage of the MSP430 line is the ability to place the device into varied low-power states, which allow interrupts to wake the MCUs when a problem is detected, but use very little power when the system is operating under normal conditions.

Power consumption of the system is very important because the secondary side is able to run for as long as possible without an external supply. Further optimization has been taken into account by implementing a supercap as the energy storage medium over a Li-Ion coin cell. By sacrificing power density for less maintenance and regulatory approval, the end user is no longer required to monitor the health of the energy storage medium. With the chosen components, the loss in total energy available is accounted for in ultra-low-power operation for a reasonable amount of time. Note that, if the device is left unchecked for an extended period of time, the system is still able to fail-safe when the energy storage device is depleted.

2.3.4 Operation Through Power Failure

The bq25570 is a nano-power boost charger and buck converter, specifically designed for ultra-low power levels and a variety of energy storage media. In this design, the ability of the bq25570 device to properly charge and maintain a supercap and the integrated low-power buck easily accomplishes the task of storage and power supply. The device saves board space by only requiring external resistors for setting parameters within the device. The device is also designed for use with energy-harvesting devices, which allow the customer to adapt the design to use a solar panel or other device to supply power for a longer backup run time. To accomplish this backup power, the device makes use of a boost input topology which is able to convert input power to the proper voltage to charge the energy storage medium, even when the generated power is in micro- or milliwatts.

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Figure 7 shows the schematic for the backup power rail generation.

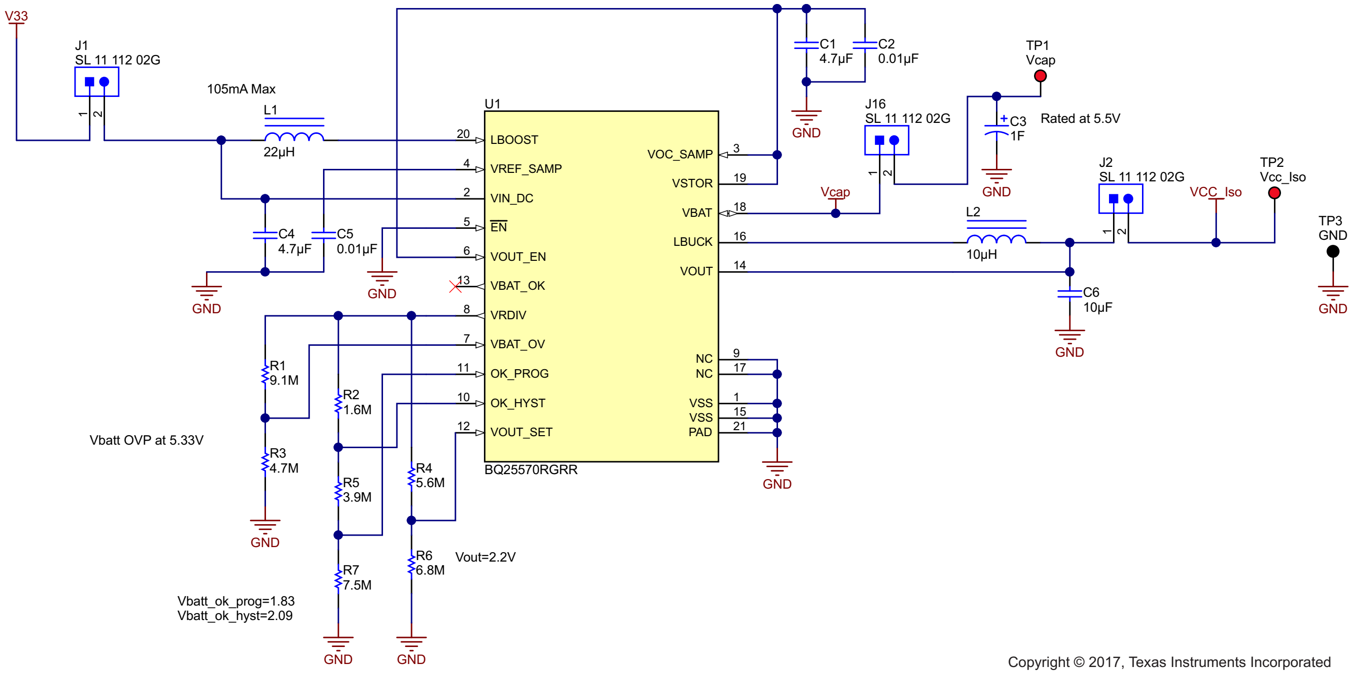

Figure 7. Backup Power Rail Generation Schematic

To further reduce power consumption and extend the operational time of the backup system, the functionality is split between the two MSP430 devices. The MSP430FR5994 LaunchPad serves as the host application processor, while the MSP430G2 LaunchPad functions as the temperature window monitor. These devices are delineated through two separate voltage rails in this design: VCC and VCC_Iso. In the event of a power failure, VCC becomes inaccessible and the main application processor ceases functionality, charge management, and standard supervision.

The backup system continues to provide power to the G2 processor and TMP303 devices. If a fault does occur in this time, the TMP303 device can signal the G2 to wake up and record the event, while also signaling any external protection devices to open the power path to the battery back and disconnect it from whatever is causing the fault. Upon regaining power, the application processor can then request the fault logs from the G2 and make a decision on how to proceed.

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3 Hardware, Software, Testing Requirements, and Test Results

3.1 Required Hardware

The required hardware is as follows:

- Laptop computer with USB port
- Thermal stream or environmental chamber
- Thermocouple (attached to TMP303)
- Digital 5½ multimeter
- 3.3-V power supply

3.1.1 Hardware

Figure 8 shows an image of the TIDA-01528 board.

NOTE: On Rev A of the board, the LaunchPad headers have a silkscreen on the top that does not match the actual socket label. The socket label that is correct is on the bottom side of the board. These labels have been updated and fixed in the files available under *Design Files* .

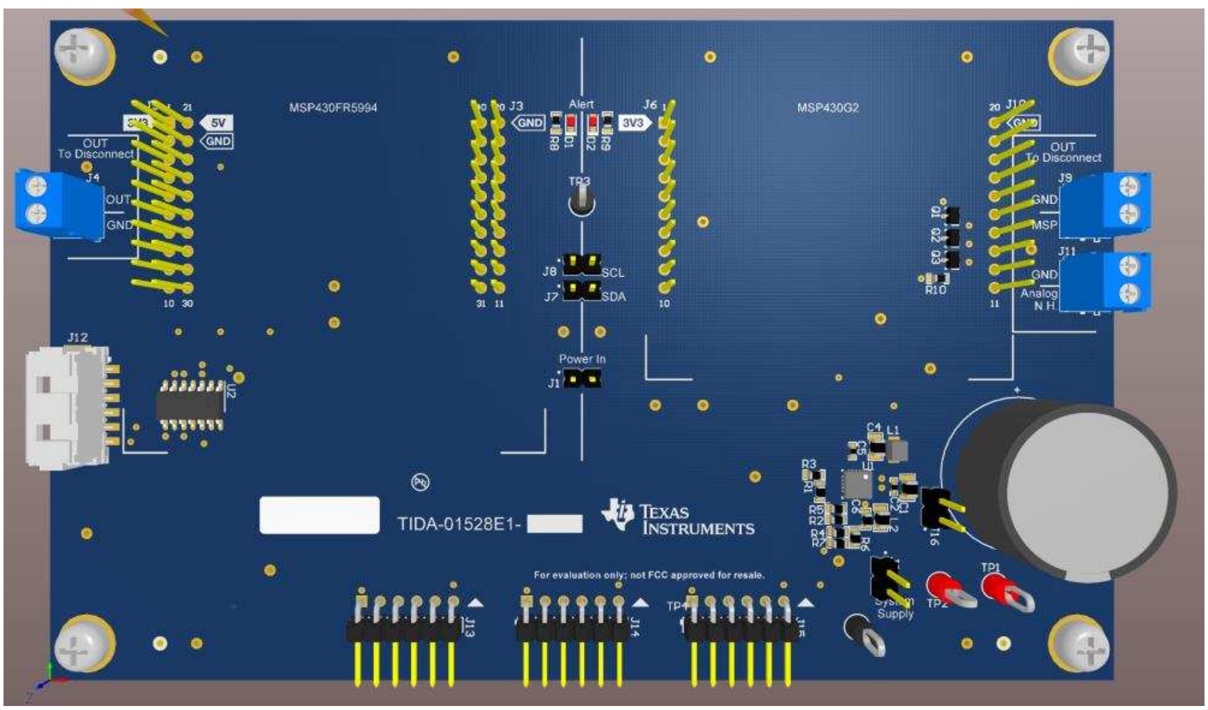

Figure 8. TIDA-01528 Board Overview

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3.2 Testing and Results

3.2.1 Test Setup

3.2.1.1 Start-Up

1. Remove the jumpers across J1, J7, J8, and remove any external connections that may be present

3.2.1.2 Main Power Rail Bring-Up

1. Power up the board by first connecting the MSP430FR5994 LaunchPad to the main board.
2. Measure the voltage between TP1 and ground (TP4); this is the starting voltage of the capacitor.
3. Connect a USB cable.
   - Note that, if the supercap is completely discharged, TI recommends to first use a 5-V power supply because it can initially draw a bit of current.
4. Measure the voltage at the pins labeled *5V* and *3.3V* on the LaunchPad and verify that they are regulating at 5 V and 3.3 V, respectively.
5. Place a current meter across J16 to connect the supercap to the regulation circuit and measure the charge current in a later step.
6. Place a jumper across J1 to power up the power supply of the secondary protection circuit.
7. Measure the charge current using the meter placed in the previous step 6.
8. Remove the Jumper from J1.
9. Remove the current measuring lines and place a jumper across J16.
10. Replace the jumper across J1.

3.2.1.3 Secondary Power Rail Bring-Up (See Table 3 for Specific Test Results)

1. Place a jumper across J2 to power up the secondary power rail.
2. The MSP430G2 then starts up. Place jumpers across J7 and J8 to enable communication between the two LaunchPad Development Kits.
3. Place a voltmeter across TP2 and Ground and measure the voltage of the secondary rail.
4. Take three flex-PCBs and orient the arrow on the connectors with the arrow on the main board, connecting them to J13, J14, and J15.
5. After connecting all flex-PCBs, all alert lights (D1, D2) turn off at room temperature.

3.2.1.4 Supercap Run-Time Tests (See Table 5 for Specific Test Results)

1. Return all flex-PCBs to room temperature.
2. Remove the jumper across J1.
3. Remove the jumper on J2 and ensure there is a jumper on J16.
4. Place the current meter across J1.
5. Continue to charge the supercap until the current meter reads less than 1 mA.
6. After the current meter reads close to 0 A, remove the meter connections across J1.
7. Place a voltmeter between TP2 and GND.
8. Place a jumper across J2 and begin powering the secondary system. Start a timer and allow the system to run solely off the supercap.
9. When the voltage is no longer regulated on the secondary rail and drops to 0 V, record the amount of time the system was operational.

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3.2.1.5 External Connector for Other Battery Management System (BMS) Devices

1. J12 Allows the use of an external battery management device with an analog temperature input without having to populate a second thermistor. These outputs correspond in the following way:
   a. J13 pin 3 from the left must be equal to pad 2 (from top).
   b. J14 pin 3 from the left must be equal to pad 3.
   c. J15 pin 3 from the left must be equal to pad 4.

3.2.2 Functional Test Results

Table 3. Secondary Rail Validation Checks

MEASUREMENT TERMINAL	EXPECTED	ACTUAL	PASS
J4	0 V	0 V	Yes
J9	0 V	0 V	Yes
J11	1.8 V to 2.2 V	1.85 V	Yes

Table 4. Flex-PCB Thermal Test

MEASUREMENT TERMINAL	EXPECTED	ACTUAL	PASS
J4	5 V	4.96 V	Yes
J9	1.8 V	1.85 V	Yes
J11	0 V	0 V	Yes

Table 5. Backup Power Run Time

DURATION
1 day 2 hours 12 minutes

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4 Design Files

4.1 Schematics

To download the schematics, see the design files at TIDA-01528.

4.2 Bill of Materials

To download the bill of materials (BOM), see the design files at TIDA-01528.

4.3 PCB Layout Recommendations

For a proper thermal probe implementation, make the following key considerations:

- Trace connections to SMD pads and vias must be teardropped to decrease the likelihood of fatigue failure at a sharp junction.
- A large ground plan connected to both sides of the PCB must interface with both the TMP303 and NTC thermistor. Vias connecting the planes help ensure sufficient heat flow between both sides of the PCB and, subsequently, accurate system temperature readings.
- A hatched ground plan provides a good trade-off between thermal absorption and flexibility in the PCB.

Figure 9 shows the TMP303 probe layout.

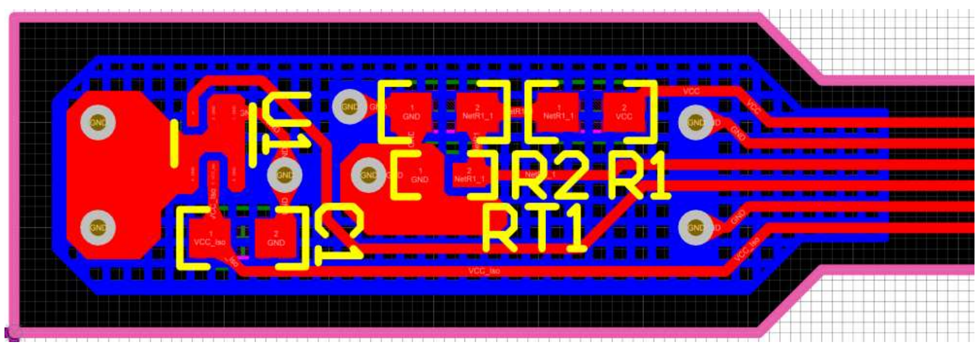

Figure 9. TMP303 Probe Layout

4.3.1 Layout Prints

To download the layer plots, see the design files at TIDA-01528.

4.4 Altium Project

To download the Altium project files, see the design files at TIDA-01528.

4.5 Gerber Files

To download the Gerber files, see the design files at TIDA-01528.

4.6 Assembly Drawings

To download the assembly drawings, see the design files at TIDA-01528.

5 Software Files

To download the software files, see the design files at TIDA-01528.

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6 Related Documentation

1. Texas Instruments, *TMP303 Easy-To-Use, Low-Power, 1°C, Low-Supply Temperature Range Monitor In Micropackage*
2. Texas Instruments, *bq25570 Nano Power Boost Charger and Buck Converter for Energy Harvester Powered Applications*

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