Texas Instruments

TI POWER

TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

ANDRIA MCINTYRE

SYSTEMS CONSIDERATION FOR MONITORS FOR HIGH CELL COUNT INDUSTRIAL APPLICATIONS

Agenda

- High cell count battery applications
  - Cell chemistries and Li-ion
- Protections for Li-ion batteries
  - Protector vs. Monitor vs. gauge
  - Overvoltage, undervoltage, temperature, and current
- Cell balancing
- Advanced battery packs
  - Gauges and monitors
  - FET configuration
- Device stacking

Systems with high cell counts

ESS / UPS/ BBU

eBikes / eScooters

Garden tools

Power tools

Vacuum cleaners / vacuum robots

Drones

← Higher Cell count Lower →

Battery technology comparison

Li-ion

Specification	Lead-Acid	NiCd	NiMH	Cobalt	Manganese	Phosphate
Specific Energy Density (Wh/kg)	30 – 50	45 -80	60 -120	150 -190	100 – 135	90 - 120
Cycle Life (80% discharge)	200 – 300	1,000	300 – 500	500 – 1,000	500 - 1,000	1,000 – 2,000
Over charge tolerance	High	Med	Low	Low	Low	Low
Self-discharge/month (room temp)	5 – 15%	20%	30%	<5%	<5%	<5%
Safety Requirement	Thermally stable	Thermally stable, fuses common		Protection circuit mandatory		
In use since	1881	1950	1990	1991	1996	1999

Safety standards

Latest safety standards:

- Basic over-voltage protection
- Under-voltage, current, and temperature protections
- Advanced protection features
- Primary and secondary protection requirements

Safety certification standards

- UL 2595 – General requirements for battery-powered appliances
- UL 1642 – Standard for lithium batteries

International safety standards

- IEC 62133 – Safety requirements for portable sealed secondary cells, and for batteries made from them, for use in portable applications
- IEC 61508 – Functional safety

United Nations classifications on the transport of dangerous goods

- UN 3171 – Battery-powered vehicle or battery-powered equipment
  - Applies to scooters, eBikes, and hoverboards too!
- UN 3480 – Lithium ion batteries
- UN 3481 – Lithium ion batteries packed with equipment including lithium ion polymer batteries

Packing instructions

- PI 965 – 970 – Packing instructions for lithium-based battery products

Battery electronics options

Protector

- Simple, hardware-based protection to respond to unsafe conditions like over-voltage, under-voltage, over-current, over-temperature, under-temperature, over-current, or short circuit

Lowest complexity

Monitor

- Measures individual cell voltages
- Measures current (coulomb counting)
- Measures die temperature and external thermistors
- Cell balancing to extend battery run-time and battery life
- Protections with flexible thresholds
- Communicates data and status to MCU or stand-alone gauge

Highest flexibility

Gauge

- Reports capacity, run-time, state-of-charge
- Enhanced protections
- Black box features to diagnose battery failure
- Extends run-time of battery due to accurately determining how much capacity is remaining
- Extends lifetime by dynamically controlling healthy, safe, fast charging
- Authentication, state-of-health, traceability…

Highest integration

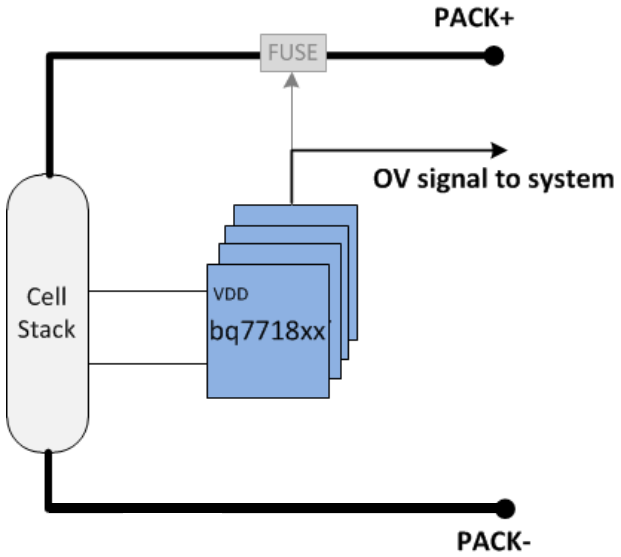
Protections – overvoltage

Why it matters

- Charging above rated voltage causes lithium plating
- Reduction in capacity due to reduction in free lithium ions
- Possibility of metallic lithium dendrites causing short circuit between electrodes
- Possibility of over-heating

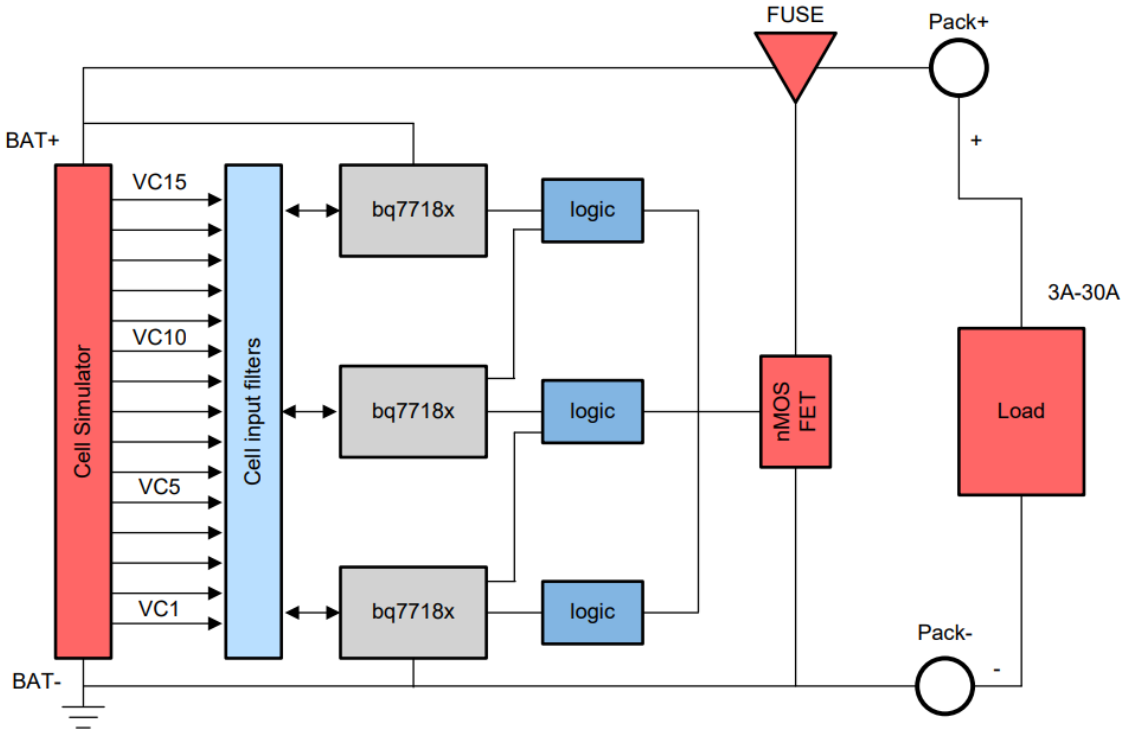
How a protector works

- Monitors each cell voltage in the stack
- Overvoltage threshold depends on cell chemistry
- Delay, hysteresis and output control for the FET depends on system



TIDA-00108

Stacked bq7718 secondary protection reference design for 60-V / 15-S industrial battery packs



- Simple architecture allows stacking of multiple secondary protectors to implement 10s-15s
- Each cell monitored independently with embedded delay timer to prevent false trips of in-line fuse

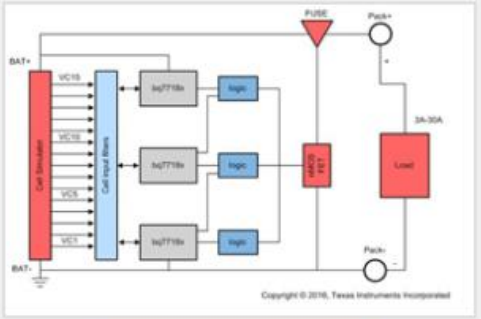
www.ti.com/tool/TIDA-00108

TIDA-00108

Stacked bq7718 secondary protection reference design for 60-V / 15-S industrial battery packs

Schematic/Block Diagram

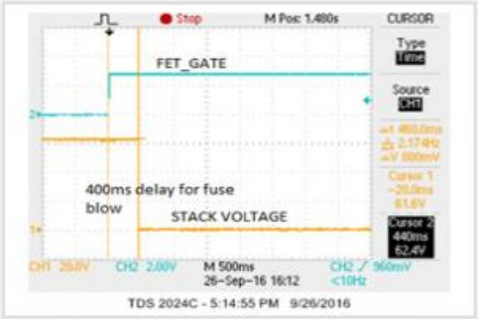
Quickly understand overall system functionality.



Download Schematic

Design Guide

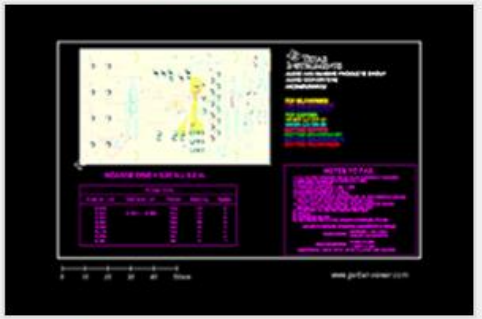
Get results faster with test and simulation data that's been verified.



Download Design Guide

Design Files

Download ready-to-use system files to speed your design process. Get Viewer.



Download Design Files

Protections – undervoltage

Why it matters

- Lithium ion chemistries can have electrode breakdown if over-discharged or stored for extended periods below ~2 V (see cell manufacturer datasheets for specifics) – increasing self-discharge rate
- Below ~2 V, copper in the anode current collector is dissolved into electrolyte. When charged above 2 V again, copper is deposited randomly, potentially causing a short circuit
- Below ~2 V, cathode can break down gradually, releasing oxygen by lithium cobalt oxide or lithium manganese oxide resulting in permanent capacity loss

How a protector works

- Monitors each cell voltage in the stack
- Undervoltage threshold depends on cell chemistry
- Delay, hysteresis and output control for the FET depends on system

Protections – temperature

Why it matters

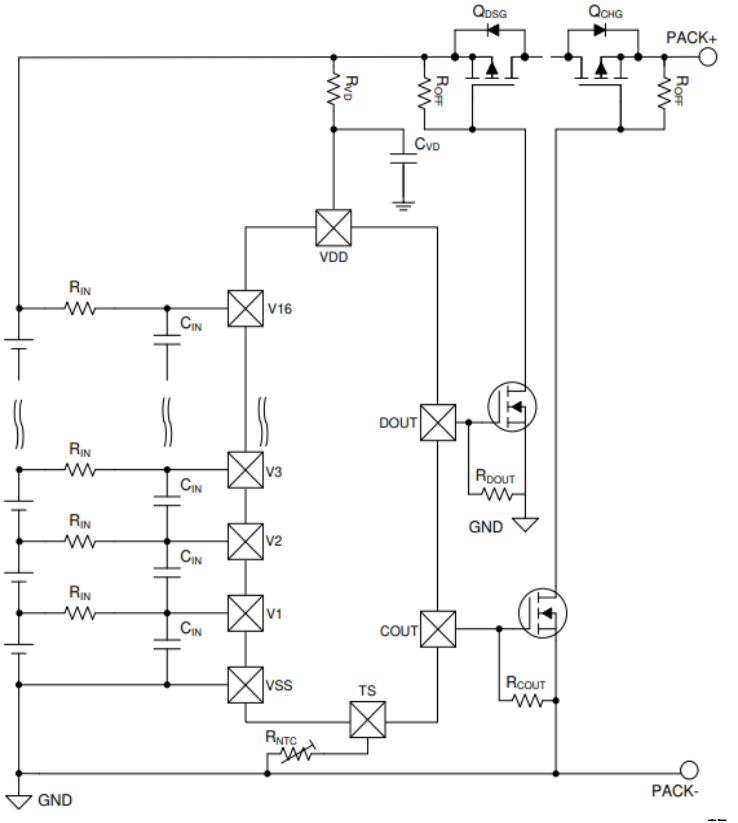
- Under-temperature in charge and discharge (UTC, UTD)
  - Cold temperatures reduce current carrying capability and effective capacity of cell, making lithium plating more likely. It is common to reduce charge current at cold temperatures – see JEITA for details
- Over-temperature in charge and discharge (OTC, OTD)
  - High temperatures increase resistances and I2R losses, potentially leading to thermal runaway. It is common to reduce charge voltage at high temperatures – see JEITA
- Thermal runaway is possible if there is positive feedback for current, temperature and resistance increases – potentially dangerous and important to avoid

How a protector works

- NTC thermistors are placed in system where temperatures may become critical (hot or cold)
- The protector monitors voltages across the NTC, calculates temperature and takes action based on threshold pertaining to OTD, OTC, UTD, or UTC

Voltage and temperature protections using BQ77216 or BQ77207

- The BQ77216 (3S-16S) and BQ77207 (3S-7S) family of battery protectors has the following features:
  - Protection for OV, UV, OT, OW
  - High accuracy OV protection:
    - ± 10 mV at 25 °C
    - ± 20 mV from 0 °C to 60 °C
  - Fixed internal delay timers, detection thresholds, and output drive types for COUT and DOUT
  - Low power consumption ICC ≈ 1 µA
  - Low leakage current per cell input < 100 nA with OW detection disabled
- Fault detection starts internal delay timer that triggers outputs to active state upon time expiration
- Used in handheld gardening and power tools, eScooters, or eBikes



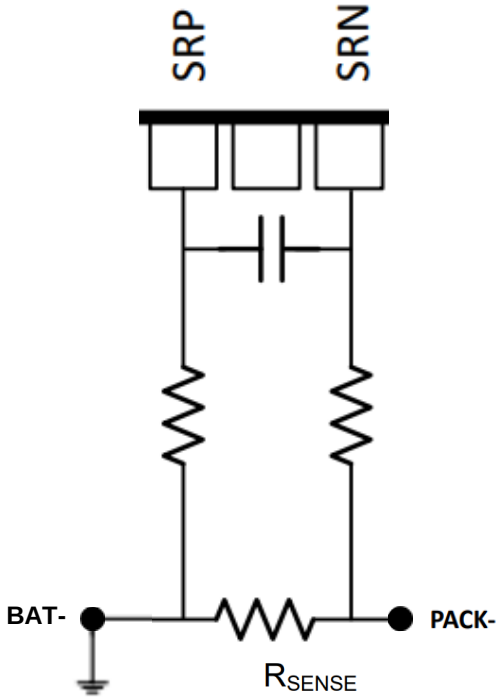
Protections – currents

Why it matters

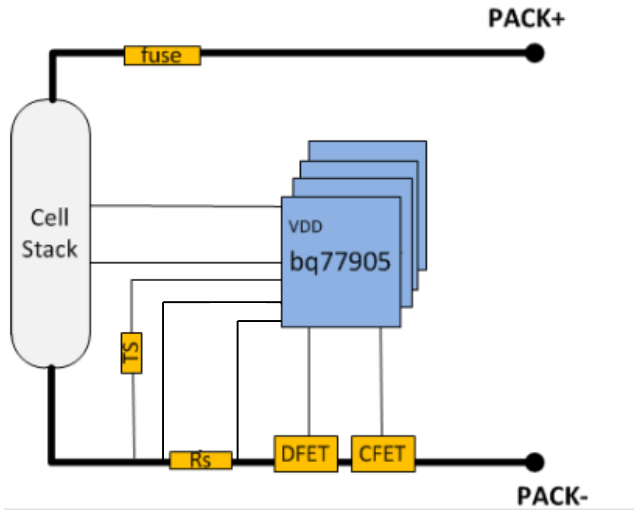
- Pack terminals can be exposed, and are at risk of being shorted together, so short-circuit discharge (SCD) protection is needed
- Loads may exceed safe operating currents - overcurrent discharge (OCD) may be needed
- If a non-approved charger may be used, a separate overcurrent charge (OCC) may be needed

How a protector works

- Using a sense resistor (R_{SNS}), the voltage across R_{SNS} (V_{SRP}-V_{SRN}) is measured and compared against the thresholds for OCD and SCD



Example with under-voltage, current, and temperature protections



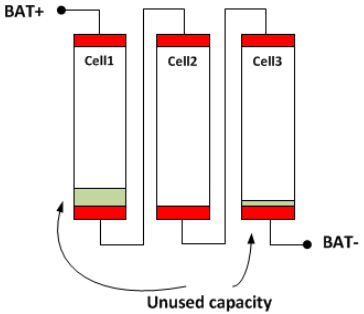
Example block diagram with BQ77905
(or BQ77915 which also includes cell balancing)

Example solution with basic protections:

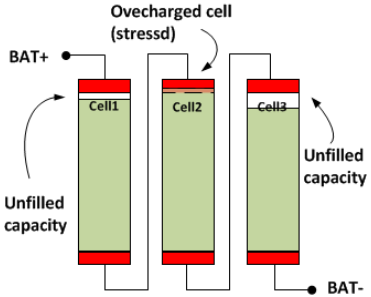
- Over-voltage
- Under-voltage
- Overcurrent discharge (2 levels)
- Short circuit
- Open wire detection
- Over-temperature charge
- Over-temperature discharge
- Under-temperature charge
- Under-temperature discharge

Cell balancing – Why it matters

Reduction in runtime

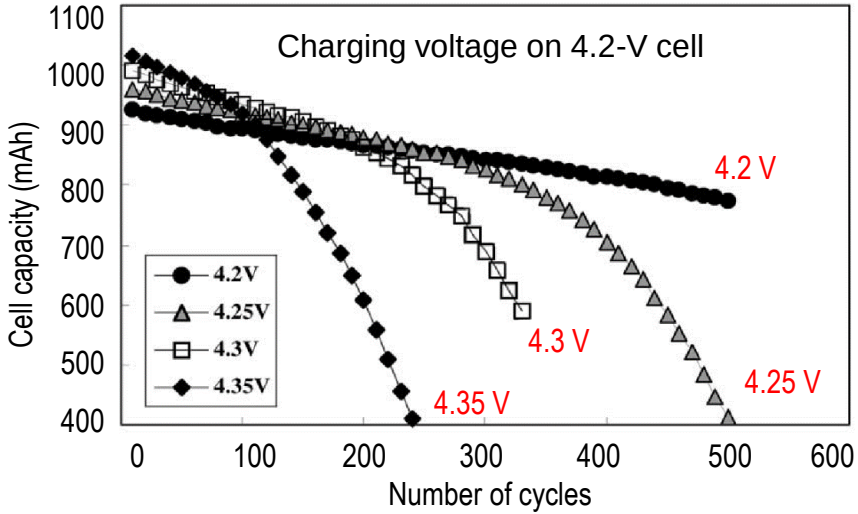


During discharge



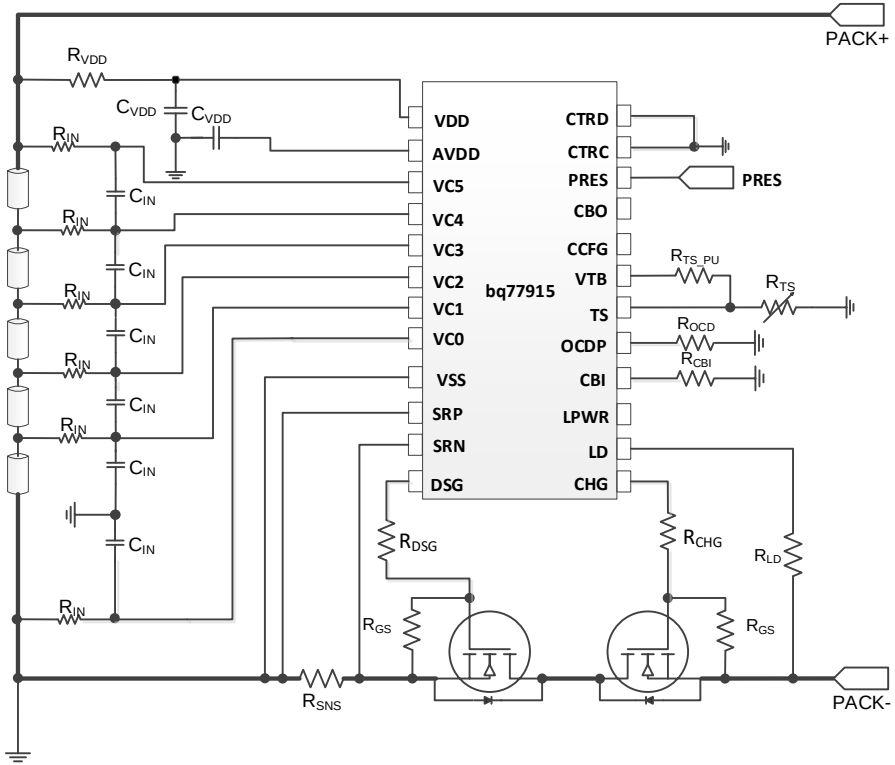
During charge

Degrading cycle life of battery pack



"Factors that affect cycle-life and possible degradation mechanisms of a Li-ion cell based on LiCoO2", Journal of Power Sources 111 (2002) 130-136)

Basic protections with cell balancing



- Provides basic protections and built-in voltage-based balancing algorithm
  - Over-voltage
  - Under-voltage
  - Overcurrent discharge (2 levels)
  - Short circuit
  - Open wire detection
  - Over-temperature charge
  - Over-temperature discharge
  - Under-temperature charge
  - Under-temperature discharge
- Supports external balancing FETs for higher balancing current

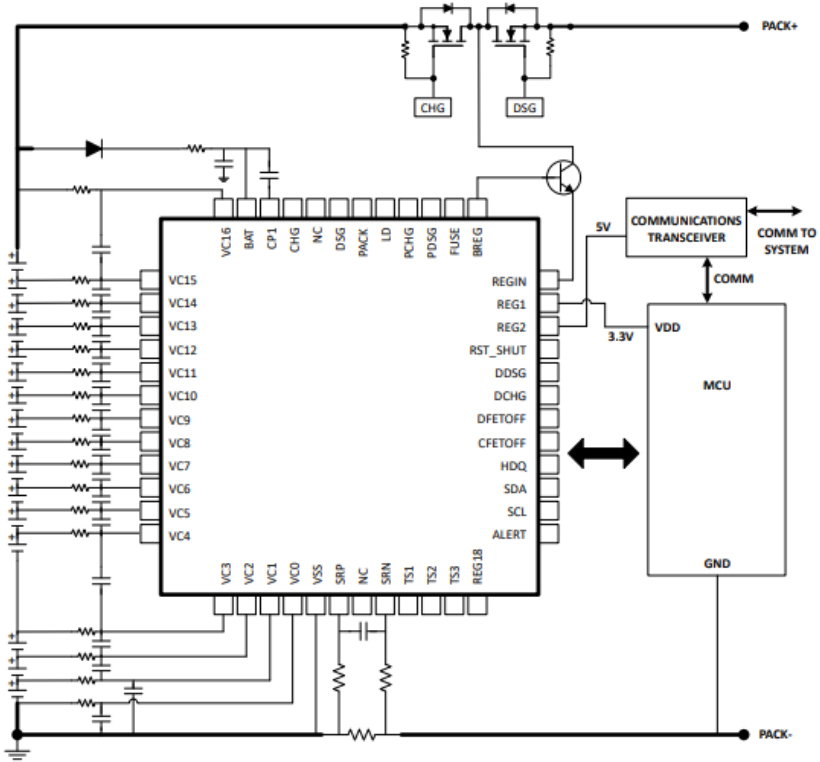
Advanced battery packs with monitors + MCU

When to use a monitor

- Communicating cell voltages and currents to MCU
- Protection threshold customizability

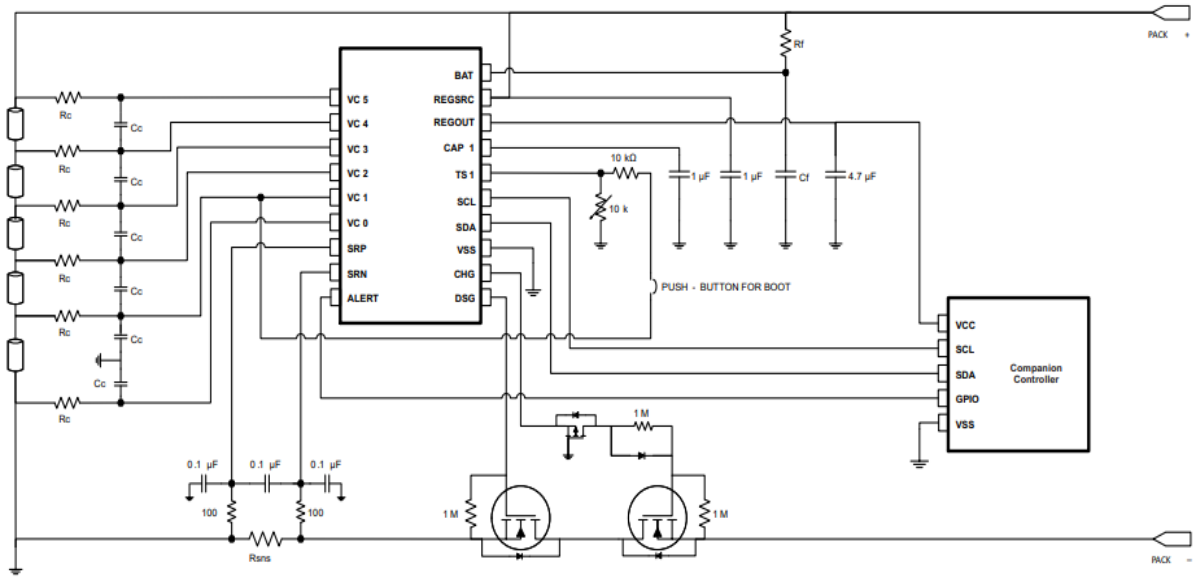
What can you do with a monitor?

- Measure individual cell voltages
- Measure current (coulomb counter)
- Cell balancing
- Measure die temperature and external thermistors
- Communicate data and status with an MCU
- Monitors also typically include protection features



BQ76952 monitor typical application circuit with MCU

Advanced battery packs – BQ769x0 monitor



- Solution integrates following functions:
  - Digitizing V/I/T data
  - HW-based protection
  - Duty cycle between cell balancing and measurement
- Removes tasks from MCU and system designer
  - Competitive on solution cost with easier design
- Full customization on protections and recovery
- System designer has full flexibility on BMS functions

Low-side vs. high-side FETs

- High-side switching
  - Allows continuous communication between host and monitor due to preserved ground connection
  - Requires charge pump and high-side FET drivers (integrated in BQ769x2)
- Low-side switching
  - No continuous communication
  - Often used with isolated interface or when low-side switching is required
  - Requires low-side FET drivers (integrated with BQ769x0)
- 2 terminal battery is on or off regardless of whether switches are on the low or high side

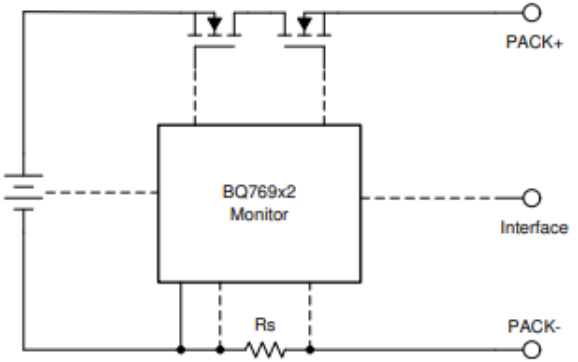


Figure 1-1. High-Side FETs

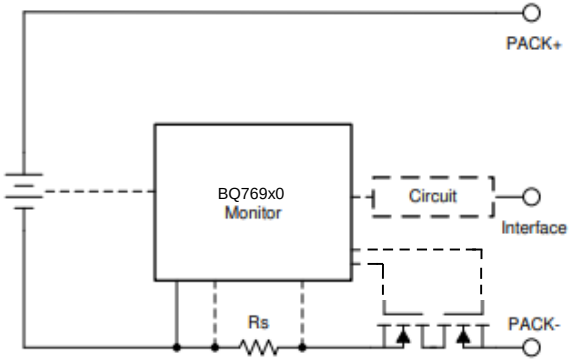
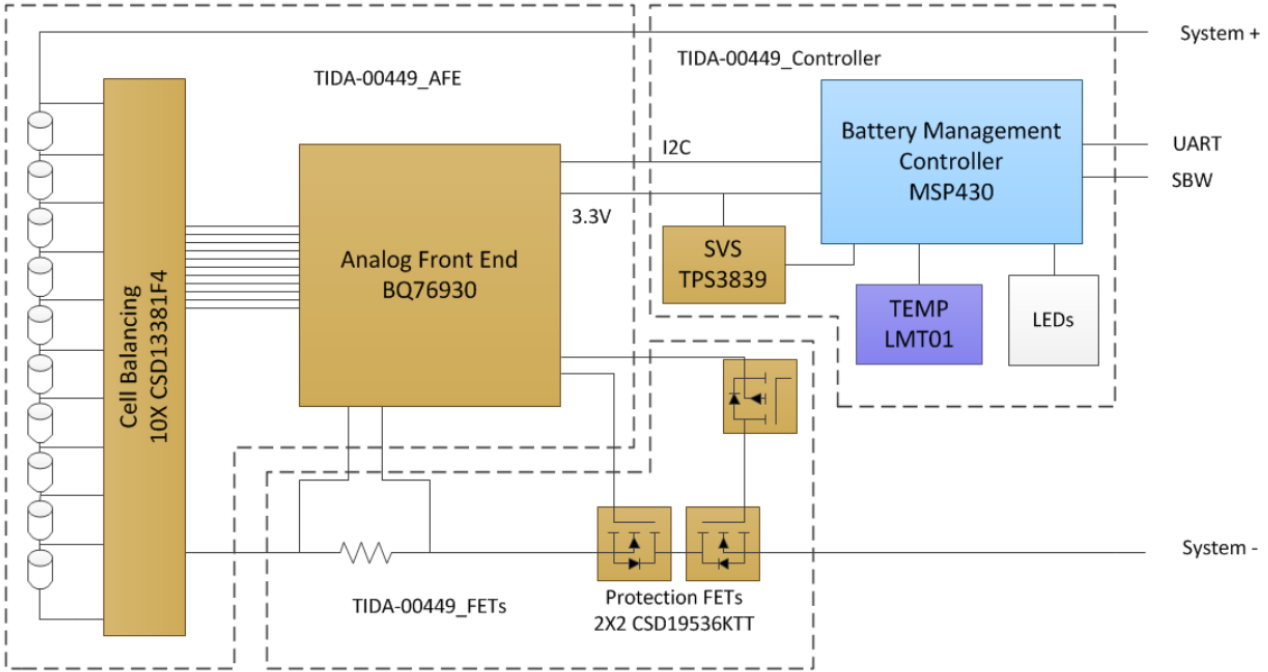


Figure 1-2. Low-Side FETs

TIDA-00449
10s battery pack monitoring, balancing, and comprehensive protection 50-A discharge reference design

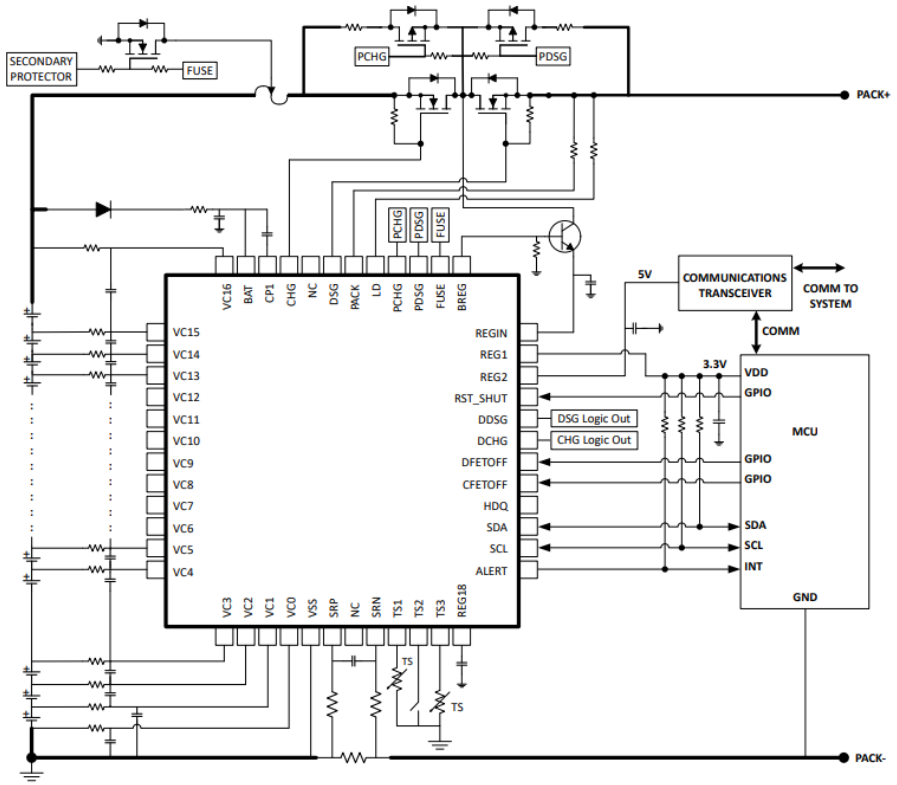


- Reference design with BQ76930 10S battery monitor and MSP430 MCU
- External N-Channel cell balancing FETs
- MCU sample code available for basic communication with AFE

www.ti.com/tool/TIDA-00449

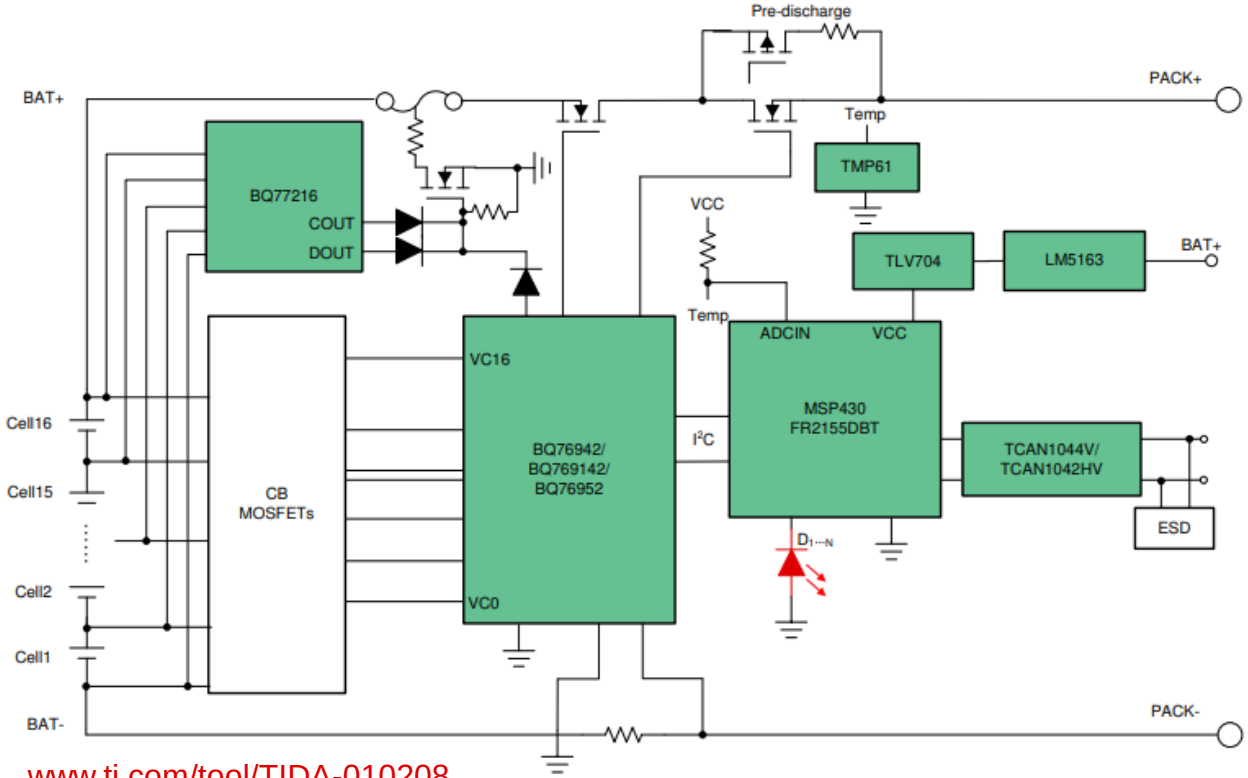
High cell count battery monitoring using BQ769x2

- The BQ76942 (3S-10S) and BQ76952 (3S-16S) family of battery monitors + protectors supports up to 16 series cells and provides cell voltage, current, and temperature monitoring
- Two independent ADCs – Support for simultaneous current and voltage sampling
  - High-accuracy coulomb counter with input offset error < 1 µV (typical)
  - High accuracy cell voltage measurement < 10 mV (typical)
- Primary protection for OV, UV, SCD, OCD1/2/3. OCC, OTC, OTD, UTC, UTD, OTF, precharge timeout, and a host watchdog.
- Integrated charge pump for high-side NFET protection with optional autonomous recovery.
- Integrated secondary chemical fuse drive protection
- Autonomous or host-controlled cell balancing



TIDA-010208

10s–16s battery pack reference design with accurate cell measurement and high-side MOSFET control



www.ti.com/tool/TIDA-010208

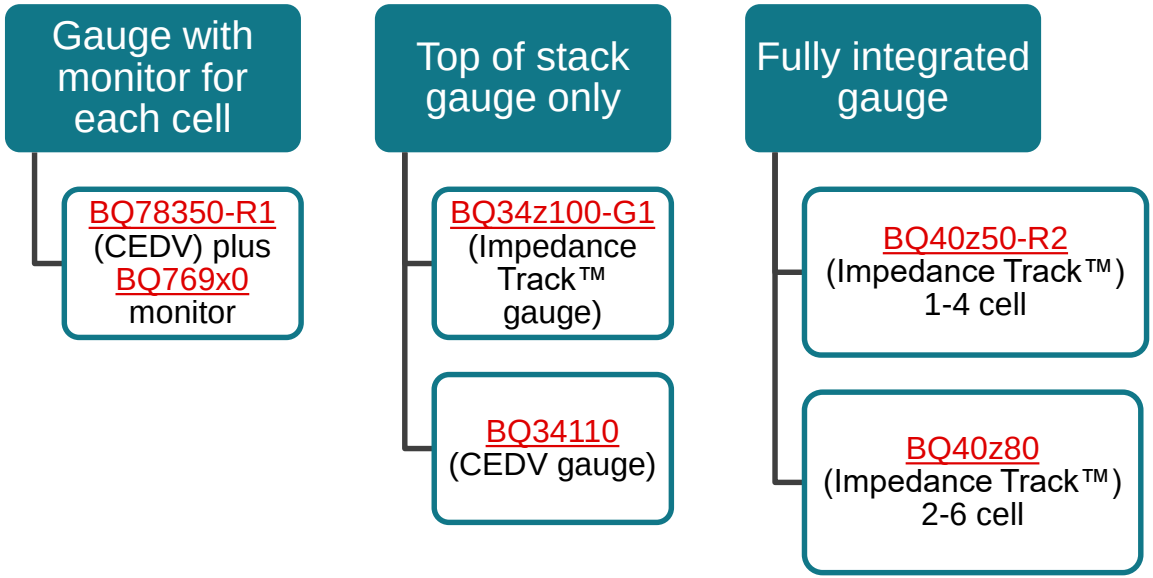
- 10-16S solution includes Bq76942/142/52 battery monitor, secondary protection, and high-side N-FETs
- High cell count BQ77216 protector
- 100-µA current consumption in standby mode
- 10-µA current consumption when in shipping mode

Battery gauging

What can a battery gauge do in your system?

- Provide estimate of remaining charge in the battery during use
- Provide estimate of present charge during charging
- Provide accurate current and voltage data during operation
  - For system optimization
  - For display to the customer
  - For diagnostic and characterization during development
- Determines aging: state of health = full charge capacity / design capacity
  - For replacement or warranty determination
- Black box recorder
- Authentication of battery
- Enhances safety

Gauge topologies



- Different gauge types available for different system topologies
- BQ78350-R1 is a companion gauge designed for the BQ769x0 monitor
- BQ34z100-G1 and BQ34110 are bolt-on gauges that measure stack voltage instead of individual cell voltages
  - Can be used with high cell count batteries
- BQ40Z80 is a fully-integrated gauge used for systems with 6 cells or less

Increasing cell count with stacking

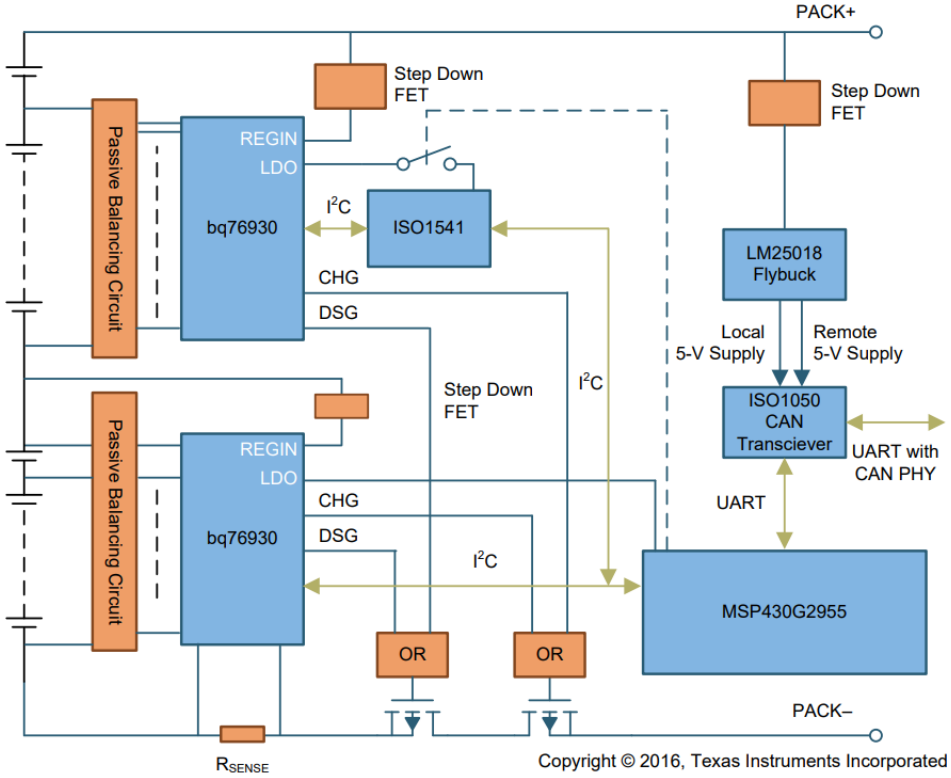
- Sometimes, there may not be a single-chip solution for monitoring or protection that supports the required number of cells

- In these cases, it may be necessary to stack multiple devices to implement a solution that covers the full number of cells in the system

- Stacking presentation link:
  - training.ti.com/how-stack-non-automotive-protectors-and-monitors-high-cell-count-applications

TIDA-01093
Industrial battery management module for 20S applications reference design

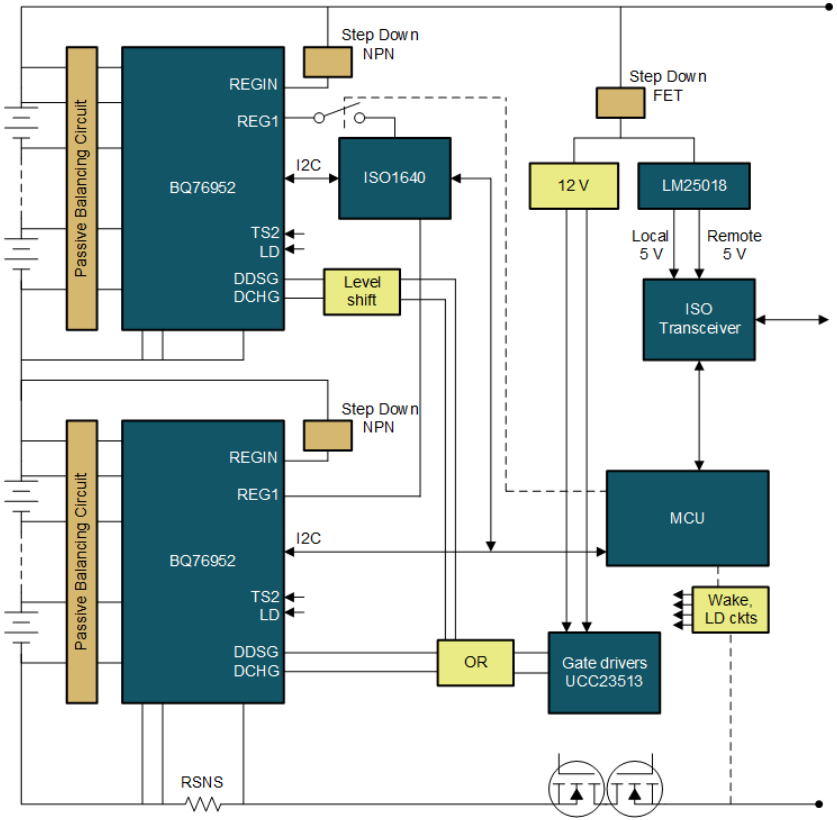
- Demonstrates 20S system using two BQ76930 (10S) devices
- Same design has been scaled to use two BQ76940 (15S) devices
- I2C buses from each device routed to host MCU, with upper device using ISO1541 2.5-kV I2C isolator
- Protection signals from two stacked devices combined using level shifting circuit network



www.ti.com/tool/TIDA-01093

BQ769x2 stacking guide
industrial battery management module for 32S applications

- Demonstrates a 32S system using two BQ76952 (16S) devices
- I2C buses from each device routed to host MCU, with upper device using ISO1640 Hot-Swappable Bidirectional 2.5-kV I2C isolator
- Low-side FETS driven by UCC23513 single channel isolated gate driver
- Protection signals from two stacked devices combined using level shifting circuit network



Summary

- High cell count lithium batteries have benefits but require consideration
- Advanced battery packs may need additional features
  - Cell balancing, high-side FET drive, battery monitoring, or battery gauging
- High cell counts may necessitate stacking
- TI reference designs are available for deeper understanding
  - TIDA 00108: www.ti.com/tool/TIDA-00108
  - TIDA 00449: www.ti.com/tool/TIDA-00449
  - TIDA 010208: www.ti.com/tool/TIDA-010208
  - TIDA 01093: www.ti.com/tool/TIDA-01093

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