TI POWER

Design considerations for high-cell-count battery packs in industrial applications

Battery Management Deep Dive Training

October 2020

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Systems with high cell counts

ESS / UPS/ BBU

E-bikes / E-scooters

Garden tools

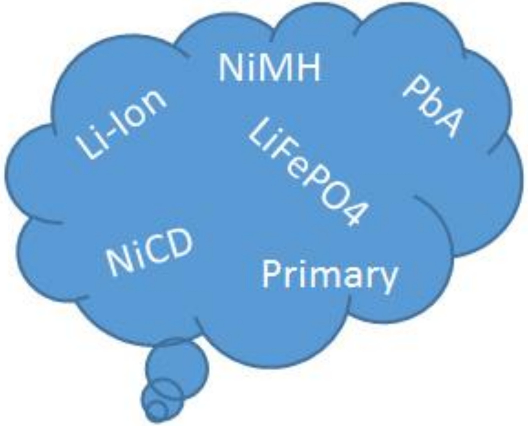
Power tools

Vacuum cleaners / vacuum robots

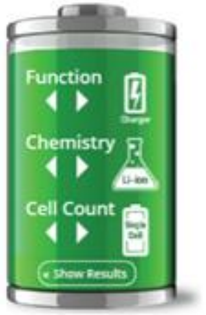
Drones

← 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



Challenges for high-cell-count industrial batteries

- Latest safety standards
  - Basic over-voltage protection
  - Under-voltage, current and temperature protections
  - Advanced protection features
  - Primary and secondary protection requirements
- Cell balancing
- Advanced battery packs with monitor and MCU
- High side FETs vs. low side FETs
- Battery gauging
- Increasing cell count with stacking

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, e-bikes 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 overvoltage, undervoltage, overcurrent, overtemperature, under temperature, overcurrent 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

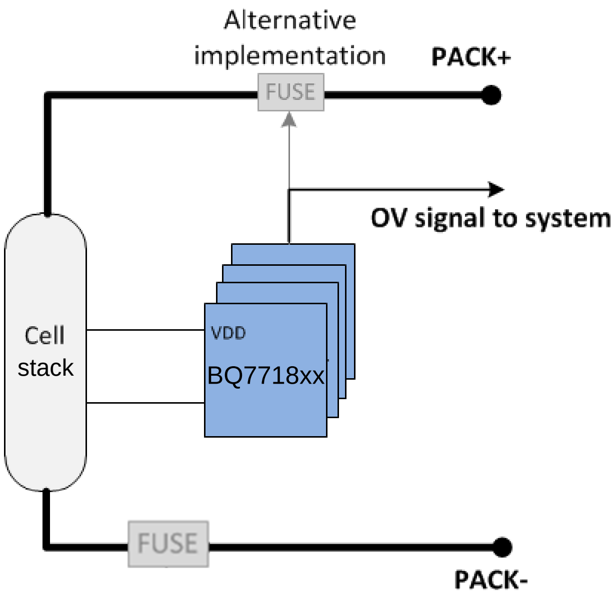
Protections – Overvoltage

Why it matters

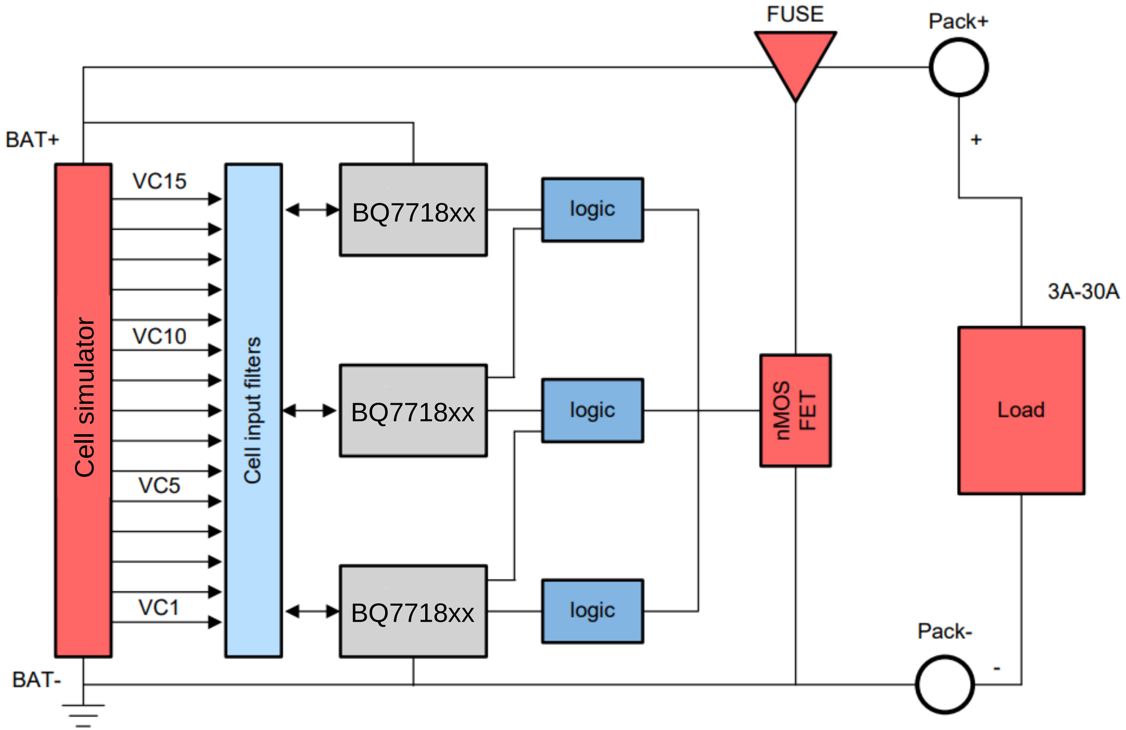
- Charging above rated voltage causes lithium plating
- Reduction in capacity due to a reduction in the free lithium ions
- Possibility of metallic lithium dendrites causing a short circuit between the electrodes
- Possibility of overheating

How a protector works

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



TIDA-00108 – Stacked BQ7718 secondary protection reference design for 60 V / 15S industrial battery packs

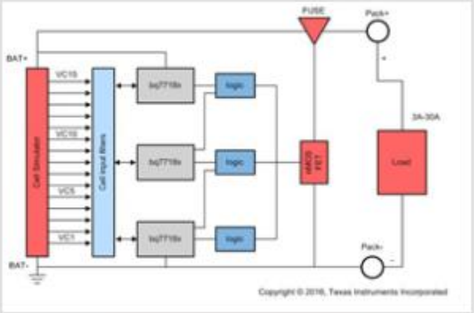


- Simple architecture allows multiple secondary protectors to be stacked to implement 10S-15S
- Each cell is monitored independently with an embedded delay timer provided to prevent false trips of the in-line fuse

TIDA-00108 – Stacked BQ7718 secondary protection reference design for 60 V / 15S industrial battery packs

Schematic/Block Diagram

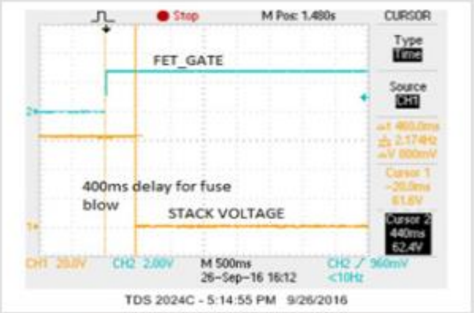
Quickly understand overall system functionality.



Download Schematic

Design Guide

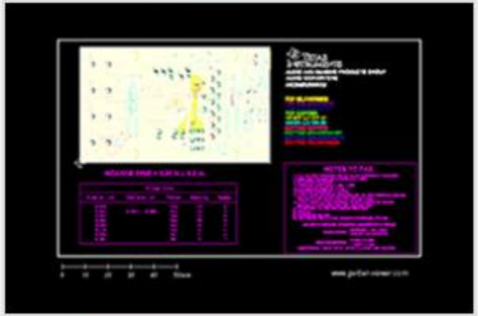
Get results faster with test and simulation data that's been verified.



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

How a protector works

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

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

Protections – Temperature

Why it matters

Under temperature in charge and discharge (UTC, UTD)

- Cold temperatures reduce the current carrying capability of the cell, reduce the effective capacity and make lithium plating more likely. It is common to reduce the charge current at cold temperatures – see JEITA for details

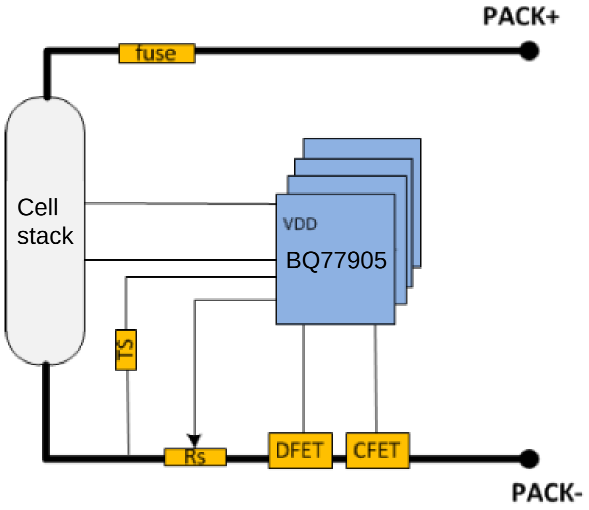
Overtemperature in charge and discharge (OTC, OTD)

- High temperatures increase the resistances and I^2R losses, potentially leading to thermal runaway. It is common to reduce the 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 the system where temperatures may become critical (hot or cold)
- The protector monitors the voltages across the NTC, calculates the temperature and acts based on the threshold set based on OTD, OTC, UTD or UTC

Example with undervoltage, current and temperature protections



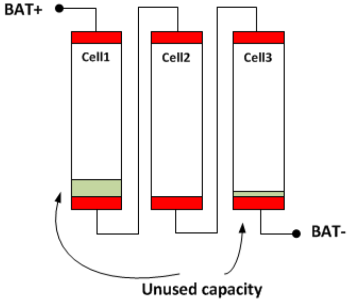
Example block diagram with BQ77905 (or BQ77915 which also includes cell balancing)

Example solution with basic protections:

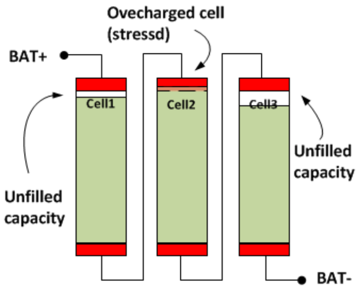
- Overvoltage
- Undervoltage
- Overcurrent discharge (2 levels)
- Short circuit
- Open wire detection
- Overtemperature charge
- Overtemperature discharge
- Under temperature charge
- Under temperature discharge

Cell balancing – Why it matters

- Reduction in runtime

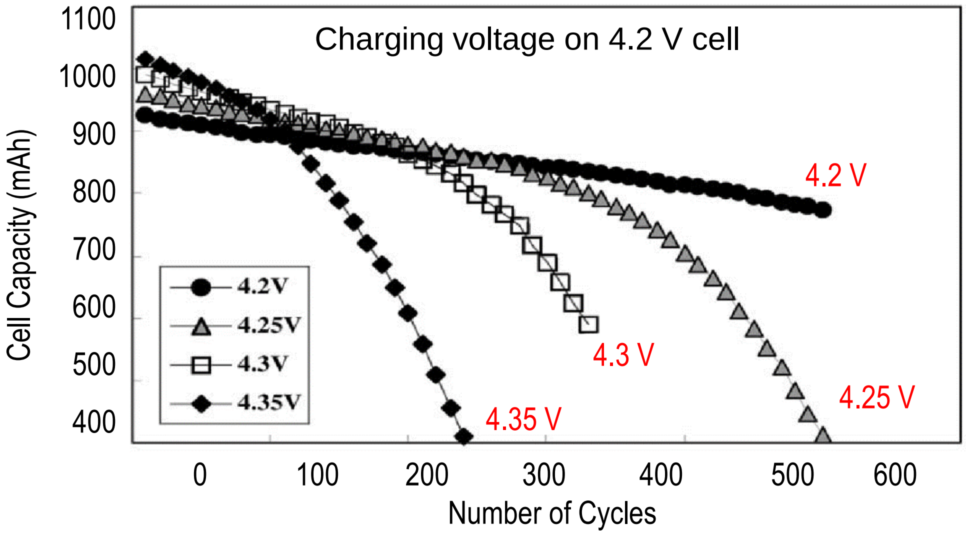


During discharge

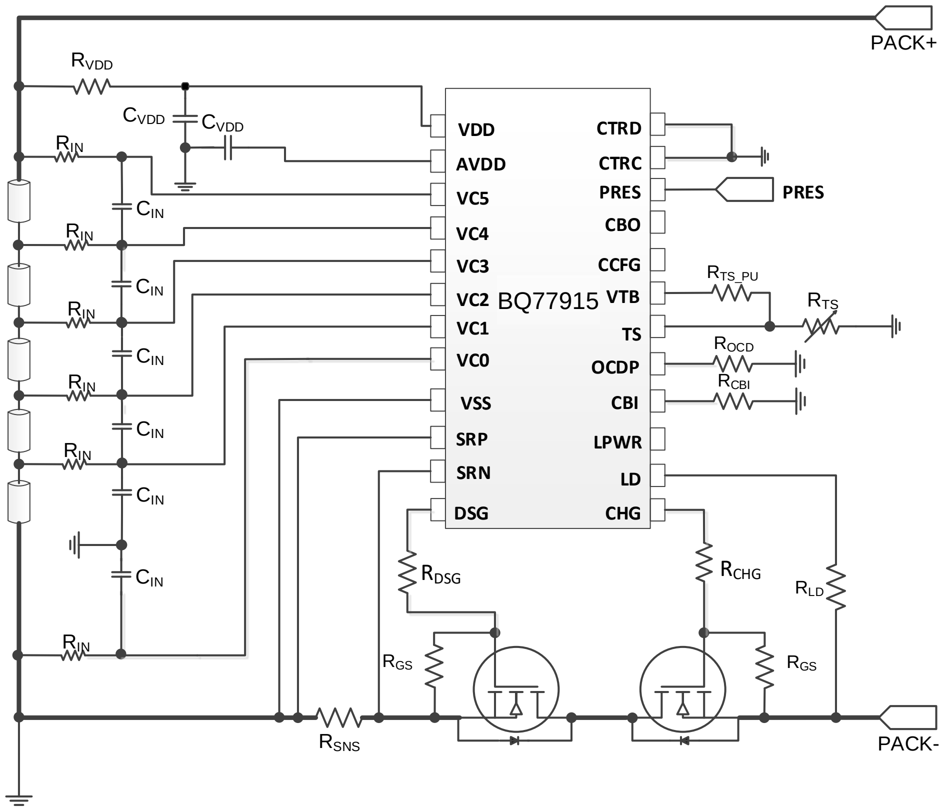


During charge

- Degrading cycle life of the battery pack



Protections with cell balancing



Provides full suite of protections, but also includes a built-in voltage-based balancing algorithm

- Overvoltage
- Undervoltage
- Overcurrent discharge (2 levels)
- Short circuit
- Open wire detection
- Overtemperature charge
- Overtemperature discharge
- Under temperature charge
- Under temperature discharge

Also supports external balancing FETs for higher balancing current

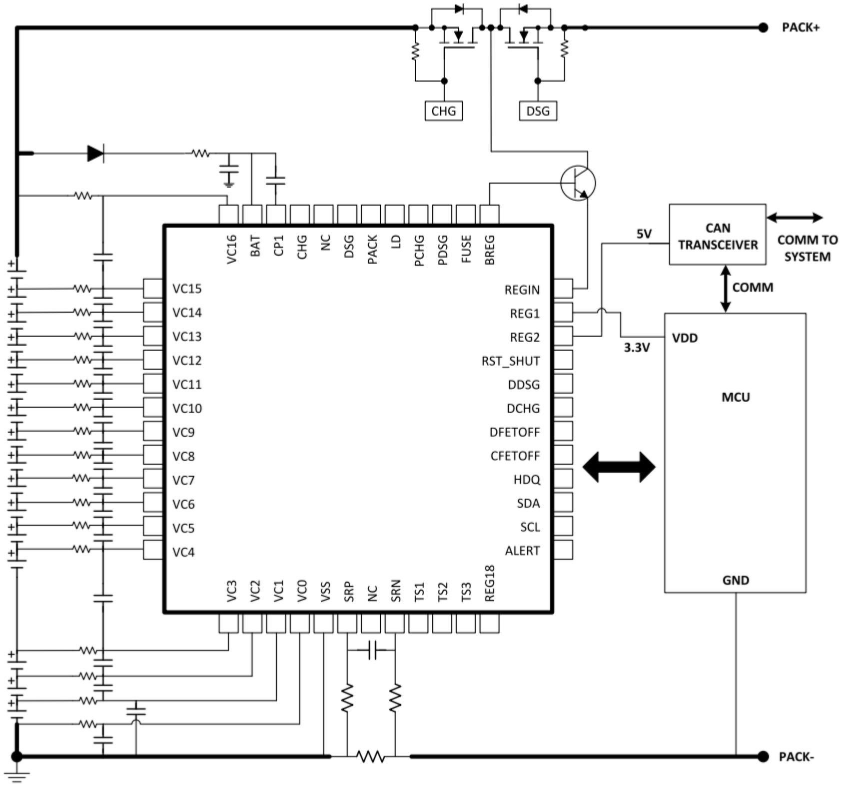
Advanced battery packs with monitors + MCU

When to use a monitor

- Do you need to communicate cell voltages and currents to an MCU?
- Do you want more flexibility on thresholds for protections?

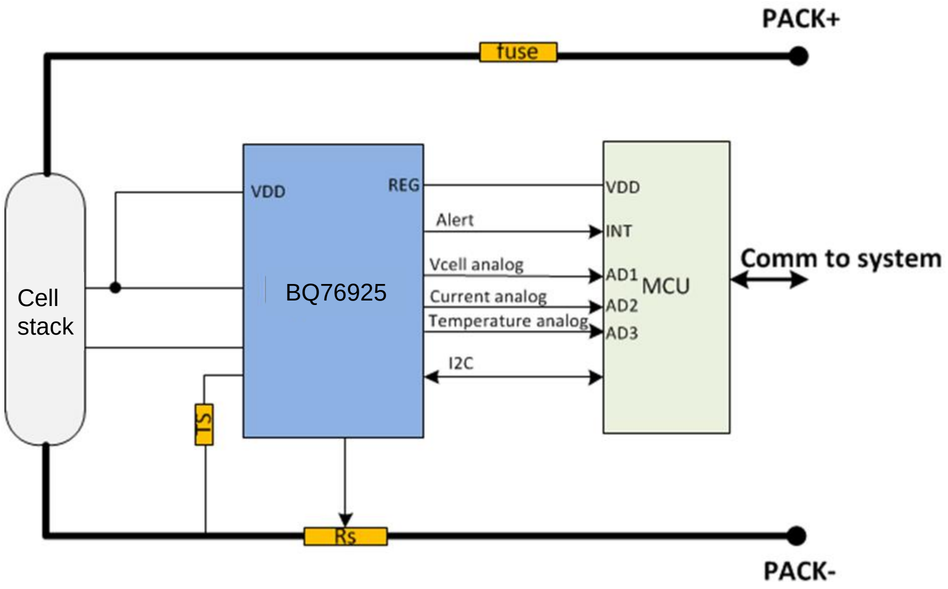
What can you do with a monitor?

- 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



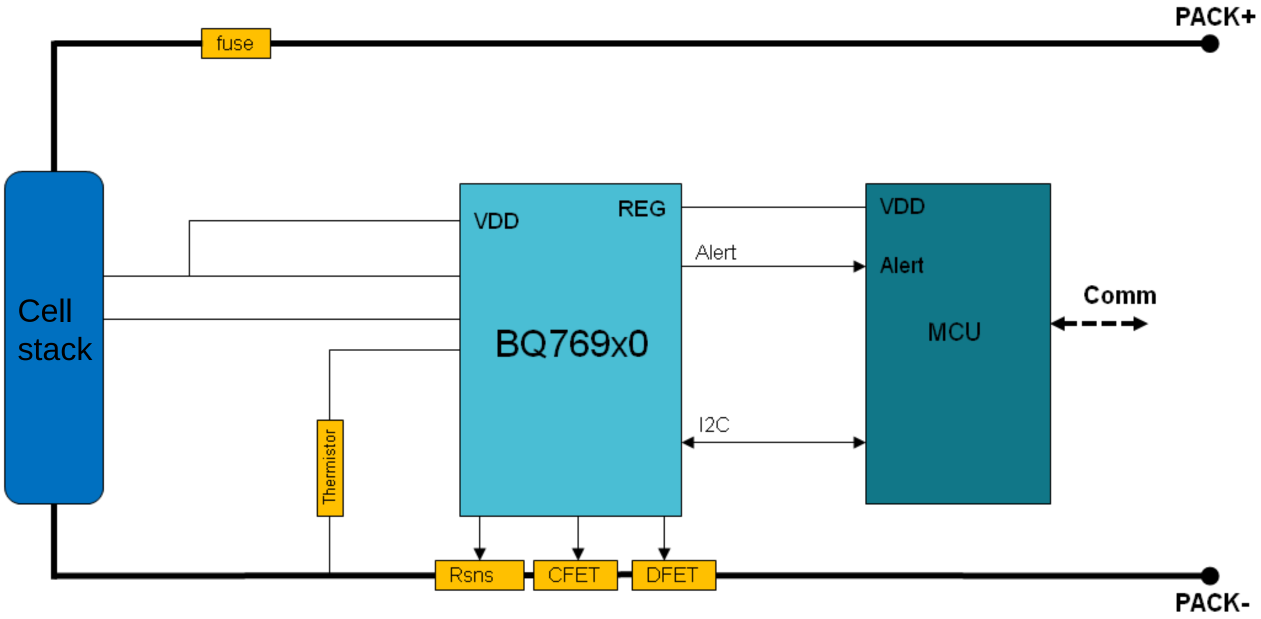
BQ76952 monitor typical application circuit with MCU

Battery with V/I/T information to system



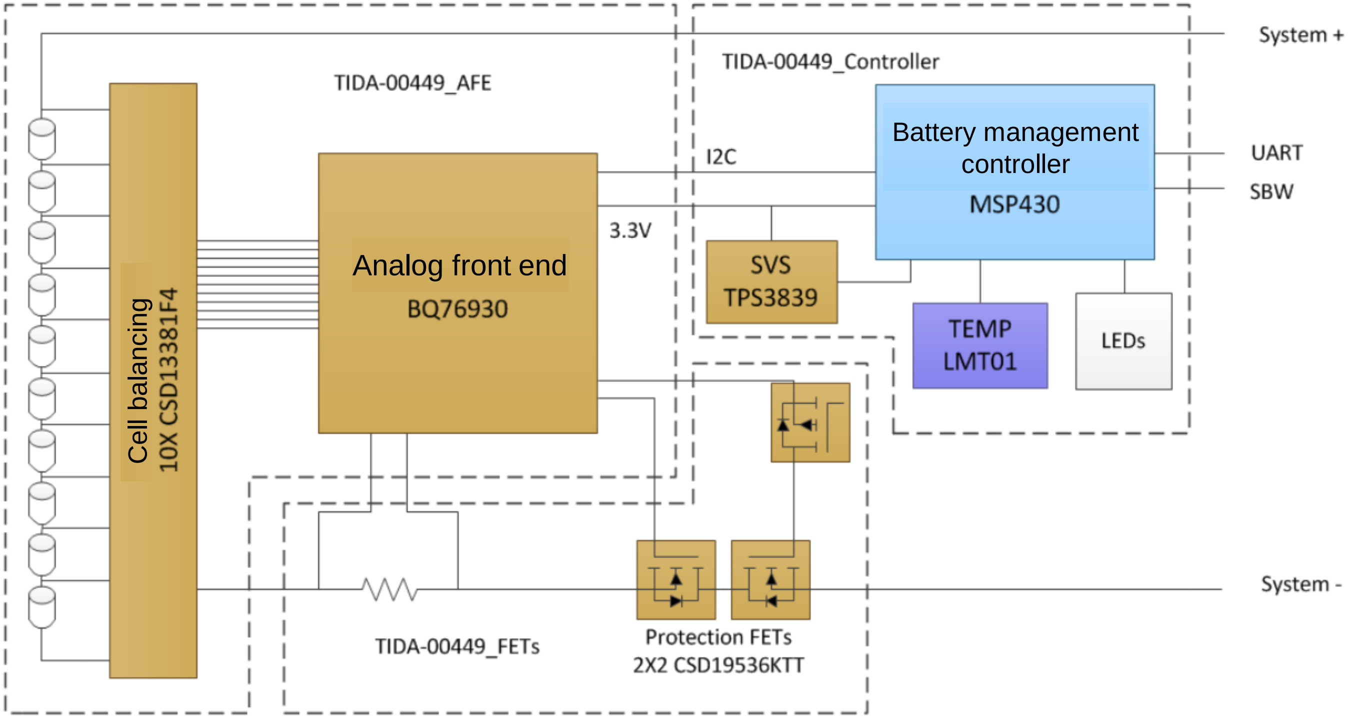
- System has basic battery information and maintains full control of the end equipment performance including battery protection
- MCU can create customized cell balancing to optimize runtime and extend battery life
- MCU is responsible for converting the data into digital form for use by the system

Advanced battery packs – Monitor with digital output



- This solution integrates functions like digitizing the V/I/T data, HW based protection, duty cycle between cell balancing and measurement etc. – removes tasks from MCU and system designer to remain competitive on solution cost with easier design
- Full customization on protections and recovery
- System designer has full flexibility on BMS functions

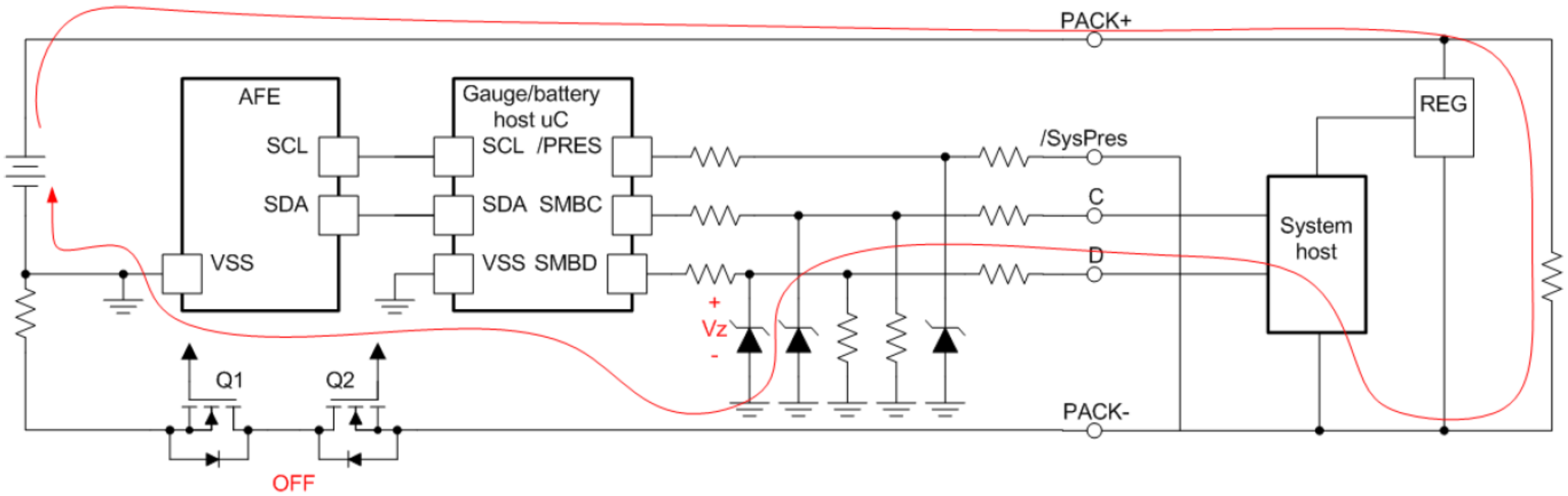
TIDA-00449: 10S battery pack monitoring, balancing and comprehensive protection – 50 A discharge reference design



Reference design using BQ76930 10S battery monitor, MSP430 MCU and external N-channel cell balancing FETs

MCU sample code available for basic communication with AFE

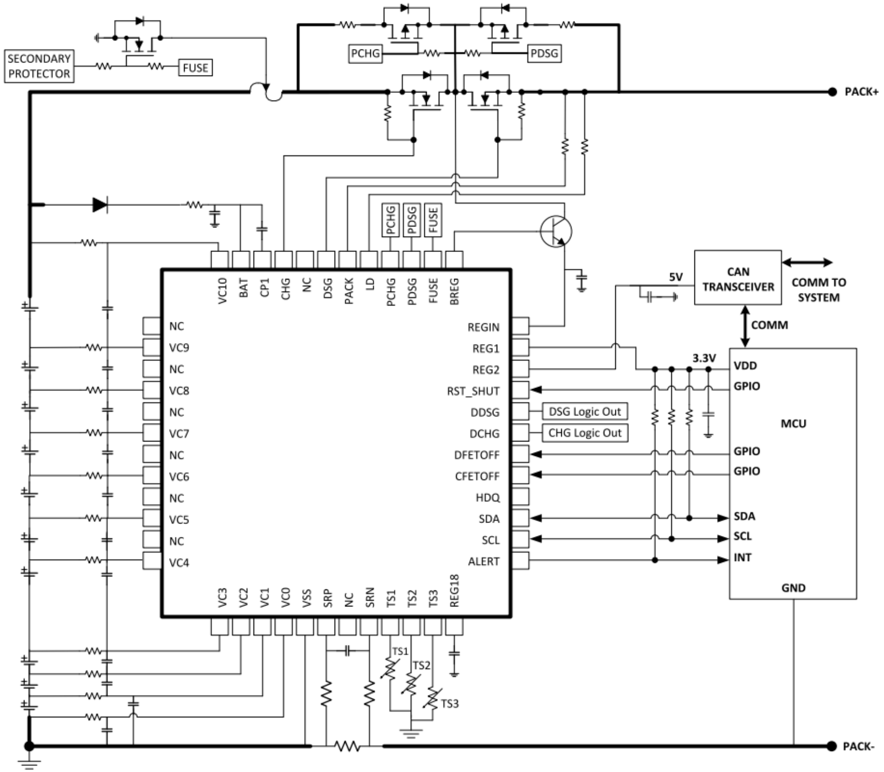
Low side vs. high side FETs



- A 2-terminal battery is on or off regardless of whether switches are on the low side or the high side. On batteries with an external communications port, there can be a leakage path from the signal to the reference.
- High side switching allows ground referenced signaling

High cell count battery monitoring using BQ769X2

- The BQ76942 (3S-10S) and BQ76952 (3S-16S) family of battery monitor + protectors support up to 16 series cells and provide 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



Battery gauging

What can a battery gauge do in your system?

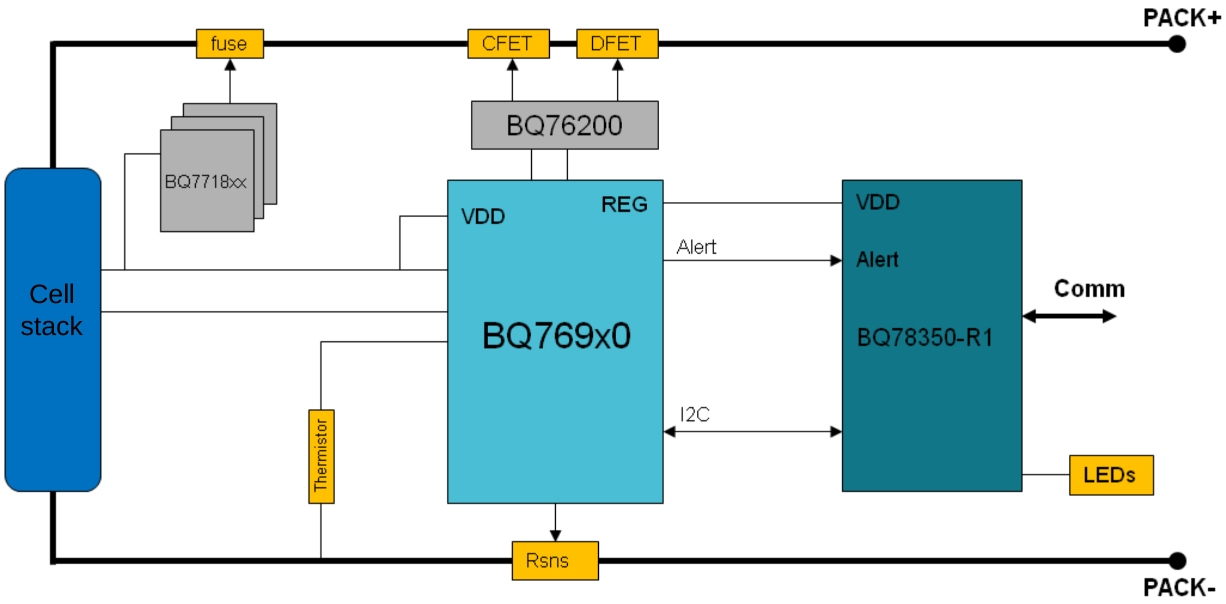
- Provides an estimate of remaining charge in the battery during use
- Provides an estimate of present charge during charging
- Provides accurate current and voltage data during operation
  - For system optimization
  - For display to the customer
  - For diagnostic and characterization during development
- 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

Multiple different gauge types are available depending on the system topology. BQ78350-R1 is a companion gauge that is specifically designed for the BQ769x0 monitor. The BQ34Z100-G1 and the BQ34110 are bolt-on gauges that measure the stack voltage instead of individual cell voltages, so these can be used with high cell count batteries. If the cell count is 6 cells or less, there is a fully integrated gauge available – the BQ40Z80.

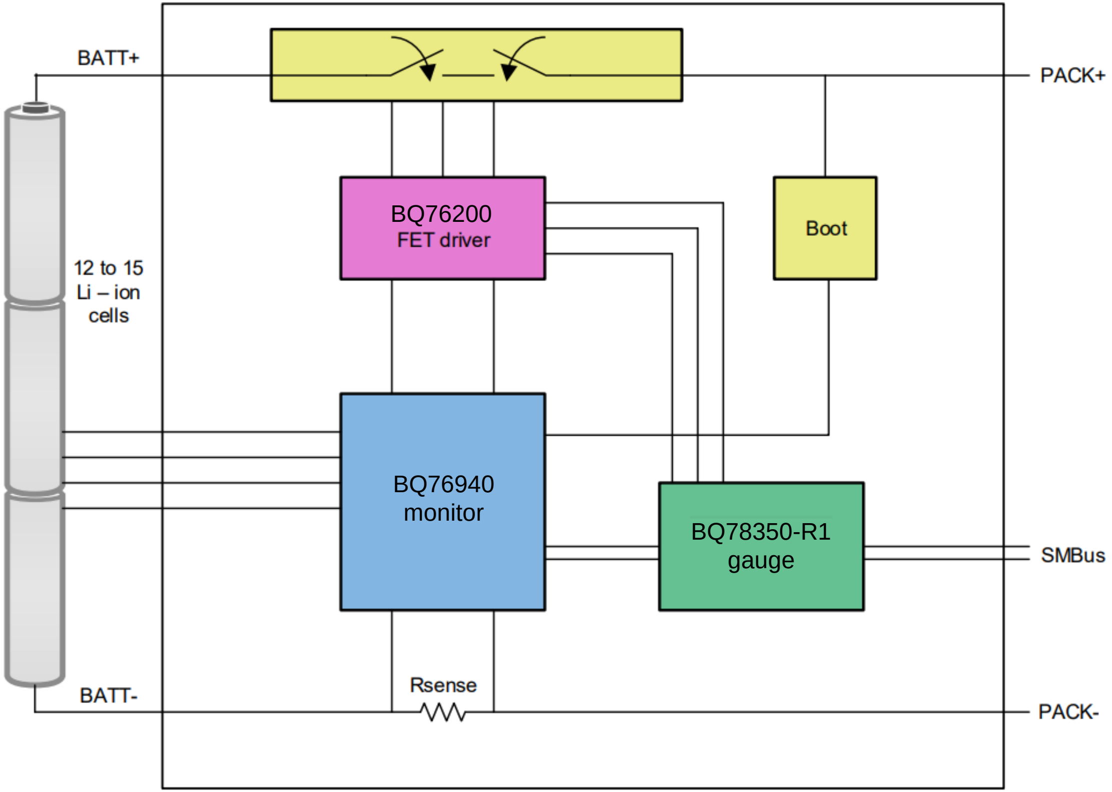
- **Gauge with with monitor for each cell**
  - BQ78350-R1 (CEDV) plus BQ769x0 monitor
- **Top of stack gauge only**
  - BQ34Z100-G1 (Impedance Track™ gauge)
  - BQ34110 (CEDV gauge)
- **Fully integrated gauge**
  - BQ40Z50-R2 (Impedance Track) 1-4 cell
  - BQ40Z80 (Impedance Track) 2-6 cell

Monitor example system considerations – Secondary protection, high side FETs, gauging



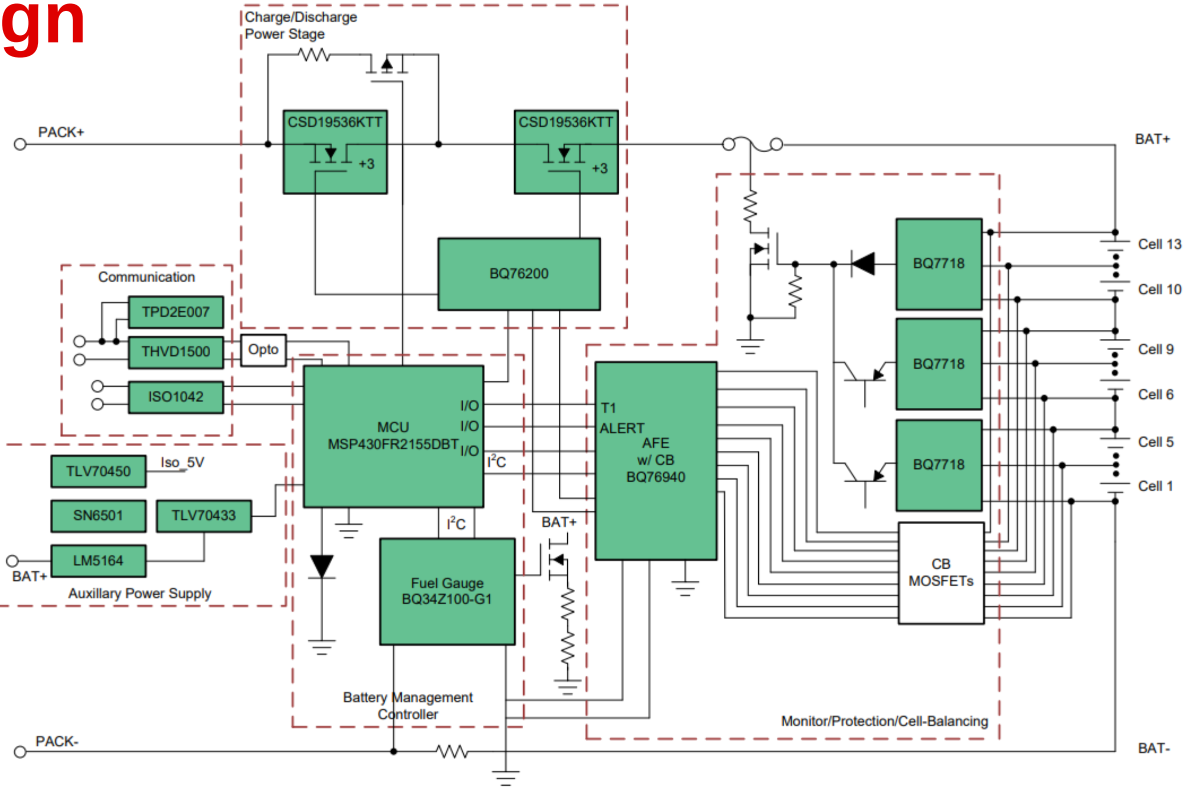
- Many Li battery related standards call for charge fault protection redundancy
- Using a 2nd level OV protection + a monitor provides such functionality
- With low side FETs, communication to system is disconnected at fault state
- Many industrial systems require communication between battery pack and the charger system before charging can start – using high side protection ensures communication is allowed even at fault state

TIDA-00792: Multicell 36-48 V battery management system reference design



- 12 to 15 cell reference design uses BQ76200 high side driver using N-channel MOSFETs
- External cell balancing
- BQ78350-R1 battery gauge is used for estimation of system run-time

TIDA-010030: Accurate gauging and 50 µA standby current, 13S, 48 V Li-ion battery pack reference design



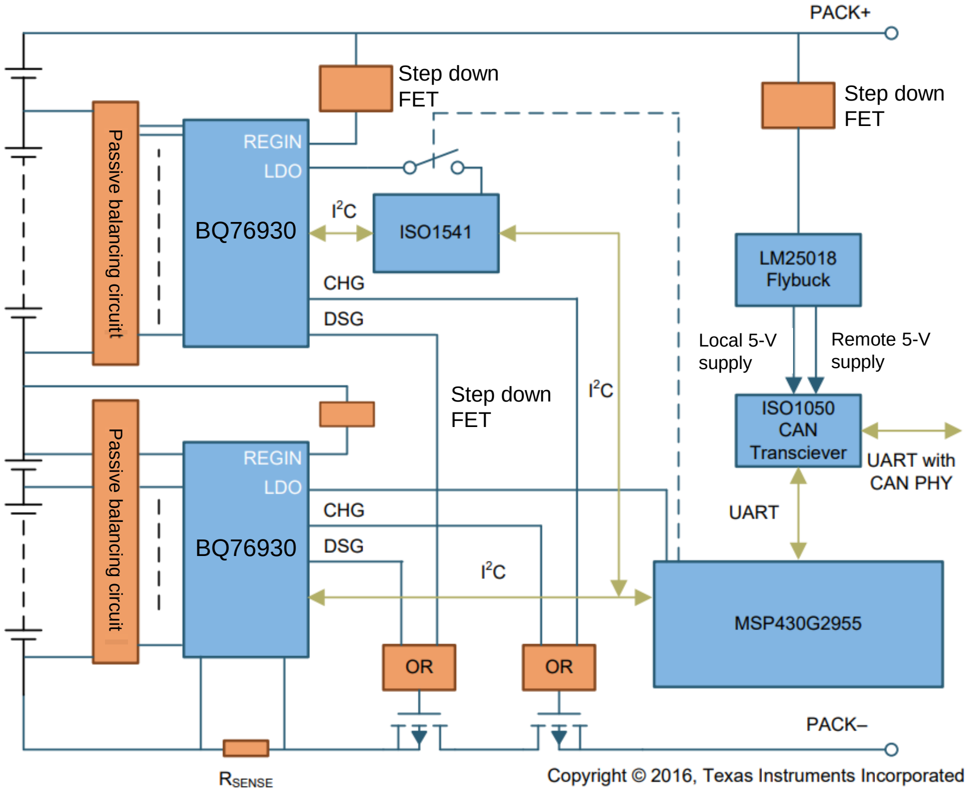
- 13S solution includes BQ76940 battery monitor, secondary protection, high side FET driver and BQ34Z100-G1 battery gauge
- 50 µA current consumption when in standby mode, 15 µA current consumption when in shipping mode

Increasing cell count with stacking

- In the design of high cell count battery management systems, 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

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

- Demonstrates a 20S system using two BQ76930 (10S) devices
- Same design has been scaled to use two BQ76940 (15S) devices
- The I^2C buses from each device are routed to a host MCU, with the upper device using an ISO1541 2.5 kV I^2C isolator
- The protection signals from the two stacked devices are combined using a level shifting circuit network



Summary

- High cell count lithium batteries are attractive due to high energy density but require basic protections at a minimum. More advanced protections may be needed depending on the application.
- More advanced battery packs may need additional features such as cell balancing, high side FET drive to allow communication with protections triggered, battery monitoring for accurate V/I/T measurements for advanced decision making or battery gauging for accurate SOC estimation.
- Stacking may be necessary for very high cell count batteries.
- Several TI reference designs are available as examples to understand different topologies and options available.

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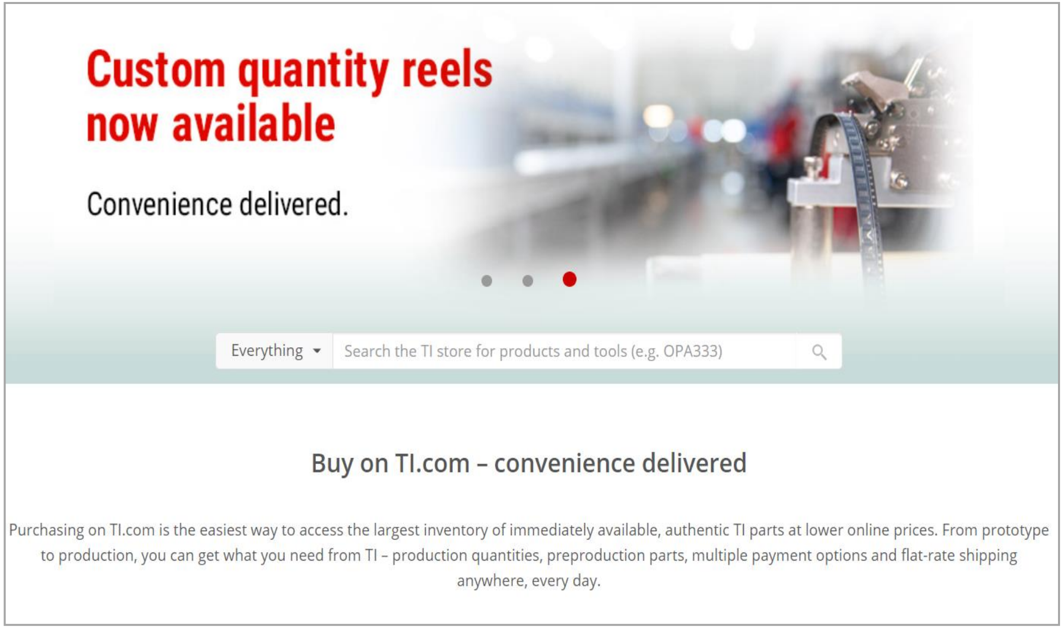

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