Texas Instruments

TI POWER

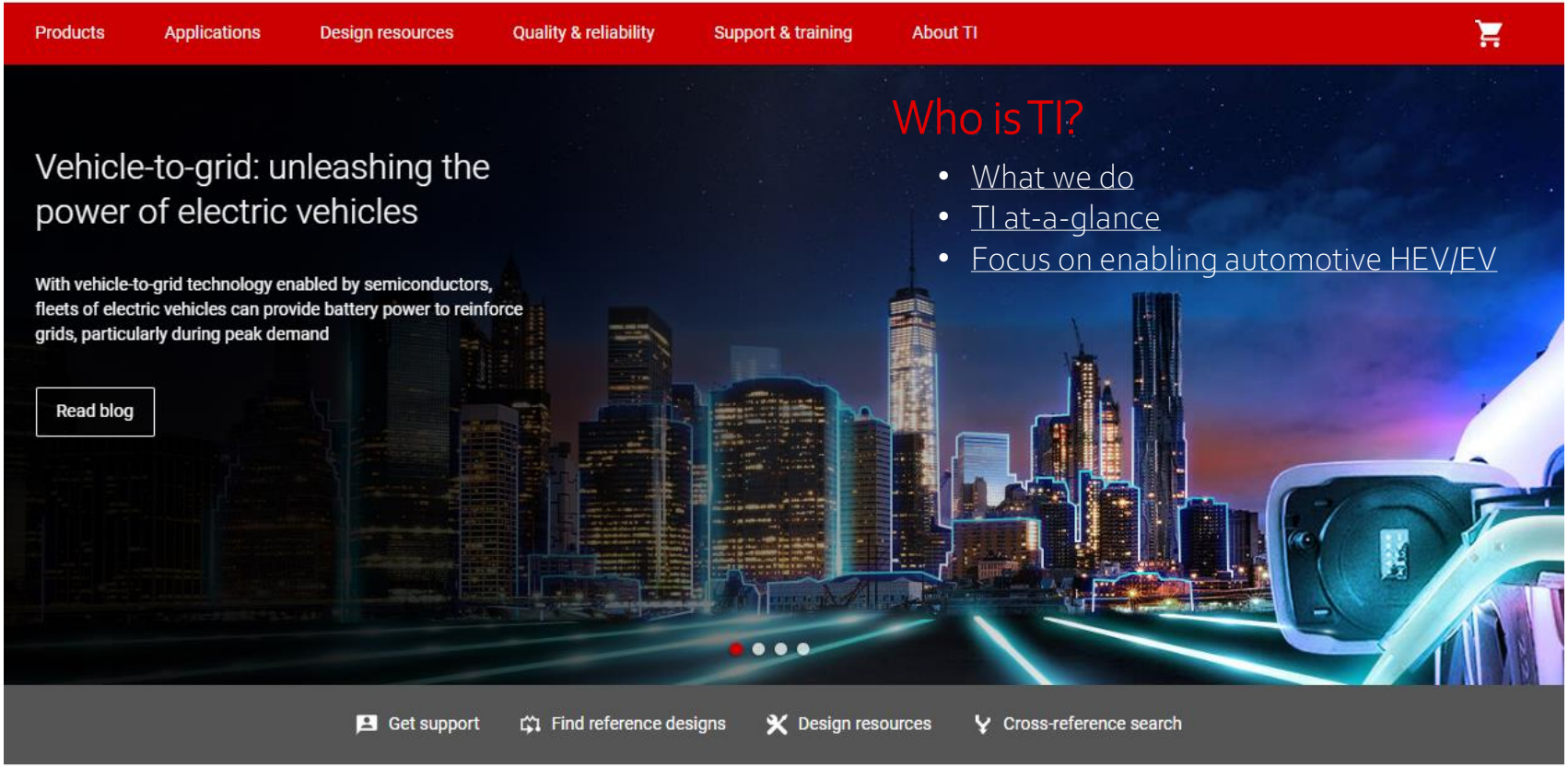
TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

TAYLOR VOGT

DESIGNING HIGH CELL COUNT AUTOMOTIVE APPLICATIONS WITH BQ79616-Q1

Agenda

- TI HEV/EV background
- Automotive battery architectures
- Common system level care-abouts
- Designing with TI battery monitors
- Q&A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Vehicle-to-grid: unleashing the power of electric vehicles
With vehicle-to-grid technology enabled by semiconductors, fleets of electric vehicles can provide battery power to reinforce grids, particularly during peak demand
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Who is TI?
What we do
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Focus on enabling automotive HEV/EV
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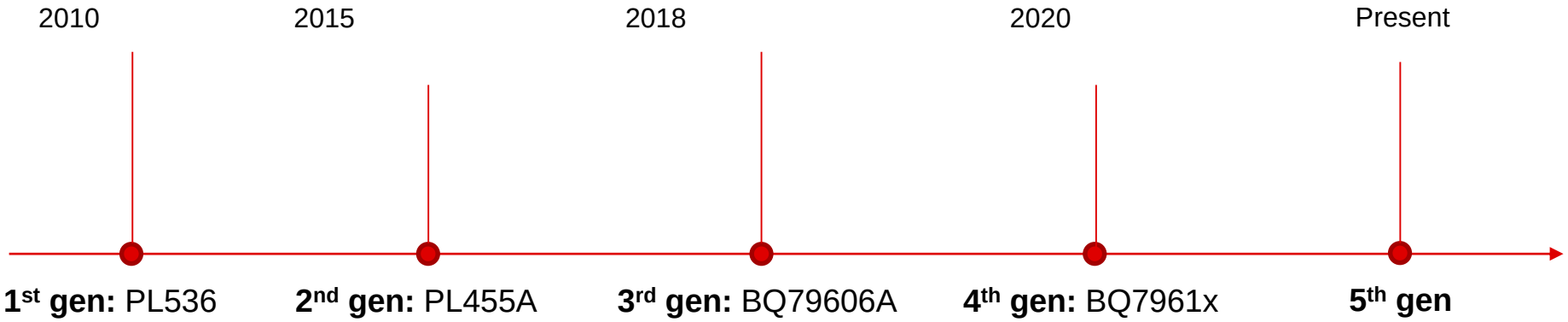
TI is top supplier for auto EV BMS ICs since 2010



Experience: Team growth and innovations over five generations of BMS technology

Impact: We support many top automotive Tier 1 suppliers and OEMs

Global Reach: Engagements with customers across the world

Partnerships: Long standing developments with multiple generations of HEV/EV OEMs

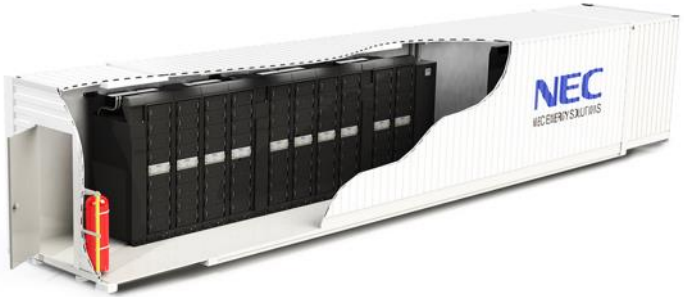
What is a high cell count application?

- Generally more than 12S (series cells), usually at high voltage (>50 V)

Chevy Bolt
60 kWh
350 V

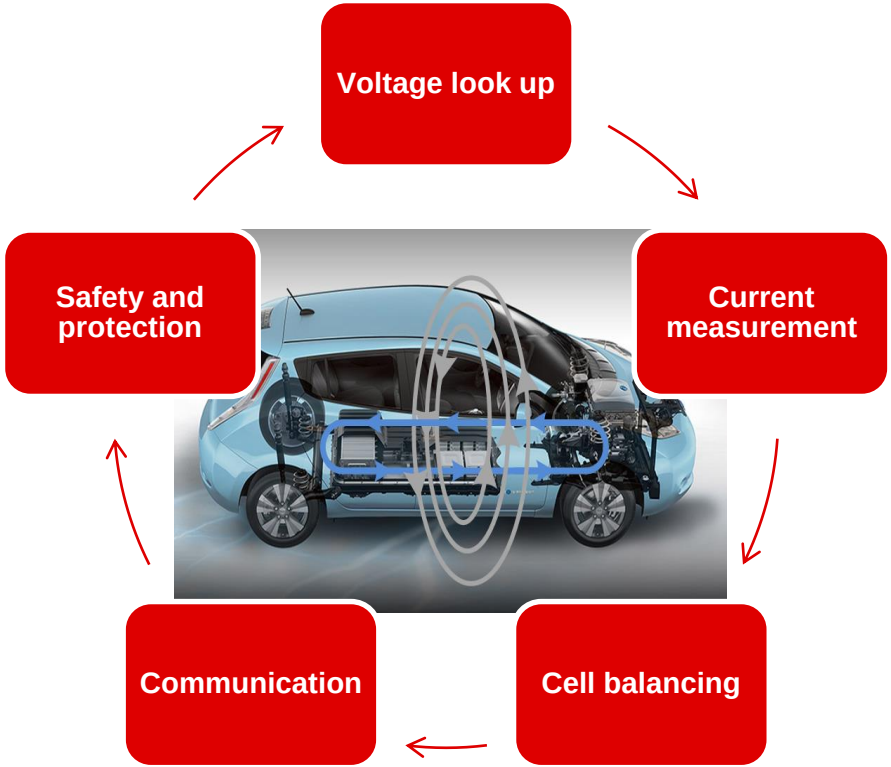
www.gm.ca

Tesla Model S
75-100 kWh
~375 V



ESS
for grid stability /
renewable integration
575 kWh

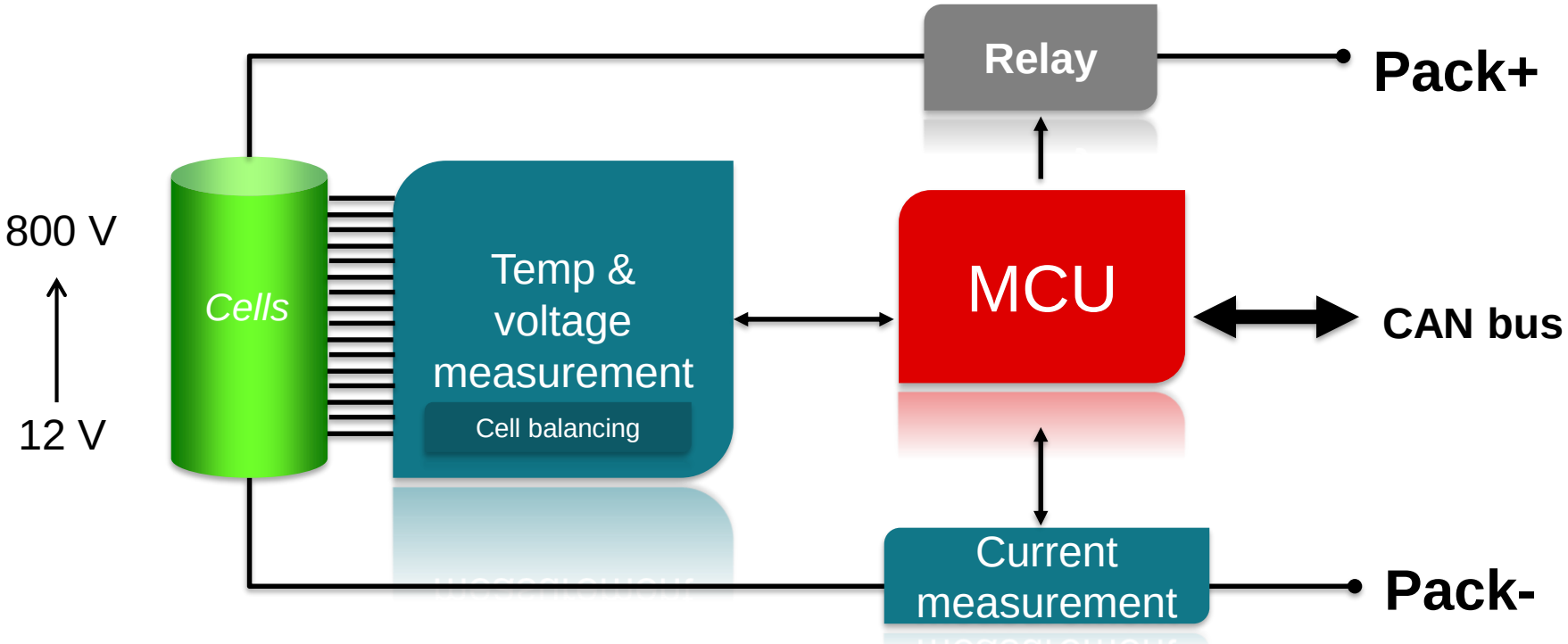
What does a TI battery monitor do for the system?



- Maintain safe operation
- Extend life time
- Fully utilize energy

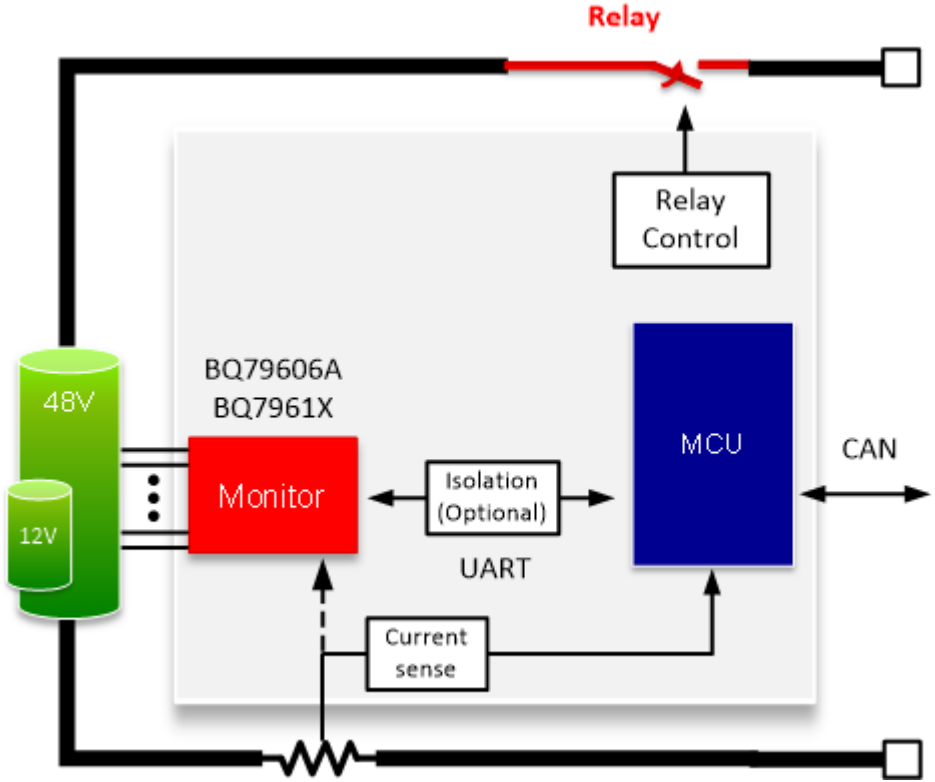
Automotive battery architectures

Automotive battery - high level architecture



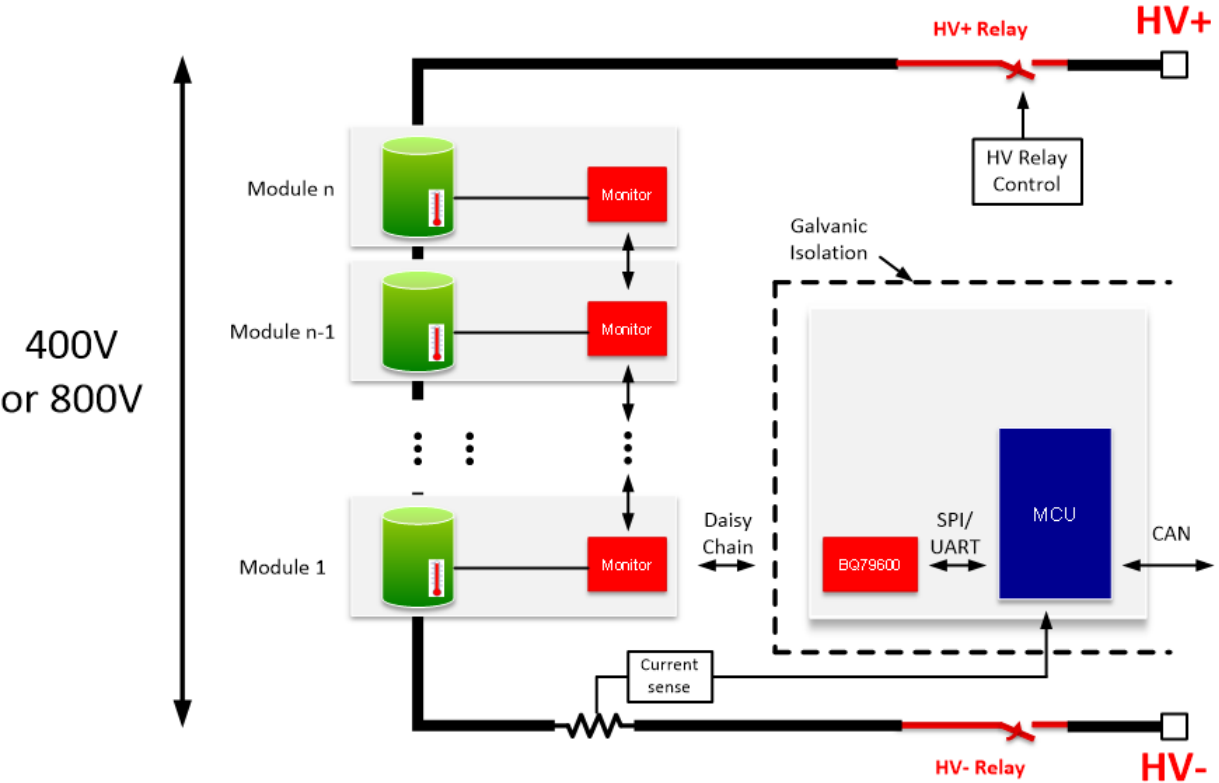
TI has scalable solutions for all: 12-V / 24-V / 48-V / 400-V / 800-V systems

Automotive battery architecture: 12 V / 48 V



- Single device solution
- Monitor IC takes temperature and each cell's voltage
- 48-V system may need isolation, depends on OEM requirement
- Passive balance

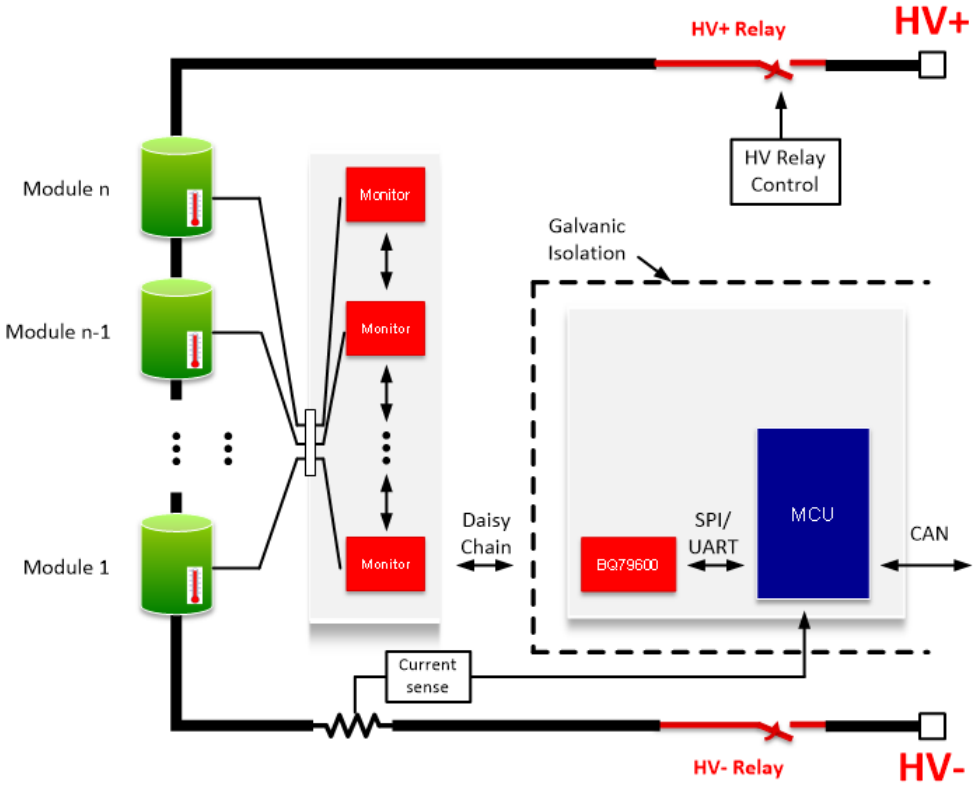
Automotive battery architecture: 400 V / 800 V



Distributed

- Each module can be 3 – 20+ battery cells in series
- Each monitor IC on its own PCB
- Each monitor IC is connected by daisy chain cable
- Check out BQ79606A, BQ79616

Automotive battery architecture: 400 V / 800 V



Centralized

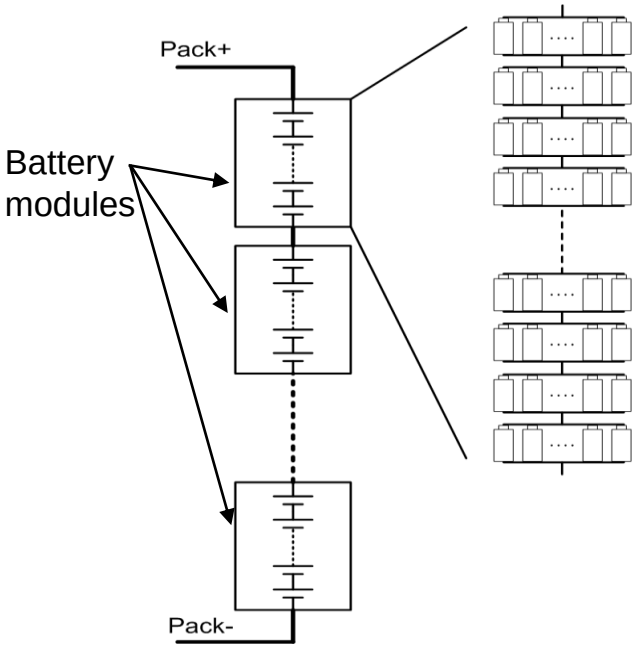
- All monitor ICs are on the same PCB
- Each device is isolated by capacitors

Hybrid

- Mix of distributed and centralized
- Example of 12S board

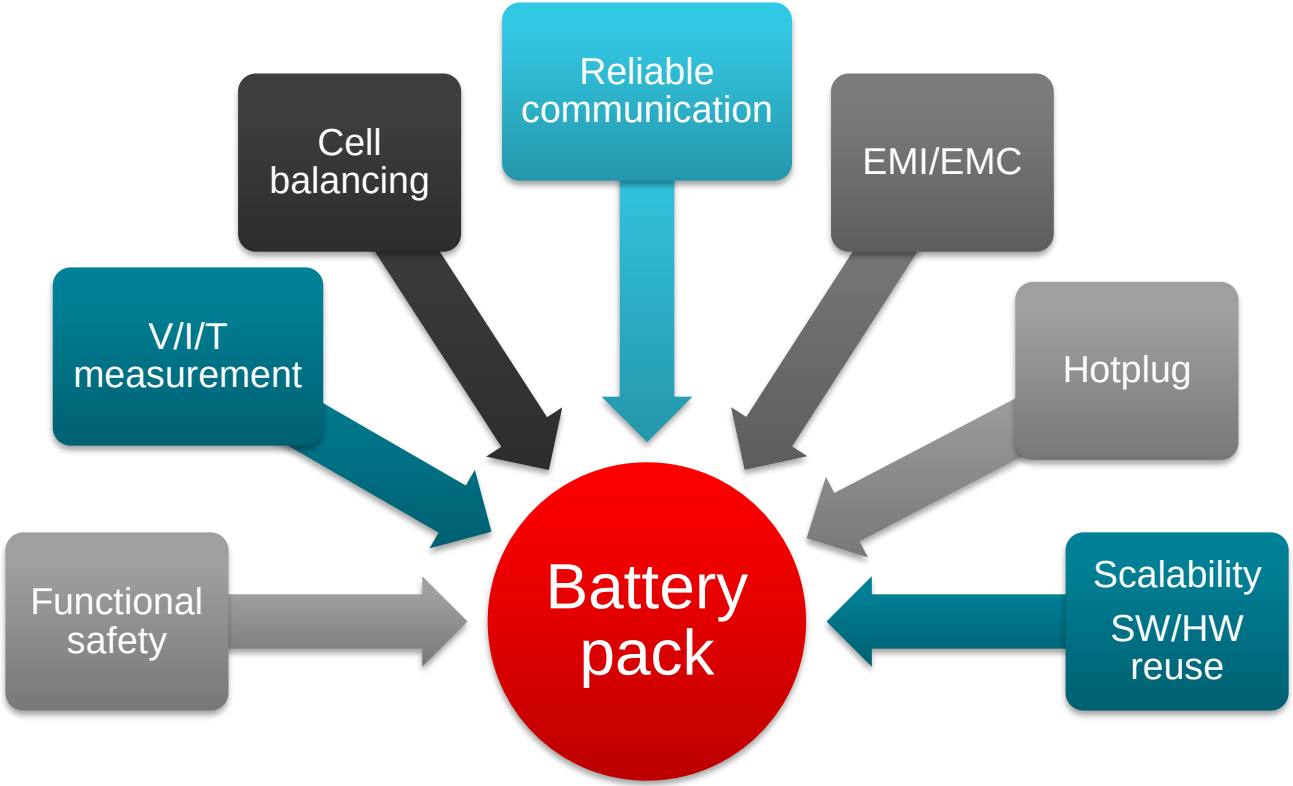
High cell count design challenges

- Very high current (100s of ampere)
- Harsh noise environment (accuracy, communication)
- Wide temp range -40 – 125 ºC
- Physically larger battery pack
  - Worse cell imbalance/aging due to large temperature gradient
  - More difficult to connect cells in order
  - Cell connections more fragile (likely to break)
  - Harness routing
- Thermal management
- Mechanical design
- Functional safety requirements in automotive



System level care-abouts

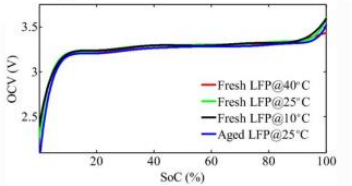
Major system level care-abouts

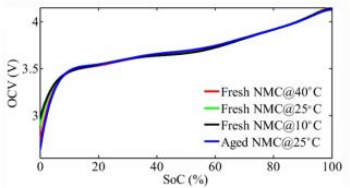


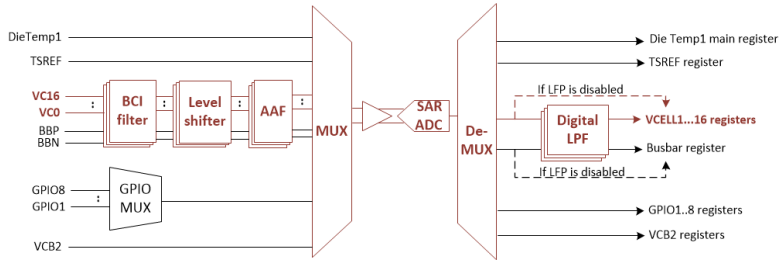
Cell voltage measurements

Why? To improve lifetime and maximize full charge efficiency of the pack. Especially for LFP batteries where there is an extremely flat discharge profile.

– Flat discharge profile makes it difficult to precisely track SOC%







- Built-in front end filter for each cell voltage input to reduce high frequency noise before ADC conversion.
- Dedicated Bulk Current Injection (BCI) filter to ensure measurement accuracy even in presence of common mode noise such as from the AC motor or inverter.
- Built-in post ADC low pass filter for each cell voltage input
  - Reduce system noise and improve cell voltage integrity before reporting to MCU
  - Post ADC process: provide filtered data without the need to take longer ADC conversion time
- Fast cell voltage measurement. All 16 cells measurements in 128 us

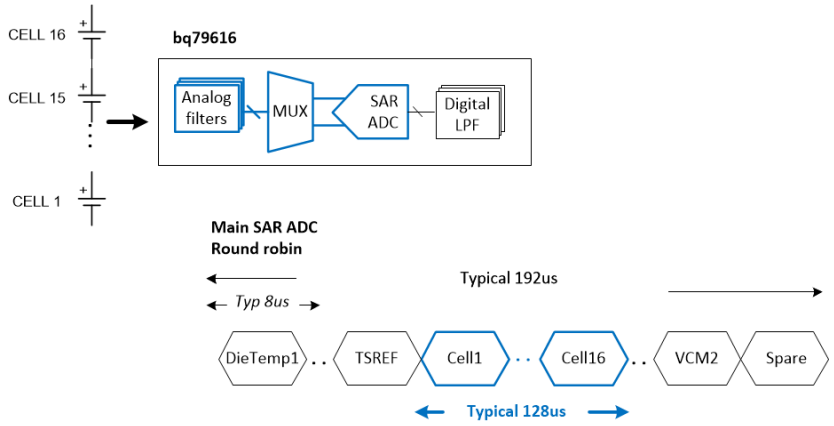
Source: Chinese Journal of Mechanical Engineering

Synchronize cell voltage measurements

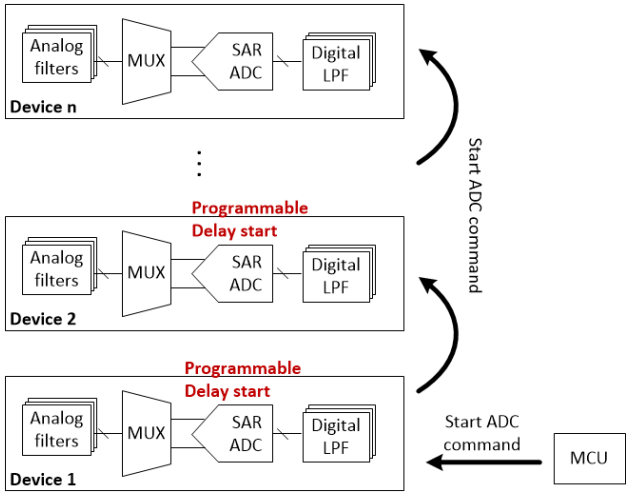
Why? To improve state-of-charge (SoC) and state-of-health (SoH) calculation/estimations.

In single device:

Minimal cell measurement slew delta



In daisy chain: Align ADC start time

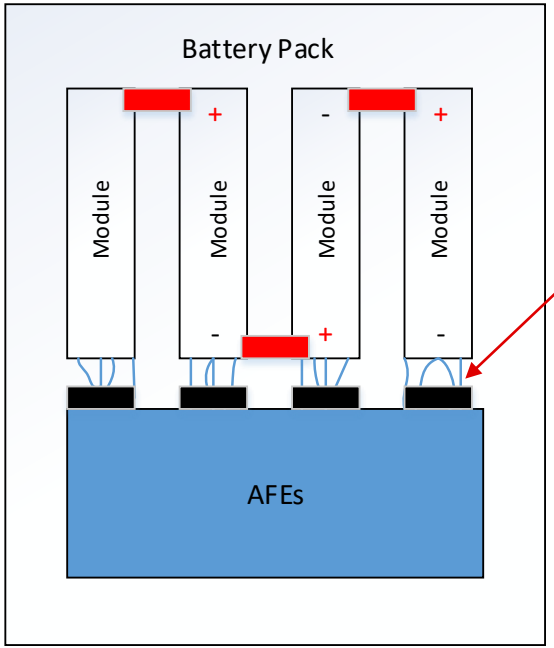


Only 120-us voltage measurement delta among the entire battery pack

Cell voltage filtering and hotplug

Why? To improve efficiency of the pack and hotplug robustness, with minimal external BOM cost

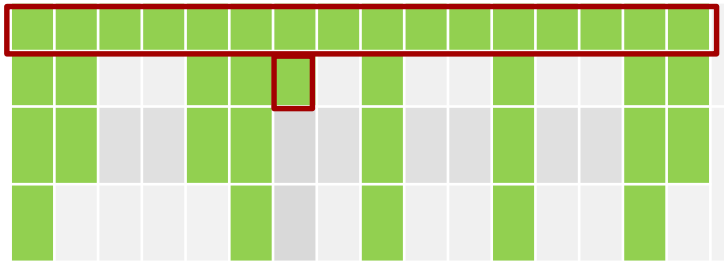
- Highly accurate monitoring
- Support random battery cell/module connections during hotplug events
- BQ7961x can accomplish w/ only simple different RC filters
  - Low voltage & <1-uF cap (16-V rated cap)
  - No diode clamp
  - No single ended high voltage cap
  - No additional cell-side differential cap



Cell balancing control

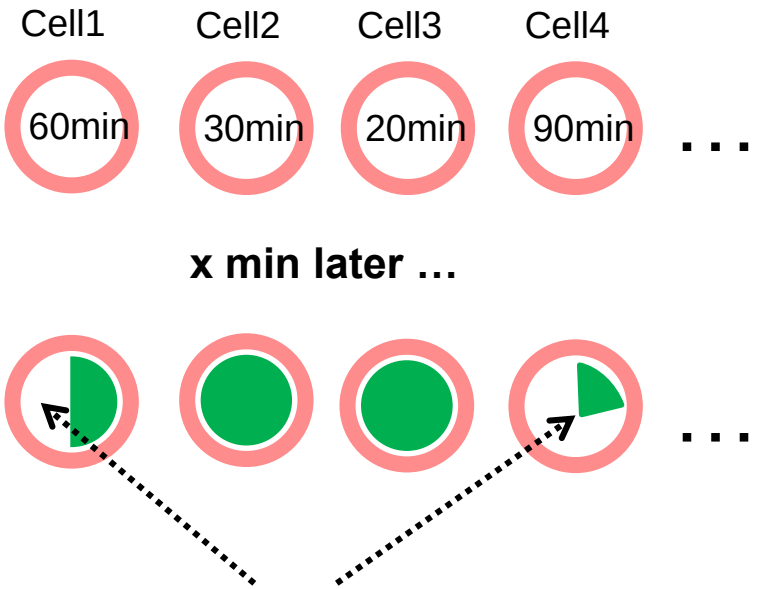
Why? To improve efficiency and lifetime of the pack, it is important to keep the battery cell voltages consistent

	Auto CB control	Manual CB control
Control	Always duty cycle between odd and even	Only turn on the channels that are enabled
Stop conditions	Timers (up to 10 hr), AND cell voltage threshold	Timers (up to 10 hr), AND cell voltage threshold
Thermal pause	Yes	Yes

CB1	CB2	CB3	CB4	CB5	CB6	CB7	CB8	CB9	CB10	CB11	CB12	CB13	CB14	CB15	CB16	Valid or invalid setting	Manual CB control
																Invalid setting	Total enabled channels >, OR > 2 consecutive channels are enabled
																Valid	Ok, device turns on the enabled channels

- **Auto CB control** can support all the configuration list above

CB remaining timers



- Each cell can set with a different balancing time
- CB thermal pause function
  - Good for hardware thermal control
  - But system may lose track of the total balancing time for SOC calculation
- CB remaining timers
  - Keep track of the remaining balancing time on each cell
  - MCU can read this information anytime (only valid if CB is running)

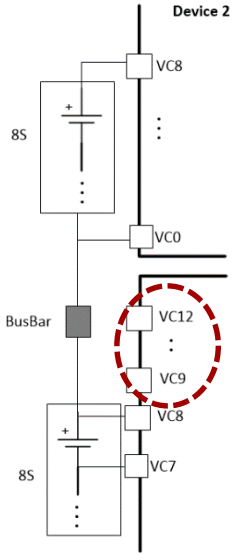
MCU can read out the remaining balancing time

Better balancing time tracking, better capacity estimation

Small module size and bus bar

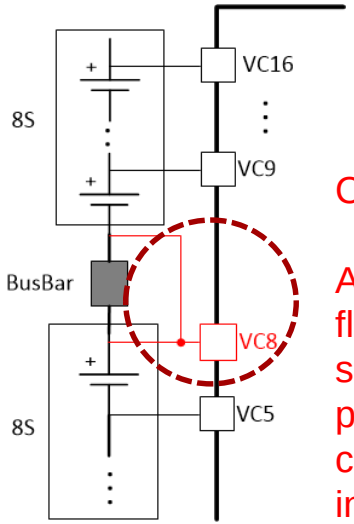
Why? Varying cell module sizes drive the need for flexible bus bar location measurements between modules

- It's not necessary to "measure" the bus bar but with small module size, the solution is potentially "wasting channels"
- E.g., 8S module connects to 12S device



Wasted channels

- To utilize all possible channels, bus bar needs to be connected to sense input; even measurement on bus bar itself is not required

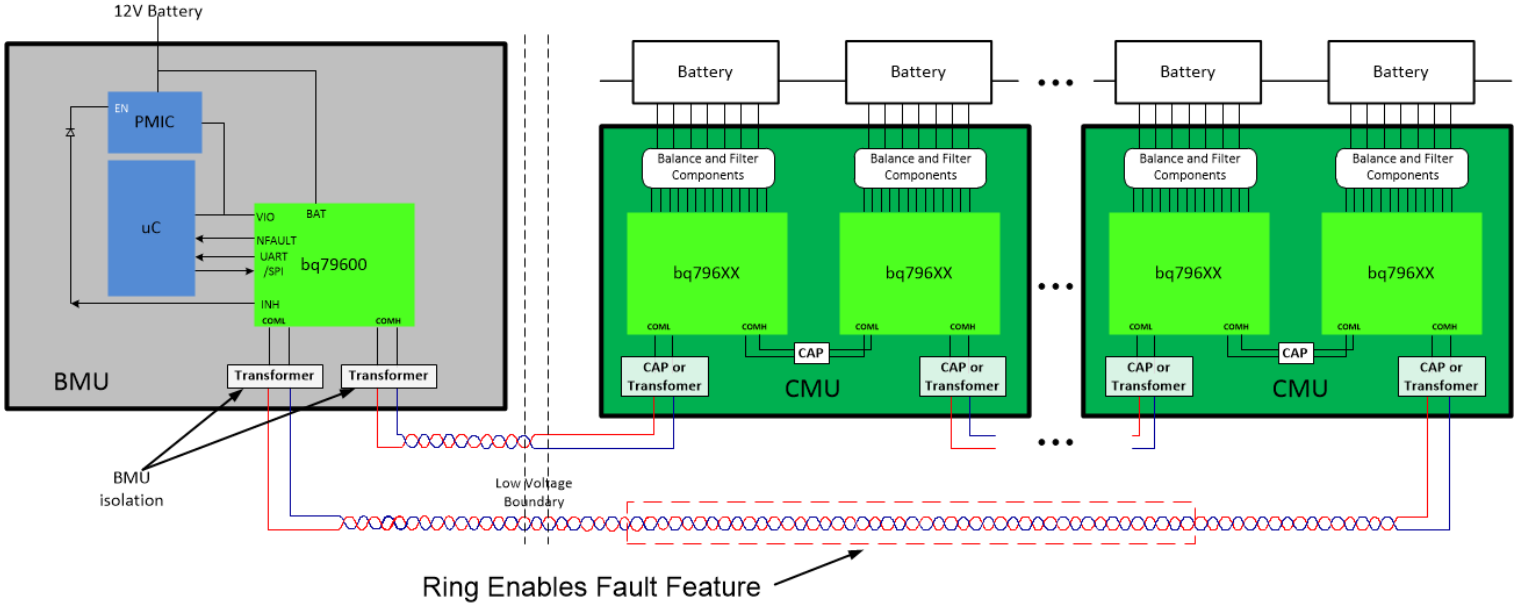


Cannot have this connection!

Although most current should flow through the bus bar, a small current may still be present through the connection in red, potentially injecting to the IC pin

Scalable, stackable communications

Why? Using an optimized, unique daisy chain communication protocol, the battery monitors can be stacked up to support various battery pack sizes



Reference schematic

Communication isolation

High flexibility on isolation component selection:

– **Cap-only isolation:**

- Using high voltage series caps to couple isolation
- Cheapest solution, but currently only recommend on same PCB due to EMI/robustness concerns. Add a series choke when connecting across PCBs

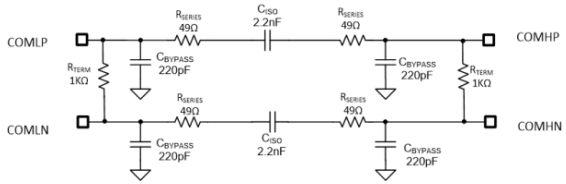
– **Cap-choke isolation:**

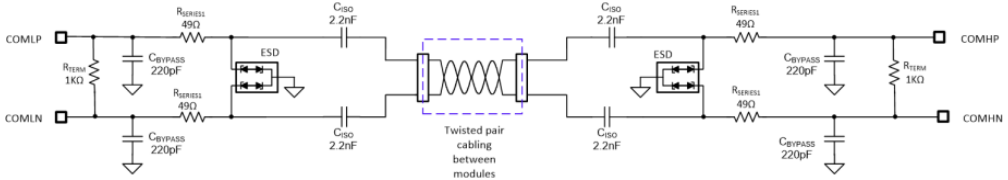
- Same as cap-only above but adding a high inductance common mode choke in series with the capacitors
- Second to XFMR in robustness

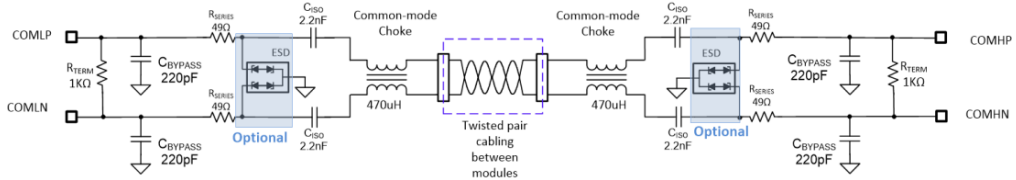
– **Transformer isolation:**

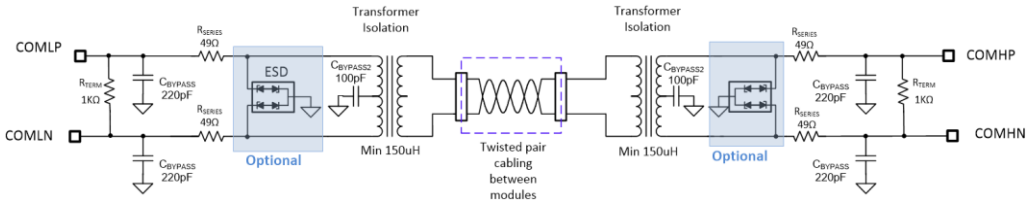
- Most robust but also most costly
- Challenge of varying part #s which inductance and other characteristics can impact signal quality when mixed with other types.

Same PCB can use cap -only:

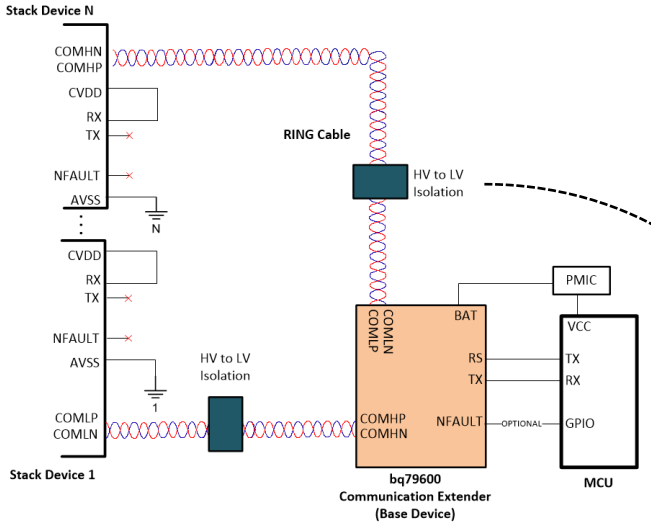






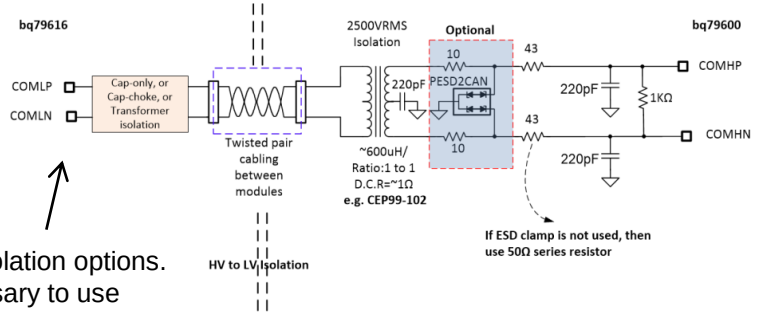


Reference schematic
Communication extender & optional RING



BQ79600 supports either SPI or UART communication to MCU

- Work with BQ79600 communication extender
- Use transformer isolation on BQ79600 side, but flexible isolation choice on the cell-module side
- Support RING connection with a single BQ79600



Flexible isolation options. Not necessary to use transformer

Why is EMC important?

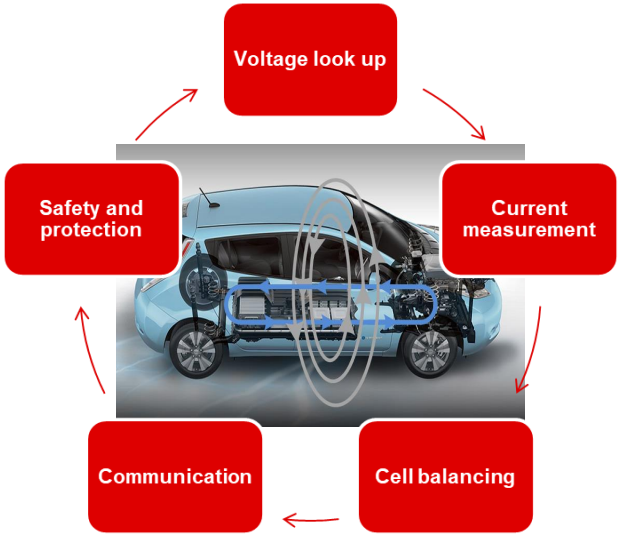
ABS Failure

- Early Antilock Braking Systems (ABS) systems on both aircraft and automobiles were susceptible to electromagnetic interference.
- Accidents occurred when the brakes functioned improperly because EMI disrupted the ABS control system.

Blackhawk Crashes

- Between 1981 and 1987, five *Blackhawk* army helicopters crashed and killed or injured all on board when flew too near radio broadcast transmitters.
- Cause: insufficient immunity of flight (on-board) control electronic sub-system against high intensity radiated fields (HIRF) that produced uncommanded movements while flying past radio broadcast towers. (Source: NASA Reference Publication 1374 July 1995)

Why is EMC important?

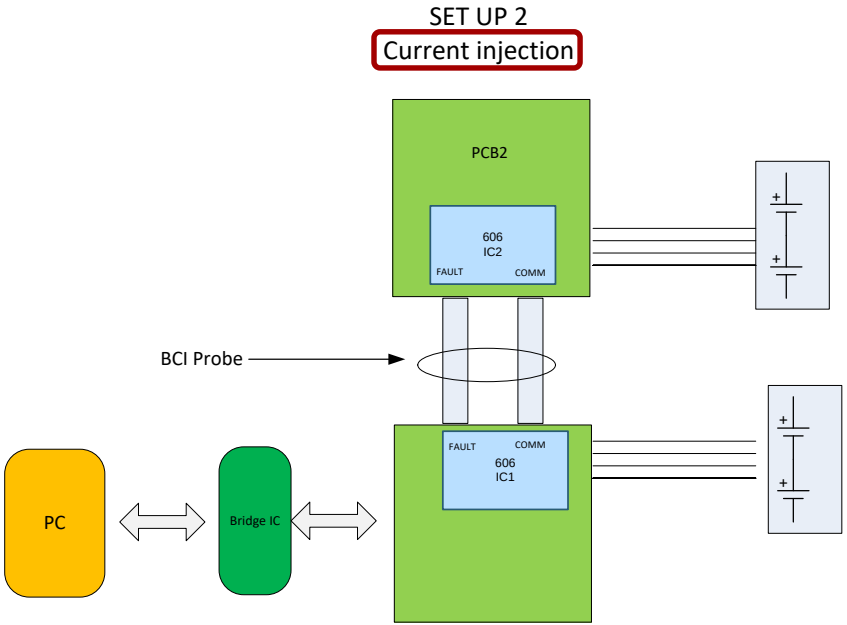


- Maintain safe operation in harsh conditions
- Ensure robust communications to the pack at all times
- Minimize impact of noise on measurements

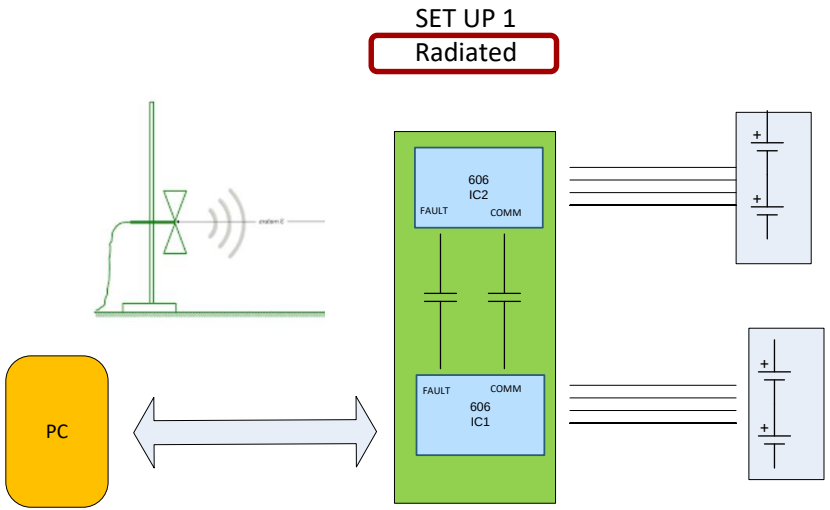
Automotive OEMs require robust and thorough validation testing to ensure the system is safe and reliable amidst the harshest of noisy conditions and weather

BCI and immunity test setup

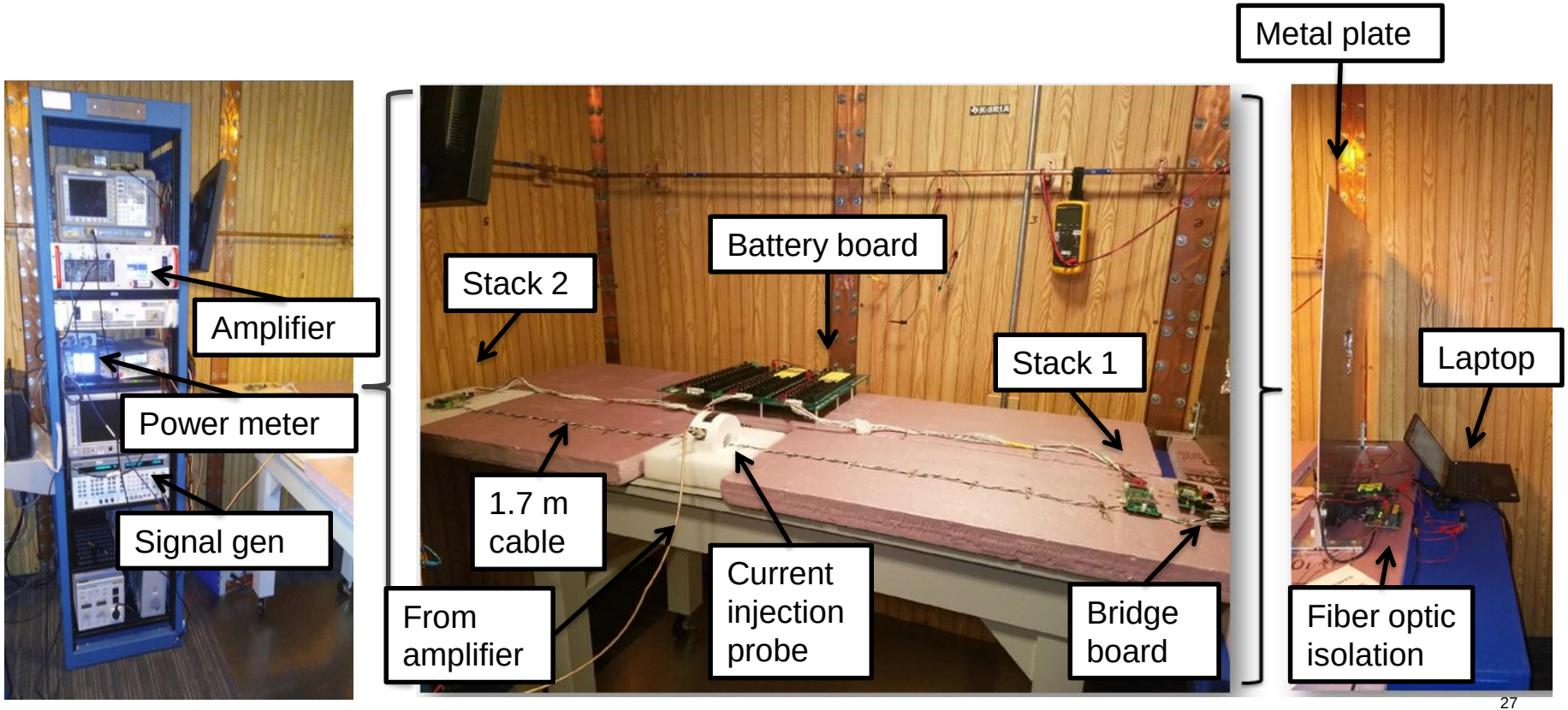
Communication cables between ICs in different PCBs



Communication traces between ICs in the same PCB



Bulk current injection (BCI) setup



Designing with TI battery monitors

BQ79616 and family – monitoring solutions

Target application	Cell module monitoring	Cell module monitoring w/ current sense	48-V system	Battery junction box
Cell measurement	✓	✓	✓	Divided down HV measurement
Temperature measurement	✓	✓	✓	✓
Current measurement	✗	✓	✓	✓
Daisy chain	✓	✓	✗	✓
Pin package	64-HTQFP	64-HTQFP	64-HTQFP	64-HTQFP

BQ796XX devices enable ASIL-D safety systems, and tested under harsh EMC/hotplug conditions

BQ79631: U/I sensor for BJB/BDU

Target features

- **Voltage measurements**
  - **Up to 16 channels differential ADC inputs completed in 192us**
  - Integrated front end RC filers & post ADC low pass filters
  - **Target 1% accuracy.**
- **Current measurement**
  - **Low side shunt** current sense with 24-bit sigma-delta ADC
  - Input range = +/-**100 mV?** with target accuracy **0.3%**
  - **Low offset of +/- 1.5 uV**
- **Up to 8 GPIOs as (GPIO / ADC input / Temp sense / SPI master)**

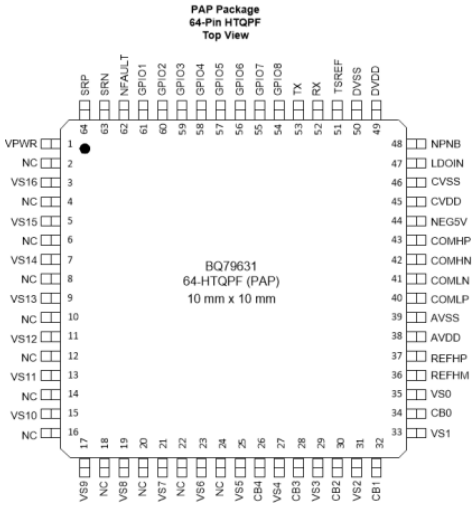
Value proposition

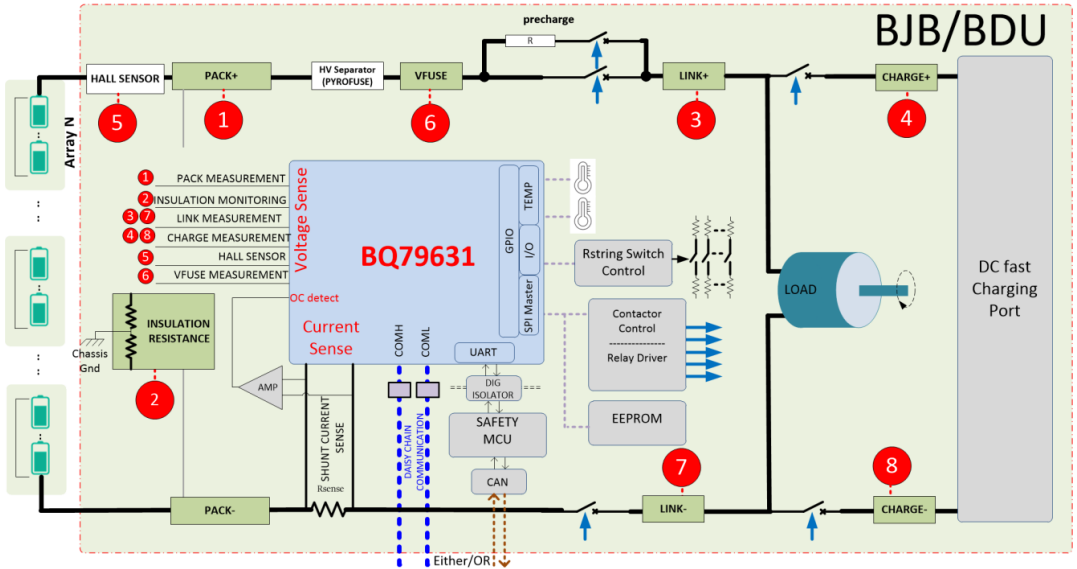
Simplifies BJB/BDU system by eliminating safety MCU, CAN transceivers and multi-wire interface

Synchronized current & voltage measurements; syncs with other cell and UI monitors in BQ796xx family

UART or daisy chain communication.

Integrated current sensing high voltage and insulation resistance sensing





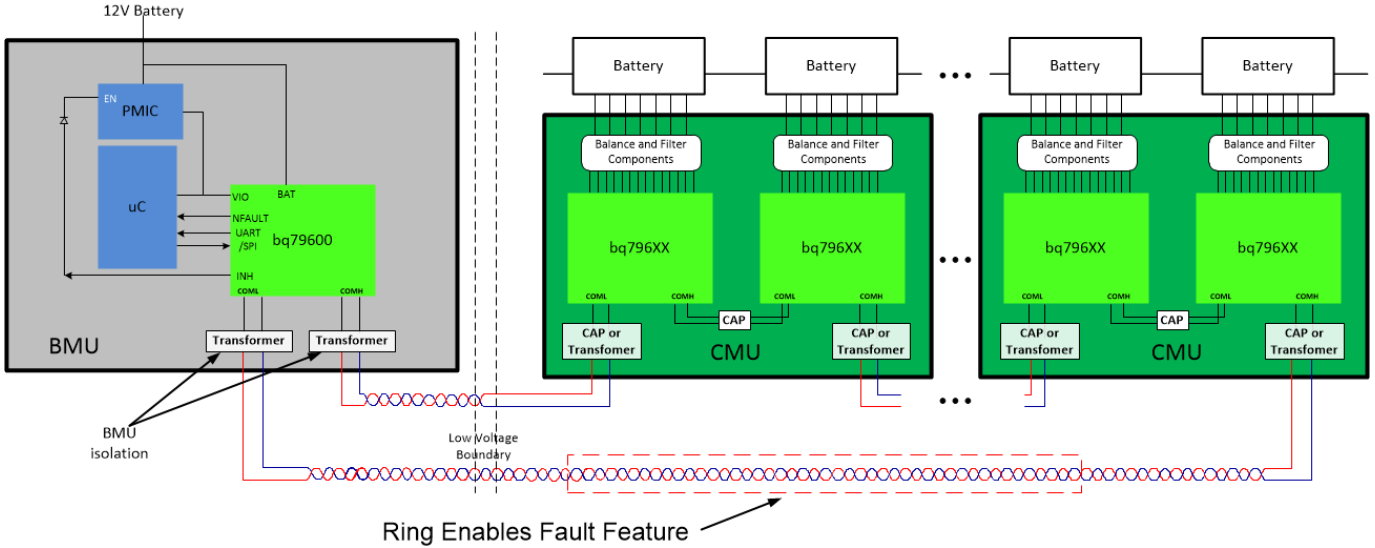
BQ79600-Q1 UART/SPI to daisy chain bridge IC

Features

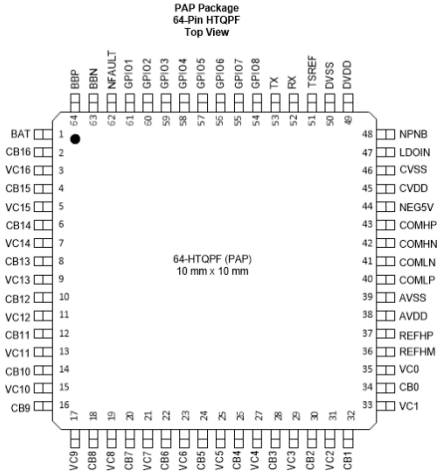
- **ASIL D capable at BMS system level**
- **Support ring architecture with only 1 bridge device**
- **Automatically wakes up BMS system when fault is detected**
- **Ambient temperature range: –40 °C to +125 °C**
- **1-Mbps UART/ 2-Mbps SPI host interface supporting 3.3/5-V logic**
- **Powered by 5-V supply or 12-V battery; IDDQ shutdown < 9 µA**
- **Support BQ7961x-Q1 and BQ79606-Q1 (w/o fault daisy chain)**

Benefits

- **System BOM cost saving with ring architecture**
- **Total solution is ASIL D capable with BQ battery monitoring IC**
- **Reduce workload of MCU, save power on 12-V battery**
  - BMU can be “offline” even CMU does activities like CB
  - BMS automatically wakes up if fault is detected
- **Robust daisy chain interface supporting transformer (inter board) or caps (same board)**



What is BQ79616-Q1?

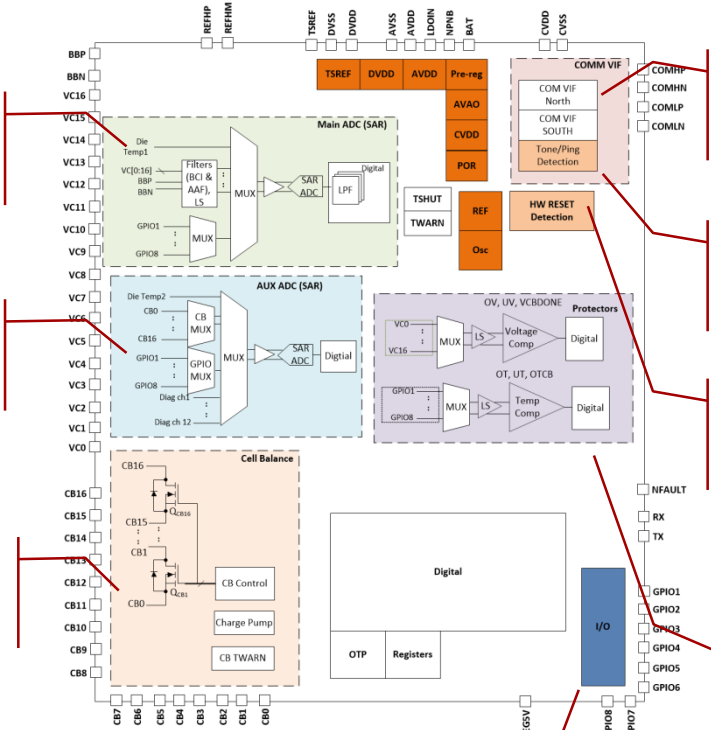


- **16S stackable battery monitor**
- **Same package/pinout on 12S/14S variants**
- **Support min of 6S (9 V) operation**

Main ADC
Measure V_{CELL}, bus bar (if used) and temperatures

AUX ADC
Redundancy for main measurement. Mainly use for diagnostic. Also measure V_{BAT}

Cell balancing
Internal CB w/ typ 2.5 Ω $R_{DS(ON)}$. Support I_{CB} 240 mA w/ thermal management



Vertical interface
Bi-directional daisy chain communication requires 1 twisted cable pair. Also supports RING communication

Tone/ping detection
Handle critical power transition signal (e.g., WAKE, SHUTDOWN etc.). Implemented in pure analog. Operates in all power modes

HW RESET
Independent HW reset detection block implemented in pure analog. Operates in all power modes

Integrated HW protectors
HW comparators, independent of ADC operation, for OV, UV, OT, UT detection

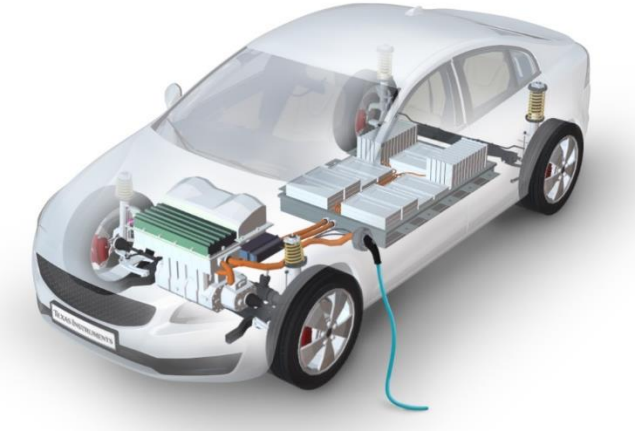
Can operate in SLEEP mode. These are also used for CB voltage/thermal detection

GPIOs
8 GPIOs: can be use for NTC thermistor or auxiliary voltage input measurement. Can also be used for SPI master

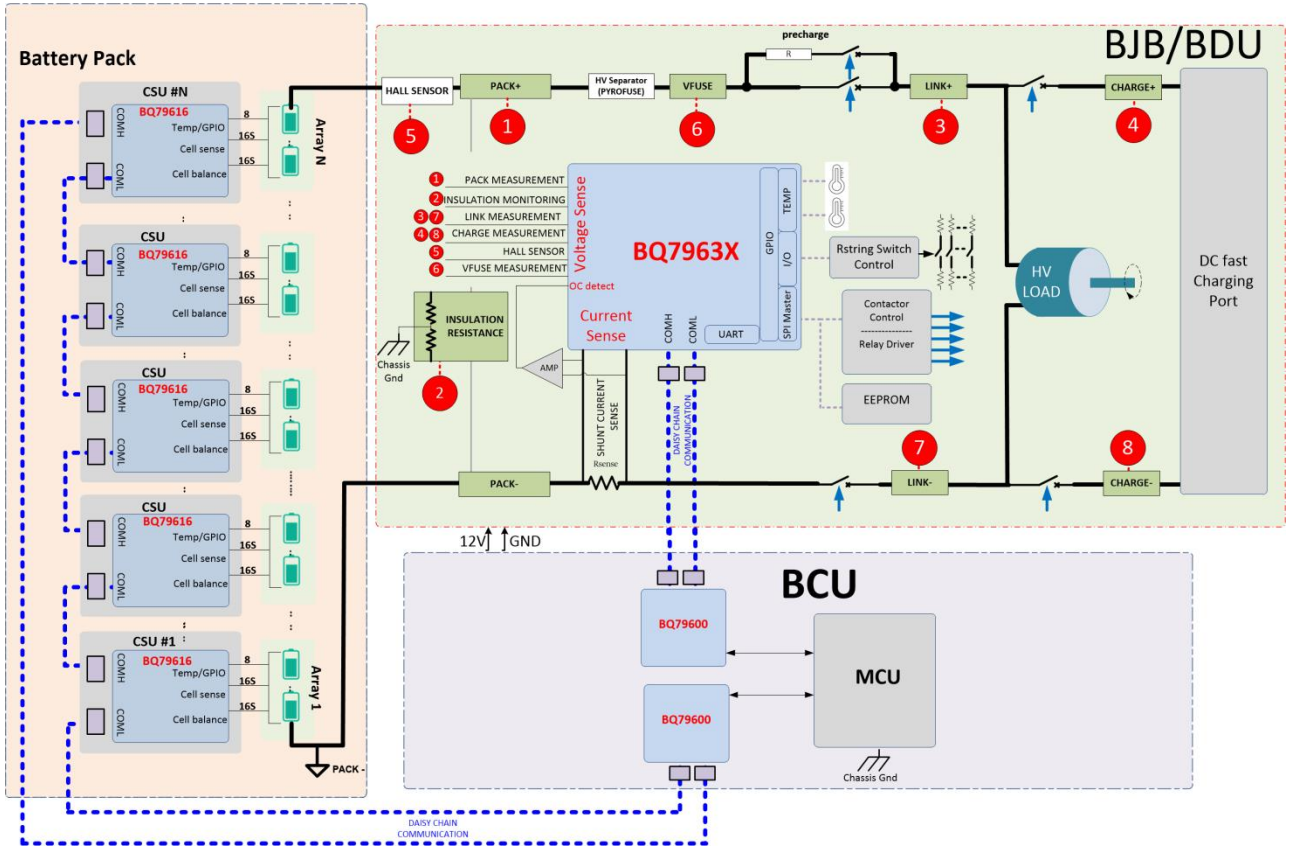
BQ79612/614 shares the same pin-package and same block diagrams

System flexibility

- Support varying module sizes
- Bus bar support
- Daisy chainable
- Software compatible
- Solutions for voltage/current/resistance monitoring



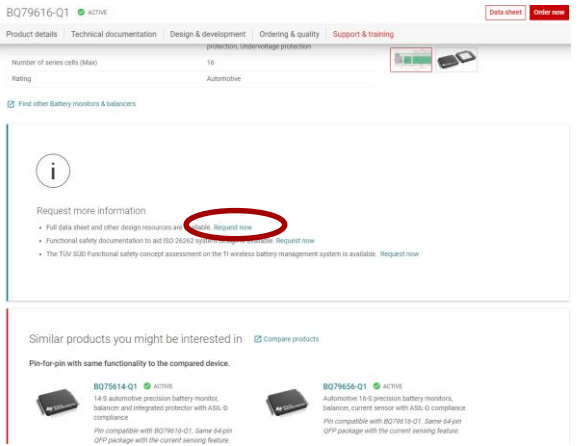
Example system block diagram



Benefits

- Eliminates safety MCU and CAN transceivers in BJB/BDU
- Eliminates numerous connections in BCU and BJB interface ,reduces board size and increases system flexibility.
- Simplifies hardware and MCU software development.
- Synchronized V/I measurements
- Compatible with daisy chain of CSU monitors.

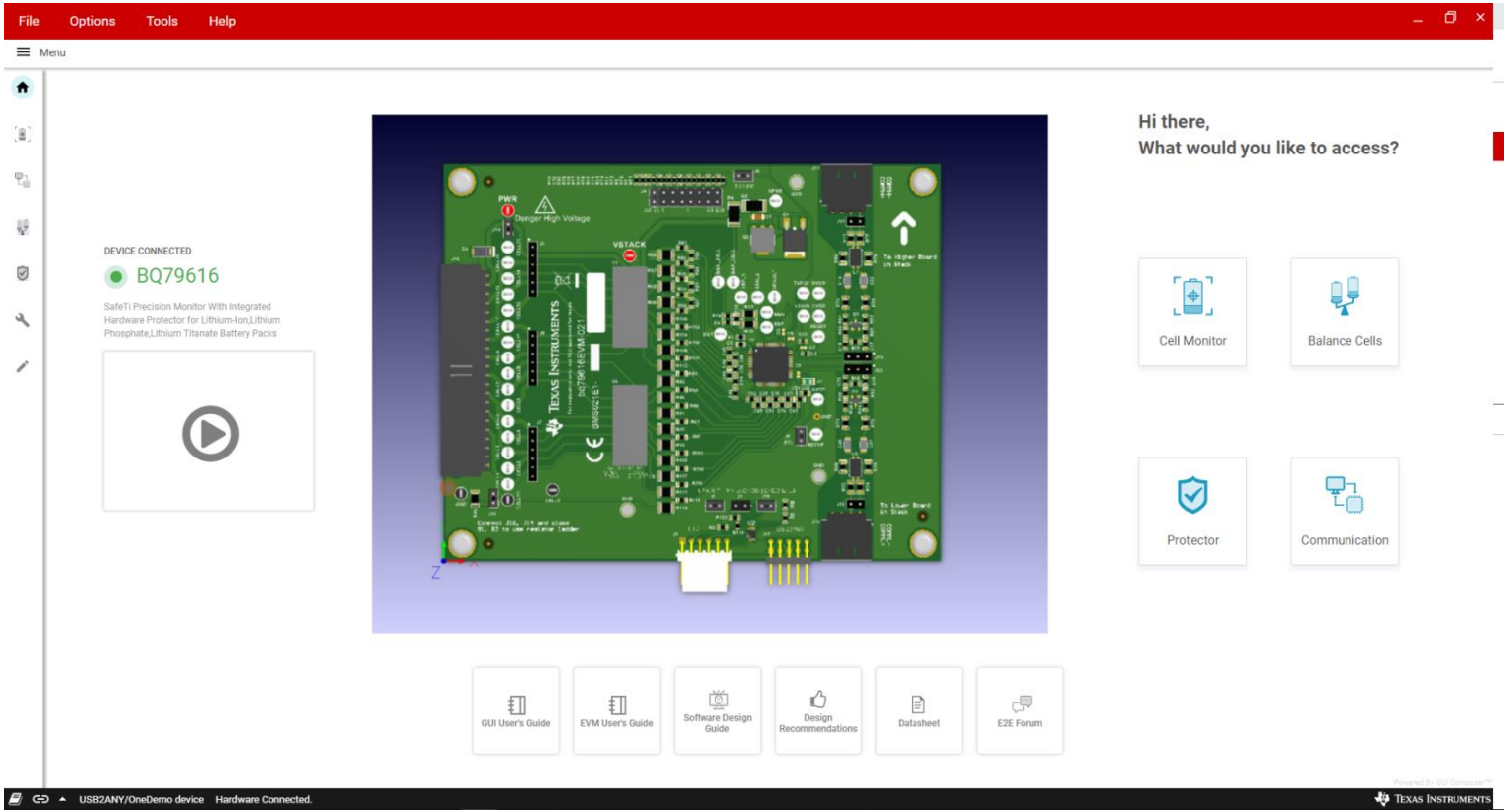
How to get started?



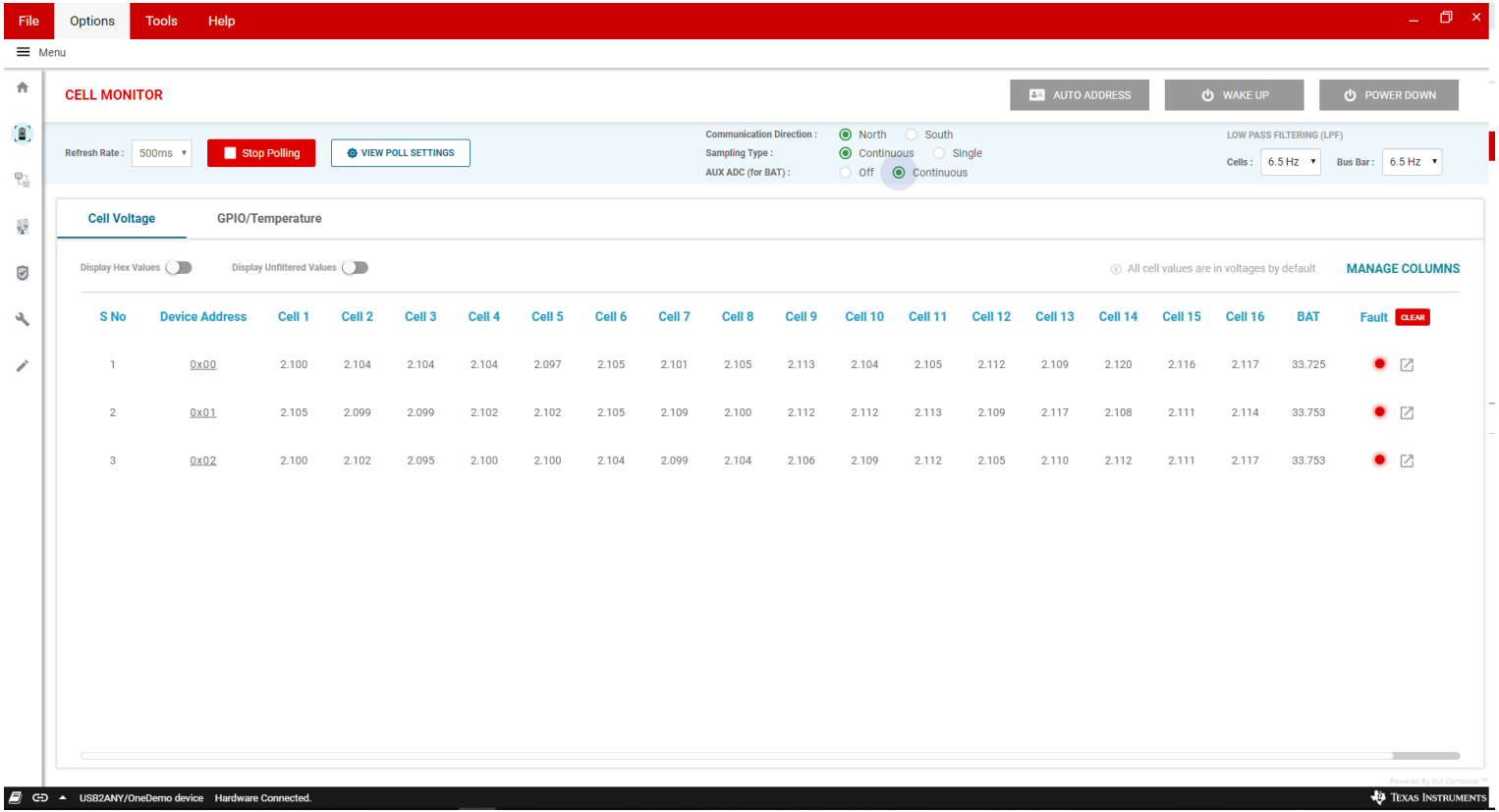
1) Determine system requirements:
   - Pack voltage, safety, protection, peripherals, mechanical structure/layout, etc.
2) Review and digest TI collateral:
   - Apply for mySecureSW access shown on the right here:
   - Review datasheet and design recommendations application notes
   - Evaluate our EVM schematic/layout once available
   - Download GUI, review example code
3) Evaluate EVM hardware and experiment with TI GUI/example code
4) Design custom hardware/software to implement complete system

Contact TI engineers via https://e2e.ti.com/ for top level support

BQ7961X demo – homepage



BQ7961X demo – cell monitor Page



BQ7961X demo – cell monitor board details

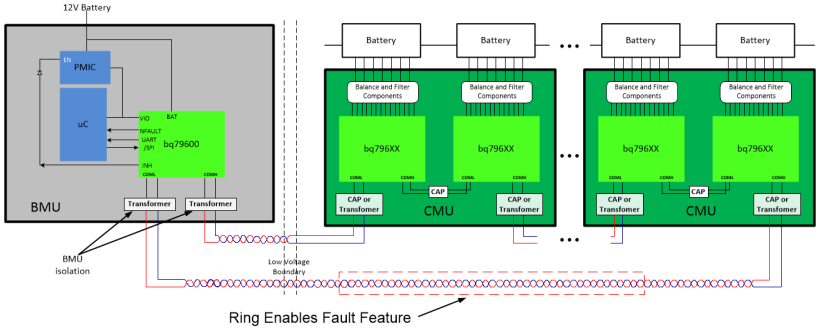
BQ7961X MCU development platforms

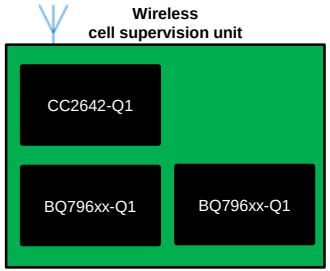
- TMS570 LaunchPad
- Sitara MCU AM263x:
  - TMDSCNCD263 evaluation board | TI.com
  - LP-AM263 evaluation board | TI.com
  - AM263x software
- Develop in C using Code Composer Studio: https://www.ti.com/tool/CCSTUDIO
- TI example code in mySecureSW
- Enables developers to connect the launchpad UART lines directly to our EVM and begin collecting data or easily modify code sequences
- Software design reference guide
  - Explains communication protocols and example commands to program

Looking to the future

Industry Trends 2020

- Wired & wireless systems
- Cell-to-chassis architectures
- Cell chemistries (LFP/NMC)
- Highly accurate monitoring
- Reduce software overhead/complexity
- Scalability and flexibility
- Efficient power usage and BOM
- Reliability and robustness





-> Enable HEV/EV longer range, quicker charge, safer and more affordable

Q&A

Resources

Industry Trends 2020

- Visit TI.com:
  - What we do
  - TI at-a-glance
  - Focus on enabling automotive HEV/EV

- Visit the BQ79616-Q1 product folder for white papers, app notes, and datasheets to get started evaluating!
- mySecure Software link for example code and other collateral
- Code Composer Studio: https://www.ti.com/tool/CCSTUDIO
- Contact TI engineers via https://e2e.ti.com/ for top level technical support

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