TI *Live!* INDIA AUTOMOTIVE SEMINAR

ANKUSH GUPTA

BMS SOLUTIONS FOR 48-V AND 400-V/800-V EV/HEV BATTERIES

Agenda

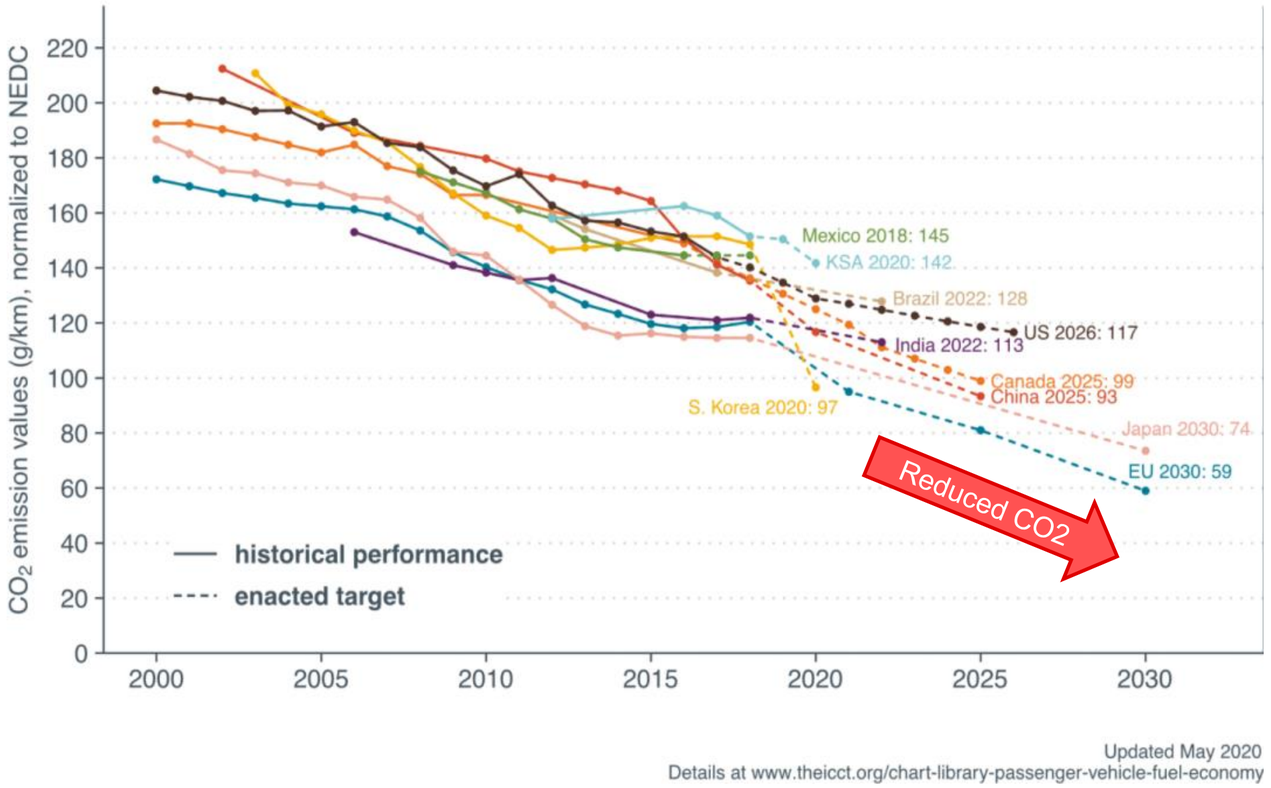
- EV/HEV industry trends
- 48V battery BMS solutions
- 400V/800V battery BMS solutions
- Summary

EV/HEV industry trends

EV/HEV industry trends

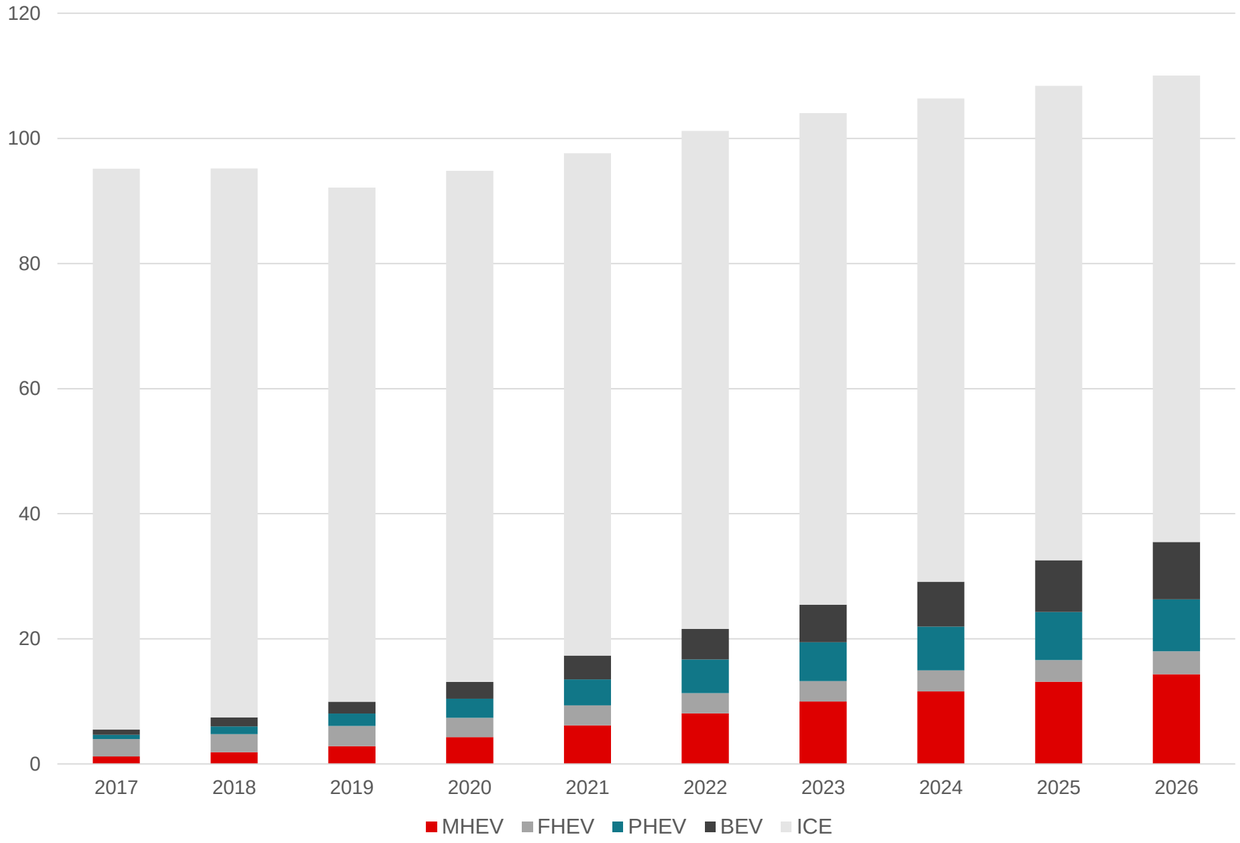
- Emission regulations around the world are driving the adoption of EVs/HEVs

Emission targets getting lower, phasing in 2020



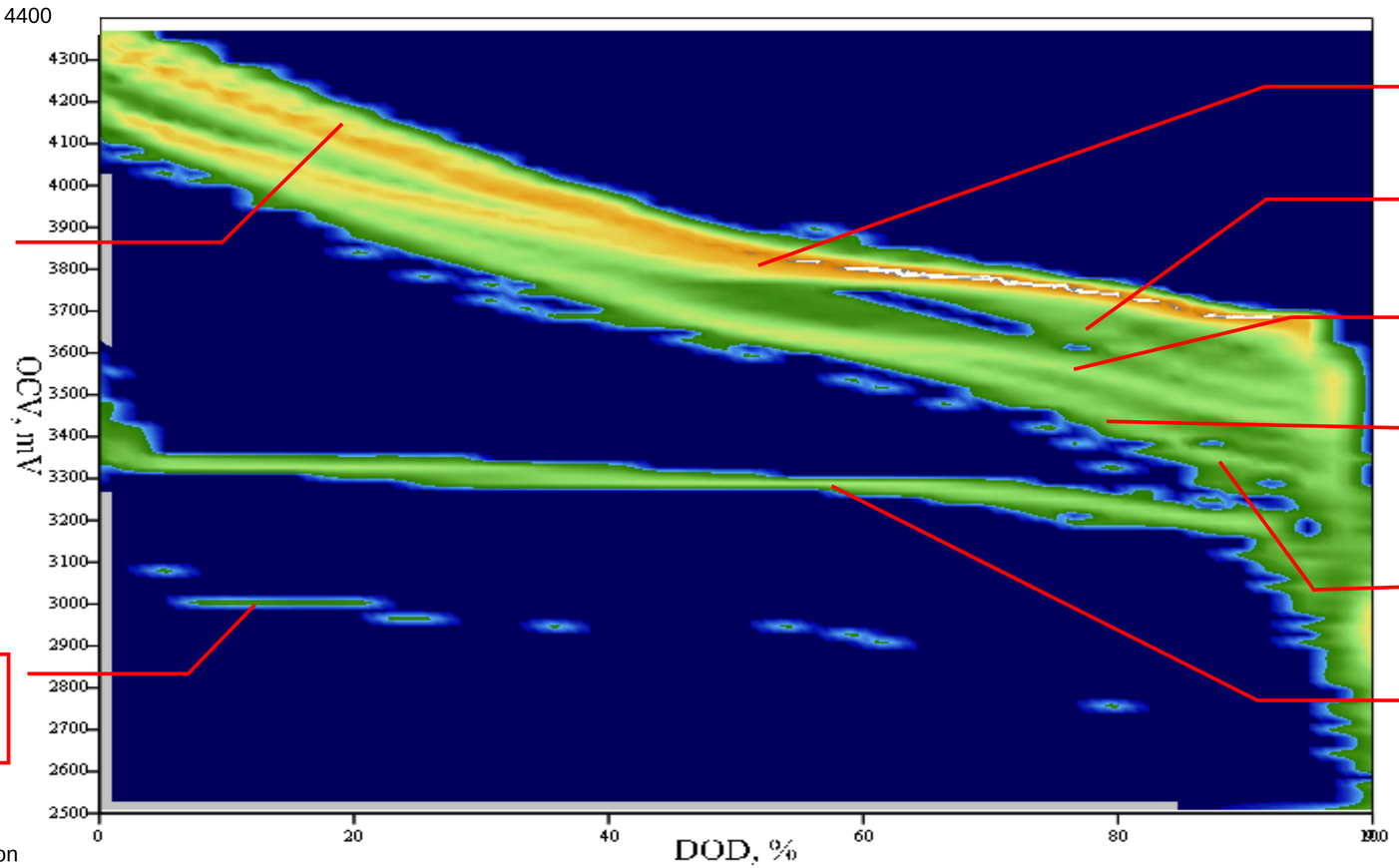
Penalty payments for excess emissions!

WW vehicle sales and projections



Source: Strategy Analytics

Various battery cell chemistries available in the market



High voltage $LiCoO_2$, manganese spinel, $LiMn_2O_4$

Lithium titanate anode

$LiCoO_2$

NMC (nickel, cobalt, manganese, 30% each)

NCA (nickel, cobalt, aluminum)

Doped $LiNiO_2$

Si-containing carbon anode (3-5 % Si)

$LiFePO_4$

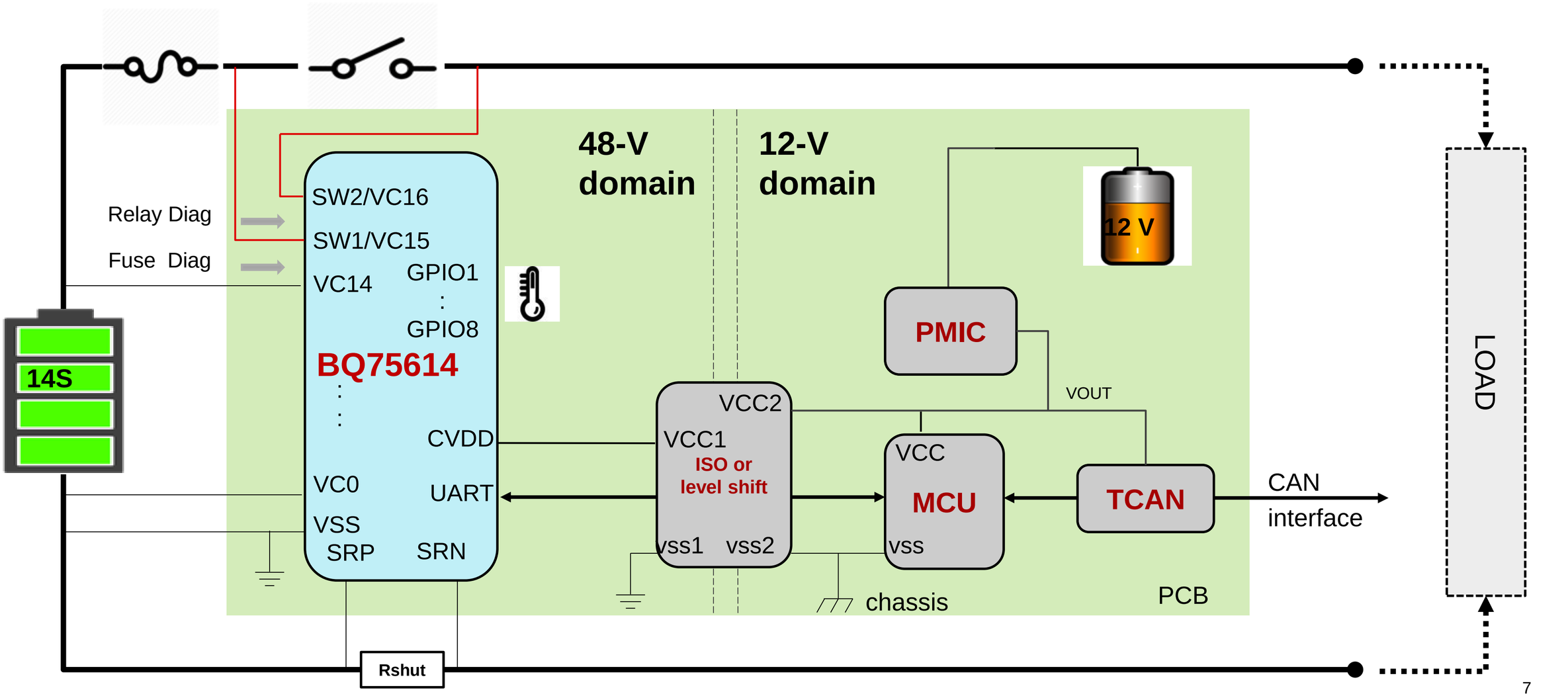
* Hotter color means more common

- Cost will limit favorability of LTO in this application due to inherent series cell counts
- NMC and LFP have most potential for mainstream success based on cost
- Higher impedance of NMC makes active cooling a basic system requirement
- LFP could be optimized to further reduce impedance and potentially reduce/eliminate the need for active cooling

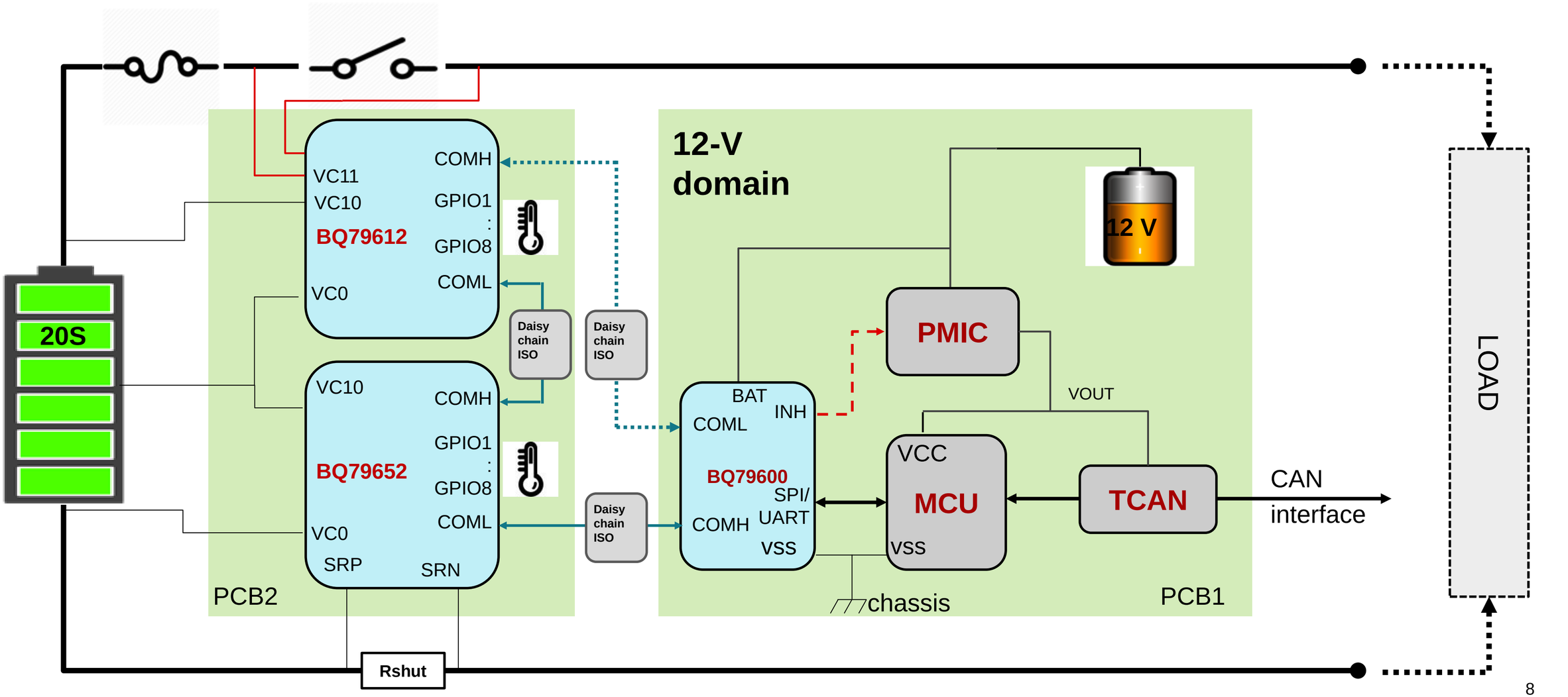
48V battery BMS solutions

48-V system architecture

Topology variation:
- Microcontroller (MCU) on 48-V side, isoCAN



48-V system architecture with lithium-titanate battery



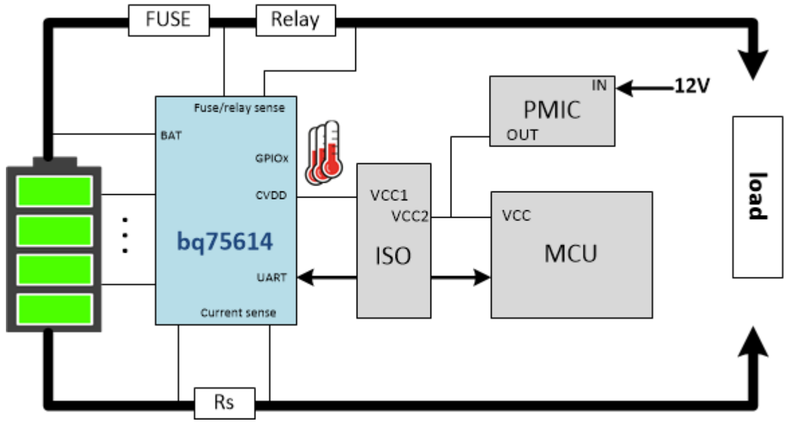
BQ75614: 48-V 14S to 16S battery monitor

Features

- **ASIL-D Voltage/temperature** measurement and **communication**
- **ASIL-D current** measurement with dedicated 16-bit sigma-delta ADC
- **Integrated current sensing:**
  - Input range = **+/-100mV** with **0.75ms to 12ms** conversion time options
  - Synchronized current & cell voltage measurements
  - Accuracy of **+/-0.3% (>300uV input); 1.5uV (<=300uV input)**
- **Integrated fuse & relay diagnostic**
- **Voltage Accuracy** +/-3.5mV over full temperature range post soldering
  - **All 14 cell voltage measurements** complete in **112us**
  - **Integrated front end RC filters** on voltage measurement path
  - **Integrated post ADC digital low pass filters** w/ as low as 6.5Hz f_{cutoff}
- **Built-in 2nd level protector** for OV/UV/OT/UT
- **Fault interrupt signal** to system MCU for quick action
- **UART communication** to system MCU
- **External load support** to power digital isolator
- **Internal cell balancing** with integrated balancing FET
  - Optional device controlled odd/even duty cycle w/out constant host system monitoring, or
  - Complete MCU controlled balancing
  - Option to **pause CB progress** at OT detection and **automatically resume** when temp drops
- **100ms FDTI mode**
- **Package: 64-pin QFP**

Benefits

- **Provide device level ASIL-D. No special SW requirement from MCU.**
  - Part of the ASIL-D family with 16S, 14S,12S monitor for HV system and 48V system
  - All devices sharing same package/pinout, functional control and register map
  - Learn one, learn all. Maximize MCU code reuse and system level fault analysis.
- **Similar time average between current and cell voltage measurements for more accurate SOC calculation**
  - **Similar timing options** on current sense conversion time and cell voltage LPF setting
  - **Integrated post ADC low pass filters** provides high integrity level of DC voltage measurement by filtering out system noise (e.g. invertor/charger/heater/motor rotation etc) for best SOC calculation
- **Built-in 2nd level protector** with user programmable OV/UV/OT/UT threshold independent of ADC measurement



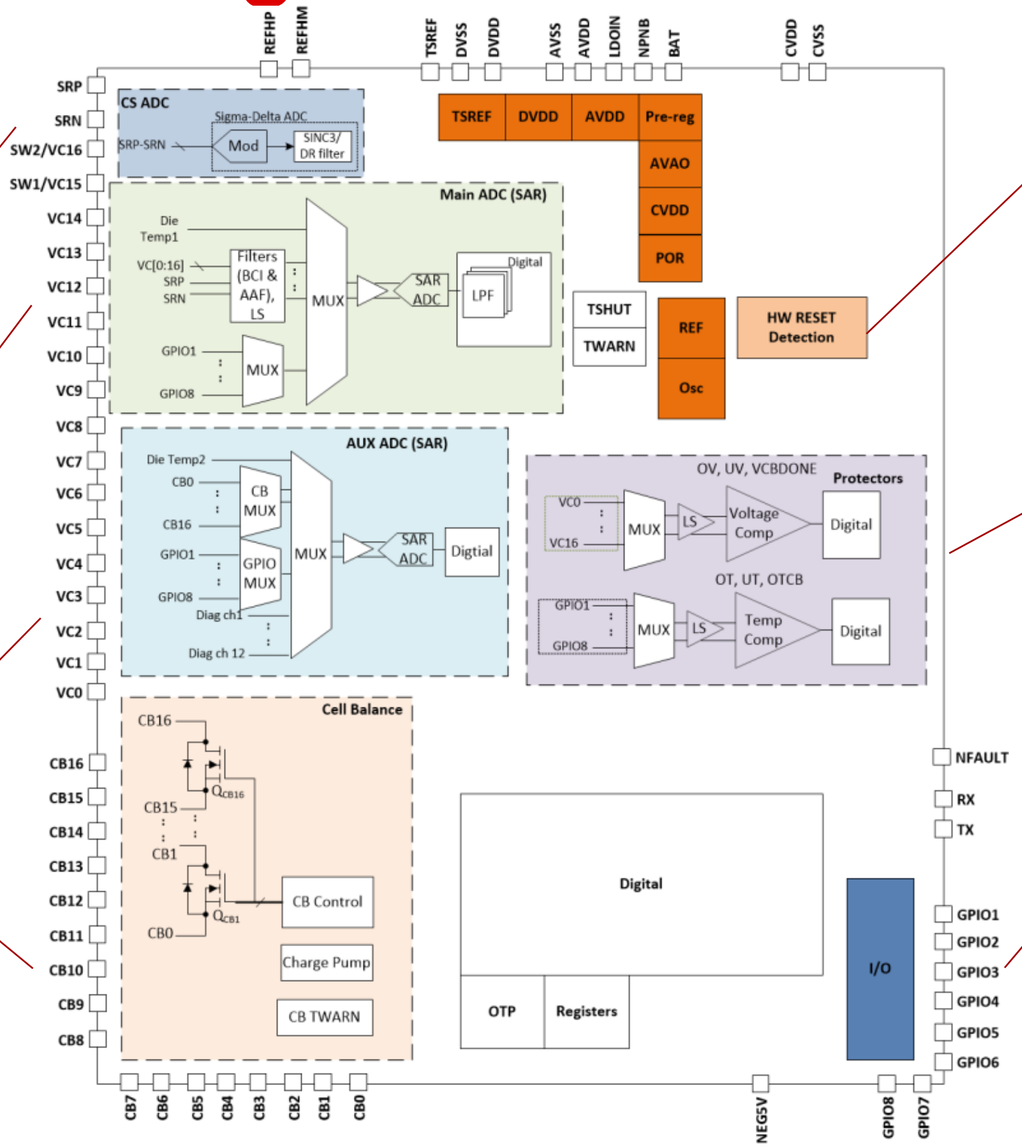
BQ75614 block diagram

Current ADC
- High accuracy
- Fast data rate
- SINC3 low pass filter

Main ADC
- Vcell measurement
- Temperature measurement

AUX ADC
- Redundant path
- Diagnostic channel
- Measure VBAT etc.

Cell balancing
- 300-mA balancing @ 60 C
- Dynamic thermal management

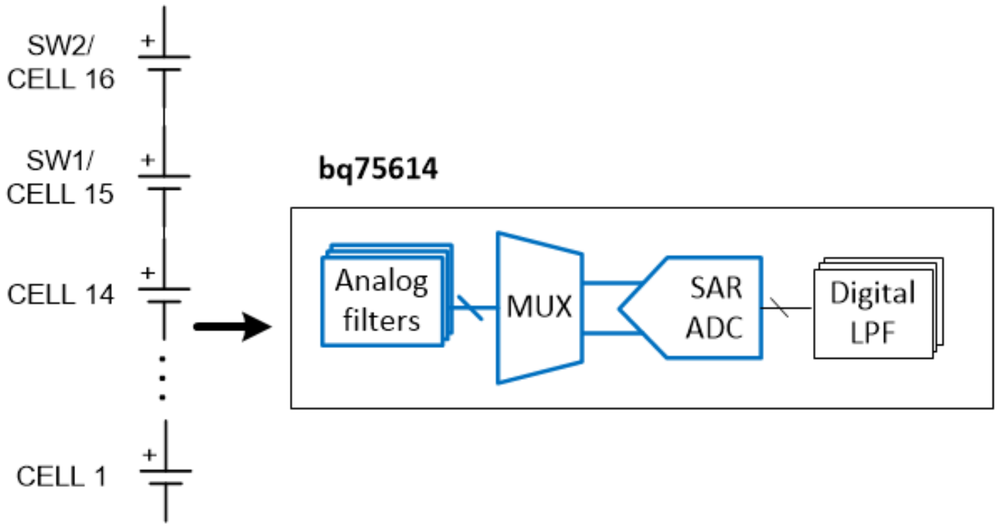


Hardware reset
- Emulate POR reset
- pure analog
- Available in all power modes

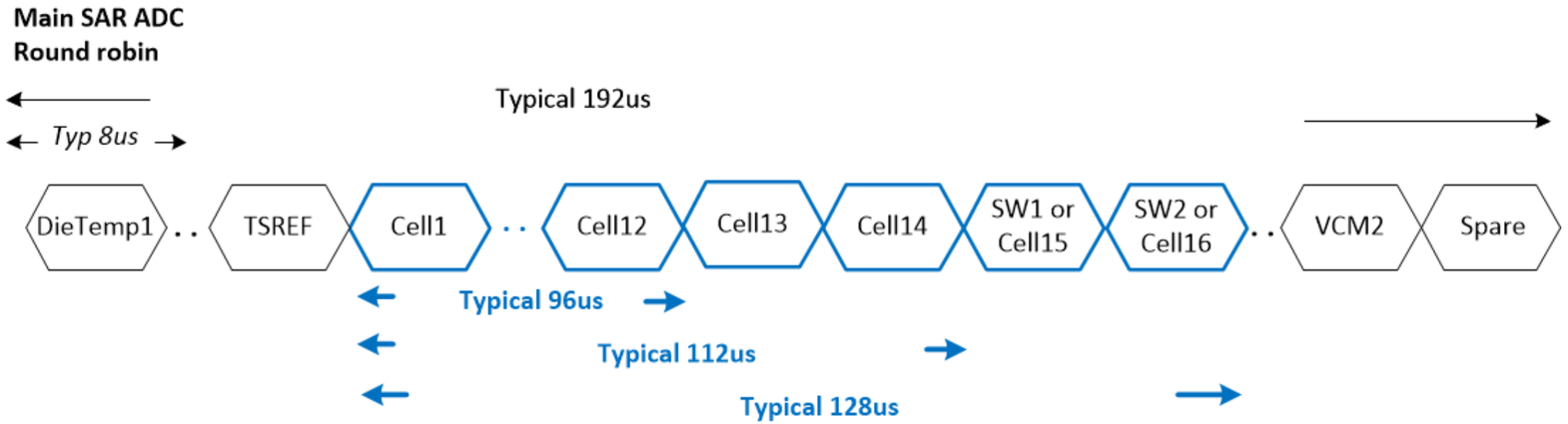
Secondary hardware protectors
- Hardware comparators independent of ADC
- OV, UV, OT, UT
- Operate in sleep mode

GPIOs
- 8 GPIOs
- NTC thermistor
- Analog voltage input
- SPI master

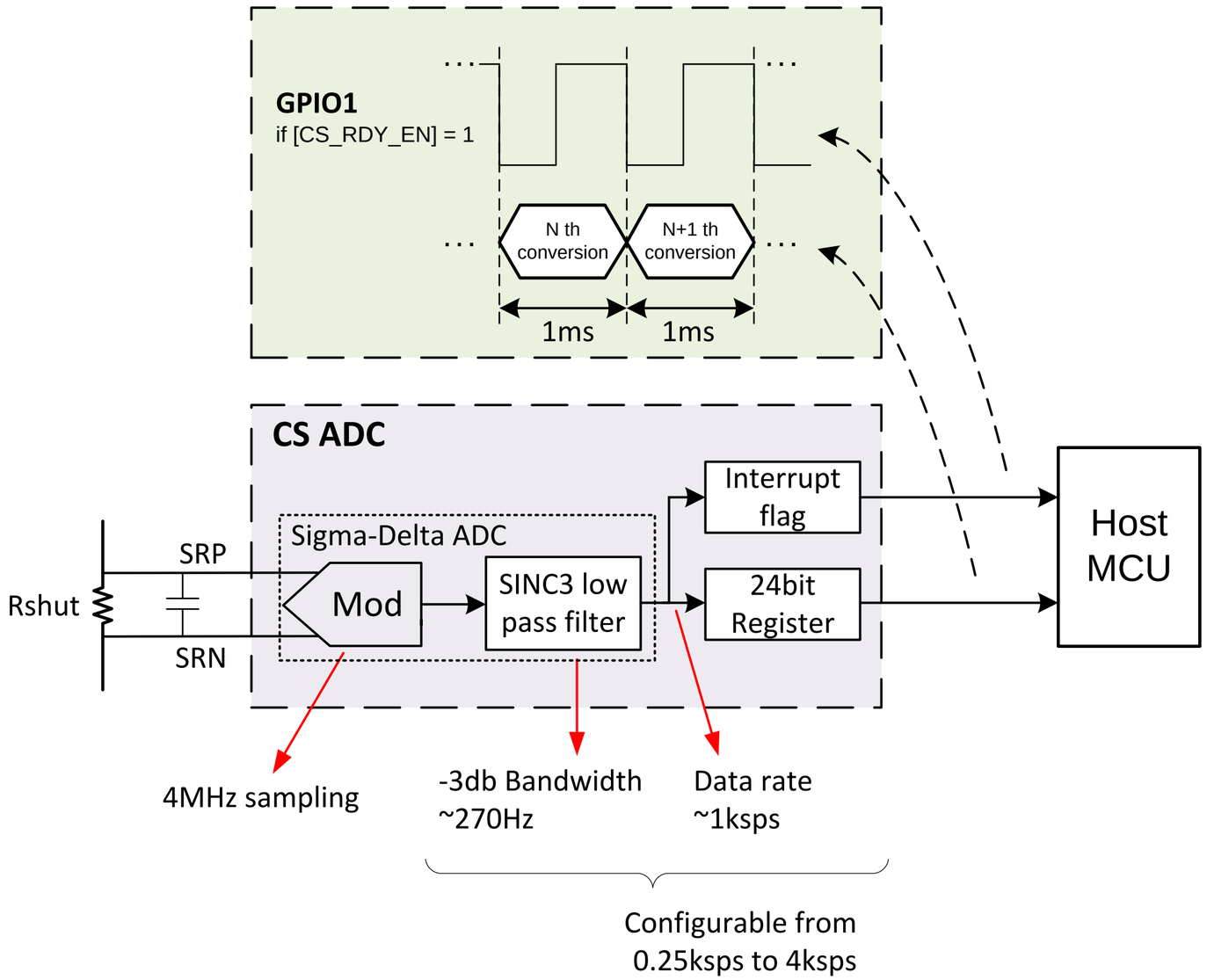
Cell voltage measurement



- Cell voltage is synchronized with in 112 us
- Cell voltage is refreshed every 192 us
- Integrated digital low-pass filter (6.5 Hz, 53 Hz, etc. configurable)

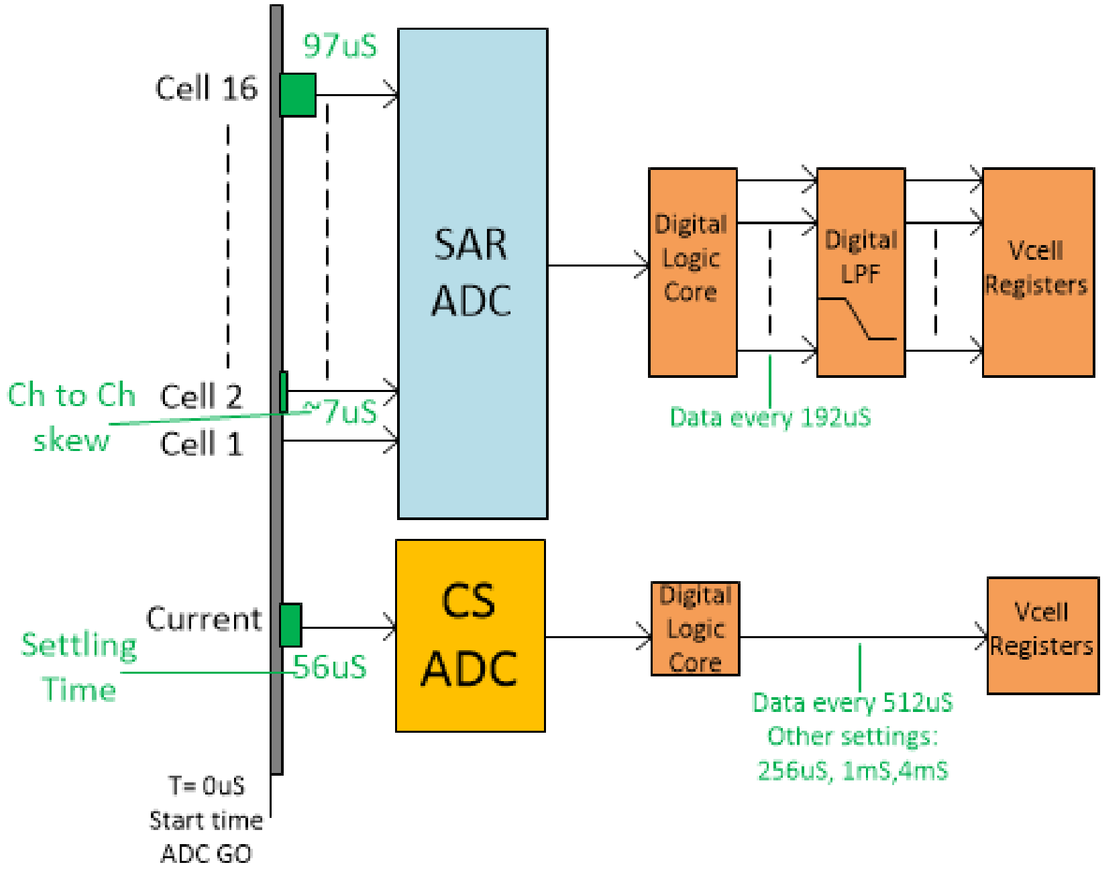


Current measurement



Parameter	Value	Comment
Input range	+/- 122.5 mV	
Offset	+/- 1.5 uV	Full temp range
Gain error	+/- 0.4%	Full temp 0.3%
Effective number of bits (ENOB)	16.5 bits	@ 1 ksps
Data rate	1 ksps	Configurable
Resolution	14.6 nV/LSB	24-bit result

VI signal path

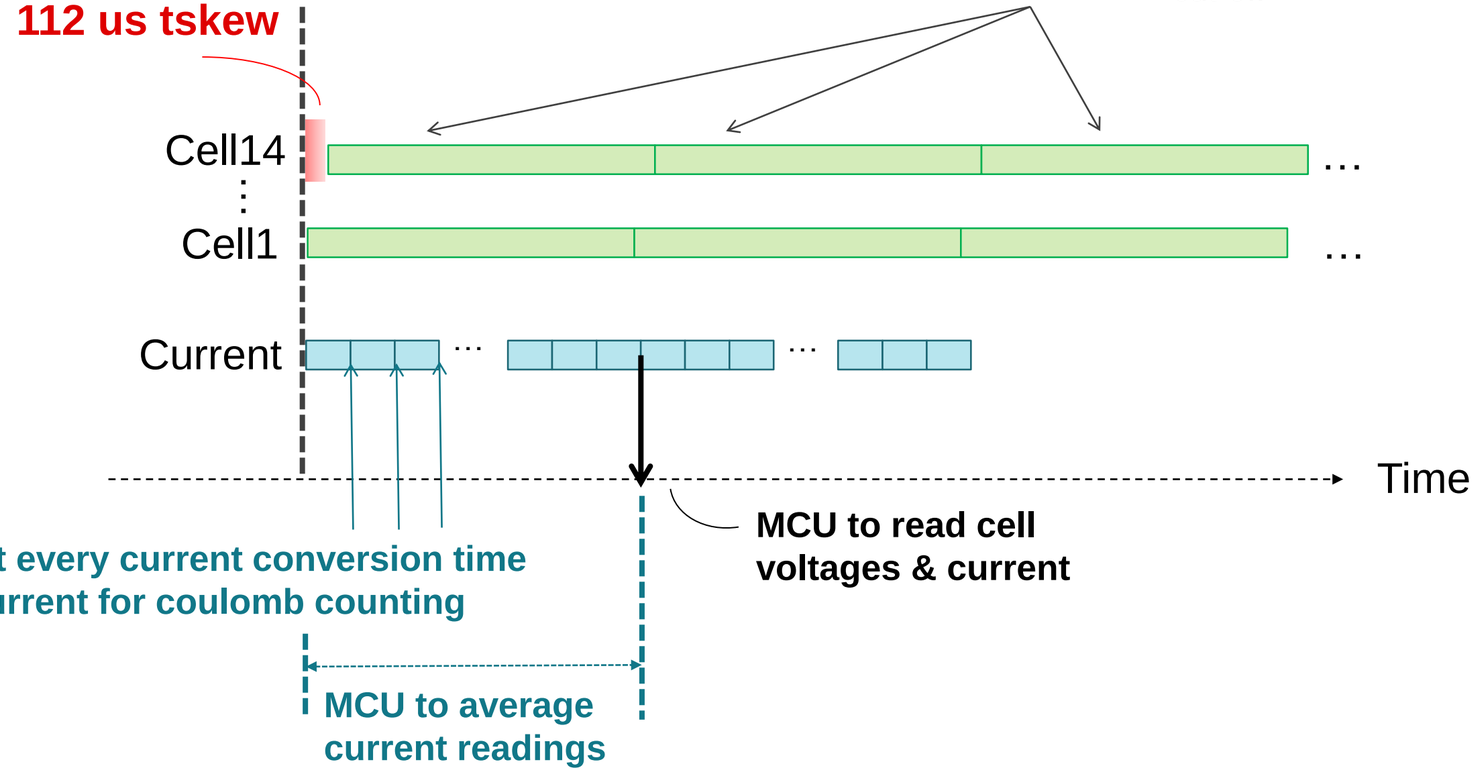


- Vcell analog-to-digital converter (ADC) has a digital low-pass filter (LPF) in the data path. This LPF needs to be accounted for when considering accuracy of voltage measurement.
- For accurate voltage and current sync, the current measurement needs to have the same amount of filtering as the voltage.
- This filter time constant can be much greater than the difference between V and I data readout rates.

Voltage/current synchronization

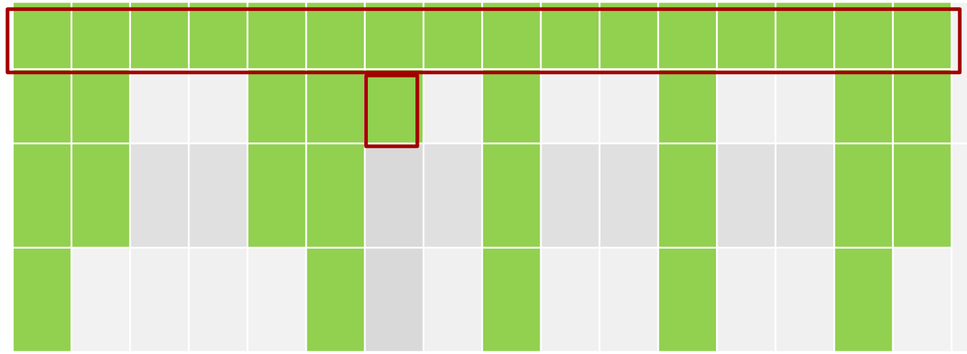
Cell voltage average through digital low-pass filter

Average time based on selected $f_{cut\text{-}off}$



Cell balancing control

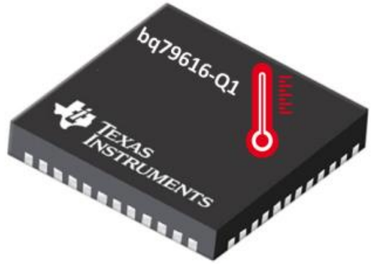
	Auto CB control	Manual CB control
Control	Always duty cycle between odd and even	Only turn on the channels that are enabled
Stop conditions	Timers (up to 10 hr) and cell voltage threshold	Timers (up to 10 hr) and cell voltage threshold
Thermal pause	Yes	Yes

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 configurations listed above.

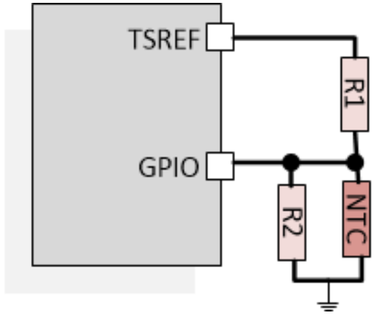
CB thermal pause

CB TWARN



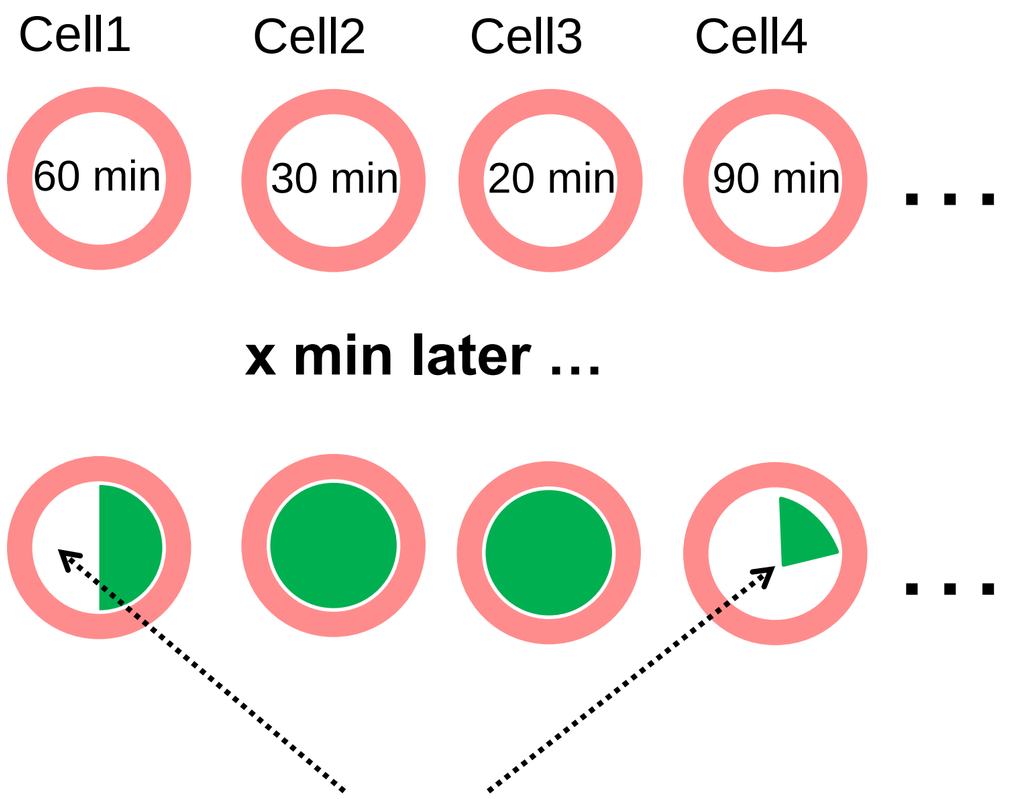
- Monitor through internal die temperature.
- Pause CB if die temp > 105^{o} C.
- Recover with 10^{o} C hysteresis.
- Always on.

Thermistor OTCB



- Monitor through external thermistor.
- Pause CB if thermistor measurement > OTCB threshold (programmable).
- Resume CB with COOLOFF hysteresis (programmable).
- Register bit enable.

CB remaining timers



MCU can read out the remaining balancing time. Better balancing time tracking and capacity estimation.

- 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).

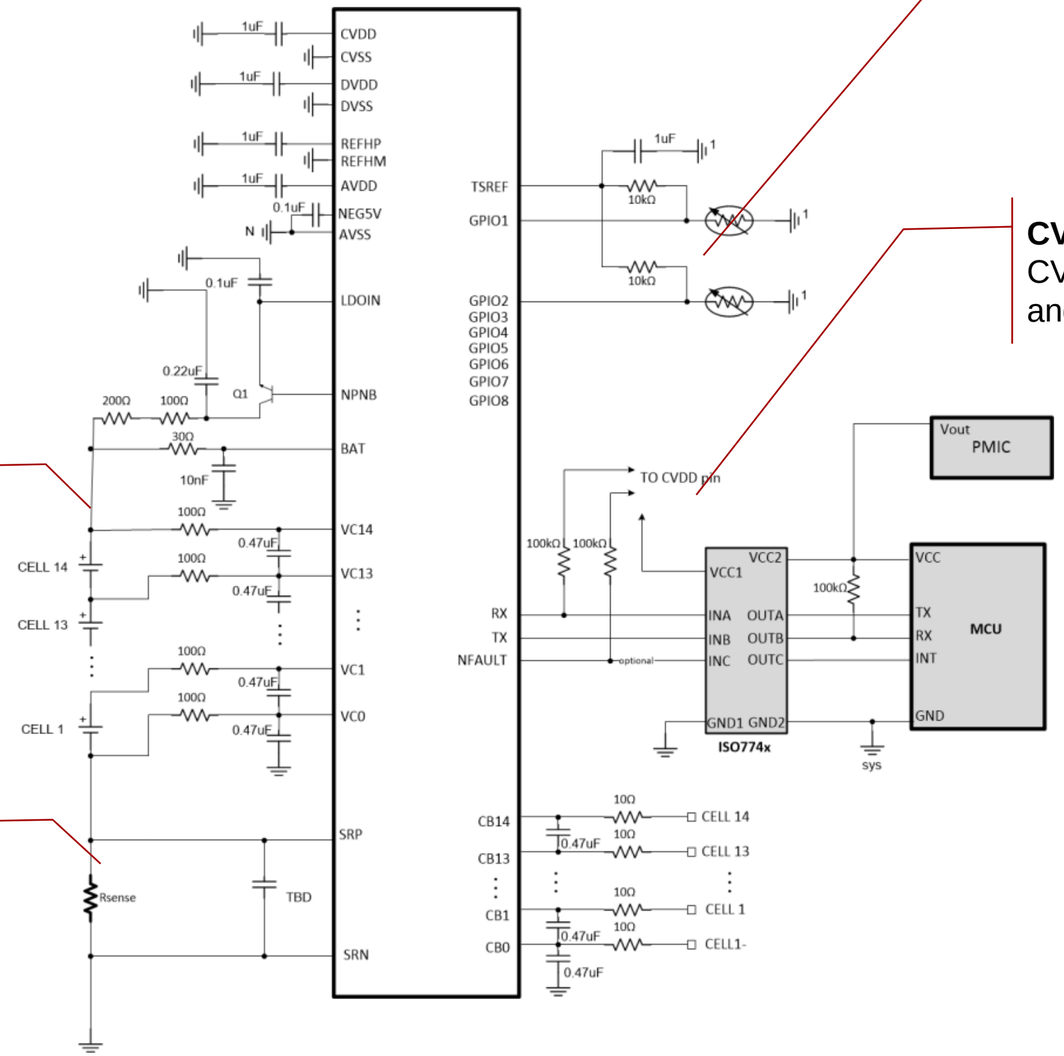
BQ75614 reference schematic

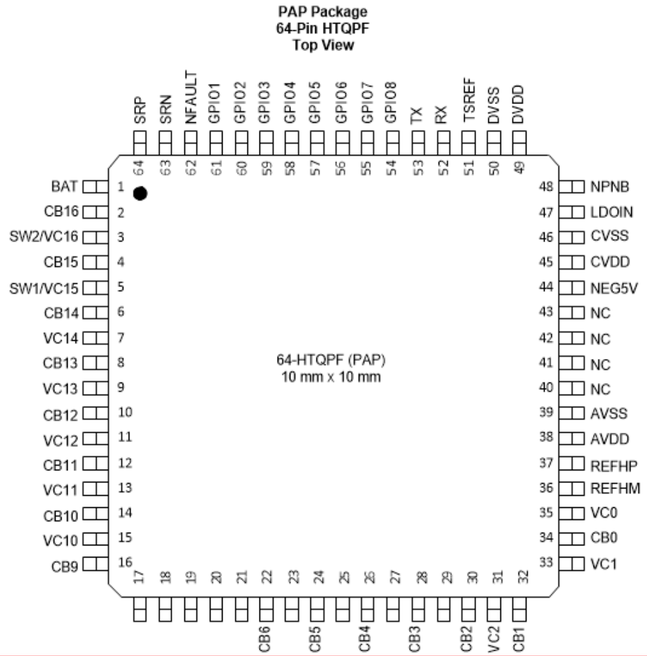
8 GPIOs
All can be used for thermistor connection, or option to take 1 GPIO to single MCU whenever current conversion is done (for coulomb counting calculation)

CVDD to power digital isolator
CVDD can support up to 5 mA in **shutdown** and 10 mA in **active** and **sleep** modes

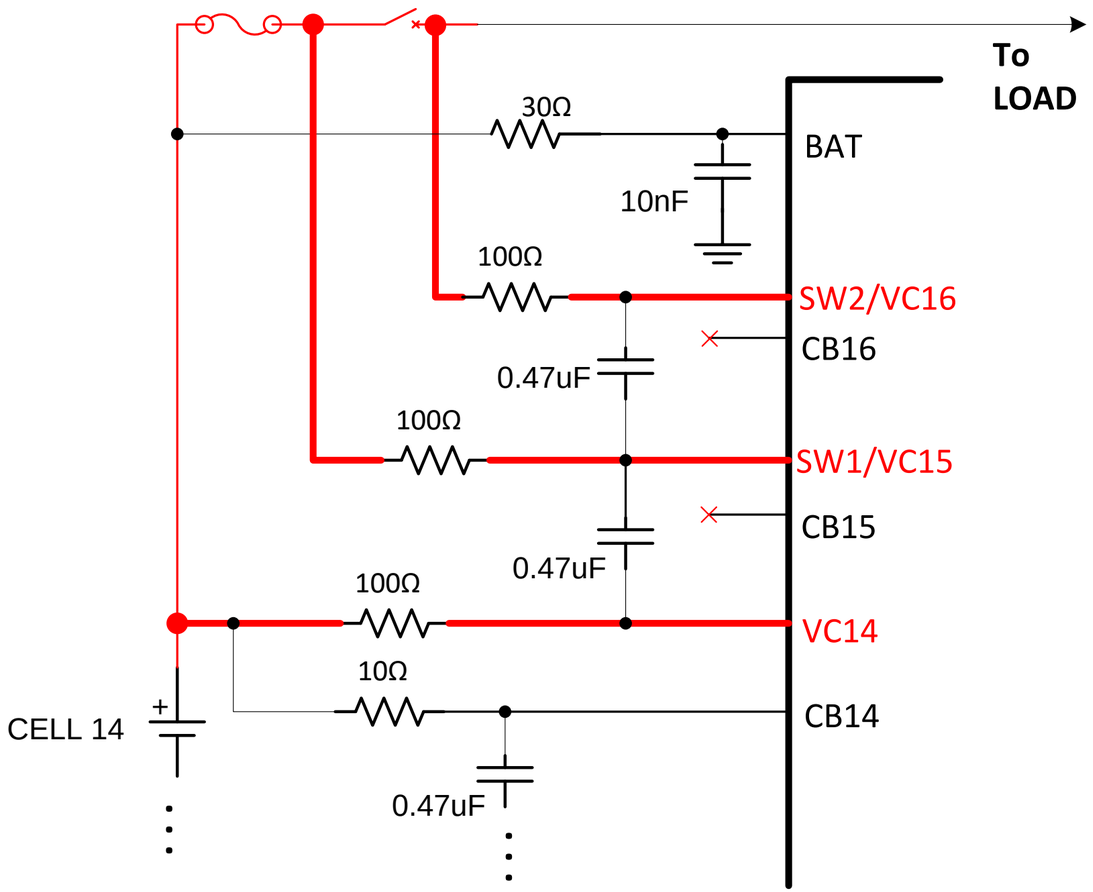
Filtered Vcell measurements
Built-in front-end filters + programmable post ADC digital LPF for best SOC/SOH calculation

Integrated current sense
Sync'd current and cell voltages measurements for best SOC/SOH calculation



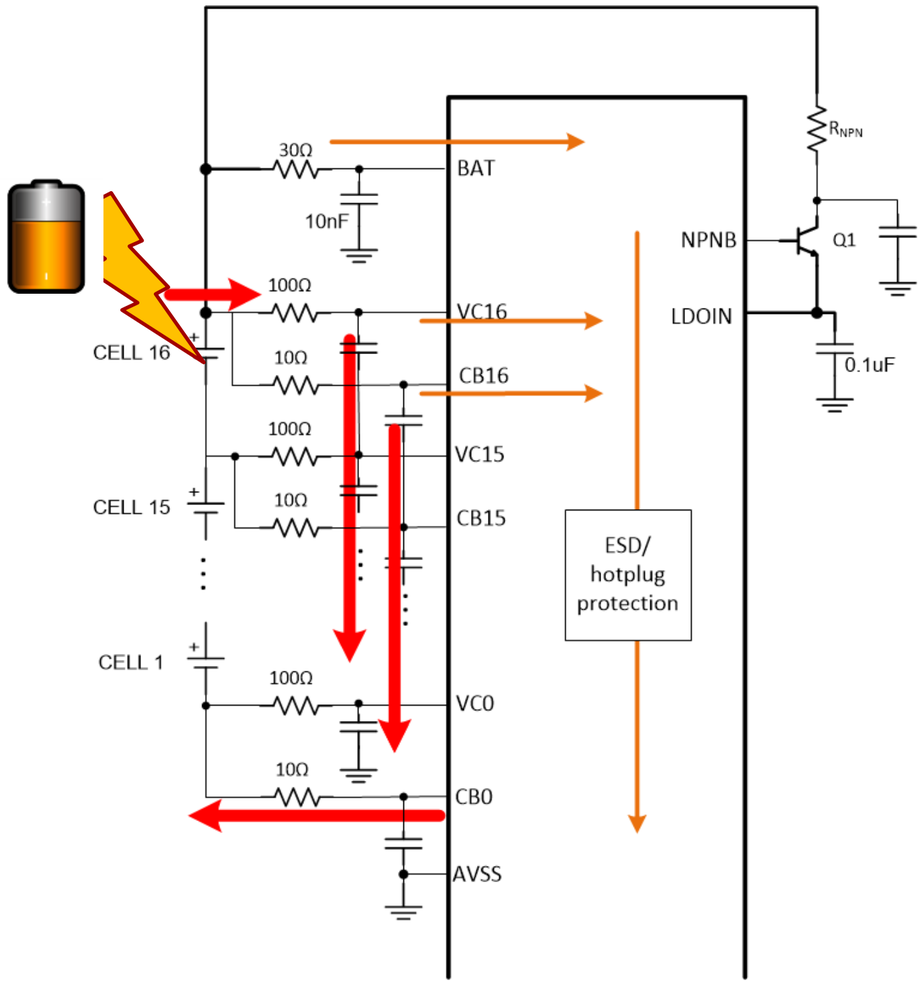


BQ75614 fuse and relay diagnostic



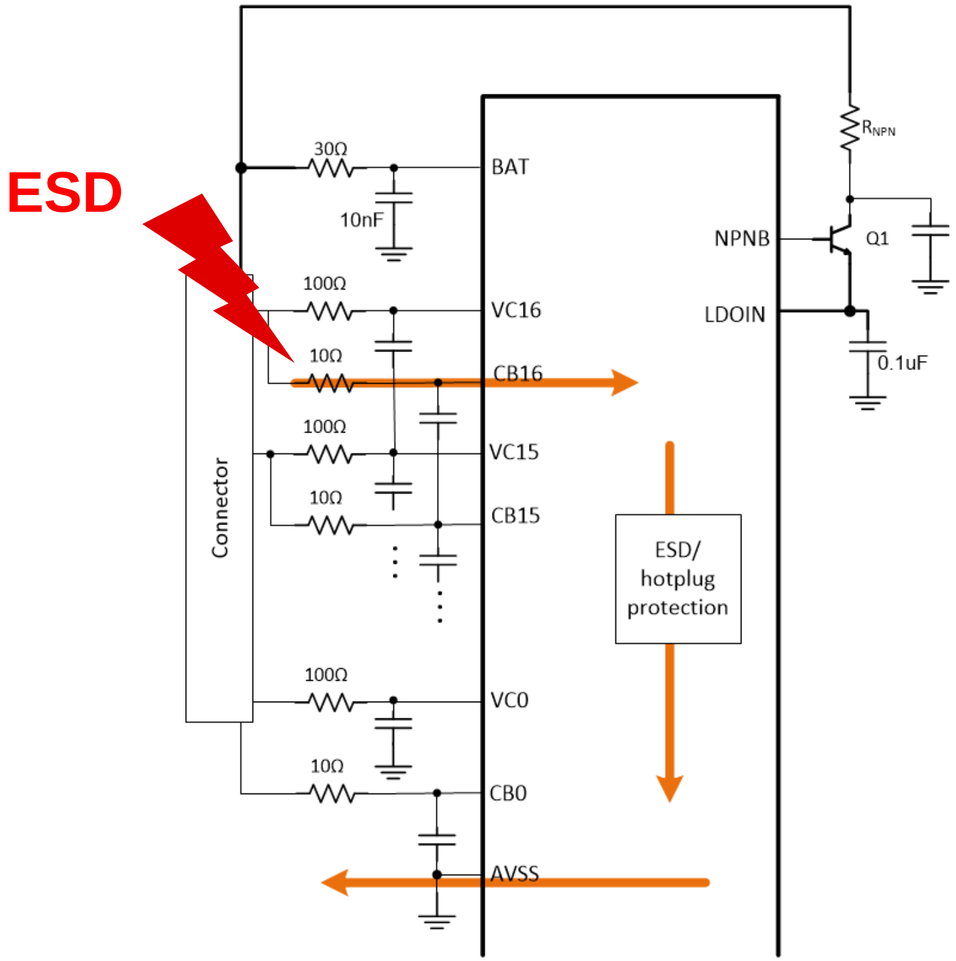
Diagnostic	Open/blown	Close
Fuse	(SW1-VC14) <<0V • SW1 will be pull down by the load	SW1-VC14 = ~0V • Depends on current flow and fuse impedance (e.g. +/-0.3V)
Relay	(SW2-SW1) <<0V • SW2 will be pull down by the load	(SW2-VC1) = ~ 0V • Depends on current flow and fuse impedance (e.g. +/-0.3V)

What is a hotplug event?



- A hotplug event is different than an electrostatic discharge (ESD) event in several ways:
  - The input voltage in a hotplug event doesn't collapse as in an ESD event (because a battery cell is an energy source).
  - The current path, peak current and RC response in a hotplug event varies depending on the hotplug path.
- To protect from a hotplug event, the goal is to size the RC constant and control the ESD/hotplug protection circuit so that the majority of the current flow is routed through the external RC components.
- Device pins absolute max rating are also sized with the goal to sustain during the hotplug event.

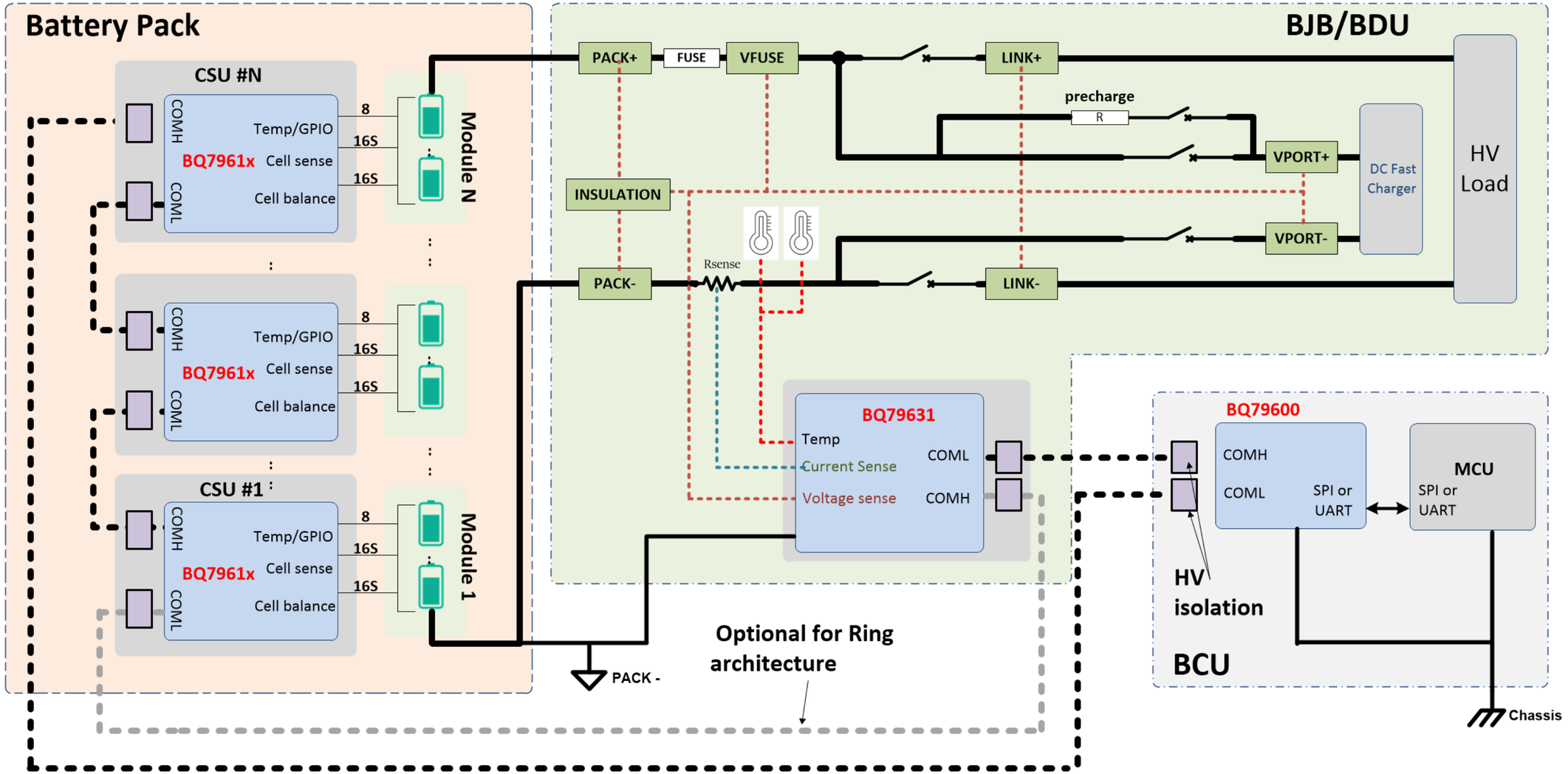
ESD protection



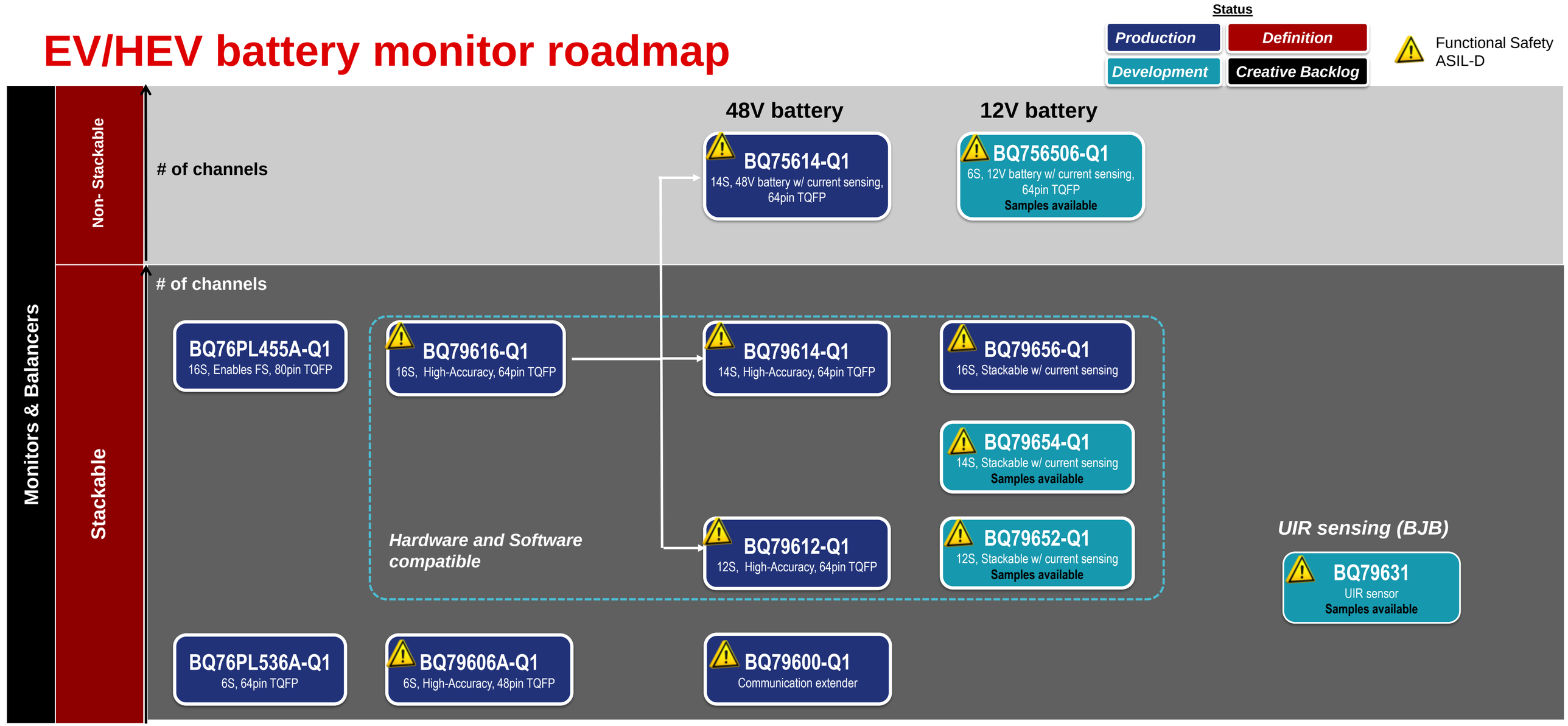
- In an ESD event, the on-chip ESD production circuit provides a low impedance path to discharge the ESD strike.
- The input voltage (spike voltage) collapses as the ESD protection is triggered, resulting in short event.
- Current flow path in an ESD is similar on each pin.

400V/800V battery BMS solutions

400V/800V BMS system block diagram



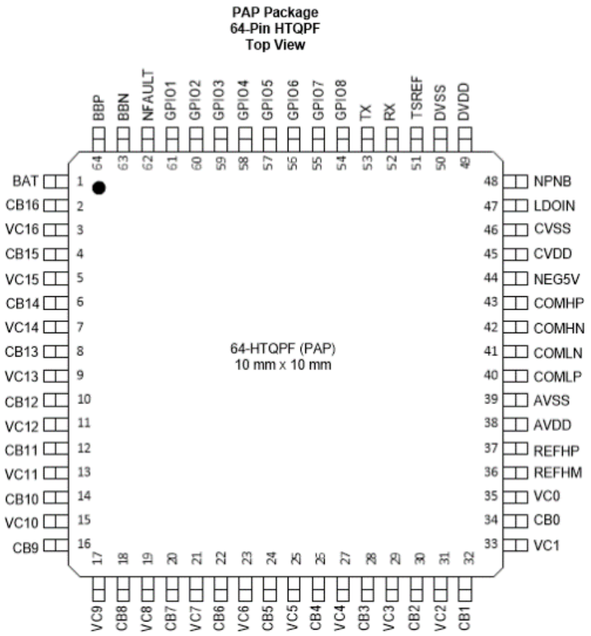
EV/HEV battery monitor roadmap



Key differentiators and value proposition of BQ796xx family

Differentiation	Value proposition
Accuracy • Measures true cell voltage with less than ±3mV error at EOL • Measures battery current with less than ±0.3% gain error	Highly accurate state of charge and state of health estimation of the battery, thereby reducing battery size and cost for a given driving range.
Robustness • Higher voltage margin on pins to handle transients • Robust daisy chain communication with system reset • Automatic thermal management during cell balancing	Highly robust solution that is immune to EMC disturbances.
Safety • Full built-in diagnostics with redundancy paths • ASIL-D per ISO 26262 for voltage, current, temperature, and communication	Enables a safer system and significantly reduces software overhead.
System cost • High system integration • Supports 1 bus bar without wasting any channel	Lowest system cost and higher flexibility.

What is BQ79616?

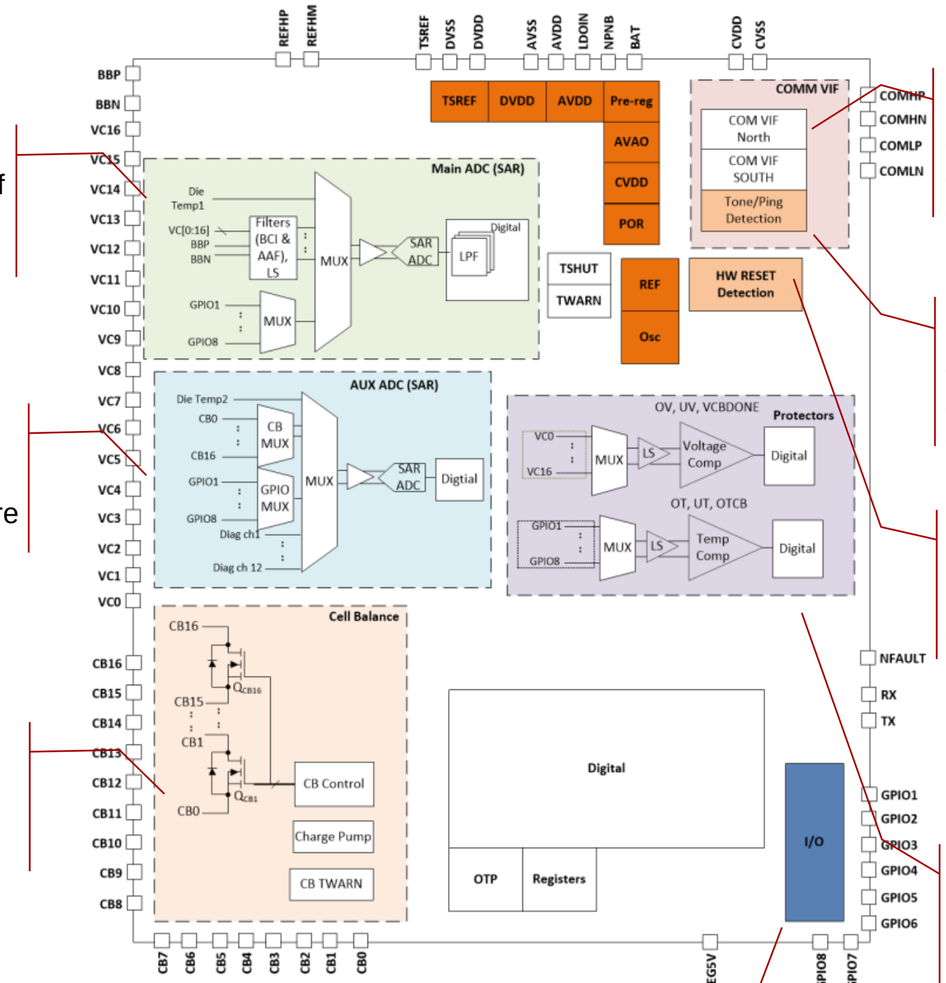


- **16S stackable battery monitor**
- **Same package/pinout on its 12S/14S variants**
- **Support min of 6S (9V) operation**

Main ADC
Measure VCELL, busbar (if used) and temperatures

AUX ADC
Redundancy for Main measurement. Mainly use for diagnostic. Also measure VBAT

Cell Balancing
Internal CB w/ typ 2.5Ω Rdson.
Support Icb 240mA w/ thermal management



Vertical Interface
Bi-directional daisy chain communication requires 1 twisted cable pair. Also support RING communication

Tone/Ping Detection
Handle critical power transition signal (e.g. WAKE, SHUTDOWN etc). Implemented in pure analog. Operate in all power modes

HW RESET
Independent HW Reset detection block implemented in pure analog. Operate in all power modes

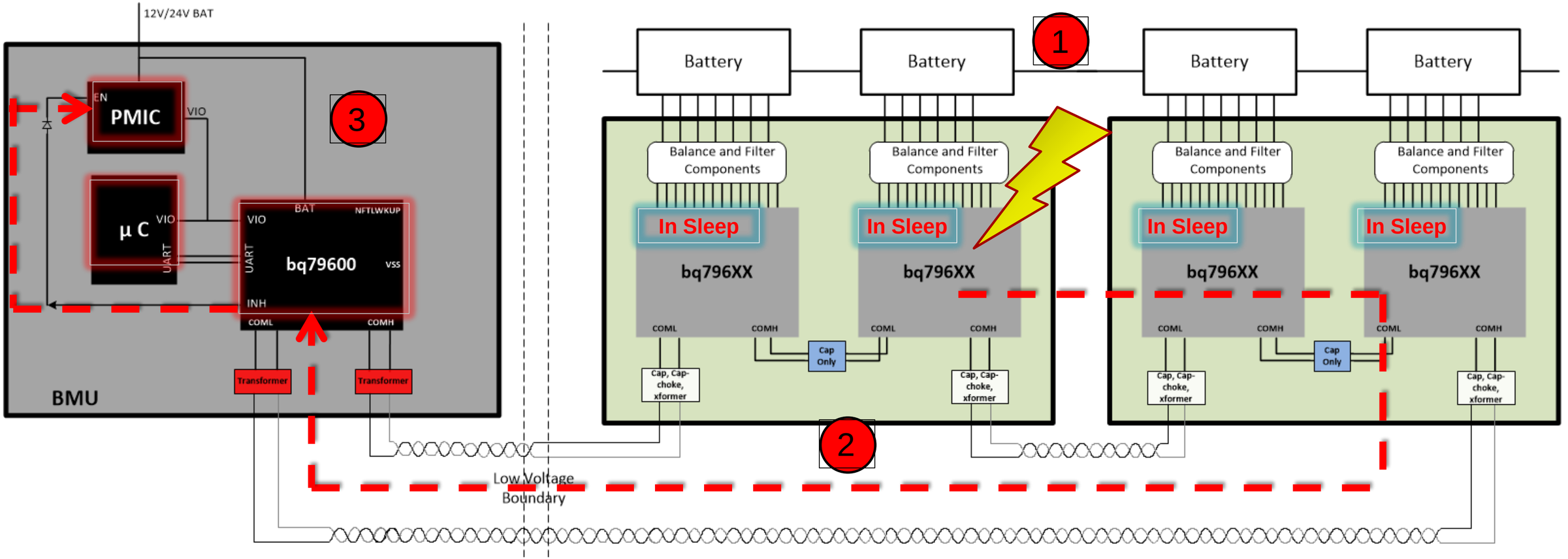
Integrated HW Protectors
HW comparators, independent of ADC operation, for OV, UV, OT, UT detection.

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 use for SPI master

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

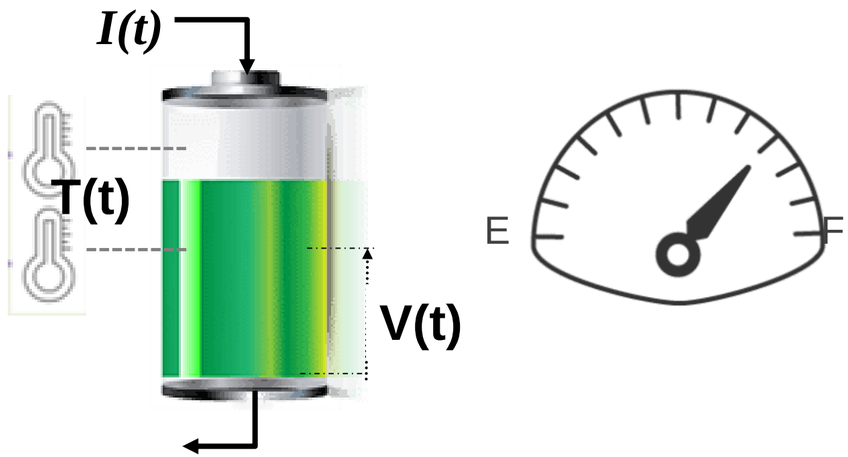
BQ79600 + BQ7961x: Auto wake up system at fault



1) Detect Fault in Sleep Mode
2) Fault tone transfers through communication line to the BQ79600 (Ring Cable is needed)
3) BQ79600 wakes up, and then wakes up PMIC and uC

Defining accuracy

- An SOx gauge algorithm (running on MCU) needs to have data from the battery through various measurements
  - Battery cell voltage
  - Current flowing into and out of the battery pack
  - Battery cell temperature

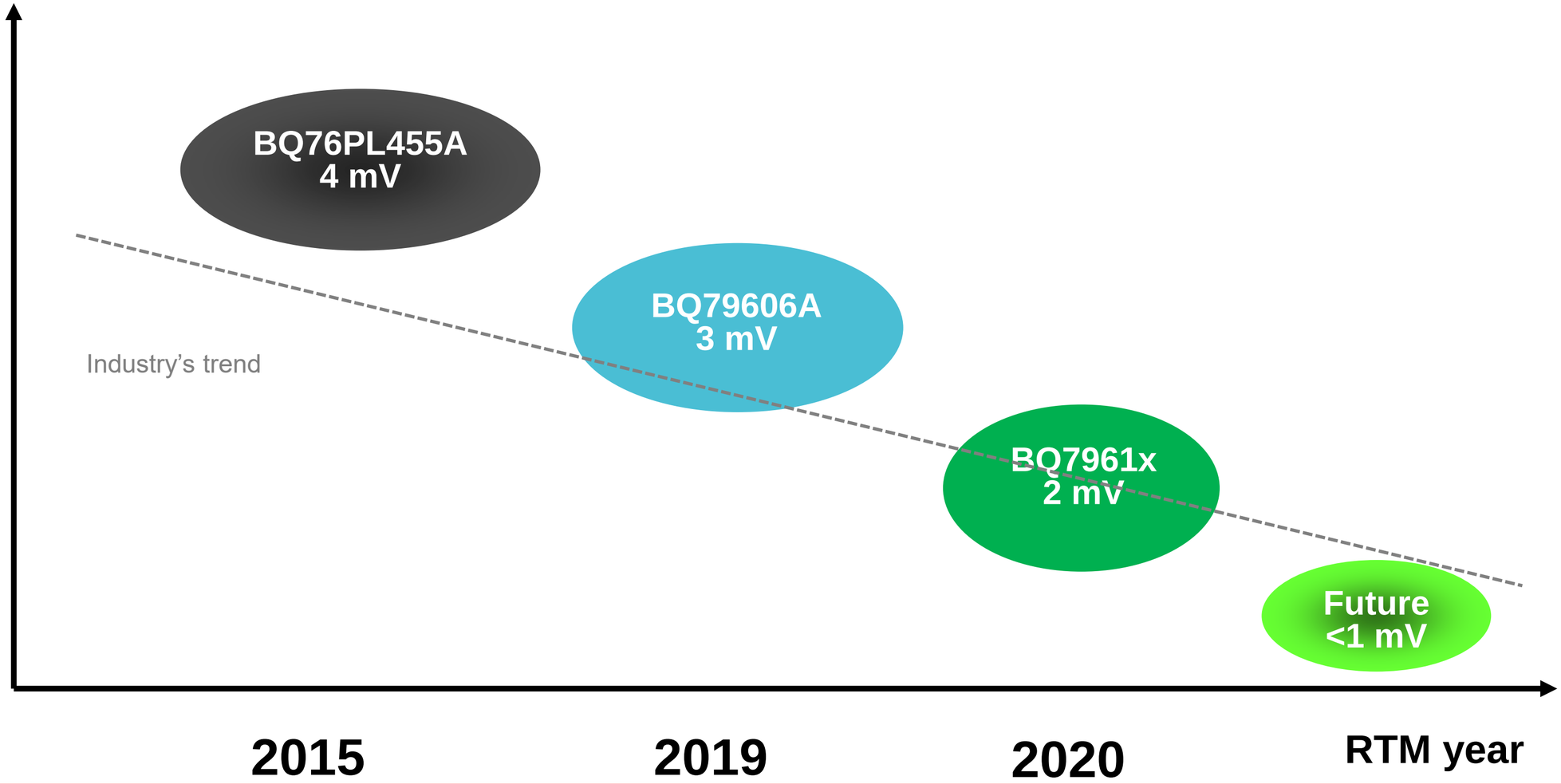


- Measurement accuracy is dependent upon the monitors' and balancers' hardware and is independent of gauging algorithm accuracy
- SOx gauge algorithm accuracy is dependent upon the robustness of the gauging algorithm and the monitors' and balancers' measurement accuracy
  - Poor measurement accuracy can lead to poor gauging accuracy

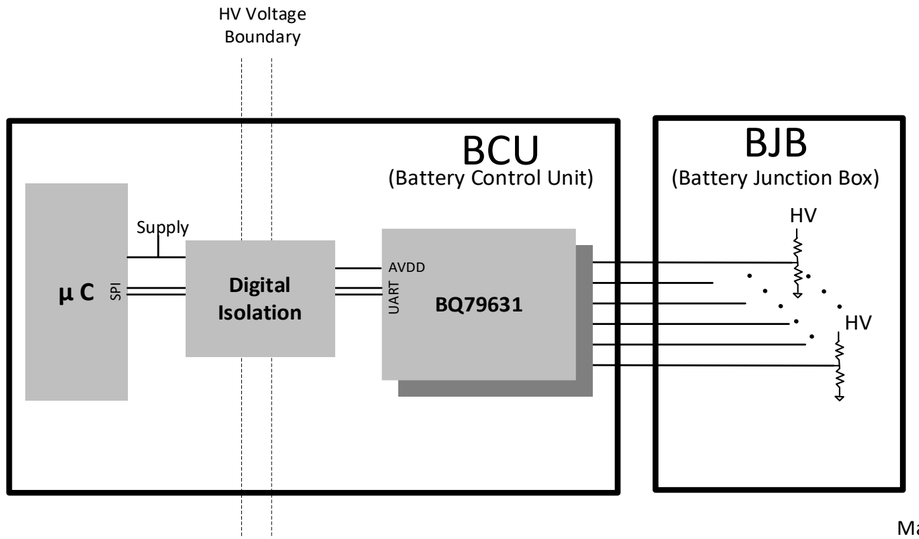
SOX : State-of-X → X: charge, health, power, energy

Monitors’ and balancers’ accuracy roadmap

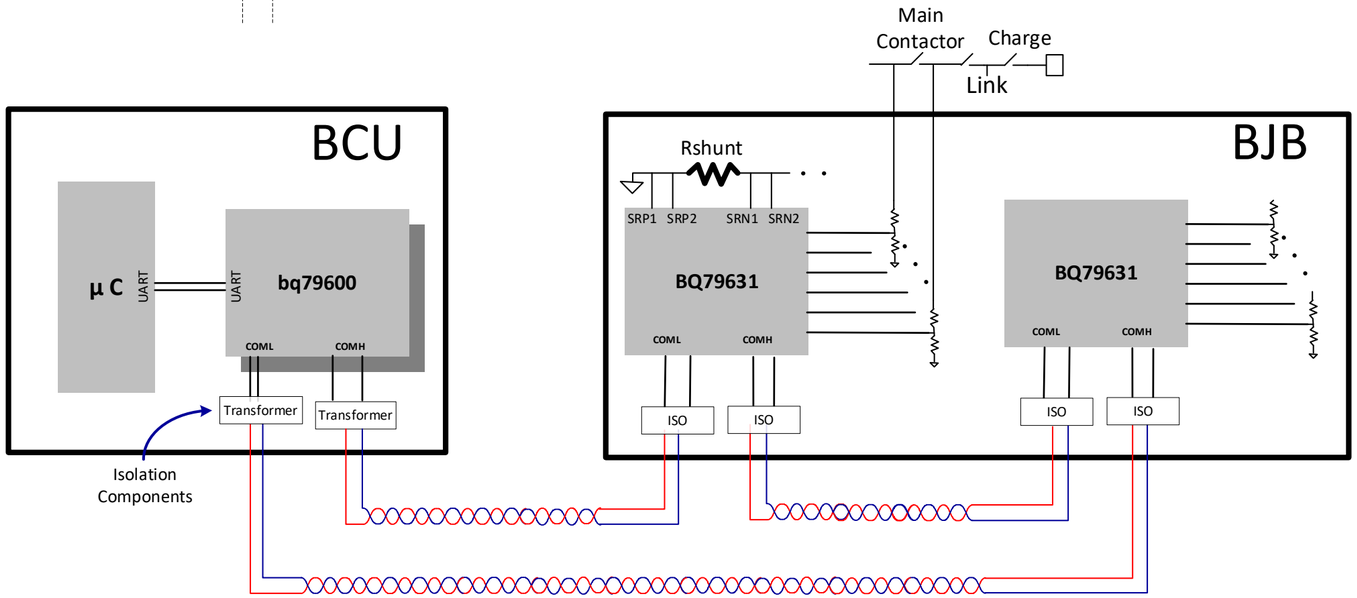
Vcell total channel accuracy error [mV]



Comm supports both traditional and intelligent BMSs

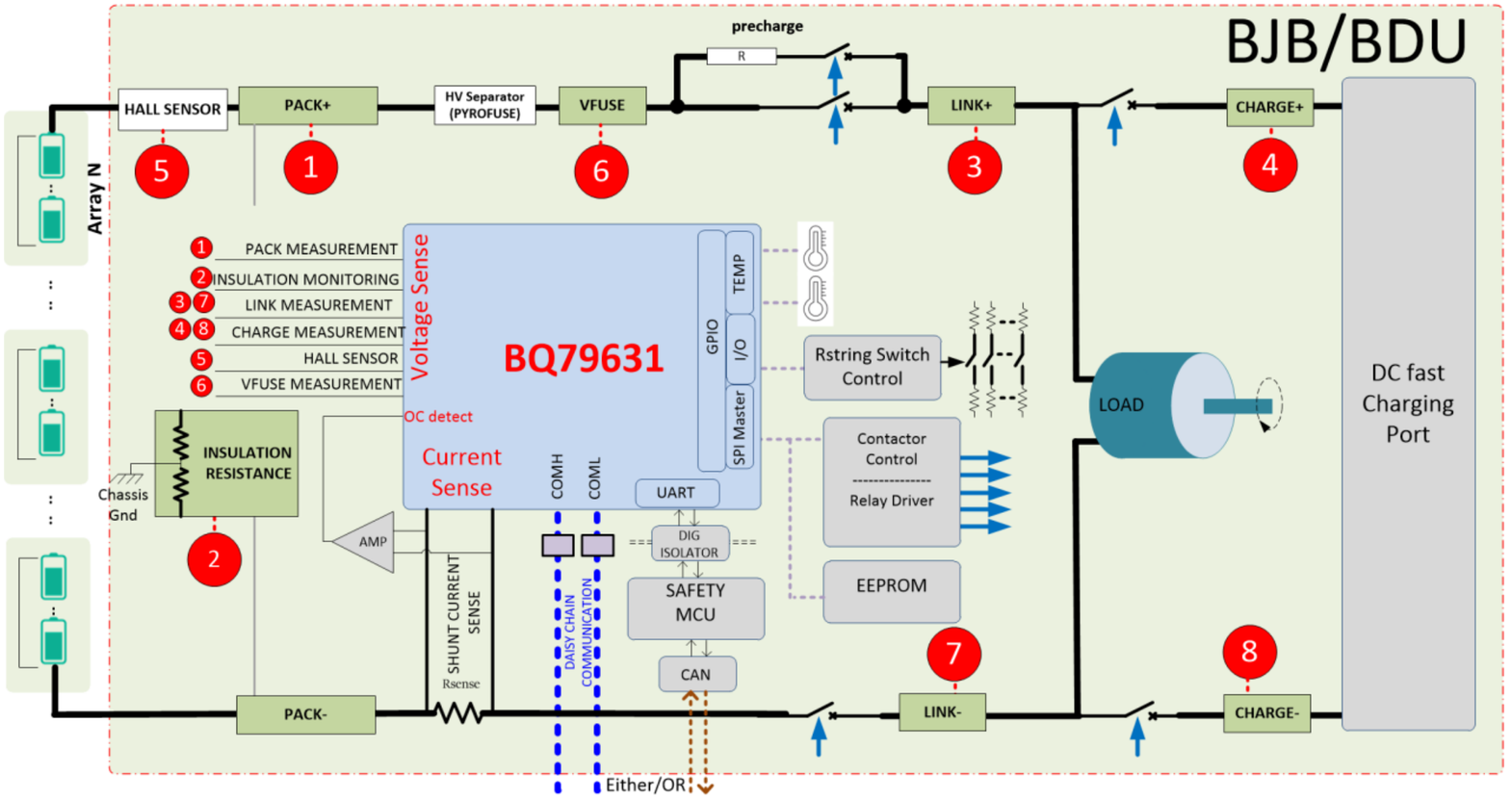


- Traditional UART-based communication.



- Intelligent BMS: communication over daisy chain.
- Can also be connected in same daisy chain as cell monitors.

UIR sensor – Voltage measurements



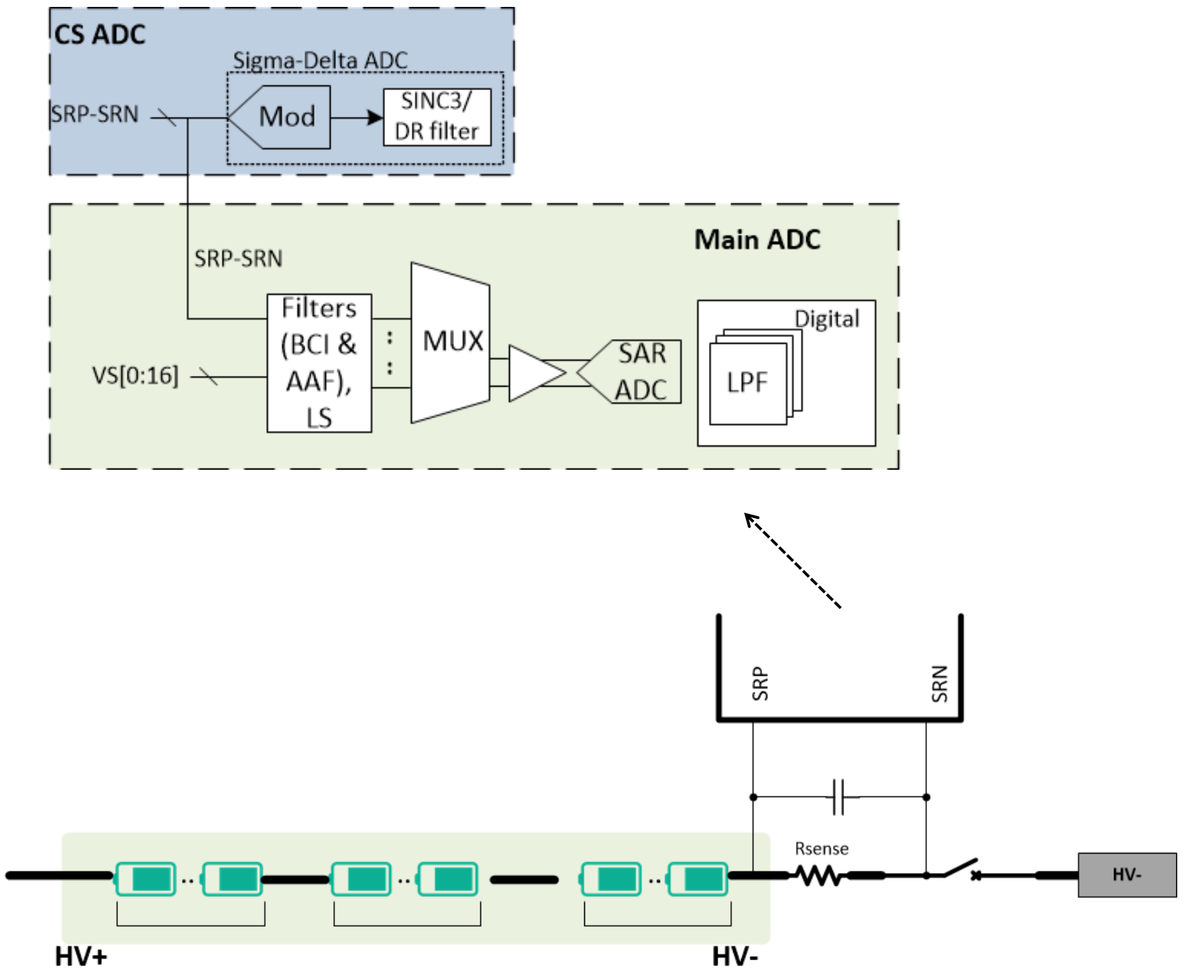
Voltage measurements:

- Indicate the status of contactors and fuses.
- Power calculations.
- Temperature measurements.
- Measure the DCFC voltage.

Key measurement properties:

- Accuracy to support <1% error in high-voltage estimations.
- All high voltages are divided down using resistor strings.
- Voltage measurement inputs need to have extremely low leakage to avoid affecting measurements.

UIR sensor - Current measurements



Current measurements:

- Measure load currents such as current in the drive motor.
- Measure the charging current.
- Battery power calculations.
- Cell impedance calculations.

Key measurement properties:

- Very high accuracy (typically <0.3% error from measurement).
- Conversion rates and characteristics to match cell voltage measurement properties (cycle time, filter, etc.). This helps achieve good VI sync between cell voltage and current, which helps in accurate power, cell impedance, and state-of-charge and state-of-health calculations.

Summary

A Scalable Battery Monitor Family

Battery Type	12V Li-Ion	48V	High Voltage (400V/800V)	
Target Application	Cell module monitoring	Cell module monitoring	Cell module monitoring	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

Summary

- TI continues to invest heavily in automotive battery monitors & balancers portfolio, innovations continue to come quickly with the market fast evolving.

- A complete BMS solution (cell monitor, UIR sensor, communication bridge) with BMICs that offer:
  - Best in class **accuracy**
  - Industry leading voltage & current **synchronization**
  - **Scalable** solution supporting various array sizes, chemistries and batteries
  - **Lowest** total system cost

- Significant capacity expansion ongoing. Multi factory flows planned to ensure supply continuity.

- A big team of expert systems/applications/functional safety engineers available to readily provide on-site support along with local field applications engineers.

TEXAS INSTRUMENTS

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