MC3377x Battery Cell Controllers for Battery Management Systems

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SECURE CONNECTIONS FOR A SMARTER WORLD

Agenda

- Automotive BMS trends and requirements
- Product portfolio and key features
- Typical applications
- Enablement tools
- Summary

Key Take-Away

- Power control system value proposition:
  - Efficient system BOM
  - Inherent functional safety
  - Scalable system & SW
  - Power efficient operation
- MC3377x Battery Cell Controller portfolio:
  - Comprehensive portfolio in production for up to ASIL-D e-mobility and industrial applications
  - Superior life-time measurement accuracy, BOM integration and functional safety support

Automotive BMS Trends and Requirements

Market Update – Electrification Moving Beyond The Hype

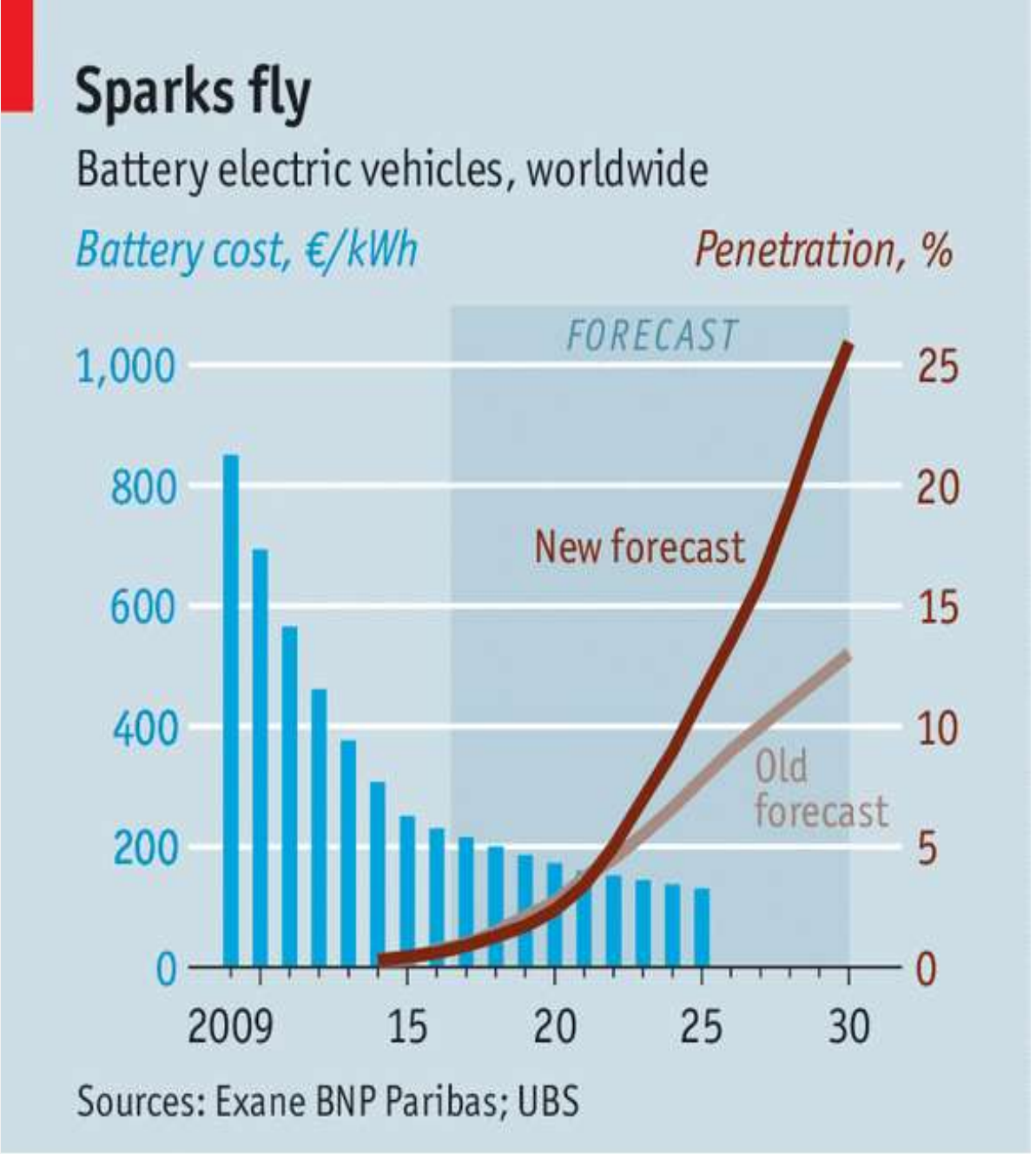
Auto makers being sued for not complying with emissions standards

Some car makers investing in battery production to secure supply

Car makers announcing partnerships to address emerging markets

Many countries plan to ban diesels and petrol cars in the next 20-30 years

Many car makers announcing new hybrid/EV models in future line up



Electric Drivetrain Adoption Accelerating

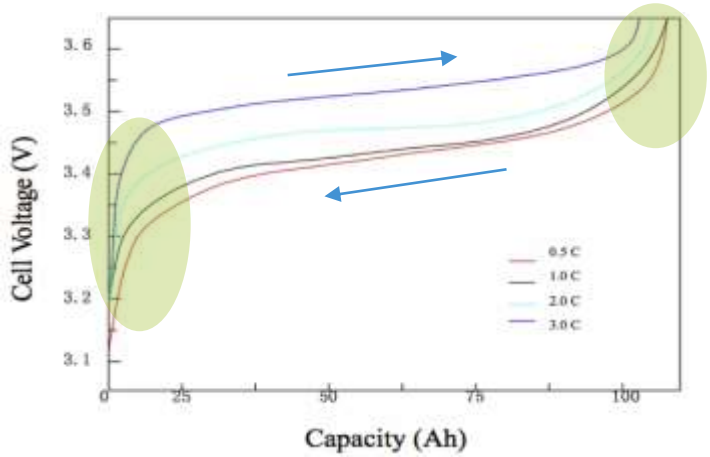
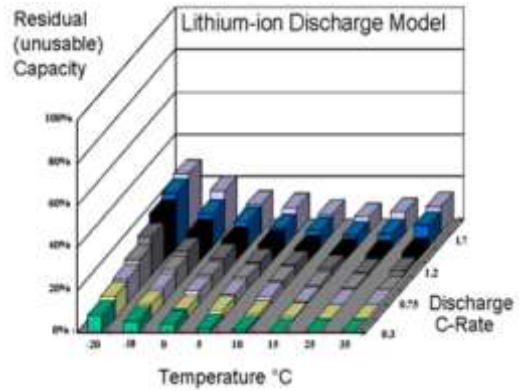
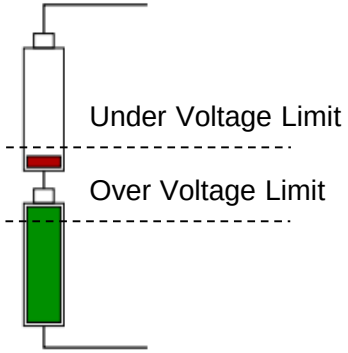
Drivers:

- Changing demographics and vehicle ownership
  - Ride-sharing, urbanization
- Policy makers
  - Imposing fleet regulations on fuel economy and CO2 emission
  - Offering tax incentives for low emission vehicles
- Technology trends
  - Battery technology development leads to lower battery costs

Impact:

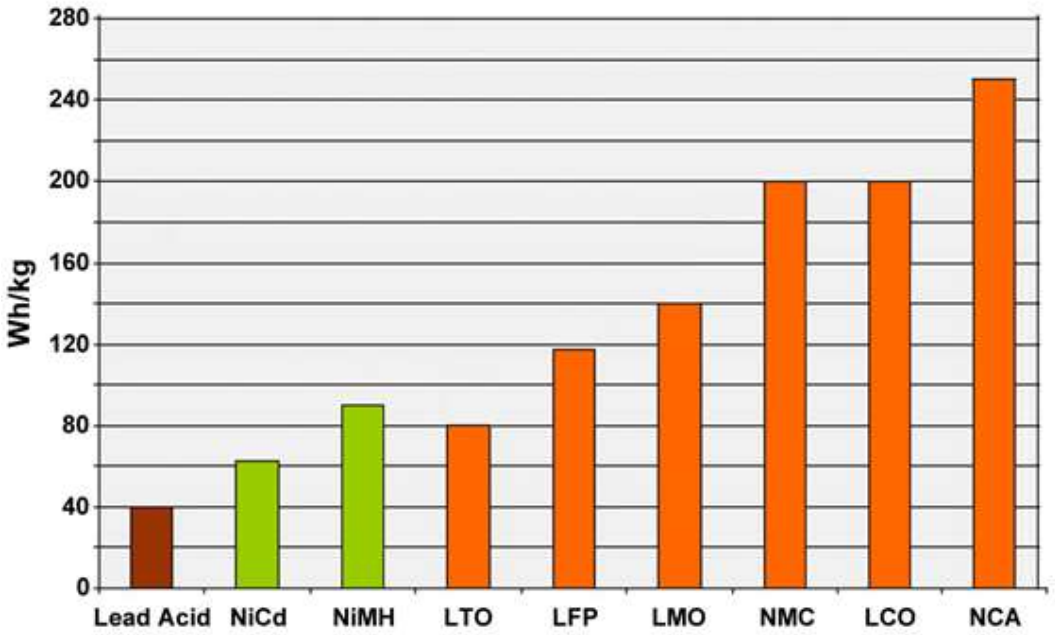
- Compliance challenging with ICE only
- EV penetration forecast increased for 2025
- Examples of OEMs with EV plans:
  - Ford promised 13 new electrified cars in the next 5 years
  - VW plan 30 BEVs by 2025, making up to 25% of sales
  - Daimler, up to 20% of sales will be EV by 2025.

Main Functions of BMS systems

	Safety	Performance	Multi-Cell function
			
	Danger: • Over voltage • Extra heat • Unstable chemical stage • Thermal runaway=>fire/explosion • Low temperature charge	**Requirements:** • Safe & fast charging • Discharge optimization • State of charge (SOC) estimation • State of health (SOH) estimation	**Challenges:** • Up to hundreds of cells • Manufacture mismatch • Capacity degradation • Lifetime degradation
Key BMS Functions	V/I/T measurement	V/I/T measurement Coulomb counting Internal resistance calculation	Cell balancing

Lithium-Ion Cell Chemistries

Name	Chemistry	Symbol	Nominal voltage	Full charge	Full discharge
LCO	Lithium Cobalt Oxide	$LiCoC_2$	**3.6V**	4.2V	3.0 V
LMO	Lithium Manganese Oxide	$LiMn_2O_4$	**3.7V**	4.2V	3.0 V
LFP	Lithium Iron Phosphate	$LiFePo_4$	**3.3V**	3.65V	2.5V
NCA	Lithium Nickel Cobalt Aluminum Oxide	$LiNiCoAlO_2$	**3.6V**	4.2V	3.0 V
NMC	Lithium Nickel Manganese	$LiNiMnCoO_2$	**3.6V**	4.2V+	3.0 V
LTO	Lithium Titanate	Li_2TiO_3	**2.4 V**	2.85V	1.8 V

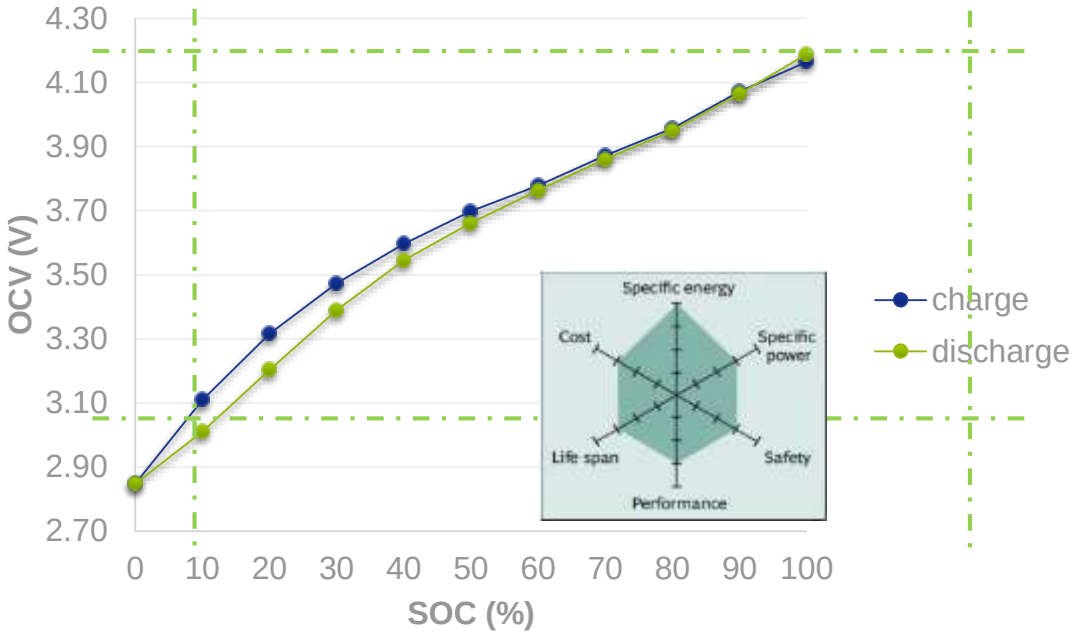


http://batteryuniversity.com/learn/article/types_of_lithium_ion

Open Circuit Voltage vs State of Charge

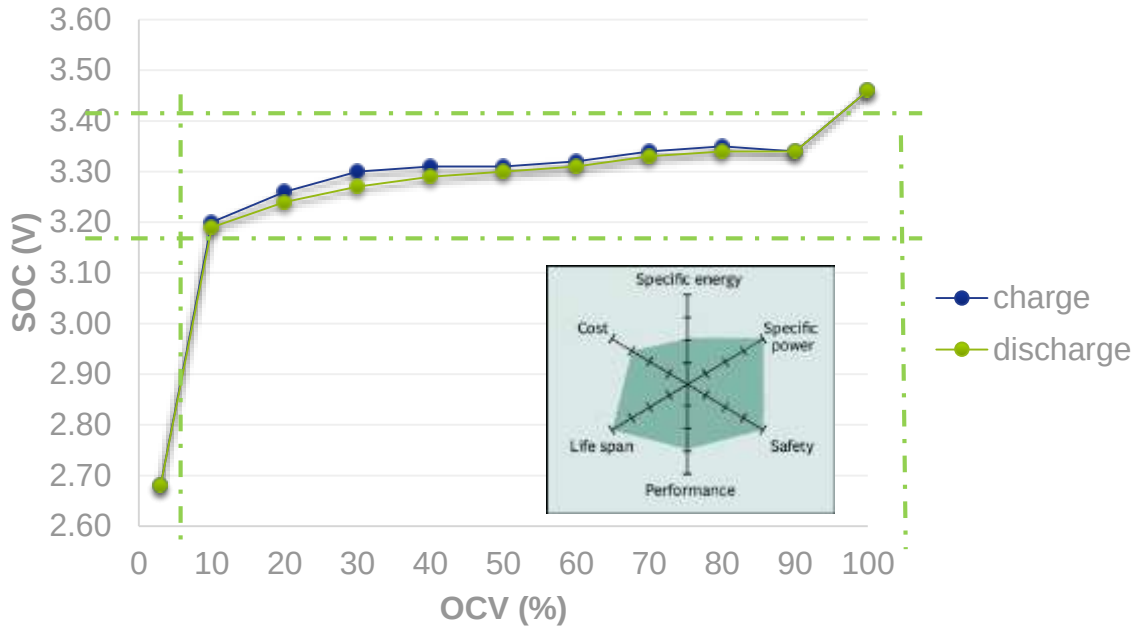
SOC accuracy depends on voltage measurement accuracy

NMC



1 V ≡ 80% SOC
(12,5 mV/1% SOC)

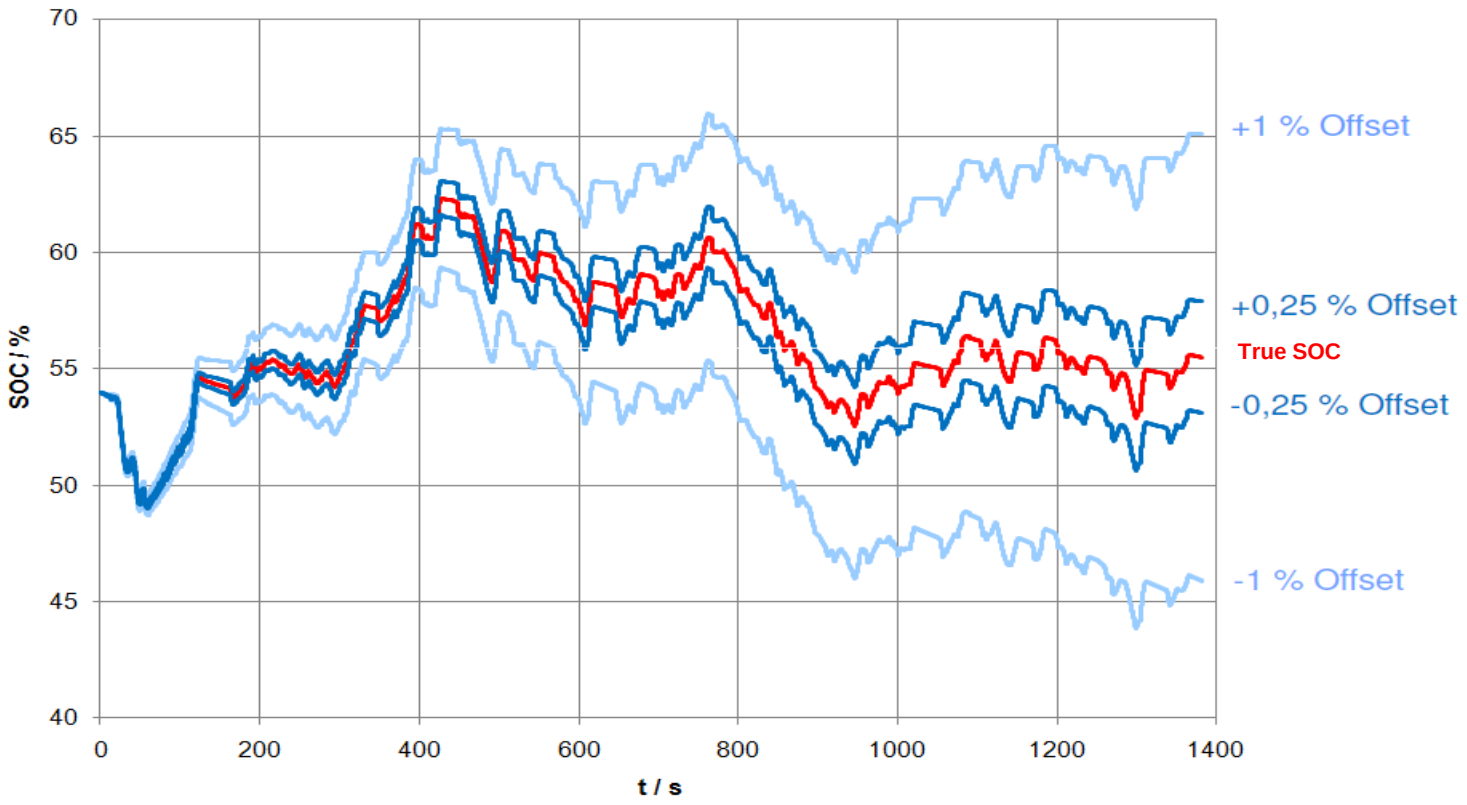
LFP



140 mV ≡ 80% SOC
(1,75 mV/1% SOC)

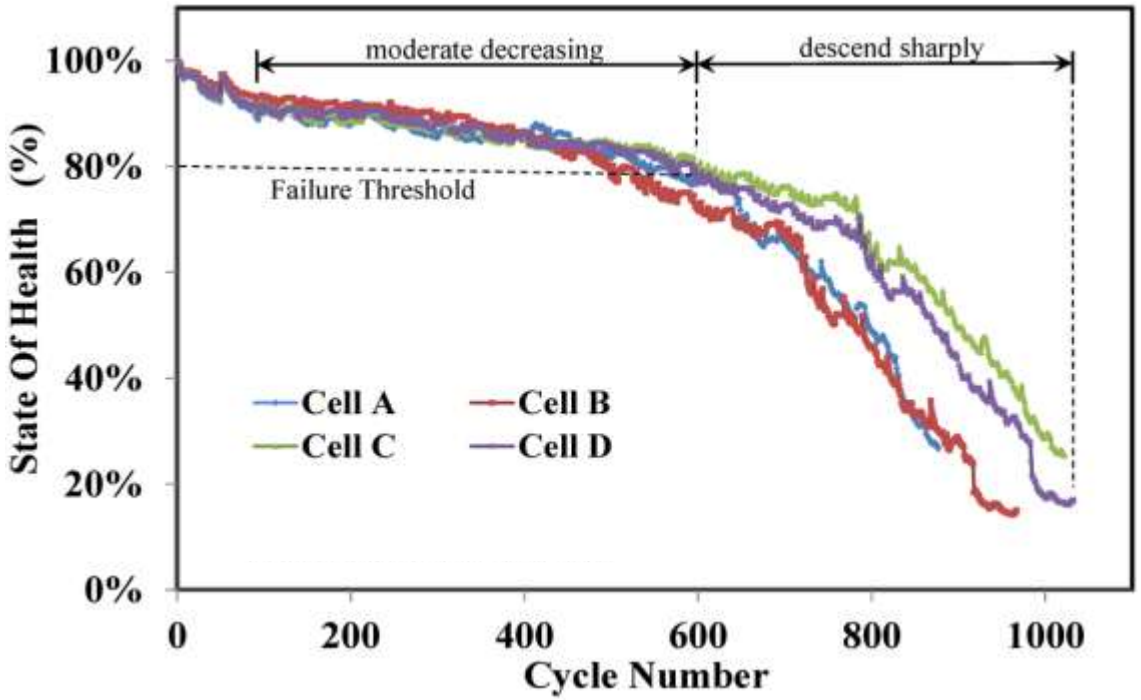
SOC Estimation

- Initial state of change estimation is necessary and needs to be accurate
- Then current is integrated by using the Coulomb counting function
- SOC accuracy depends on measurement accuracy of both current and voltage



SOH Estimation

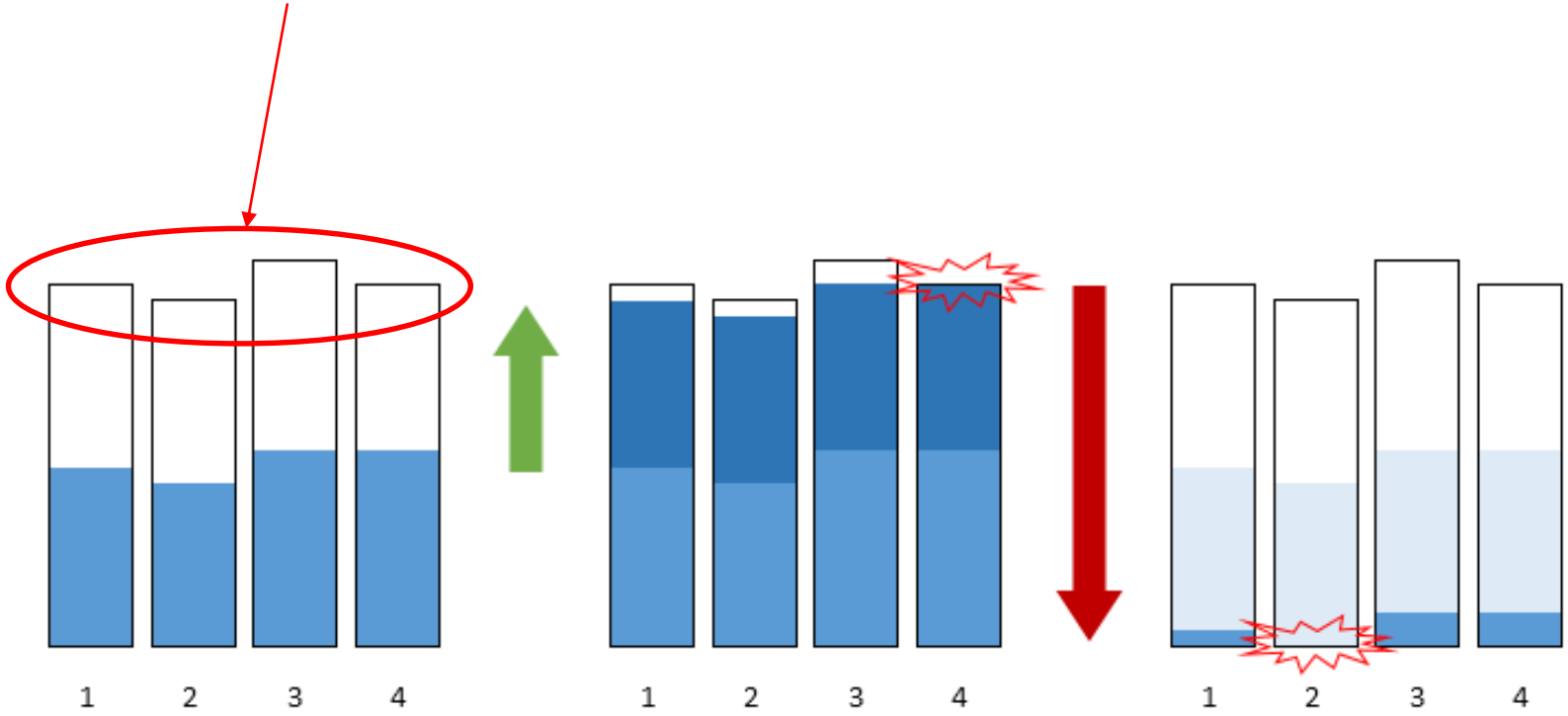
- State of Health = SOH
- Internal cell resistance is one of the many factors used to determine SOH
- SOH measurement requires a good synchronization of current and voltage measurements – typically 100 us



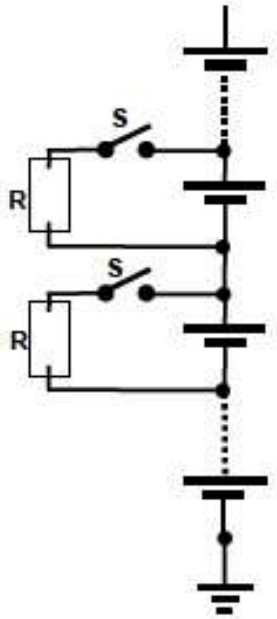
$$SOH = \left(\frac{R_i}{R_0}\right) * 100$$

Cell Capacity / Charging Mismatch

- Slight mismatch in capacity during manufacturing, additional mismatch during lifetime
- This results in wasted capacity during both charge and discharge
- Cell balancing is used to equalize SOCs



Passive Cell Balancing



Safety is Critical for Lithium-Ion Battery Applications

- Battery over-voltage (OV)
  - Secondary chemical reactions triggered: battery overheating, smoke emission, inflaming or explosion are very likely. OV typically close to 4 V
- Thermal runaway (OT):
  - Can start a positive temperature feedback mechanism, with the same consequences as an OV. OT typically close to 60 °C
- Battery under-voltage (UV):
  - Results in progressive breakdown of the electrodes substances. With LFP cells this may happen over a few cycles. UV typically close to 2 V
- Battery over-current (OC):
  - May result in the melting of the battery contactors. Major safety issue: impossibility to open the contactors and inability to drive the system to the disabled safe state
- Battery under-temperature (UT):
  - Loss of robustness of the contactors, reduction of the battery capability to provide current, dendrites. Need to limit current to avoid damage
- Need to comply with stringent safety standards –ISO 26262 for Automotive

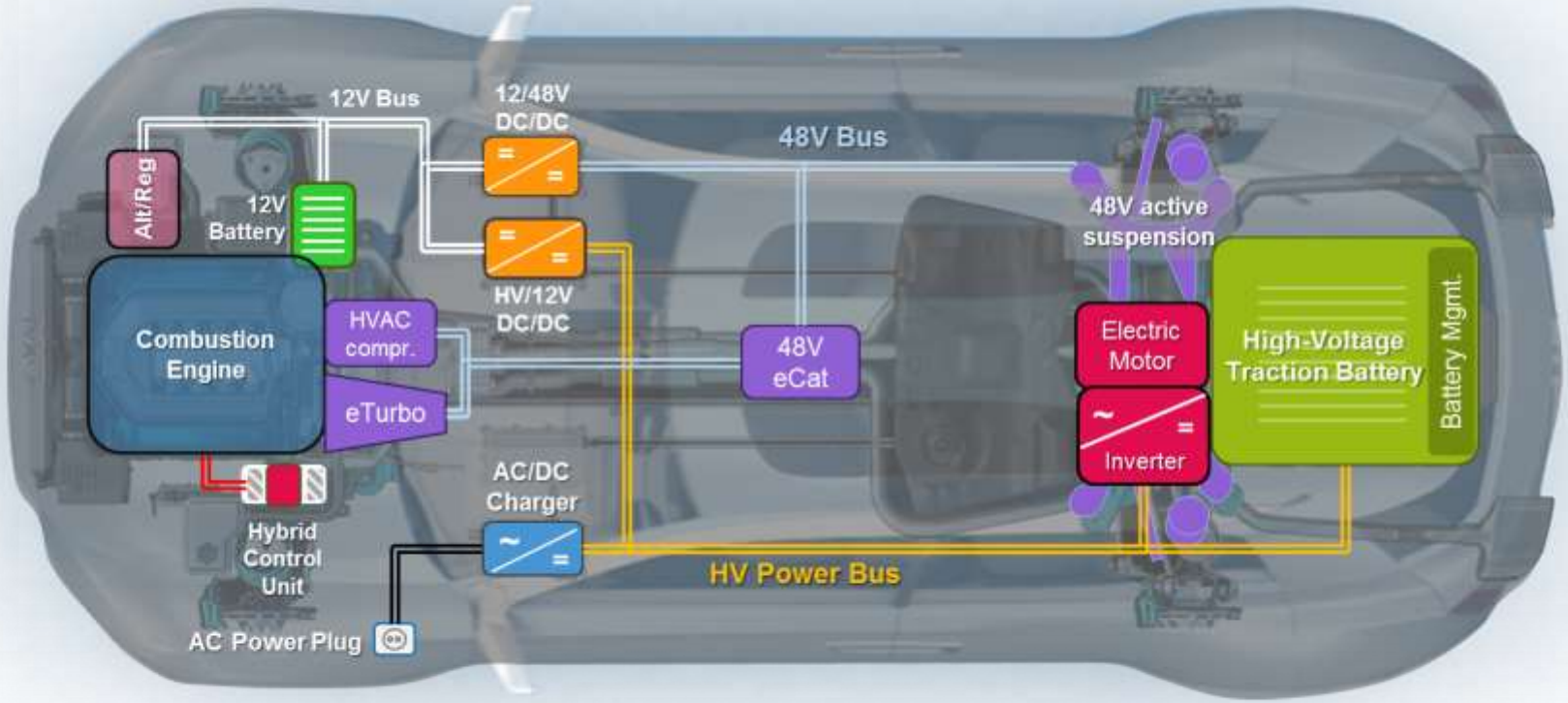
BMS System Solution Portfolio and Key Features

Mastering xEV Power for Efficient Energy Management

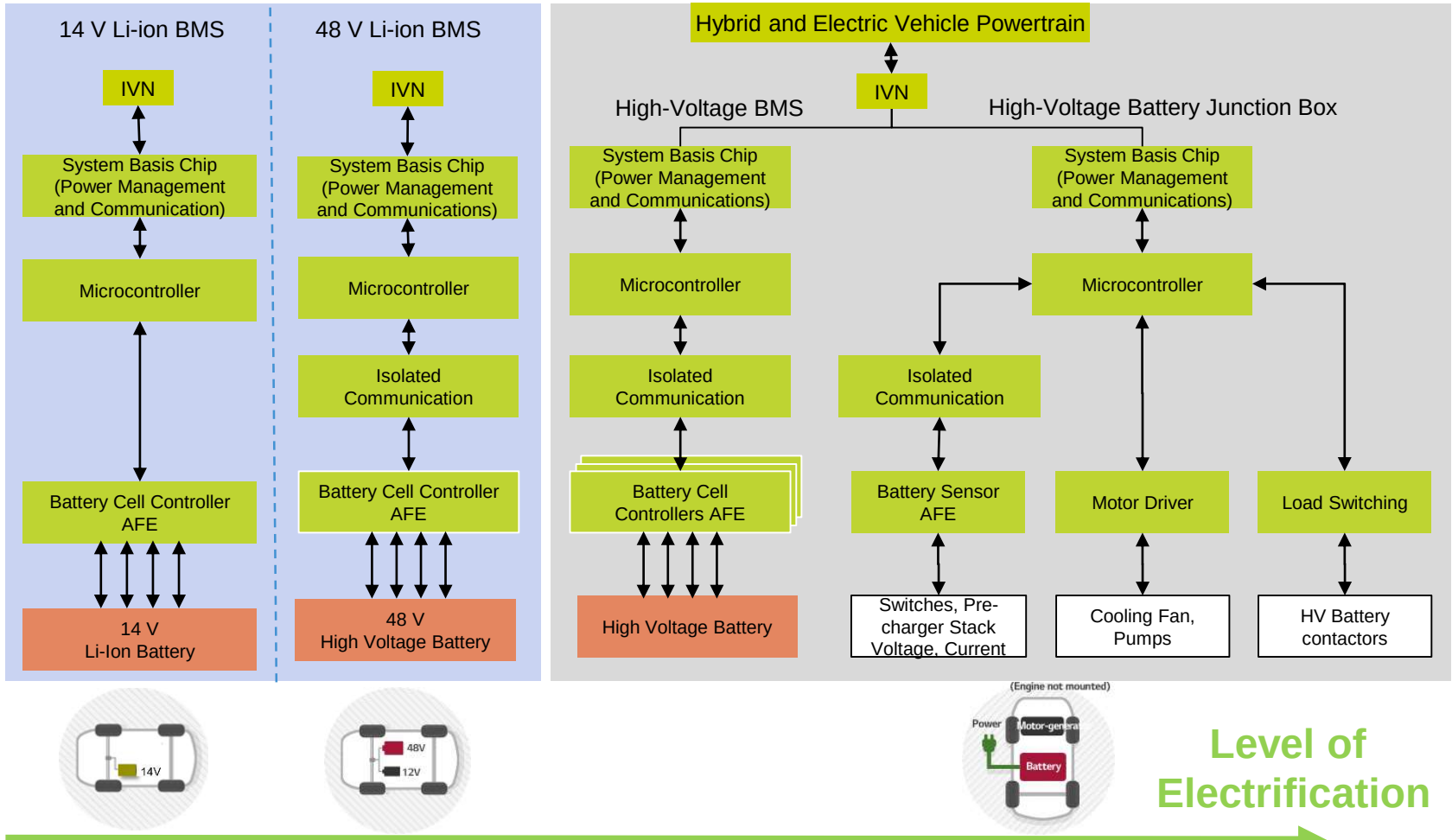
Optimized power system control solutions

Key differentiation points:

- Efficient system BOM
- Inherent functional safety
- Scalable system & SW
- Power efficient operation

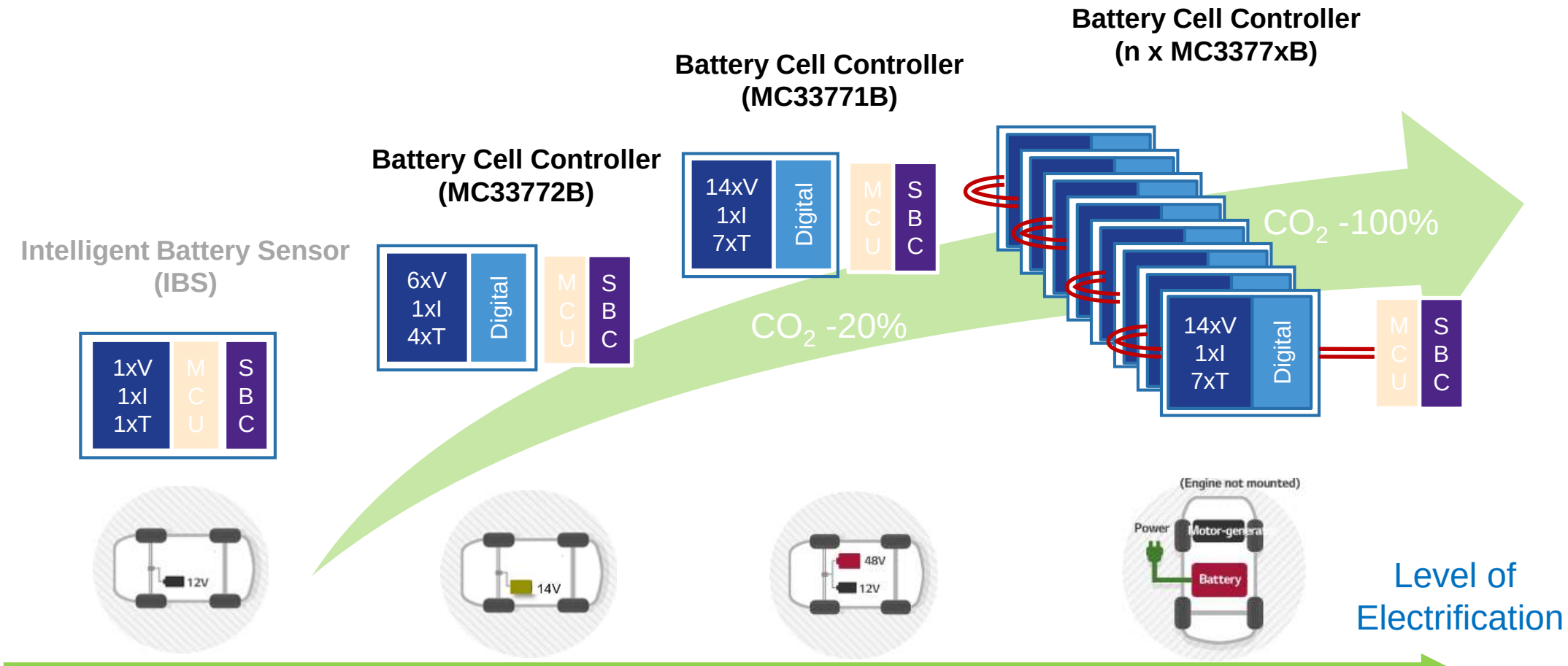


Automotive Li-ion BMS Application Overview



Scalable Battery Cell Controller Portfolio

Addresses all battery management configurations maximizing HW/SW reuse



Scalable Battery Cell Controller Portfolio

Targets Broad Range of Battery Management Applications

E-mobility

- Automotive
- Light EV
- Battery tram, ferry
- Urban delivery vehicles
- E-bike/scooter/snow scooter…
- …

Industrial

- Robot
- Autonomous guided vehicles
- Agricultural applications
- E-wheelchair
- …

Energy Storage System

- Smart grid ESS
- Home ESS
- UPS
- …

Consumer

- Hand tooling
- Garden tooling
- …

NXP MC33771/2 Battery Cell Controller Solution

Differentiating Points

Battery topology flexibility

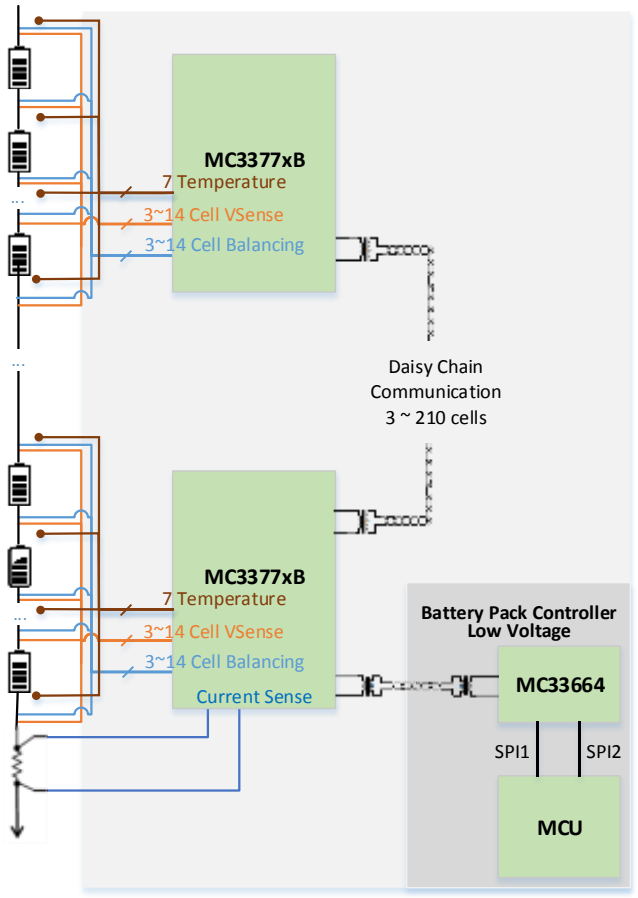
- Scalable SW & HW compatible BMS solution supporting **4 to 210 cells per daisy chain**
- MC33771B (7 to 14 cells) & MC33772B (3 to 6 cells) fully compatible
- Supporting centralized, distributed daisy chain, distributed CAN

High integration level

- Synchronized on-chip current sensor
- Synchronized on-chip coulomb counter
- Integrated passive balancing (300 mA per ch)
- Integrated power regulator

Fast & robust communication & DAQ

- 4.0 Mbps SPI or isolated 2.0 Mbps differential communication with transformer
- < 546 us conversion time for all measurements
- 3.6 ~ 4.1ms for sending command and read back **96** cell 16-bit voltage data



High lifetime measurement accuracy

- **± 0.8 mV** total voltage measurement error (after soldering & 1000 hrs HTOL aging)
- ± 0.5% total stack voltage measurement
- ± 0.5% accuracy integrated current sensor

Diagnosis and functional safety supporting ISO 26262 w/ single chip

- Single chip ASIL C capable (easy ASIL D)
- Sleep mode OV/UV and temperature monitor
- **> 40** integrated safety mechanisms detecting internal and external faults

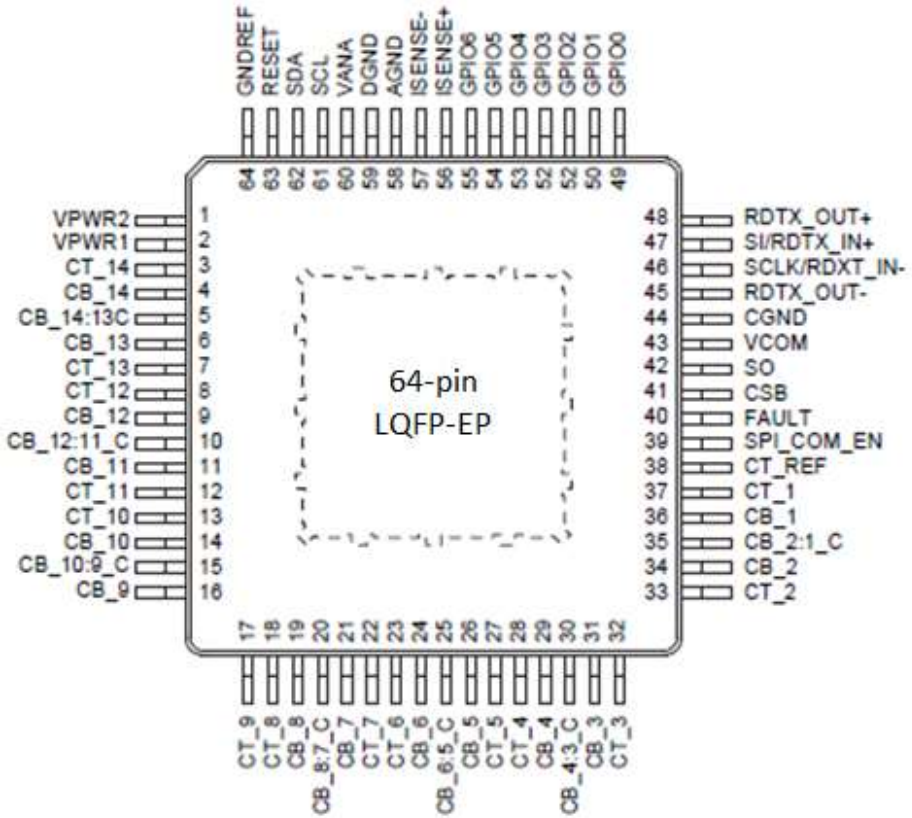
Automotive robustness

- ESD, EMC; Hot Plug, AEC-Q 100
- Temp range: -40°C to 105°C
- Operational low-power mode

MC33771 – 14 Cell Battery Cell Controller AFE

Key features

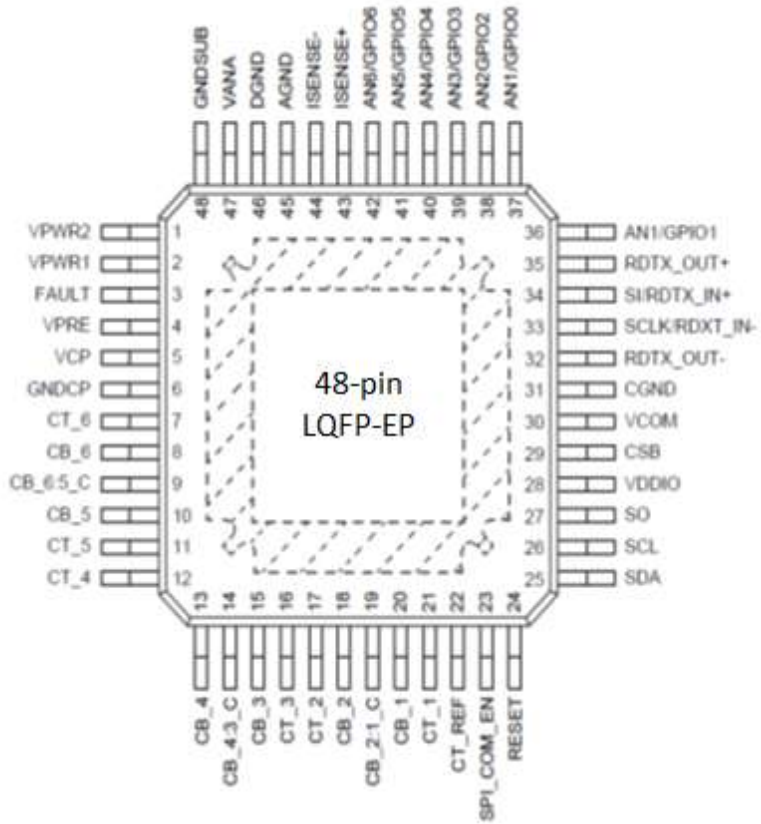
- **High-performance integrated functions**
  - Operating voltage: 9.6V ≤ VPWR ≤ 61.6 V operation, 75 V transient
  - Life-time guaranteed high accuracy 14 cell voltage measurement channels
  - 4.0 Mbps SPI or isolated 2.0 Mbps differential communication
  - Synchronized on-chip current measurement with ±0.5% accuracy (±1500 A)
  - Synchronized on-chip Coulomb counter (also in low-power mode)
  - 7 ADC/GPIO/temperature sensor inputs
- **Comprehensive integrated functional safety features**
  - Designed to support ISO 26262, up to ASIL D safety capability
  - Automatic OV/UV and temperature detection routable to fault pin
  - Integrated sleep mode OV/UV and temperature monitoring
  - OV/UV, over/under temperature fault verification
  - Detection of internal and external faults, i.e. open line, short, and leakage
  - Integrated balancing diagnostics
- **Quality & robustness**
  - AEC-Q100 automotive Qualified
  - Temp range: -40°C to 105°C
  - Operational low-power mode
  - Hot plug capable
  - EMC/ESD robustness



MC33772 – 6 Cell Battery Cell Controller AFE

Key features

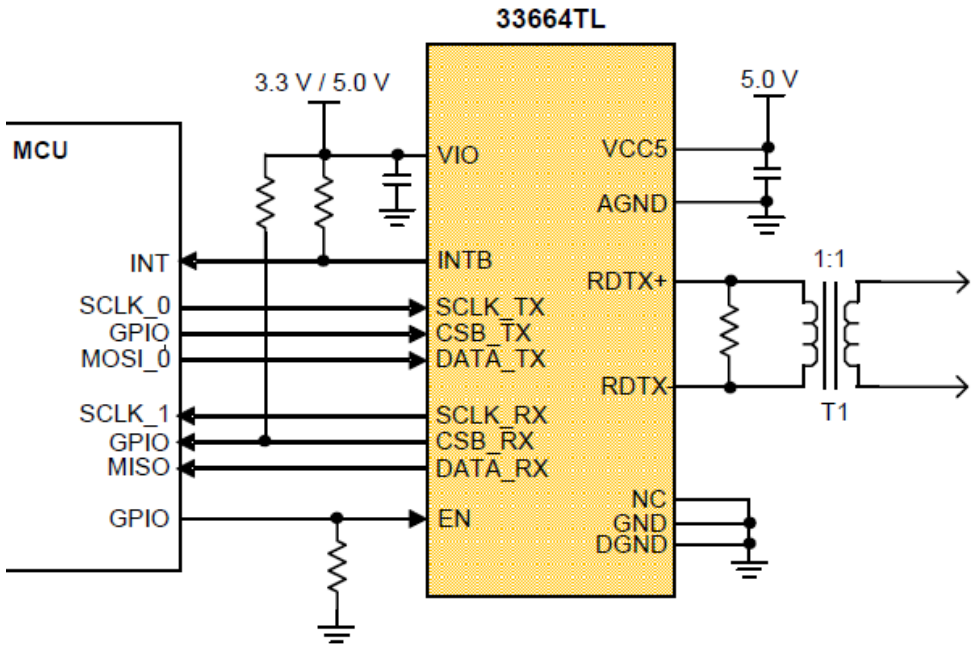
- High performance integrated functions
  - Operating Voltage:
    - 5V ≤ VPWR ≤ 30 V operation, 42V transient (for SPI communication)
    - 7V ≤ VPWR ≤ 30 V operation, 42V transient (for TPL communication)
  - Life-time guaranteed high accuracy 6 cell voltage measurement channels
  - 4.0 Mbps SPI or isolated 2.0 Mbps differential communication
  - Synchronized on-chip current measurement with ±0.5% accuracy (±1500A)
  - Synchronized on-chip Coulomb counter (also in low-power mode)
  - 7 ADC/GPIO/temperature sensor inputs
- Comprehensive integrated functional safety features
  - Designed to support ISO 26262, up to ASIL D safety capability
  - Automatic OV/UV and temperature detection routable to fault pin
  - Integrated sleep mode OV/UV and temperature monitoring
  - OV/UV, over/under temperature fault verification
  - Detection of internal and external faults, as open lines, shorts, and leakages
  - Integrated balancing diagnostics
- Quality & robustness
  - AEC-Q100 automotive Qualified
  - Temp range:
    - -40°C to 125°C (for SPI communication)
    - -40°C to 105°C (for TPL communication)
  - Operational low-power mode
  - Hot plug capable
  - EMC/ESD robustness

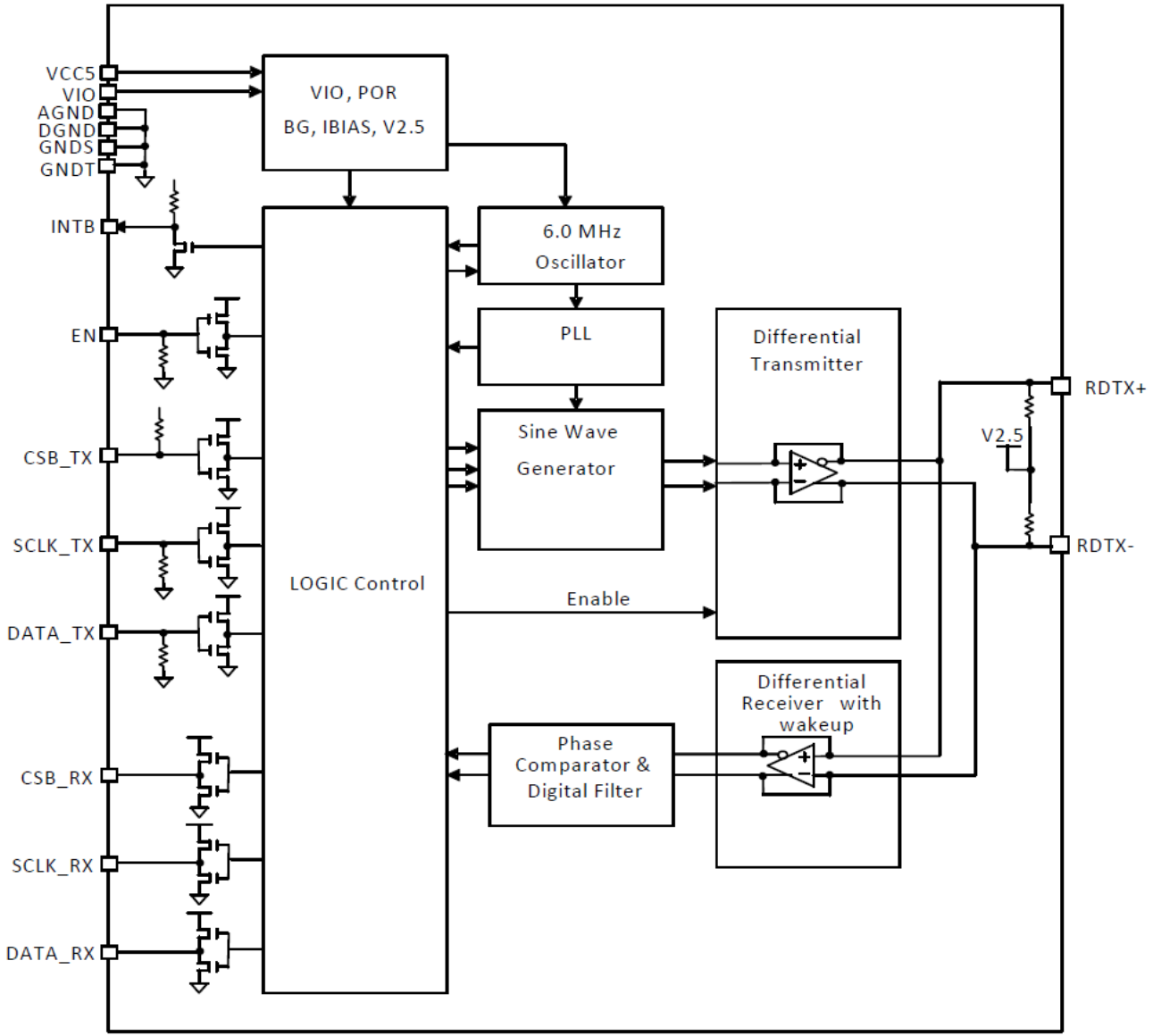


MC33664ATL Transformer Physical Layer

Features:

- 2 Mpbs Isolated Network Communication rate
- Dual SPI architecture for message confirmation
- Robust conducted and radiated immunity with wake-up
- 3.3 V and 5.0 V compatible logic thresholds
- Engineered for 5 meter, 15 node system
- Low current sleep mode with automatic wake-up
- Sine wave transmission for low radiated emission

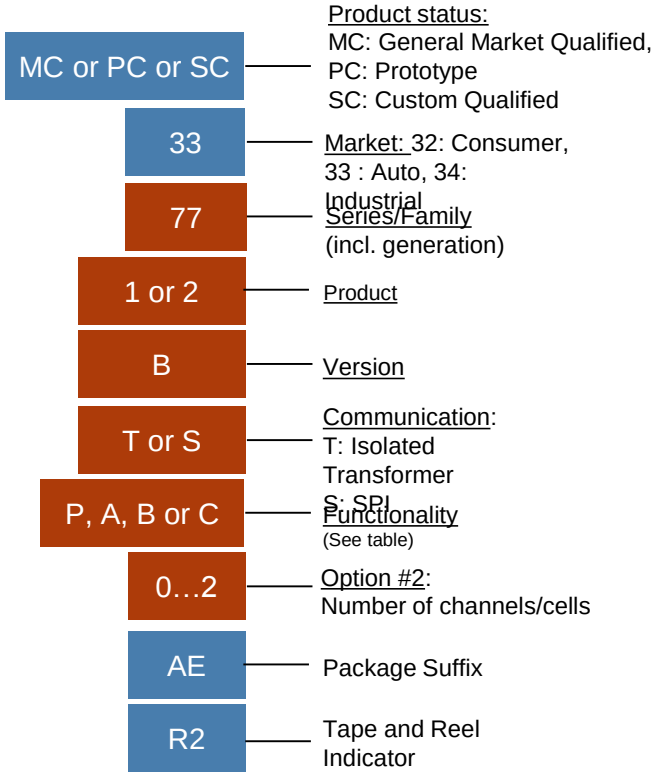




Portfolio - Battery Cell Controller

Premium for 14/ 48 V BMS	Advanced for HVBMS	Basic for redundancy	Current for HV junction/ switch box
MC3377xBS**P** (SPI comm) MC3377xBT**P** (TPL comm)	MC3377xBS**A** (SPI comm) MC3377xBT**A** (TPL comm)	MC3377xBT**B** (TPL comm)	MC33772BT**C** (TPL comm)
Precise differential cell voltage measurement	Precise differential cell voltage measurement	Precise differential cell voltage measurement	Precise differential cell voltage measurement
Cell OV/UV	Cell OV/UV	Cell OV/UV	Cell OV/UV
Synchronized current measurement	Synchronized current measurement	Synchronized current measurement	Synchronized current measurement
Coulomb count	Coulomb count	Coulomb count	Coulomb count
Cell balancing	Cell balancing	Cell balancing	Cell balancing
Temp measurement, O/U temperature	Temp measurement, O/U temperature	Temp measurement, O/U temperature	Temp measurement, O/U temperature
Functional verification & diagnostics	Functional verification & diagnostics	Functional verification & diagnostics	Functional verification & diagnostics
Communication • 2 MHz half duplex differential • SPI 4 MHz	Communication • 2 MHz half duplex differential • SPI 4 MHz	Communication • 2 MHz half duplex differential • SPI 4 MHz	Communication • 2 MHz half duplex differential • SPI 4 MHz
Package: 64/48-ld LQFP EP	Package: 64/48-ld LQFP EP	Package: 64/48-ld LQFP EP	Package: 48-ld LQFP EP
Temp range: -40 C to +105C	Temp range: -40 C to +105C	Temp range: -40 C to +105C	Temp range: -40 C to +105C

MC3377xB Battery Cell Controller Part Numbering



Functionality & Communication

Part Number	Precise differential cell voltage measurement		Temperature		Cell Balancing	Current Channel	Coulomb counter	Communication	
	CTx	Cell OV/UV	Measurement	OT/UT				SPI	Half Duplex Differential
MC3377xBTPy	✓	✓	✓	✓	✓	✓	✓	✓	✓
MC3377xBSPy	✓	✓	✓	✓	✓	✓	✓	✓	NO
MC3377xBTAy	✓	✓	✓	✓	✓	NO	NO	✓	✓
MC3377xBSAy	✓	✓	✓	✓	✓	NO	NO	✓	NO
MC3377xBTB1	✓	✓	NO	NO	NO	NO	NO	✓	✓
MC33772BTC0	NO	NO	✓	✓	NO	✓	✓	✓	✓

Number of precise differential cell voltage measurement channels

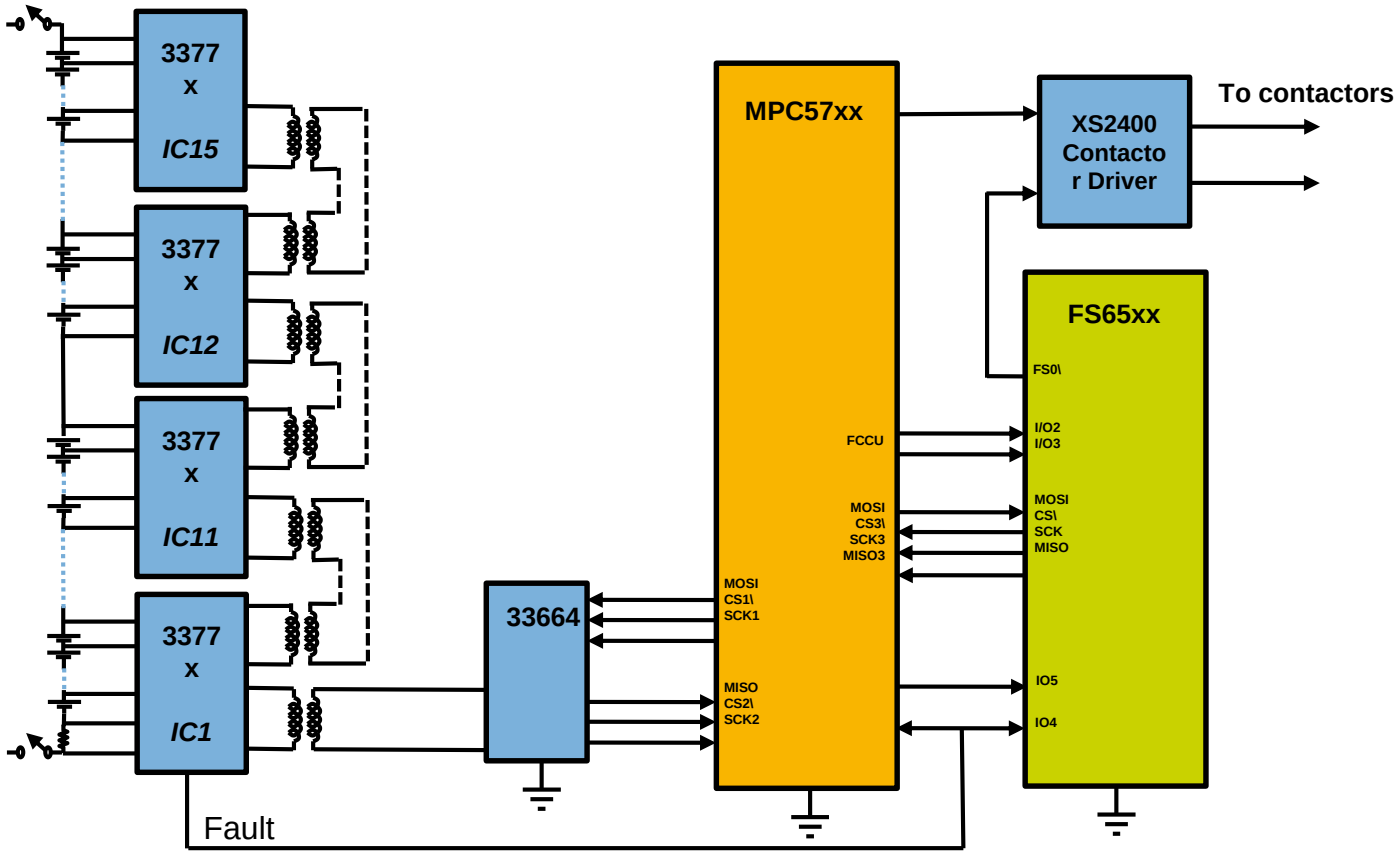
	x = 1	x = 2
y = 0	N/A	0
y = 1	14	6
y = 2	8	4

Typical Automotive Applications

xEV Battery Management System Solution

High accuracy platform scalable across voltage and functional safety

- MC3377x battery cell controller with best in class life-time measurement accuracy, BOM integration, and functional safety support
- MC33664 transformer physical layer high speed isolated transceiver
- FS65 robust fail-silent SBC with operation from 36 V down to 2.7 V
- MPC5775B secure multi-core 32-bit lockstep MCU with advanced timers and ADCs
- XS2400 60 V fully protected and programmable quad/dual high side driver



MPC5775B Microcontroller: Ultra-Reliable MCUs Built on Power Architecture® Technology

Performance – High-performance and integration for powertrain control within a power envelope of previous-generation MCUs

Advanced timers and ADCs – (Optional) eTPU timers and Sigma-Delta ADC converters allow for advanced filtering using on-chip knock hardware

Quality, security and redundancy – AEC-Q100 qualification testing, on-chip security encryption protection using CSE and TDM for tamper proofing, and lockstep cores help support ASIL-D and SIL-1 functional safety (ISO26262/ IEC61508) requirements

Features

- AEC-Q100 Grade1, Ta 125°C
- Ethernet, CAN-FD
- Precision timers and ADC
- Ultra-Reliable MCU

Success Stories

- Engine management
- Hybrid and electric motors
- Transmissions

Target Applications

- Battery management
- Safety critical applications
- Electric DC motor control
- Ethernet connectivity
- Aerospace engines

Product Longevity

SAFE ASSURE

For more information, visit NXP.com/MPC5777C

MPC5775B Specifications

Flash	4.25 MB	**Timer/PWM**	32ch eMIOS
RAM	512 KB	**Other**	128-ch DMA, ECC, 12ch SENT, Zipwire®, MSB, 2ch PSI-5
Core	2x z7(1 in LS)	**Analog**	70-ch ADCs and 12-ch SD-ADCs
Speed	Up to 220 MHz/core	**Ethernet**	Ethernet (FEC)
Package	416 and 516 MAPBGA	**SCI/SPI**	5/5
Op Range	3.0 V - 5.5 V	**CAN**	2 x MCAN-FD and 4 x FlexCAN
Temp	-40 to +125 °C	**Security**	CSE, TDM, WDOG, CRC

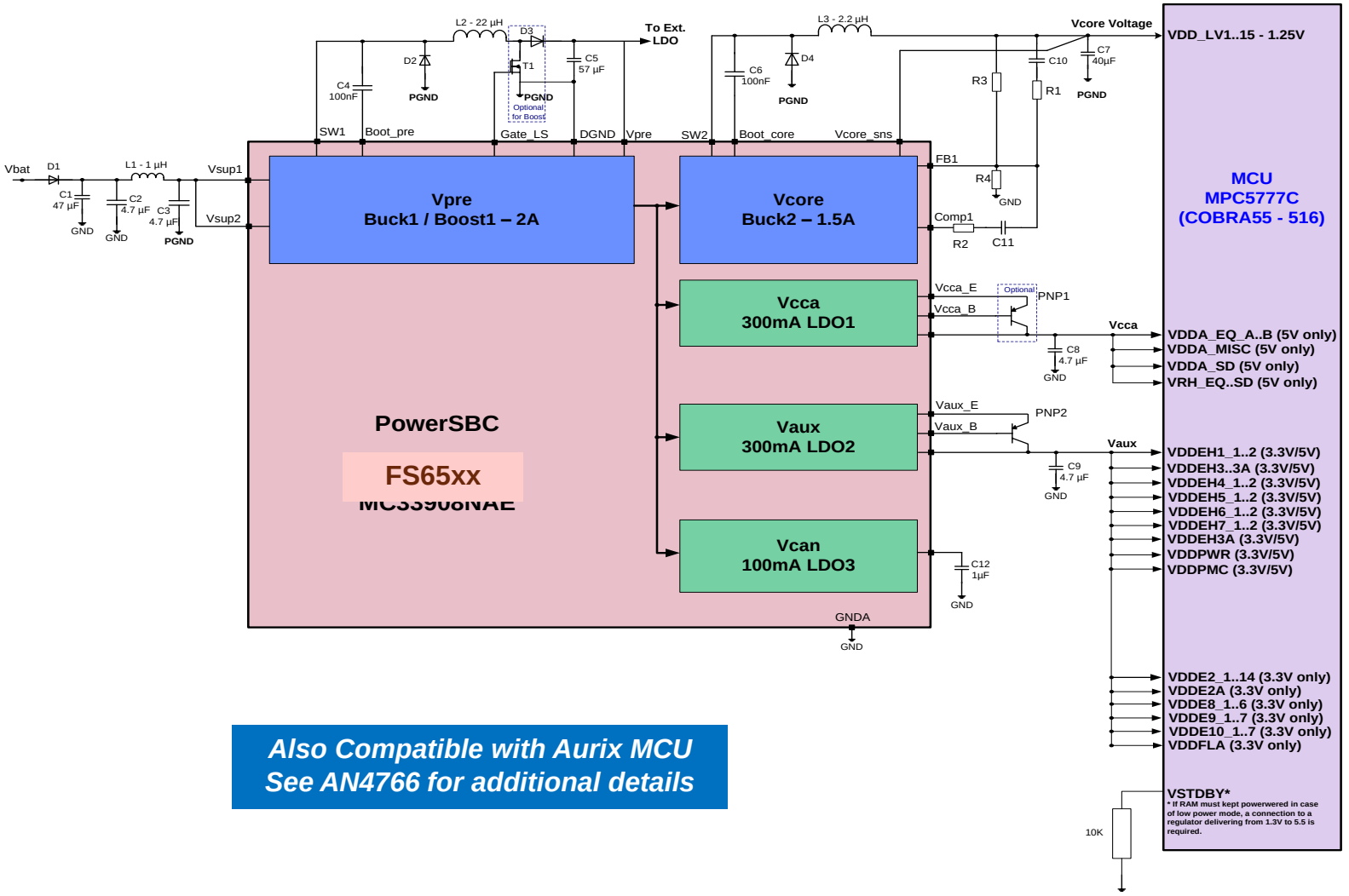
Orderable Samples

Part Number	Temp Range	Package
SPC5775BDK3MME2	-40 to +125 °C	416-pin MAPBGA

Evaluation Tools

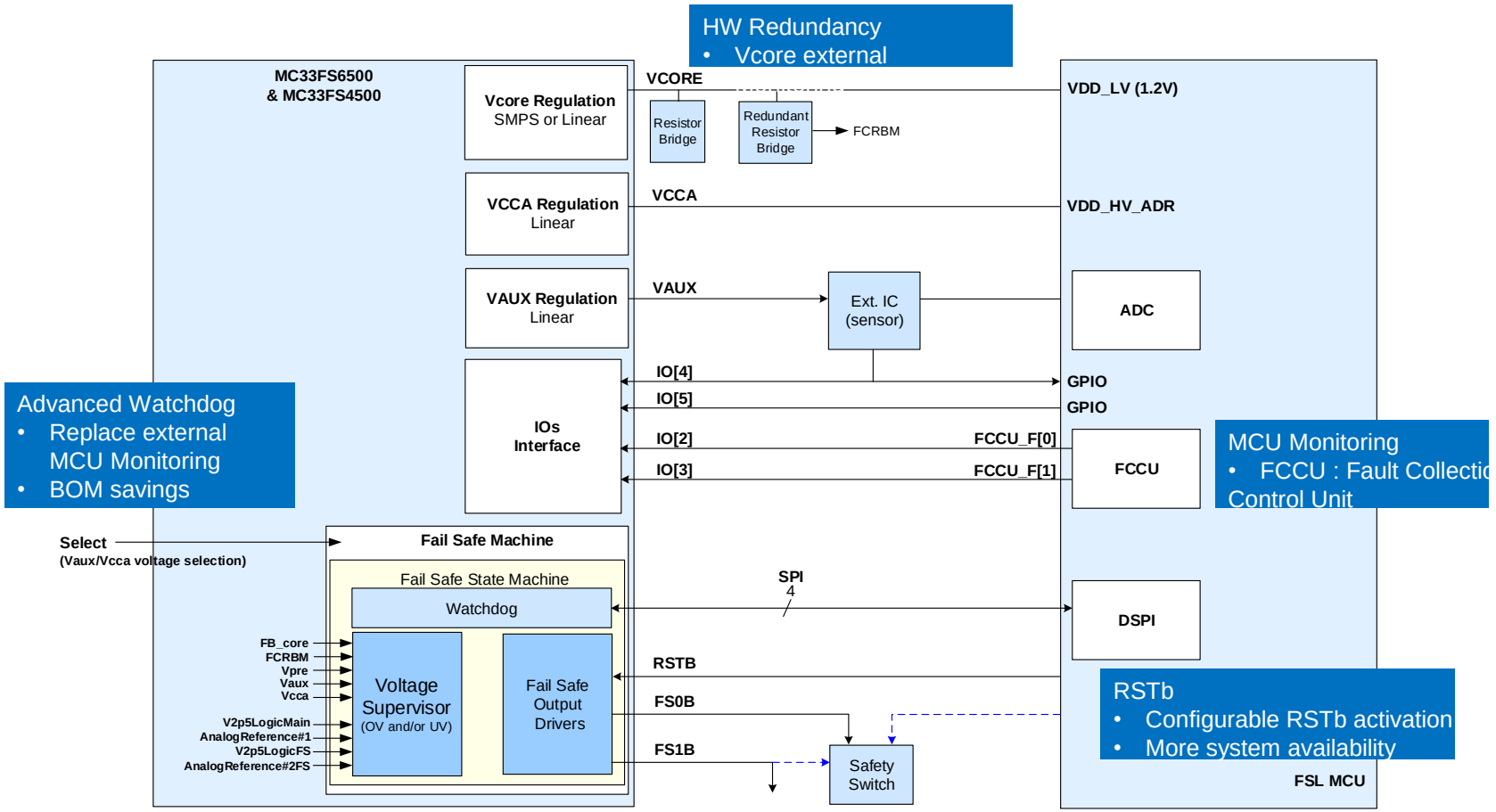
Evaluation Tools	MPC5775BE-416DS 416-pin adapter	MPC57xxxMB motherboard		
Drivers	NVM/ Flash drivers	AUTOSAR MCAL drivers (SDK)		
	S32 Design Studio – S32DS			
Partners	GreenHills, WindRiver (Diab)	Lauterbach	iSystem	P&E Micro, ETAS and PLS

FS65xx: Safety SBC Power Tree



Also Compatible with Aurix MCU
See AN4766 for additional details

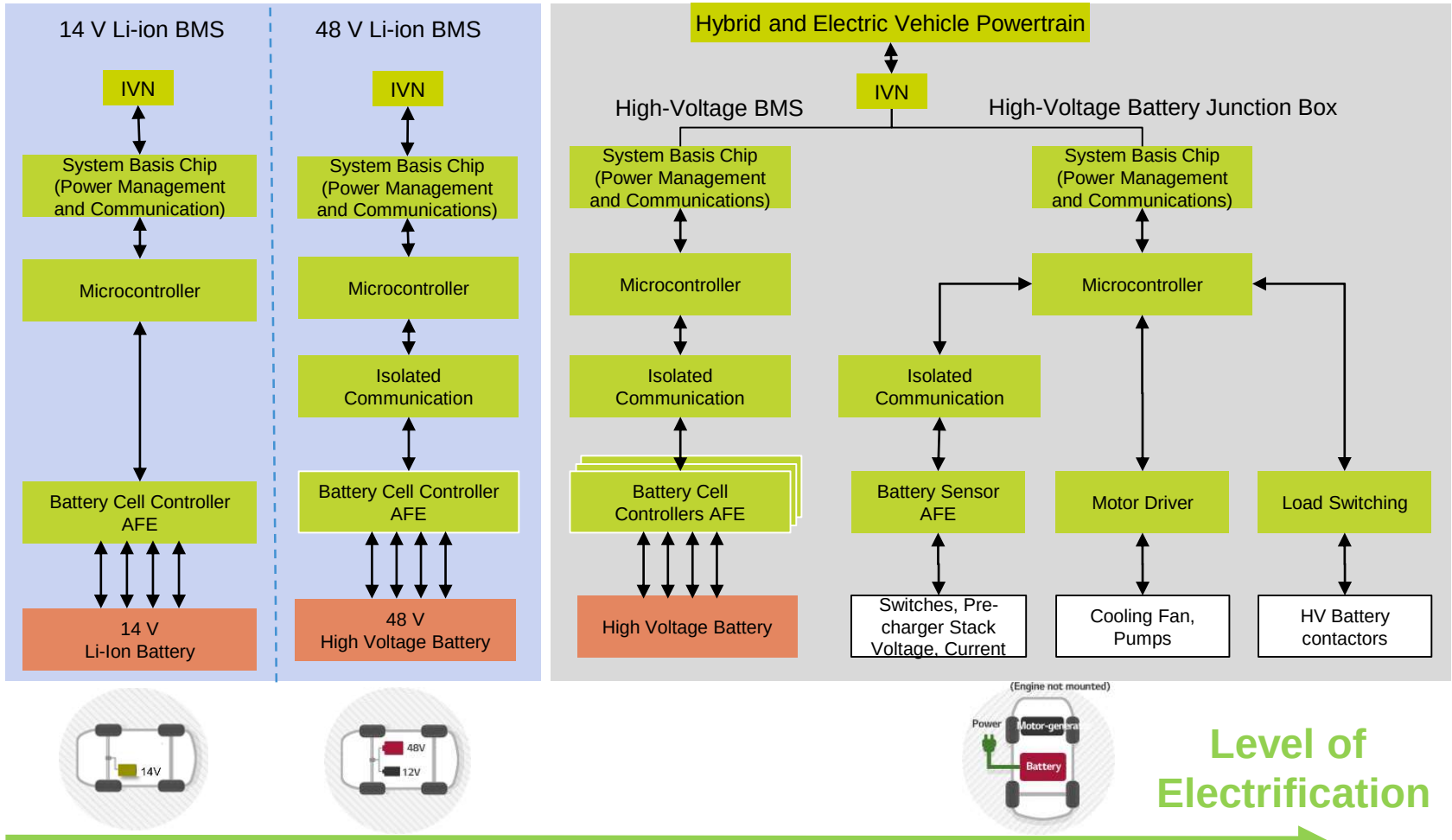
FS65 / FS45 : Functional Safety Block Diagram



Independent Fail Safe State Machine
- Power Management Monitoring Unit (UV / OV)
- Analog & digital Built In Self Test to minimize Latent Faults
- Own supply to reduce common cause failure

Fail Safe Pin (FS0b) :
- Redundant system Fail Safe enabler
- Second Fail Safe pin to assert safety path with configurable delay after failure

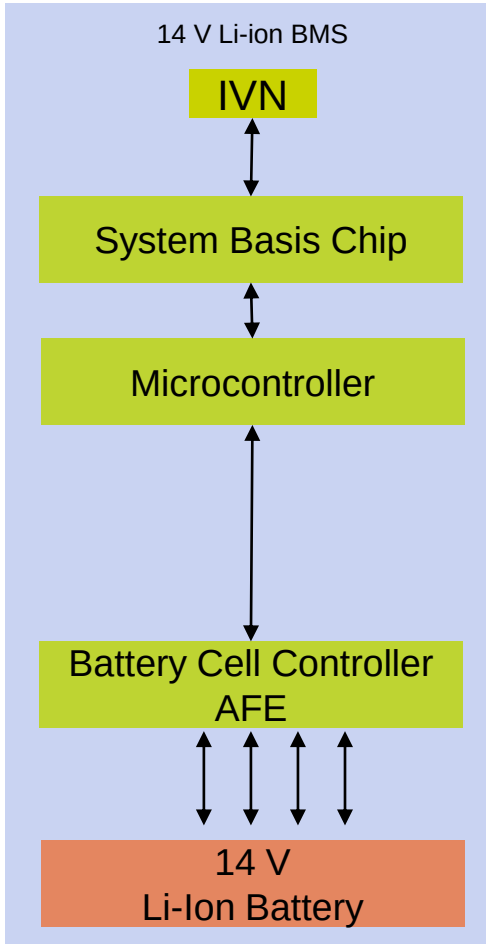
Automotive Li-ion BMS Application Overview



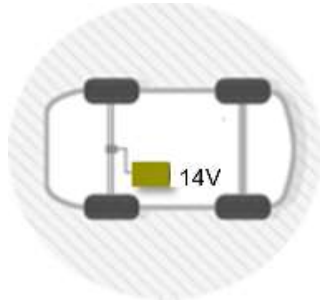
Single-Chip 14 V Li-Ion BMS Solution

Key features

- Single-chip 14 V BMS AFE
  - 3~6 cell voltage measurement (Error <0.8 mV)
  - Integrated balancing FET (<300 mA)
  - 7 GPIO / AIN (<10 mV Abs. Error)
  - Integrated current sensing (±0.5%)
  - Integrated Coulumb counting
- Dual MCU and safety PMIC architecture
  - S32K144 – Cortex M4F MCU
  - KEA – Cortex M0+ MCU
  - FS45 – Safety & Power Management System IC
- Target ISO 26262 ASIL-C and IEC 61508 SIL 3 System level certification



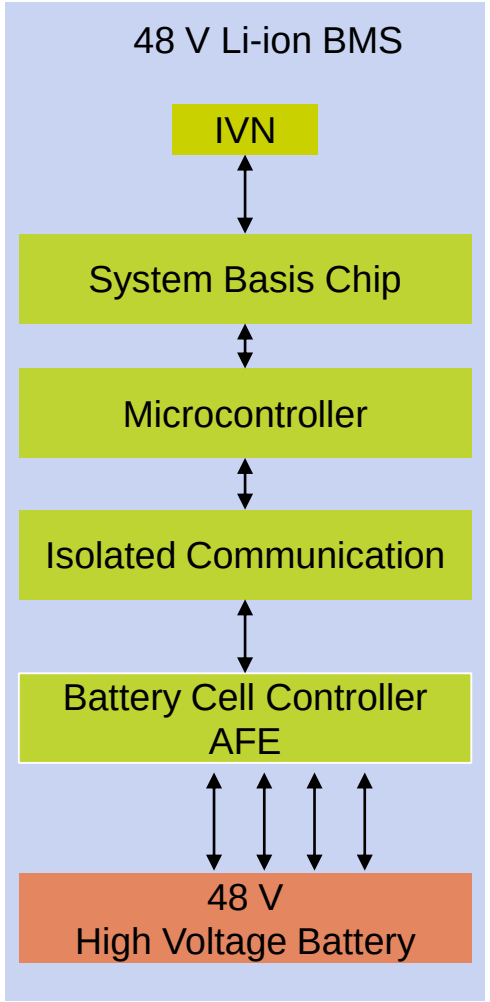
Advanced Start-Stop
14 V Li-ion Battery



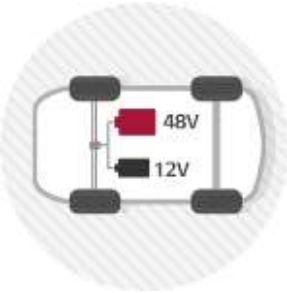
Typical 48 V Li-Ion BMS application

Key features

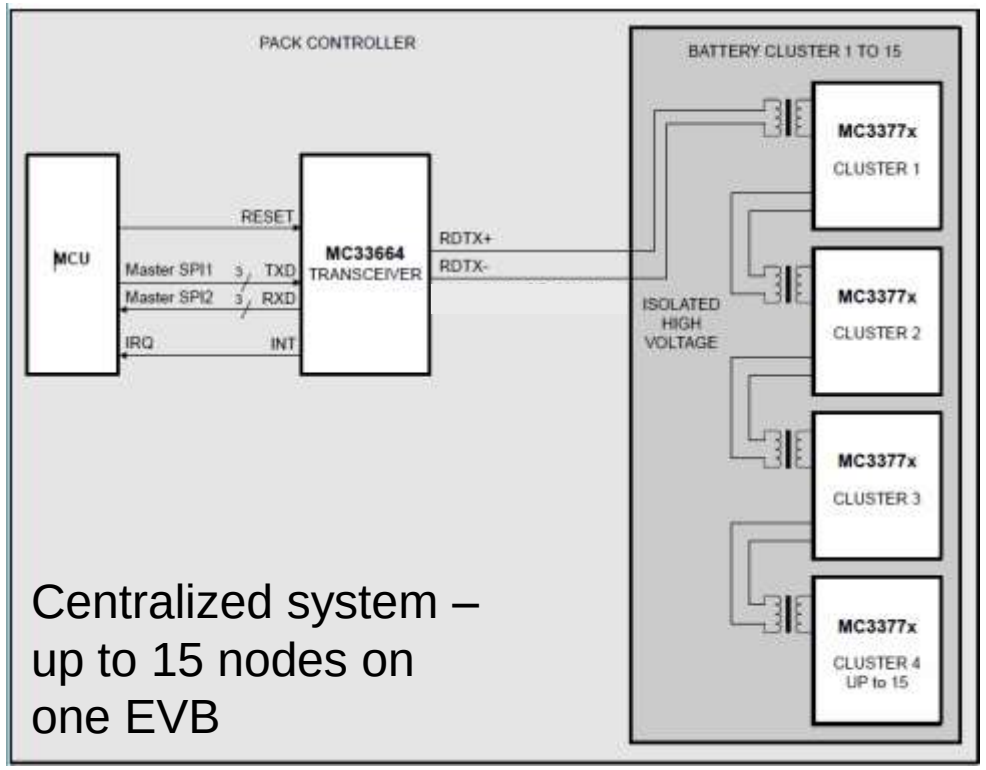
- Single-chip 48 V BMS AFE
  - 7~14 Cell voltage measurement (Error <0.8 mV)
  - Integrated balancing FET (<300 mA)
  - 7 GPIO / AIN (<10 mV Abs. Error)
  - Integrated current sensing (±0.5%)
  - Integrated coulumb counting
- High functional safety solution
- Scalablable to support 20-cell LTO with stacked MC33771 + MC33772 solution



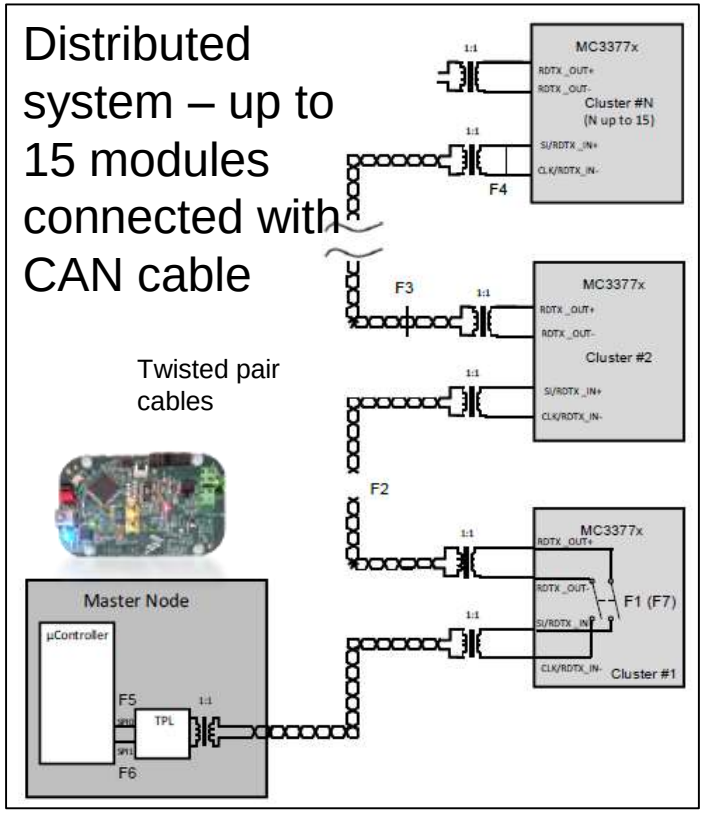
Single-chip BMS for 14-cell system



TPL Centralized / Distributed Architectures



Centralized system – up to 15 nodes on one EVB



Cell terminal

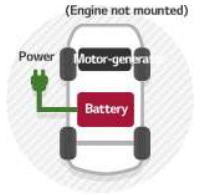
Cell terminal

Cell terminal

- Longer measurement cable length to cells
- Increase EMC impact on measurement cables
- Higher cell wiring cost – lower com cost

- Shorter measurement cable length to cells
- Higher com cost (2 transformers + wiring)
- Reduce EMC impact on measurement cables

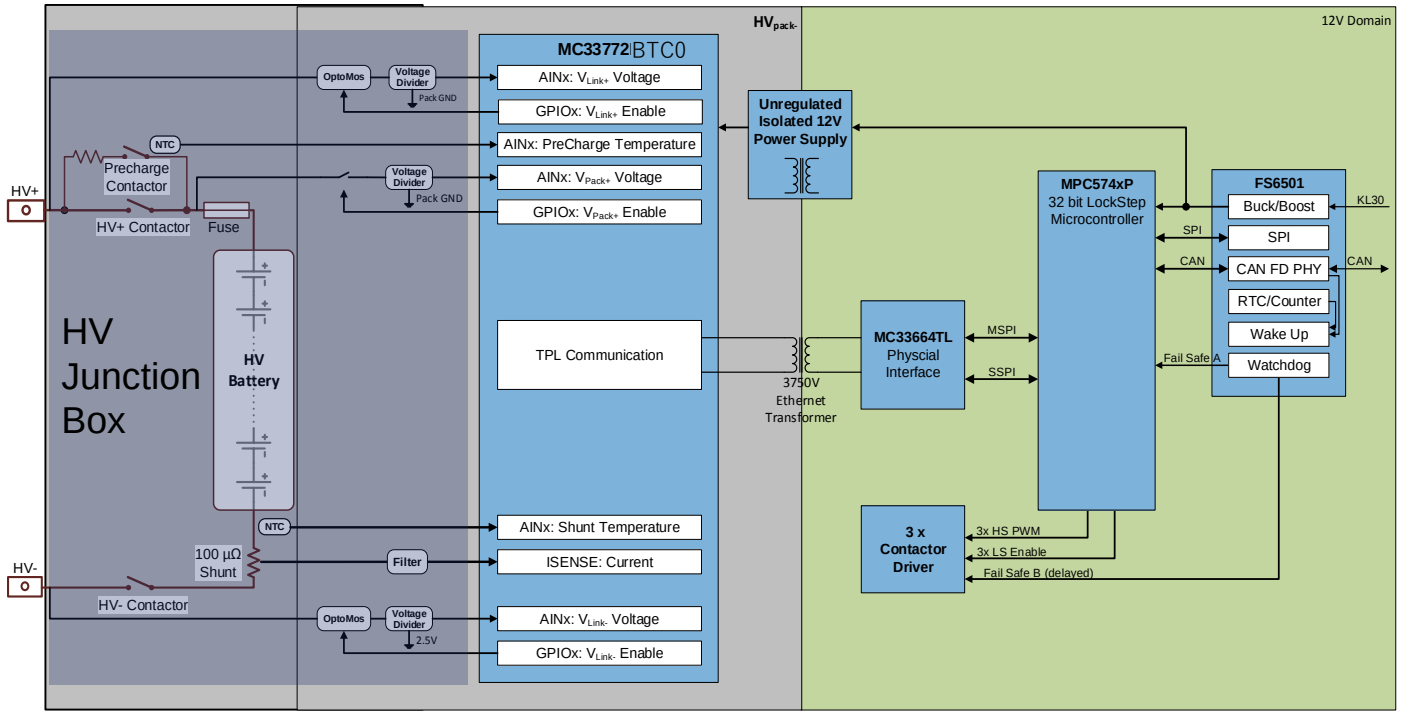
Typical HV Battery Junction/Switch Box Controller



EV/PHEV
High Voltage Li-ion Battery

Key Features

- Dedicated AFE solution for junction box monitoring:
  - 7 GPIO / AIN (<10 mV Abs. Error)
  - Integrated current sensing (±0.5%)
  - Integrated coulumb counting
- Single-chip ASIL-C AFE
- Dual-MC33772BTC0 supports redundant current sensing with 14 GPIO/AIN



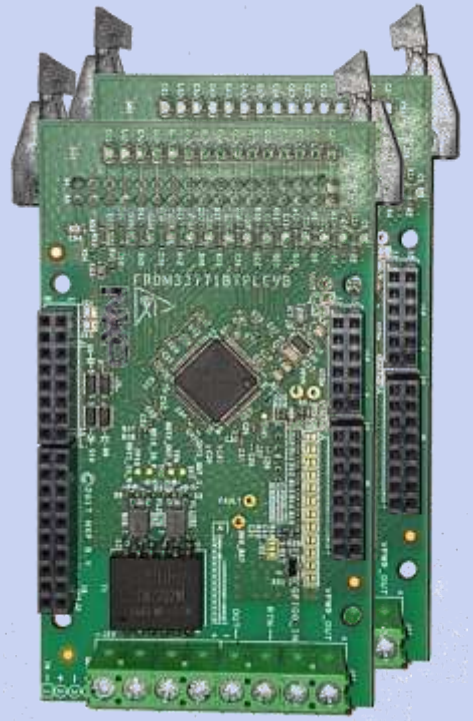
BCC Enablement Tools & Reference Designs

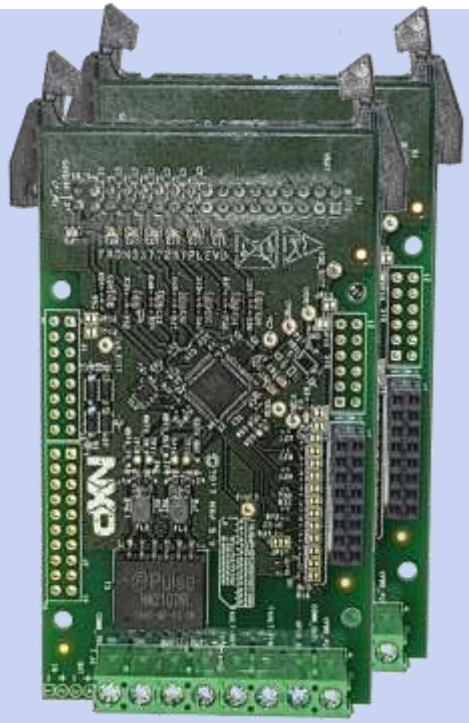
Battery Cell Controller Evaluation Boards

MC33664 Freedom Kit
- FRDM33664BEVB

MC33771B Evaluation Kits (14 cell)
- FRDM33771BTPLEVB
- FRDM33771BSPIEVB

MC33772B Evaluation Kits (6 Cell)
- FRDM33772BTPLEVB
- FRDM33772BSPIEVB



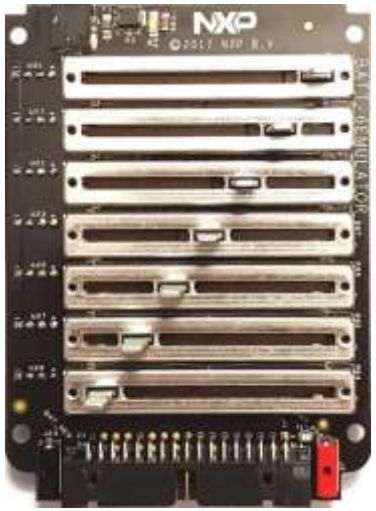


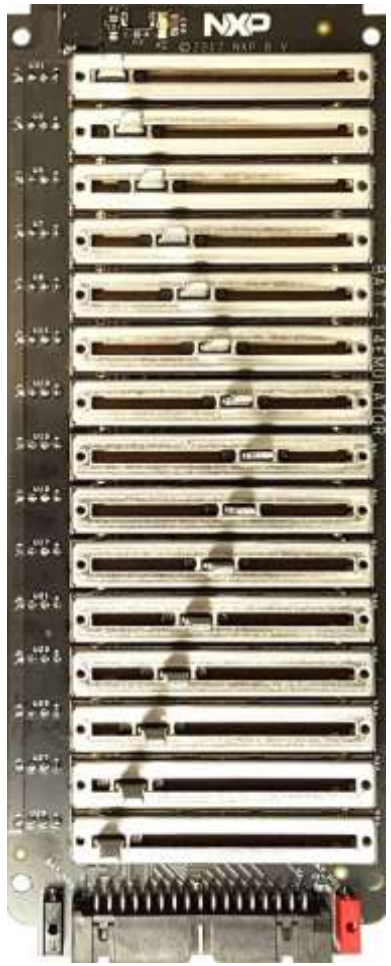
Available via nxp.com

Battery Pack Evaluation Boards

14-Cell AAA Battery Pack
(compatible with 6-Cell)

6 / 14-Cell Battery
Emulator



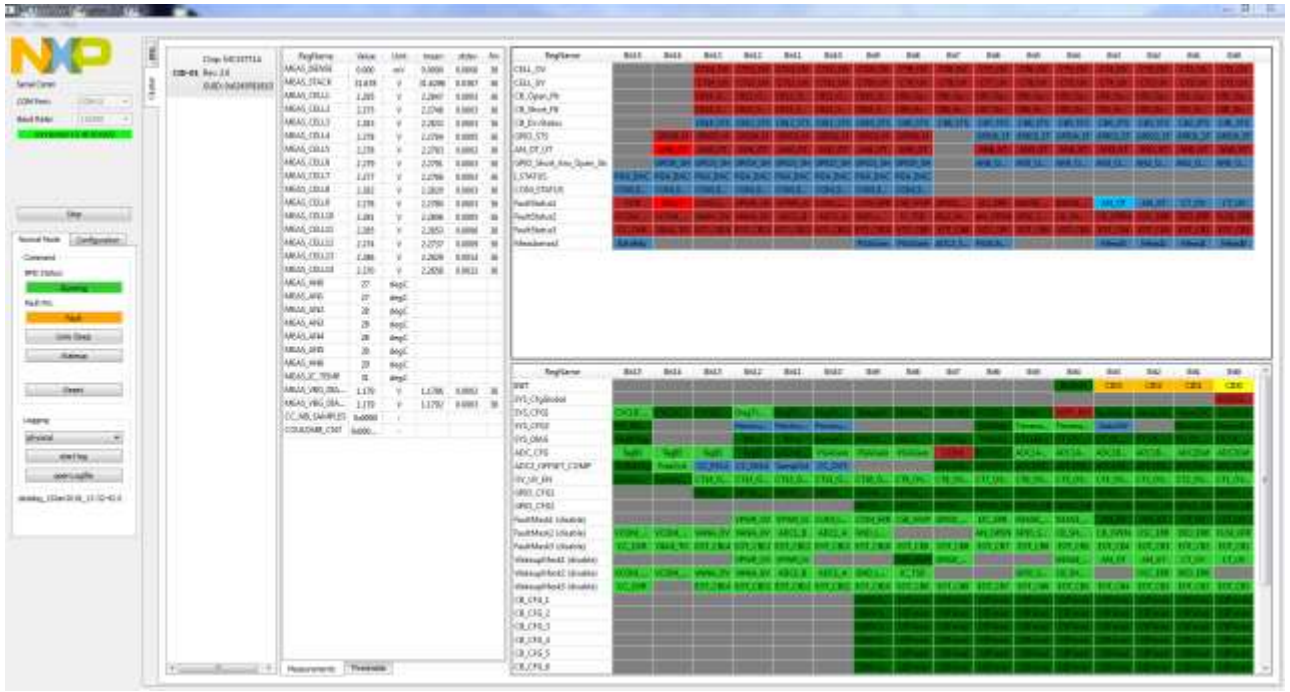


Available via nxp.com

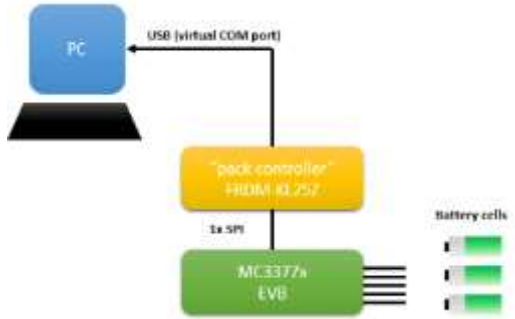
NXP BCC Evaluation GUI

Available Now

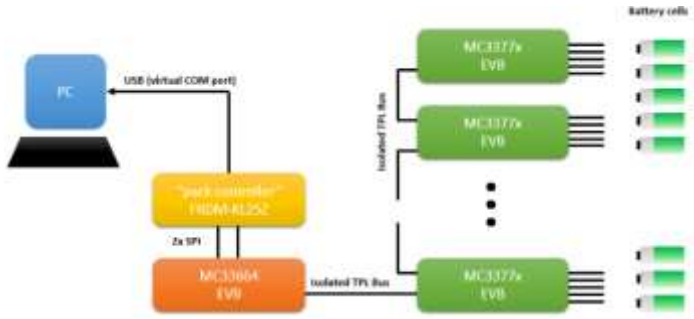
PC GUI SW



SPI set-up



TPL set-up



Battery Cell Controllers Reference Design

High Voltage Battery Pack Controller

- Full featured Hardware + Software set
- Complete system with Microcontroller + PowerSBC + BCC + TPL
- Easily scalable from 1 to 15 MC33771 devices
- Configurable MC33771 communication: SPI or TPL
- Supports PowerPC and Kinetis uC families
- Easy microcontroller swap through uC daughter card
- Supports CAN communication with Master ECU

Distributed High Voltage Battery Pack Controller

- Available with MC33771 and MC33772
- Distributed system
- Micro controller
- ASIL C

Centralized High Voltage Battery Pack Controller

- 98 Cell pack controller – 7xBCC14
- Centralized system
- Micro controller
- Safety features

Battery Cell Controllers Reference Design

ASIL-D Safety BMS

- 6 cells Li-Ion BMS with MC33772 battery cell controller
- Target ISO26262 ASIL-D and IEC 61508 SIL 3 System level certification
- Dual MCU and safety PMIC architecture
  - S32K144 – Cortex M4F MCU
  - KEA – Cortex M0+ MCU
  - FS45 – Safety & Power Management System IC

48 V Li-Ion Auto Battery

- 48 V single-chip BMS solution with MC33771
- CAN output
- ASIL C
- AutoSAR SW

14 V Li-Ion Auto Battery

- 14 V single-chip BMS solution with MC33772
- ASIL C

Electric Bike Pack

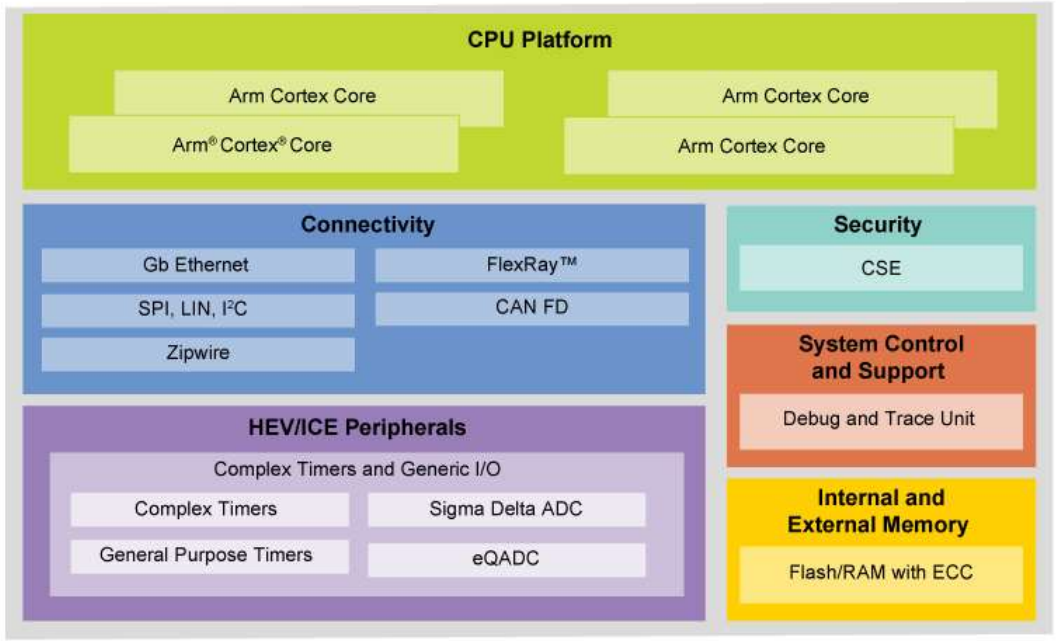
- 36 V – 10-cell pack – 1 BCC14
- Kinetis KE06
- Charging control
- Monitors voltage, current, temperature
- Passice cell balancing
- Estimation of SOC, SOH
- Communication with LIN, CAN

(under development)

GreenBox: Vehicle Electrification Development Platform

Development platform with advanced performance, peripherals and multi-core Arm® environment for engineers to begin development on NXP's next generation of Hybrid Electric Vehicle (HEV) MCUs. GreenBox supports the development of HEV and motor control applications with two models:

- S32PDEVPL-KITC includes the peripheral board for HEV and internal combustion engine applications.
- S32SDEVPL-KITP includes the peripheral board for motor control and battery management applications.



Features

- High-performance compute board with 4 x Arm Cortex® A53-based cores with NEON operating at up to 1 GHz
- Peripheral control board with the complex timers, filters and analog modules to support HEV or motor control applications
- Numerous automotive communication interfaces: Gb Ethernet, CAN-FD, LIN, UART, JTAG, SDHC, PSI5, SENT
- Interfaces directly to standard and complex timers and ADC modules
- Fully regulated switching power supply with 12 V power input

Summary

Product Differentiation

NXP's battery cell controller solution enables reliable, safe and BOM optimized Li-Ion cell control applications with low-cost, high-speed isolated communication

Low BOM & overall system cost	High-performance, high-speed isolated communication	Automotive robustness
No need for external current sensor, external balancing, diagnostics and functional safety monitor.	Avoid expensive isolated CAN communication while maintaining isolation, high-speed and safe communication.	No damaging of devices at customer assembly. Avoids external components for robustness protection.

• Current measurement
• Coulomb counting
• Current wakeup
• Current voltage synchronization
• Integrated passive balancing
• Integrated diagnostics and functional safety
	• Sine phase encoded asynchronous communication
	• Safe protocol:
	  • 8bitCRC
	  • Bit count
	  • Cluster ID
	  • TAG ID
	  • Data address
	• High speed : 2 Mbps TPL, 4 Mbps SPI
	• High immunity, low radiated emissions
	• Robust design for BCI>200 mA
	• Voltage isolation level: >3750 Vrms
		• Proven automotive high volume process and package technology
		• Protected cell terminal inputs, power and ground pins
		• Hot connect

Contact & Support

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Further supports via

  - NXP Community: https://community.nxp.com/

- Technical Documents Shared under NDA via NXP DocStore

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