MC3377x Battery Cell Controllers for Battery Management Systems

Hunter Zhu

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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

Daimler to recall 3 million diesel cars across Europe in a bid to cut emissions

The company, which owen the Hernedes and Smart brands, said that its loand of management had approved measures to competitions, including egzons of investment.



Britain to ban sale of all diesel and petrol cars and vans from 2040

theguardian

Plans follow French commitment to take polluting vehicles off the road owing to effect of poor air quality on people's health



O Menders Influent parts an analysis point (argent incommendation) in a particularity in (R. Paning-paper Parts Manufacture) (Delta (Integra))

Renault plans foray into energy market with mega battery



Auto makers being sued for not complying with emissions standards

Many countries plan to ban diesels and petrol cars in the next 20-30 years Daimler lays foundation for one of the biggest and most modern battery factories in the world



Some car makers investing in battery production to secure supply

Car makers announcing partnerships to address emerging markets

Many car makers announcing new hybrid/EV models in future line up Renault, Nissan, Dongfeng Motor partner to develop electric cars in China



Volvo, Betting on Electric, Moves to Phase Out Conventional Engines



Volvo isn't the only company betting big on electric cars - here are 11 SUVs arriving by 2020

4 Volvo plag in hybrid at an auto show in Beijing in 2014, Tep: Adde: Torocha Presentate Agency

Sparks fly

Battery electric vehicles, worldwide

Battery cost, €/kWh Penetration, % FORECAST 25 1,000 800 20 New forecast 600 15 400 10 Old forecast 200 2009 20 25 30 15 Sources: Exane BNP Paribas; UBS

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

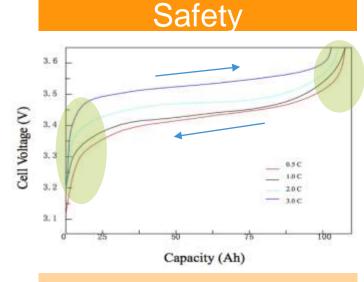
Impact:

- 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.

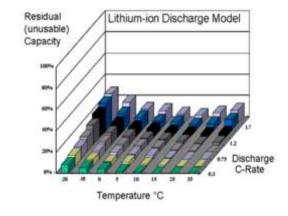
Economist.com



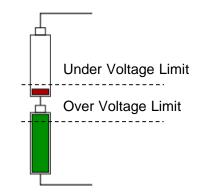
Main Functions of BMS systems



Performance



Multi-Cell function



Danger:

- Over voltage
- Extra heat
- Unstable chemical stage
- Thermal runaway=>fire/explosion
- Low temperature charge

Key BMS Functions

V/I/T measurement

Requirements:

- Safe & fast charging
- Discharge optimization
- State of charge (SOC) estimation
- State of health (SOH) estimation

V/I/T measurement Coulomb counting Internal resistance calculation

Challenges:

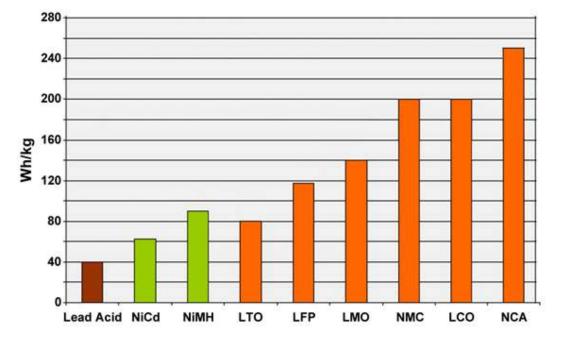
- Up to hundreds of cells
- Manufacture mismatch
- Capacity degradation
- Lifetime degradation

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 ₂ O 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 ₂ TiO ₃	2.4 V	2.85V	1.8 V

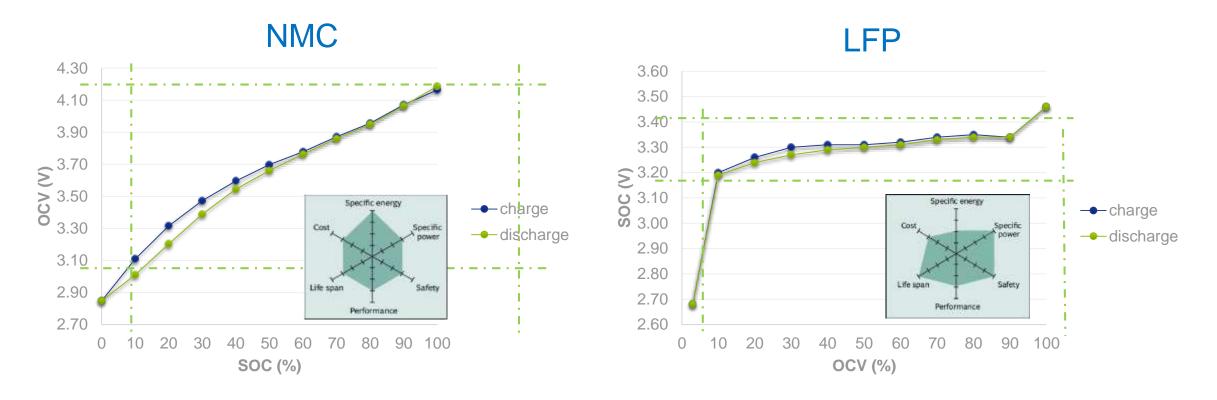


http://batteryuniversity.com/learn/article/types_of_lithium_ion



Open Circuit Voltage vs State of Charge

SOC accuracy depends on voltage measurement accuracy

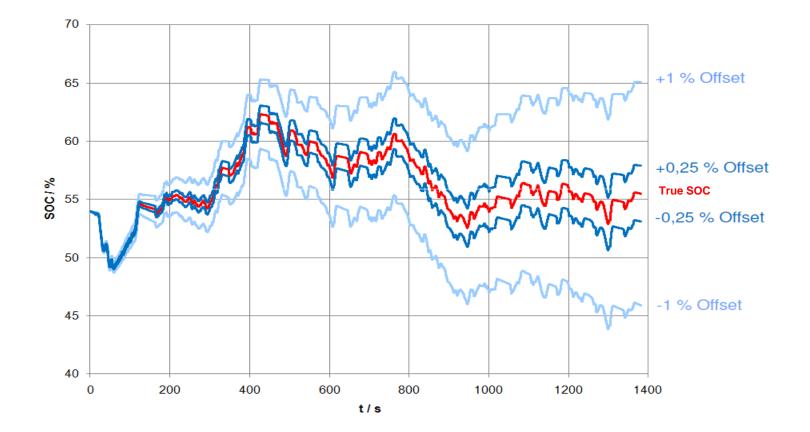


140 mV ≡ 80% SOC (1,75 mV/1% SOC)

1 V ≡ 80% SOC (12,5 mV/1% SOC)

SOC Estimation

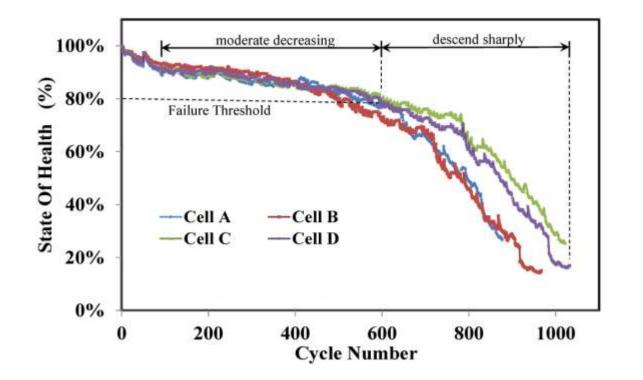
- Initial state of change estimation is necessary and needs to be accurate
- Then current is integrated by using the Coulomb counting function
- SOC accuracy depends on measurement accuracy of both current and voltage





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

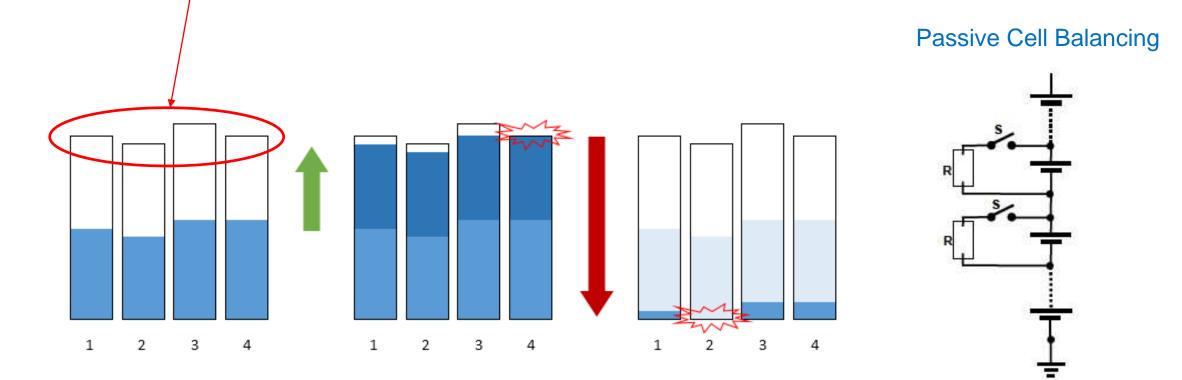


$$SOH = \left(\frac{R_i}{R_0}\right) * 100$$



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



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





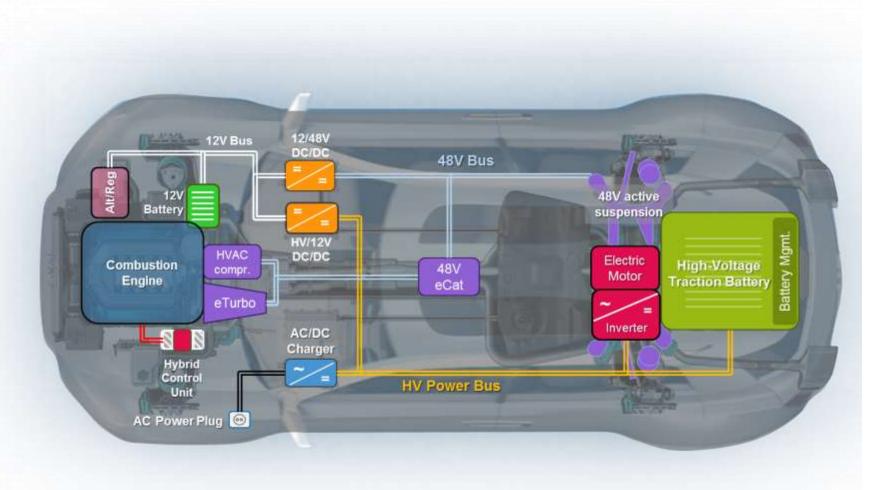


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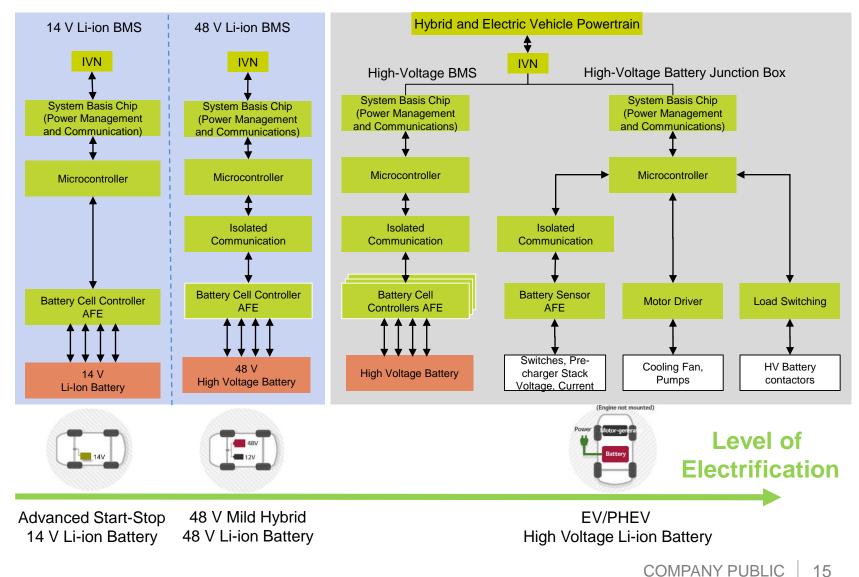
Mastering xEV Power for Efficient Energy Management Optimized power system control solutions

Key differentiation points:

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



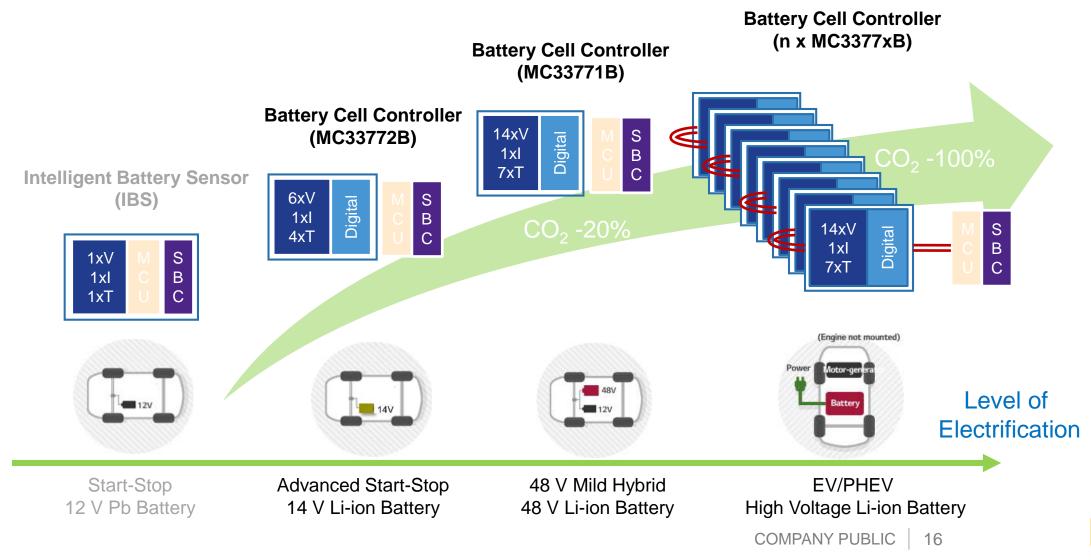
Automotive Li-ion BMS Application Overview





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

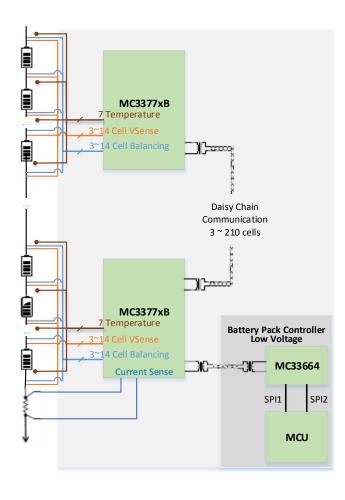
- Scalable SW & HW compatible BMS solution supporting **4 to 210 cells per daisy chain**
- MC33771B (7 to 14 cells) & MC33772B (3 to 6 cells) fully compatible
- Supporting centralized, distributed daisy chain, distributed CAN

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

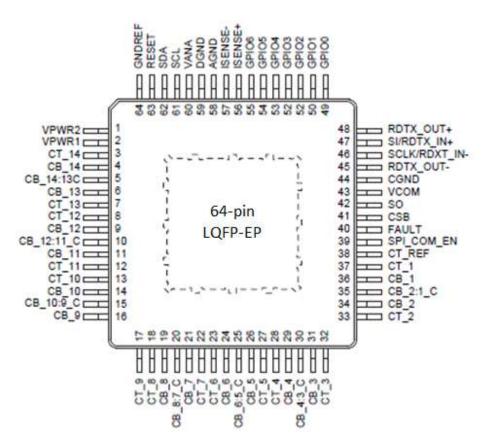


MC33771 – 14 Cell Battery Cell Controller AFE

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





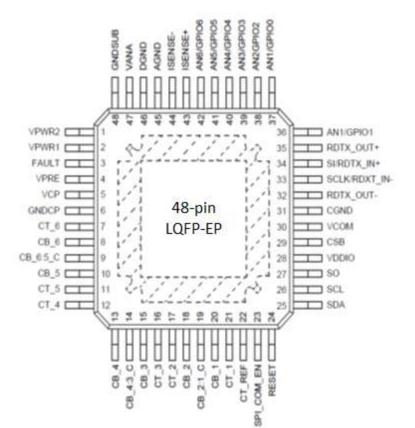
MC33772 – 6 Cell Battery Cell Controller AFE

Key features

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High performance integrated functions

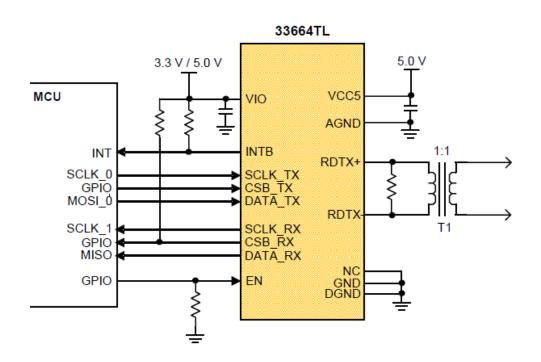
- Operating Voltage:
- 5V ≤ VPWR ≤ 30 V operation, 42V transient (for SPI communication)
- 7V ≤ VPWR ≤ 30 V operation, 42V transient (for TPL communication)
- Life-time guaranteed high accuracy 6 cell voltage measurement channels
- 4.0 Mbps SPI or isolated 2.0 Mbps differential communication
- Synchronized 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

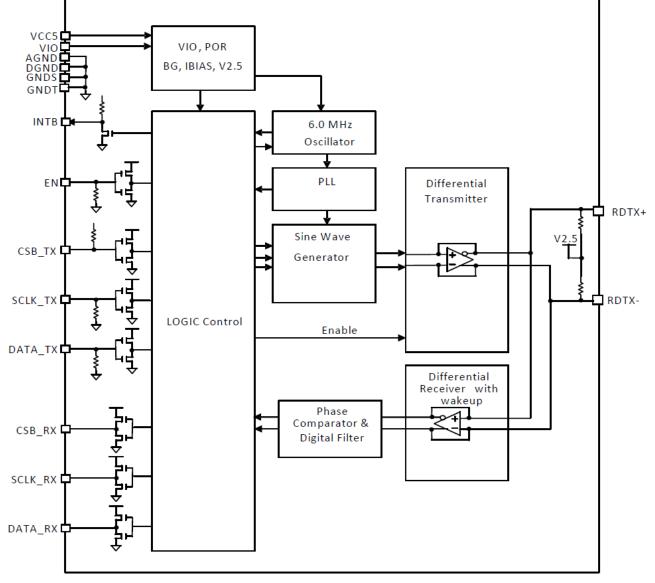


MC33664ATL Transformer Physical Layer

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

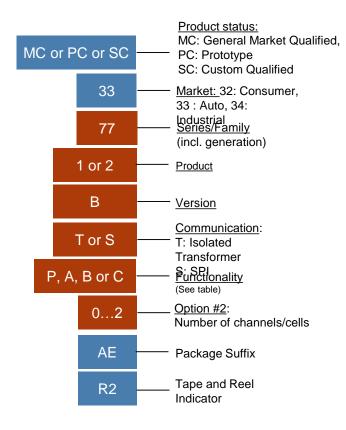
Premium for 14/ 48 V BMS	Advanced for HVBMS	Basic for redundancy	Current for HV junction/ switch box
MC3377xBS P (SPI comm) MC3377xBT P (TPL comm)	MC3377xBS A (SPI comm) MC3377xBT A (TPL comm)	MC3377xBT B (TPL comm)	MC33772BT C (TPL comm)
Precise differential cell voltage measurement			
Cell OV/UV	Cell 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			
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			







MC3377xB Battery Cell Controller Part Numbering



Functionality & Communication

		lifferential cell neasurement	Tempera	iture	Cell	Gurrent	Couloumb	Communication			
Part Number	CTx	Cell OV/UV	Measurement			Channel	counter	SPI	Half Duplex Differential		
MC3377xBTPy	J	J	J	J	1	J	J	J	J		
MC3377xB <mark>SP</mark> y	J	J	J	J	J	J	J	J	NO		
MC3377xBTAy	J	J	J	J	J	NO	NO	J	J		
MC3377xB <mark>SA</mark> y	J	J	J	1	J	NO	NO	J	NO		
MC3377xBTB1	J	J	NO	NO	NO	NO	NO	J	J		
MC33772BTC0	NO	NO	J	J	NO	J	J	J	J		

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



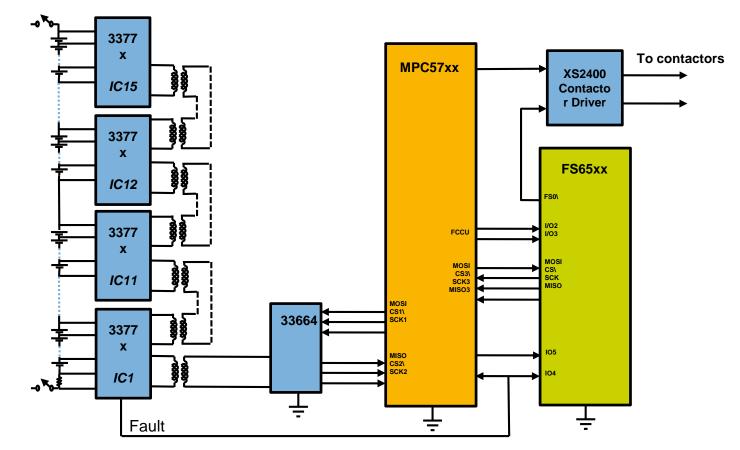




xEV Battery Management System Solution

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, onchip 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



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	Package 416 and 516 MAPBGA		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					

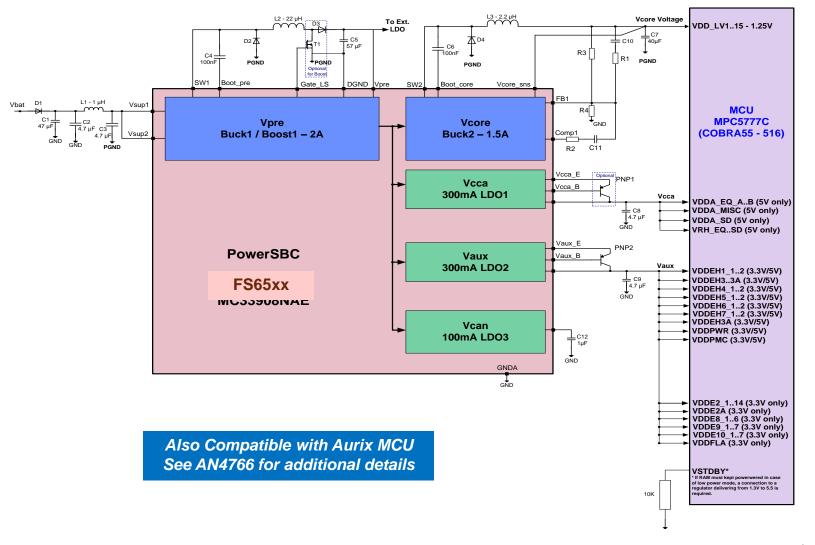
Evaluation Tools

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



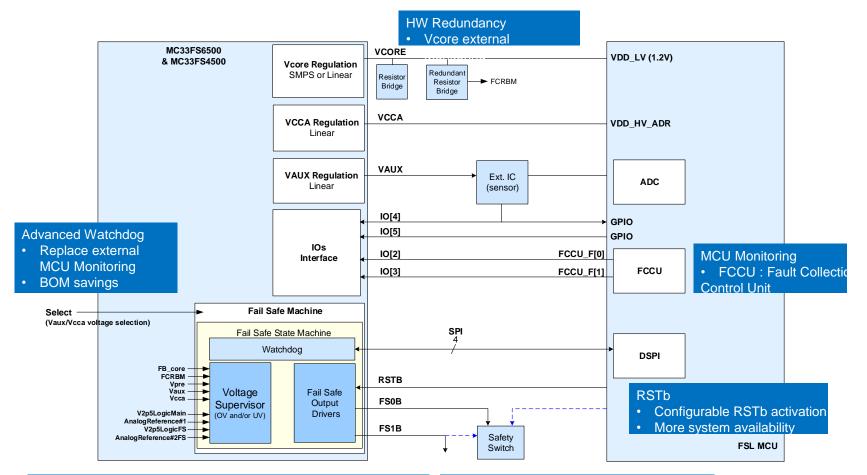
For more information, visit NXP.com/MPC5777C

FS65xx: Safety SBC Power Tree



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FS65 / FS45 : Functional Safety Block Diagram



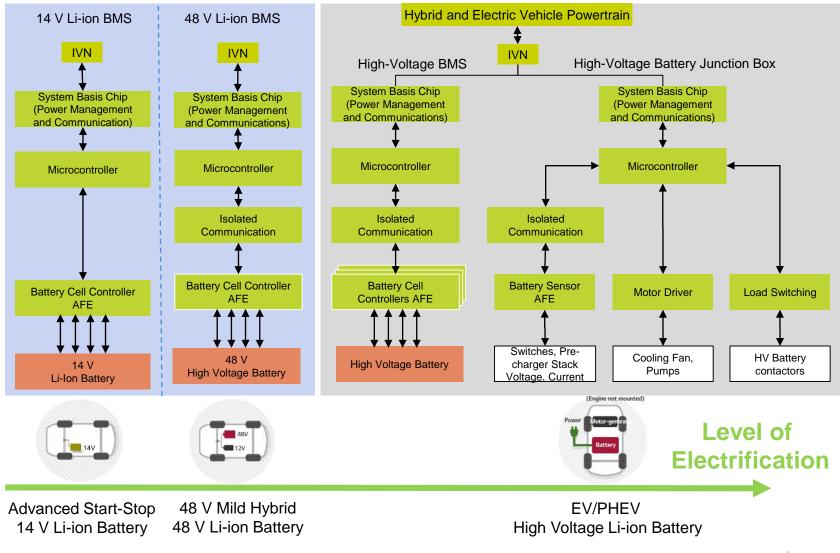
Independent Fail Safe State Machine

- 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

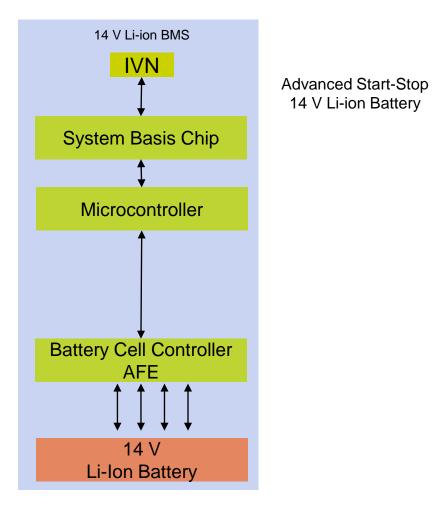


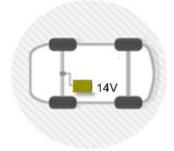


Single-Chip 14 V Li-Ion BMS Solution

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



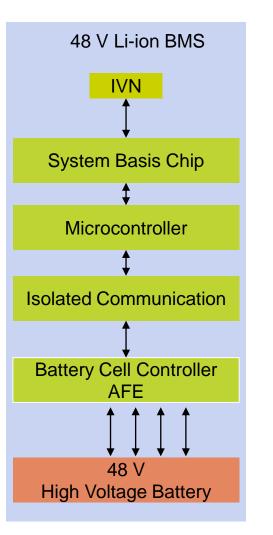




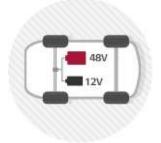
Typical 48 V Li-Ion BMS application

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

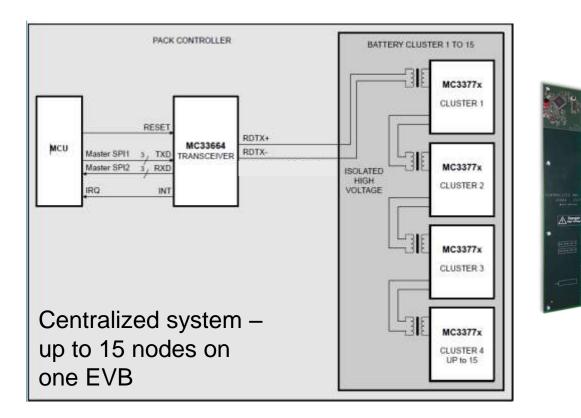


Single-chip BMS for 14-cell system

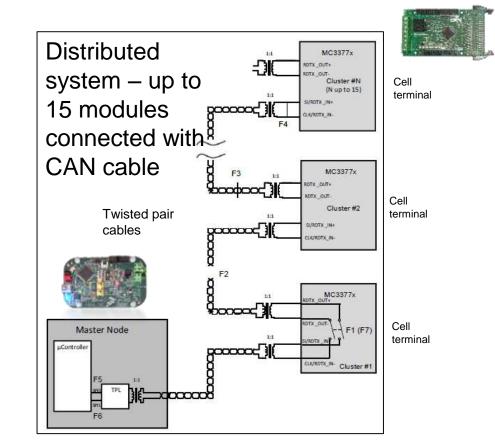




TPL Centralized / Distributed Architectures



- 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



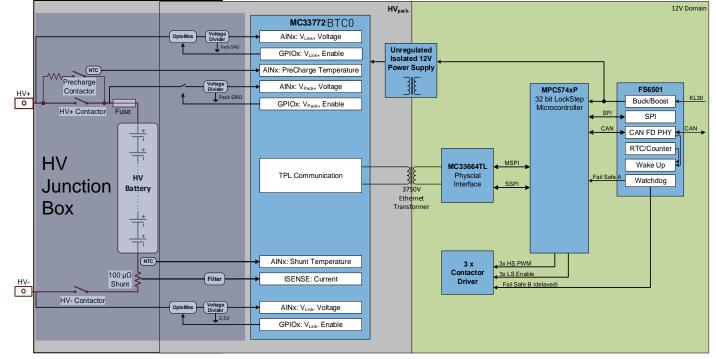


EV/PHEV High Voltage Li-ion Battery

Typical HV Battery Junction/Switch Box Controller

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

Available via nxp.com



6 / 14-Cell Battery

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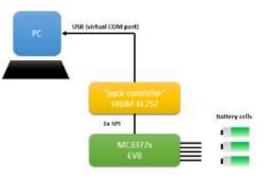
NXP BCC Evaluation GUI

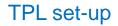
Available Now

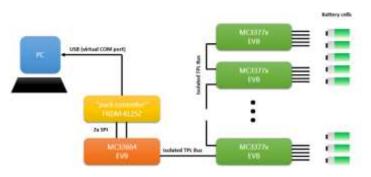
PC GUI SW

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SPI 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)









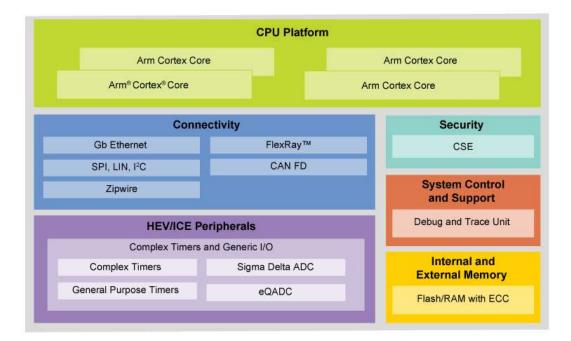
GreenBox: Vehicle Electrification Development Platform

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









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

Key Contacts

- BMS Segment Manager: Antonio Leone antonio.leone@nxp.com
- BMS Application Manager: Philippe Perruchoud philippe.perruchoud@nxp.com

Regional Business Development Manager

- AMEC: Don Laybourn <u>don.laybourn@nxp.com</u>
- GC: Hunter Zhu <u>hunter.zhu@nxp.com</u>
- EMEA Mass Market: Emmanuel Carcenac <u>emmanuel.carcenac@nxp.com</u>
- Japan: Naoki Kumura <u>naoki.kumura@nxp.com</u>
- Korea: Collin Song <u>collin.song@nxp.com</u>
- South Asia: Deepak Kashyap <u>deepak.kashyap@nxp.com</u>

Further supports via

- NXP Community: https://community.nxp.com/
- Technical Documents Shared under NDA via <u>NXP DocStore</u>





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