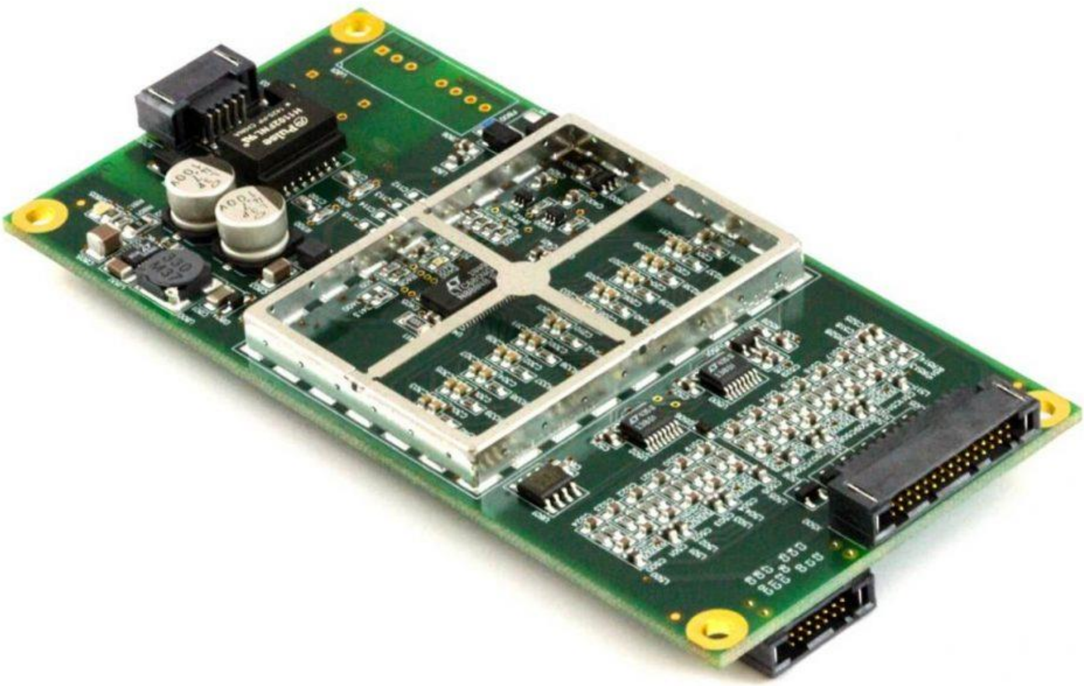
LION SMART BMS

Model	Battery	Charge Times
Toyota Prius PHEV	4.4kWh Li-ion, 18km (11 miles) all-electric range	3h at 115VAC 15A; 1.5h at 230VAC 15A
Chevy Volt PHEV	16kWh, Li-manganese/NMC, liquid cooled, 181kg (400 lb), all electric range 64km (40 miles)	10h at 115VAC, 15A; 4h at 230VAC, 15A
Mitsubishi iMiEV	16kWh; 88 cells, 4-cell modules; Li-ion; 109Wh/kg; 330V, range 128km (80 miles)	13h at 115VAC 15A; 7h at 230VAC 15A
Smart Fortwo ED	16.5kWh; 18650 Li-ion, driving range 136km (85 miles)	8h at 115VAC, 15A; 3.5h at 230VAC, 15A
BMW i3 Curb 1,365kg (3,000 lb)	Since 2019: 42kWh, LMO/NMC, large 60A prismatic cells, battery weighs ~270kg (595 lb) driving range: EPA 246 (154 mi); NEDC 345km (215 mi); WLTP 285 (178 mi)	11kW on-board AC charger; ~4h charge; 50kW DC charge; 30 min charge.
Nissan Leaf*	30kWh; Li-manganese, 192 cells; air cooled; 272kg (600 lb), driving range up to 250km (156 miles)	8h at 230VAC, 15A; 4h at 230VAC, 30A
Tesla S* Curb 2,100kg (4,630 lb)	70kWh and 90kWh, 18650 NCA cells of 3.4Ah; liquid cooled; 90kWh pack has 7,616 cells; battery weighs 540kg (1,200 lb); S 85 has up to 424km range (265 mi)	9h with 10kW charger; 120kW Supercharger, 80% charge in 30 min
Tesla 3 Curb 1,872 kg (4072 lb)	Since 2018, 75kWh battery, driving range 496km (310 mi); 346hp engine, energy consumption 15kWh /100km (24kWh/mi)	11.5kW on-board AC charger; DC charge 30 min
Chevy Bolt Curb 1,616kg; battery 440kg	60kWh; 288 cells in 96s3p format, EPA driving rate 383km (238 miles); liquid cooled; 200hp electric motor (150kW)	40h at 115VAC, 15A; 10h at 230VAC, 30A 1h with 50kWh

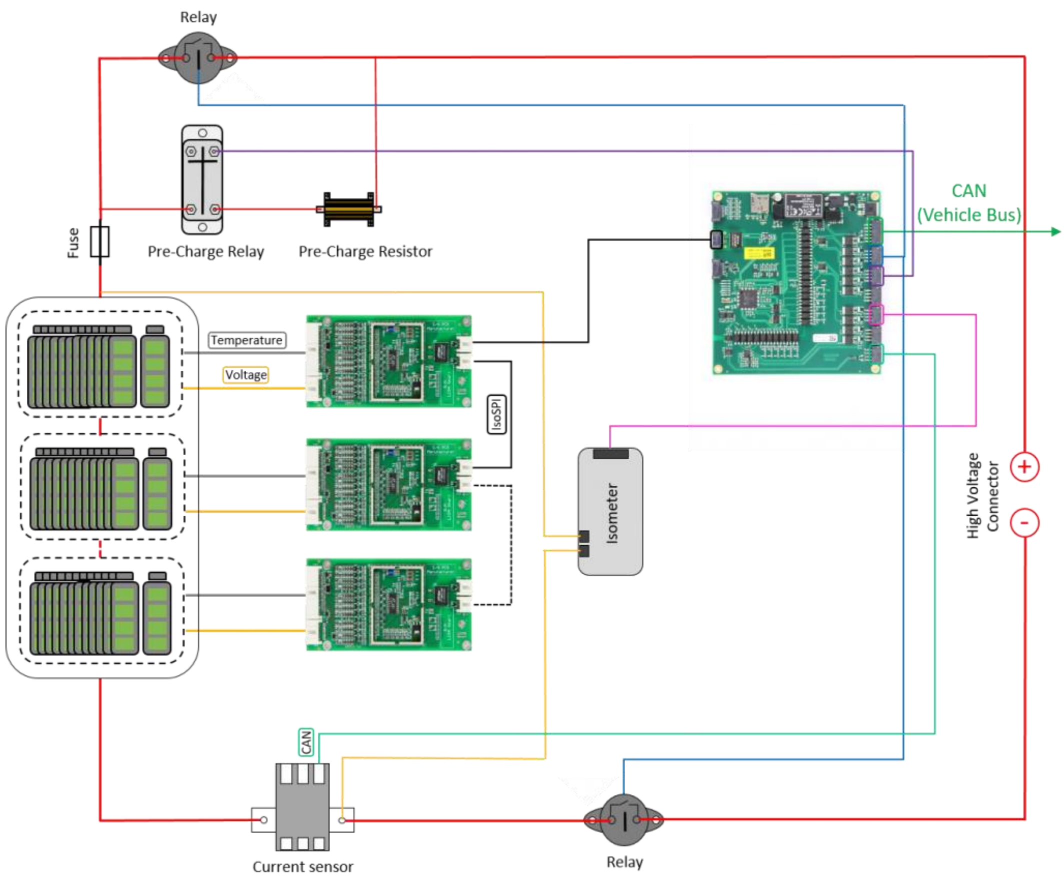
BMW i3 is a pure electric vehicle. In a BMW i3, a total of 96 battery cells are installed. Twelve cells are combined into one module and eight modules are put together to go into the vehicle in the form of a pack.

BMW I3 use the proven lithium-manganese (LMO)battery with a NMC blend, packaged in a prismatic cell.

Model	Battery	Charge Times
BMW i3 **Curb 1,365kg**	Since 2019: 42kWh, LMO/NMC, large 60A prismatic cells, battery weighs ~270kg (595 lb)	11kW on-board AC charger; ~4h charge; 50kW DC charge; 30 min charge.

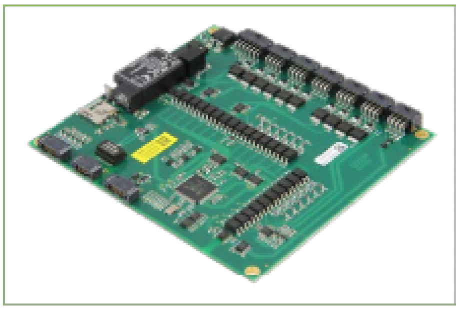


BMS System Architecture- Simpled Block Diagrams



The Li-BMS consists of the control module LION Control Module with a central processor unit which can be flexibly connected to up to 16 measurement modules LION Measure Module via a bus system. The system features a very fast and precise measurement of cell voltages and cell temperatures.

LION Control Module



Technical Specifications	LCM
Dimensions	
LxWxH	142 x 130 x 17 mm
Weight	120 g
Environment	
Operating temperature	-40°C…+85°C
Storage temperature	-50°C…+105°C
Power supply	
Operating voltage	9...18 V, 12 V nominal
LCM Current consumption	100 mA, typically 150 mA
LCM + peripheral current consumption	Max. 15 A
Breaker outputs	
Number of switching channels	7
Switching current single	≤ 5 A
Switching current total	≤ 15 A
Digital inputs	
Number of input channels	7
Input voltage	12 V
Analog inputs	
Number of input channels	4
Input voltage	0...12 V
Operating temperature monitoring	
Number of sensors	1
Memory	
EEPROM	128 KB
MicroSD	4 GB
Communication interfaces	
isoSPI	1x
CAN, HS, up to 1 Mbits/s	2× (public/private)
UART, TTL	1x 57.6 kBaud

*Passive Balancing

*Up to 12 cell

Cell Data Measurement

•Cell voltages: up to 18 channels per measurement module with a measuring range from 0 V to 5.0 V

• Cell temperatures: up to 12 channels per measurement module with a temperature measuring range from -40°C to +85°C

Cell Monitoring and Balancing

• Compliance with defined voltage and temperature limits

• Battery power forecast for other control devices

• Passive balancing with equalization up to 50 mA (optionally expandable to 4 A)

Utilization of Additional Analog Sensors

• Insulation resistance: e.g. Bender ISOMETER® 3204

• Current flow: e.g. Isabellenhütte ISAscale® IVT

Circuit Breaker Control

• Control of the contactors with a 12 V coil voltage (high-side, low-side and pre-charge contactors)

• Additional outputs for controlling the cooling fan or pump

Communication

• CAN external/internal (e.g. Isabellenhütte ISAscale® IVT)

• UART for development (WebGUI)

• isoSPI for module’s internal communication

• Status and diagnostic output

Data Logging

• Storage on internal MicroSD card

• External Database Connection

Open and Scalable Software Architecture

• Up to 16 Measure Modules per Control Module

• System size up to 800 V

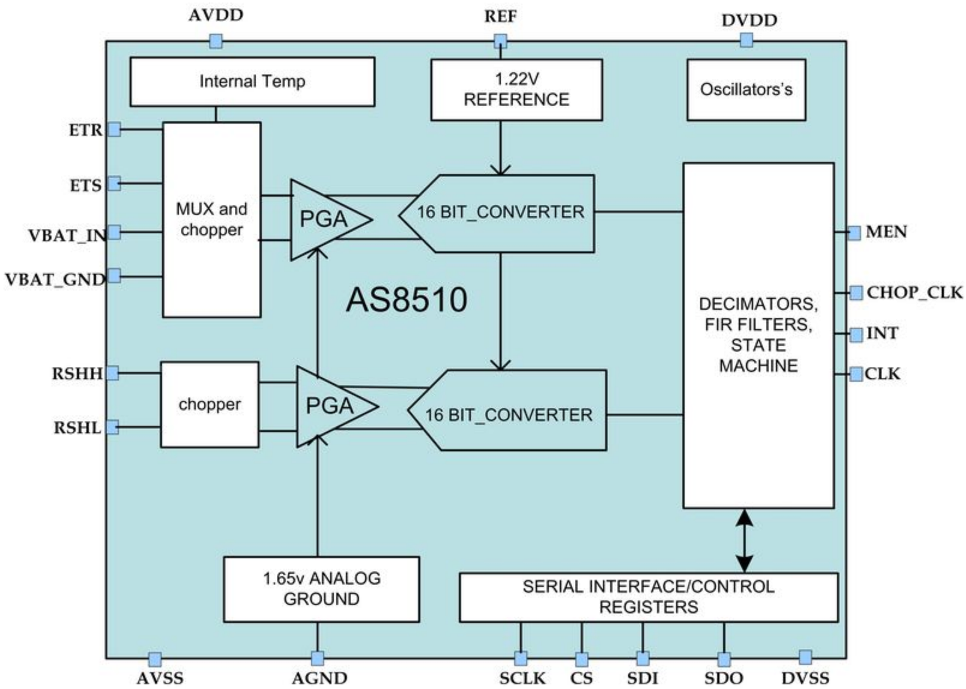
• Flexible expansion of functions and adaptation to your own requirements

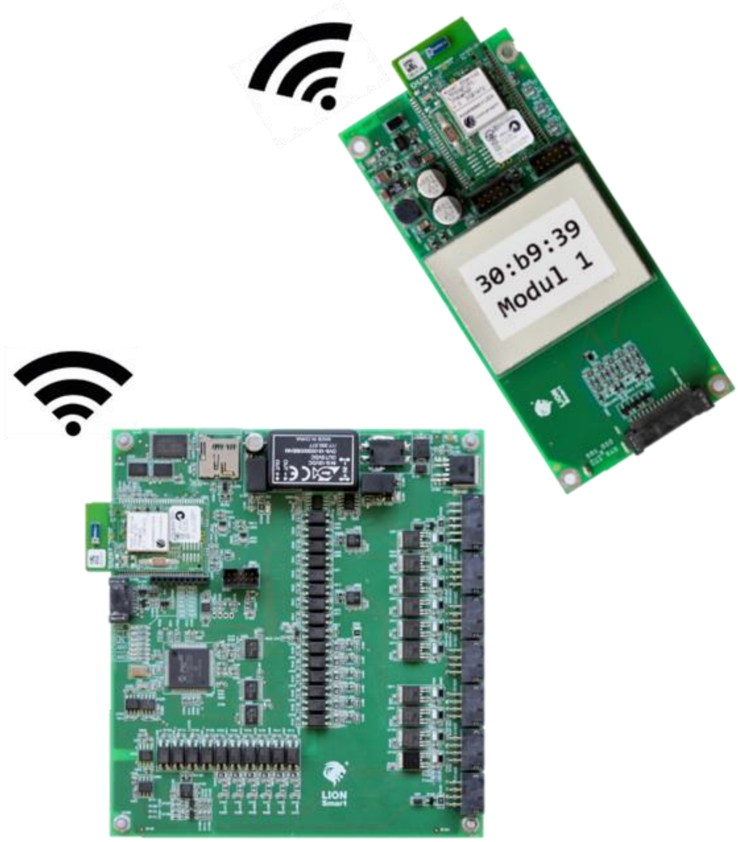
• Seamless integration into own algorithms, e.g. for SoC and SoH calculation

• Open code base (standard ANSI-C99), API for commercial development path

BMW is using the AS8510, an integrated automotive data acquisition front-end integrated circuit (IC) from ams AG, a leading provider of high performance analog ICs and sensors, to provide extremely accurate battery voltage and current measurements in its i3 electric vehicles (EVs).

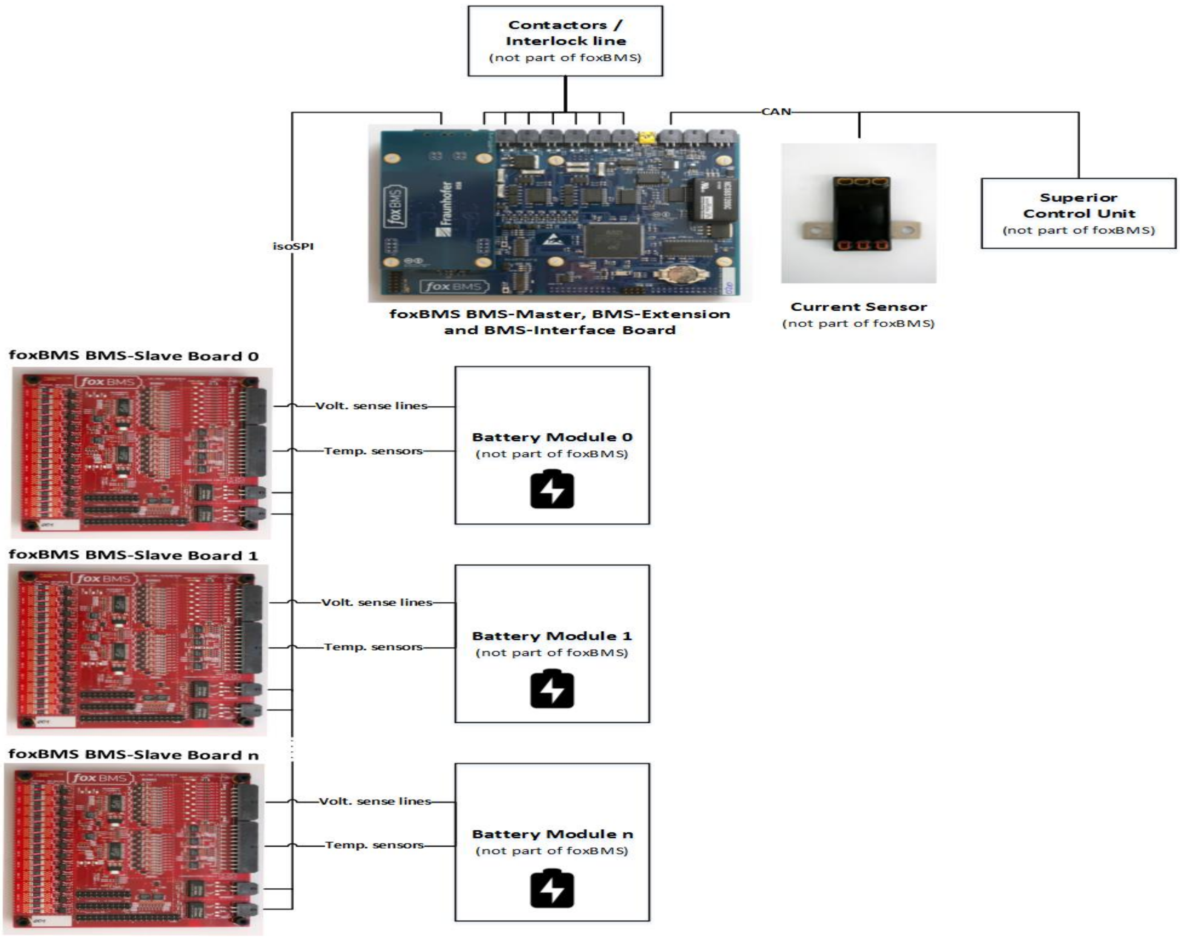
The battery management system (BMS) monitors battery voltage and battery current of the 400V li-ion battery powering the cars' electric motors, and ensures the functional safety of the vehicle's battery systems.

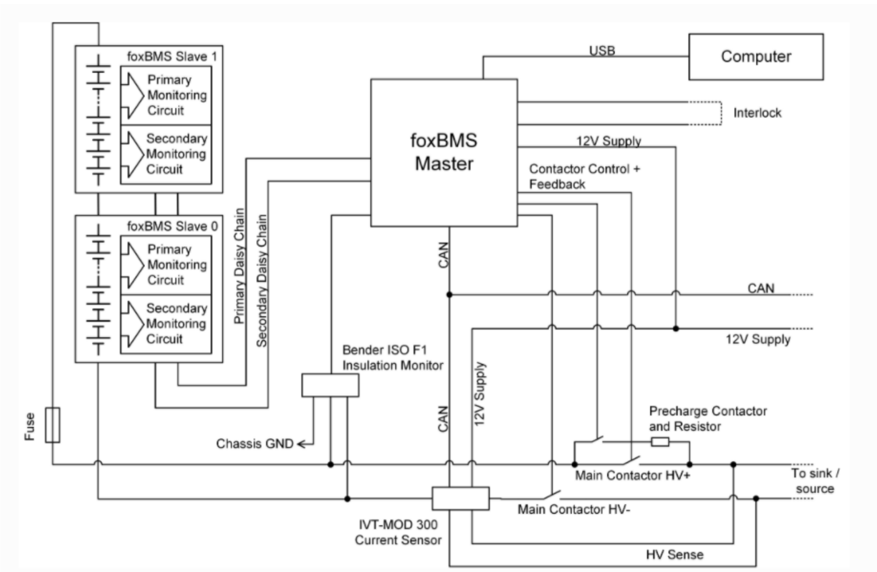




What is the fox BMS ?

foxBMS is a research and development platform aimed to be used to develop battery management systems (BMS) for rechargeable energy storage systems based on lithium-ion batteries (LIB) or comparable electrochemical rechargeable accumulator cells (e.g., other chemistries like lithium-sulfur, sodium-ion or even all-solid-state batteries), lithium-ion capacitors (LIC), electric double-layer capacitors (EDLC or supercapacitors). The lithium-ion battery packs or battery modules are a major source of hazards and are not part of the foxBMS platform.The main purposes of the battery management system are charge monitoring and keeping the battery cells in their safe operating area to ensure optimal safety and the longest battery lifetime.


Contactors /
Interlock line
(not part of foxBMS)
CAN
isoSPI
foxBMS BMS-Master, BMS-Extension
and BMS-Interface Board
Current Sensor
(not part of foxBMS)
Superior
Control Unit
(not part of foxBMS)
foxBMS BMS-Slave Board 0
Volt. sense lines
Temp. sensors
Battery Module 0
(not part of foxBMS)
foxBMS BMS-Slave Board 1
Volt. sense lines
Temp. sensors
Battery Module 1
(not part of foxBMS)
foxBMS BMS-Slave Board n
Volt. sense lines
Temp. sensors
Battery Module n
(not part of foxBMS)


foxBMS Slave 1
Primary
Monitoring
Circuit
Secondary
Monitoring
Circuit
foxBMS Slave 0
Primary
Monitoring
Circuit
Secondary
Monitoring
Circuit
Primary Daisy Chain
Secondary Daisy Chain
USB
Computer
foxBMS
Master
Interlock
12V Supply
Contactor Control +
Feedback
CAN
CAN
12V Supply
Bender ISO F1
Insulation Monitor
12V Supply
CAN
Fuse
Chassis GND
Precharge Contactor
and Resistor
Main Contactor HV+
To sink /
source
Main Contactor HV-
IVT-MOD 300
Current Sensor
HV Sense

Block diagram showing the typical topology of a battery system

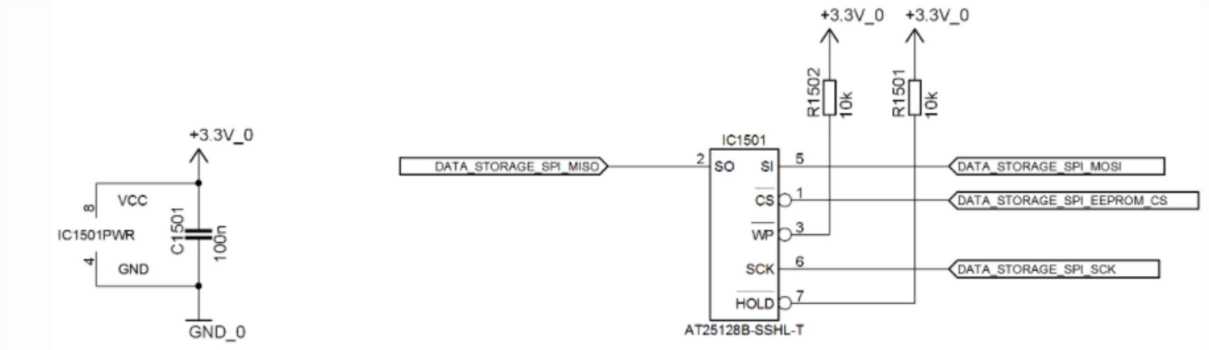
The interfaces of the foxBMS Master Unit are:

Connection	Description
Supply Voltage DC	12VDC-24VDC supply input
Ground Fault Detector	Connection for the insulation monitor to detect an error (Bender ISOMETER IR155-3203)
CAN0	Galvanically isolated connection on foxBMS Master Unit for additional sensors (IVT-MOD-300)
Primary USB	Galvanically isolated USB connection to microcontroller on the primary side for flashing and communication
Contactors 0-8	Power contactors between battery and the supplied load
Interlock	Galvanically isolated connection between the microcontrollers and connector control
Daisy Chain (Primary/Secondary)	Connection for the next BMS-Slave Board in the battery system
Secondary USB	Galvanically isolated USB connection to microcontroller on the secondary side for flashing and communication
CAN1	Galvanically isolated connection on BMS-Extension Board
RS485	Galvanically isolated RS485 interface as alternative for CAN or USB
Isolated GPIO	Galvanically isolated general purpose IO for user specific needs
Isolated NOC	Galvanically isolated Normally Open Contact interface for any purpose left to the user
Analog Inputs	Analog inputs for any purpose left to the user
Memory Card	Data storage for the primary microcontroller

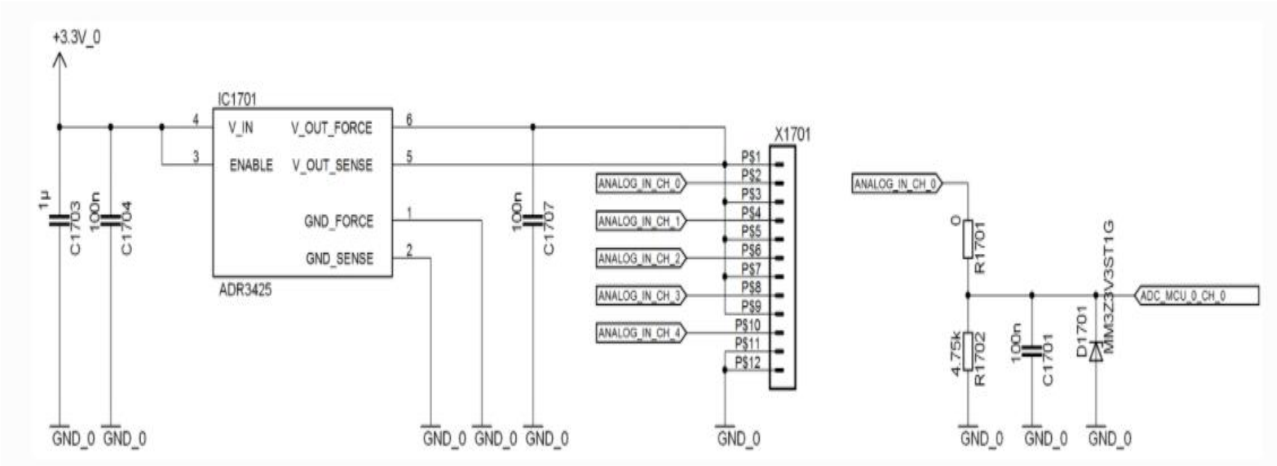
The interfaces of the fox BMS Slave Unit are:

Connection	Description
12 Cells	13 voltage sense connections for 12 cells
8+16 Temperatures	Temperature sensor connection (one for each cell)
4 Daisy Chains	Primary and secondary daisy chain connections to the next and to the previous BMS-Slave Board

EEPROM:



Non isolated analog inputs:

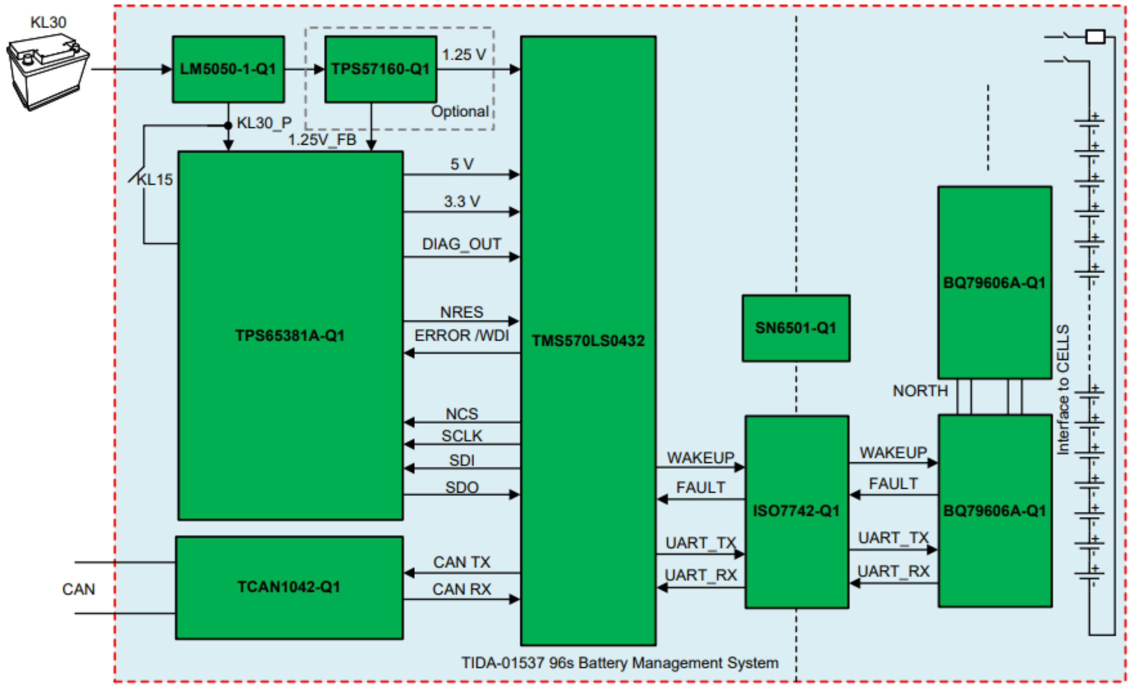


Passive Cell Balancing:

The passive balancing circuit is realized by a parallel connection of two 68Ω discharge resistors that can be connected to each single cell in parallel. The MOSFET switches (T1500-T1511) that control the connection to the cells are controlled by the primary LTC6811-1 monitoring IC. The secondary LTC6811-1 does not support balancing. The resistor value of 2x 68Ω results in a balancing current of about 100mA at a cell voltage of 3.6V. This current results in a power dissipation of about 0.36W per balancing channel (at 3.6V).

TEXAS INSTUREMENTS

Figure 1. TIDA-01537 Block Diagram



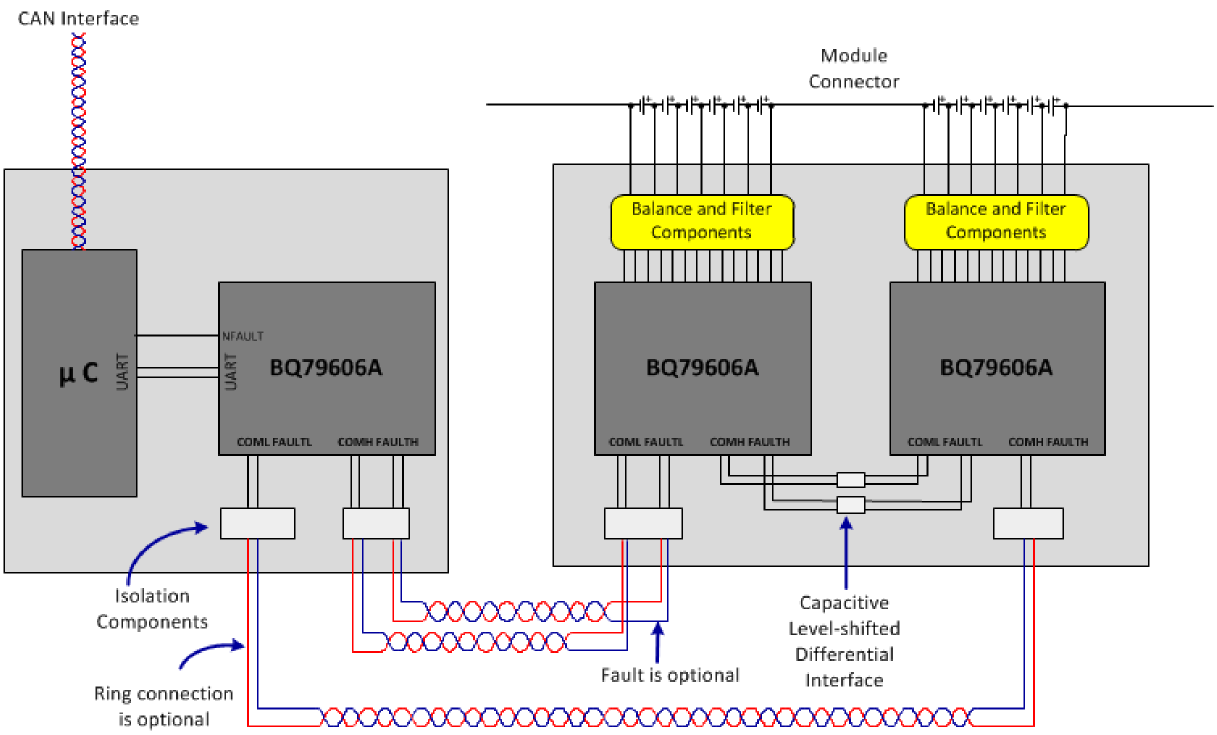
Features:

- Scalable cell supervision circuits from 6s to 96s
- Accurate cell voltage measurements
- Onboard PMIC diagnosis
- Onboard BQ79606A-Q1 diagnosis
- Onboard capacitive isolation
- Robust hot-plug performance
- 500 kbps external CAN communication

Description

This reference design is a small-sized cell supervision demonstrator design for a centralized battery management system (BMS). Its configurable capacitive isolation daisy-chain solution enables monitoring and protecting cells ranging from 6-series to 96-series, which allows its use in BMS systems ranging from 24 V to 400 V. In hybrid or electric vehicles (HEV/EVs), a high-voltage lithium-ion battery stores the energy required for traction and housekeeping. The lithium-ion cells in the battery must be monitored while charging and discharging. This design provides a solution for monitoring lithium-ion cell voltages accurately and communicating the data externally via various interfaces such as CAN and bqStudio.

Figure 2. BQ79606A-Q1 Simplified System Diagram



The BQ79606A-Q1 device provides simultaneous, high accuracy, channel measurements for three to six battery cells. With the inclusion of a daisy chain communication port, the BQ79606A-Q1 device is stack able (up to 51 devices) to support the large stack configurations found in battery packs for electrified automotive drive trains. Providing a Delta Sigma converter per cell input, the BQ79606A-Q1 allows simultaneous measurement of the battery voltages, providing a true snapshot of the voltage of the cells.

BQ79606A-Q1 features:

• Highly-accurate cell voltage measurements

• Monitor and communication functions: SafeTI™-26262 ASIL-D compliant

• Integrated cell-balancing MOSFETs up to 150 mA

• Integrated high-voltage AFE filter components • Designed to pass BCI testing

Figure 3. BQ79606A-Q1 Block Diagram

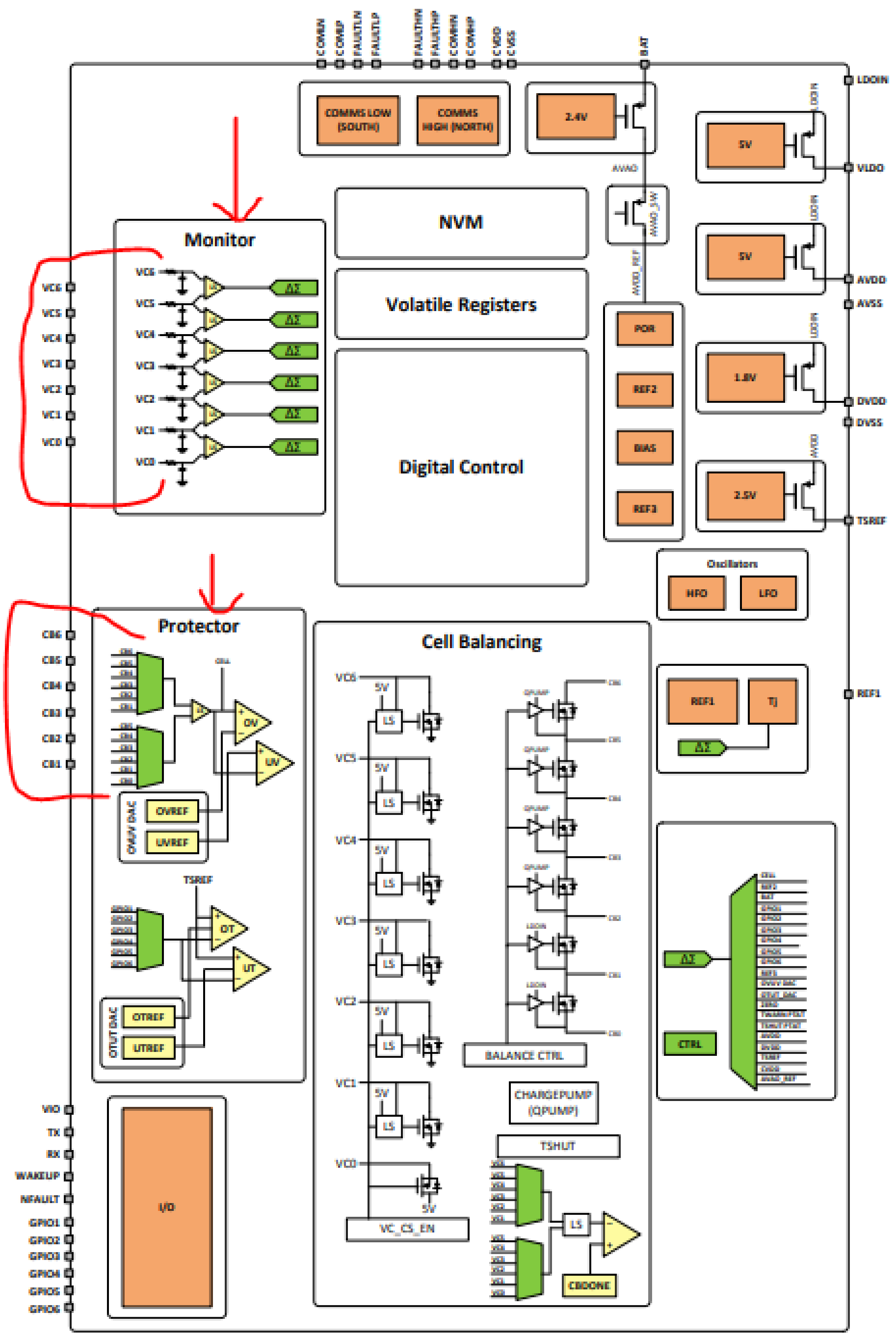
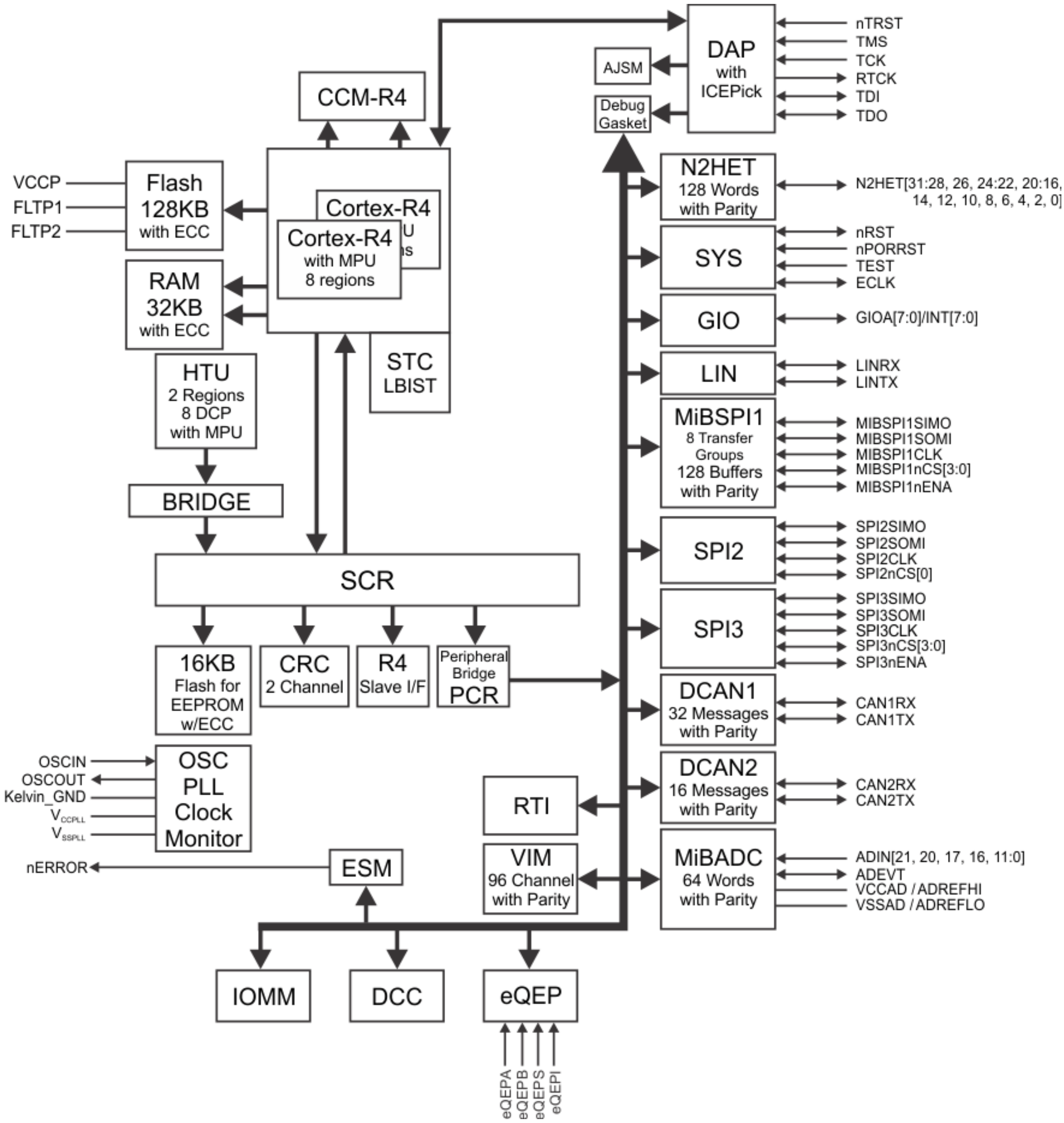


Figure 4. TMS570LS0432 Block Diagram



The TMS570LS0432 device is a high-performance automotive-grade micro controller for safety-relevant systems. The safety architecture includes dual CPUs in lockstep, CPU and Memory BIST logic, ECC on both the flash and the data SRAM, parity on peripheral memories, and loopback capability on peripheral I/Os. The CPU offers an efficient 1.66 DMIPS/MHz, and has configurations that can run up to 80 MHz, providing up to 132 DMIPS. The device supports the big-endian (BE32) format.

TMS570LS0432 features:

• ARM® Cortex® R4 32-bit RISC CPU

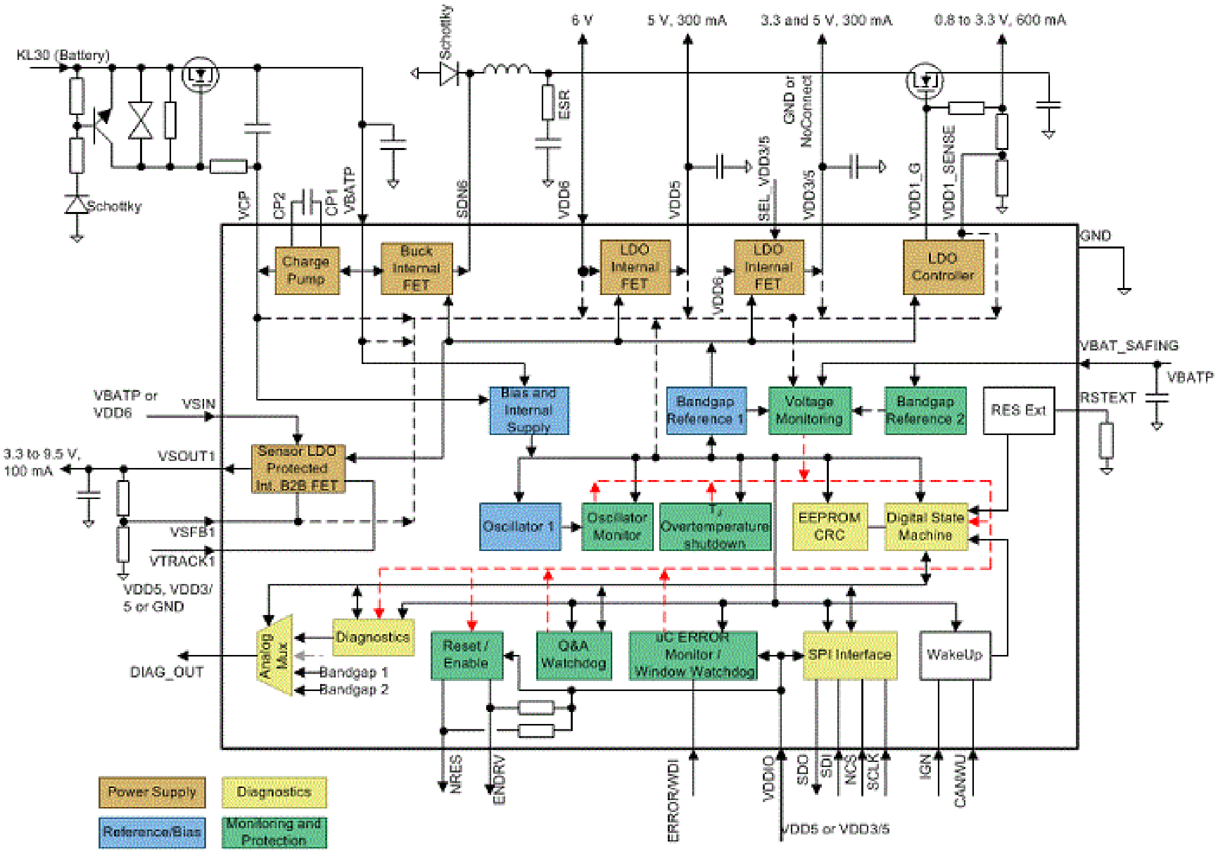
• Dual CPUs Running in lockstep

• Error-signaling module with error pin

• Frequency-Modulated Phase-Locked Loop (FMPLL) With built-in slip detector

• Two CAN controllers (DCANs) • Next generation high-end timer (N2HET) module

Figure 5. TPS65381A-Q1 Block Diagram



The TPS65381A-Q1 device is a multi-rail power supply designed to supply micro controllers (MCUs) in safety-relevant applications. The TPS65381A-Q1 device integrates multiple supply rails to power the MCU, controller area network (CAN), or FlexRay, and an external sensor. An asynchronous-buck switchmode power-supply converter with an internal FET converts the input supply (battery) voltage to a 6-V preregulator output. This 6-V pre-regulator supplies the other regulators 5 V, 3.3 V, and adjustable core supply. The device supports wake up from IGNITION or wake up from the CAN transceiver.

TPS65381A-Q1 features:

• 6-V asynchronous switch mode pre regulator with internal FET, 1.3-A output current

• Charge pump: Typically 12 V above battery voltage

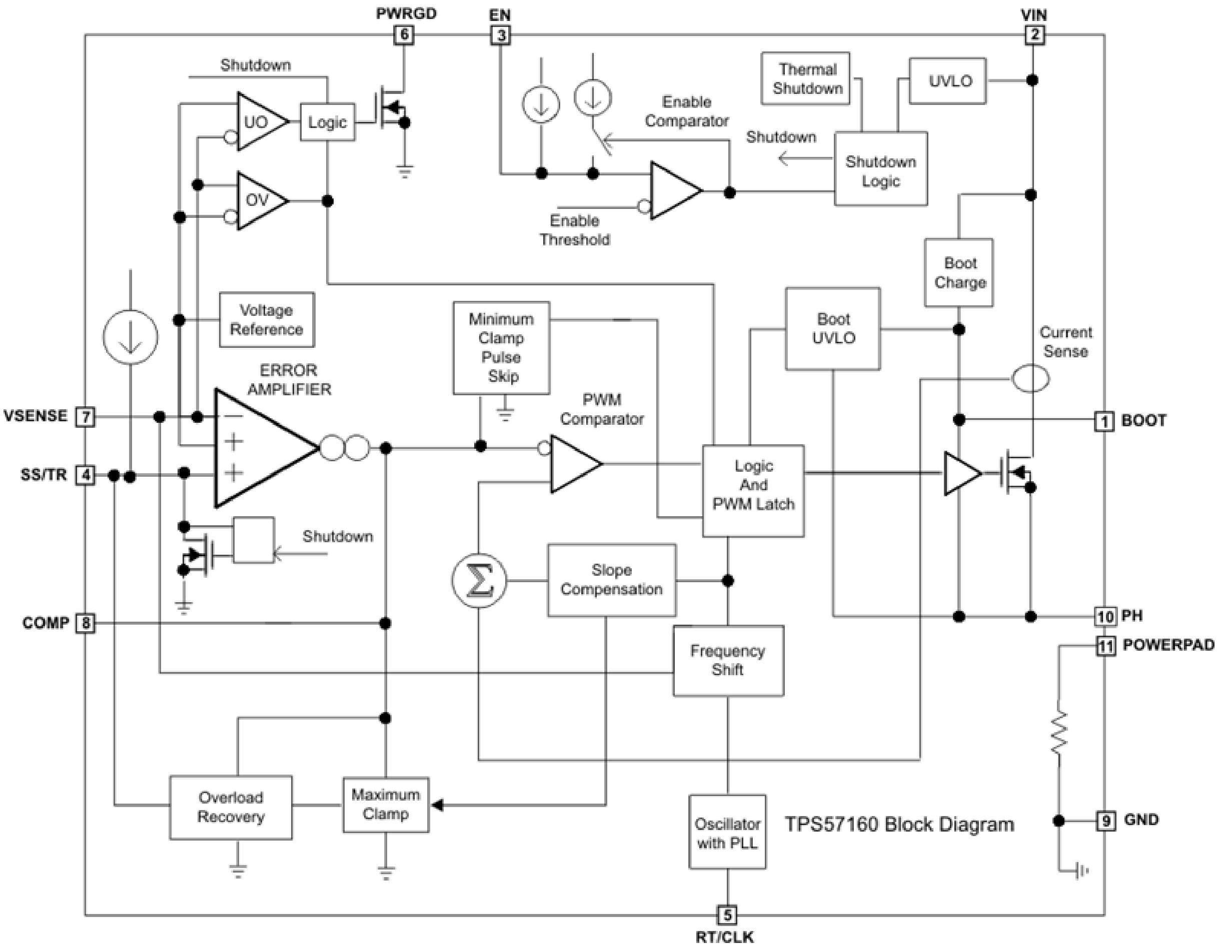
• Independent undervoltage and overvoltage monitoring on all regulator outputs, battery voltage, and internal supplies

• All supplies with internal FETs protected with current-limit and over temperature shutdown

• Watchdog: Trigger mode (OPEN, or CLOSE window) or question and answer mode

• Diagnostic output pin allowing MCU to observe through a multiplexer internal analog and digital signals of the device

Figure 6. TPS57160-Q1 Block Diagram



The TPS57160-Q1 device is a 60-V 1.5-A step-down regulator with an integrated high-side MOSFET. Current-mode control provides simple external compensation and flexible component selection. A lowripple pulse-skip mode reduces the no load, input supply current to 116 µA. Using the enable pin, shutdown supply current is reduced to 1.5 µA. Undervoltage lockout is set internally at 2.5 V but can be increased using the enable pin. The output voltage startup ramp is controlled by the slow-start pin that can also be configured for sequencing or tracking. An open-drain power-good signal indicates the output is within 92% to 109% of the nominal voltage.

TPS57160-Q1 features:

• 3.5-V to 60-V input voltage range

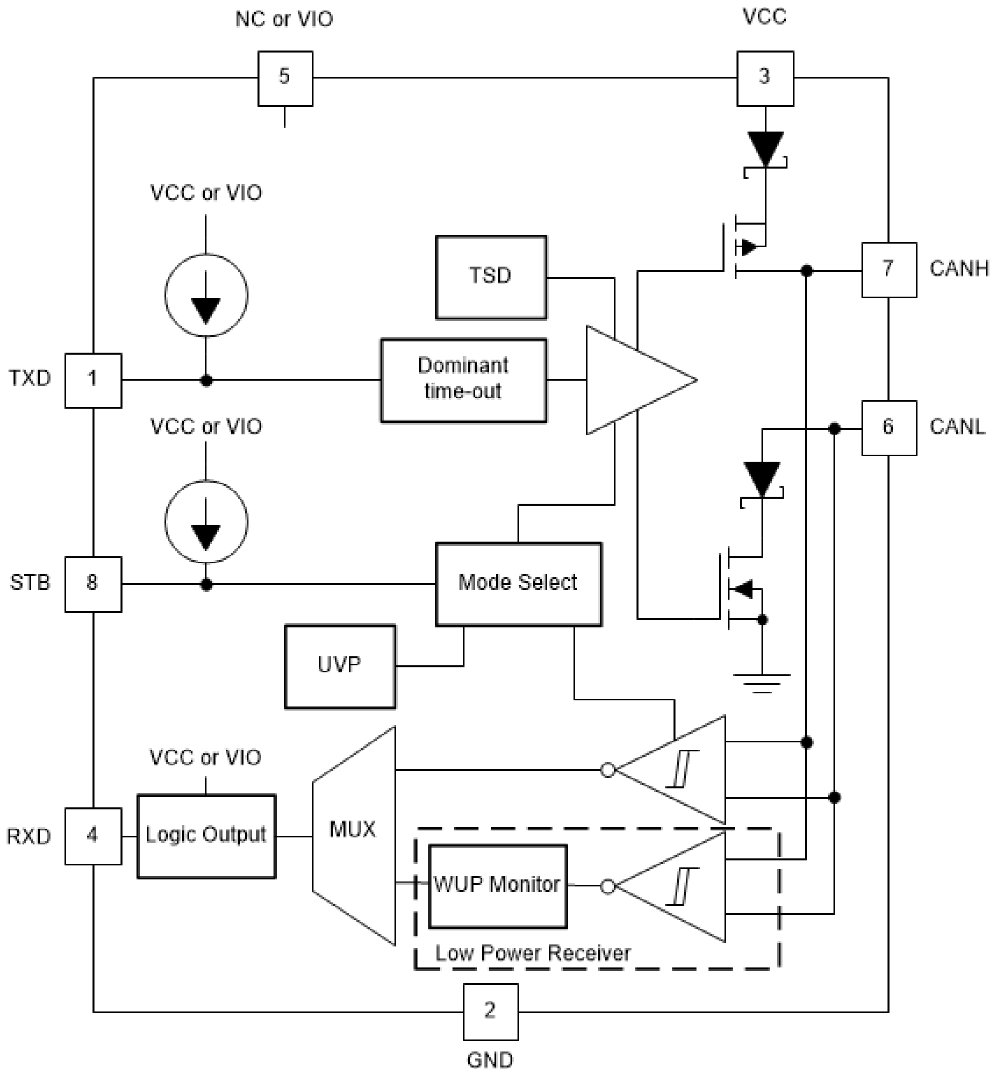
• 200-mΩ high-side MOSFET

• 100-kHz to 2.5-MHz switching frequency

• Adjustable undervoltage lockout (UVLO) voltage and hysteresis

• Adjustable slow start, sequencing

Figure 7. TCAN1042-Q1 Block Diagram



This CAN transceiver family meets the ISO11898-2 (2016) high-speed CAN physical layer standard. All devices are designed for use in CAN FD networks up to 2 Mbps (megabits per second). Devices with part numbers that include the "G" suffix are designed for data rates up to 5 Mbps, and versions with the "V" have a secondary power supply input for I/O level shifting the input pin thresholds and RXD output level. This family has a low power standby mode with remote wake request feature. Additionally, all devices include many protection features to enhance device and network robustness.

TCAN1042-Q1 features:

• I/O voltage range supports 3.3 V and 5 V MCUs

• Typical loop delay: 110 ns

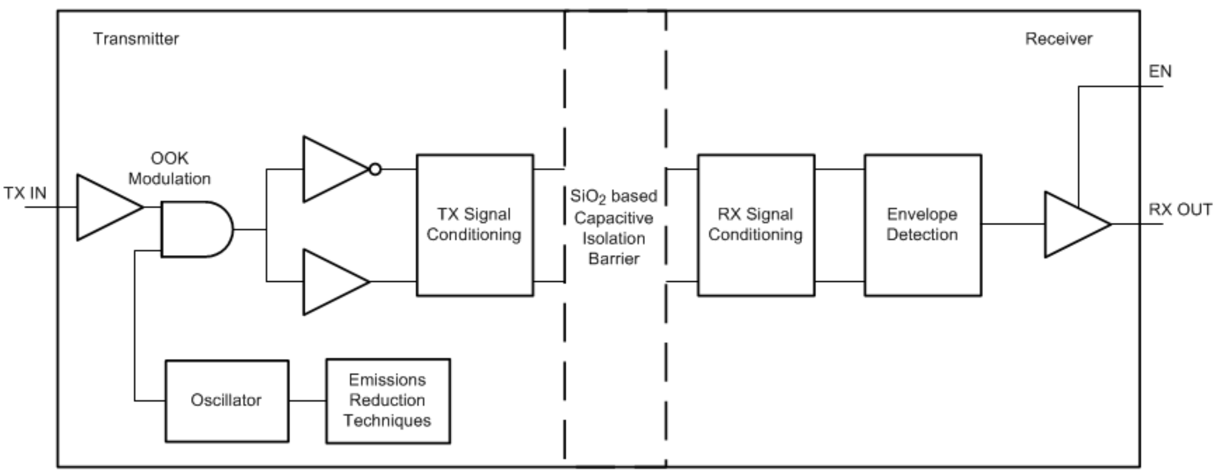
• Ideal passive behavior when unpowered

• Bus fault protection: ±58 V (non-H variants) and ±70 V (H variants)

• Receiver common-mode input voltage: ±30 V

• Short and symmetrical propagation delay times and fast loop times for enhanced timing margin

Figure 8. ISO7742-Q1 Block Diagram



The ISO774x-Q1 devices provide high electromagnetic immunity and low emissions at low power consumption, while isolating CMOS or LVCMOS digital I/Os. Each isolation channel has a logic input and output buffer separated by silicon dioxide (SiO2) insulation barrier. This device comes with enable pins which can be used to put the respective outputs in high impedance for multi-master driving applications and to reduce power consumption. The ISO7740-Q1 device has all four channels in the same direction, the ISO7741-Q1 device has three forward and one reverse-direction channels, and the ISO7742-Q1 device has two forward and two reverse-direction channels. If the input power or signal is lost, default output is high for devices without suffix F and low for devices with suffix F.

ISO774x-Q1 features:

• Signaling rate: Up to 100 Mbps

• Low propagation delay: 10.7 ns typical (5-V supplies)

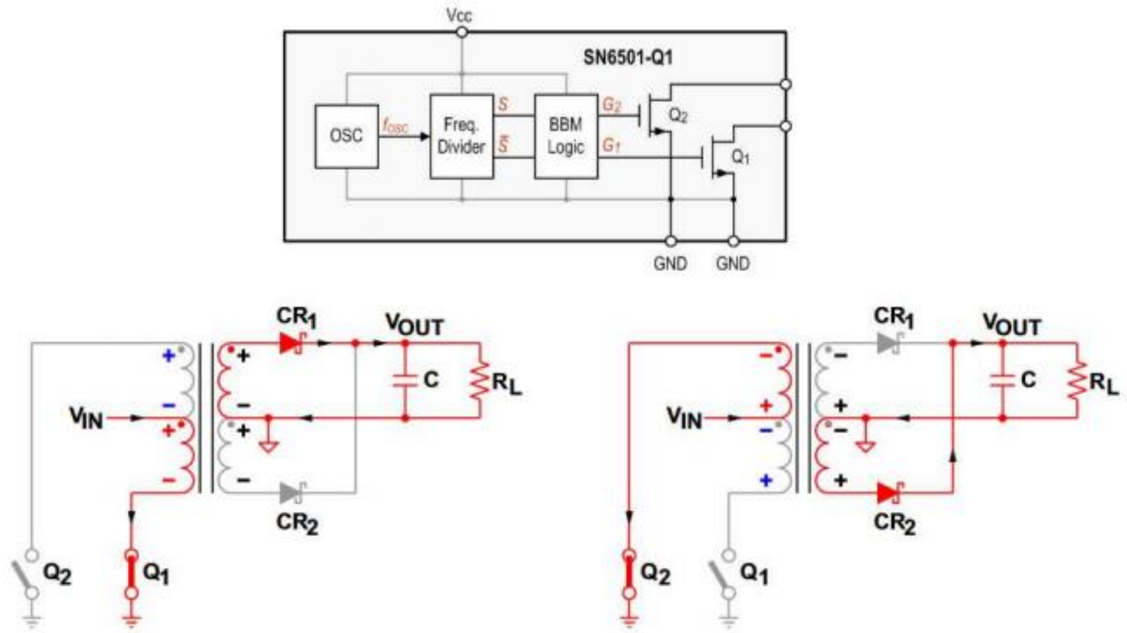
• High CMTI: ±100 kV/µs typical

• Default output high and low options

• Isolation barrier life: > 40 years

• Wide-SOIC (DW-16) and QSOP (DBQ-16) package options

Figure 9. SN6501-Q1 Functional Block Diagram



The SN6501-Q1 device is a monolithic oscillator, power-driver, specifically designed for small form factor, isolated power supplies in isolated interface applications. The device drives a low-profile, center-tapped transformer primary from a 3.3-V or 5-V DC power supply. The secondary can be wound to provide any isolated voltage based on transformer turns ratio. The SN6501-Q1 consists of an oscillator followed by a gate drive circuit that provides the complementary output signals to drive the ground referenced N-channel power switches. The internal logic ensures break-before-make action between the two switches.

SN6501-Q1 features:

• Push-pull driver for small transformers

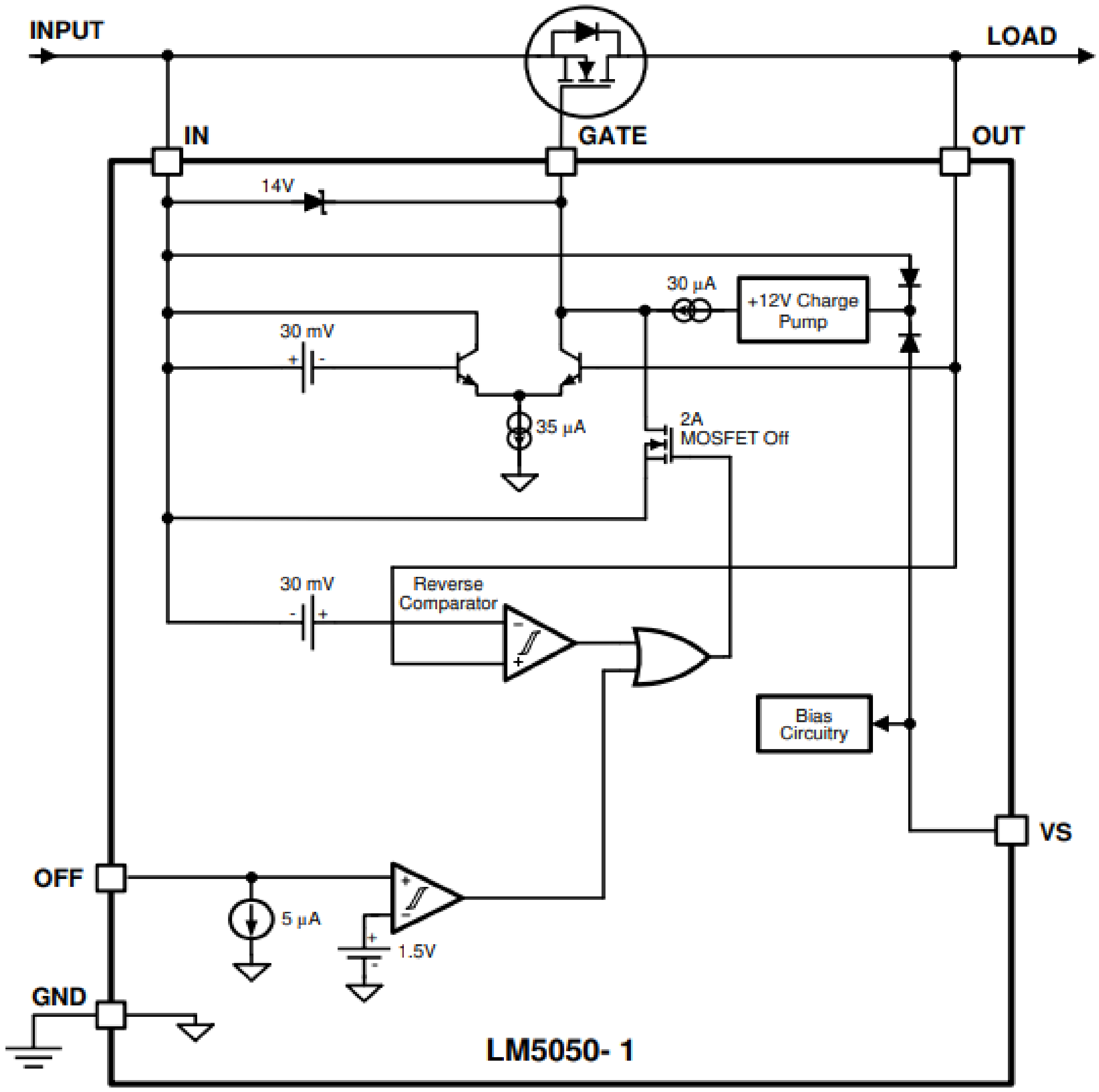
• 5-V supply: 350 mA (Max)

• 3.3-V supply: 150 mA (Max)

• Low ripple on rectified output permits small output capacitors

• Small 5-pin SOT-23 package

Figure 10. LM5050-1-Q1 Block Diagram

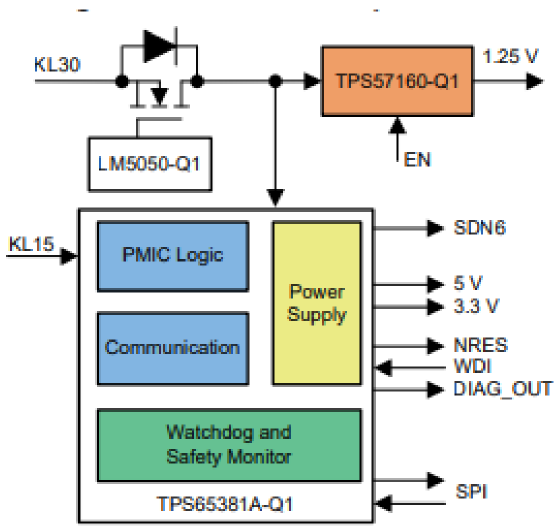


The LM5050-1-Q1 high-side ORing FET controller operates in conjunction with an external MOSFET as an ideal diode rectifier when connected in series with a power source. This ORing controller allows MOSFETs to replace diode rectifiers in power distribution networks thus reducing both power loss and voltage drops. The LM5050-1/-Q1 controller provides charge pump gate drive for an external N-Channel MOSFET and a fast response comparator to turn off the FET when current flows in the reverse direction. The LM5050-1 and LM5050-1-Q1 can connect power supplies ranging from 5 V to 75 V and can withstand transients up to 100 V.

LM5050-1-Q1 features:

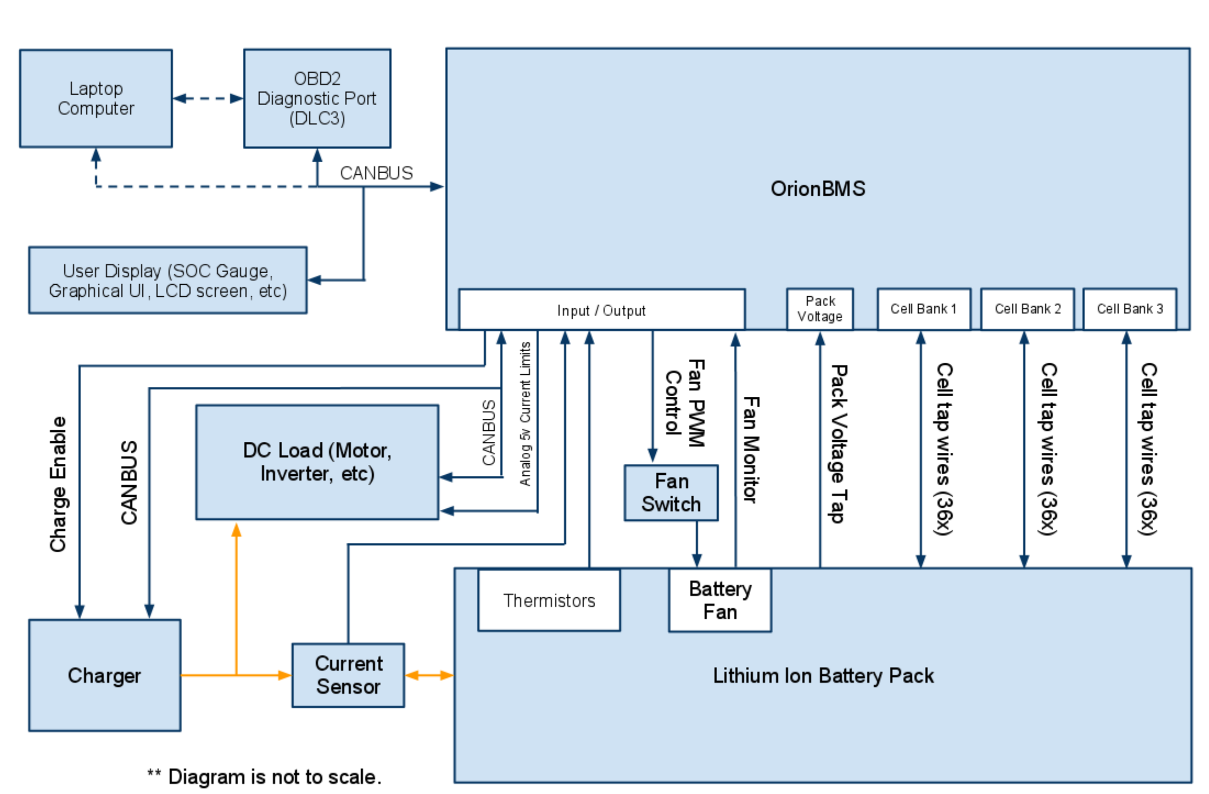
- 2-A peak gate turnoff current
- Fast 50-ns response to current reversal
- Minimum VDS clamp for faster turnoff
- Available in standard and AEC-Q100 qualified versions LM5050Q0MK-1 (up to 150°C TJ) and LM5050Q1MK-1 (up to 125°C TJ)
- Package: SOT-6 (thin SOT-23-6)

Figure 11. TIDA-01537 Input Power



In the LM5050-1-Q1 device, a high-side MOSFET controller is used to support reverse-polarity protection. The LM5050-1-Q1 device has an internal charge pump and VDS monitor to support the application. There is a need to place a diode in a forward direction in between the GND of the LM5050-1-Q1 to the KL31 (battery ground). Choose the MOSFET based on the maximum load current from KL30. In the TIDA01537 design, there are no power-hungry loads such as power relays, solenoids, and motors. Adopt the input power structure based on the maximum load and protection requirements such as peak transients, reverse polarity, and jump start conditions. DC/DC (VDD6) from the TPS65381A-Q1 device can supply a maximum output current of 1.5 A–2.5 A. TPS65381-Q1 LDOs can generate 5 V, 3.3 V, and core voltage (1.x V). VDD5 supports up to 300 mA, the configurable LDO VDD3/5 can drain up to 300 mA maximum. The core supply is critical to most of the control units, the TPS65381A-Q1 device can support up to 600 mA. The TPS57160-Q1 is used to support microcontrollers which require more than a 600-mA core supply.

Using the Orion BMS with Tesla Battery Modules



The Orion 2 BMS and Orion Jr BMS products are compatible with the widely popular Tesla battery modules found in the Model S / X electric vehicles. These modules use a proprietary chemistry developed by Tesla in conjunction with Panasonic that delivers a unique combination of high power output while still retaining an industry leading energy density. They are a popular choice for aftermarket projects.

Depending on which vehicle the Tesla module came from, the actual build-up of the module may be slightly different. At the time this document was written, the Model S and Model X battery modules remain the most commonly used, though the recently released Tesla Model 3 battery packs are likely to grow in popularity quickly.

For the Model S variant of the battery module (which this document will focus on), the battery is comprised of 6 total cells in series (for a nominal voltage of 22.2v) with a variable number of 18650 style cells connected in parallel ranging from ~40 cells up to ~80 cells depending on which model vehicle the pack originated from. This means each module could have nearly 500 discrete battery cells inside it. Because the BMS itself is only concerned with the number of cells in series, however, the exact number of cells in parallel does not impact how the modules are wired to the Orion BMS.

Below is a picture of a 22.2v Tesla Model S / X battery module:

Revision A Tesla Module Pinout

Battery Connector J3

1	2	3	4	5	6
Green (Cell 5+)	BLANK	Orange (Cell 3+)	BLANK	Brown (Cell 1+)	BLANK

Tesla Circuit Board

Viewed from the back side of the J3 connector

Battery Connector J4

1	2	3	4
BLANK	Yellow (Cell 4+)	BLANK	Blue (Cell 6+)

Tesla Circuit Board

Viewed from the back side of the J4 connector

Battery Connector J5

1	2	3	4
BLANK	Black (Cell 1-)	BLANK	Red (Cell 2+)

Tesla Circuit Board

Viewed from the back side of the J5 connector

Temperature Connector

1	2	3	4
Blue (Therm #1+)	Yellow (Therm #1-)	Blue (Therm #2+)	Yellow (Therm #2-)

Tesla Circuit Board

Viewed from the front side of the temperature connector

Revision B Tesla Module Pinout

Battery Connector

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Green (Cell 5+)	BLANK	Orange (Cell 3+)	BLANK	Brown (Cell 1+)	BLANK	BLANK	BLANK	Black (Cell 1-)	BLANK	Red (Cell 2+)	BLANK	Yellow (Cell 4+)	BLANK	Blue (Cell 6+)

Viewed from front side of battery connector

Temperature Connector

1	2	3	4
Blue (Therm #1+)	Yellow (Therm #1-)	Blue (Therm #2+)	Yellow (Therm #2-)

Viewed from front side of temperature connector

Revision C Tesla Module Pinout

Battery Connector 1

1	2	3	4	5	6	7
Cell 6+	BLANK	Cell 4+	BLANK	Cell 2+	BLANK	Cell 1-

Viewed from the front side of 7 pin connector

Battery Connector 2

1	2	3	4	5
Cell 1+	BLANK	Cell 3+	BLANK	Cell 5+

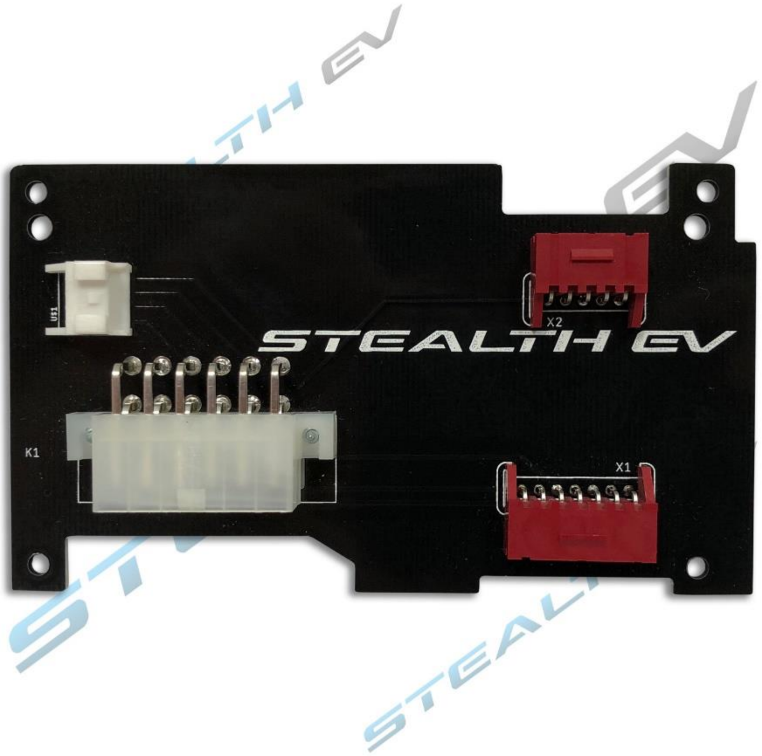
Viewed from the front side of 5 pin connector

Temperature Connector

1	2	3	4
Blue (Therm #1+)	Yellow (Therm #1-)	Blue (Therm #2+)	Yellow (Therm #2-)

Viewed from the front side of temperature connector

Tesla Model S & X Battery Module BMS Cell Tap Board:



Built to replace the standard Tesla BMS boards found in Tesla Model S and Model X battery modules. Fits 60, 70, 75, 85, 90, and 100 kWh series modules. Designed to work as a cell tap that can relay voltage of all 6 module battery groups and both temperature thermistors to your BMS of choice. Both temperature sensors are 10k thermistors and are NOT polarity sensitive. Not all applications will use both thermistors, but we recommend using at least one of the two for monitoring temperatures to maintain battery health. Comes with 12-pin connector and 16 crimp pins. Crimp pins fit 22-18 AWG cell tap wires. We use these with Orion BMS systems.

Li SMART BMS

Topology	PMU	Control Modular (LCM)		
	MMU, CMU	Measure Module (LMM)		
Operation purpose	BEV, PHEV, HEV, storage applications			
Cell chemistry	Any lithium-ion			
Maximum pack size (serial cells/voltage)	192 cells/ 800 V			
Features	LCM	SOC/SOH estimation, voltage/temperature/current control, temperature monitoring, ground-fault detection (optional), contactor and pre-charge control		
	LMM	Balancing, voltage/temperature monitoring		
Balancing current	50 mA			
Power supply	LCU	Power	1,8 W (150 mA @ 12 V)	
		Possible voltages	9 V – 18 V	
	LMM	Power	0,12 W (2 mA @ 60 V)	
		Possible voltages	10 V – 70 V	
Communication	IsoSPI	LMM ↔ LMM, LMM ↔ LCM		
	CAN, USB, UART	LCM ↔ exterior devices		
	Master (optional)	Bluetooth, SPI		
Current measurement	Shunt or hall-effect sensor (external)			
Main IC and characteristics	LCM	Microchip PIC32		
	LMM	LTC6804		
		Voltage	Accuracy	1,5 mV
		Temperature	Accuracy	1,5 °C
Additional features	Software to adjust BMS settings, open source software			
Location	Germany			
Quality of public information	good			

Table A.30. LION Smart's Li-BMS V4 [76].

Table A.20. Orion BMS - Extended Size and Orion BMS – Junior [64].

Topology	Modular	
Operation purpose	BMW i3	
Maximum pack size (serial cells/voltage)	96 cells/ 360 V	
Main IC and characteristics	Cell monitoring	Linear LTC6802G-2, LTC6801G, Freescale MC9S12P64
Location	Germany	

Charging times (for 0 – 80% charge)		~ 45 min from fast-charging station (50 kW, DC) ~ 3.10 h from BMW i Wallbox (11 kW / 16 A / 380 V) ~ 9.40 h from BMW i Wallbox (3.7 kW / 16 A / 240 V) ~ 15.00 h from domestic socket (2.4 kW / 10 A / 240 V)

FOX BMS

Topology	PMU	FoxBMS master (master)		
	MMU, CMU	FoxBMS slave (slave)		
Operation purpose	BEV, PHEV, HEV, aviation, space, marine, railway, industrial applications			
Cell chemistry	Any lithium-ion			
Maximum pack size (serial cells/voltage)	Arbitrary			
Features	Master	SOC/SOH estimation, voltage/temperature/current control, current monitoring, gorund-fault detection, contactor and pre-charge control		
	Slave	Balancing, voltage/temperature monitoring		
Balancing current				
Power supply	Power	1,8 W (150 mA @ 12 V)		
	Possible voltages	10 V – 26 V		
Communication	Master	CAN, RS232, USB, EEPROM, RS485, isoNOC		
	Slave	Iso-SPI, SPI		
Current measurement	CAN based current sensor (external)			
Main IC and characteristics	Master	IC	MCU 0, MCU 1	
	Slave	IC	LTC 6820, STM32F429	
		Voltage	Accuracy	1,2 mV
		Sampling frequency	> 3 kHz	
Additional features	Software to adjust BMS settings, adaptable (also centralized topology possible)			
Location	Germany			
Quality of public information	Good - excellent			

Orion BMS

Topology	PMU, MMU, CMU	Orion (Jr) BMS	
Operation purpose	Orion BMS	BEV, PHEV, HEV	
	Orion Jr BMS	Scooter, golf carts, solar, wind, backup apllications	
Cell chemistry	Any lithium-ion		
Maximum pack size (serial cells/voltage)	Orion BMS	180 cells/ 2000 V	
	Orion Jr BMS	16 cells/ 60 V	
Features	SOC/SOH/impedance estimation, balancing, voltage/temperature/current monitoring and control, ground-fault detection, contactor control		
Balancing current	Orion BMS	200 mA	
	Orion Jr BMS	150 mA	
Power supply	Orion BMS	Power	3 W (250 mA @ 12 V)
		Possible Voltages	8 V – 16 V
	Orion Jr BMS	Power	1,1 W
		Possible Voltages	11 V – 60 V
Communication	CAN	BMS ↔ BMS, BMS ↔ exterior devices	
	RS232	BMS ↔ programming and diagnostic interface	
Current measurement	Shunt or hall-effect sensor (external)		
Main IC and characteristics	Voltage	Accuracy	1,5 mV
		Resolution	0,25%
	Sampling frequency	33 Hz	
Additional features	Software to adjust BMS settings		
Certified standards	ISO 7637, EN 50498:2010, 2004/104/EC		
Costs	Orion	$760 - $1680	
	Orion Jr	$425 - $460	
Location	USA		
Quality of public information	Excellent		

Table A.20. Orion BMS - Extended Size and Orion BMS – Junior [64].

Topology	Modular	
Operation purpose	BMW i3	
Maximum pack size (serial cells/voltage)	96 cells/ 360 V	
Main IC and characteristics	Cell monitoring	Linear LTC6802G-2, LTC6801G, Freescale MC9S12P64
Location	Germany	

TESLA MODEL S

Topology	Modular	
Operation purpose	Tesla Model S	
Maximum pack size (serial cells/voltage)	96 cells/ 400 V	
Balancing	passive	
Main IC and characteristics	Cell monitoring	TI chip
Location	USA	

Table A.24. Tesla Motors' Model S-BMS [68].

Topology	PMU	Battery pack Management Unit (BMU)		
	MMU, CMU	Cell Management Unit (CMU)		
Operation purpose	BEV, PHEV, HEV			
Cell chemistry	Any lithium-ion			
Maximum pack size (serial cells/voltage)	256 cells/ 1000 V			
Features	BMU	SOC estimation, pack-voltage/temperature monitoring, voltage/temperature/current control, ground-fault detection, contactor and pre-charge control		
	CMU	Balancing, voltage/temperature monitoring		
Balancing current	250 mA			
Communication	CAN	CMU ↔ BMU, BMU ↔ exterior devices		
Current measurement	Shunt sensor (external)			
Main IC and characteristics	CMU	Voltage	Accuracy	1 mV
			Resolution/frequency circuit 1	24 bit/ 1 Hz
			Resolution/ frequency circuit 2	12 bit/ several kHZ
		Temperature	Accuracy	2 °C
Additional features	Software to adjust BMS settings			
Location	Australia			
Quality of public information	Good - excellent			

Table A.25. Tritium's IQ BMS [69].

Topology	PMU, MMU, CMU	U-BMS-series
Operation purpose	BEV, PHEV, HEV, marine, industrial, storage applications	
Cell chemistry	Any lithium-ion	
Maximum pack size (serial cells/voltage)	U-BMS-LV	150 V
	U-BMS-LVM	150 V/ 1000V (distributed)
	U-BMS-HV	450 V
	U-BMS-SHV	700 V
Features	SOC estimation, balancing, voltage/temperature/current monitoring and control, ground-fault detection, contactor and pre-charge control	
Communication	CAN	BMS ↔ exterior devices
Location	USA	
Quality of public	Regular	