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TI POWER

TI *Live!* BATTERY MANAGEMENT SYSTEMS SEMINAR

TERRY SCULLEY

STACKING SYSTEMS FOR UPS / BBU / ESS APPLICATIONS

Agenda

- ESS system architectures
- BQ769x2 overview
- <10-KWh, 12-48-V solution
- BQ796xx overview
- >200-KWh, 1500-V solution
- 10- 50-KWh, 48-250-V solution
- ESS common challenges

SYSTEM ARCHITECTURES

ESS applications

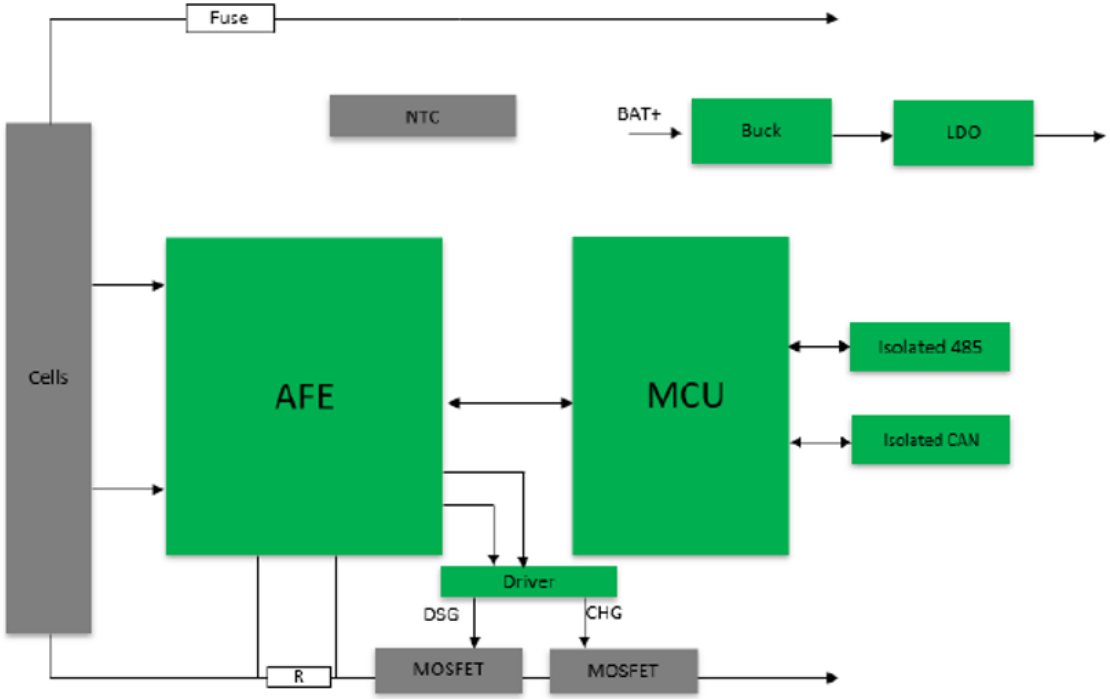
~10kWhr
Residential storage, server backup

100 ~ 250kWhr
Commercial / office storage

~MWhr
Wind power storage
Solar farm storage
Grid peak shaving

<10-KWh, 12 – 48-V solution

- Current sense through AFE
- Usually one AFE is sufficient
- Depending on the AFE, either the AFE or the MCU can drive the CHG & DSG protection FETs



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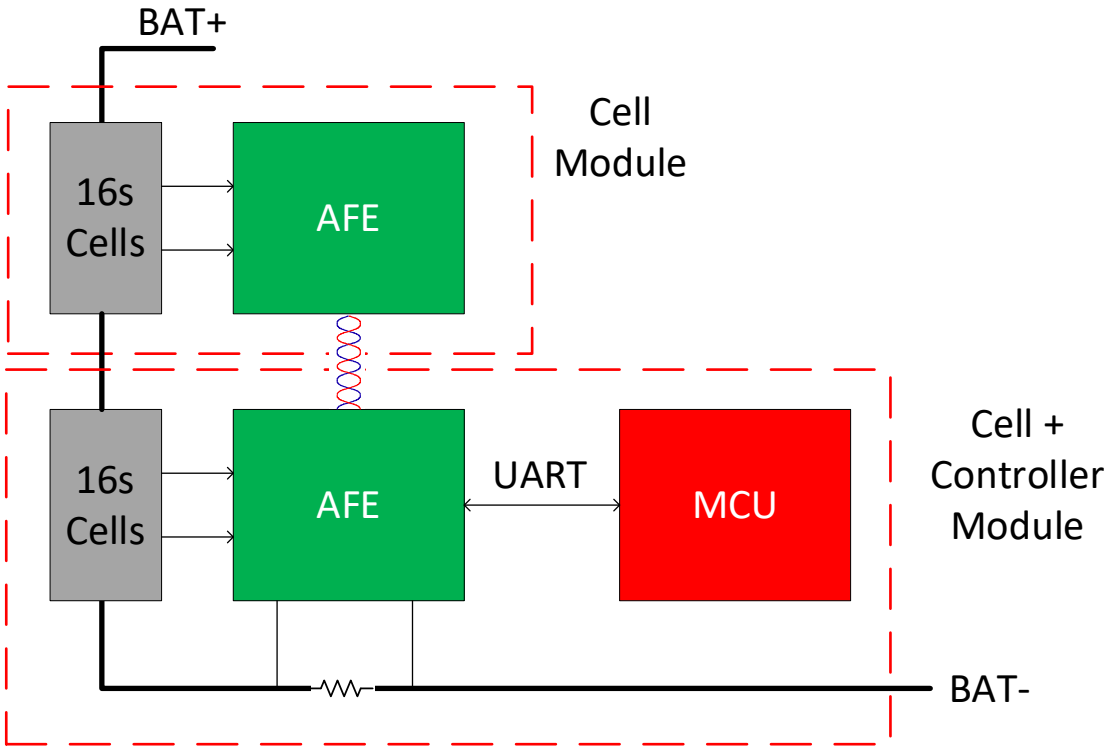
10- 50-KWh, 48-V – 250-V solution

- Current sense can be implemented in the lower AFE module or a separate controller module
- Extra power consumption in the lower device can cause imbalance between modules.



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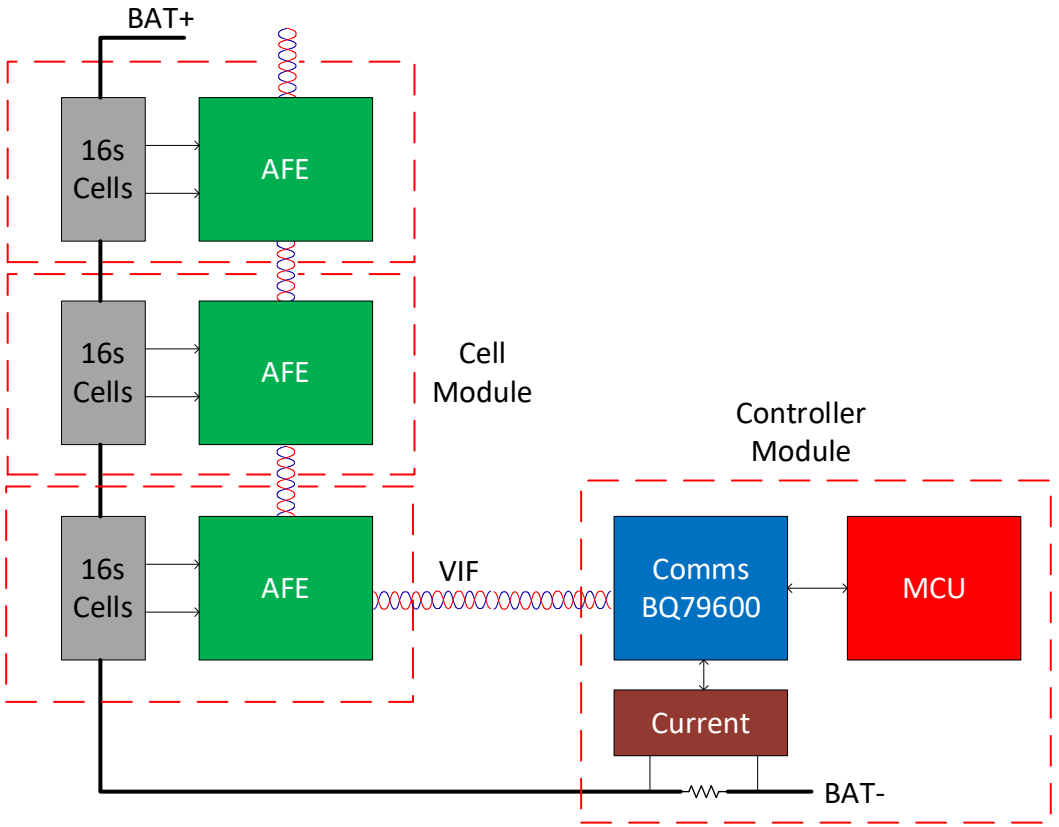
>200-KWh, 1500-V solution

- Modular stacked design for flexible choice of power level
- Controller module may be physically distant from cell modules
- Current sense may be in the controller module



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SOLUTIONS FOR EACH SYSTEM

BQ76942 (10s), BQ769142 (14s), BQ76952 (16s)
3s – 16s battery monitor and protection

Features

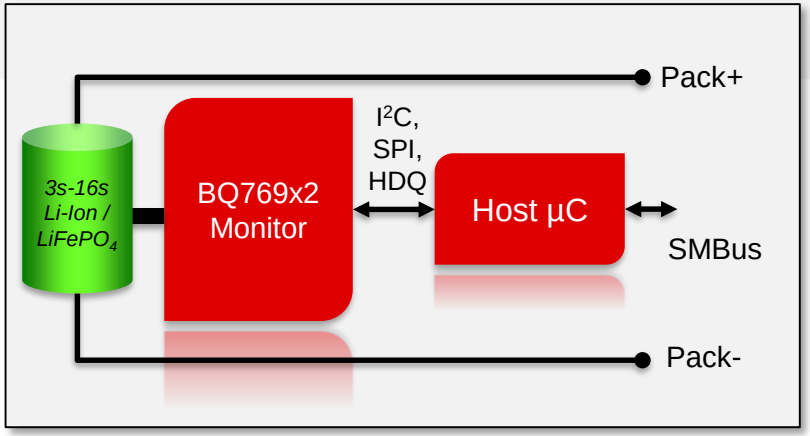
- Digital data with 16/24-bit ADC and 16/24-bit coulomb counter
- Fast data refresh rate: all cells measured every 63ms, current every 3 ms (31.5 ms & 1.5 ms in FAST mode)
- Integrated high side nFET drivers
- High voltage accuracy: +/-5 mV(typ), +/-10 mV from 0 ~ 60ºC
- Extensive suite of primary and secondary protections
- Flexible communication options: I2C w/CRC, SPI w/CRC, HDQ
- Dual Programmable LDOs, 1.8 V~5 V, up to 45 mA each
- Low Power Modes: SLEEP (20 uA), DEEPSLEEP (9 uA)
- Package: 48-pin TQFP

Applications

- Energy storage systems
- Power & garden tools
- Vacuums & appliances
- E-bike, E-scooter, LEV

Benefits

- Precision data supports pack analytics & proprietary gauging algorithms
- Multiple power modes used to optimize system operation
- Random cell attach robustness simplifies production line
- Support for up to 9 thermistors allows temperature measurement at multiple pack locations



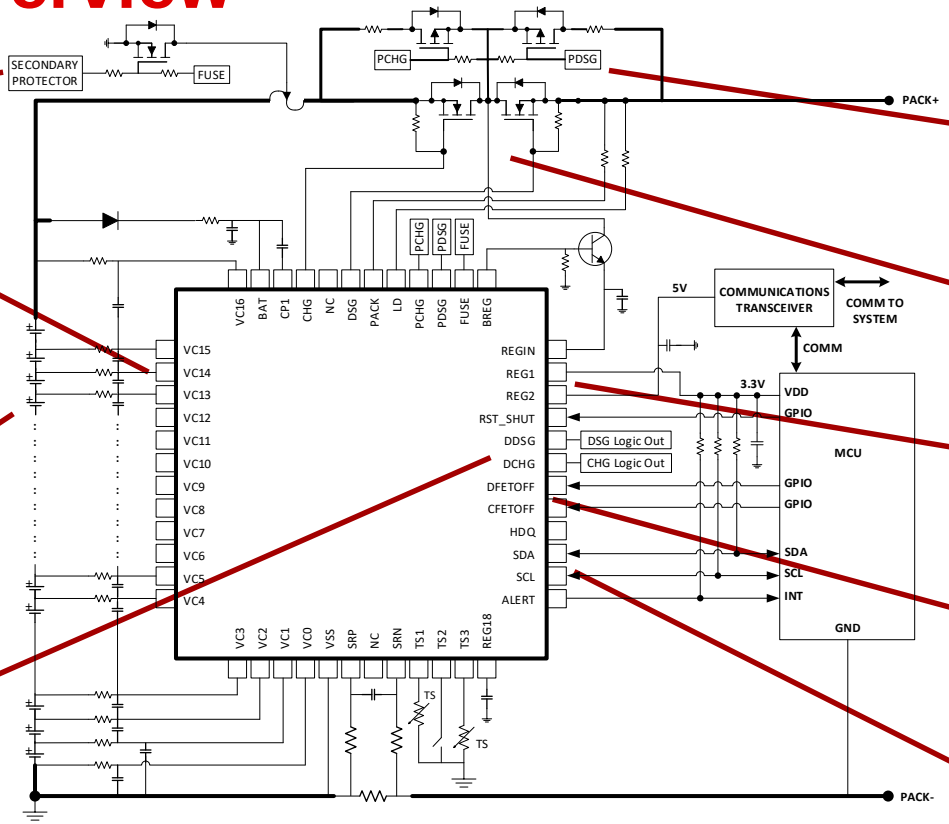
BQ769x2 overview

Secondary protection
Works with external secondary protector

Integrated CB FETs
Up to 50mA CB current

Random cell attach order
High voltage tolerance on cell Input pins

Digital CHG and DSG output
Can use as alternative Charge/Discharge fault signal



Integrated PFET drivers
e.g. to slowly charge up the capacitive load at system startup

Integrated high-side NFET drivers

Programmable REG1 and REG2 (1.8 V / 2.5 V / 3.0 V / 3.3 V / 5 V) e.g., to power CAN transceiver or MCU

External **HW shutdown** or **reset control** and fast **FETOFF control**

I2C or **HDQ** or **SPI**

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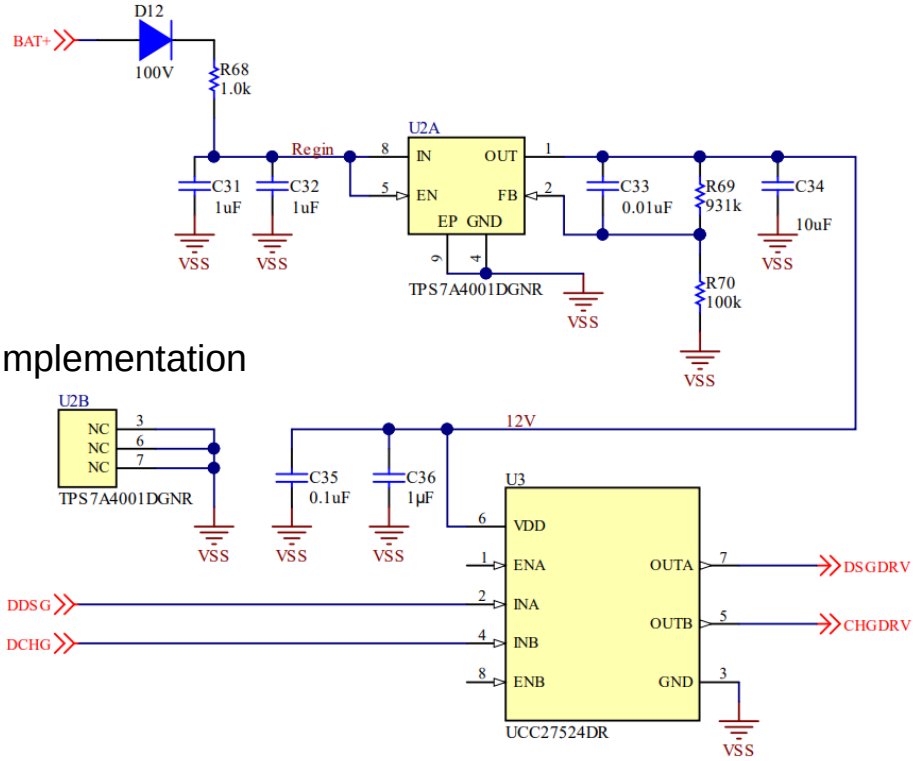
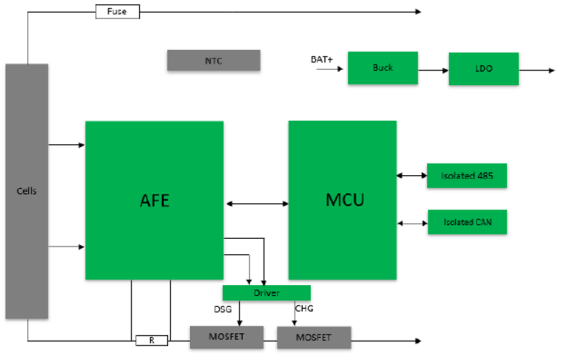
10-KWh solution using BQ769x2

Low-side protection FETs

FET driver implementation





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BQ79616/4/2 & BQ79656/4/2 overview

Target features

- **ASIL D Voltage/temperature** measurement and **communication**
- **Cell count of 16S/stack up to 63 ICs**
- **Dedicated busbar measurement**
- **Voltage Accuracy** -2.2 mV / +1.5 mV
  - **All 16 cell voltage measurements** complete in **<128 us**
  - **Integrated front end RC filters** on voltage measurement path
  - **Integrated post ADC digital low pass filters** w/ as low as 6-Hz f_{cutoff} option
- **BQ79656** adds **integrated current measurement** capability
- **Built-in 2nd level protector** for OV/UV/OT/UT & **embedded differential Fault signal** through vertical communication interface
- **Robust Daisy Chain communication** with data re-clocking & ring architecture
  - **Support capacitive, choke and transformer** comm. isolation
- **UART communication** to system MCU; **SPI Master**
- **HW Reset:** POR-like event w/out battery removal
- **Internal cell balancing** with 2.5-Ω Rdson at **240 mA/80 ºC** (8-channel balancing)
  - Or effective 120 mA/80 ºC on concurrent balancing all channel
  - Optional device controlled odd/even duty cycle w/out constant host system monitoring, or manual control to turn on adjacent CBFET
  - **Independent configurable balancing timer range from 10s to 10hrs**
  - **Thermal management** to pause/resume CB progress w/. Internal CBFET temperature and external NTC measurement
- Optional **module balancing** with built-in timer and stack voltage cut-off setting
- **100-ms FDTI mode**
- **Package: 64-pin QFP**

Benefits

- **IC level ASIL D. No special SW requirement**
- **Learn one, learn all, applies to multiple platforms**
  - Part of the ASIL D family with 16S, 14S,12S monitor for HV system and 48-V system
  - All devices sharing same package/pinout, functional control and register map
  - Dedicated bus bar measurement allow same schematic on various module size design
- **Minimal BOM count & voltage measurement accuracy and integrity for SOC calculation**
  - simple differentiate front end RC filters (no voltage clap, no single ended cap)
  - **Integrated post ADC low pass filters** provides high integrity level of DC voltage measurement by filtering out system noise (e.g. invertor/charger/heater/motor rotation etc) for best SOC calculation
- **Robust Daisy Chain communication**
  - Strong voltage drive strength (20mA) with +/-20V tolerant on receiver + data reclocking
  - HW reset can be initiated by MCU to create POR-like reset
- **Additional features to allow flexibility system design and system robustness**
  - **Embedded fault function via comm line** w/out extra fault cable/isolation need
  - **Ring Architecture** on vertical communication like to support reverse communication direction in case of broken cable
  - **Built-in 2nd level protector** with user programmable OV/UV/OT/UT threshold independent of ADC measurement, allowing critical cell monitoring in SLEEP mode

BQ79616 overview

Support random hotplug w/o external clamps

ASIL-D cell voltages measurement

ASIL-B Integrated window comparators

Internal CB up to 240mA. Allow adjacent cells to be on at the same time.

Built-in thermal management to automatically pause/resume CB

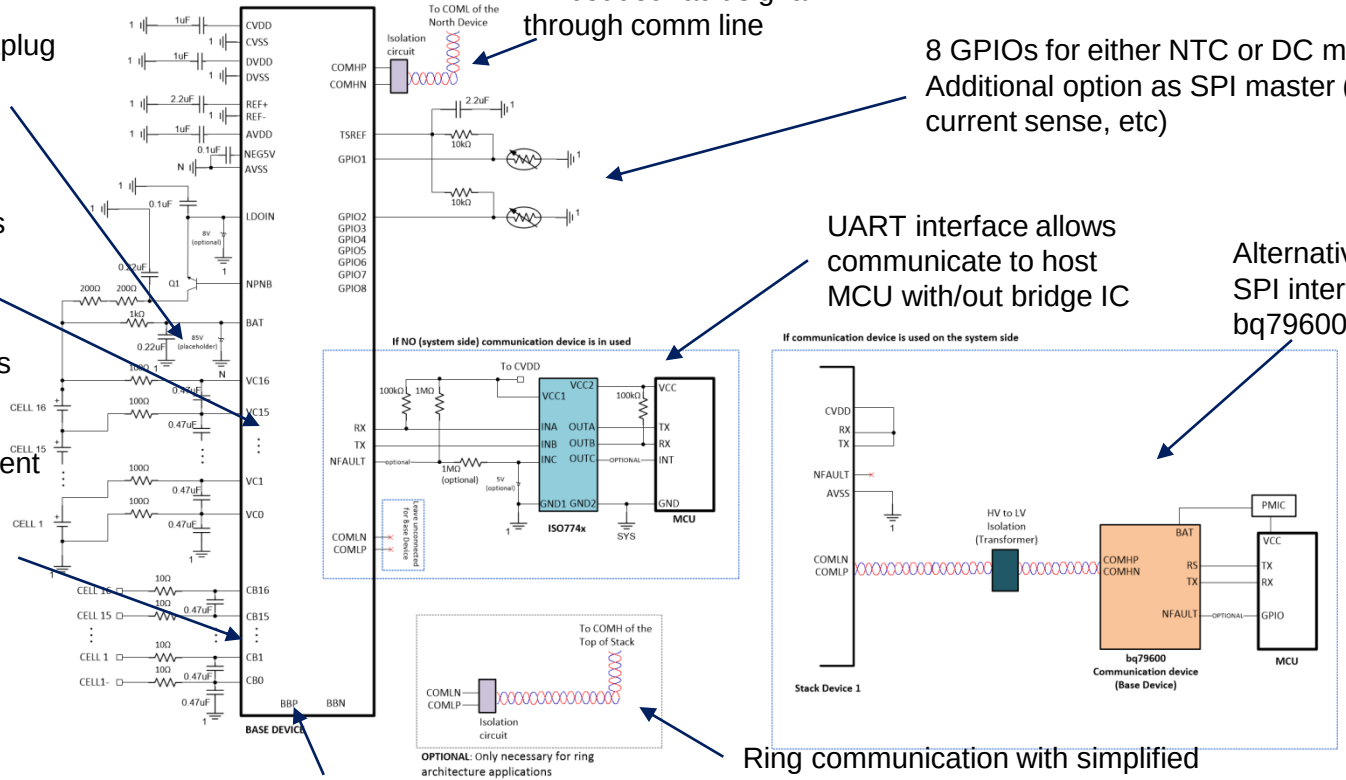
Embedded fault signal through comm line

ASIL-D temperature measurement.

8 GPIOs for either NTC or DC measurement. Additional option as SPI master (e.g. EEPROM, current sense, etc)

UART interface allows communicate to host MCU with/out bridge IC

Alternatively, UART or SPI interface if using bq79600 bridge IC



Bus bar measurement

Ring communication with simplified control sequence

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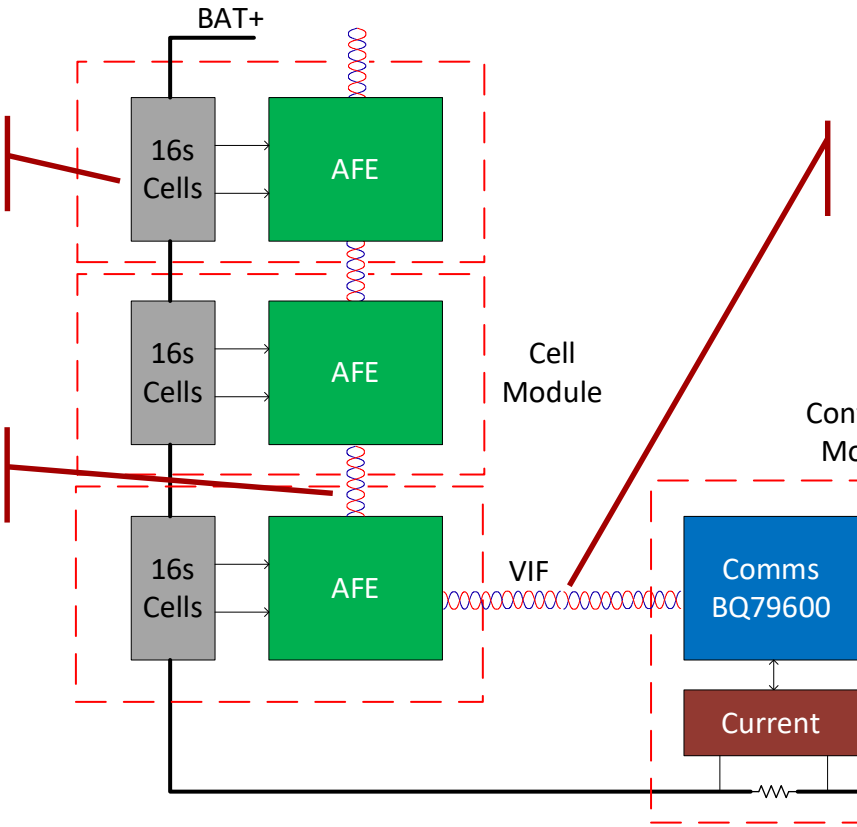
>200-KWh solution



Individual module
one BQ79616 supports up to 16s in each module

Vertical Interface (VIF)
supports communications between modules

Comms to controller module
can use UART on same PCB, or VIF for transmission over meters of cabling to BQ79600 bridge device

Comms to MCU
BQ79600 bridge supports UART or SPI

Current sense
can be supported by using BQ79656 in bottom cell module, or separate discrete solution

50-KWh solution

- Can use either product family

- BQ796xx family
  - Higher accuracy and speed of measurements
  - Integrated vertical stacking interface

- BQ769x2 family
  - Integrated NFET drivers with charge pump
  - Low power operation
  - Lower cost

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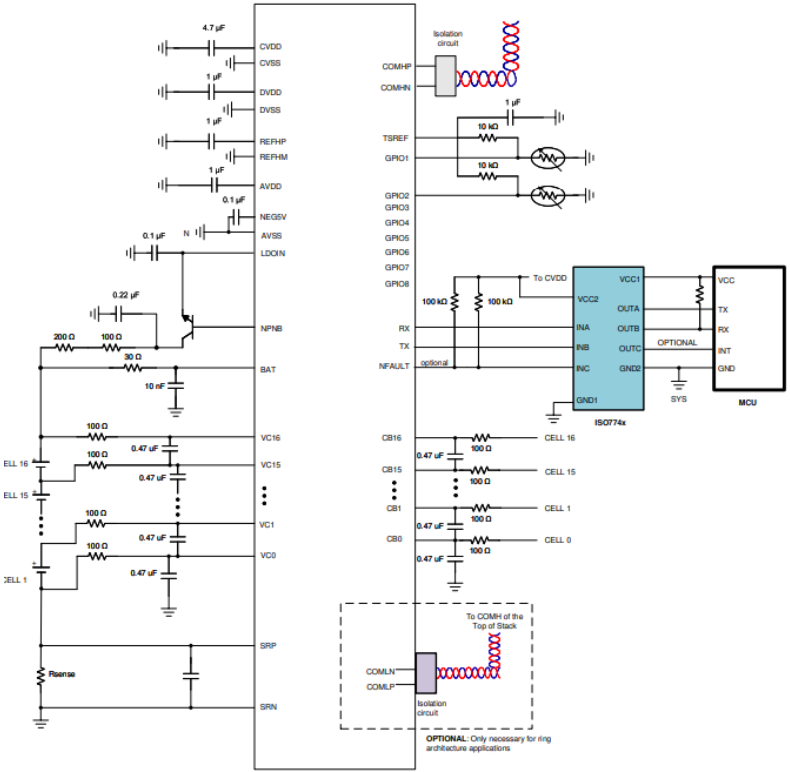
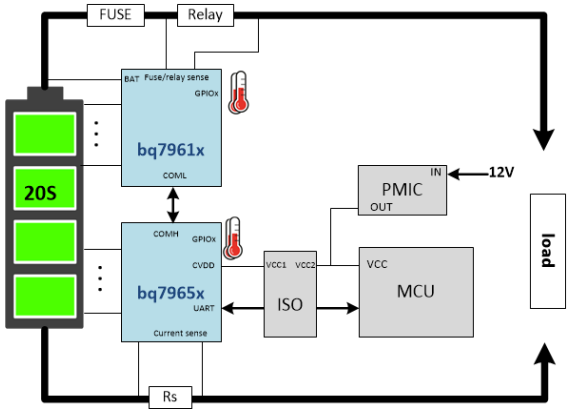
50-KWh solution using BQ796xx





Current sense:

- Input range = **+/-100 mV**
- Accuracy of **+/-0.3% (>300-uV input); 1.5uV (<=300-uV input)**
- Synchronized current & cell voltage measurements

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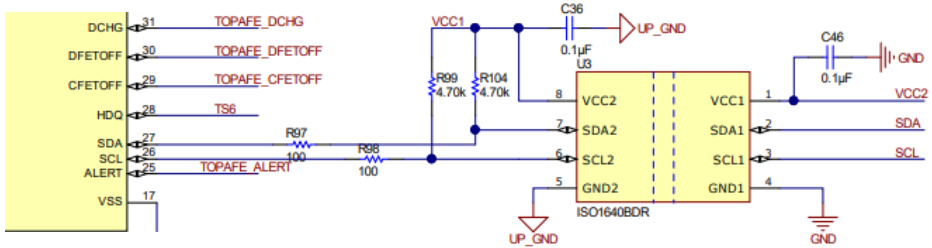
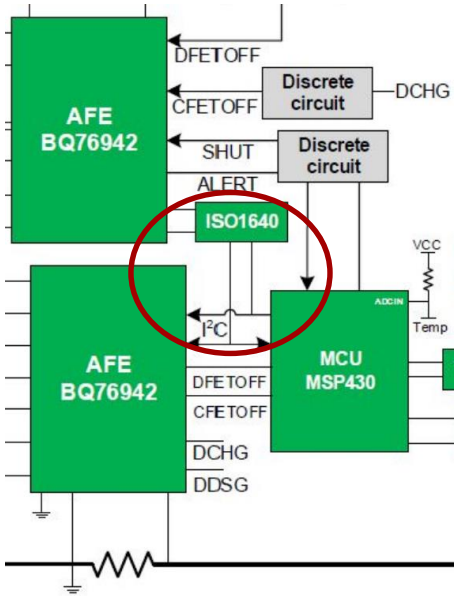
50-KWh solution consideration

- A system can be implemented based on the BQ769x2 or the BQ796xx device family.
- Low-side current sensing can be implemented in the lower AFE or on the MCU side
- A digital isolator or level shifting is used to communicate between upper and lower devices





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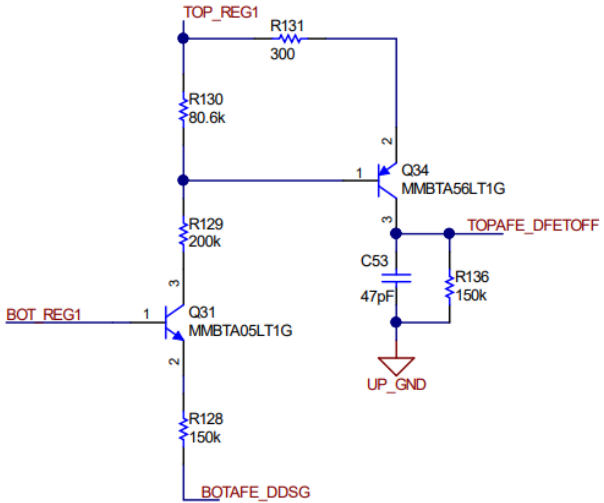
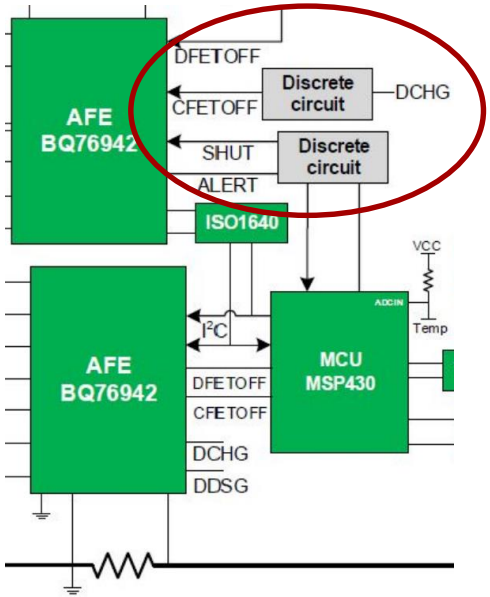
50-KWh solution using BQ769x2

- Level shifting on the control signals from the MCU to the top device is needed, due to the voltage level differences
- Top device fault pins control





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ESS COMMON CHALLENGES

Cell voltage accuracy

- Directly related to SOC, SOH calculations
- Critical for safety, protection
- BQ769x2: ±5 mV at 25°C
- BQ796x6: -2.2 mV / 1.5 mV at 25°C

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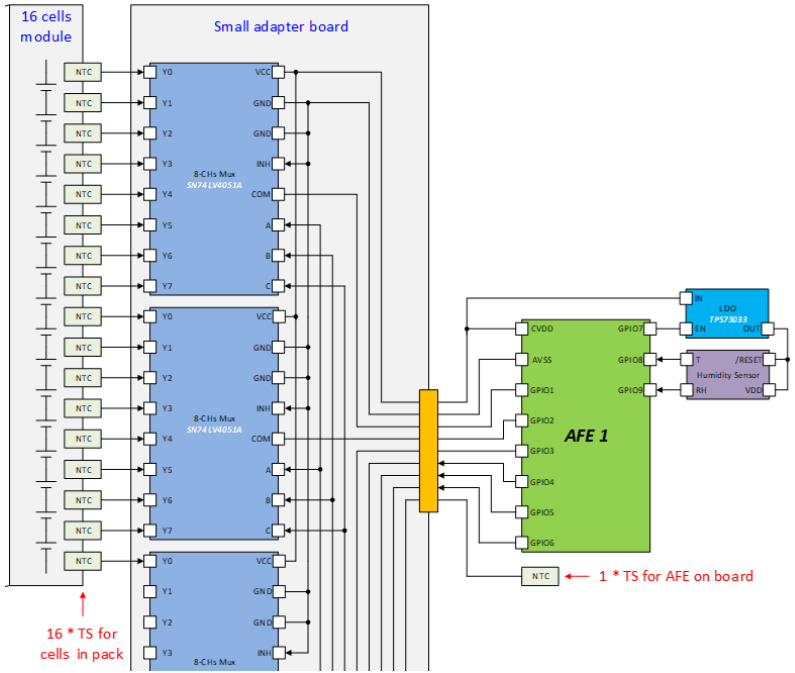
Thermistors

- Higher energy level systems have high thermal concerns - more thermistors needed
- Implemented through external MUX to AFE GPIOs
- MUX may be on a separate connector board
- Filtering at the input of the MUX is needed depending on the wire length and noise



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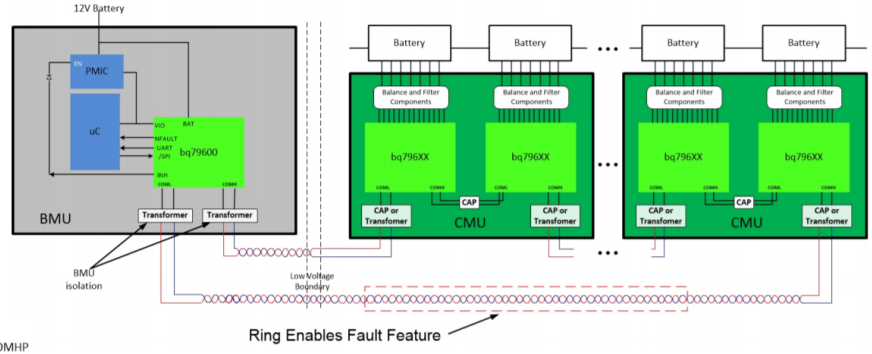
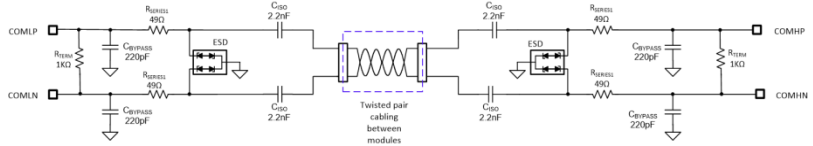
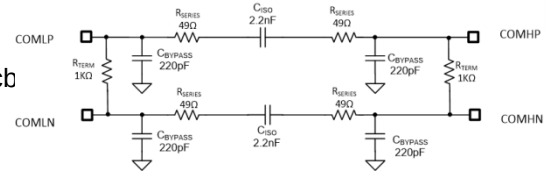
Isolation between devices



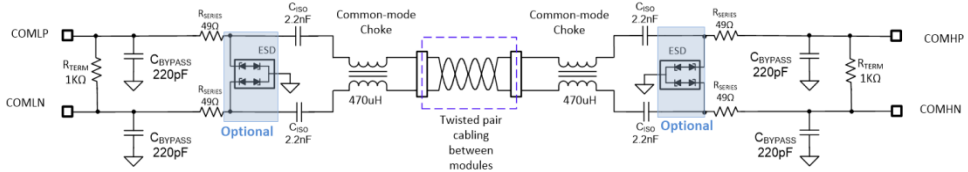
1. Cap only isolation



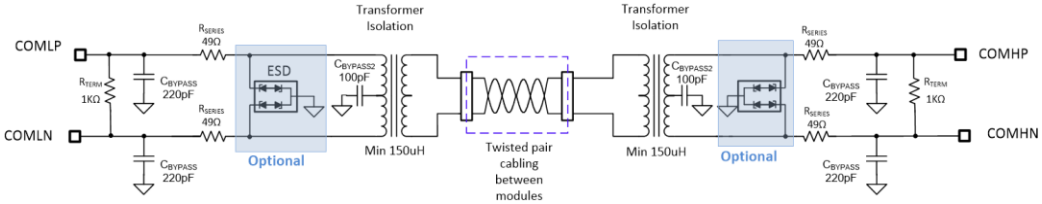
No need for ESD diode if devices are on the same pcb



2. Cap-choke isolation



3. Transformer isolation



- High flexibility on isolation selection
  - Cap-only isolation
    - Best for ICs on the same PCB
    - Can be used for cable lengths < 2 m
  - Cap-choke and transformer isolation
    - Suitable for cable lengths > 2 m
    - Less expensive than transformer isolation
  - Transformer isolation
    - Most effective for removing common-mode noise from the system

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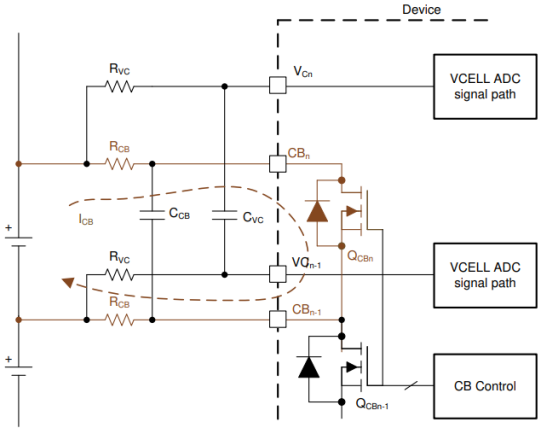
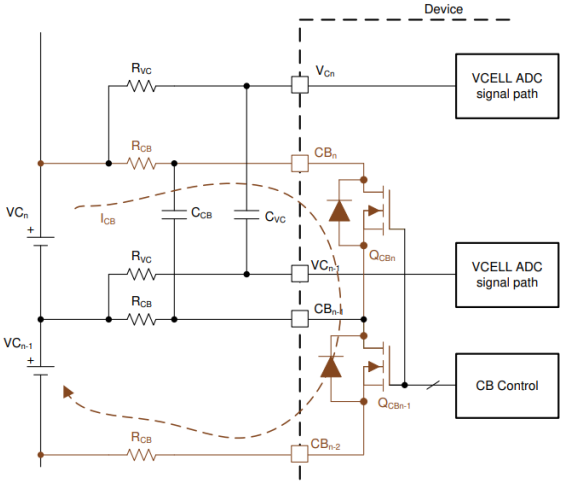
Cell balancing

- Passive internal vs external CB
- Adjacent cell balancing can be supported manually
- The BQ796xx family includes separate pins for balancing vs measuring. The BQ769x2 family shares the same pins for both.



(a) Cell balancing with internal CBFET



(b) Cell balancing with 2 consecutive CBFETs on

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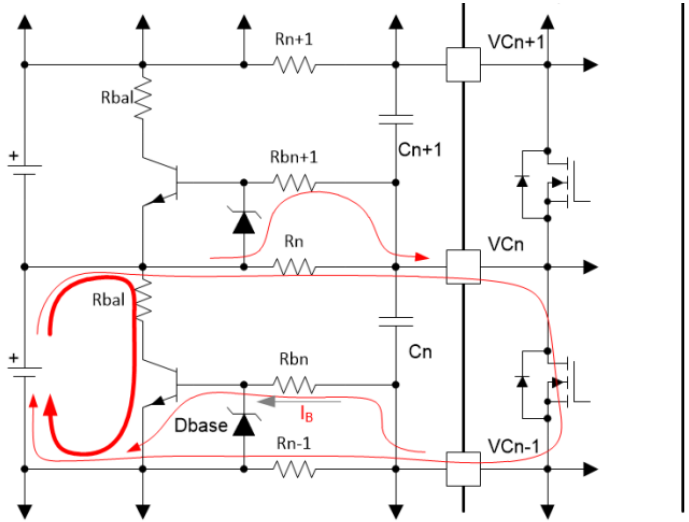
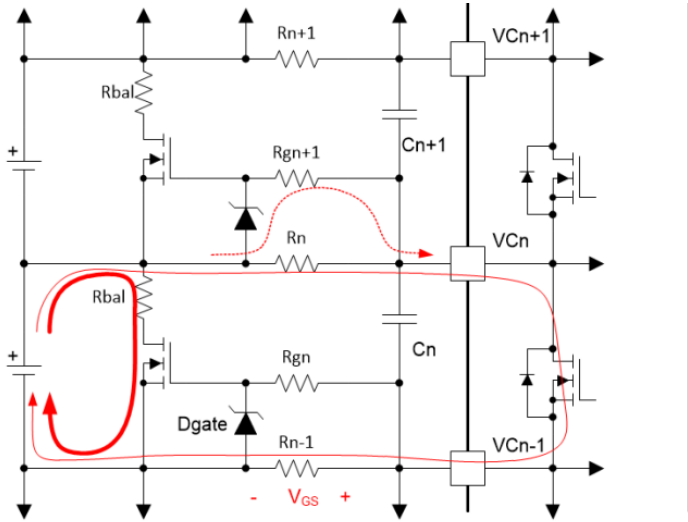
Cell balancing - cont

- For higher current cell balancing, external FETs or BJTs can be used





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Auto timeout when comms fail

9.5.4.3.6 COMM_TIMEOUT_CONF

Address	0x0019							
NVM	**Bit 7**	**Bit 6**	**Bit 5**	**Bit 4**	**Bit 3**	**Bit 2**	**Bit 1**	**Bit 0**
Name	SPARE	CTS_TIME[2:0]			CTL_ACT	CTL_TIME[2:0]		
Reset	0	0	0	0	0	0	0	0

SPARE = Spare

CTS_TIME[2:0] = Sets the short communication timeout. When this timer expires, the device sets the *FAULT_SYS[CTL]* bit. This can be used as an alert to the system to prevent a long communication timeout.
000 = Disables short communication timeout (default at reset)
001 = 100 ms
010 = 2 s
011 = 10 s
100 = 1 min
101 = 10 min
110 = 30 min
111 = 1 hr

CTL_ACT = Configures the device action when long communication timeout timer expires.
0 = Sets *FAULT_SYS[CTL]* and sends device to SLEEP mode (default at reset)
1 = Sends the device to SHUTDOWN. *FAULT_SYS[CTL]* bit will not be set.

CTL_TIME[2:0] = Sets the long communication timeout. When this timer expires, the device takes the action configured by the *[CTL_ACT]* bit.
000 = Disables long communication timeout (default at reset)
001 = 100 ms
010 = 2 s
011 = 10 s
100 = 1 min
101 = 10 min
110 = 30 min
111 = 1 hr

- The BQ796xx family supports an auto timeout if comms fail
- COMM_TIMEOUT_CONF register provides settings to put device into SHUTDOWN and alert the MCU. Then MCU can decide to restart the device by resume auto Addressing
- The BQ769x2 supports a similar feature called “host watchdog”

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Summary

- With ESS systems ranging from <48V up to >1000V, a variety of solutions are needed to span the full range
- Both the BQ769x2 and BQ796xx product families implement voltage, current, and temperature measurement and protection for up to 16s packs.
  - The BQ769x2 integrates high-side NFET drivers and multiple low power modes, enabling a highly integrated solution for 10-kWh systems, and can be extended to ~50-kWh stacked systems with external isolators.
  - The BQ796xx family offers a well tailored solution for 50-kWh and higher capacity systems, providing high speed, high accuracy measurements, and a vertical stacking interface, enabling robust communications across cables between modules.

References

- BQ796xx Battery Monitor and Protector Family
  https://www.ti.com/product/BQ79616-Q1
  https://www.ti.com/product/BQ79656-Q1
  https://www.ti.com/product/BQ79600-Q1

- BQ769x2 Battery Monitor and Protector Family
  https://www.ti.com/product/BQ76942
  https://www.ti.com/product/BQ769142
  https://www.ti.com/product/BQ76952

- Using Low-Side FETs with the BQ769x2 Battery Monitor Family
  https://www.ti.com/lit/an/sluaa84a/sluaa84a.pdf

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