TI POWER

# How to stack non-automotive protectors and monitors in high cell count applications

Battery Management Deep Dive Training

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# Stacking in high cell count applications

- In the design of high cell count battery management systems, there may not be a single-chip solution for monitoring or protection that supports the required number of cells
- In these cases, it may be necessary to stack multiple devices to implement a solution that covers the full number of cells in the system
- This presentation reviews how to meet this requirement using TI's non-automotive battery monitors and protectors in a stacked configuration, focusing on:
  - Secondary protection using the BQ7716/8 and BQ2947 product families
  - Primary protection using the BQ77905 and BQ77915 product family
  - Monitoring using the BQ76920 (3S-5S), BQ76930 (6S-10S), BQ76940 (9S-15S), BQ76942 (3S-10S) and BQ76952 (3S-16S) product families

# Realizing a high cell count secondary protection solution

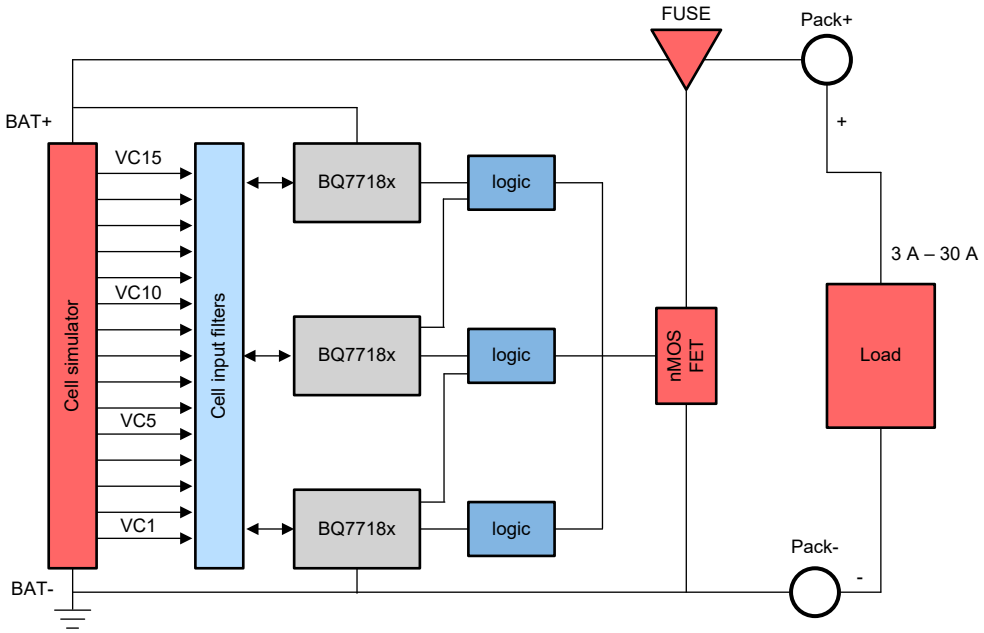
# High cell count secondary protection

- TI's multicell secondary protectors, such as the BQ7716/8 and BQ2947 families, support packs with up to 4S or 5S configurations
- The devices provide an output which is asserted when one or more cell voltages exceed the programmed overvoltage (OV) threshold
- The output pin is tolerant of up to 30 V relative to the device's VSS pin
- Device options are available with the output controlled as an open-drain active-low or CMOS active-high when a fault is detected
- The output pin can be used to excite a chemical fuse, permanently disabling the pack in the event of a fault

# High cell count secondary protection

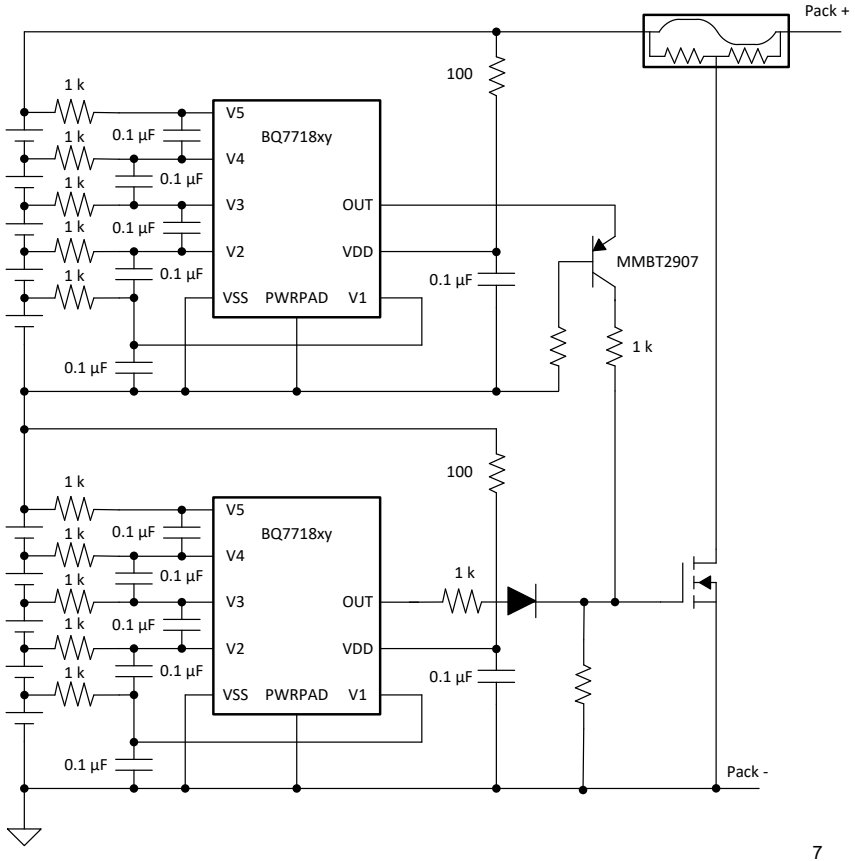
- For multicell configurations exceeding 5S, multiple protectors can be stacked to realize OV protection for each individual cell in the pack

- A conceptual diagram of this approach is shown for a 15S pack



# High cell count secondary protection

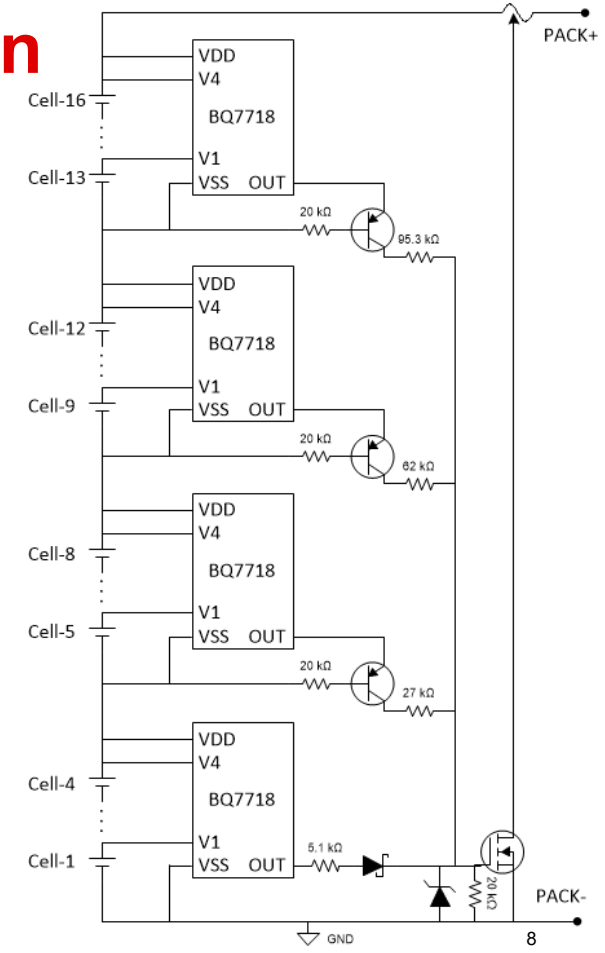
- The logic combining each OUT signal from the individual BQ7718 devices is shown (10S system)
- The version of the device with CMOS active-high output is selected
- The external PNP and associated circuitry is used to OR the signals together at ground level
- The combined fault signal then controls the pulldown NFET to trigger the chemical fuse



# High cell count secondary protection

- A simplified schematic of a 16S system using 4 stacked BQ7718 is shown
- The output of each BQ7718 is converted to a current, which is summed at the NFET gate through a 20 kΩ resistor
- The series resistance in each path can be adjusted based on the range of voltages expected at each location in the cell stack

This circuit is included on the EVM of the BQ76952 (see http://www.ti.com/tool/BQ76952EVM)



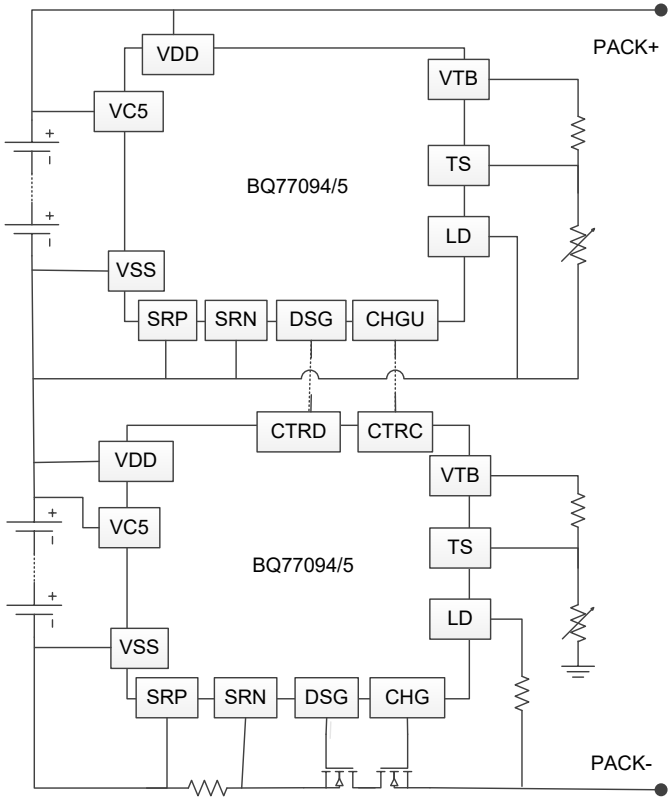
# High cell count secondary protection

- This stacking scheme can be extended to higher cell count systems, although the external circuitry may need modification to support the required range of voltage expected
- It is important to remember that each individual protector device must have at least two cells in use
- The system should not be configured with only one cell in use on a device
- For example, to implement a 6S system, do NOT configure one device to support 5 cells and the second device to support 1 cell

# Realizing a high cell count primary protection solution

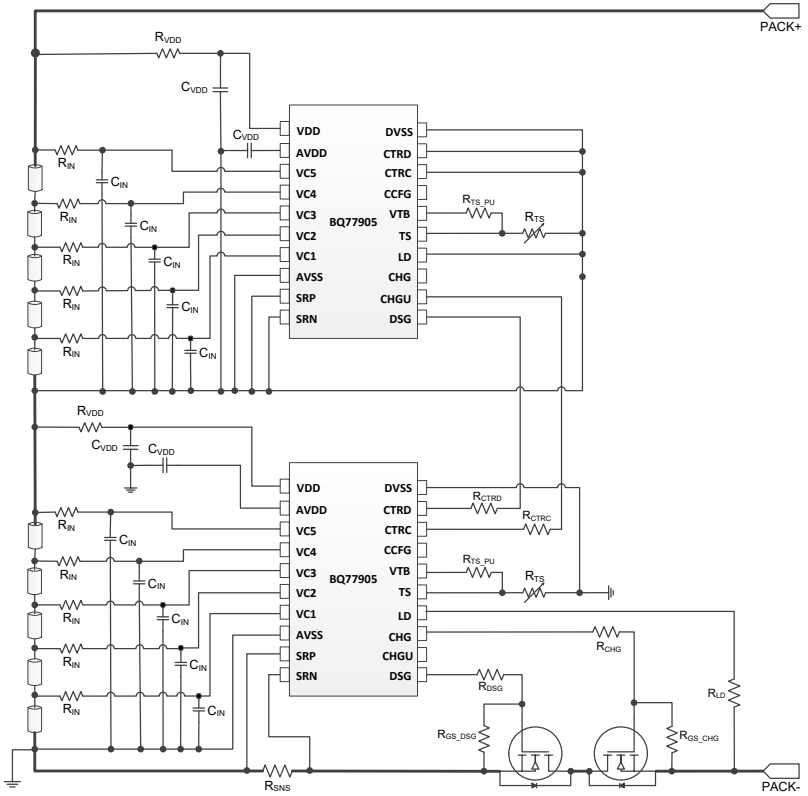
# High cell count primary protection

- The BQ77905 and BQ77915 family of primary protectors support from 3 to 5 series cells and provide a full suite of protection, including OV, UV, OW, SCD, OCD1/2, OTC, OTD, UTC and UTD
- The BQ77915 also adds autonomous cell balancing
- Primary protection for systems with over 5 series cells can be realized using multiple devices stacked
- Each device in the stack can implement OV, UV, OW and temperature protections
- The lowest device monitors the sense resistor and provide current protections



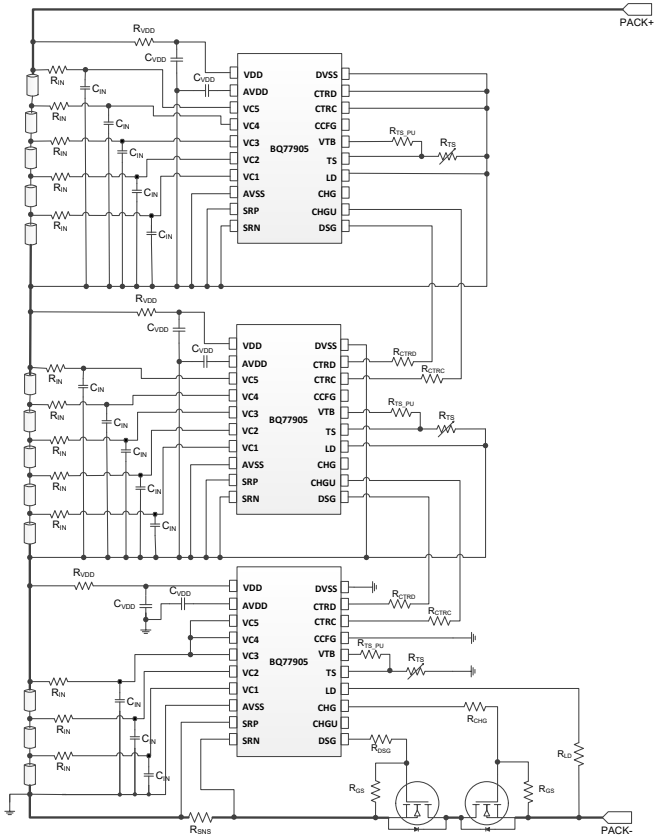
# High cell count primary protection

- The BQ779x5 integrate support for stacking, so the external PNP circuitry shown earlier is not required
- These devices include CTRC and CTRD input pins, which can be used to disable the lower device's CHG and DSG drivers based on the decision of the upper device
- These products include low side NFET drivers, which are utilized on the bottom device



# High cell count primary protection

- The CTRC and CTRD pins allow an upper device to disable the FETs on the next lower device, so decisions can flow downward to the bottom device
- These pins are connected to the local DVSS on the top device in the stack
- When stacked, the DSG and CHGU pins of an upper device connect to the CTRD and CTRC pins of the next lower device through 10 MΩ resistors
- The pins include ~7 ms filtering internally to avoid unintentional turnoff



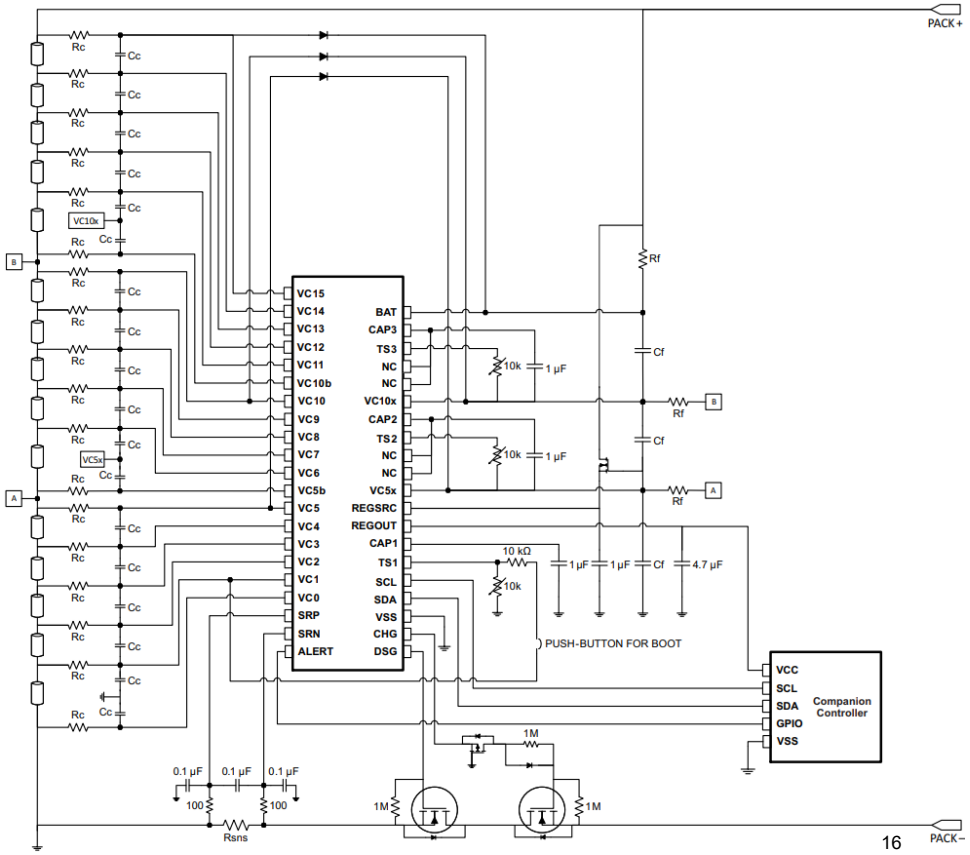
# High cell count primary protection

- This stacking scheme can be extended to higher cell count systems, although the delay for a signal in the upper device to reach the lowest device will accumulate through each set of debouncing
- It is important to remember that each individual protector device must have at least three cells in use, shorting unused cells beginning at the top (cell-5, then cell-4)
- It is recommended to eliminate cells from the lowest devices in a stack first, to provide stronger signals from the upper device to the lower device CTRx pins
- Application notes focused on stacking these devices can be found at:
  - http://www.ti.com/lit/an/slua774a/slua774a.pdf
  - http://www.ti.com/lit/an/slua906/slua906.pdf

# Realizing high cell count monitoring using BQ769x0 battery monitors

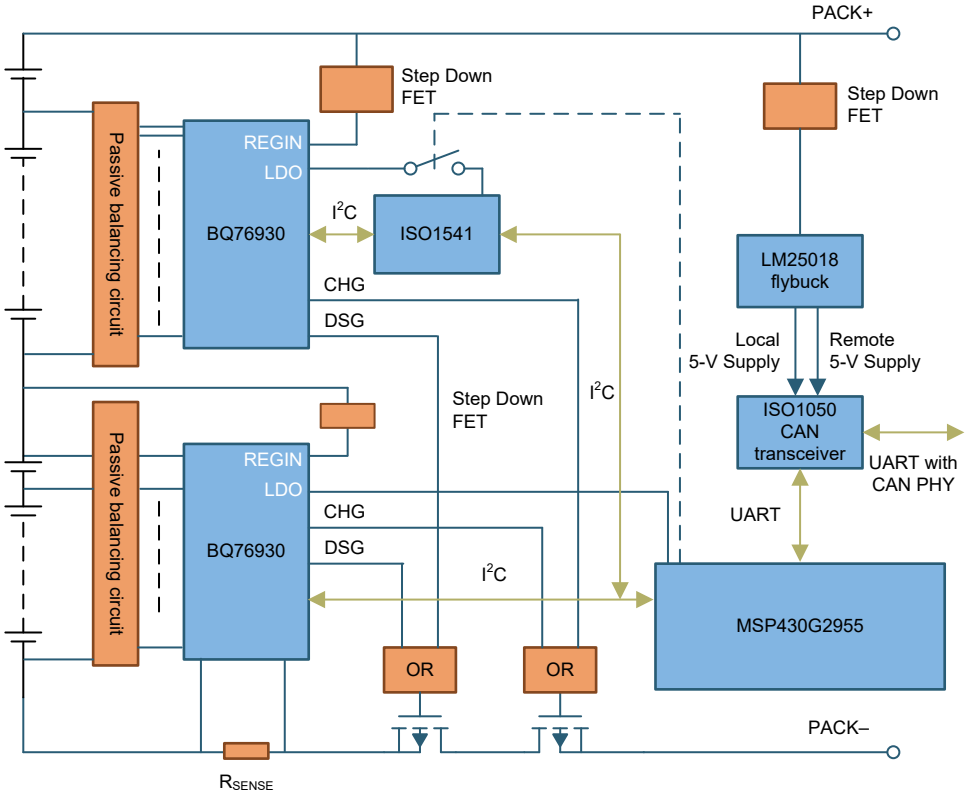
# High cell count battery monitoring using BQ769x0

- The BQ76920 (3S-5S), BQ76930 (6S-10S) and BQ76940 (9S-15S) family of battery monitor + protectors support up to 15 series cells and provide cell voltage, current and temperature monitoring, as well as primary protection for OV, UV, SCD and OCD
- When stacked, the protection signals need to be combined at ground level to control the low-side protection FETs
- A mechanism is also needed to communicate with each device's $I^2C$ interface



# High cell count battery monitoring using BQ769x0

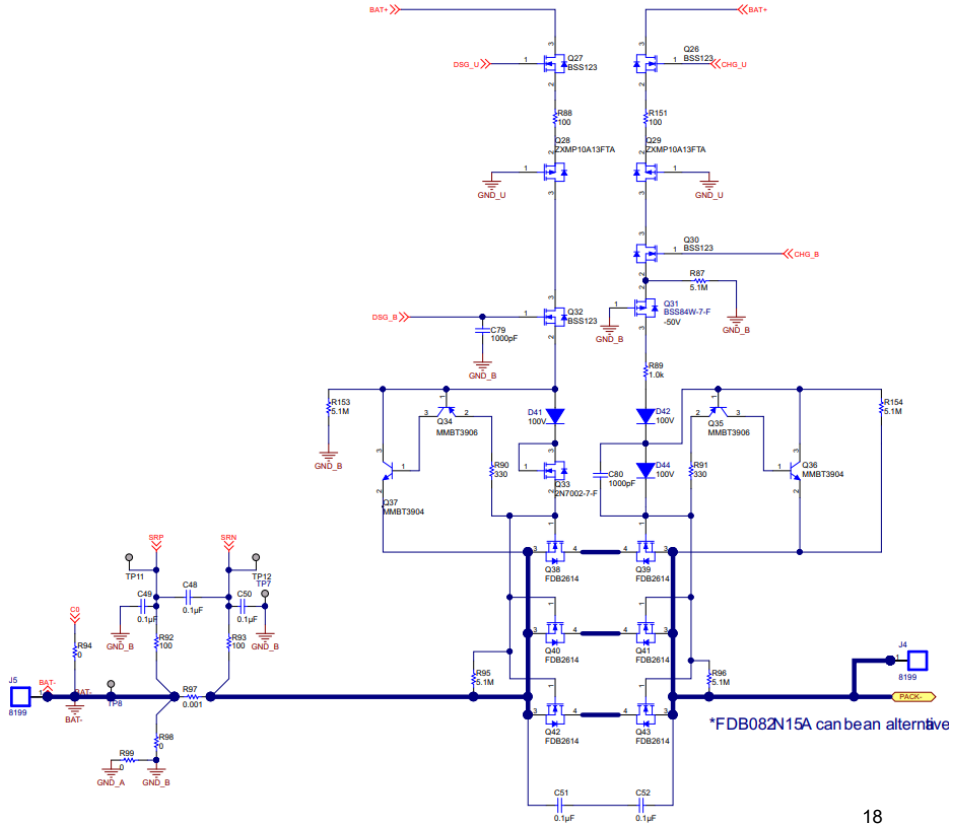
- The TI Design TIDA-01093 demonstrates a 20S system using two BQ76930 (10S) devices
- External circuitry is used to control the low side protection NFETs
- The I²C buses from each device are routed to a host MCU, with the upper device using an ISO1541 2.5 kV I²C isolator
- This scheme can be used to realize higher cell count systems, such as stacking two or more BQ76940 (15S) devices



# High cell count battery monitoring using BQ769x0

## Combined protection solution

- The protection signals from the two stacked devices are combined using a level shifting circuit network, shown here from TIDA-01093
- The series FETs Q26/27/28/29/30/31/32 are used for level shifting, disabling the FET drive signal whenever either signal from the upper or lower device triggers (falls)
- The circuitry involving Q33/34/35/36/37 and diodes D41/42/44 are included to provide a faster turnoff of the FETs when a protection triggers.



# High cell count battery monitoring using BQ769x0

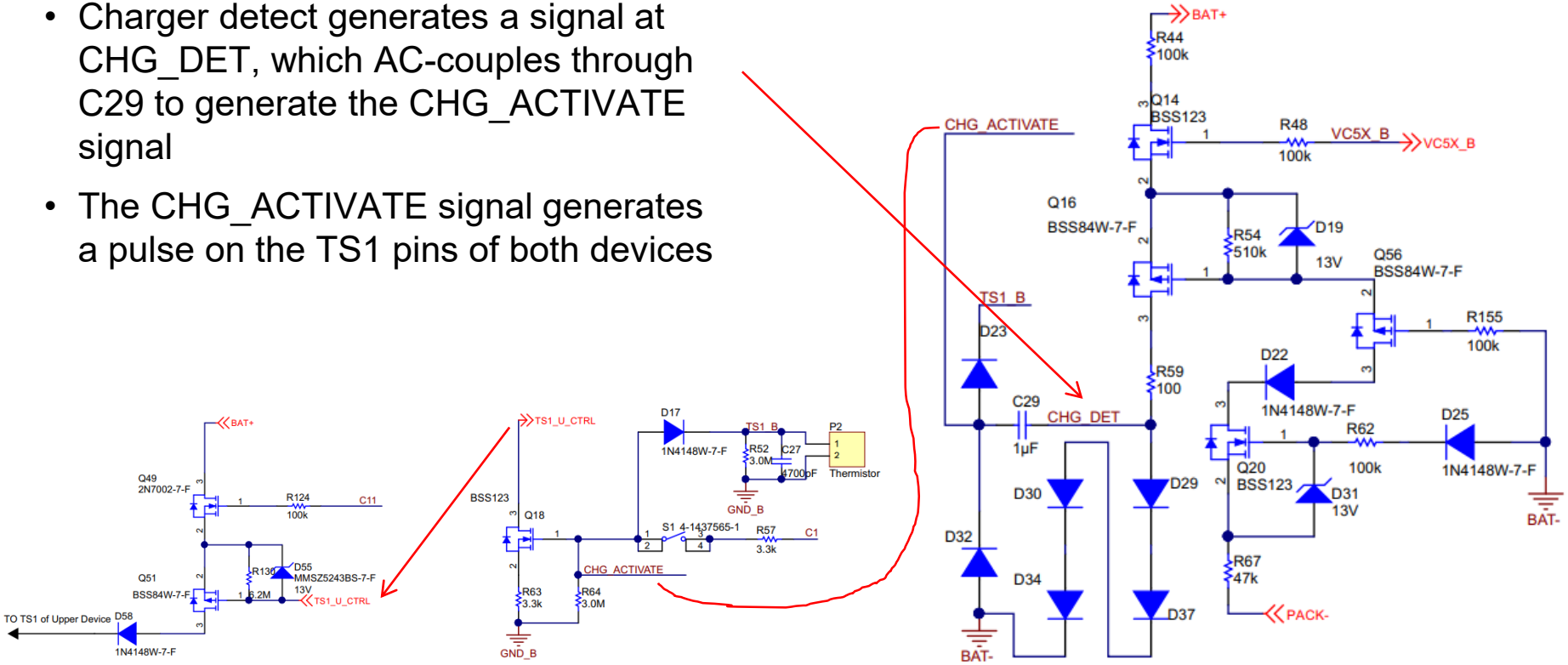
## Wakeup from SHUTDOWN

- A solution is also required to wake the pack from SHUTDOWN mode
- The BQ769x0 devices require a positive voltage on the TS1 pin of each device to awaken them from SHUTDOWN
- This can be accomplished using a charger detect scheme or a pushbutton
- The charger detect scheme used in TIDA-01093 relies on PACK- being pulled ~4 V or more below BAT- when a charger is attached and the CHG FET is disabled. The circuitry generates a level change when the charger is first attached.
- This level is then AC-coupled to the TS1 pins of each device, generating a short pulse to wake each device
- A pushbutton can also be used to similarly AC-couple a signal to each TS1 pin

# High cell count battery monitoring using BQ769x0

## Wakeup from SHUTDOWN

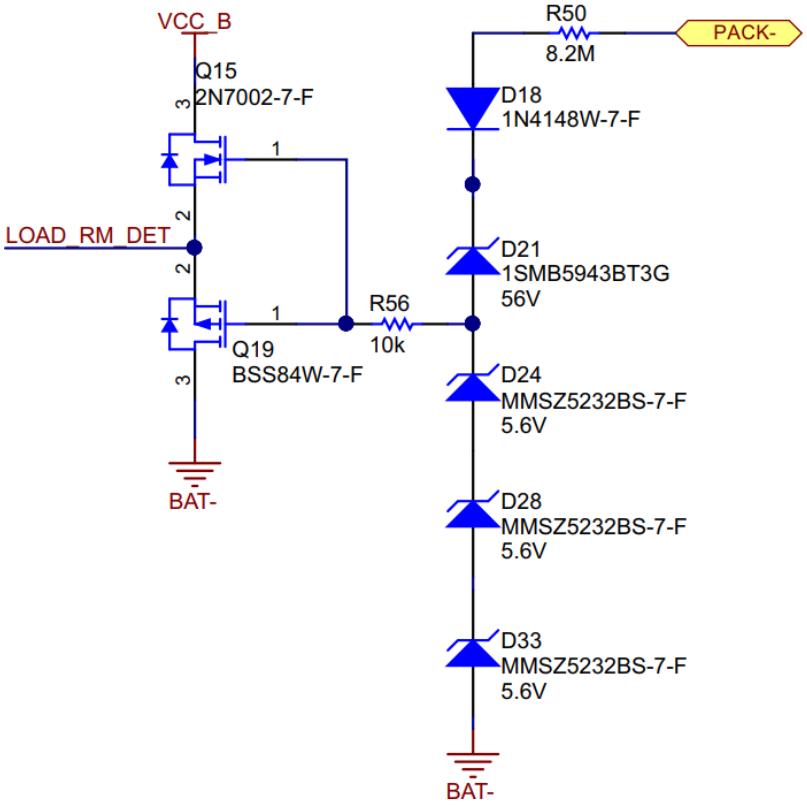
- Charger detect generates a signal at CHG_DET, which AC-couples through C29 to generate the CHG_ACTIVATE signal
- The CHG_ACTIVATE signal generates a pulse on the TS1 pins of both devices



# High cell count battery monitoring using BQ769x0

## Load detect

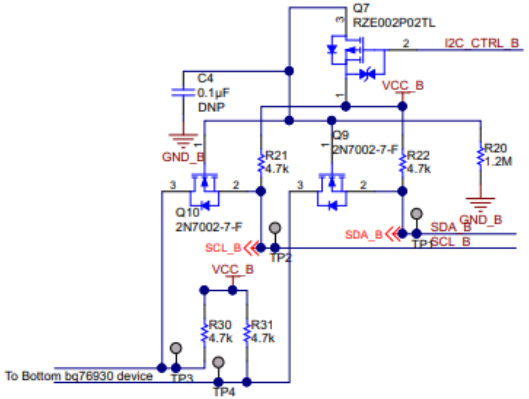
- Load detection is often important, in order to determine whether the load has been disconnected, after a short circuit discharge event has occurred
- The circuit shown implements a detect signal which can be read by the host processor
- When a short is detected and the DSG FET is disabled, but no charger is attached, PACK- will rise to PACK+
- If the load is removed, the circuit will pull PACK- to BAT- with a small leakage current

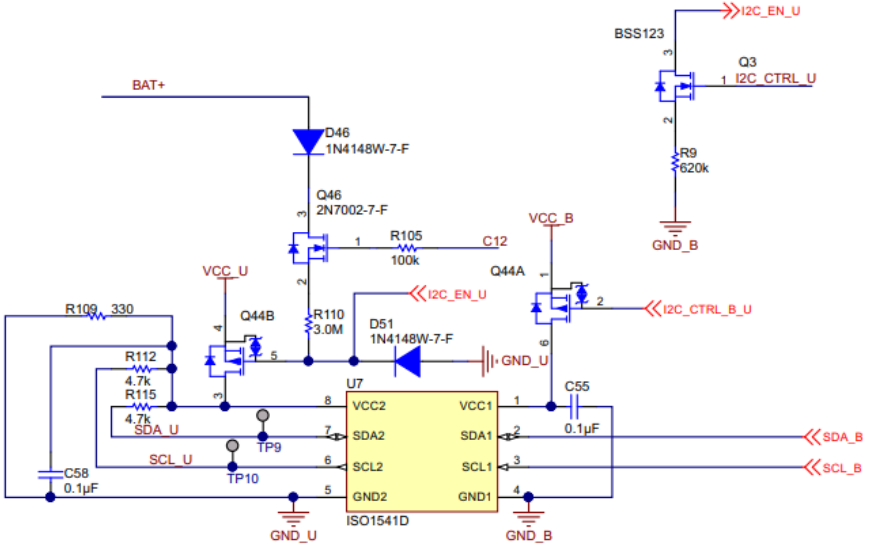


# High cell count battery monitoring using BQ769x0

## I²C communication

- Communication is necessary between the host processor and each device in the stack
- The I²C bus on the host processor is muxed to the two devices based on a GPIO from the host. This allows both devices to use the same I²C address.
- The communication to the upper device is realized using an ISO1541 2.5 kV I²C isolator

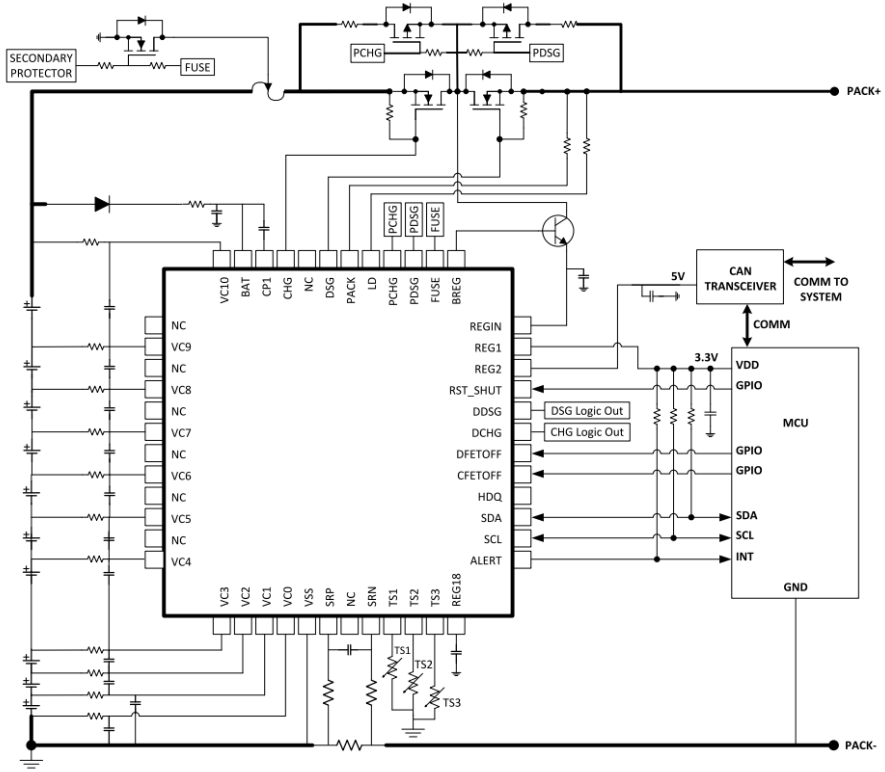


# Realizing high cell count monitoring using BQ769x2 battery monitors

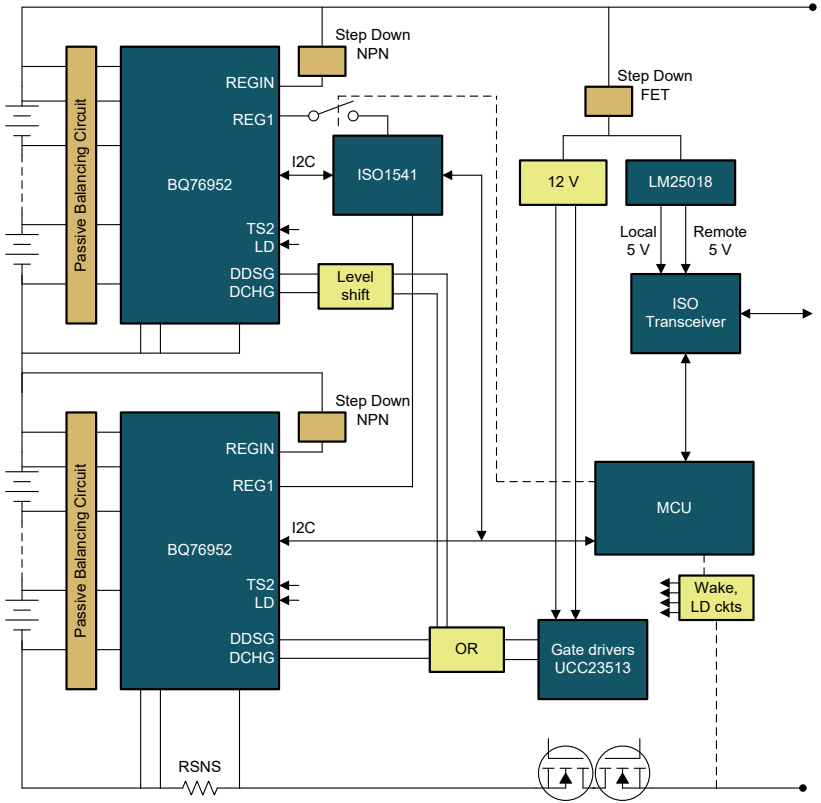
# High cell count battery monitoring using BQ769x2

- The BQ76942 (3S-10S) and BQ76952 (3S-16S) family of battery monitor + protectors support up to 16 series cells and provide cell voltage, current and temperature monitoring, as well as primary protection for OV, UV, SCD, OCD1/2/3, OCC, OTC, OTD, UTC, UTD, OTF, precharge timeout and a host watchdog
- The devices include high side FET drivers, but the high side DSG driver is difficult to use in a stacked configuration
- Thus, the protection signals can be combined at ground level to control low side protection FETs



# High cell count battery monitoring using BQ769x2

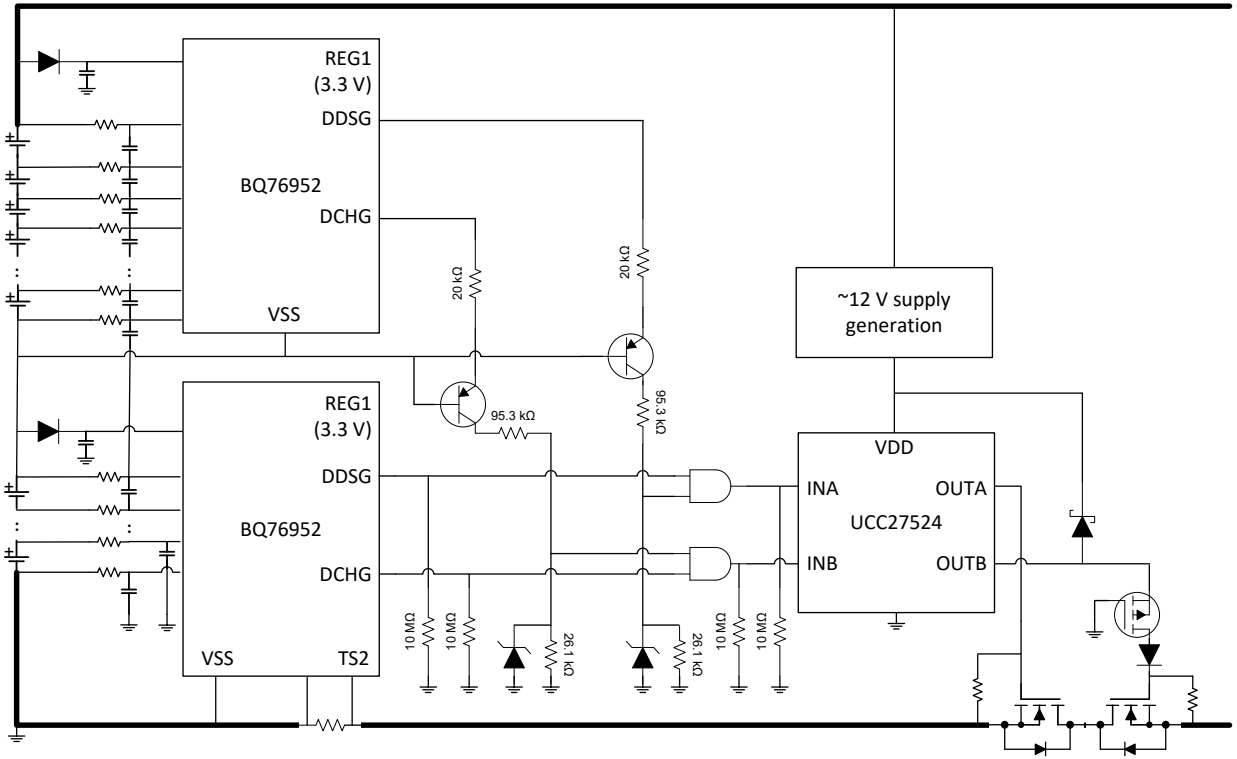
- Multiple BQ769x2 devices can be stacked to implement a high cell count system, as depicted here
- External circuitry is used to control low side protection NFETs
- The I²C buses from each device are routed to a host MCU, with the upper device using an ISO1541 2.5 kV I²C isolator
- Additional circuitry is required to wake both devices from SHUTDOWN mode and for load detection when protection FETs are disabled



# High cell count battery monitoring using BQ769x2

## Combined protection solution

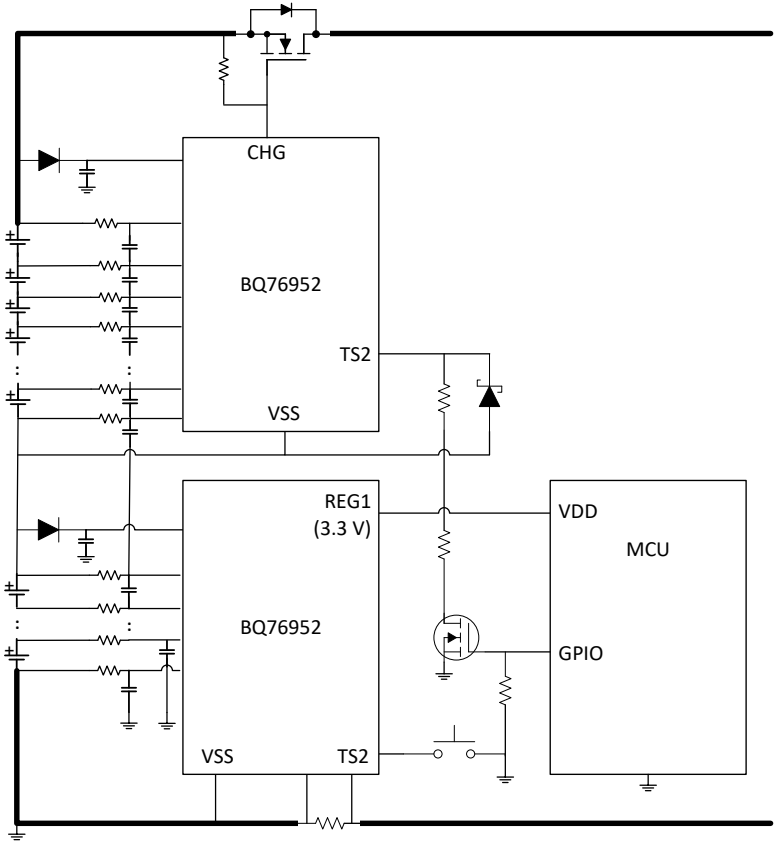
- The BQ769x2 devices provide logic-level outputs that match the controls used for the high side FET drivers
- These outputs are driven based on the local LDO of each monitor, which has programmable voltage up to 5 V
- The signals can be combined from stacked devices to control low side NFETs



# High cell count battery monitoring using BQ769x2

## Wakeup from SHUTDOWN

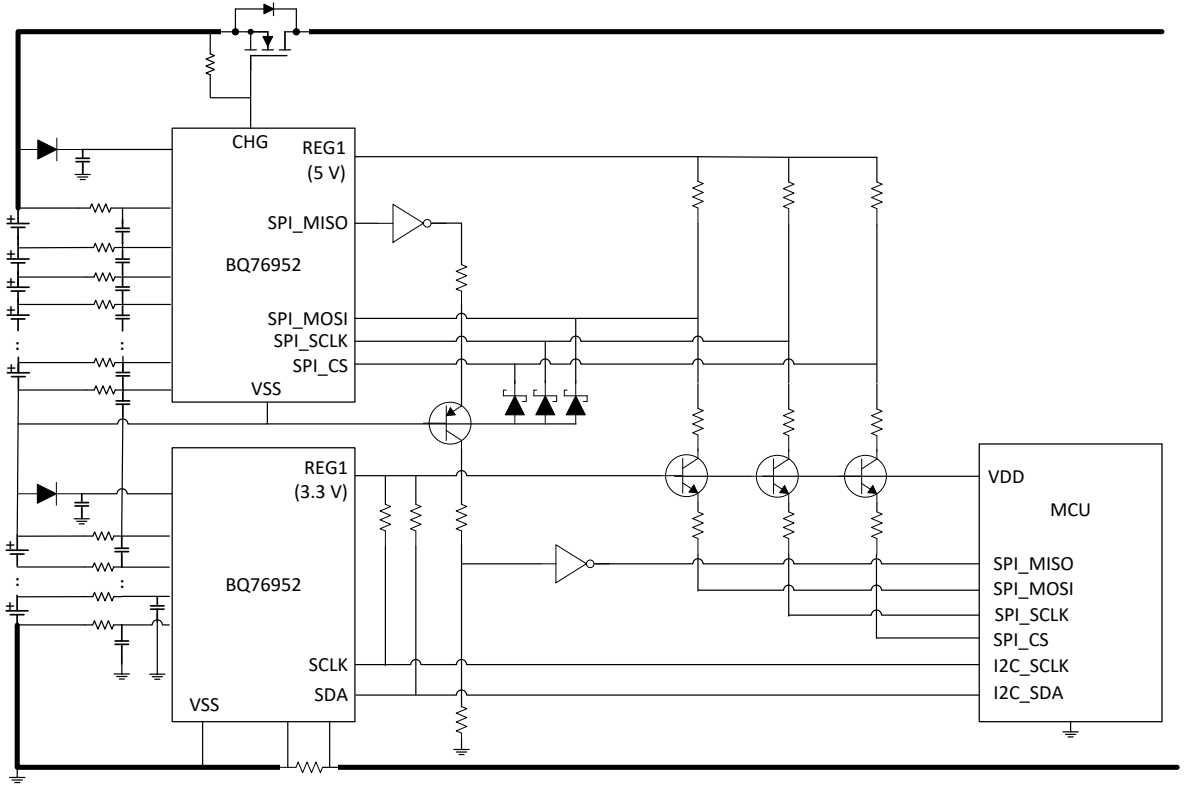
- The BQ769x2 devices integrate two methods of wakeup from SHUTDOWN:
  - A voltage applied to the LD pin (normally occurs when a charger is connected)
  - The TS2 pin provides a weak ~5 V level with ~5 MΩ source impedance while in SHUTDOWN
  - Pulling this pin to VSS, such as by a button press or driven low from an external signal, will wake the device, as shown here
- Wakeup by charger attach can also be implemented using the LD pin on each device, with appropriate circuitry to limit the voltage at each pin



# High cell count battery monitoring using BQ769x2

## Serial communication

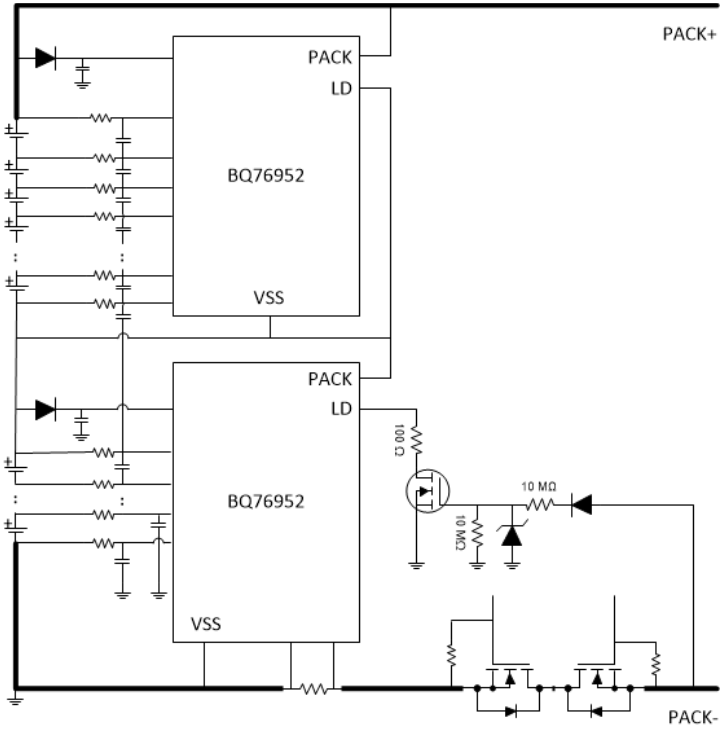
- The BQ769x2 devices support up to 400 kHz I²C, SPI and HDQ communications. Each device can be configured with a separate I²C address.
- Communication to the upper device(s) can be realized using an ISO1541 2.5 kV I²C isolator, as in the TI Design TIDA-01093
- Another option is level shifting using discrete circuitry. An example using SPI is shown here.



# High cell count battery monitoring using BQ769x2

## Load detection

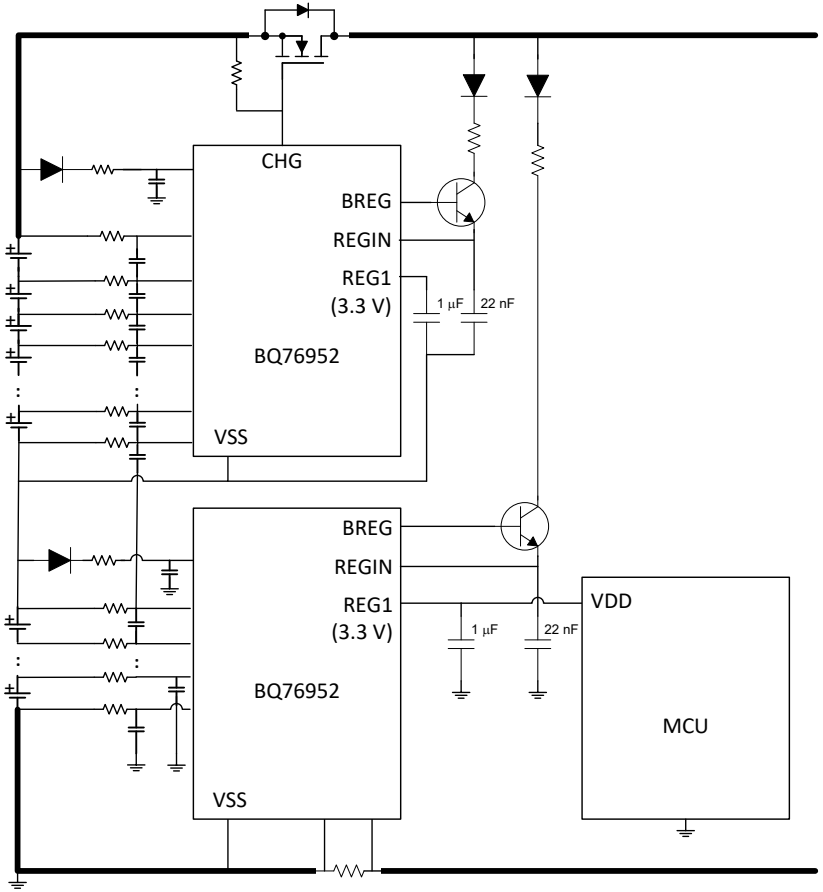
- The BQ769x2 devices include load detect functionality to determine if the load has been removed from a pack while the FETs are disabled
- This detection can be used for recovery after a short/overcurrent has resulted in the FETs being disabled
- The load detect functionality is designed for use with high side FETs
  - With FETs off, the device will periodically source a ~100 µA current out of LD and measure the voltage on the pin
  - If the voltage is above a ~4 V threshold, the device will detect the load has been removed
- This feature can be used in a stacked configuration with low side FETs with additional external circuitry



# Additional considerations

# Additional considerations

- Avoid imbalance caused by unequal power dissipation within the stack
  - Each device in the stack should be configured to enable the same set of modules / components internally, to keep their power dissipation balanced
  - Especially ensure any external circuitry powered from the LDOs of the stacked devices is also balanced
  - If this is a concern, the supply voltage for each monitor and their associated LDOs can be drawn from top of stack



# Additional considerations

- Random cell attach across the entire stack of cells is not always supported; this needs careful attention to follow the guidelines for each device
- Cell attach must be done in a way that avoids blowing an inline fuse
- The BQ769x2 battery monitor family supports customer production line programming of settings into one-time programmable (OTP) memory
  - If this will be utilized, it is important to plan to make sure this can be implemented properly
  - For example, each device will initially have the same $I^2C$ address. It is necessary to communicate with one specific device, to modify its $I^2C$ address, without also programming other devices.
  - This can generally be achieved by driving particular cell inputs with specific voltages while programming a selected device on the production line

# Summary

- Battery monitoring and protection systems for high cell count systems can be implemented by stacking individual protectors and monitors
- Additional circuitry is generally needed to support communications, protections, load detection and wakeup from a shutdown state
- Special considerations must be taken during production, to ensure each device in the stack can be programmed as needed, requirements for attaching cells is followed and an inline fuse is not inadvertently blown

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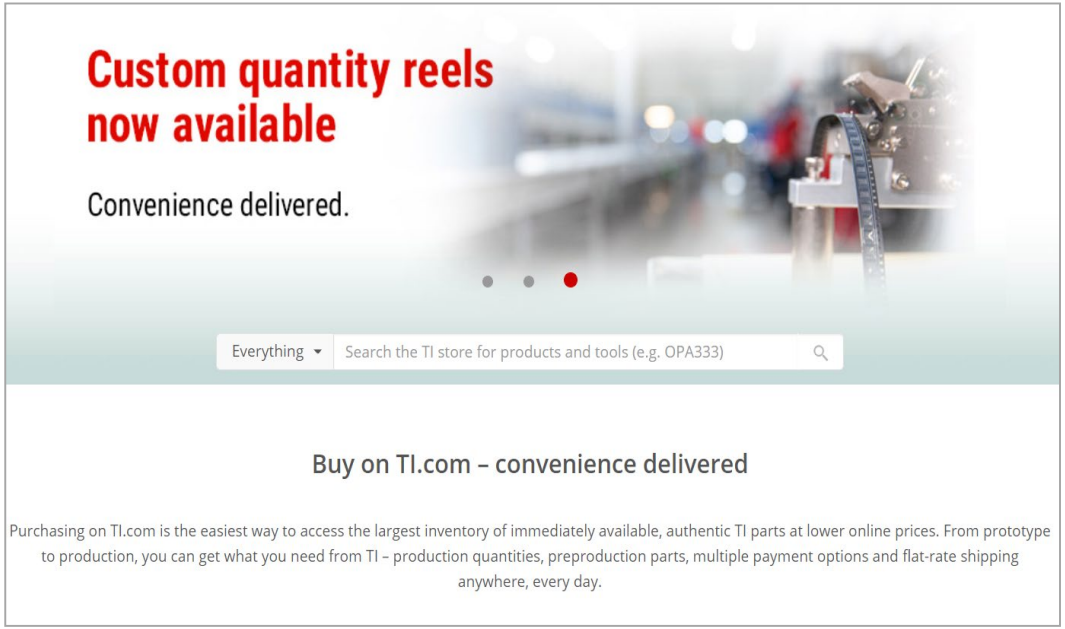


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