Application Report
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bq20z80 and bq2084 Gas Gauge Circuit Design

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ABSTRACT

Each component in the bq20z80 and bq2084 chipset reference designs is explained in this application report. Design tradeoffs and alternative circuits are provided, where appropriate.

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1 Introduction

The bq20z80 and bq2084 advanced gas gauge chipsets have approximately 90 components in the reference design for a 4-cell application. For clarity, these components are grouped into the following classifications: High Current Path, Gas Gauge Circuit, AFE/Secondary Current Protection, and Secondary Voltage Protection.

The discussion is based on the 4-cell reference design for the bq20z80 chipset. The complete schematic is available at the end of this document.

2 High Current Path

The high current path begins at the Pack+ terminal of the battery pack. As charge current travels through the pack, it passes through protection FETs, a chemical fuse, the lithium-ion cell connections, the sense resistor, then returns to the Pack– terminal. In addition, some components are placed across the Pack+ and Pack– terminals to reduce effects from electrostatic discharge (ESD).

2.1 Protection FETs

The P-channel Charge, Precharge, and Discharge FETs should be selected for a given application. Most portable battery applications are a good match for the Si4435DY device or equivalent. The Precharge FET could usually be implemented with a less expensive device, but often the same device is used in order to reduce the number of unique components.

The Vishay Si4435DY is an 8.8-A, 30-V device with Rds(on) ranging from 20 mΩ to 35 mΩ depending on the gate drive voltage.

If a Precharge FET is used, R26 is calculated to limit the precharge current to the desired rate. Be sure to account for the power dissipation of the series resistors. The precharge current is limited to (Vcharger – Vbat) / R26 and maximum power dissipation is (Vcharger – Vbat)2 / R26. The gates of all p-channel protection FETs are pulled up to the source with a high value resistor to ensure they are turned off when the gate drive is open.

Depending on the charger type, C22 is used in Figure 1 to slow down the operation of the charge FET. This capacitor can be deleted if there is no concern about excessive inrush current when the charger turns on. The capacitor may not be ideal if pulse charging is used.

C13 and C18 help to protect the FETs during an ESD event. The use of two devices ensures normal operation if one of them becomes shorted. In order to have any effect, the copper trace inductance of the capacitor leads must be designed to be as short and wide as possible. Ensure that the voltage rating of both C13 and C18 are adequate to hold off the applied voltage if one of the capacitors becomes shorted.

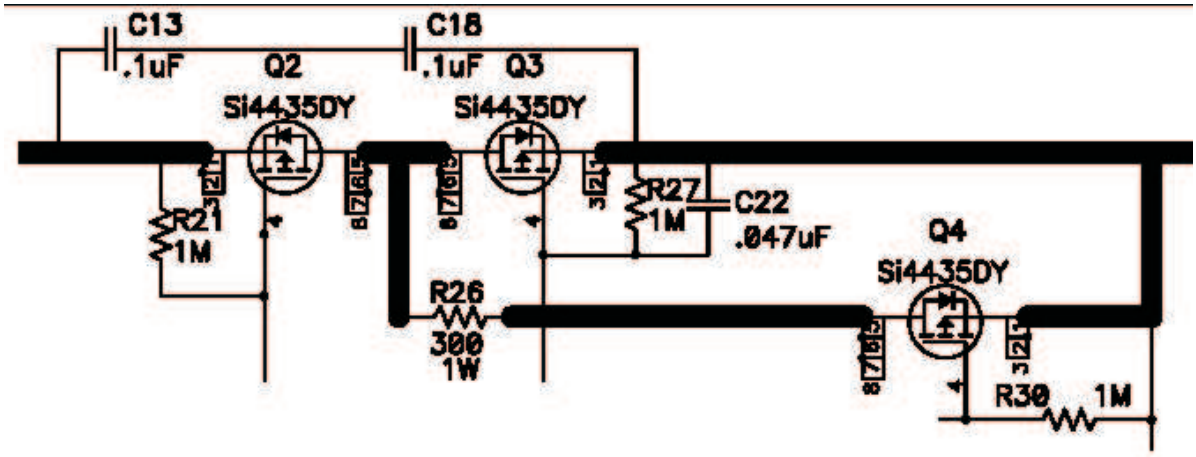


Figure 1. Protection FETs

2.2 Chemical Fuse

The chemical fuse (Sony Chemical, Uchihashi, etc.) is blown under command from either the bq29400 secondary voltage protection IC or from the SAFE pin of the gas gauge device. Either of these events applies a positive voltage to the gate of Q1 in Figure 2, which then sinks current from the third terminal of the fuse causing it to ignite and open permanently.

It is important to carefully review the fuse specifications and match the required ignition current to that available from the N-channel FET. Ensure that the proper voltage, current, and $R_{ds(on)}$ ratings are used for this device.

Optionally, a blocking diode can be inserted in series with the fuse terminal 3 to prevent false fuse ignition in the event of a reverse connection of charger or cells. In this case, current flows through the body diode of Q1 and operates the fuse without any command from the integrated circuits.

Because the gate pulldown resistor (R14) does not consume any power under normal operation, it is made relatively low to reduce the possibility of false gate activation due to PC board contamination.

The jumper, JP1, may be used to remove the possibility of false fuse activation during cell connection or debug operations. Alternately, a removable jumper could be placed between the gate of Q1 and ground.

D3 is used to sense that the fuse has blown. This is discussed in this document under the heading *Safe Circuitry*.

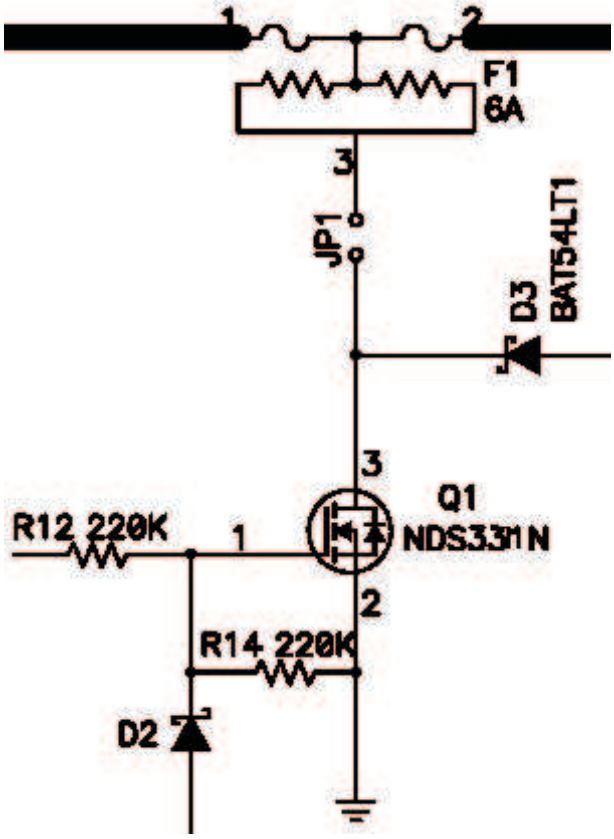


Figure 2. Chemical Fuse

2.3 Lithium-Ion Cell Connections

The important thing to remember about the cell connections is that high current flows through the top and bottom connection and, therefore, the sense leads at these points must be made with a Kelvin connection to avoid any errors due to drop in the high current copper trace. Some designs have even extended the Batt+ and Batt– sense connections all the way to the cells themselves with additional wires or a flex circuit.

The circled location 1 in Figure 3 indicates the Kelvin connection of the most positive battery node. Circled locations 2 and 3 are equally important. Note that the ground symbol at location 3 is only associated with UI, the secondary overvoltage protection device.

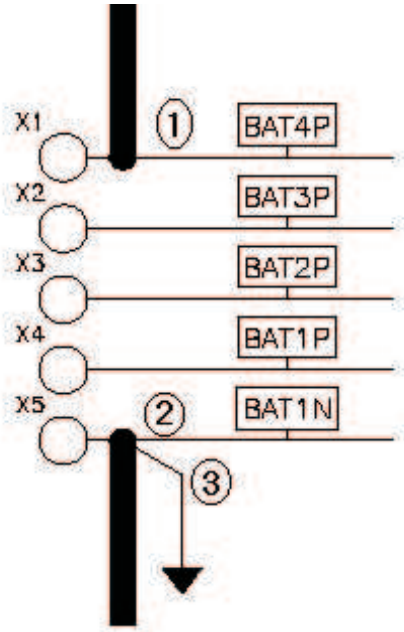


Figure 3. Lithium-Ion Cell Connections

2.4 Sense Resistor

As with the cell connections, the qualities of the Kelvin connections at the sense resistor are critical. Not only the sense lines, but the connection of low current digital ground and low current analog ground systems must be made in a careful manner.

The sense resistor should have a temperature coefficient no greater than 75 ppm in order to minimize current measurement drift with temperature. The value of the sense resistor should be chosen to correspond to the available overcurrent and short-circuit ranges of the bq29312. (See the tables in SLUS546). Parallel resistors can be used as long as care is used to ensure good Kelvin sensing.

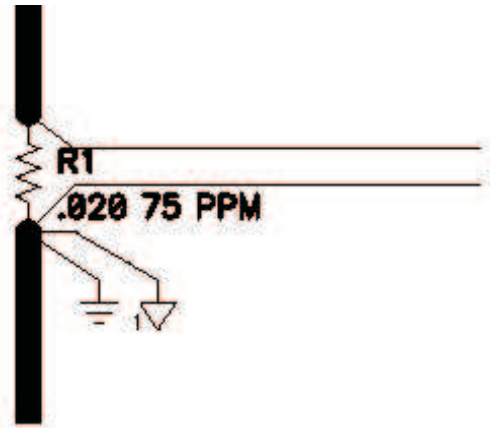


Figure 4. Sense Resistor

2.5 ESD Mitigation

A pair of series 0.1-µF capacitors is placed across the Pack+ and Pack– terminals to help in the mitigation of external electrostatic discharges. The two devices in series ensure continued operation of the pack if one of the capacitors should become shorted.

Optionally, a tranzorb such as the SMBJ2A may be placed across the terminals to further improve ESD immunity.

3 Gas Gauge Circuit

The gas gauge circuit includes the bq20z80/bq2084 and all of its peripheral components. These components are divided into the following groups: LEDs, oscillator and phase-locked loop filter, differential low pass filter, power supply decoupling / RBI / master reset, system present, SMBus communication, and SAFE circuit.

3.1 LEDs

The LEDs are associated with current limiting resistors R33 through R37. It is better to place the resistors on the IC side as they offer some ESD protection to the gauge in the event of ESD entry from human contact near the LEDs.

The display switch just yanks the bq20z80/bq2084 pin 17 to ground to generate an interrupt. It is pulled up to 3.3 V with a 100K resistor. If your packaging is arranged to permit an ESD hit to the switch, you may want to insert a clamping diode, and/or RC damping here also.

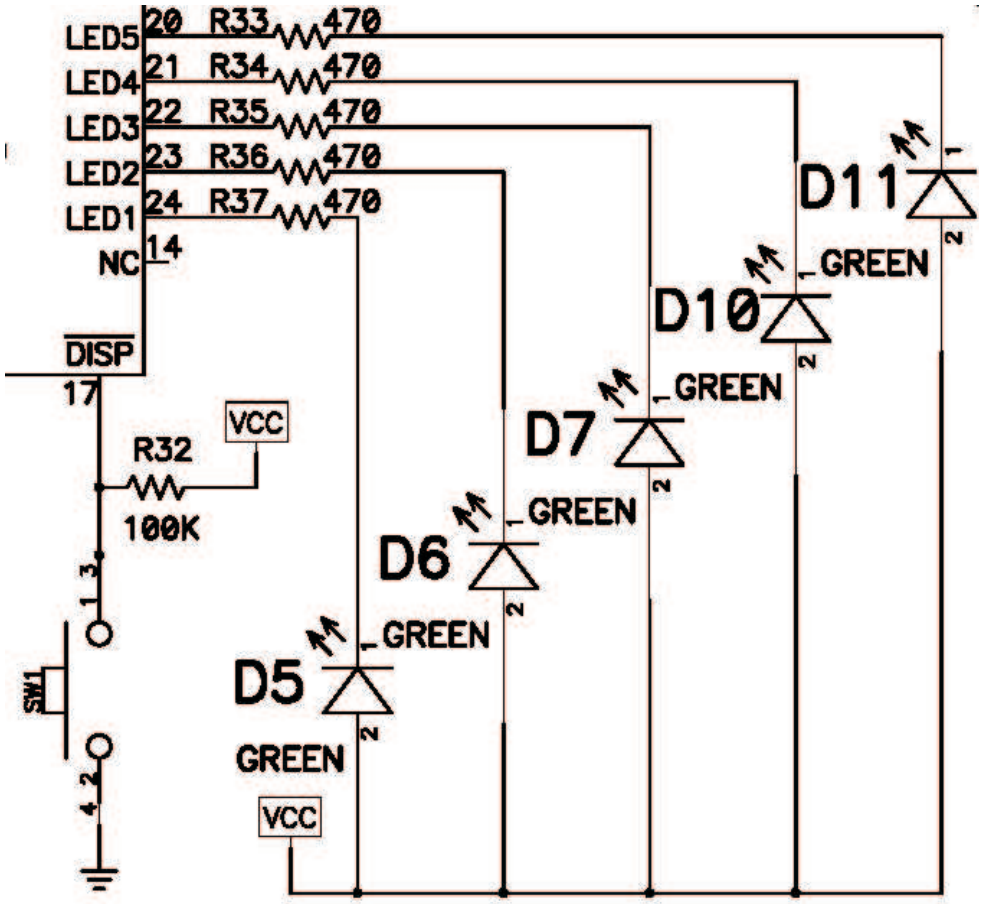


Figure 5. LEDs and Display Switch

3.2 Oscillator and Phase-Locked Loop Filter

The 100-kΩ resistor R38 sets the 32.768-kHz clock frequency for the gas gauge. The accuracy of this clock is important, as it directly affects the accuracy of the coulomb counter as it integrates measured current over time. For this reason, the accuracy of the 100-kΩ oscillator resistor should be at least 0.2% with temperature coefficient of 75 ppm or better.

The gas gauge uses an internal phase-locked loop to multiply the 32.768-kHz time base to a much higher frequency for the microcontroller clock. The VCO input of the PLL requires a low pass filter, which is implemented by R42, C27, and C28. The use of a 1% resistor and 5% capacitors is recommended. Do not change the value of these components.

Each of these four components requires attention to layout and should be located near its respective IC pins.

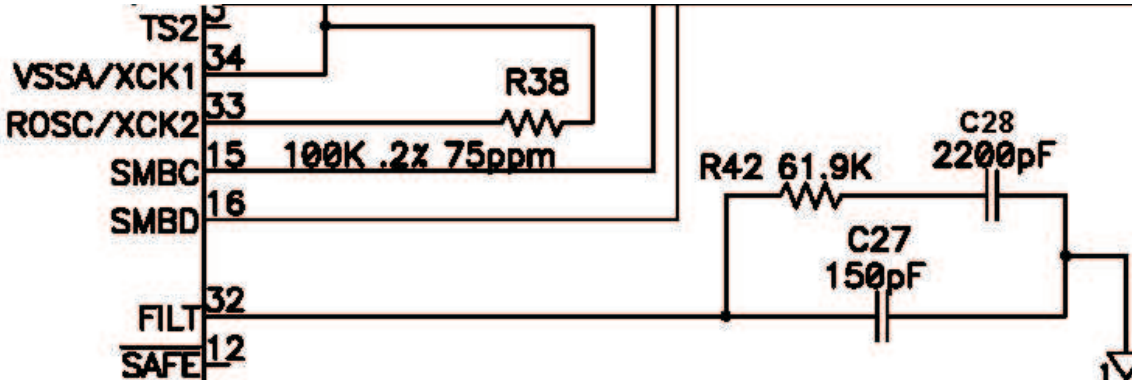


Figure 6. Oscillator Resistor and Phase Lock Loop Filter

3.3 Differential Low Pass Filter

A differential filter as shown in Figure 7 should precede the current sense inputs of the gas gauge. This filter eliminates the effect of unwanted digital noise, which could cause offset in the measured current. Even the best differential amplifier has less common-mode rejection at high frequencies. The amplifier input stage may rectify a strong RF signal, which then may appear as a dc offset error.

Five percent tolerance of the components is adequate because capacitor C19 shunts C14/C15 and reduces AC common-mode rejection arising from component mismatch. It is important to locate C19 close to the gas gauge pins 27 and 28. The other components should also be relatively close to the IC. The ground connection of C14 and C15 should be close to the IC.

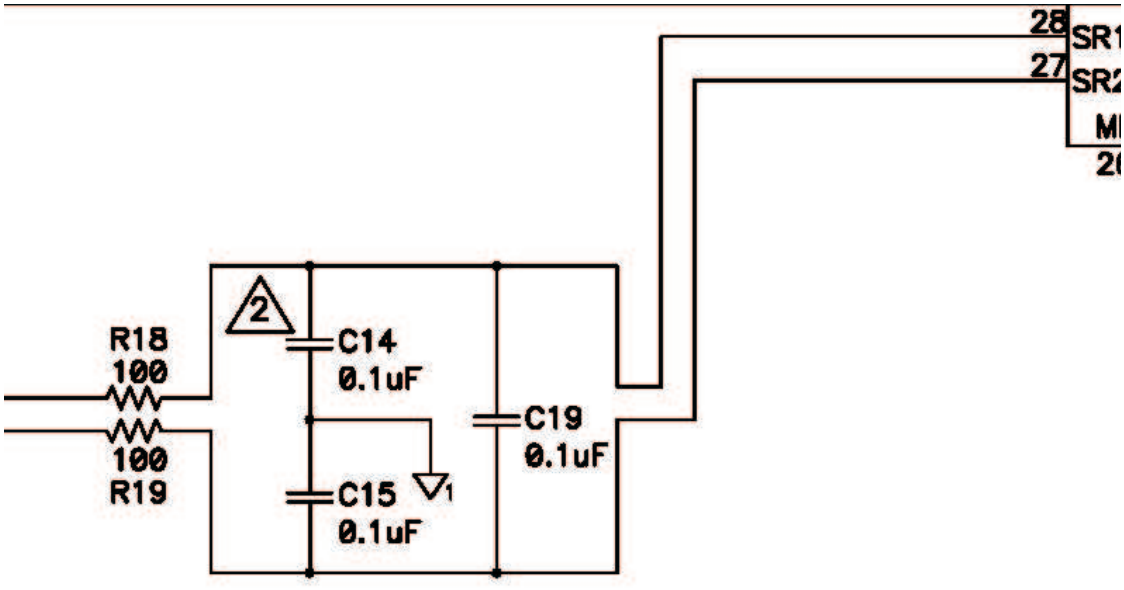


Figure 7. Differential Filter

3.4 Power Supply Decoupling, RBI, and Master Reset

Power supply decoupling is important for optimal operation of the bq20z80 and bq2084 advanced gas gauges. As shown in Figure 8, two decoupling capacitors are recommended. Note, however, that the 0.47-µF capacitors do not prevent partial resets of the gas gauge during severe ESD events. These partial resets are not harmful, because all required information is backed up and is restored by a recovery routine after the reset.

However, some reliability groups are not satisfied with this approach, preferring to prevent the partial resets from occurring. An ESD event is quite brief with the equivalent frequency approaching 1 GHz. The 0.47-µF capacitors, which are required for lower frequency decoupling, are not effective at UHF frequencies and beyond. Standard 68-µF to 100-pF ceramic capacitors are effective, however, and can prevent partial resets if placed in parallel with the 0.47-µF devices. They must be located as close as possible to the respective power input pins.

The 10-Ω resistor further helps to isolate digital noise from the analog measurement system. Also, because the input to the Power On Reset (POR) circuit is connected to VDDA, it is important to make it more sensitive to power disruption than the VDDD pin.

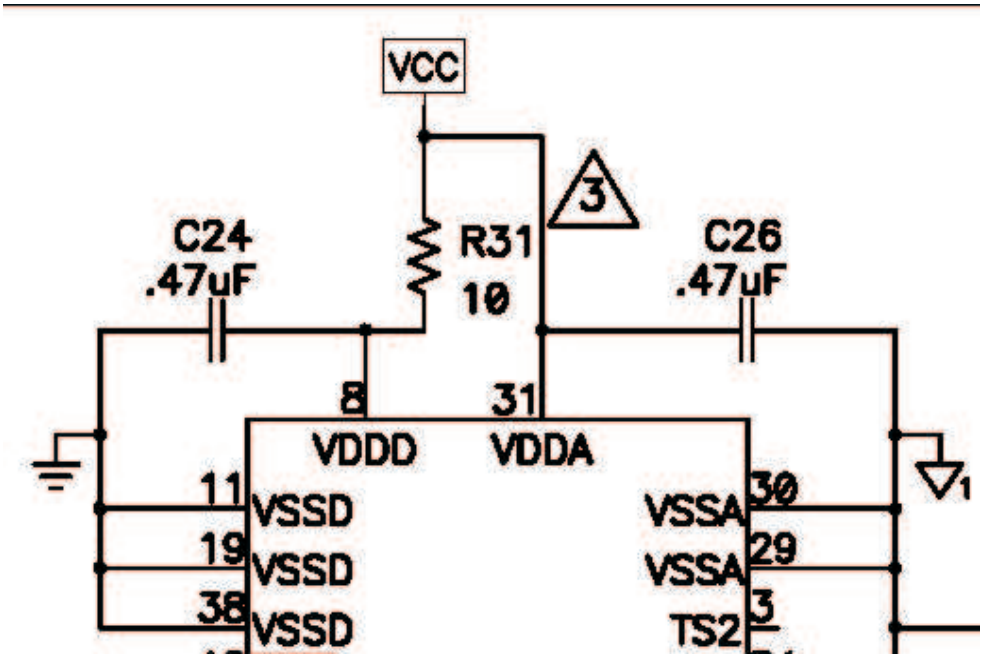
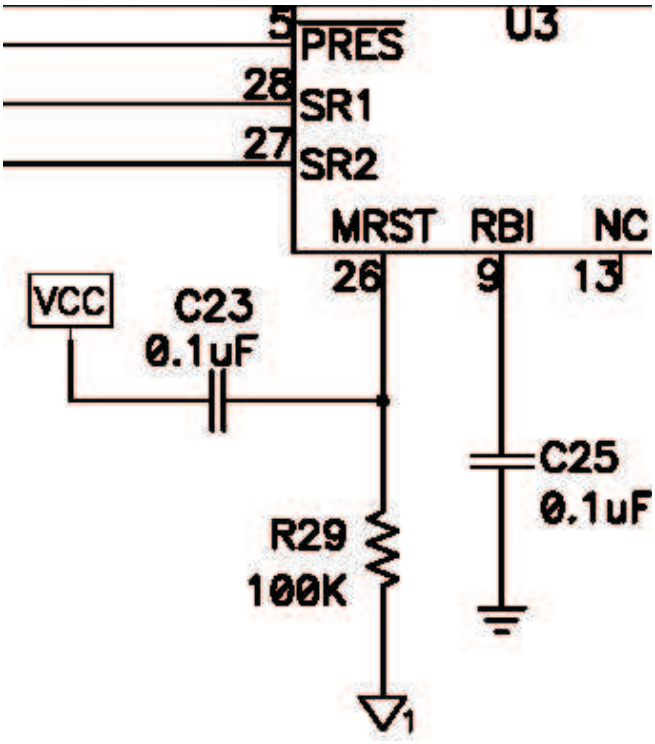


Figure 8. Power Supply Decoupling

The RBI pin is used to supply backup RAM voltage during brief, transient power outages. The partial reset mechanism just referred to uses the RAM to restore the critical CPU registers following a temporary loss of power. A standard 0.1-µF ceramic capacitor is connected from pin 9 to digital ground as in Figure 9.

C23 and R29 form an RC network, which holds the MRST pin high for the time constant during power-on-reset. While this network is required for the bq20z80, it is **NOT** required for the bq2084. In the latter case, MRST may be tied directly to ground or to ground through a low value resistor.



NOTE: C23 and R29 not required for bq2084

Figure 9. RBI Capacitor and Master Reset

3.5 System Present

The System Present signal is used to inform the gas gauge whether the pack is installed into or removed from the system. In the host system, this signal is grounded. The $\overline{\text{PRES}}$ pin of the bq20z80/bq2084 is occasionally sampled to test for System Present. To save power, a 5-kΩ pullup resistor is powered by the PU output on pin 4 only during a brief 4-µs sampling pulse once per second.

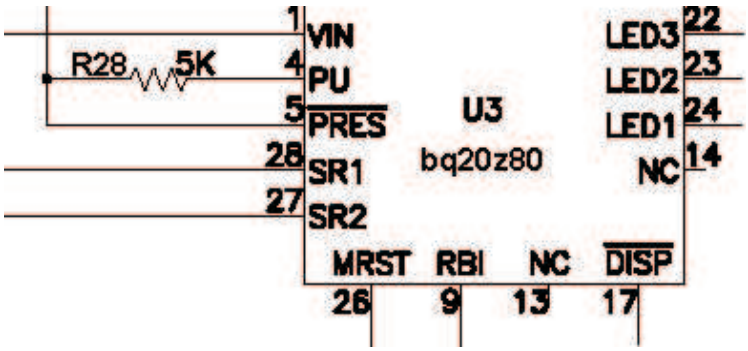


Figure 10. System Present Pull-Up

Because the System Present signal is part of the pack connector interface to the outside world, it must be protected from external ESD hits. R45 and the 5.6 V D8 provide protection for positive pulses, while R39 limits the current that would flow out of the IC in parallel with the current through D8 for negative pulses. Observe the voltage rating of D8 in order to maintain signal integrity and avoid electrical stress to the IC. When the system present function is not used, it should be connected to ground.

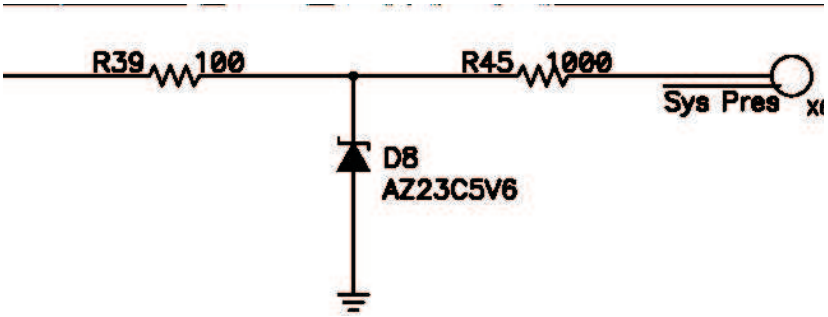


Figure 11. System Present ESD Protection

3.6 SMBus Communication

As with the System Present pin, the SMBus clock and data signals interface to the outside world on the pack connector. Each signal employs an ESD protection scheme similar to that used in Figure 11 for System Present. It should be noted, however, that the 5.6-V zener diode must have nominal capacitance less than 100 pF in order to meet the SMBus specifications. The AZ23C5V6 is a recommended device. Also, the resistor on the pack side is only 100 Ω to maintain signal integrity. Note that the zener will not survive a long-term short to a high voltage.

R46 and R47 provide pulldown for the communication lines. When the gas gauge senses that both lines are low (such as during removal of the pack), the device performs auto offset calibration and then goes into sleep mode to conserve power.

ESD protection operates as with the System Present network shown in Figure 11. For the SMB clock signal R43 and part of D9 provide clamping for positive ESD pulses, whereas R40 limits the current from the IC in parallel with D9 for negative ESD pulses.

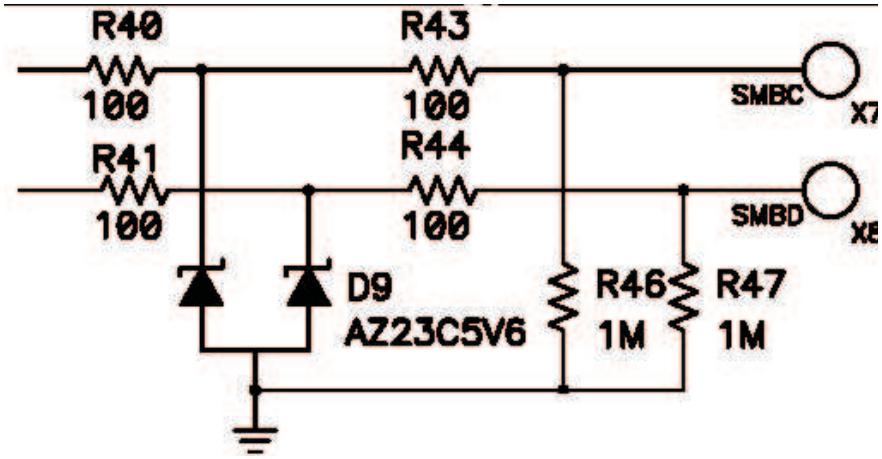


Figure 12. SMB Communication

3.7 SAFE Circuitry

The SAFE output (pin 7) of the bq20z80 is designed to blow the chemical fuse if various safety criteria are violated. The PFIN input (pin 18) is used to monitor the state of the secondary voltage protection IC.

Q1 ignites the chemical fuse when its gate is high. R12, R14, and D2 form a logical OR gate which enables the Q1 gate if either the SAFE signal or the output of the bq29400 device go to the high state. The 7-V output of the bq29400 is divided in half by R12 and R14 which provides adequate gate drive for Q1 while guarding against excessive back current from D2.

Many circuit designers prefer to add a capacitor to ground from the gate of Q1. Although this is generally good practice, especially for RFI immunity, note that the chemical fuse is a comparatively slow device and is not affected by any sub-microsecond glitches that may come from the SAFE output during the cell connection process.

When the fuse is commanded to ignite, D3 becomes forward-biased, which notifies the gas gauge of the situation. In this manner, the output of U1 can be recorded for future fault analysis.

The bq2084 requires a slightly more complex circuit, because SAFE is not implemented on pin 7. Both devices have the low-active $\overline{\text{SAFE}}$ signal available on pin 12. The use of $\overline{\text{SAFE}}$ requires an additional FET to invert the signal and ensure proper operation.

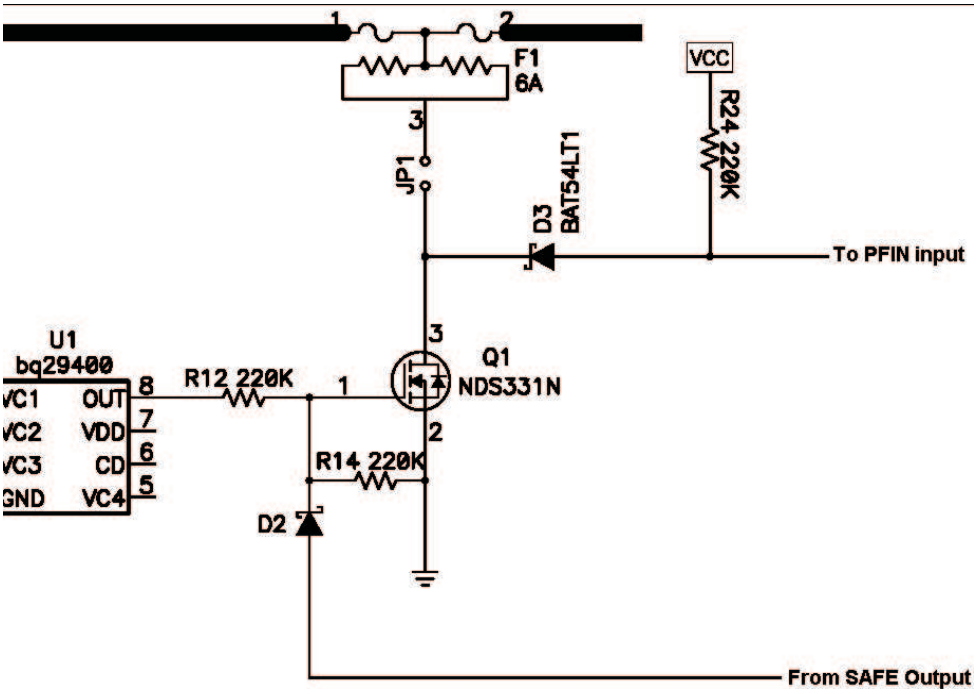


Figure 13. bq20z80 SAFE Circuit

4 AFE/Secondary Current Protection

The bq29312 analog front end (AFE) provides secondary overcurrent and short-circuit protection, cell balancing, cell voltage multiplexing, voltage translation, and the low dropout 3.3-V regulator for the gas gauge. The following discussion covers cell and battery inputs, pack input, sleep and PMS inputs, FET control output, regulator output, temperature output, and cell voltage output.

4.1 Cell and Battery Inputs

Each cell input is conditioned with a simple RC filter with a time constant of at least 10 µs. This filter provides ESD protection during cell connect and acts to filter unwanted voltage transients. The resistor value allows some tradeoff for cell balancing versus safety protection.

Internal FETs in the bq29312 provide an approximate 400-Ω resistance, which can be used to bypass charge current in individual cells that may be overcharged with respect to the others. (Of course, this is not done during the low duty cycle voltage measurement phase.) If the filter is built with 1-kΩ resistors and 0.01-µF capacitors, the cell-balancing feature is not effective because the total bypass resistance across a cell is 1000 + 1000 + 400 = 2400 Ω. As the reference design indicates, 100-Ω resistors and 0-µF capacitors are recommended. Values between 200 Ω and 470 Ω can provide limited cell-balancing functionality.

The BAT input (pin 1) uses a diode (D1) and 1-µF capacitor (C11) to isolate and decouple it from the cells in the event of a transient dip in voltage caused by a short-circuit event.

Also, as described previously in the High Current Path section, the top and bottom nodes of the cells must be sensed at the battery connections with a Kelvin connection to prevent voltage-sensing errors caused by a drop in the high current PCB copper.

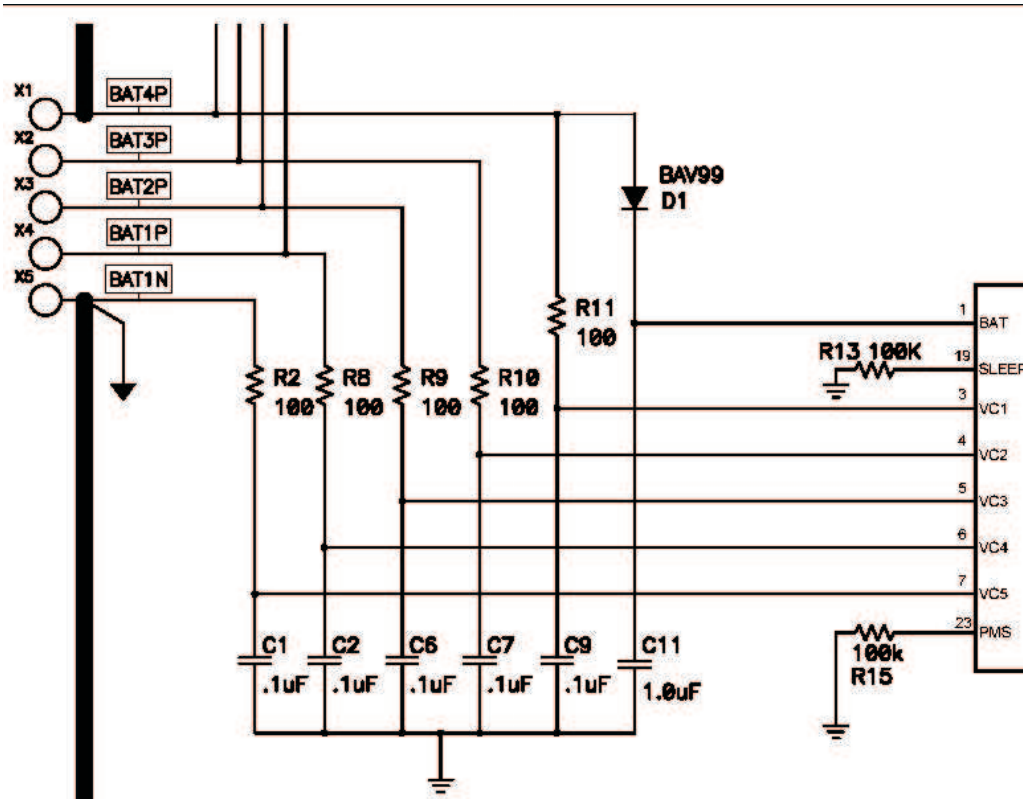


Figure 14. Cell and BAT Inputs

4.2 PACK Input

The PACK input provides power to the AFE from the charger. This way, the device continues to function normally even if the cell voltage is depleted. The PACK input uses a diode (D4) and 0.47-µF capacitor (C17) to isolate and decouple it from the Pack+ input. This guards against input transients and prevents mis-operation of the gate driver in the event of a reverse charger connection. Ensure that the voltage ratings of D4 and C17 are adequate to withstand the full system voltage.

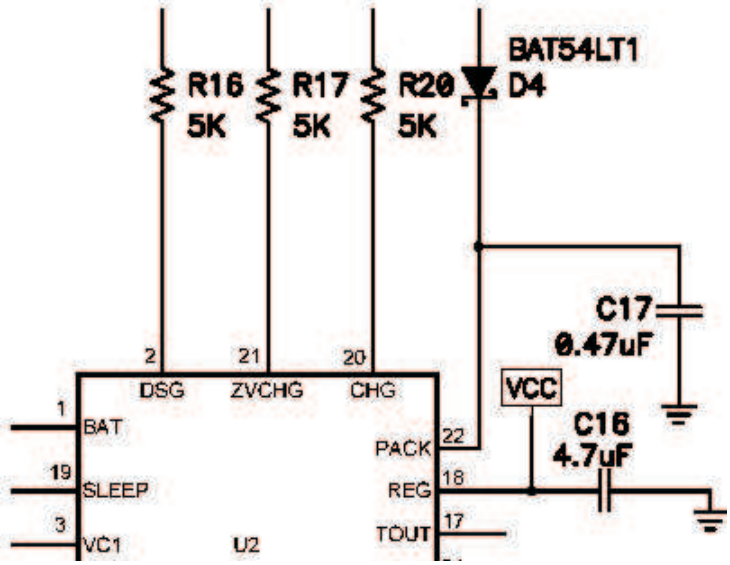


Figure 15. PACK Input

4.3 Sleep and PMS Inputs

The sleep pin is generally not used, but should be grounded through a 100-kΩ resistor. The PMS pin, depending on the desired operating mode, should also be tied to ground or PACK through a 100-kΩ resistor. The resistor for the sleep pin is to improve ESD susceptibility and can be eliminated only if a short path can be used to connect it directly to pins 12 and 15.

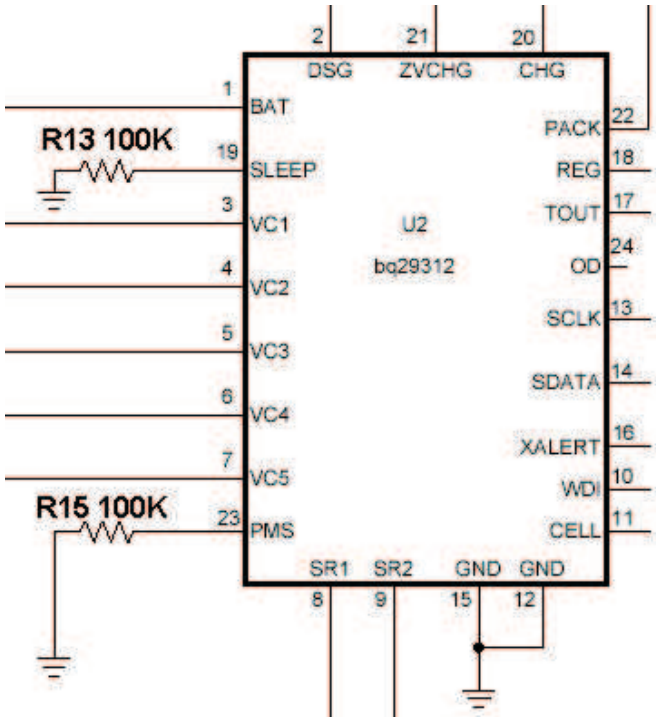


Figure 16. SLEEP and PMS Inputs

4.4 FET Control Outputs

The three FET control outputs are simply coupled to the gates of the protection FETs with 5-kΩ resistors. These resistors, with the gate-source capacitance, determine the switching time of the FETs. As mentioned in the Protection FETs discussion of High Current Path section of this document, the charge FET often uses an additional *slow-down* capacitor from its gate to source to limit di/dt when the charger is first applied.

4.5 Regulator Output

The low dropout regulator within the bq29312 requires capacitive compensation on its output. In order to guarantee the integrity of the compensation, the 4.7-μF capacitor should be placed close to the REG output (pin 18).

4.6 Temperature Output

TOUT (pin 17) provides thermistor drive under program control. R22 and R25 are specific 1% resistors for optimization of the recommended Semitec NTC103AT, or equivalent thermistor. Because this thermistor is normally external to the board, C21 is provided for ESD protection.

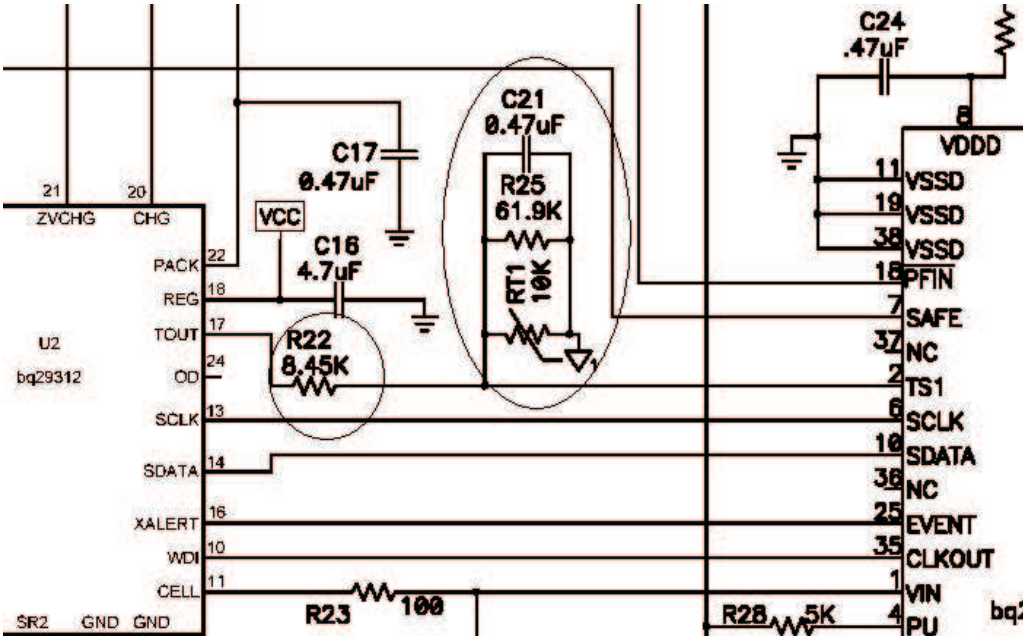


Figure 17. Thermistor Drive Output

4.7 Cell Voltage Output

The CELL output requires an RC filter composed of a 100-Ω resistor and 0.1-μF capacitor. This filter stabilizes the output amplifier in the bq29312 and provides the required filtering for the input of the gas gauge A/D converter.

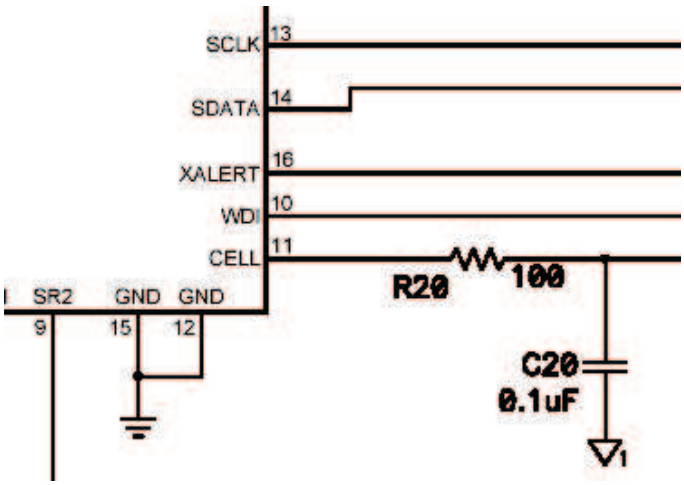


Figure 18. CELL Output

5 Secondary Voltage Protection

The bq29400 provides secondary overvoltage protection and commands the chemical fuse to blow if any cell exceeds the internally referenced threshold. The peripheral components are cell input filters and a time delay capacitor.

5.1 Cell Inputs

An input filter is provided for each cell input. This filter comprises resistors R4, R5, R6, and R7 along with capacitors C3, C4, C5, and C8. Note that this input network is completely independent of the filter network used as input to the bq29312. To ensure independent safety functionality, the two devices must have separate input filters.

Note that because the filter capacitors are implemented differentially, a low voltage device can be used in each case.

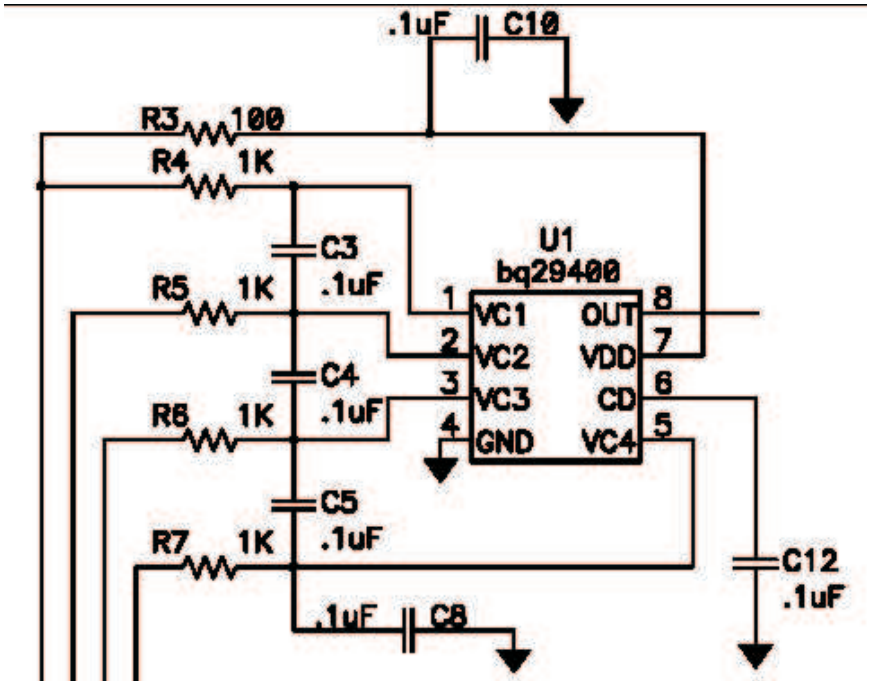


Figure 19. bq29400 Cell Inputs and Time Delay Capacitor

5.2 Time Delay Capacitor

C12 sets the time delay for activation of the output after any cell exceeds the threshold voltage. The time delay is calculated as td = 1.2 V × DelayCap(μF) / 0.18 μA.

6 Reference Design Schematic

The reference design schematic appears on the following page.

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