There are many design considerations for high cell count batteries when it comes to gauging and protection. Today I will go through some of the most common challenges presented by these systems.
You are most likely familiar with single cell battery applications like cell phones, mp3 players, wearables, and the like. There are many applications which need more power, and therefore use a combination of cells to create higher voltage and higher current battery packs. Some of the most common are shown here. One of the highest cell count applications is electric vehicles, but since this topic requires considerations of automotive quality and other unique application considerations, I am not covering it here. Power tools are typically less 13S or less, which means there are 13 cells in series for a typical voltage of 48V or less. Battery back up systems are typically provide an adjustable 12V output, and the battery configuration varies. Vacuum cleaning robots and battery powered stick vacuums are typically between 4S and 7S, whereas drones can also have packs configured in that range. Most notebooks are 2S to 4S, but now some gaming notebooks are 5S, and may go higher in the future. The cell chemistries in each application differs, but each needs gauging and protection.
Many high cell count applications choose Li-Ion batteries, which is the most common battery chemistry for a variety of applications, but other chemistries are still used depending on the application. Due to their many benefits, their popularity has helped drive down the cost of Li-Ion cells significantly since they were introduced in 1991. Li-ion batteries have the highest cycle life other than NiCd, but have less self-discharge and higher energy density. This makes them ideal for applications that need a lot of power, but need the batteries to be small and light. This combination of affordable, high density, quick-charging rechargeable batteries has enabled Li-ion batteries to be used in many applications that have formerly been corded or have used small gasoline powered engines. However, high cell count Li-ion battery packs require more care in the charging and protection circuitry, as they are not tolerant of over-charging, can not be trickle charged like Lead-Acid, and require protection circuitry.

## Battery technology comparison

<table>
<thead>
<tr>
<th>Specifications</th>
<th>Lead-Acid</th>
<th>NiCd</th>
<th>NiMH</th>
<th>Cobalt</th>
<th>Manganese</th>
<th>Phosphate</th>
</tr>
</thead>
<tbody>
<tr>
<td>Specific energy density (Wh/kg)</td>
<td>30 – 50</td>
<td>45 – 80</td>
<td>60 – 120</td>
<td>150 – 190</td>
<td>100 – 150</td>
<td>90 – 120</td>
</tr>
<tr>
<td>Internal resistance (mΩ/V)</td>
<td>&lt;8.3</td>
<td>17 – 33</td>
<td>33 – 50</td>
<td>21 – 42</td>
<td>6.6 – 20</td>
<td>7.6 – 15.0</td>
</tr>
<tr>
<td>Cycle life (80% discharge)</td>
<td>200 – 300</td>
<td>1,000</td>
<td>300 – 500</td>
<td>500 – 500</td>
<td>1,000 – 1,000</td>
<td>1,000 – 2,000</td>
</tr>
<tr>
<td>Fast-charge time (hrs.)</td>
<td>8 – 16</td>
<td>1 typical</td>
<td>2 – 4</td>
<td>2 – 4</td>
<td>1 or less</td>
<td>1 or less</td>
</tr>
<tr>
<td>Overcharge tolerance</td>
<td>High</td>
<td>Moderate</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
<tr>
<td>Self-discharge/month (room temp.)</td>
<td>5 – 15%</td>
<td>20%</td>
<td>30%</td>
<td>&lt;5%</td>
<td>&lt;5%</td>
<td>&lt;5%</td>
</tr>
<tr>
<td>Cell voltage</td>
<td>2.0</td>
<td>1.2</td>
<td>1.2</td>
<td>3.6</td>
<td>3.8</td>
<td>3.3</td>
</tr>
<tr>
<td>Charge cutoff voltage (V/cell)</td>
<td>2.40 (2.25 float)</td>
<td>Full-charge indicated by voltage signature</td>
<td>Full-charge indicated by voltage signature</td>
<td>4.2</td>
<td>4.2</td>
<td>3.6</td>
</tr>
<tr>
<td>Discharge cutoff volts (V/cell, 1°C)</td>
<td>1.75</td>
<td>1</td>
<td>1</td>
<td>2.5 – 3.0</td>
<td>2.5 – 3.0</td>
<td>2.8</td>
</tr>
<tr>
<td>Peak load current**</td>
<td>5C</td>
<td>20C</td>
<td>5C</td>
<td>&gt;3C</td>
<td>&gt;30C</td>
<td>&gt;30C</td>
</tr>
<tr>
<td>Peak load current* (best result)</td>
<td>0.2C</td>
<td>1C</td>
<td>0.5C</td>
<td>&lt;1C</td>
<td>&lt;10C</td>
<td>&lt;10C</td>
</tr>
<tr>
<td>Charge temperature</td>
<td>-20 – 50°C</td>
<td>0 – 45°C</td>
<td>0 – 45°C</td>
<td>0 – 45°C</td>
<td>0 – 45°C</td>
<td>0 – 45°C</td>
</tr>
<tr>
<td>Discharge temperature</td>
<td>-20 – 50°C</td>
<td>-20 – 65°C</td>
<td>-20 – 65°C</td>
<td>-20 – 65°C</td>
<td>-20 – 65°C</td>
<td>-20 – 65°C</td>
</tr>
<tr>
<td>Maintenance requirement</td>
<td>3 – 6 months (equalization)</td>
<td>30 – 60 days (discharge)</td>
<td>65 – 90 days (discharge)</td>
<td>None</td>
<td>None</td>
<td>None</td>
</tr>
<tr>
<td>Safety requirements</td>
<td>Thermally stable</td>
<td>Thermally stable, fuses common</td>
<td>Protection circuit mandatory</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Time durability</td>
<td>&gt;10 years</td>
<td>&gt;10 years</td>
<td>&gt;10 years</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>In-use since</td>
<td>1881</td>
<td>1950</td>
<td>1990</td>
<td>1991</td>
<td>1996</td>
<td>1999</td>
</tr>
<tr>
<td>Toxicity</td>
<td>High</td>
<td>High</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
<td>Low</td>
</tr>
</tbody>
</table>

Source: batteryuniversity.com. The values shown are generic, specific batteries may differ.

**C** refers to battery capacity, and this unit is used when specifying charge or discharge rates. For example, 0.2C for a 100 Ah battery = 50 A.

**Peak load current = maximum possible momentary discharge current, which could permanently damage a battery.**
Depending on the type of product being produced, it may fall under a variety of safety standards and certifications. One of the most broadly applicable is the Underwriter Laboratories, or UL, 2595 which is the general requirement for battery-powered appliances. If your product has an integrated or detachable battery up to 75V, this standard will likely apply to you. This standard only covers the battery safety, and not all safety concerns, so other standards may apply. Also, this standard doesn’t apply to the battery charger, but only the battery and it’s protection requirements to address the risk of fire or explosion only, and not toxicity which is inherent to the battery chemistry. The UL1642 standard addresses many of the functional tests required for the cells themselves, which are usually addressed by the cell maker, not the system maker.

Since many products are developed for use all over the world, it is necessary to consider international standards. Many standards overlap each other, and this is the case with many International electrotechnical Commission, or IEC, standards such as IEC62133, which overlaps UL1642. Many countries participate in the Certification Body scheme, where participating laboratories are able to give manufactures a simplified way of obtaining multiple national safety certifications for their products. Right now, there are around 50 countries that accept the CE and CB marking scheme.

After you’ve considered the safety standards that your cell supplier has to meet, and the safety standards that your system has to meet, you also need to consider the special requirements for shipping your product that integrates a high cell count battery. Several United Nations classifications may apply, such as UN3171 which applies to battery-powered vehicles and equipment, which include hoverboards, e-bikes, scooters, and much more. The International Air Transport Association, IATA, issues battery guidance for safe transport by air, including guidance on the amount of charge that can be in the cells. Packing Instructions, PI, 965 through 970 apply to shipping batteries safely depending on the type of battery and whether they are shipped loose or in the end equipment.
Example of UL2595 compliance with BQ40z80

- The standard requires protection against the following:

<table>
<thead>
<tr>
<th></th>
<th>Addressed by BQ40z80 protections</th>
</tr>
</thead>
<tbody>
<tr>
<td>Short circuit</td>
<td>short-circuit protections</td>
</tr>
<tr>
<td>Motor is locked</td>
<td>over-current protections</td>
</tr>
<tr>
<td>Heating</td>
<td>over-temperature protections</td>
</tr>
<tr>
<td>Charging protection</td>
<td>smart charge algorithm</td>
</tr>
<tr>
<td>Individual cell</td>
<td>over-voltage protections</td>
</tr>
<tr>
<td>Over charge current</td>
<td>smart charge algorithm</td>
</tr>
</tbody>
</table>

NOTE1: There are additional tests on Li-ion battery charging system and is required to permanently fail the battery pack if the cell voltage is over certain level which are addressed by the FUSE function on the BQ40z80, but the UL2595 calls for redundancy and cannot just rely on a single circuit. This is addressed by the secondary protector BQ771803 on the BQ40z80 EVM schematic.

NOTE2: There is a list of tests to pass the IEC 61000-4-2 standard (the board level ESD). The standard includes functional safety (and software reliability requirement if MCU is used) for the SCF (safety critical function) circuit. If the protection circuit cannot comply with the required tests and ESD, then it has to be evaluated through the function safety requirement. This will be system level and board layout dependent. The BQ40z80EVM schematic has spark gaps and ESD devices, but additional protections may be needed.

Here I give an example of how a single gauge plus protector from TI can provide compliance to UL2595. The standards covers many different topics, and I am highlighting some of them here. The bq40z80 is a multicell gauge and protector for 2S to 7S applications. The device is configurable to meet many different applications, with adjustable settings for short-circuit, over-current, over-voltage, and over-temperature faults. The configuration of the gauge and protection features is important, as incorrect configuration could mean the protection is there, but will not trip when desired. The bq40z80 also address the IATA, air-transport, concerns with an IATA_SHUT bit, where the relative state of charge is checked before entering shutdown.

Another useful feature is the IATA_Charge, where in production the device will charge until the RSOC is below the IATA RSOC Threshold, and then disable the CHG FET. This allows for the battery pack to have an acceptable amount of energy to comply with air transport regulations.

In some regulations, a secondary protector is required. On the bq40z80 EVM, the bq771807 is used in conjunction with the bq40z80 to provide this “belts and braces” approach to safety, so that if one protection mechanism fails, another mechanism is still there. The secondary protection method is usually to blow a fus to disconnect the battery from the system.
All products need safety, but specific applications vary. Most of the standards are for safety and compliance when new, however the behavior and performance of a battery will change during its lifetime. Lithium based batteries may have specific age-related issues that could cause problems as the battery ages such as forming dendrites due to stresses during charging and discharging, is physically altered due to swell/contract cycles, is subjected to extreme temperatures or physical stress during use. The basic over-voltage and under-voltage protection may not be nuanced enough to get optimal performance and safety during the life of the battery pack. Additionally, information about the stresses that occur during the life of the product use may be useful for field diagnostics and warranty information. In these applications, a full gauge, in addition to the protection, provides this information such as state of charge, full charge capacity, state of health, individual cell monitoring and protection, and lifetime and black box information.

A general rule of thumb is that advanced gauging is most important for applications that have short run times, as the device may need to squeeze every bit of energy out of the battery during use. A good example is a robot vacuum with a charging dock. In this case, the gauge is not providing the battery state of charge or health information to the user, but to the microprocessor in the system. Accurate gauging and tracking the state of health of the battery is important so that the vacuum robot can maximize the time cleaning, and still be able to get back to the charger to re-charge. If the gauge is not accurate, the vacuum may overestimate the amount of energy left, and go back to the dock too soon thereby not cleaning as much as possible.
Let’s look at a few of the protections for a battery pack. The most basic protection is over-voltage. Why does this matter? For Li-Ion batteries, charging above the rated voltage causes lithium plating, which reduces the capacity due to the reduction in the free lithium ions. There is also the possibility of dendrites forming causing a short between the electrodes.

A protector monitors the cell voltage for each cell in the stack. The over-voltage threshold depends on the cell chemistry and the datasheet parameter of the cell vendor. The delay, hysteresis, and output control for the FET depends on the system configuration.

An example of a high side FET protector is the BQ718xx series, with many different threshold options. If you don’t see one that meets your needs, let us know and we can potentially make one that does.

The devices can be used together to cover 5S through 20S or more applications.
Protection – under-voltage

Why it matters

• Lithium ion chemistries can have a breakdown of the electrode materials if over-discharged or stored for extended periods below ~2V (see cell manufacturer datasheets for specifics) – this increases the self-discharge rate
• Below ~2V, copper in the anode current collector is dissolved into the electrolyte. When charged above 2V again, the copper is deposited randomly, potentially causing a short circuit.
• Below ~2V, the cathode may also break down gradually, releasing oxygen by the lithium cobalt oxide or lithium manganese oxide. This results in permanent capacity loss.

How a protector works

• Monitors each cell voltage in the stack
• The under-voltage threshold depends on the cell chemistry
• The delay, hysteresis and output control for the FET depends on the system

Example of a protector with CUV

• The BQ77905xy series of parts is a simple protector with multiple options
• Stackable for high cell count applications
• If a configuration is not yet available, contact your TI representative for possible customization

The next most common cell protection is under-voltage. Li-ion chemistries can have a breakdown of the electrode materials if they are over-discharged or stored for extended periods of time at too low of a voltage. Because of this, monitoring of the individual cell voltage is needed, and the DSG FET needs to open when the CUV, cell undervoltage, is reached. The cell undervoltage threshold varies depending on the cell chemistry, so again, one protector doesn’t fill all applications.

The BQ77905 is a simple protector with multiple options, and is stackable for high cell count applications. Again, if you don’t see a version of this part with the thresholds you need for your application, please let us know.
Protection is also needed for excessive currents, especially for high cell count applications where additional power is available. Since pack terminals can be exposed, and are at risk of being shorted together, a short-circuit discharge (SCD) protection is needed. Loads may exceed safe operating currents, so over-current discharge (OCD) may be needed. If a non-approved charger may be used, a separate over-current charge (OCC) may be needed.

Protection devices include all three thresholds, and some have multiple thresholds with different response times. Two examples of protectors are shown with the bq77905 and the bq77915. With the bq77915, the OCD thresholds are available with different delay options. If your application needs a specific protection threshold and delay, please contact us.
Li-Ion cells are complex chemical systems, and like most chemical reactions, they are sensitive to temperature. Unlike Lead-Acid and NiCd, Li-Ion does not like to be charged when cold. Cold temperatures reduce the current carrying capability of the cell, reduce the effective capacity, and makes lithium plating more likely. One standard, JEITA, addresses this problem by mandating that Li-Ion cells not be charged below 0°C. However, some battery manufacturers and systems have different requirements, and want the secondary protector to allow charging at a slightly lower threshold, and have the primary protector in a gauge, as well as a smart charger, to take care of the first level of protection for cold charging.

At high temperatures, there is the possibility of thermal runaway, where there is positive feedback for current, temperature, and resistance increasing to a point where it is uncontrollable and potentially dangerous. JEITA also addresses this case, and typically charge is reduced when temperatures reach 45°C. Again, many systems let the primary gauge/protector and smart charger handle this condition, and the secondary protector is there in case of a failure.

The temperature is detected by the protector by sensing the voltage at a pin connected to a negative thermal coefficient thermistor, or NTC. The NTC is placed in the system where the temperatures may become critically cold or hot. As the temperature increases, the NTC resistance decreases, and the protector monitors the voltage across the NTC, calculates the temperature, and takes action based on the threshold set based on the over-temperature in discharge, over-temperature in charge, undertemperature in discharge, and undertemperature in charge. Many options for the thresholds are possible, and a few are shown here for the bq77905 family.
In summary, the protector is needed for a Li-Ion based battery pack, and can be used by itself, or as secondary protection with a gauge or monitor. Three different product families are shown here, with the simplest device being the bq7718 family providing cell over-voltage protection only. As with many engineering problems, there are a variety of ways to solve the problem. These families give you choices depending on your system needs.

### BQ7718xx, BQ77905, BQ77915 comparison

<table>
<thead>
<tr>
<th>Protection</th>
<th>BQ7718xy</th>
<th>BQ77905xy</th>
<th>BQ77915xy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cell under-voltage (CUV)</td>
<td>N/A</td>
<td>1.2 – 3 V</td>
<td>1.2 – 3 V</td>
</tr>
<tr>
<td>Over-current discharge (OCD1 and OCD2)</td>
<td>N/A</td>
<td>OCD1: 10 to 85 mV OCD2: 20 to 170 mV Voltage across R_{SNS} (V_{SRP}-V_{SBN})</td>
<td>OCD1: 10 to 85 mV OCD2: 20 to 170 mV Voltage across R_{SNS} (V_{SRP}-V_{SBN})</td>
</tr>
<tr>
<td>For different magnitude and duration</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Over-current charge (OCC)</td>
<td>N/A</td>
<td>N/A</td>
<td>5 to 80 mV Voltage across R_{SNS} (V_{SRP}-V_{SBN})</td>
</tr>
<tr>
<td>Short-circuit discharge (SCD)</td>
<td>N/A</td>
<td>40 to 340 mV Voltage across R_{SNS} (V_{SRP}-V_{SBN})</td>
<td>40 to 340 mV Voltage across R_{SNS} (V_{SRP}-V_{SBN})</td>
</tr>
<tr>
<td>Over-temperature discharge (OTD)</td>
<td>N/A</td>
<td>65 or 70 C</td>
<td>65 or 70 C</td>
</tr>
<tr>
<td>Over-temperature charge (OTC)</td>
<td>N/A</td>
<td>45 or 50 C</td>
<td>45 or 50 C</td>
</tr>
<tr>
<td>Under-temperature discharge (UTD)</td>
<td>N/A</td>
<td>-20 or -10 C</td>
<td>-20 or -10 C</td>
</tr>
<tr>
<td>Under-temperature charge (UTC)</td>
<td>N/A</td>
<td>-5 or 0 C</td>
<td>-5 or 0 C</td>
</tr>
</tbody>
</table>
Up till now, we have only discussed protectors. All of the protectors are stackable, so they can be scaled to meet the cell count needed in the systems we discussed. The protectors we discussed are usually the second level of protection, and the first level of protection comes from a monitor or a gauge. If you want to communicate the cell voltages and currents to a MCU for system level decisions, but don’t need a pre-packaged gauge solution, then a monitor may be the right choice. If you need more flexibility on the thresholds and timing for the protections, both a monitor and a gauge+protector will give you that ability.

Using the example of the BQ769x0 family of monitors, these devices provide a way to measure the individual cell voltages, current, provide cell balancing, die temperature, AND they are able to communicate this information to a MCU.

That sound like a lot of information, and it is. It can be used to gauge system performance, diagnostics, and estimate run time. However, the gauging function is not done with a monitor.
So the next question is – what can I do with a gauge? With the bq769x0 family of monitors, there is a companion CEDV gauge available called the bq78350-R1. This gauge provides an estimate of the remaining charge in the battery during use, and can be tuned for the type of load, how the information is displayed and reported, and for the operating environment. The gauge also provides an estimate of the charge in the battery during charging.

Some gauges are able to provide information about the state of health, as well as record critical use information, called lifetime data, as well as be a black-box recorder to inspect what happened during a permanent fail event. Not all gauges behave the same, or have the same features, and like the protectors and monitors, TI provides several different solutions for gauging high cell count applications.
Before I get into the specifics of the high cell count gauging solutions, allow me to briefly cover the difference between two gauging algorithms from TI. Compensated End of Discharge voltage, or CEDV, is one algorithm. Impedance Track™ or IT, is the second algorithm. Each has benefits and constraints, so a little background may be useful.

**Gauging algorithm options**

- Compensated end of discharge voltage (CEDV)
- Impedance Track™ (IT)
  - Highly accurate
  - System or pack topology
CEDV uses current integration for gauging. The gauge has accurate information about the amount of energy into and out of the battery. The CEDV algorithm calculates the 7% and 3% remaining state of charge values in real time based on load and temperature. This way, the user is alerted prior to the battery reaching zero. There is a complex formula that takes into account self discharge and temperature effects. This method, of course, relies on learning full charge capacity by discharging the battery below 7% at least occasionally, which is one constraint of CEDV gauges.

CEDV learning before fully discharged

Fixed voltage thresholds

- It is too late to learn when 0% capacity is reached → learning FCC before 0%
- We can set voltage threshold that corresponds to given percentage of remaining capacity
- However, true voltage corresponding to 7% depends on current and temperature
Since temperature and self-discharge current also impacts the amount of available energy in the pack, the model needs to account for these variables as well. Here you can see the calculated 7% value under different discharge currents, with one curve shown in pink and the other in blue. The model uses the present state of charge, current, and temperature to estimate the SOC=7% value under these different conditions.

- Modeling last part of discharge allows to calculate function $V(SOC, I, T)$
- Substituting SOC=7% allows to calculate in real time CEDV2 threshold that corresponds to 7% capacity at any current and temperature
There are 7 key parameters that affect the performance of the CEDV gauge. These parameters are defined by modeling the cell over two different current levels and three different temperatures. Parameters EMF and C0 define function to calculate the open circuit voltage using the existing state of charge and temperature.

Parameters R0, R1, and T0 define the cell resistance based on the state of charge and temperature. R1 defines the slope of the resistance based on the state of charge, R0 the magnitude of the resistance, and T0 the slope of resistance dependence on temperature.

Parameter TC defines additional resistance increase at temperatures below 21°C:

Parameter C1 allows to shift whole function to the left. In this case, EDV2 is reached earlier and so reserve capacity is provided. 1 Unit of C1 shifts function by 0.39%
In summary, the CEDV gauge takes current integration and seven constants that describe the battery and system behavior to provide an estimate of the SOC for the battery pack. Characterizing the cell for CEDV, as well as requiring periodic full charge–discharge cycles are requirements for accurate gauging with a CEDV gauge. Also, the aging of the battery is only approximated, and is estimated by compensating the cell resistance based on cycle count.
Now let’s look at an Impedance Track gauge, and see how it is different. The CEDV gauge utilized coulomb counting, which does not account directly for cell impedance changes during aging, self-discharge, must have full-to-empty learning cycles, must develop a cell model with every cell maker, and although charge entering and leaving is measured, the total energy is still dependant on a complex model which becomes less accurate with cell aging.

Impedance track directly measures the effect of discharge rate, temp, age and other factors by learning cell impedance. This allows a calculation of the remaining capacity and full charge capacity, which changes as the battery changes.
Before going into Turbo Mode too much, let’s review some of the terms for gauging. The open circuit voltage is the voltage that the cell will reach when completely relaxed with no load or charge. The depth of discharge is an indicator for how empty the system is, and does not depend on load or temperature or system characteristics. The remaining capacity is the usable capacity of the battery from the present depth of discharge to empty. The full charge capacity is the usable capacity from full to empty. This is different than design capacity, which is the capacity on the cell datasheet. The full charge capacity is dynamic and learned over time. The state of charge is what most people expect to see on the device, and shows the remaining capacity divided by the full charge capacity, giving a percent value.
The open circuit profile of cells is fairly consistent if the cells are made the same way. Here is data showing the discharge curve for five different manufacturers. Most of the voltage measurements were within 5mV of each other. Since the open circuit voltage database can be used with different manufacturers, a generic database allows significant simplification of fuel-gauge implementation at the user side. These cell profiles are called ChemIDs by TI, and they are available through our gauge tools. Also, you can use a tool called GPChem tool. Click on the link provided to see a tutorial on how to use the tool to match your cell with the TI database of cells.
The Impedance Track algorithm uses the chemID as a starting point for the resistance table, and the table is updated during charge and discharge cycles. The gauge needs to complete at least one full learning cycle prior to shipping to have the most accurate gauging at the start of customer use. During the discharge cycle, the resistance table, Ra table) is updated and stored in RAM. This table is then used to better predict the state of charge. The updating process happens naturally during the use of the product, and reflects the actual parameters of the cell during the life of its use.

- The resistance in data flash (Ra table) is updated after 10% (and after 80% DOD after 3%) intervals of DOD

- During entire interval (for example from 50 to 60% DOD) we take resistance measurements every 50 sec and store them in RAM

- Many resistance measurements are stored in RAM before GG reaches an actual grid-point (for example DOD exceeds 60%) and makes an update of Ra in data-flash by doing linear regression from the points stored in RAM
So now let’s look at a few high cell count gauge approaches. The first is a gauge with a monitor for each cell. This can be done with the BQ78350-R1 as the CEDV gauge, and the BQ769x0 devices for the monitor/protector for up to 5S, 10S, or 15S applications.

The second approach is a top-of-stack gauge where the individual cells are not monitored by the gauge. A protector is usually used with this approach. The BQ34z100-G1 is the Impedance Track™ gauge, and the BQ34110 is the CEDV version.

If you need a fully integrated gauge with individual cell monitoring and primary protection, as well as gauging, then the bq40z50 or bq40z80 is the right approach. These gauges improve the accuracy of the gauging, reduce the size, and provide flexibility in protection and performance.
The BQ78350-R1 is the companion fuel gauge for the BQ769x0 family of monitors that we have previously discussed. This is a CEDV based gauge that supports high cell and high current battery packs. The algorithm is completely self-contained, and does not require a separate MCU to run any FW. The monitor provides all the voltage and current information required to execute the CEDV algorithm with a simple two-chip solution that is scalable from 3S to 15S. This gauge supports batteries up to 320Ah, with charge/discharge current up to 320A. Lifetime data logging of critical parameters, state of health indication, and support for LCD or LED display. We haven’t discussed authenticaton, which is a whole other presentation, but this gauge also support SHA-1 authentication to enable the creation of battery packs that can only be used with specific end equipment. This is important for some applications where the entire system needs to be guaranteed safe and compatible, such as eBikes, eScooters, hoverboards, etc.
Gauge topologies

- **Gauge with monitor for each cell**
  - BQ78350-R1 (CEDV) plus BQ769x0 monitor

- **Top of stack gauge only**
  - BQ34z100-G1 (Impedance Track™ gauge)

- **Fully integrated gauge**
  - BQ40z50-R2 (Impedance Track) 1-4 cell
  - BQ40z80 (Impedance Track) 2-7 cell

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BQ34110
Multi-chemistry gas gauge for rarely discharged applications

BQ34110 Features
- CEDV fuel gauge only for Li-ion, polymer, LiFePO4, NiMH and lead acid
- Rarely discharged application end-of-service/state-of-health determination
- Large capacity batteries supported (>65Ah)
- High current applications supported (>32A)
- Suitable for packs 2.5V to ~65V
- Low operating current of <140µA with <64µA in sleep
- External 103AT NTC thermistor supported
- Two-wire (I2C) communications
- Configurable warning (/A1,/A2) outputs
- 14-pin TSSOP

Benefits
- Enables end-of-service determination without risking guaranteed service time/large discharges
- Very simple setup configuration
- Multiple chemistry support
- Accurate fuel gauging
- Independent of protection solution and cell balancing requirements
- Capable of gauging very high series cell batteries

Applications
- Battery backup applications
- UPS
- Asset tracking

The BQ34110 is a top of stack gauge that uses the CEDV algorithm. It only monitors the highest voltage in the pack, divided down and presented to the ADC, and also has a second ADC as a dedicated coulomb counter for current integration. One of the unique features about the BQ34110 is the end of service state of health determination for rarely discharged applications such as battery backup applications. For these applications, they do not go through the typical charge/discharge cycles that allow the gauge to determine the state of health of the battery. In this case, there is a very small, adjustable discharge level that allows the gauge to determine if the state of health of the battery has degraded during its use to a point where it can not guarantee the delivery of the rated power for the rated duration. For example, a battery back up system may guarantee a certain power for 100s, and when the system is no longer able to deliver that, the BQ34110 will indicate this information to the host. The BQ34110 can be used in conjunction with monitors or protectors as needed to meet the safety and compliance standards for these applications.
The BQ34z100-G1 is the impedance track version of the top of stack gauge, and has the added accuracy benefits that impedance track provides. Impedance track is specifically useful for LFP, or lithium iron phosphate battery packs, as these have a very flat OCV curve. The IT algorithm takes this into account during the resistance table updates, which provides a high accuracy for LFP battery packs.

### BQ34z100-G1 Features

- Impedance Track™ fuel gauge capacity estimation for Li-ion, polymer, LiFePO4, PbA, NiMH and NiCd
- Large capacity batteries supported (>65Ahhr)
- High current applications supported (>32A)
- Suitable for packs 2.5V to ~65V
- Low operating current of <140μA, sleep <64μA
- SHA-1 authentication
- External thermistor supported
- Optional interfaces
- Single wire (HDQ) / two-wire (I2C) communications
- 1 or 4 LED display – more with expander IC
- Configurable warning signal
- 14-pin TSSOP

### Benefits

- Add-on gauge that can be added to a wide variety of high cell / large capacity / high current packs
- Independent of protection solution and cell balancing requirements
- Resistor divided pack level gauging with good accuracy
- Single wire HDQ saves on connector pin cost
- Authenticates only legitimate packs for overall system safety
- No customer algorithm or F/W development needed, enables fastest time to market
- LED display of capacity for visual indication
- TSSOP package suitable for industrial application

### Applications

- Energy storage systems
- Battery backup, UPS and wireless base stations
- Power assist, eBike
- Cordless home appliances
- General 12–48V battery packs

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The block diagram shows the internal components and connections of the BQ34z100-G1, including the various paths for power, signals, and communications.
Gauge topologies

- **Gauge with monitor for each cell**: BQ78350-R1 (CEDV) plus BQ769x0 monitor
- **Top of stack gauge only**: BQ34z100-G1 (Impedance Track™ gauge)
- **Fully integrated gauge**: BQ40z50-R2 (Impedance Track) 1-4 cell, BQ40z80 (Impedance Track) 2-7 cell
The BQ40z50 is a fully integrated gauge for up to 4S battery packs. It uses the latest Impedance Track algorithm, and is available in a small 4mm by 4mm then QFN package. This device is the work-horse for most notebook battery packs, and we are about to release the BQ40z50-R3, which has updates to some of the key features of this device. The BQ40z50-R3 is a firmware only release, and can be flashed onto BQ40z50-R2 hardware. One of the features unique to the BQ40z50 devices is the support of Turbo Mode, also known as Intel Dynamic Battery Power Technology, DBPT. The BQ40z50-R2 supports DBPTv2, and the BQ40z50-R3 supports DBPTv3. This algorithm calculates a 10s sustained peak power and current, as well as a 10ms max peak power and current. This allows the system to know what power levels it can achieve without hitting critical voltages at the cell level, pack level, and system level, and can be tuned to individual systems. This gauge family is full features with comprehensive protection for multicell safety, and is compatible with second level protectors.

The BQ40z50-R2 is a 1S – 4S SBS 1.1-compliant gas gauge and protector

**BQ40z50-R2 Features**
- Integrated AFE safety protector
  - Programmable
  - Voltage, current, temperature, cell imbalance
- Advanced IT gauging with JEITA & additional temp and current sub-ranges & cell balancing at rest or while charging
- Turbo mode data support
- Black box recorder
- N-channel FET drive
- Integrated 1.8V LDO
- SHA–1 authentication
- LED (up to 5) support option (BQ40z50)
- 4mm x 4mm x 0.9mm 32L–QFN

**Benefits**
- High gauging accuracy & multiple complex charging profile support
- Provides comprehensive protection for multicell safety
- Continuous cell balancing ensures maximum battery capacity is available at all times
- Turbo mode reports maximum power available at any time
- Lifetime/black box supports analysis of returned battery packs
- Reduce BOM count/lower BOM cost
- Anti-counterfeiting
- Visual display of SOC with LED indication

**Applications**
- Notebook/netbook PCs
- Medical and test equipment
- Portable robotics
- Portable instruments
- Drones
- Cordless household appliances
- Compatible 2nd level protectors

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**Texas Instruments**
The BQ40z80 is similar to the BQ40z50, but has expanded capabilities to support from 2S to 7S battery packs, keeping the same small 32-pin 4mm by 4mm thin QFN package. This part will support higher cell count applications like cordless vacuums, vacuum robots, drones, portable robotics, and battery backup systems. A future version will incorporate the end of service indication for rarely discharged applications. The BQ40z80 brings some unique features that help it be more configurable for industrial applications.
This chart shows all the new features built on top of the BQ40z50 base functionality. Because the BQ40z80 is scaled up to 7S, it naturally makes sense that high current packs will also be developed with this part. The device can natively support pack capacities up to 29Ah and battery currents up to 32A. With current scaling, the scale factor can be set between 0 and 100, with the scaled current still in 1mA resolution. To reduce losses in the sense resistor, a 1mOhm typical sense resistor is supported, but this can be smaller if larger currents are used.

The BQ40z80 has several multi-function pins that can be configured based on the specific application needs. Most unused pins can be configured as GPIO’s, with the capability of generating interrupts on pins through a flag mapping function. The flags may be OR’d or AND’ed together to trigger an interrupt on a particular GPIO pin, with up to eight different flags OR’ed onto a single pin.

Other multi-function pin functions are additional ADC inputs to monitor voltages or temperatures, a dedicated display pin to turn on the LED’s, and a presence pin to use for removable battery applications to assist in battery detection and entering/exiting lower power states.

A new feature is a pre-discharge pin, which is useful when the load is highly capacitive, such as a motor. The pre-discharge pin allows charging up the cap until a pre-determined voltage is reached, and then turning on the DSG FET. This reduces the chances of having the battery OCD and SCD protections trip when turning on the load, as soft-starts the load and reduces the current spike.

The BQ40z80 also improves the authentication capabilities with Elliptic Curve Cryptography, or ECC, as the encryption method for authentication.
If you'd like to see more about the BQ40z80, make sure to see the presentation on the BQ40z80 deep dive, where I go into specific problems that can be solved with this device. That sums up the design considerations for high cell count applications. I hope I've given you things to consider when designing the battery pack and protection for your system, as well as a few devices from TI that can help you meet your design goals.