Selecting an Impedance Track™ Gas Gauge for Li-Ion Single Cell Applications

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ABSTRACT

There are many single cell Impedance Track™ (IT) gas gauge products from Texas Instruments from which to choose. This application report provides a simple selection guide that discusses the different gas gauging requirements for a handheld system that must be considered by designers to determine which Texas Instruments Impedance Track™ gas gauge is best for a mobile application. There is a summary of the selection guide at the end of the report. Quick reference and trade-offs for each option are discussed in the main text.

1 Gauge Location

The IT gas gauges are grouped in two major categories:

- **Pack-side Gauges**: Enclosed within the battery pack casing and are likely to always be powered due to a continuous connection to the energy source (battery).
- **System-side Gauges**: Embedded in the application system circuitry, but this requires additional considerations because the user can swap between different batteries.

1.1 Pack-side Gauges

Having the gas gauge inside the pack has historically been the most common way to use a gauge. Such batteries with "brains" have been called “smart” batteries. The main advantage of using a pack-side gauge is that the gauge monitors the battery at all times with no disconnections.

Because the battery pack supplier is integrating the gauge into their packs, they usually take care of all the characterization, configuration, and programming of the gauge, thus saving the system developer significant effort and time. Another benefit of having the gauge embedded in the battery pack is that the configuration can be tailored for the specific cell chemistry that is used by that pack-maker. If multiple suppliers are used, each can have the gauge optimized to work with their particular cells. Cells from different suppliers can have slightly different voltage and resistance profiles. This can be a challenge for system-side gauges because a single gauge configuration may not match multiple suppliers’ cells as well as possible.

Embedding the gauge in the battery pack also offers a few other features. First, the gauge can store lifetime data like a black box, including maximum and minimum temperatures, voltages, and currents. This can be useful for troubleshooting and warranty purposes. Also, if the system maker is concerned about possible safety or feature limitations of third-party or counterfeit battery packs, the pack-side gauge provides an authentication function. The gauge can be programmed with a SHA-1 key at the factory and whenever a battery pack is inserted into the system it can send a random challenge to the gauge which must calculate a HMAC response using the secret key. If the response matches the expected value calculated by the host, the pack is successfully authenticated and can be used with full functionality. For example, if the system maker selects special cells which allow higher charging voltages or higher charging rates, this feature can disable the higher charging voltage or current if non-authentic packs are introduced to the system. Pack-side gauges that are currently available are the bq27541, bq27545, and bq27741 devices.

Another feature recently added to pack-side gauges is the availability of GPIOs that can be used to interrupt the host processor on specific events. This feature can save energy by preventing the host from having to continually poll the gauge. This is a feature traditionally seen only on system-side gauges, but is now available on recent pack-side gauges. The only consideration for using this feature is that an additional connector pin is required on the battery pack to carry this interrupt signal.

The main challenge with designing a pack-side gauge is the gauge presenting a continuous load to the battery even if it is just being stored while not in use. However, pack-side gauges have the capability to enter very low power modes that can allow the battery to be stored for many months without causing any significant drain from the cell. Another consideration for pack-side gauges is the communication protocol that is used. The IT gauges have I^2C (two-wire) and HDQ (single-wire) protocols available. Deciding between these protocols is based on deciding what is more important. I^2C is faster and more commonly used but requires two connector pins for connection to the system communication bus. HDQ packs require only a single connector for the communication and are typically connected directly to a GPIO of the host processor. Although the HDQ data-rate is much lower than that of I^2C, it is sufficient for the limited dataset typically read from a battery pack.

NOTE: In production, the pack-maker would typically use test points on the pack PCB to program the gauge via I^2C, but then would convert it to HDQ mode before enclosing the pack and shipping it.

1.2 System-side Gauges

Many handheld equipment makers traditionally used “dumb” battery packs without embedded fuel gauges, but accurate gauging has become a mandatory feature to meet customer expectations. To continue using the “dumb” battery packs while adding a gas gauge feature, system-side gauges require additional features. This type of gauge must be able to detect if a battery is inserted and quickly make accurate state-of-charge estimations upon a battery insertion. The initial estimations are more accurate if the battery voltage is relaxed (has not been used for some time) and no current is flowing during initialization. However, most systems begin charging or discharging immediately when a battery is inserted so the gas gauge must compensate for this current. Although initial bootup accuracy may be slightly worse than a pack-side gauge, it should converge to an accurate value over time.

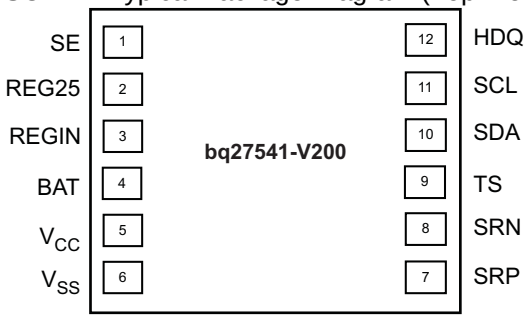
One consideration when using system-side gauges is whether a user can arbitrarily swap between different battery packs. For example, a user may have a new battery pack as well as a backup older pack which would have increased impedance and reduced capacity. The bq275xx system-side gauges have the ability to learn and store the capacity and impedance of two different packs and to quickly determine upon insertion which profile to use. Quick arbitration between these two learned profiles is necessary so that the capacity estimations and run-time predictions can be as accurate as possible. Gauges without this feature would typically require a learning cycle to regain optimum accuracy if a battery of a different age and capacity were swapped out.

Putting the gas gauge on the same PCB as the system processor does enable a few benefits. System-side gauges can include special function GPIOs that can serve as interrupts and help reduce the rate at which the system is required to communicate with the gauge to maintain an up-to-date status for the end user. Another example of using GPIOs is to disable the charger if the safe temperature range is exceeded. The system processor can do data flash programming of the system-side gauge during manufacturing testing using the I^2C bus. This infrastructure can also be used as a means to perform field updates of the data flash configuration should it be necessary. System-side gauges that are currently available are the bq27510, bq27520, bq27410, bq27425, bq27620, and bq27421 devices.

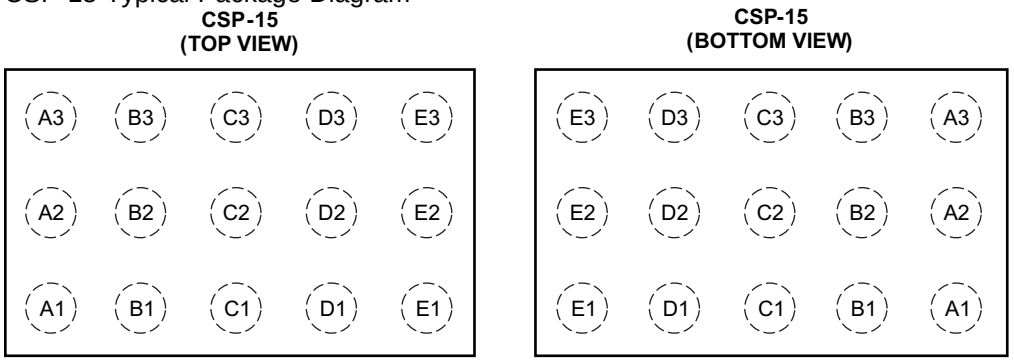
2 Package Types

The IT gas gauges may be available in Small Outline No-lead (SON) or Chip Scale Package (CSP). The advantages offered by chip scale packages include smaller size (reduced footprint and thickness) and lesser weight, but not all manufacturing assembly sites may be properly equipped to work on CSP packages. The bq27541, bq27510, and bq27410 devices are available in SON packages while the bq27520, bq27421, bq27425, bq27545, bq27620, and bq27741 devices are available in CSP packages.

SON-12 Typical Package Diagram (Top View)



CSP-15 Typical Package Diagram



3 Ease of Use

There are many factors that contribute to determine the capacity of a rechargeable battery with accuracy. It can be overwhelming to consider them all. Texas Instruments provides gas gauge products that are easy to use in addition to the products that have more advanced features. Regardless of the level of features for these types of gauges, they all have the Impedance Track™ technology which gives the best accuracy of capacity reporting over the life of the battery.

3.1 Minimum Configuration Requirement

The bq274xx line of products are system-side gauges that are intended for customers that want to quickly have a gas gauging solution without having to extensively characterize their batteries to determine cell chemistry. The bq274xx gauges are programmed with a default battery profile suitable for most lithium-cobalt cells and during operation they further refine predictions as they more accurately learn the battery capacity and resistance profile. These gauges have fewer features and options and therefore have fewer data flash parameters to configure. Although these devices have a reduced configuration data set, they still keep track of the impedance of aging batteries and provide better accuracy performance than gauges which use only coulomb counting or voltage-based methods alone. From this line of products customers can select the bq27410 device with an external sense resistor, or the bq27421 and bq27425 devices which have an internal sense resistor to reduce overall component cost and solution size.

3.2 Advanced Configuration

The bq275xx devices allow users to have access to many data values that can be reported to the end user and also more extensive configurability in data flash to customize the gauge operation specifically to the charger; system and battery to be used in a given application. These devices provide the most flexibility, features, and most accurate capacity reporting. Configuring the bq275xx device requires characterizing the cells to be used in the application so that the gauge can report the most accurate capacity upon the first discharge cycle.

4 Sense Resistor

Most TI Impedance Track™ gas gauges typically use current sense resistors to measure current from which passed charge or discharge is determined. The passed charge is one of the inputs to the gauge predictions of battery capacity, run-time, and state-of-charge. The gauges have different options available for current sense resistors.

4.1 External Sense Resistor

Most gas gauges use an external sense resistor that can be selected based on expected application loads. The typical value for external sense resistors used with TI gauges is 10 mΩ. This sense resistor value provides a balance between a value high enough to allow good current measurement but not too high as to cause large voltage drops in typical portable battery-powered products. Gauges that require external sense resistors are the bq27541, bq27545, bq27510, bq27520, bq27410, bq27545, and bq27741 devices.

NOTE: The bq27741 requires a high-side sense resistor, while the others mentioned require a low-side sense resistor. The bq27741 also integrates the second-level protector functionality and controls high-side protection NFETs, as opposed to the low-side NFETs traditionally used in single-cell battery packs. Having the NFETs and sense resistor in the high-side (between PACK+ and CELL+) adds several additional benefits. First, communication with the pack is maintained even during a fault condition where a FET is opened because the ground path is uninterrupted. The single ground plane also improves the power supply rejection ratio (PSRR) and overall noise and layout ease of the system.

4.2 Integrated Sense Resistor

System designers may want to simplify their schematic and reduce the component count on a design. The sense resistor may be integrated in some gauges. The operation of the coulomb counting and current measurement activity are the same as with an external sense resistor gauge. The designer must consider the internal sense resistor value before designing because it does not have the flexibility to change as with an external resistor solution. The bq27421 and bq27425 devices are available with an internal sense resistor and can support currents up to 2 A constant and up to 3.5 A peak on high-frequency pulsed loads.

4.3 No Sense Resistor

Applications with high load profiles can benefit from a gas gauge design that does not use a sense resistor at all. The benefits of not using a sense resistor are a reduction in component count and eliminating voltage drops across a resistor. The bq27620 device operates without a sense resistor, while still maintaining the battery capacity reporting accuracy of a gas gauge that measures current with a sense resistor.

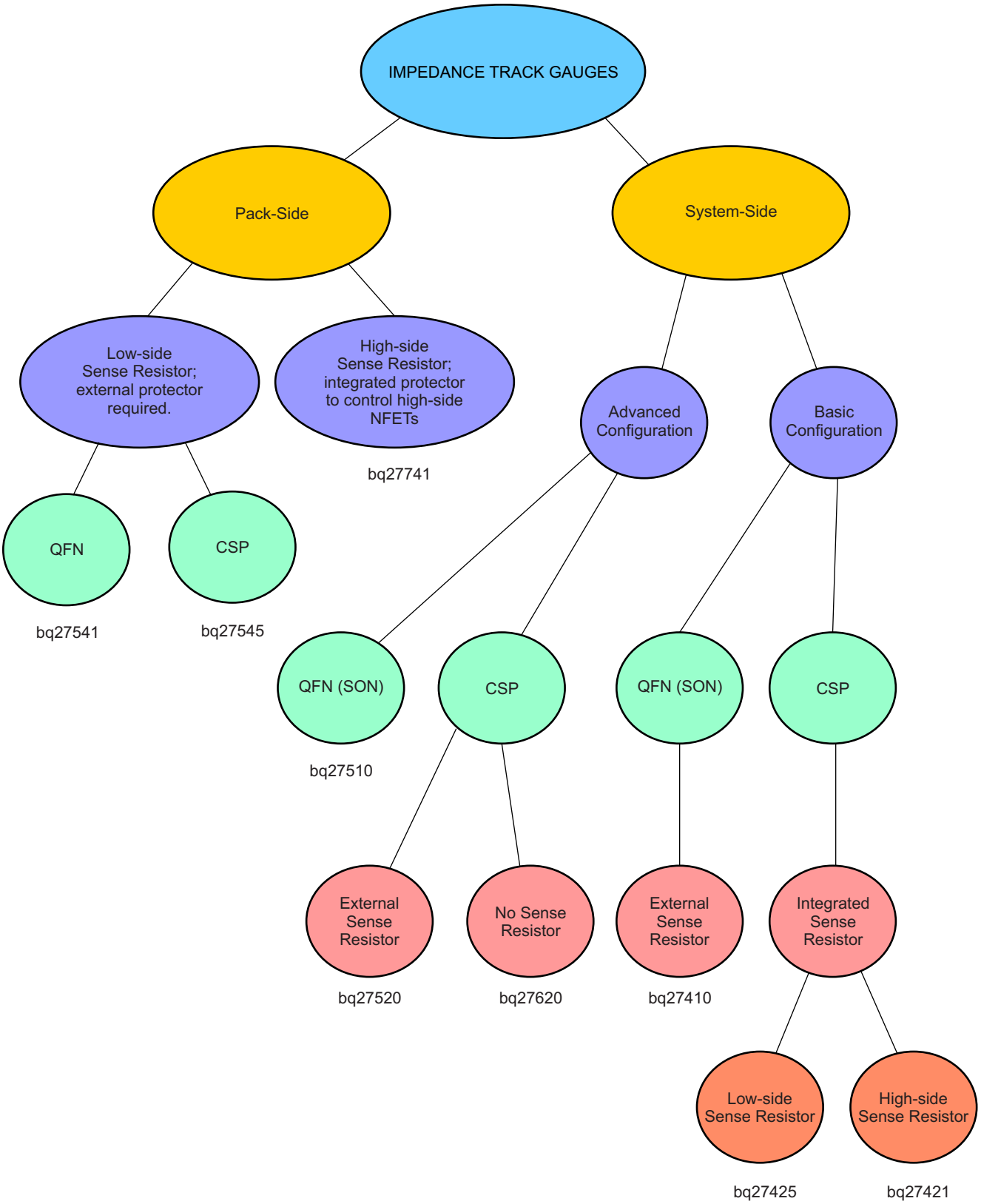


Figure 1. Gas Gauge Selection Quick Reference

Table 1. Gas Gauge Selection Quick Reference[1]

Category	Parameter	bq27520	bq27510	bq27620	bq27425	bq27421	bq27410	bq27545	bq27541	bq27741
Overview	Latest Suffix	G4	G3	G1	G2A / G2B	G1A / G1B	G1	G1	G1	G1
	Latest FW Version	v3.29	v4.00	v1.06	v2.05	v1.08	v1.03	v2.24	v2.24	TBD[2]
	Pack or System[3]	System	System	System	System	System	System	Pack	Pack	Pack
	Algorithm	IT	IT	IT-DVC	IT-LITE[4]	IT-LITE[4]	IT-LITE[4]	IT	IT	IT
	Target Maximum Error[5]	1%	1%	2%	5%	5%	5%	1%	1%	1%
	Notable Features	Advanced gauge; chip-scale package	Advanced gauge; plastic package	No sense resistor required	Simple gauge; integrated sense resistor; chip-scale package	Simple gauge; integrated high-side sense resistor; chip-scale package	Simple gauge; plastic package	Embedded in battery pack	Embedded in battery pack	Embedded in battery pack; high-side sense resistor; integrated protector
	R_{sense}	External	External	Not required	Integrated	Integrated	External	External	External	External
Package	Package Type	CSP	SON	CSP	CSP	CSP	SON	CSP	SON	CSP
	Pin Count	15	12	15	15	9	12	15	12	15
	Package Size	2,610 x 1,956 mm	2,5 x 4 mm	2,610 x 1,956 mm	2,69 x 1,75 mm	1,62 x 1,58 mm	2,5 x 4 mm	2,61 x 1,96 mm	2,5 x 4 mm	2,776 x 1,96 mm
Current	ICC Normal	118 µA	103 µA	118 µA	118 µA	92 µA	103 µA	118 µA	131 µA	170 µA
	ICC Sleep	23 µA	18 µA	23 µA	23 µA	22 µA	18 µA	23 µA	21 µA	42 µA
	ICC Hibernate	8 µA	4 µA	8 µA	8 µA	10 µA	4 µA	8 µA	6 µA	NA
	ICC Shutdown[6]	< 1 µA	NA	< 1 µA	< 1 µA	< 1 µA	NA	< 1 µA	NA	< 1 µA

(1) Values in this table are accurate as of the publication date of this document.
(2) To be determined at product release date, 2Q of 2013.
(3) Pack-side gauges are designed to be embedded inside the battery pack and always connected to the same cell.
System-side gauges have features that make them suitable for residence on the main system PCB while still being able to handle battery swapping.
(4) IT-LITE is a less flexible and less customizable version of Impedance Track™. It uses a fixed chemistry profile that cannot be customized to match a particular battery. The user must ensure their battery matches the fixed profile before selecting this gauge.
(5) Gauging error under typical charge/discharge profiles.
(6) Shutdown mode can be achieved by pulling the CE pin low (on gauges with this pin) or by using the shutdown command with the bq27421 device.
Gauges with NA do not have a CE pin or a Shutdown command.

Table 1. Gas Gauge Selection Quick Reference[(1)] (continued)

Category	Parameter	bq27520	bq27510	bq27620	bq27425	bq27421	bq27410	bq27545	bq27541	bq27741
Algorithm	Fast Resistance Scaling	yes	yes	yes	yes	yes	yes	yes	yes	yes
	Fast Qmax	yes	yes	no	no	yes	no	no	no	yes
	SOC Smoothing	yes	yes	no	yes	yes	no	yes	yes	yes
	Pack Safety Features	no	no	no	no	no	no	Authentication; Internal Short Detection; Tab Disconnect Detection	Authentication; Internal Short Detection; Tab Disconnect Detection	Authentication; Internal Short Detection; Tab Disconnect Detection; Integrated Protector (OVP, UVP, OCD, OCC, SCD)
	Maximum Capacity	32 Ah	32 Ah	8 Ah	8 Ah	8 Ah	8 Ah	32 Ah	32 Ah	32 Ah
Calibration	Calibration Style	Host-based	Host-based	Host-based	Factory calibrated	Factory calibrated	Host-based	Host-based	Host-based	Host-based
Communication	Communication Protocols	I^2C	I^2C	I^2C	I^2C	I^2C	I^2C	HDQ and I^2C	HDQ and I^2C	HDQ and I^2C
Pack-swap	Old or New Pack Arbitration	yes	yes	no	no	no	no	no	no	no
GPIO	Interrupts and GPIOs	3: SOC_INT BAT_LOW BAT_GD	1: SOC_INT or BAT_LOW or BAT_GD	3: SOC_INT BAT_LOW BAT_GD	1: SOC_INT or BAT_LOW	1: SOC_INT or BAT_LOW	I^2C	SE/HDQ	SE/HDQ	HDQ
Memory	NVM Type	Flash	Flash	Flash	EEPROM + RAM	RAM only	Flash	Flash	Flash	Flash
	BOM Count (minimum recommended)	15: IC + 8 capacitors + R_{sense} + 5 resistors	14: IC + 7 capacitors + R_{sense} + 5 resistors	4: IC + 3 capacitors	5: IC + 4 capacitors	2: IC + 1 capacitor	6: IC + 4 capacitors + R_{sense}	10: IC + 6 capacitors + R_{sense} + 2 resistors	10: IC + 6 capacitors + R_{sense} + 2 resistors	17: IC + 7 capacitors + R_{sense} + 7 resistors + dual FETs

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