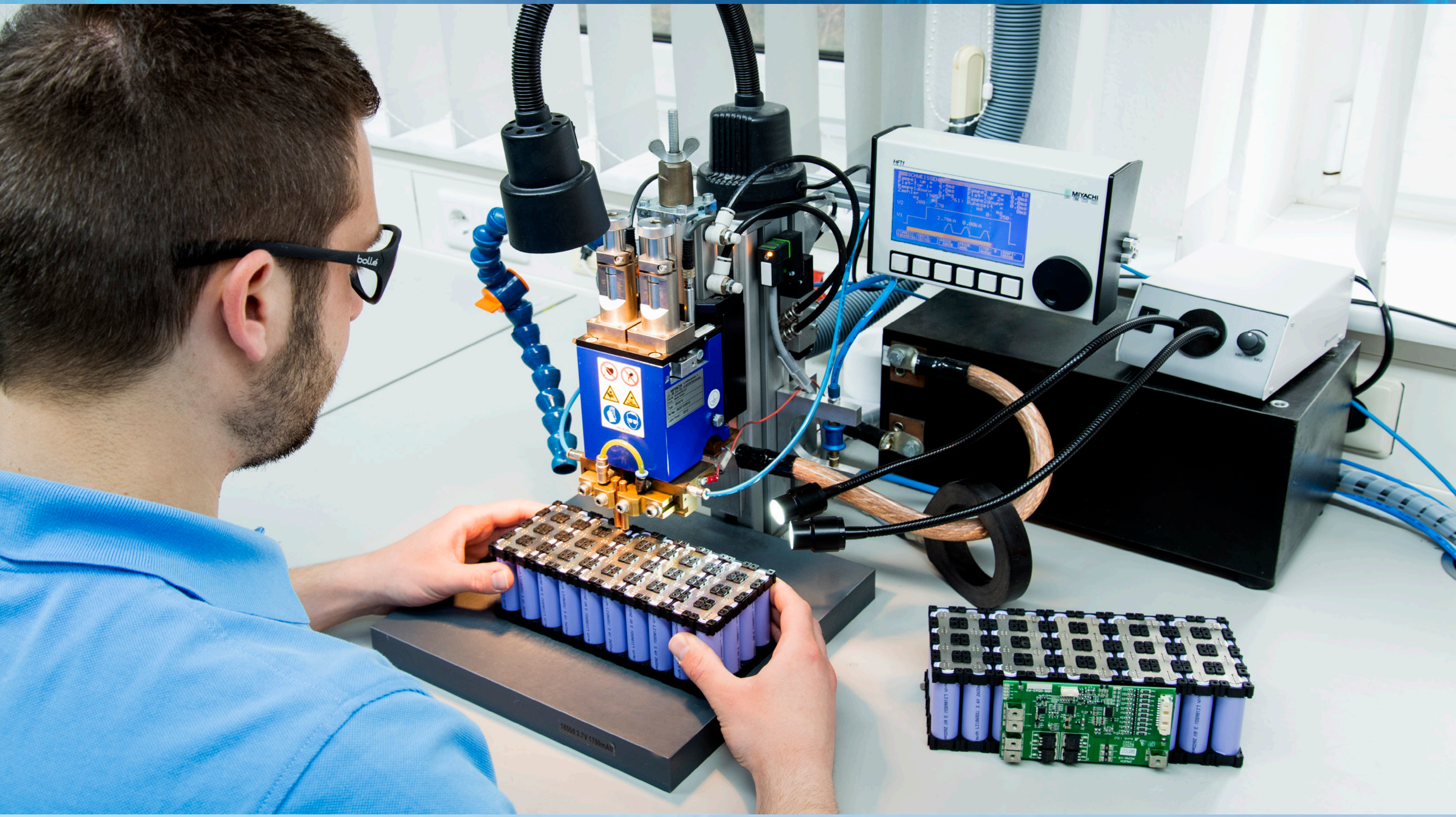
THE PULSE OF PROGRESS

SAFETY ELECTRONICS AND BATTERY MANAGEMENT FOR LITHIUM BATTERIES



JAUCH DEVELOPS

WHITEPAPER

INHALT

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1. BATTERY ELECTRONICS

Safety is paramount for lithium battery technology. Incorrect handling of lithium batteries can lead to severe consequences such as fire or explosion. Various electronic protection mechanisms are available to implement against this threat. Besides, well-tuned electronics can also significantly extend the life of a battery.

This whitepaper provides an overview of the various electronic protection mechanisms and their functionality, ranging from standard PCM to complex Battery Management Systems (BMS), which can also include fuel gauging.

2. FUNCTIONALITY OF A STANDARD PCM

Once a cell or a number of cells are connected to safety electronics, a battery is formed.

Safety starts within the cell and then extends to the battery pack by means of the Protection Circuit Module (PCM).

Safety measures have to be in place to prevent fire and explosion. Ideally, more than one level of safety has to be in place for the cell/ battery pack. The external safety measures should always be activated before the internal cell safety measures.

The basic safety offered by a PCM is:

- overvoltage protection (overcharge protection)
- undervoltage protection (deep discharge protection)
- overcurrent protection
- short circuit protection

FIG. 1: JAUCH PCM

Image: Jauch Quartz

FIG. 2: TYPICAL SCHEMATIC FOR A SINGLE CELL BATTERY

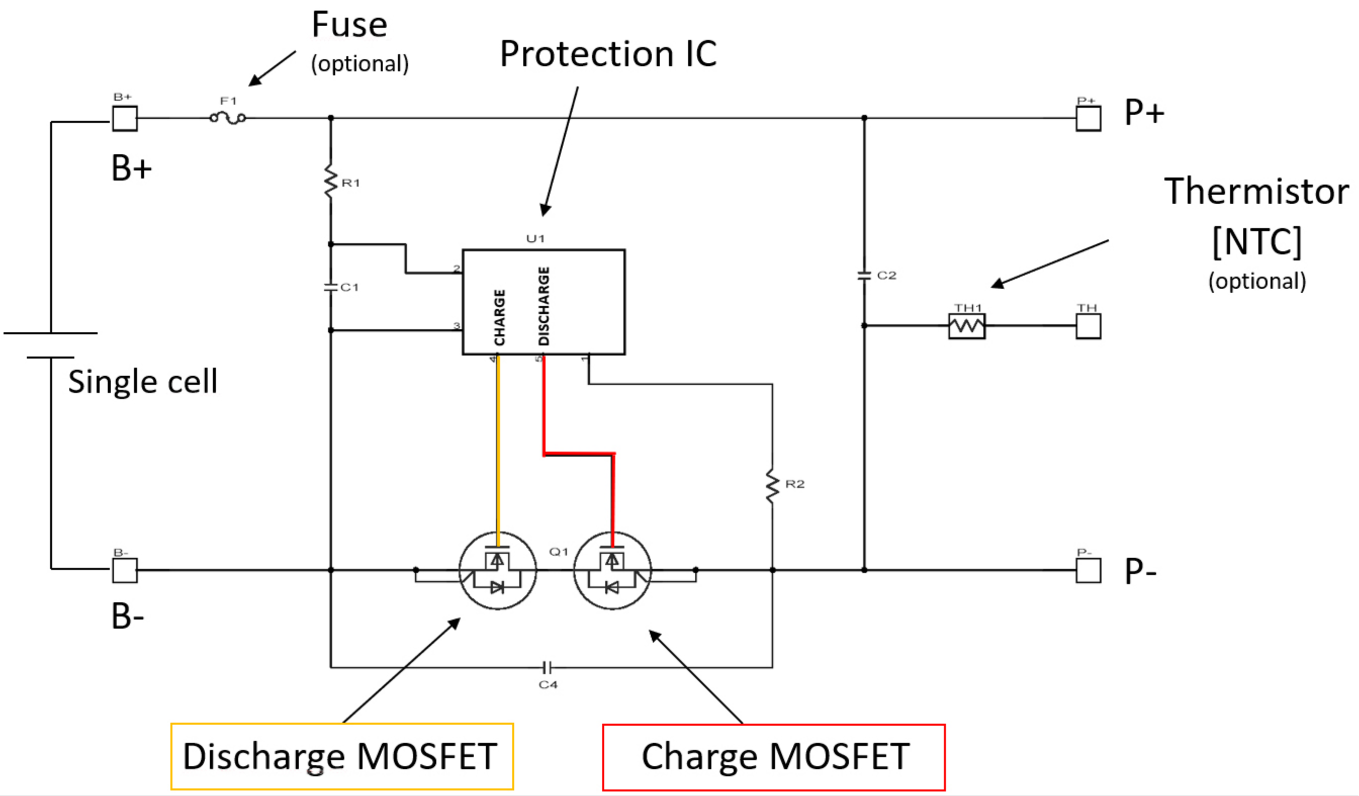

Image: Jauch Quartz

FIG. 3: TYPICAL SCHEMATIC FOR A TWO-CELL BATTERY

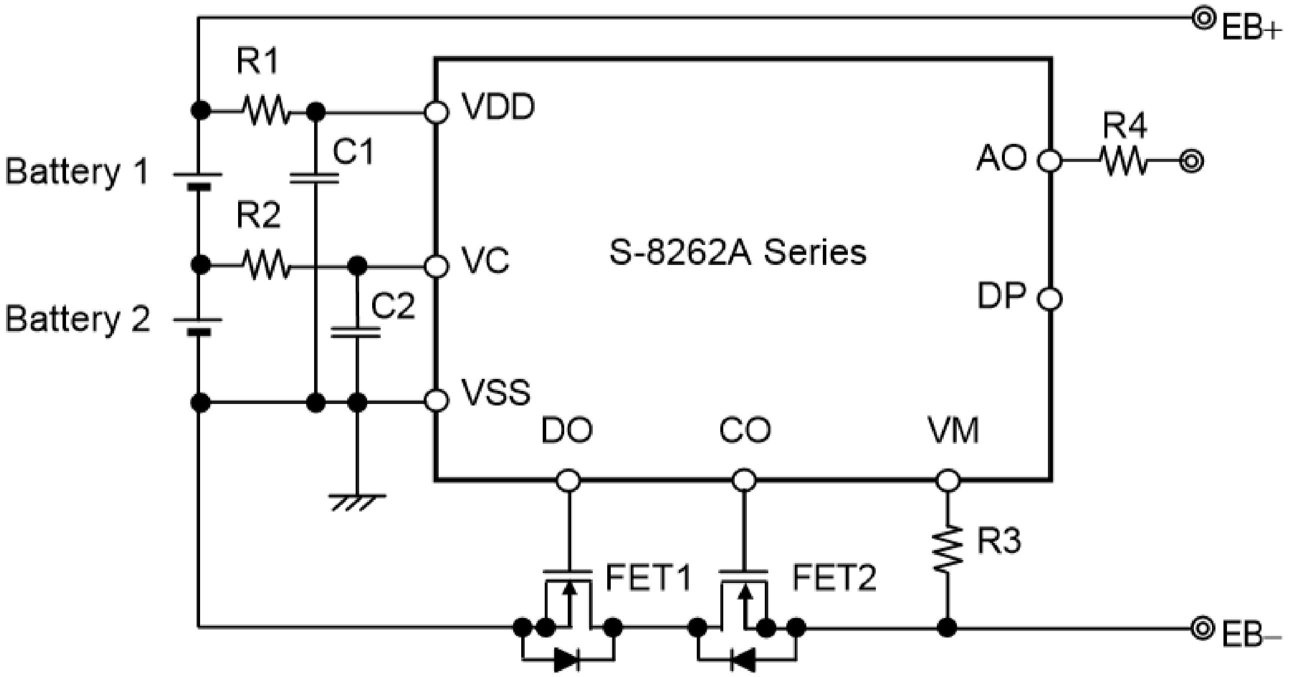

Image: Ablic data sheet

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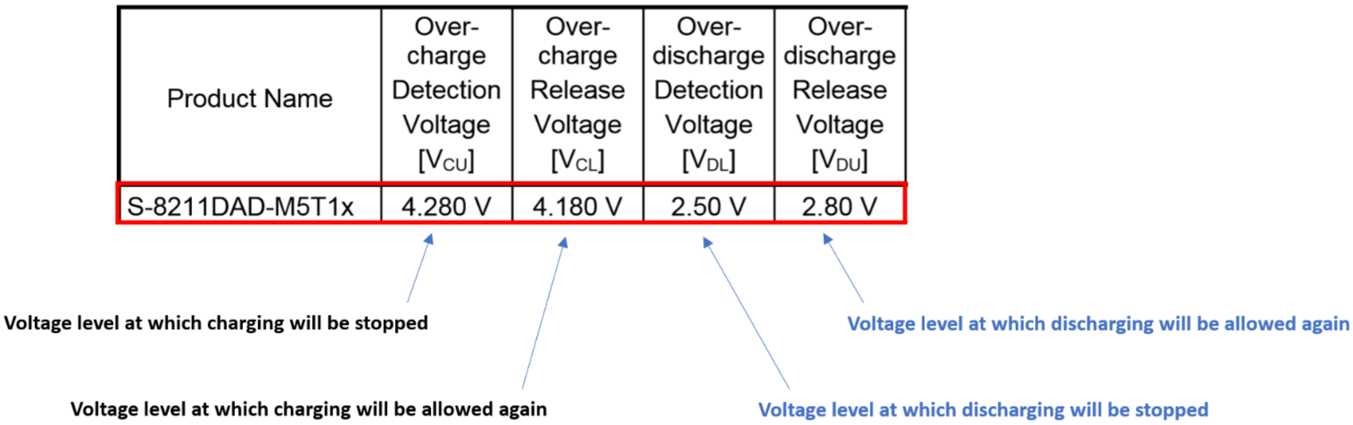
The function of a PCM within a battery is to monitor the voltage of all cells and any current flowing into or out of the battery pack. Certain safety thresholds exist within the protection IC and they are triggered when thresholds are exceeded. The protection IC then opens the charge or discharge path by means of controlling a MOSFET (electronic switch). When the voltage or current reverts away from the safety thresholds, the protection IC closes the circuit again to allow the battery pack to continue working. This is known as the recovery threshold. Therefore, the battery pack cannot be overcharged with dangerous voltages or high currents.

FIG. 4: TYPICAL PROTECTION PARAMETERS FOR AN ABLIC SINGLE CELL PROTECTION IC



Product Name	Over-charge Detection Voltage $[V_{CU}]$	Over-charge Release Voltage $[V_{CL}]$	Over-discharge Detection Voltage $[V_{DL}]$	Over-discharge Release Voltage $[V_{DU}]$
S-8211DAD-M5T1x	4.280 V	4.180 V	2.50 V	2.80 V

Voltage level at which charging will be stopped

Voltage level at which discharging will be allowed again

Voltage level at which charging will be allowed again

Voltage level at which discharging will be stopped

Image: Ablic data sheet

Protection ICs are available from manufacturers such as Ablic (former Seiko), Mitsumi, Ricoh, Texas Instruments (TI).

Overcurrent protection parameters are selected according to maximum cell ratings and a safe operational threshold for the battery pack. Customer specific peak current pulses or spikes can also be accommodated within a PCM design. This allows very short pulses of high current to be discharged above the safety threshold but blocks any constant current above that threshold level.

Short circuit current can be very high and is a safety risk to the cells and PCM electronics. Safety activates in micro seconds and does not allow this high current to flow within the cell or PCM electronics.

FIG. 5: SECONDARY ACTIVE PROTECTION FOR OVERVOLTAGE (OVERCHARGE)

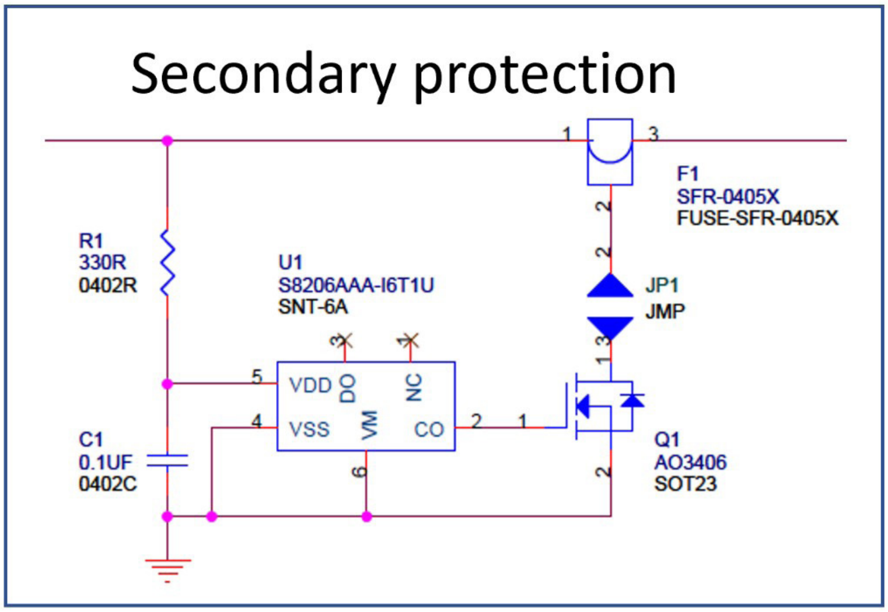


Image: Jauch Quartz

For certain customer applications or standard regulatory test certifications (UL, IEC), secondary overcharge protection is necessary. A second protection IC with a higher preset voltage threshold is designed in and connected to a fuse. If the primary protection IC fails and the charging continues (due to a faulty charger), the second IC with a higher voltage threshold activates the fuse and breaks the circuit.

There are passive components available for secondary overcurrent protection such as PTCs and fuses, but overvoltage can lead to explosion and fire once the voltage of the cell exceeds a certain threshold.

3. TEMPERATURE MONITORING

Temperature monitoring for charging is controlled by another component that is placed on or very close to the cell and allows the charger to terminate charging, if the recommended charging temperature is exceeded. This component is a Negative Temperature Coefficient Resistor – known as NTC.

An NTC resistor (or thermistor) is a thermally sensitive resistor whose resistance decreases with an increase in temperature. This change in resistance allows the charger to determine if the temperature is within a preset range during the charging process. If not – charging stops until the temperature falls back into the permissible range.

Small chip NTCs are placed onto the PCM when easy access to the cells is not possible or in case the cells are thin (polymer types) and can physically be damaged by the NTC component. The NTC measures the ambient temperature of the cell and the PCM.

Leaded NTC types are very convenient when using with cylindrical cells and large battery packs. They are able to be positioned against the metal can of individual cells without causing any mechanical issues and therefore can measure actual cell temperatures during charge and discharge. They can also be positioned to monitor ambient temperature of a battery.

FIG. 6: LEADED AND LEADLESS NTCS

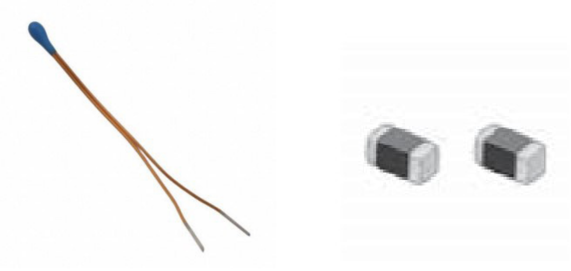


Image: Jauch Quartz

The PCM is present as backup protection in case the equipment charging or discharging the battery develops a fault. Jauch always recommends to set application usage parameters to a safe level which will activate prior to the battery’s protection thresholds and then have the PCM on the battery pack act as true secondary protection.

For a two cell PCM, the same safety functions are present as found in a single cell PCM. If either one of the two cells reach the upper or lower voltage thresholds, the appropriate MOSFETS will open and stop charge or discharge. If a voltage difference appears between the two cells which is greater than a preset value – the PCM safety will also activate to avoid charging a single cell with a higher than normal voltage.

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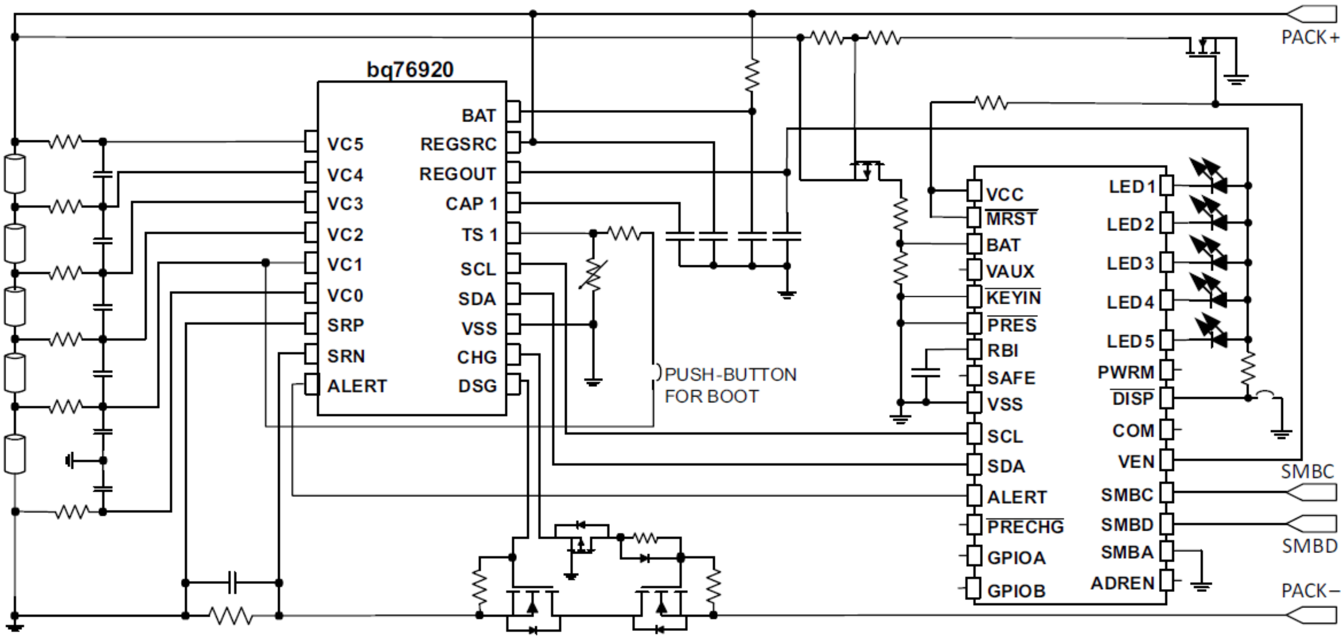
The principle of a two-cell safety circuit also applies to multi-cell protection electronics, where each cell voltage is monitored and overall safety of the pack is ensured.

The TI reference circuit below (simplified schematic version for a five-cell) will monitor the voltage for safety and, if programmed to do so, will regulate the cells with balancing to maximize on the available capacity of the pack.

FIG. 7: EXAMPLE OF A FIVE-CELL SAFETY-CIRCUIT



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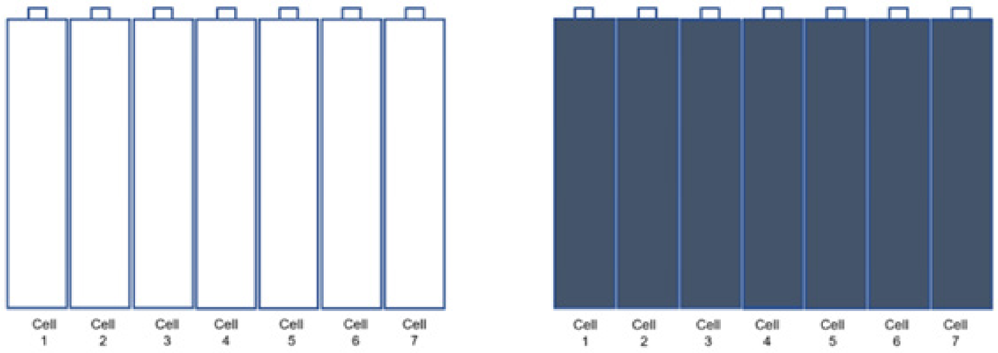
4. CELL BALANCING

As long as all cells in series have the same capacity, complete balancing is not necessary at the end of each and every charge cycle. This is the ideal situation, but in reality, variations in cell production, cell temperature and charging/ discharging rates cause cells to age differently, therefore reducing the capacity of each cell differently.

FIG. 8: IDEAL STATE OF A FULLY CHARGED/ DISCHARGED BATTERY PACK



Ideal **empty** cells/ battery pack

Ideal **full** cells/ battery pack

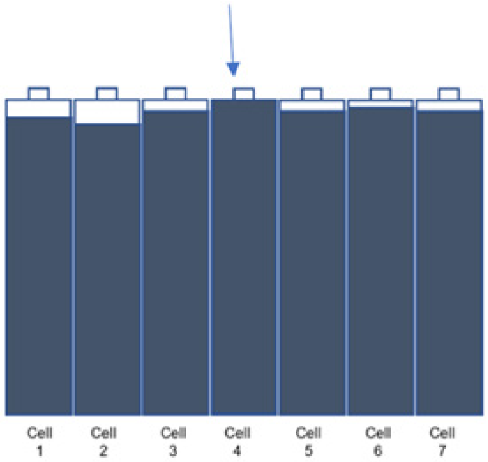
Image: Jauch Quartz

At the end of a charge, the amount of charge left in each cell is slightly different and as the battery is charged and discharged repeatedly (in the absence of balancing), this difference increases.

In Fig. 9, cell 4 has been charged fully, so overvoltage protection will activate to stop any further charging of the pack. However, the other cells of the pack have not been charged completely, therefore the battery pack has not been charged to its full potential capacity.

In Fig. 10, cell 4 is discharged fully, so undervoltage protection will activate to stop any further discharging of the battery pack. As the rest of the pack's cells have not been discharged fully, the battery pack has not been allowed to discharge its full potential capacity.

FIG. 9: BATTERY PACK WITHOUT BALANCING CHARGED "FULLY"



The cell is now full and overvoltage protection will activate to stop charging.

Image: Jauch Quartz

FIG. 10: BATTERY PACK WITHOUT BALANCING DISCHARGED "FULLY"

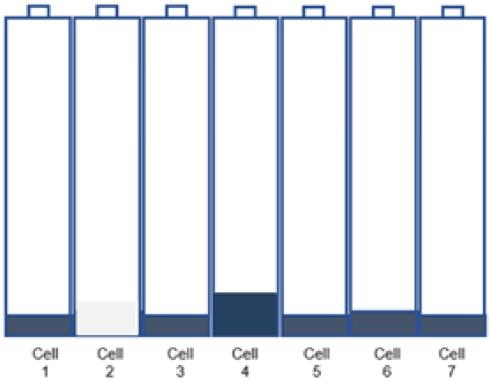


Image: Jauch Quartz

Cell Balancing is a technique of distributing maximum energy into all cells in a multi-cell, series configuration. This allows the battery pack to be charged to its maximum capacity and also helps to increase the cycle life of the battery pack.

Two or more cells in series can have cell balancing implemented. As soon as three or more cells are connected in series, cell balancing is highly recommended. There are two types of cell balancing.

Passive cell balancing – Passive balancing results in all battery cells having a similar state of charge (SoC) by simply dissipating excess charge in a bleed resistor. It may not, however, extend system run time. In Figure 9 for example, only cell 4 will be discharged and then the whole pack will be charged again. In this way, the other six cells can be charged for longer as cell 4 capacity is catching up.

Active Balancing while charging – Charge is redistributed from the stronger cells to the weaker cells, resulting in the cell stack reaching its full capacity.

Active Balancing while discharging – Charge is distributed from the stronger cells to the weaker cells resulting in a fully depleted cell stack, ready to begin charging. This then allows an actual full charge for all cells. In Figure 10 for example, cell 4 will receive charge from other cells in the pack.

The choice of selecting passive or active balancing depends upon the application. Multiple factors as for example charging time, thermal consideration, importance of longer cycle life or longer charge cycle play an important role. It is also possible to implement both active and passive balancing into the same battery pack, depending upon the solution used.

5. BATTERY MANAGEMENT SYSTEM (BMS)

A Battery Management System (BMS) is an intelligent PCM. It is a microprocessor-based circuit, programmed with a whole host of information. This includes battery safety thresholds, capacity and cell chemistry algorithms. It has the ability to monitor and control all key aspects of the battery for safety, battery health and state of charge. This information can be read out by a host system via communication lines (I2C/SMBus or CanBUS).

The intelligence a BMS brings to a battery pack can protect the cells from damage and increase its performance and lifetime. The protection can be increased to several layers of redundancy, with black box recording of fault sequence. It can be implemented when a host system needs to know the State of Charge (SoC), Time to Empty (TTE), voltage, current, temperature, cycle count (and other available parameters) of the battery pack.

It can also be necessary when protection thresholds of a PCM need to be fully customized and secondary protection with permanent failure options are required.

Jauch predominantly designs with Texas Instruments fuel gauges and protector ICs.
Here are some of the range Jauch currently incorporates into its BMS designs:

- BQ27542-G1 for single cells (see Fig. 11)
- BQ34z100-G1 for a single cell up to 16 cells in series
- BQ40z50-R1 for a single cell up to 4 cells in series (see Fig. 12)
- BQ40z80 for a single cell up to 7 cells in series
- BQ76920 / BQ76930 / BQ76940 + BQ78350-R1 for 5 to 15 cells in series

Jauch also has legacy fuel gauges which are not recommended for new designs, but may still be necessary for existing customer products. Sometimes older fuel gauges can be upgraded to the latest versions, with complete backward compatibility.

In order to have accurate fuel gauging for a particular design, the following parameters are required to perform an optimization cycle which can then be copied into all production battery packs:

- Maximum charge voltage
- Maximum charge current
- Charger termination current
- Maximum discharge current
- Customer application cut-off voltage
- Temperature range for storage and operation battery.

Other parameters of the host system are also required to ensure full compatibility. This is part of the BMS development stage to create a fully compatible, intelligent battery pack.

FIG. 11: TYPICAL CIRCUIT FOR BQ27542-G1, SINGLE CELL, IMPEDANCE TRACK FUEL GAUGE

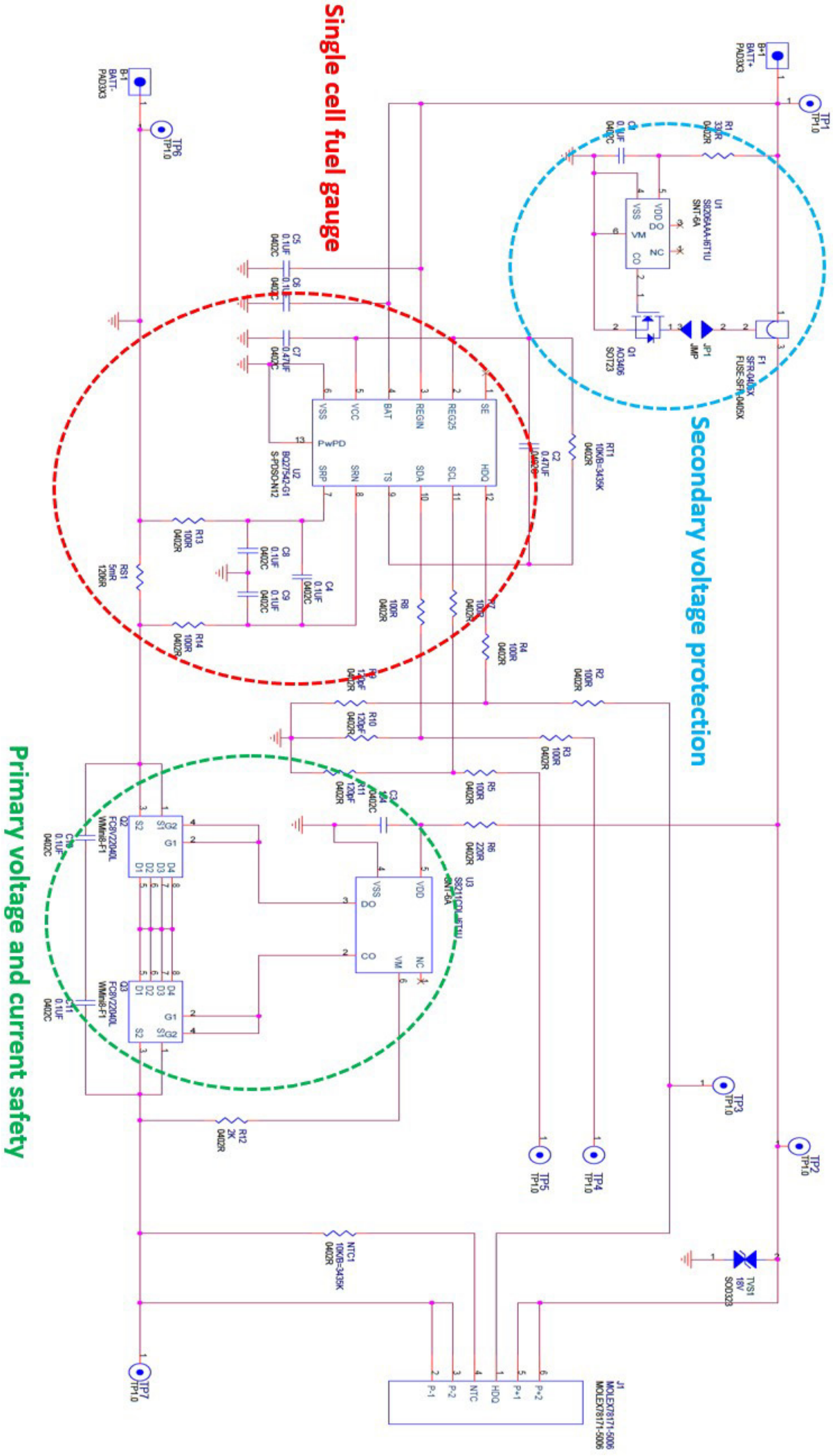


Image: Jauch Quartz

FIG. 12: TYPICAL CIRCUIT FOR A BQ40Z50-R1, MULTI CELL PROTECTOR/ FUEL GAUGE

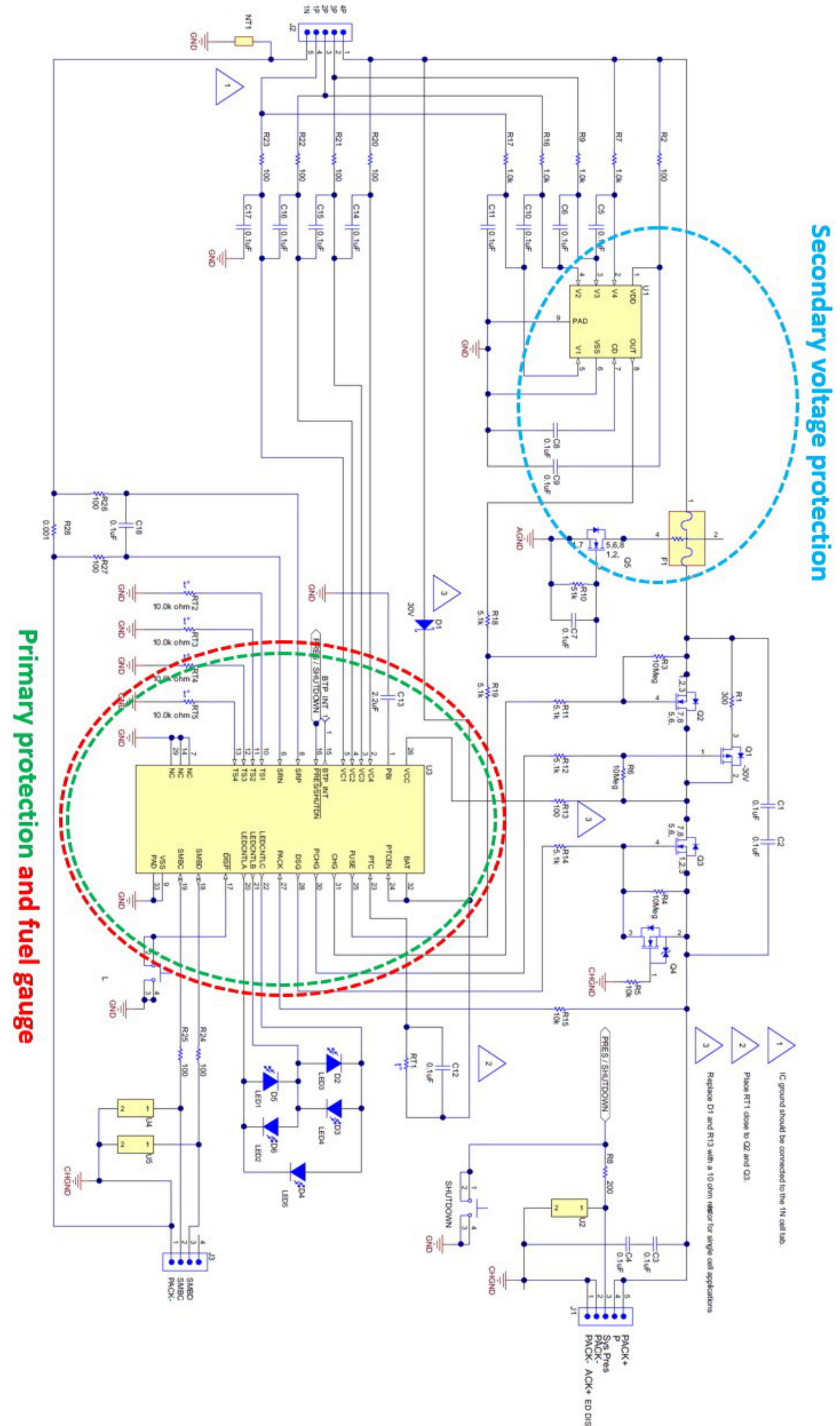


Image: Jauch Quartz

FIG. 13: AN EXAMPLE BMS FOR A 3-CELL LITHIUM ION BATTERY USING A TEXAS INSTRUMENTS BQ40Z50-R1

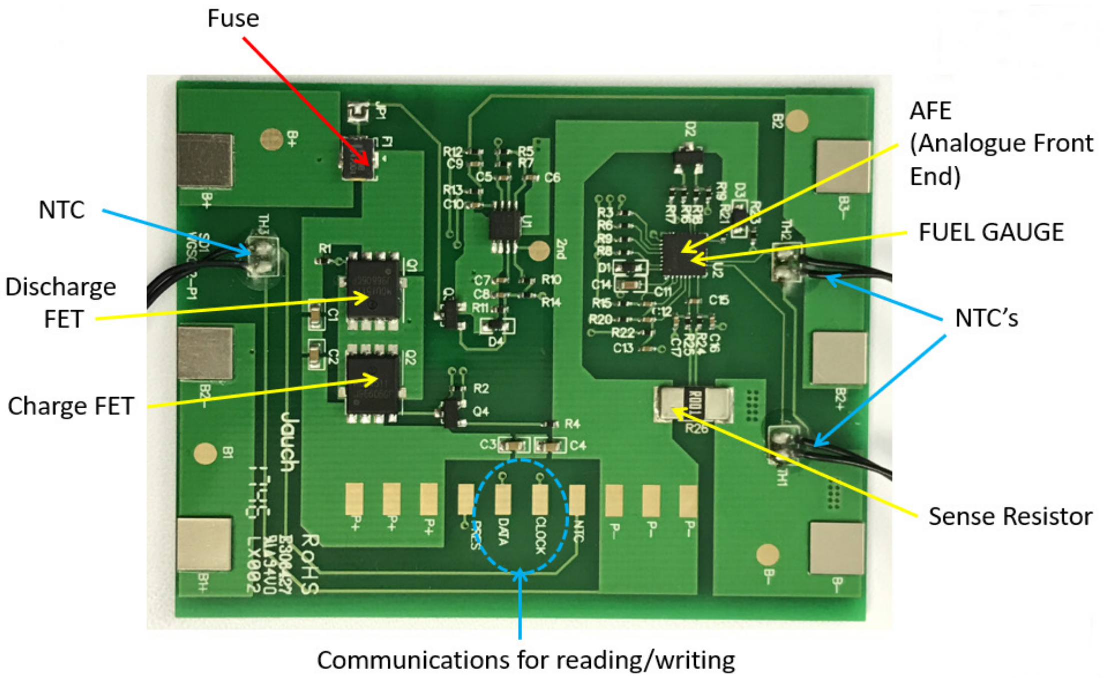


Image: Jauch Quartz

6. SMBUS COMMUNICATION

The System Management Bus (SMBus) is the most common form of communication for advanced fuel gauges. They carry information from the Smart Battery System (SBS) to a charger and/ or microcontroller (predominantly).

Smart Battery System (SBS) is a specification for managing a smart battery, usually for a portable computer. It allows operating systems to perform power management operations via a smart battery charger based on remaining estimated run times by determining accurate state of charge readings. Through this communication, the system also controls the battery charge rate. Communication is carried over an SMBus two-wire communication bus. The specification originated with Duracell and Intel companies in 1994, but was later adopted by several battery and semiconductor manufacturers.

The Smart Battery System defines the SMBus connection, the data that can be sent over the connection (Smart Battery Data or SBD), the Smart Battery Charger, and a micro-processor interface for control. In principle, any battery operated product can use SBS.

The Battery Management System (BMS) monitors the battery and reports information to the SMBus. This information can include battery type, model number, manufacturer, characteristics, State of Charge (SoC), charge/ discharge rate, remaining capacity, low threshold alarms etc.

This allows the application controller to make operational decisions on subsequent actions. A smart charger on the same SMBus connection can also intelligently charge the battery at specified.

Fig. 14 shows some simple examples of generic SMBus transactions. These transactions are read/ write words with and without packet error checking (PEC). Although a user's scope traces may not look exactly like these examples, it is easier to look at these theoretical examples and understand their content rather than considering actual scope traces. Simplified information is given in order to present only the basics of SMBus information. First, entire packets for read and write are examined. Only word communications are considered because they are common and relevant for most troubleshooting.

FIG. 14: SMBUS TRANSACTION EXAMPLES

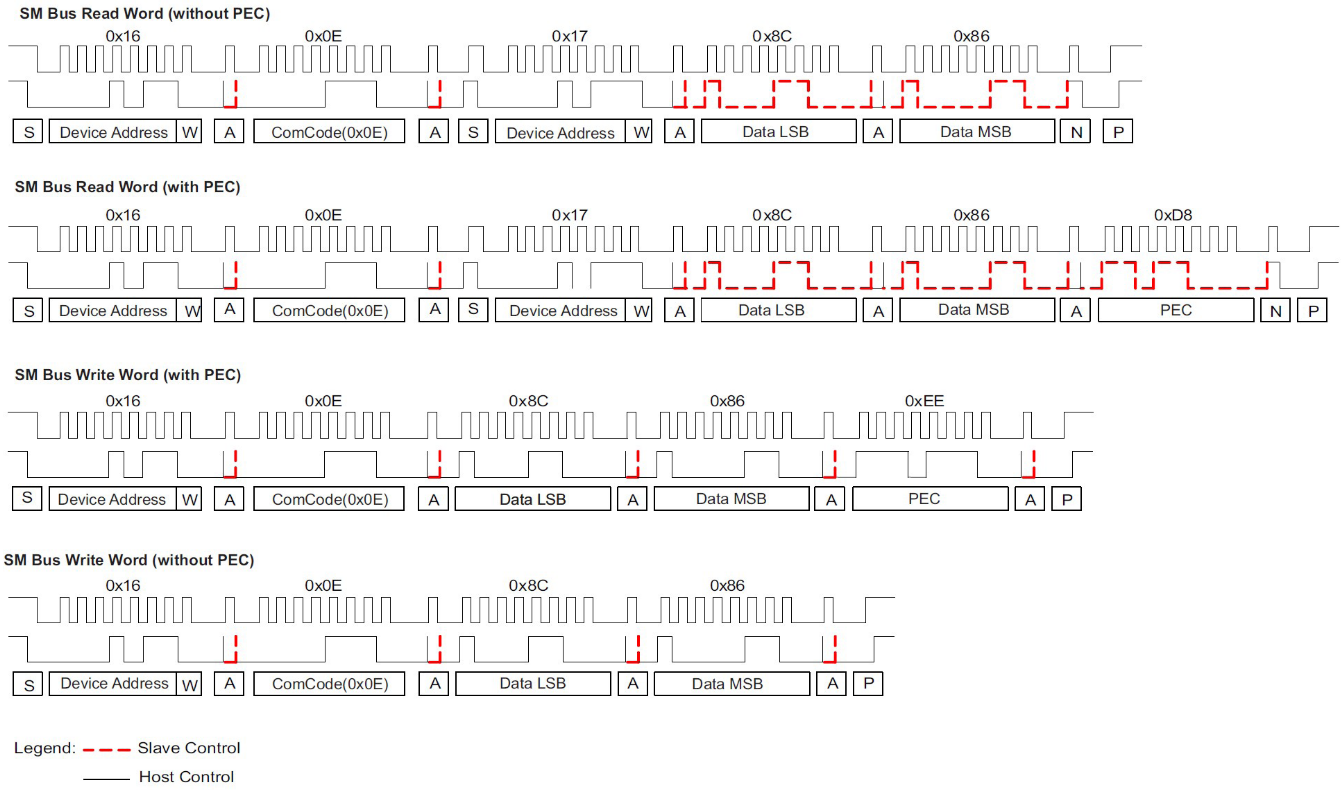


Image:Texas Instruments Incorporated

The following components make up the packet along with some of the relevant issues to consider.

- **Start bit**: Each packet of data must start with a start bit denoted with an S. The clock must wait at least 4 µs after the data line goes low before it goes low.

- **Device address 1**: The device address is sent by the host telling all slaves on the bus which slave acknowledges this particular communication packet.

- SMBus can have multiple slaves, so all other slaves that do not have this address ignore the packet. Smart batteries have device address 0x16. Thus, this packet is acknowledged by any fuel gauge.

- Only one device on the bus can have the same device address.

- The last bit of the device address is the read/ write bit. A 0 for this bit denotes a write, and a 1 denotes a read. The read/ write bit in the first device address for a read is a 0 because a command code is being written to the slave first. A write packet has only one device address because the direction (read/ write) does not change.

- **Acknowledge**: Denoted by an A. The slave must acknowledge that the device address was received.

- **Command Code**: This is the command or slave data address that is written to in a write packet or read from in a read packet.

- **Repeated start (read)**: Denoted by an S. A second start bit embedded within the packet is used to shift the bus to a read.

- **Device address 2 (read)**: The second device address in a read packet is a legacy component. Because a read operation is two packets combined with a repeated start, it is not required, because the slave responsible for this packet has already been established. The SMBus specification still requires this as part of the specification, so it is mandatory for communicating to all devices including TI fuel gauges. However, important information is in this byte such as the read/ write bit, which is set to a 1. This setting tells the slave that this packet is a read, so it is prepared to clock out data.

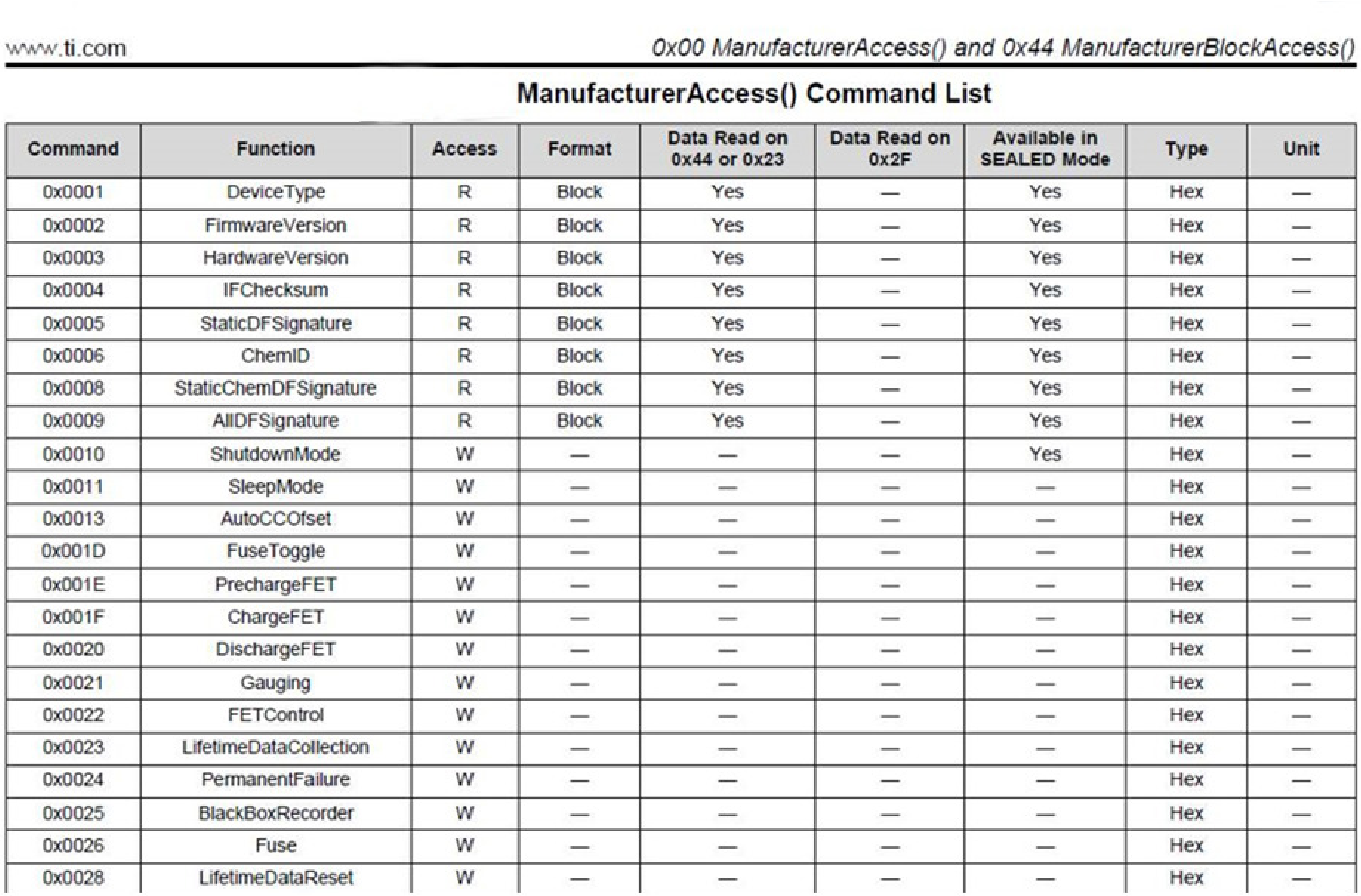
- **Data LSB**: The first byte of data is the least-significant byte of the data word. The reason why SMBus sends the LSB first is, because SMBus sends data in little-endian format. This means that data is sent in increasing numeric significance. Most modern computers store data in memory in this order.

- **Data MSB**: This is the second byte of data for the word sent and is the most-significant byte. Again, it is sent this way to conform to the little-endian format.

- **PEC**: The PEC byte is a checksum of the entire packet used to protect against data corruption.

- **Stop bit**: This is the end of the packet. It tells the slave device that the bus is done, so the slave can get ready for more communications. It is an important part of the packet. Users can experience trouble by leaving this stop bit off if they get all the data. Although TI fuel gauges will time out and reset eventually without this, it is important to keep all devices on the bus in a known state at the end of each packet sent. Even if the host has to stop the communication in the middle of the packet for some reason, the host always sends the stop bit to reset everything on the bus.

FIG. 15: PARTIAL COMMAND SET FOR TEXAS INSTRUMENT BQ40Z50-R1



www.ti.com *0x00 ManufacturerAccess() and 0x44 ManufacturerBlockAccess()*

ManufacturerAccess() Command List

Command	Function	Access	Format	Data Read on 0x44 or 0x23	Data Read on 0x2F	Available in SEALED Mode	Type	Unit
0x0001	DeviceType	R	Block	Yes	—	Yes	Hex	—
0x0002	FirmwareVersion	R	Block	Yes	—	Yes	Hex	—
0x0003	HardwareVersion	R	Block	Yes	—	Yes	Hex	—
0x0004	IFChecksum	R	Block	Yes	—	Yes	Hex	—
0x0005	StaticDFSignature	R	Block	Yes	—	Yes	Hex	—
0x0006	ChemID	R	Block	Yes	—	Yes	Hex	—
0x0008	StaticChemDFSignature	R	Block	Yes	—	Yes	Hex	—
0x0009	AllDFSignature	R	Block	Yes	—	Yes	Hex	—
0x0010	ShutdownMode	W	—	—	—	Yes	Hex	—
0x0011	SleepMode	W	—	—	—	—	Hex	—
0x0013	AutoCCOfset	W	—	—	—	—	Hex	—
0x001D	FuseToggle	W	—	—	—	—	Hex	—
0x001E	PrechargeFET	W	—	—	—	—	Hex	—
0x001F	ChargeFET	W	—	—	—	—	Hex	—
0x0020	DischargeFET	W	—	—	—	—	Hex	—
0x0021	Gauging	W	—	—	—	—	Hex	—
0x0022	FETControl	W	—	—	—	—	Hex	—
0x0023	LifetimeDataCollection	W	—	—	—	—	Hex	—
0x0024	PermanentFailure	W	—	—	—	—	Hex	—
0x0025	BlackBoxRecorder	W	—	—	—	—	Hex	—
0x0026	Fuse	W	—	—	—	—	Hex	—
0x0028	LifetimeDataReset	W	—	—	—	—	Hex	—

Image:Texas Instruments Incorporated

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Zahid Shafi has spent his entire working life in the electronics industry and worked for companies in the US, Germany, Singapore and the UK as an engineer and technical sales manager. During this time, he has acquired in-depth expertise in the field of electronics and manufacturing.

Since 2005, Shafi has been working in the lithium battery business, including design of battery electronics. Since joining Jauch Quartz in 2011 as a project manager, Shafi helps to find the best battery design solutions for Jauch customers and their applications.

List of Figures:

Sources:

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