Lunch & Learn

Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, and Balancing

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Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Today, let's look inside the electronics of a typical Li-Ion battery.

We will learn what keeps a battery safe, what determines the 'State-of-Charge' of the battery, and explain balancing.

- Safety
- Fuel Gauging
- Balancing

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Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Definitions …

- Cell vs. Battery
  - Cell is a single element
  - Battery is a collection of cells, often with a connector, etc.

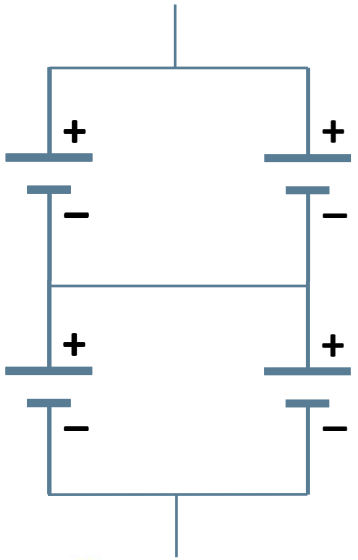
- Battery Energy = Battery Capacity = How long Battery will run
  - Amp-Hours or Watt-Hours (has a time component)
- Circuitry
  - Electronics contained in a Battery pack to provide Safety and other functions

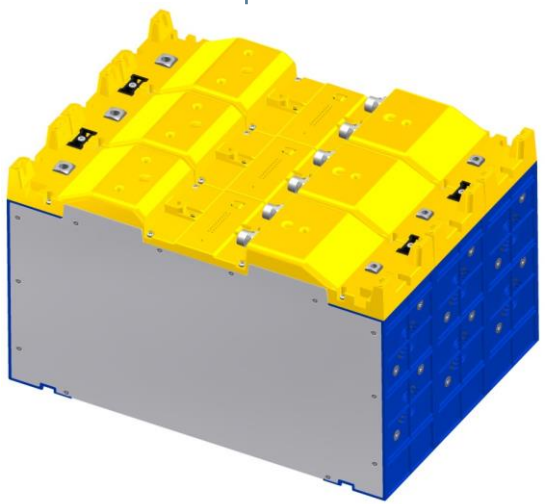
Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Definitions … continued

- Series & Parallel
  - Cells are put in Series to create higher voltages
  - Cells are put in Parallel to create more capacity
    - (Cells are connected in parallel at the cell level)
  - Batteries can be put in Series and/or Parallel

    (But with additional complexity)





- Self-Discharge
  - Apparent Cell “discharge” due to time & temperature
  - Li-Ion is 1% per month typically

Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

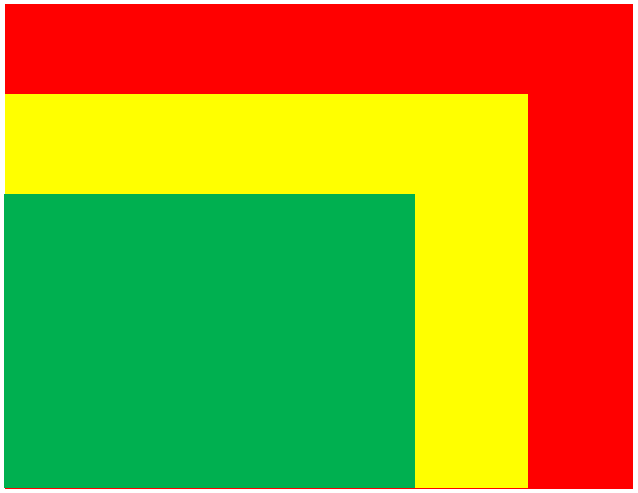
What Type of Battery?

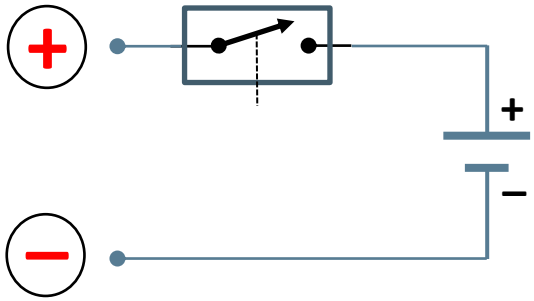
- Power Consumption of the Device and desired operating time determines the amount of Energy or Capacity that is needed.
- Needs change as Power Consumption increases.
- Here are some examples:
  - TV remote control with a primary Alkaline or Lithium Cell lasts a year or more
  - Hearing-aid primary Cell runs for a week
  - Bluetooth ear-bud prefers a small rechargeable Cell to run for hours
  - Cell Phones, Laptops require larger rechargeable Batteries (<100 Wh)
  - Mobile Robotics (fork-lifts, etc.) require larger rechargeable Battery Systems (>100 Wh)

Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Safety

- Li-Ion batteries have defined operational limits
  - Exceeding voltage or temperature limits can cause failure
- Li-Ion Battery require Safety electronic circuitry to insure the operational limits are not exceeded
- Circuitry to interrupt Charge or Discharge Current
  - Requires an electronic ‘switch’
    - Low currents: MOSFETs (transistor switches)
    - High currents: Relays and Contactors (mechanical)

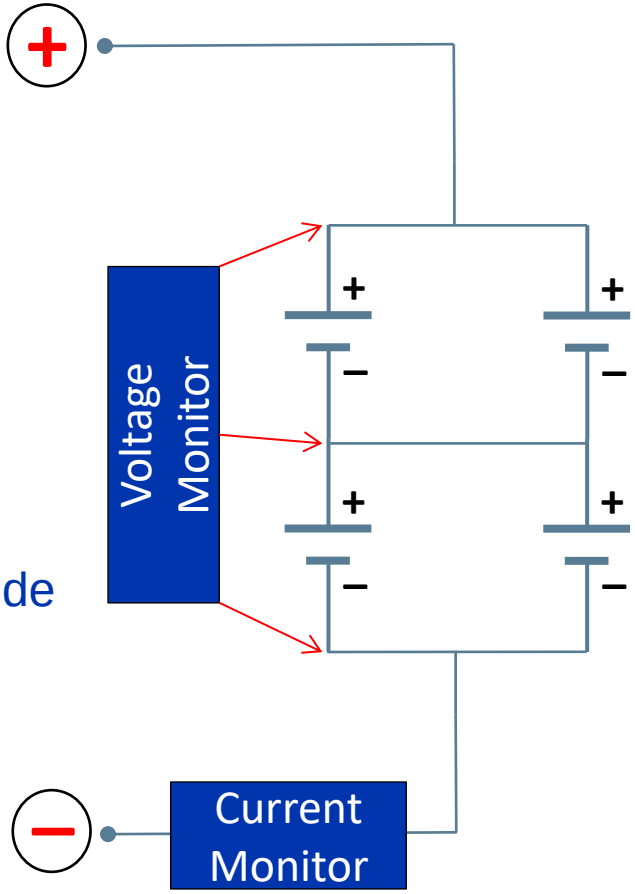




Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Safety

- Voltage Monitoring
  - Cell Voltage – Must detect each series Cell voltage
    - Over-voltage limit during charge
    - Under-voltage limit during discharge
- Current Monitoring
  - Battery Current – Detect charge & discharge magnitude
    - Multiple limits and stages:
      - Slow & Low
      - Fast & High (i.e. Short-Circuit)

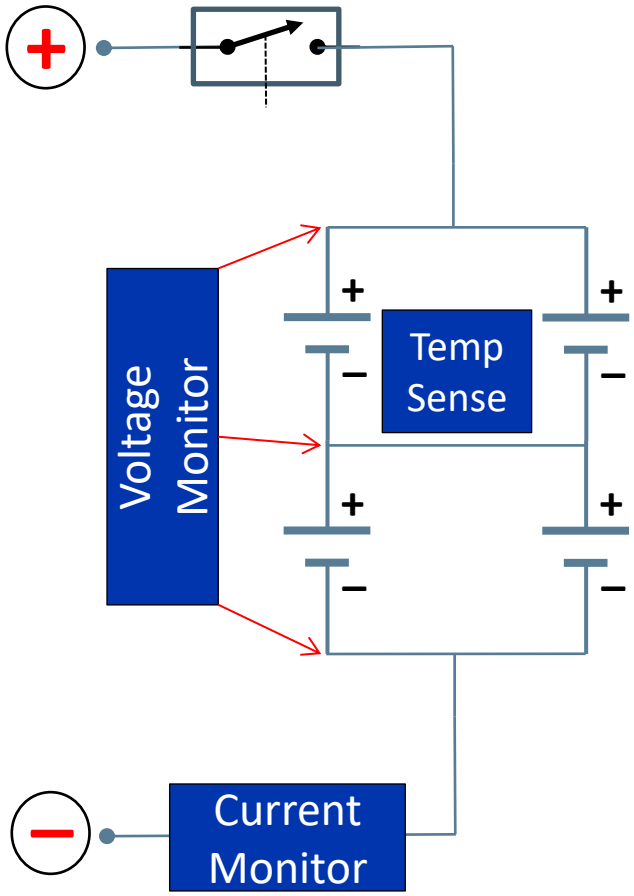


Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Safety

- Temperature Monitoring
  - Temps within limits high and low
  - Includes the Cells
  - Can also include key components (i.e. MOSFET switch)

- When any Safety condition occurs, the charge or discharge current is interrupted by the electronic switch
  - Recovery methods depend on the condition
    - Time-based
    - Removal of fault condition



Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

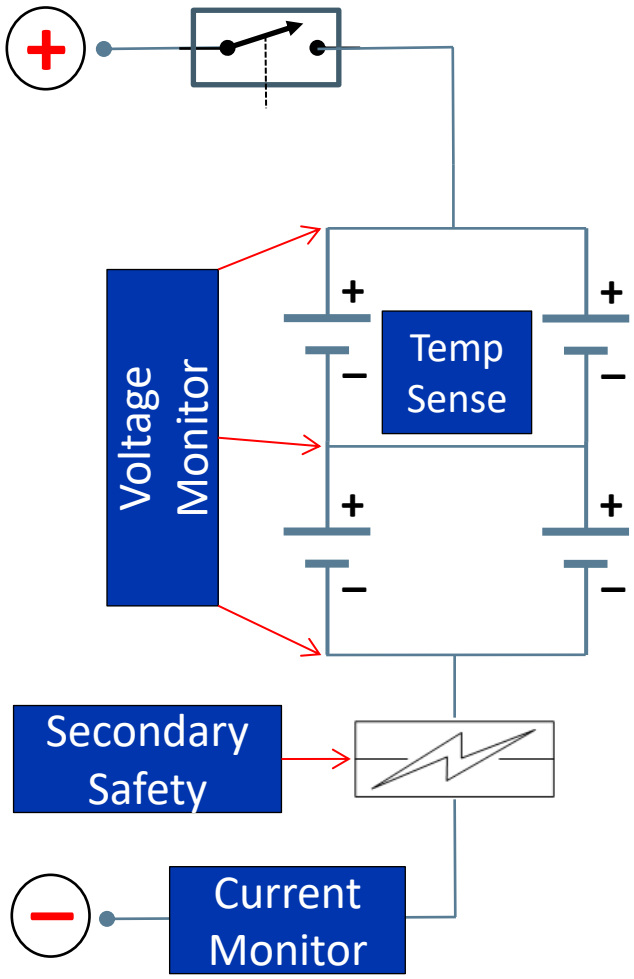
Secondary Safety

- Additional Monitoring
  - Failure of Primary Safety
  - Incongruent Readings
  - Severe Imbalance

- When a Secondary Safety condition occurs, the charge or discharge current is interrupted permanently
  - No recovery – One-time Event

Safety Circuitry protects Battery …

- … from Abuse
- … from Environmental extremes



Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

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Secondary Safety

- Additional Monitoring
  - Failure of Primary Safety
  - Incongruent Readings
  - …
- Whe… char… perm…
  - …

VARTA 4-Level Safety:

1st Level Protection - OV / UV / OC / SC / OT (non-permanent)

2nd Level Protection - OV / UV / OC / SC / OT (requires reset)

3rd Level Protection - OC / SC (fast acting, high magnitude)

4th Level Protection – Permanent

Safety Circuitry protects Battery …

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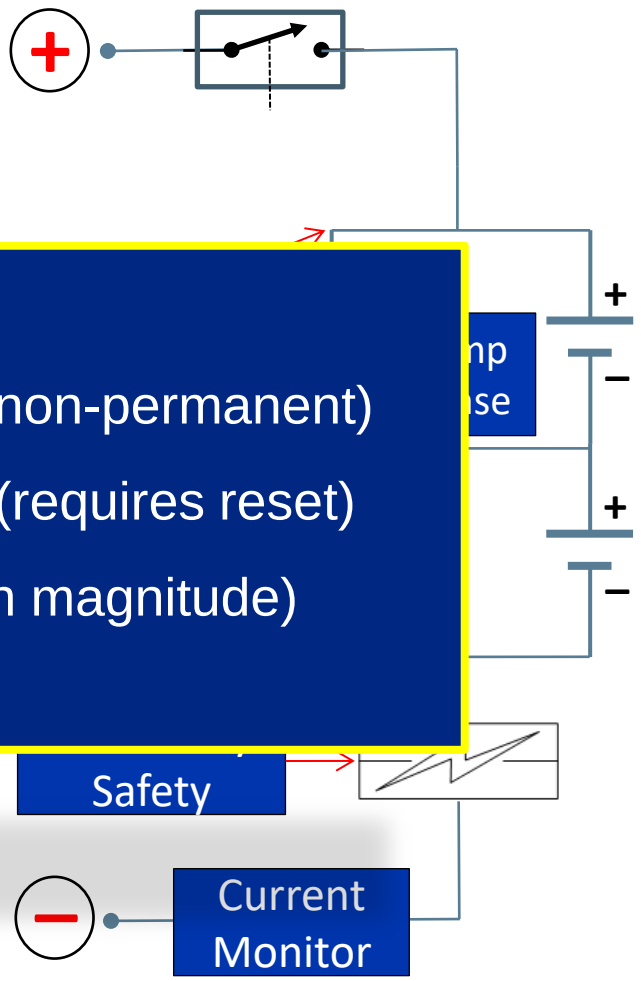
- … from Environmental extremes



Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Device Differences: Power vs. Energy

- Power = High Current, Short Duration
- Energy = Low/Medium Current, Long Duration

All Devices require Safety electronics – but the architecture will differ.

Fuel-Gauging & Balancing are used when required – not all Devices will need them.



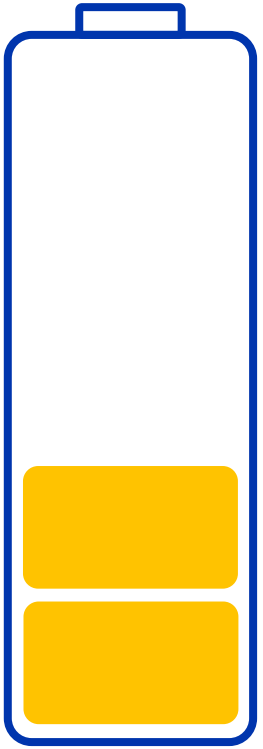
High Power **High Energy**

Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Fuel-Gauging

- State-of-Charge: Remaining Capacity of Battery
  - Relative SOC: Percentage of last Full Charge Capacity
  - Absolute SOC: Percentage of original Design Capacity
  - Calculated Value based on Measurements
- Not required in all Devices and Applications
- Can be done “in” the Battery or “in” the Device (‘system side’)

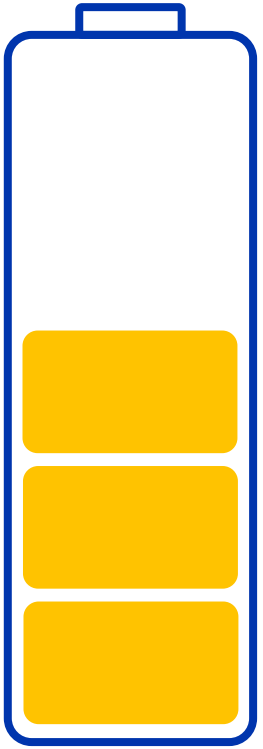
- Other functions for “State” of the Battery:
  - State-of-Health (age related analysis)
  - State-of-Function (ability to provide full operation)
  - State-of-Power (ability to accept or provide high currents)

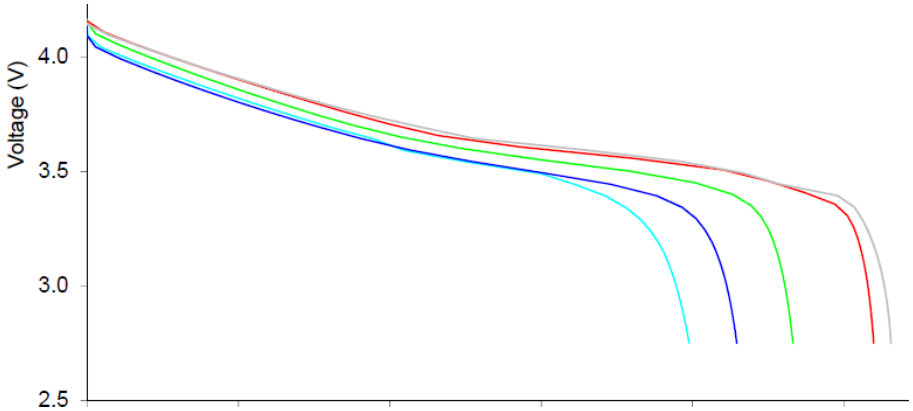


Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Fuel-Gauging: Methods

- Voltage-based:
  - Measure Voltage (during use & at rest)
  - Simple & Easy – but not very accurate – limited range
  - Issues with Age
  - Advanced methods can improve via compensation by:
    - Temperature
    - Calendar Life (time)
    - Impedance (if measureable)

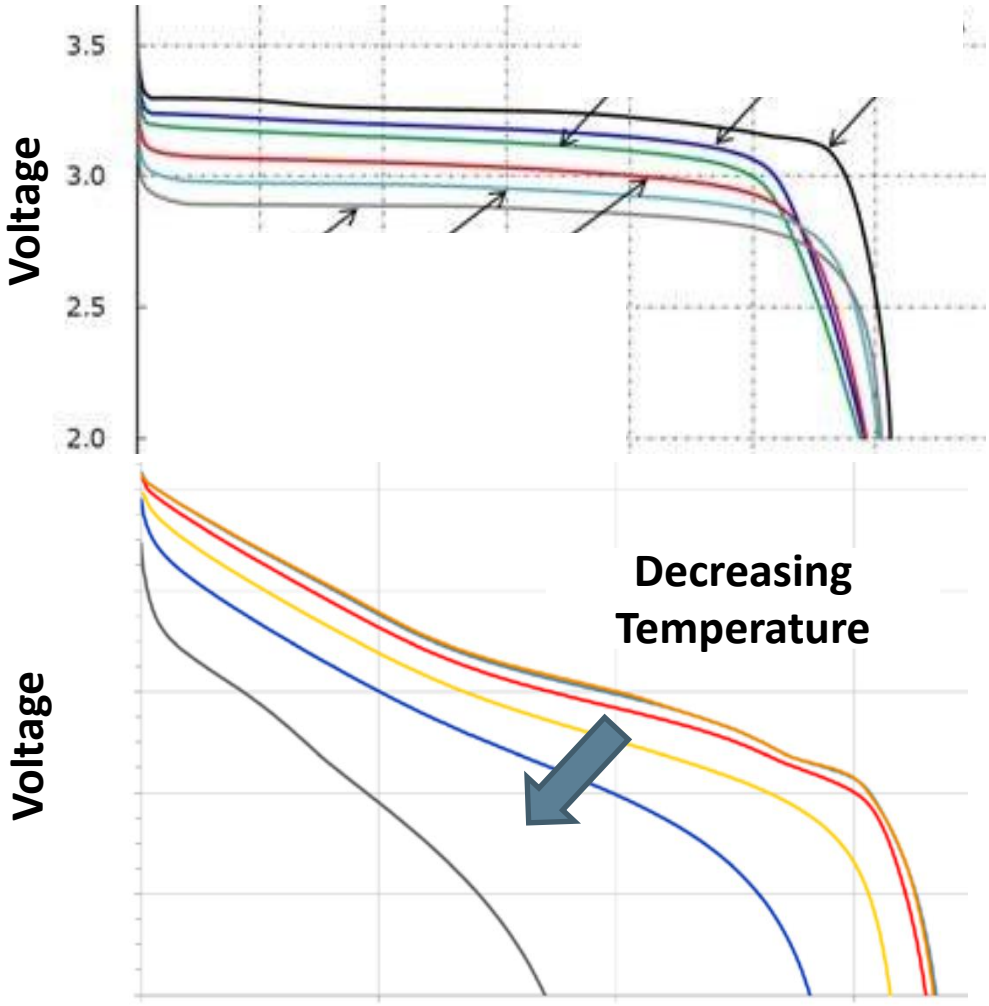




Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Fuel-Gauging: Methods

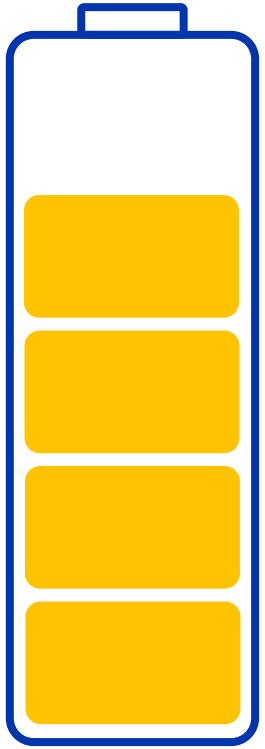
- Voltage-based:
  - Measure Voltage (use & at rest)
  - Simple & Easy – but not accurate
  - Issues with Age
  - Advanced methods compensate by:
    - Temperature
    - Calendar Life (time)
    - Impedance (if measureable)
- Does NOT work well with:
  - “Flat” voltage chemistries
  - High discharge rate applications
  - Temperature influenced chemistries



Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Fuel-Gauging: Methods

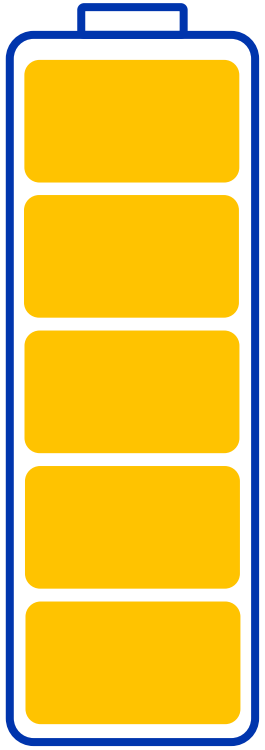
- "Coulomb" Counting:
  - Measure Current in & out of battery (and track time)
    - Current x Time = Capacity (Amp-hours)
    - Requires high accuracy for measurements & time-base
    - Still requires Voltage & Temperature measurements



- Very accurate – can provide <5% resolution
  - Can work with all chemistry variants
  - Current measurement must be scaled for device's range

Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Fuel-Gauging: Methods

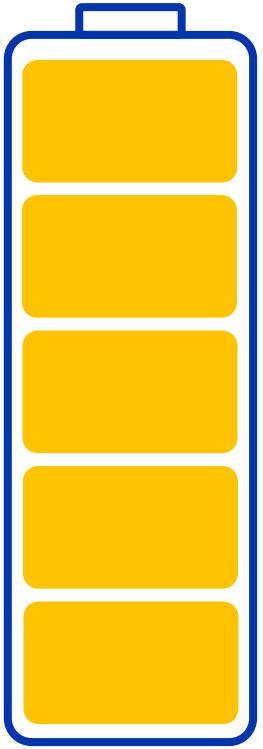


- "All of the Above"
  - Coulomb Counting with advanced modeling
  - Includes accurate Voltage & Temperature measurements
  - Requires advanced models for particular chemistry
    - Model of how the battery performs (cell data)
    - Needs usage model of device as well (typical & maxs)
- Very accurate – can provide ~1% resolution
  - Can work with all chemistry variants (if models available)
  - Adds features such as State of Health, Function, Power
  - Can provide predictive features: Run-Time-to-Empty, etc.

Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Fuel-Gauging: Methods

- "All of the Above"
  - **VARTA Fuel-Gauging:**
  - Multiple Options: Simple to Complex
  - Fit to Customer and Application Device's Needs
- Very accurate – can provide ~1% resolution
  - Can work with all chemistry variants (if models available)
  - Adds features such as State of Health, Function, Power
  - Can provide predictive features: Run-Time-to-Empty, etc.

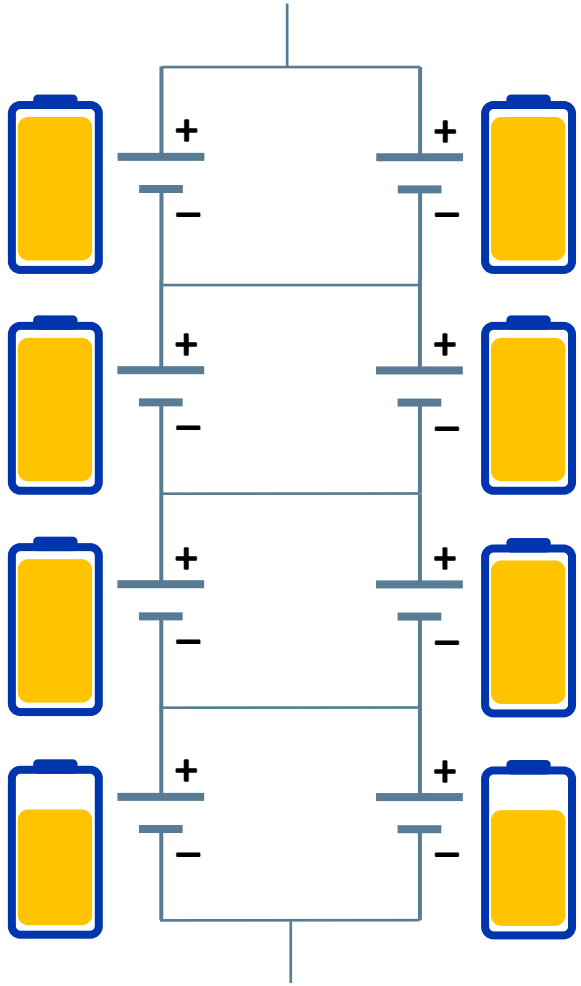


Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Balancing:

- Why is Balancing Needed?
  - Li-Ion Battery is ruled by the “weakest” Series cell
  - Typically only needed Batteries with 4+ cells in Series

- What is Balancing?
  - Restores capacity difference between Series cells
    - Parallel cells are connected together so no Imbalance



Diagrams exaggerated for explanation purposes only.

Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

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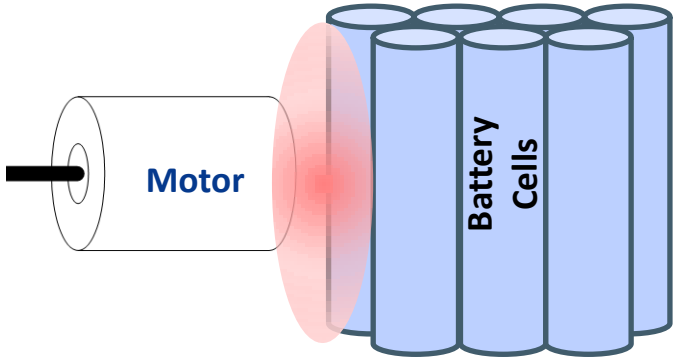
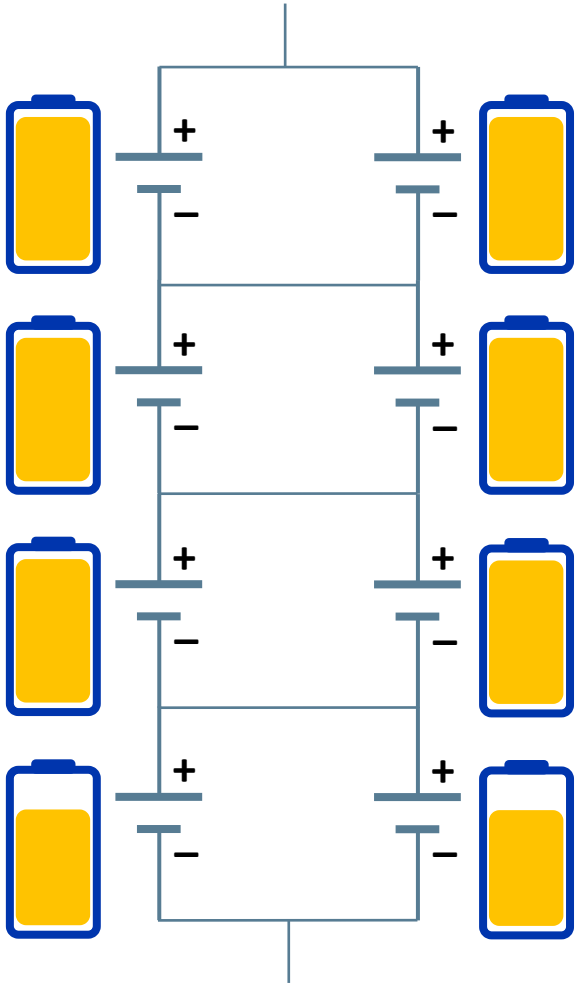
Balancing:

- Causes of Imbalance?
  - Temperature variations across Battery

    Example: Motor near one end of Battery – creates heat that only end Cells experience.



  - Differences in Self-Discharge rate of Cells
    - Accelerated by higher temperatures



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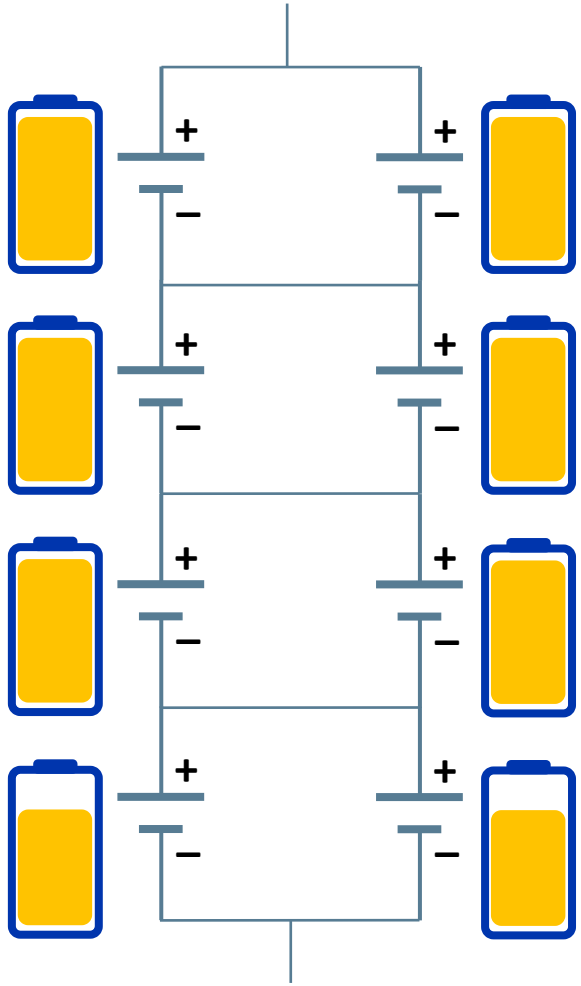
Balancing:

- Detecting Imbalance
  - Detect by Voltage differences between Series Cells
- Correcting Imbalance
  - Passive Balancing (“Bleed or Bypass” Balancing)
    - Let the lower capacity cells “catch up” during Charging: (only done during charge)
      - “Bleed” off capacity from the higher Cells
      - Resistively “burn-off” or “bypass” charge current from Cells that have higher capacity
  - Active Balancing
    - Transfer capacity from higher Cells to lower
    - More complicated but allows transfer any time



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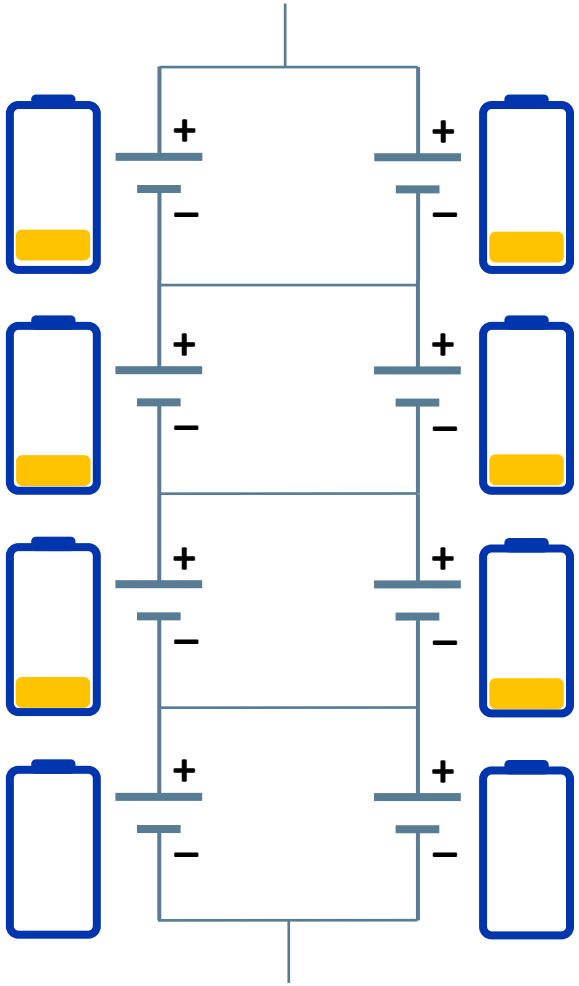
Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Balancing:

How it Works: Passive Balancing

Animation

Just after start of Charge…



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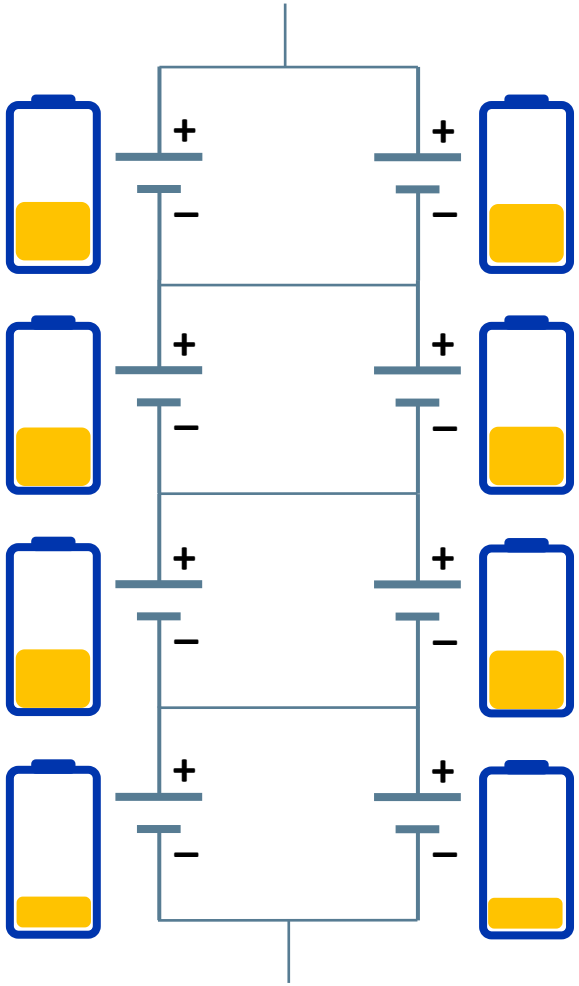
Balancing:

Passive Balancing

Animation



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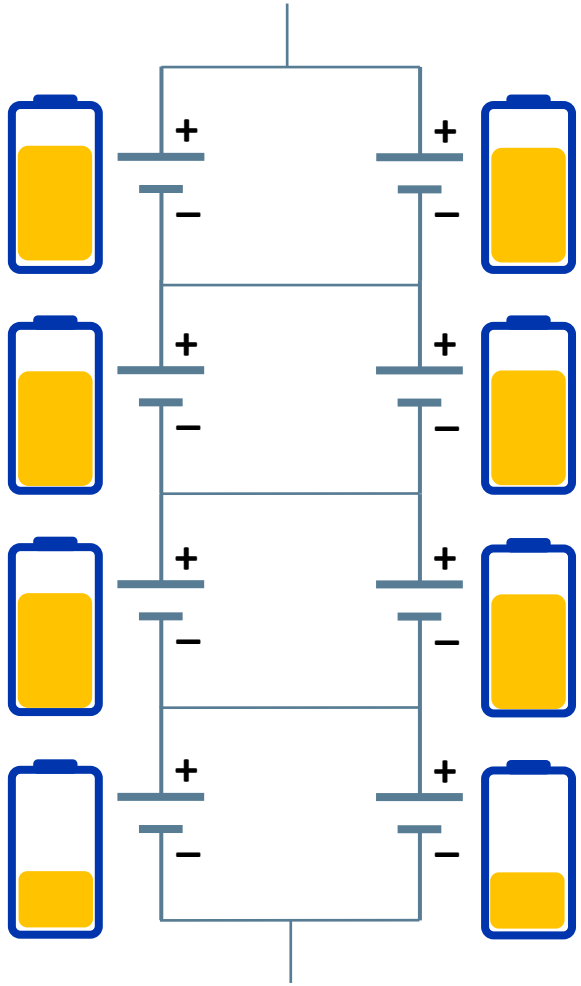
Balancing:

Passive Balancing

Animation

Higher capacity Cells have ‘bypass balance’ resistors slightly slowing their charge rate.



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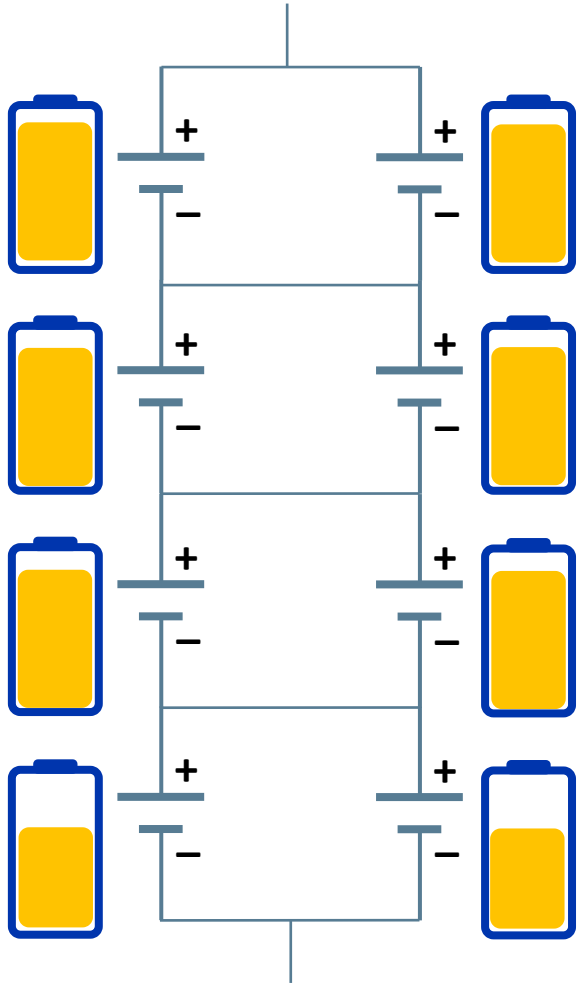
Balancing:

Passive Balancing

Animation

Lower capacity Cells “catching up”



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Balancing:

Passive Balancing

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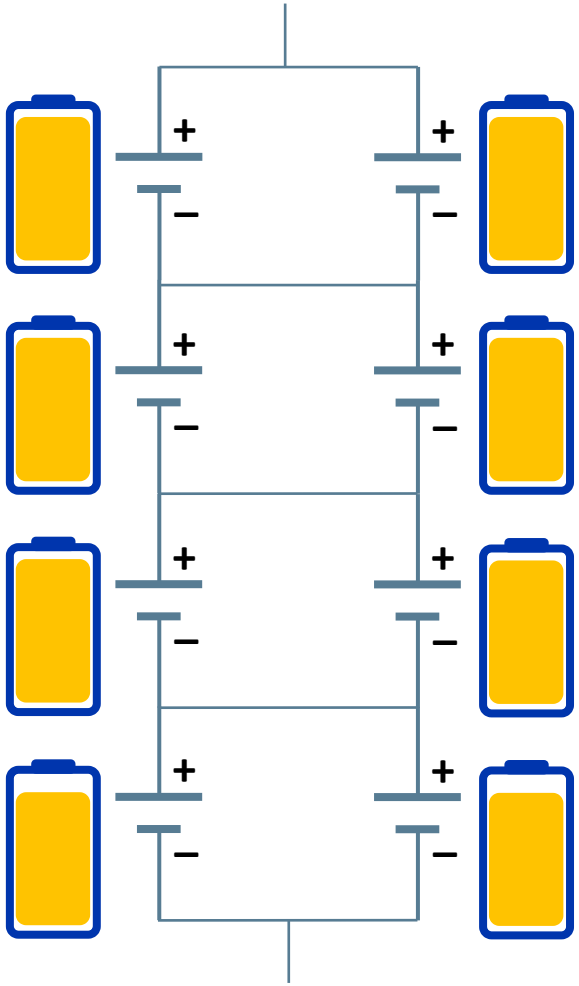

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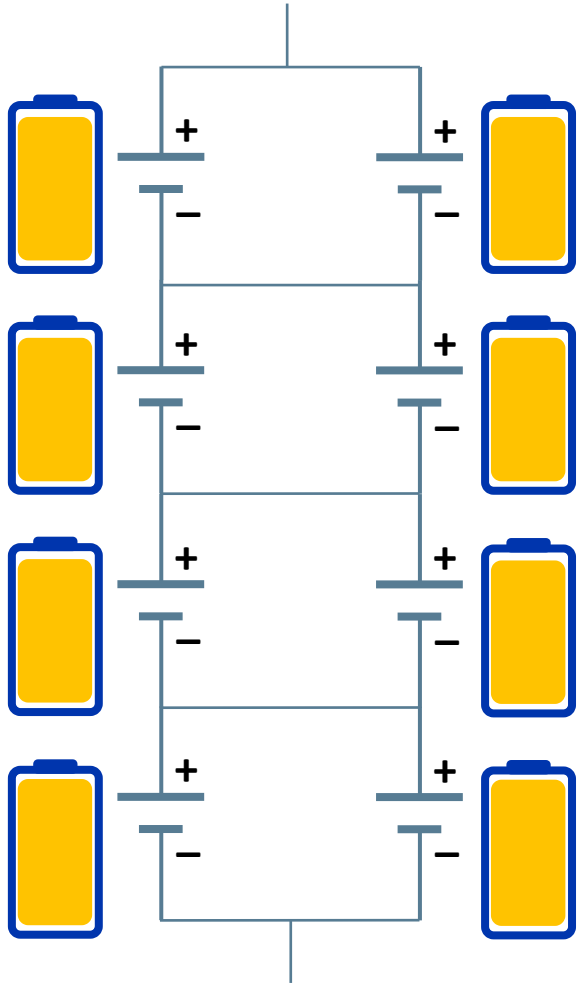
Balancing:

Passive Balancing

Animation

Charge Complete for all Cells



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Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

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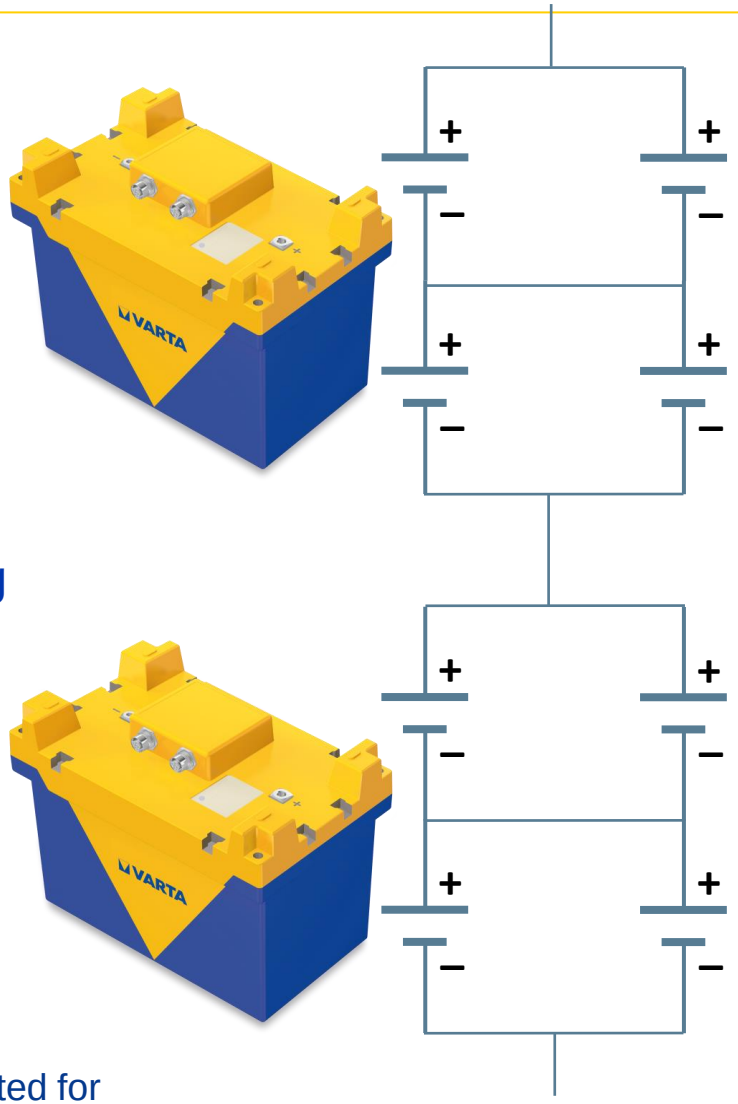
Balancing:

- Balancing stand-alone Batteries
  - Same issue for multiple Batteries in Series
- Each Battery balances Series Cells internally
  - Master controller balances Series Batteries
  - Same techniques: Passive (Bleed) Balancing



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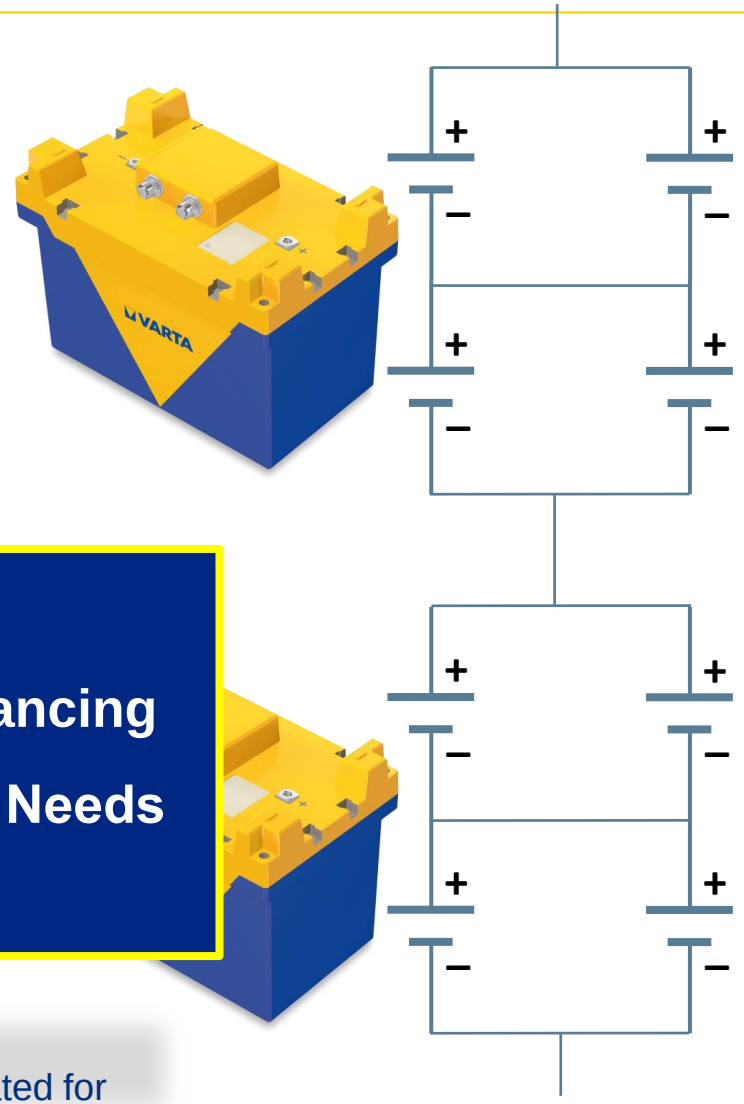

VARTA offers Passive & Active Balancing

Depending on Device Application's Needs

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Inside Li-Ion Battery Electronics: Safety, Fuel-Gauging, & Balancing

Inside the electronics of a typical Li-Ion battery.

We will learn what keeps a battery safe, what determines the ‘State-of-Charge’ of the battery, and explain balancing.

- Safety
- Fuel Gauging
- Balancing

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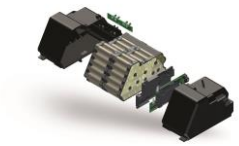
VARTA Worldwide

VARTA AG

MICROBATTERIES & SOLUTIONS

Healthcare	Entertainment	Solutions
		

Largest Manufacturer of Hearing Aid Cells (1B/yr)

www.VARTA-Microbattery.com

HOUSEHOLD BATTERIES

Consumer Batteries	Energy Storage
	

Standard & Custom Battery Packs and Energy Storage

www.VARTA-Storage.com

Consumer Coin & Cylindrical Cells; Home Energy Storage

www.VARTA-Consumer.com

VARTA Products

VARTA's Family Cells & Batteries:

- Voltages 1.5V to 48V
- Capacities 10mAh to >1500Ah
- Multiple Chemistry Options
- Coin & Cylindrical Sizes
- Pouch & Prismatic Sizes
- Embedded Battery Packs
- Consumer Removable Packs
- Industrial, Mobile Robotics Batteries
- Custom Designed Batteries
- Application Specific Standard Batteries

Cells

Easy Block/Blade/Pro

CellPac LITE

EasyPack

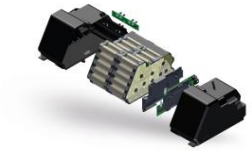
More than 130 years of innovation

1990
VARTA Lithium Cells

1995
VARTA Primary Lithium Cell assembly
+
Wire connector

2000
VARTA Customized Lithium-Polymer Pouch
+
Safety Electronic

2010
VARTA PowerPack Solutions
+
Mechanical and Electrical Design



2011
VW VARTA Joint Venture
+
New material technologies

2012
VARTA Storage Residential Energy Solutions
+
Cell and charge balancing, Power interface

2014
VARTA CoinPower Series
+
Innovative Cell-Design for highest Performance & Safety

2016
VARTA Storage Commercial Storage Solution
+
Addressing multiple energy management functionalites

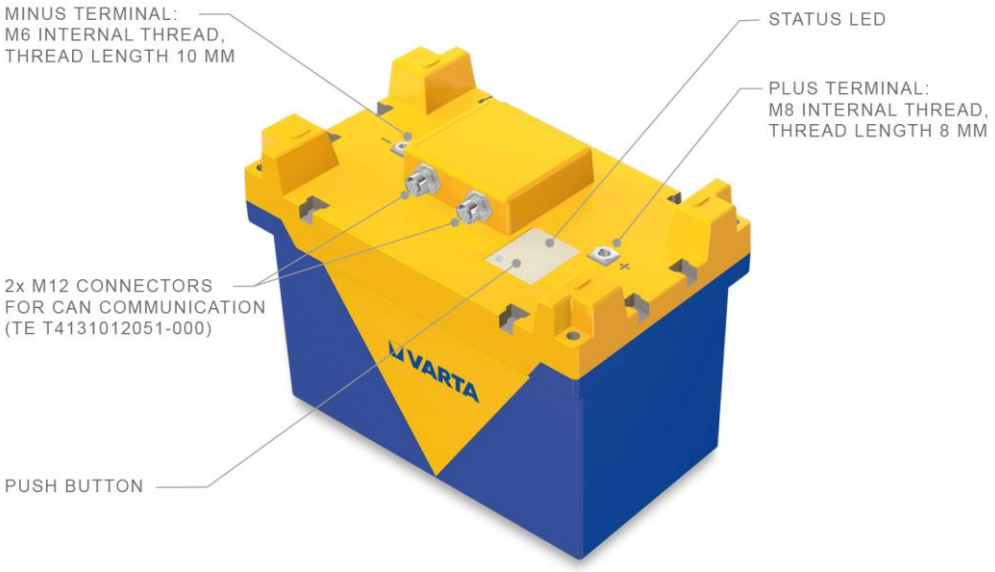
2018
New VARTA CoinPower types
+
form factors

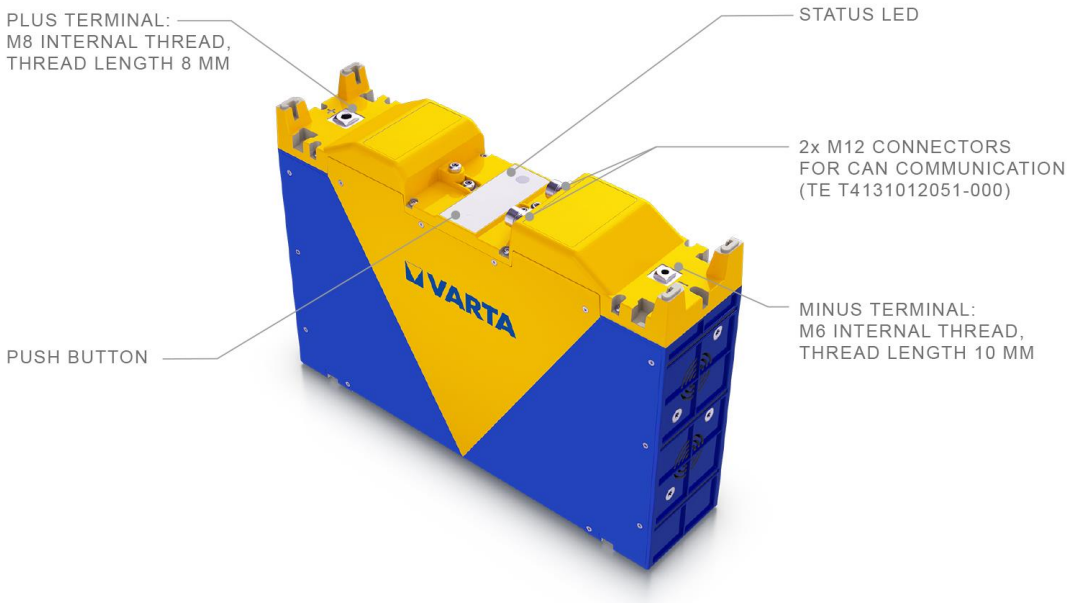
2019
Production
+
Massive Investments in production in lithium ion cells in Ellwangen and Noerdlingen

VARTA has a long history in research, development, and mass production of a variety of electro-chemistry and battery systems.

VARTA Application Specific Modular Batteries

- All batteries can be connected in parallel up to **25 battery units**
- **No** Master BMS (Battery Management System) required

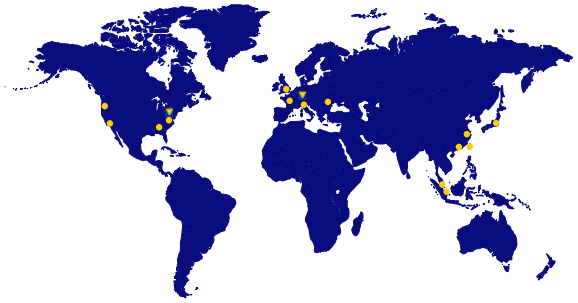




Model	Easy Block (LiFePO4)	Easy Blade (NMC)
24V	14.5 kWh (570Ah)	41.3 kWh (1600Ah)
48V	14.5 kWh (285Ah)	41.3 kWh (800Ah)

The Right Battery Partner:

- Technology Leader
- Well known in the Industry
- Standard line of products in a variety of sizes
- Previous Custom designs with well known customers
- History and Industry Experience in Battery systems
- High-volume Manufacturing Expertise (not just a Design House)
- Worldwide Reach & Support
- Multiple Manufacturing & Design locations
- Reputable firm – ideally a public company
- Financially Stable & Reliable



All past & future webinars listed at:

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