Industry trends driving high-accuracy battery monitors for HEV/EV

Battery Management Deep Dive Training

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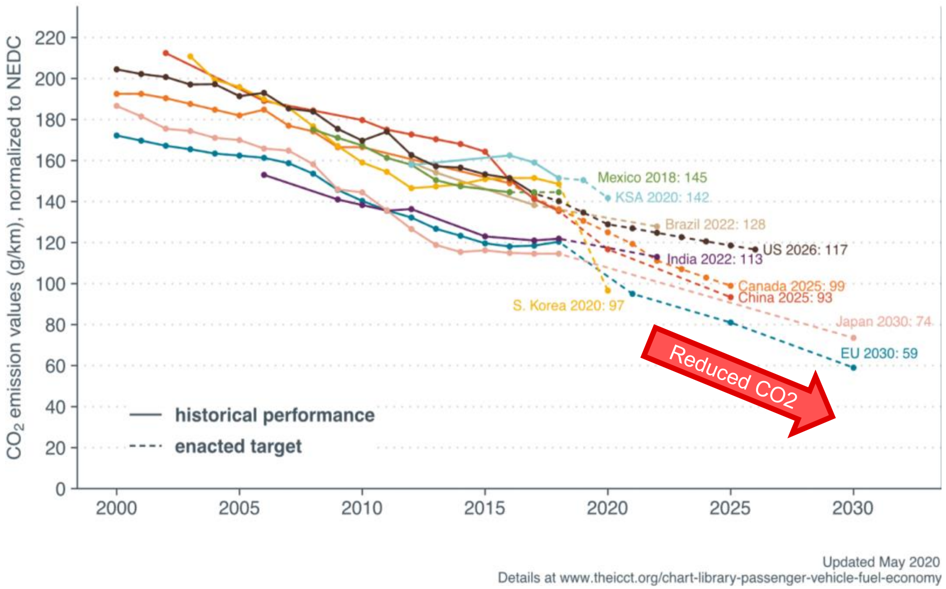
EV/HEV industry trends

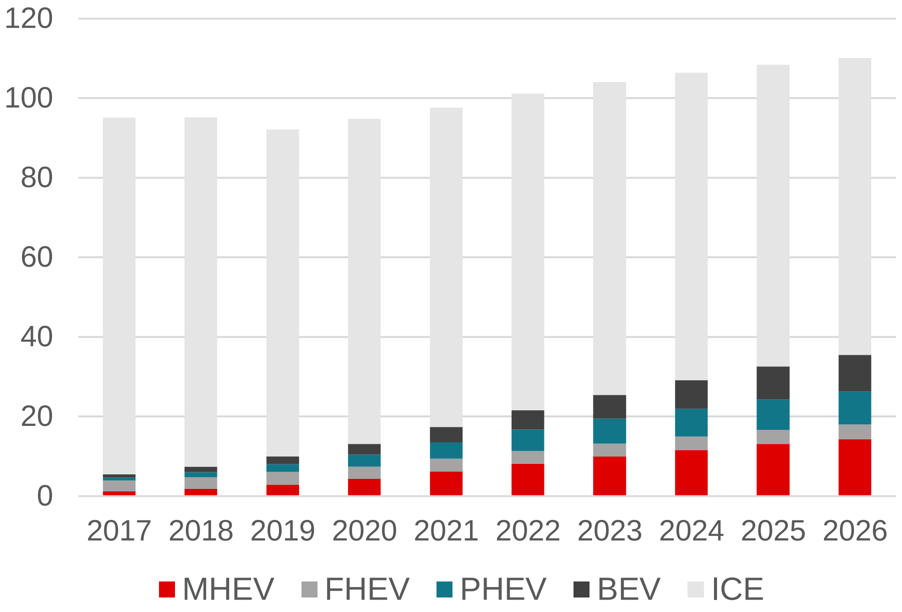
- Emission regulations around the world are driving the adoption of EVs/HEVs

Emission targets getting lower, phasing in 2020



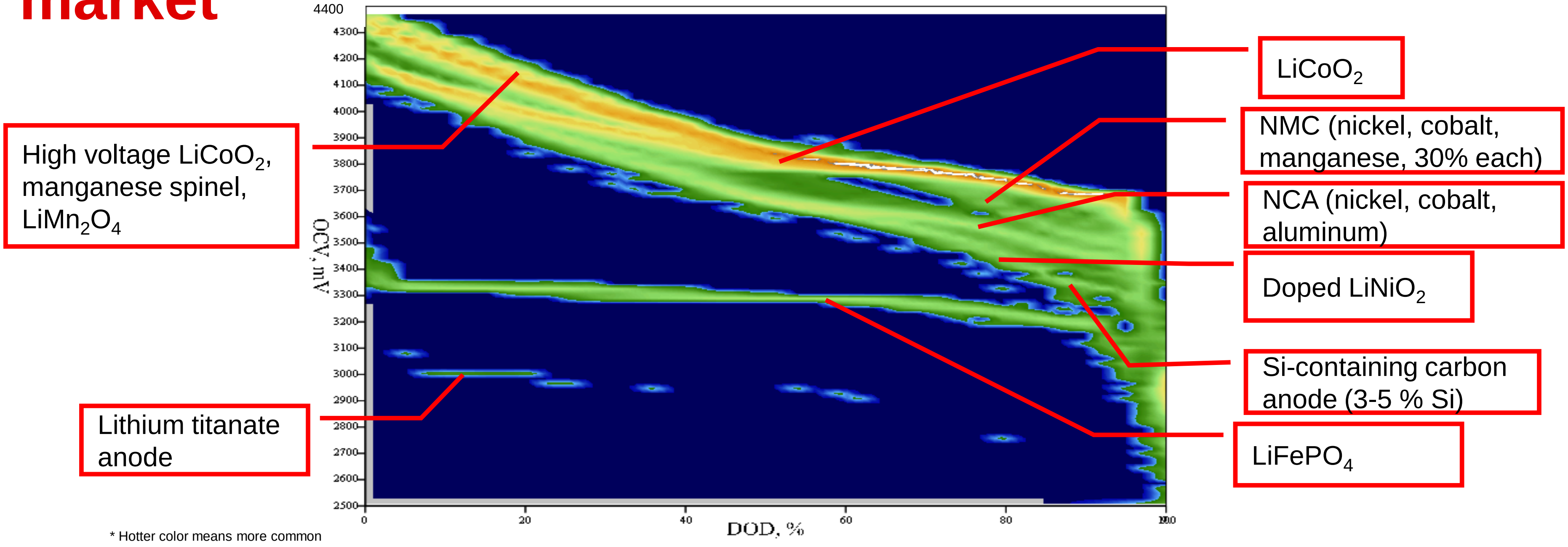
Penalty payments for excess emissions!

WW vehicle sales and projections



Source: Strategy Analytics

Various battery cell chemistries available in the market



- Cost will limit favorability of LTO in this application due to inherent series cell counts
- NMC and LFP have most potential for mainstream success based on cost
- Higher impedance of NMC makes active cooling a basic system requirement
- LFP could be optimized to further reduce impedance and potentially reduce/eliminate the need for active cooling

LFP offers several key advantages

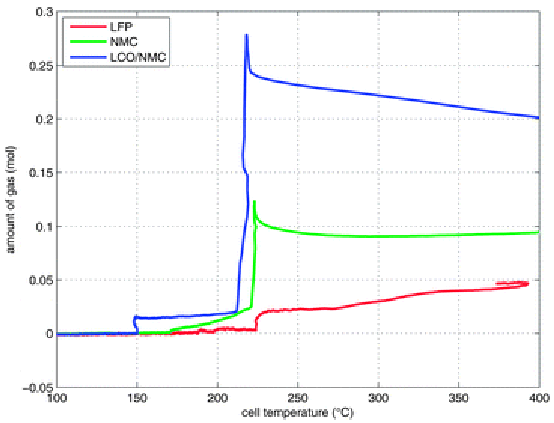
- 4 main advantages offered by LFP batteries
  - Higher safety than traditional NMC batteries
  - Ultra long cycle life enabling the use of LFP batteries in energy storage systems as a second life
  - Can safely be charged and discharged at a higher rate than traditional NMC batteries
  - Low cost

Chemistry	Voltage	Energy density	Working temp	Cycle life	Safety	Cost based on cycle life x Wh of SLA
Lead acid (SLA)	2.0 V	>35 Wh/kg	-20 - 40°C	>200	Safe	1
LCO	3.7 V	>150 Wh/kg	-20 - 60°C	>500	Unsafe w/o PCM	1.5-2.0
NMC	3.7 V	>150 Wh/kg	-20 - 40°C	>1000	Better than LCO	1.5-2.0
LFP	3.2 V	>90 Wh/kg	-20 - 60°C	>2000	Safe	0.15-0.25 lower than SLA

Higher safety of LFP

- 4 key reasons why LFP offers higher safety than traditional NMC batteries
  - LFP has higher starting temperature for exothermic reactions
  - LFP has slower exothermic reaction
  - LFP has limited heat generation
  - No oxygen is released

Battery chemistry	Thermal runaway temperature
LCO	150°C
NMC	210°C
LFP	270°C



Source: Virtual Vehicle Research

Ultra long cycle life enables second life of LFPs

Battery chemistry	Cycle life
LCO	500-1000
NMC	1000-2000
LFP	2000 and higher

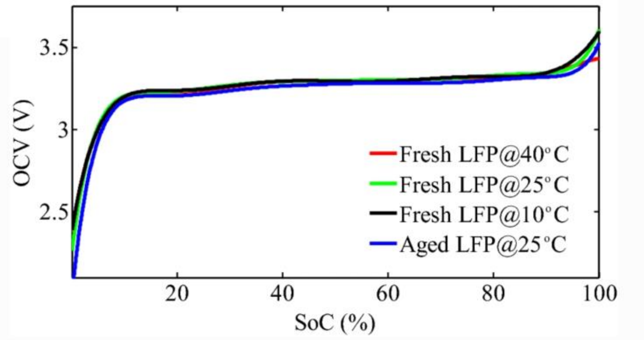
- LFP offers significantly more cycle life than NMC or LCO battery chemistries. This enables the use of LFP batteries in energy storage systems (ESS) as a second life.
- Once the state of health (SoH) of an LFP battery is reduced to 80 to 90%, the battery is removed from EV/HEV and used in ESS. This significantly helps to reduce the cost of LFP batteries.

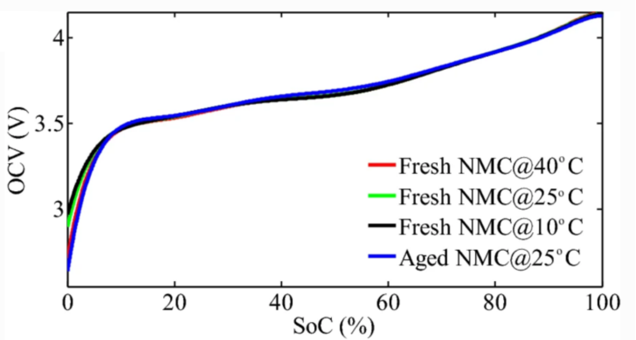
LFP has some challenges though

- 2 key challenges of LFP batteries
  - Lower energy density

Battery chemistry	Energy density
LCO	150 – 200 Wh/kg
NMC	150 – 220 Wh/kg
LFP	90 – 120 Wh/kg

  - Flat discharge profile makes it difficult to precisely track SOC%

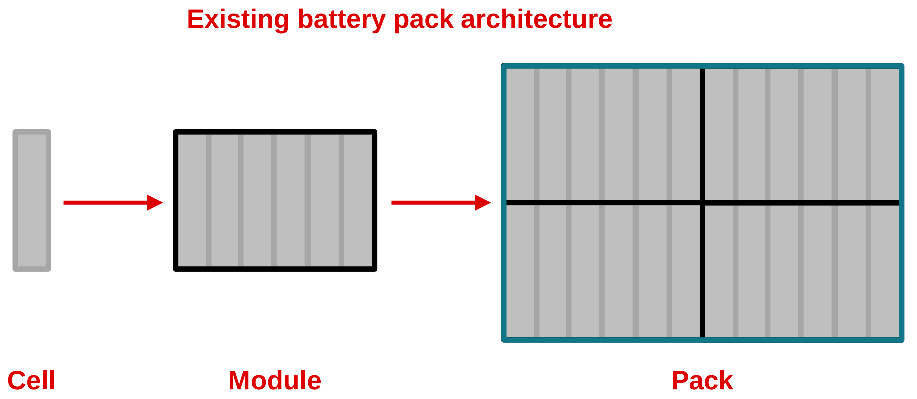


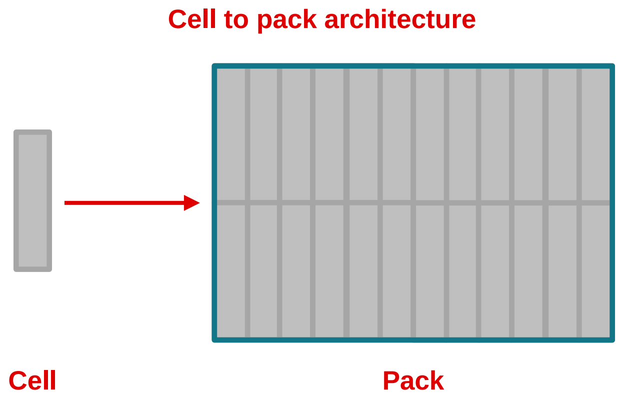


Source: Chinese Journal of Mechanical Engineering

Overcoming the lower energy density challenge

- LFPs traditionally have been most suitable for ESS applications. ESS applications are relatively less space constrained and LFPs' lower costs and longer cycle life make them a very lucrative option.
- One way to make LFPs suitable for passenger EVs/HEVs is to improve the space utilization inside the battery pack. With cell to pack technology, the space utilization can be increased by as much as 50%, thereby allowing more cells to fit inside the battery pack.



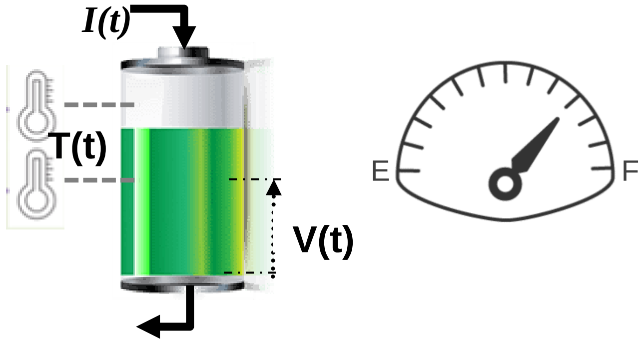


LFPs flat discharge profile requires higher accuracy of battery monitors

- The flat discharge profile of LFPs makes it very difficult to precisely estimate the SOC% of the battery
- A slight error in the OCV measurement can result in significant error in SOC% estimation
- This has presented new challenges to the monitors and balancers that are used to measure and report the open circuit voltage of the battery cells
- TI's portfolio of automotive battery monitors and balancers are continuously pushing the boundary of measuring the open circuit voltage more accurately from generation to generation

Defining accuracy

- An SOx gauge algorithm (running on MCU) needs to have data from the battery through various measurements
  - Battery cell voltage
  - Current flowing into and out of the battery pack
  - Battery cell temperature



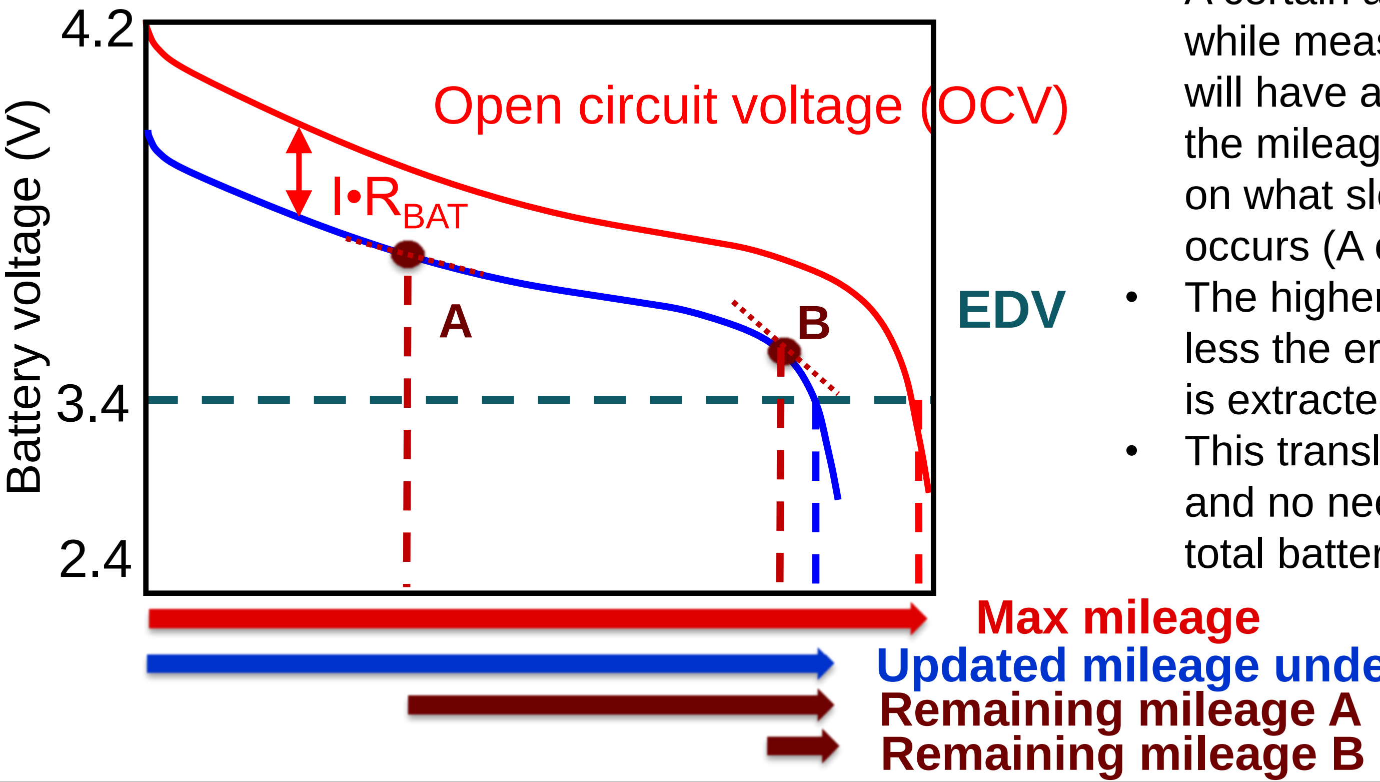
- Measurement accuracy is dependent upon the monitors’ and balancers’ hardware and is independent of gauging algorithm accuracy
- SOx gauge algorithm accuracy is dependent upon the robustness of the gauging algorithm and the monitors’ and balancers’ measurement accuracy
  - Poor measurement accuracy can lead to poor gauging accuracy

SOX : State-of-X → X: charge, health, power, energy

Monitors’ and balancers’ measurement accuracy

- Voltage
  - Accurate voltage measurements are critical for
    - Initialization of relaxed cell
    - Updates during self-discharge of cell
    - Correction for coulomb counting error
- Current
  - Accurate to enable coulomb counting to capture
    - Low sleep currents
    - Short load spikes
    - Proper passed charge
- Temperature
  - Accurate temperature measurements are critical for
    - Proper compensation of resistance
    - Proper compensation of predicted runtime

Impact of cell voltage measurement accuracy on mileage

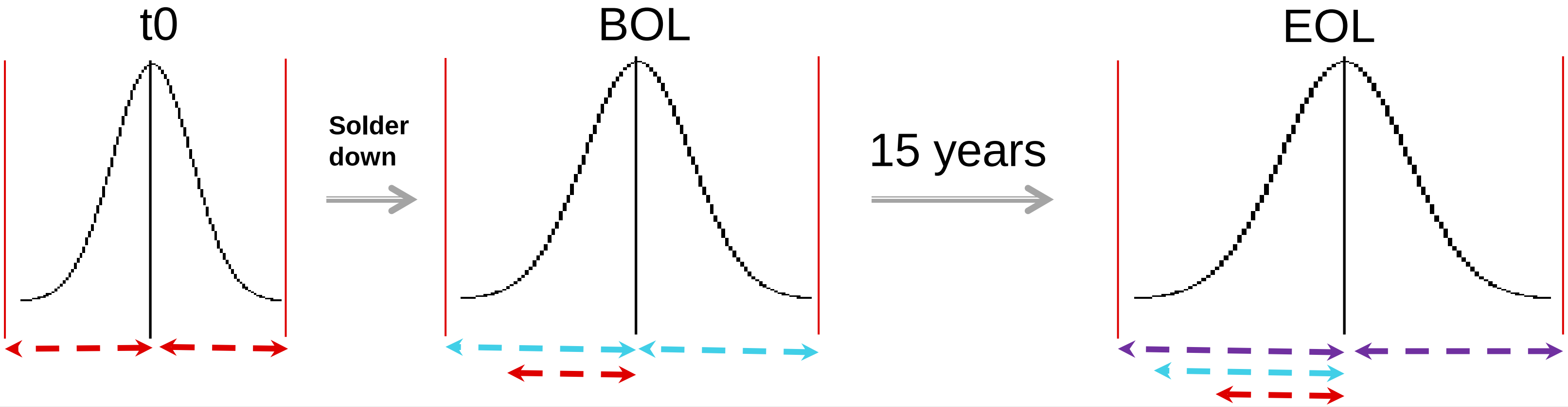


- A certain amount of error (mV) while measuring the cell voltage will have a different impact on the mileage estimate depending on what slope the measurement occurs (A or B)
- The higher the accuracy, the less the error, the more energy is extracted from the cell
- This translates to more mileage and no need to overdesign the total battery capacity

Total channel voltage accuracy – Theory

Nomenclature of the various (cell voltage measurement) accuracy errors

- Time zero (t0) = accuracy error measured on a socketed board, before the IC gets soldered down on the PCB
- Solder-down shift (SdS) = additional accuracy error induced by the mechanical stress and reflow process after the IC is soldered down on the PCB. This is an incremental error with respect to time zero.
- Beginning of life (BOL) = t0+SdS; it is the accuracy error of the IC after it has been soldered down on the PCB
- Long-term drift (LTD) = additional accuracy error due to the IC aging components that are part of the internal reference voltage. This is an incremental error with respect to BOL.
- End of life (EOL) = BOL+ LTD ; it is the total accuracy error of the IC that considers both the BOL and the additional drift due to aging



Total channel voltage accuracy – Theory

There are 2 ways to calculate the total voltage accuracy error with the different contributors

1. Linearly adding the various contributors
   - EOL = t0 + SdS + LTD
   - EOL = BOL + LTD

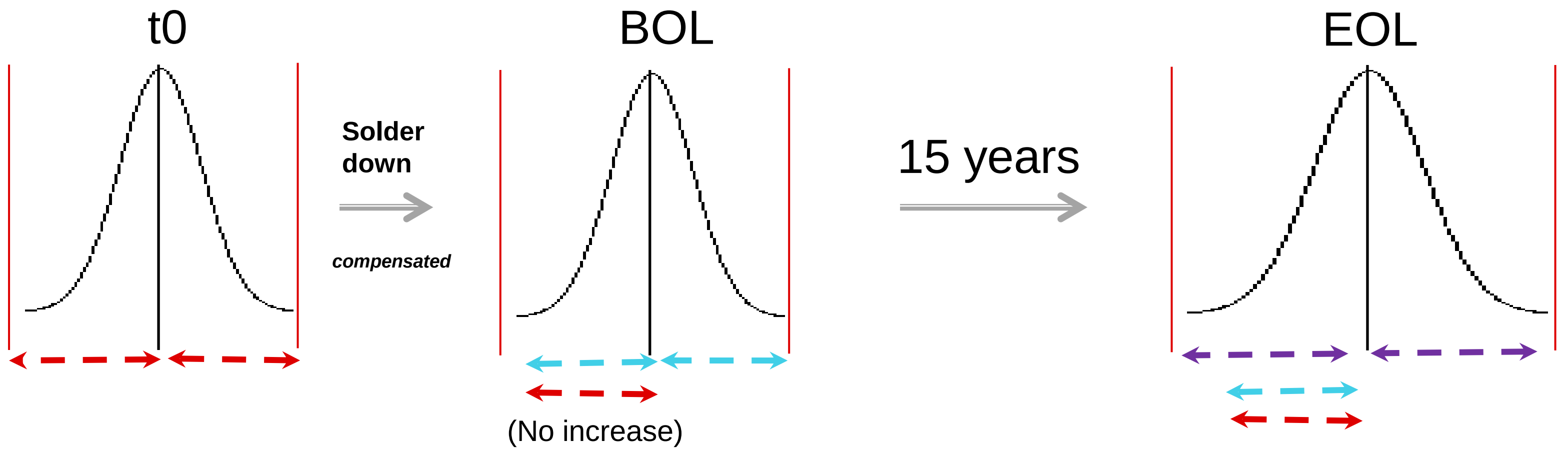
   This method is more conservative and applies when the sources of error of each contributor are correlated

2. Square root of the addition of the squares
   - $EOL=\sqrt{(BOL)^2+(LTD)^2}$

   This method is less conservative and applies when the sources of error of each contributor are uncorrelated

Total channel voltage accuracy – BQ

- TI balancers and monitors leverage innovative technology that compensates and corrects the additional error due to solder-down shift
- This makes the BOL source of error independent from voltage reference
- EOL additional shift remains dependent from the aging of the components in the reference voltage



As now the sources of error of each contributor are uncorrelated this applies: $EOL=\sqrt{(BOL)^2+(LTD)^2}$

Noise filter challenge

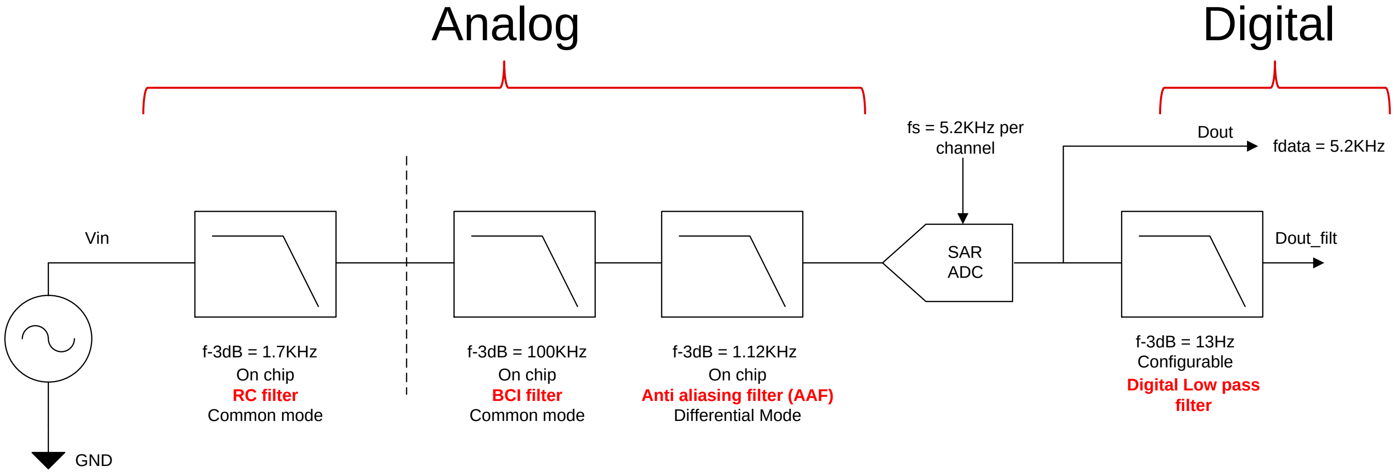
Accuracy is ‘nothing’ without noise filtering

Elaborate on accuracy in absence of noise → update DC and SOH
Accuracy when noise is present → SOC while in motion, remaining mileage

- EV battery sits in a very challenging environment
  - Noise from BCI noise on sense line, inverter induced noise, charging noise, etc.
  - Their resonance frequency can go from 100s of Hz up to 10s of MHz
- The filter design in our BQ family gives best performance with optimized BOM count

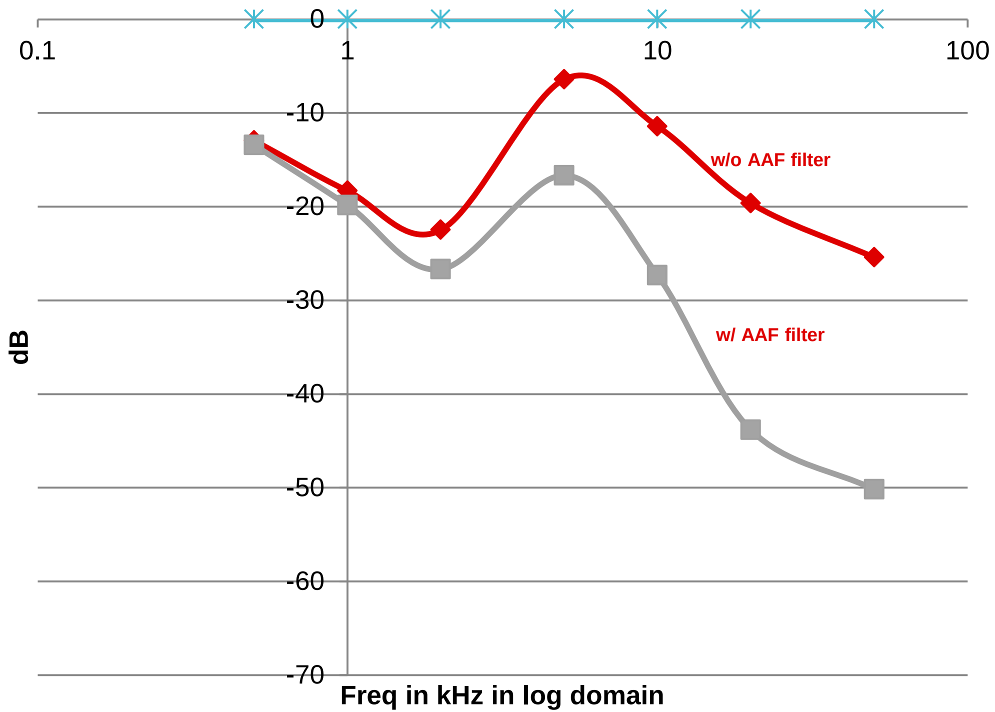
Filters – Overview

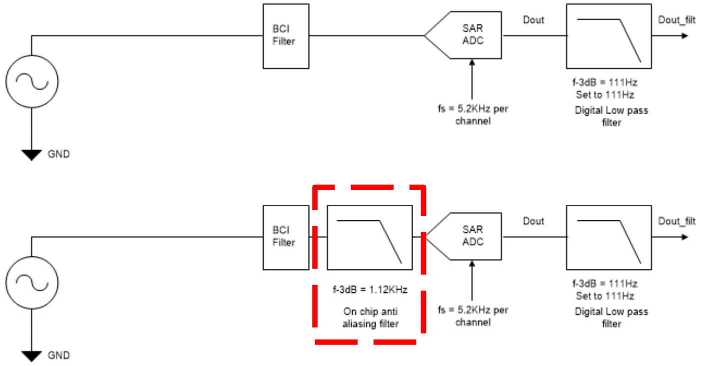
- Two types of filters are implemented in the BQ796x6 family
  - Analog (RC, BCI, AAF)
  - Digital (1st order low pass/ SINC)



BQ7961X VC signal chain simplified diagram

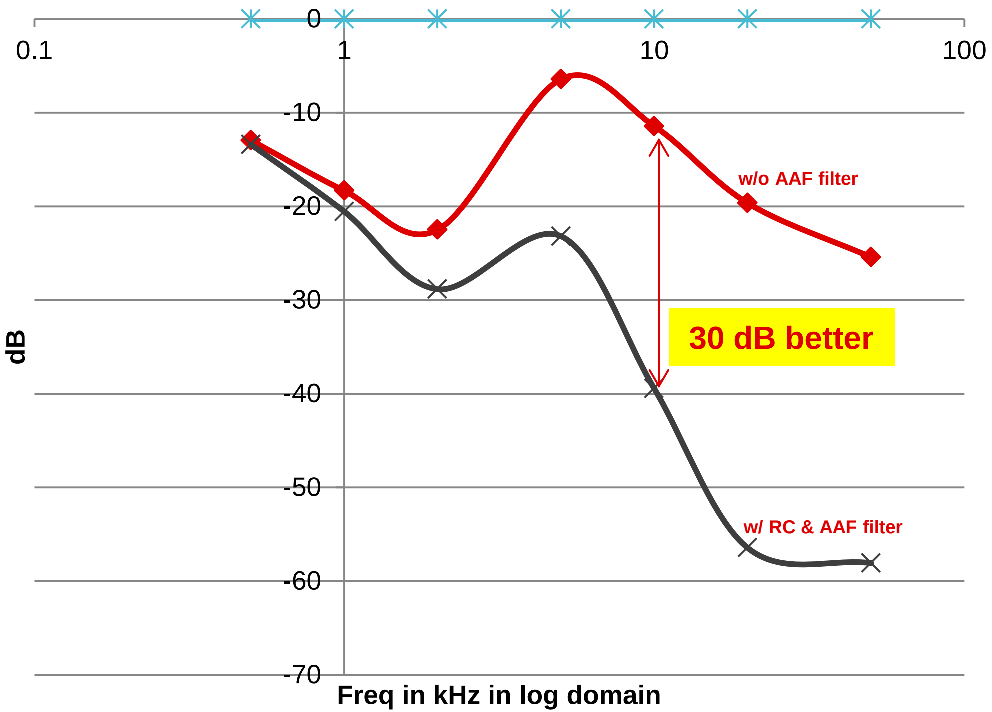
System-level benefits – RC and anti-aliasing filters

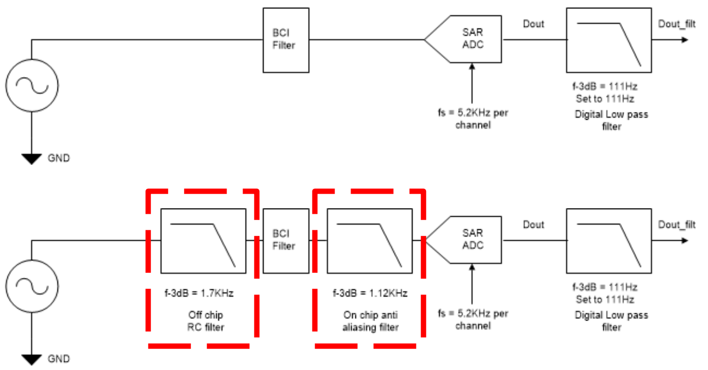




Without AAF or ineffective AAF, digital filter is not effective

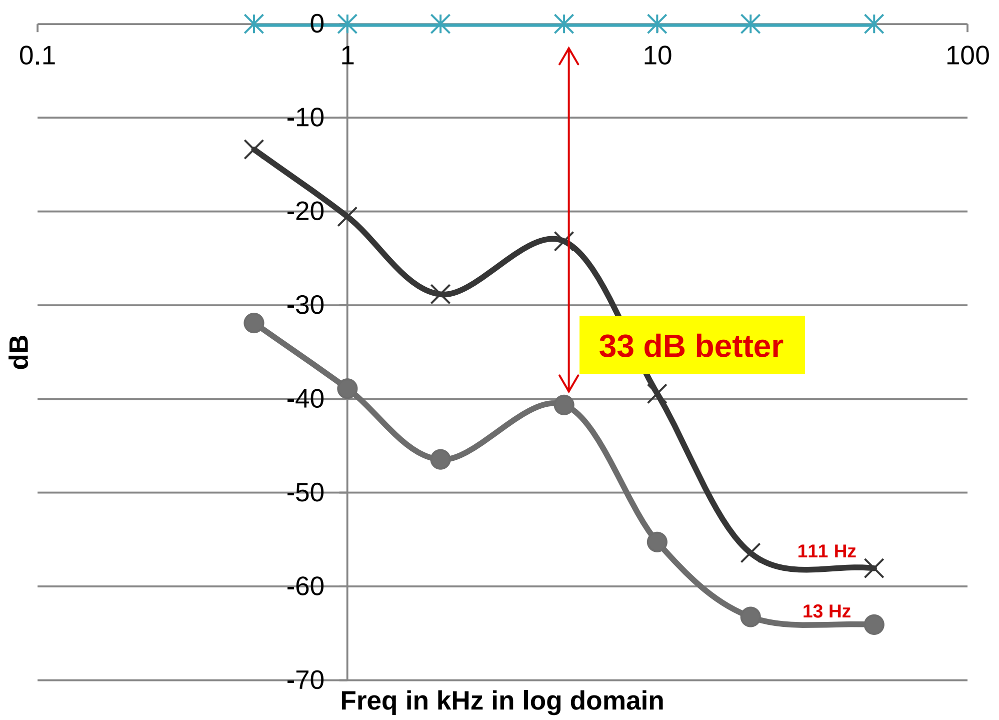
System-level benefits – RC and anti-aliasing filters

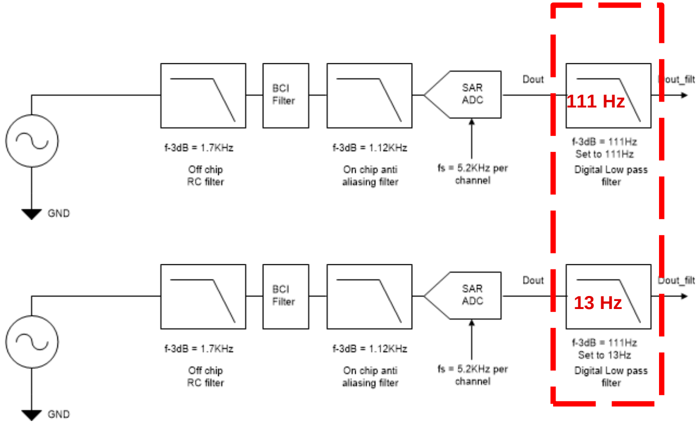




- With 2 filters, noise attenuation 20-30dB better
- Smaller external C value

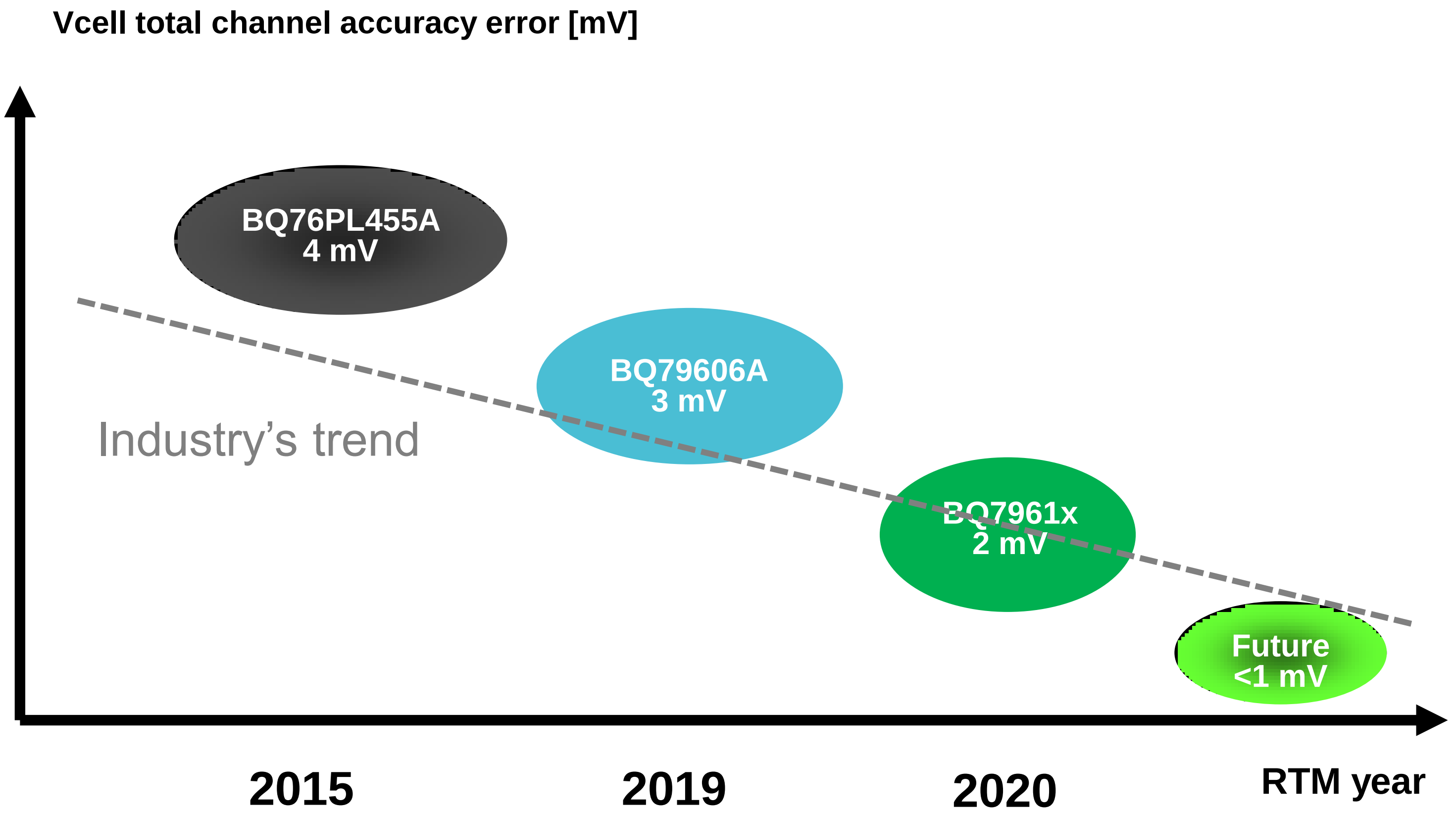
System-level benefits – Digital low pass filter (1)





- Save signal processing workload on MCU and
- Suppress AC noise > 40 dB

Monitors’ and balancers’ accuracy roadmap



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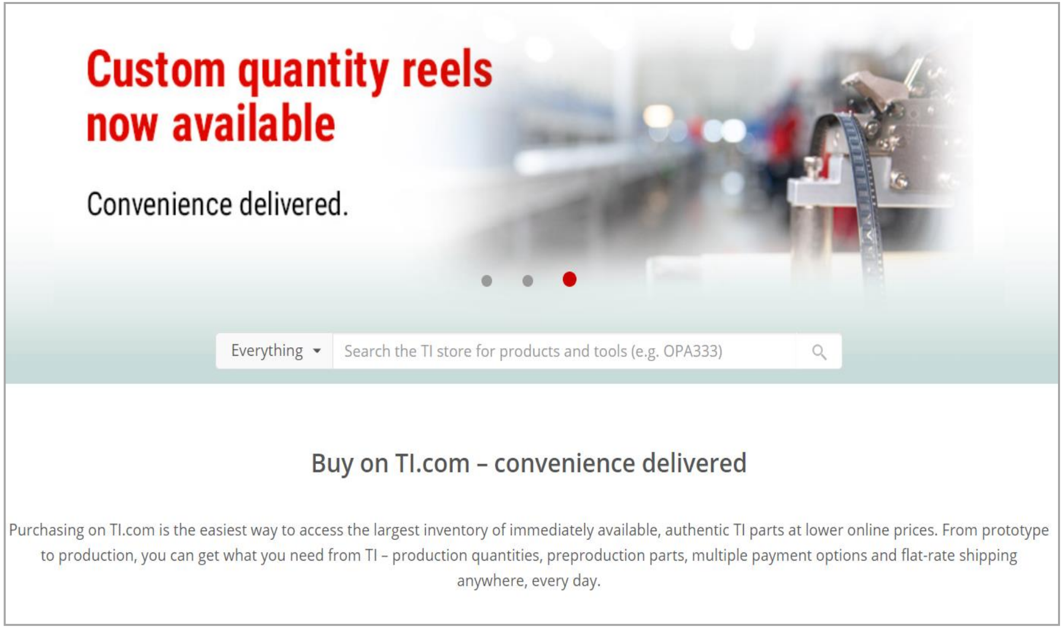

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