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The Trends and Future Solutions in Battery Test

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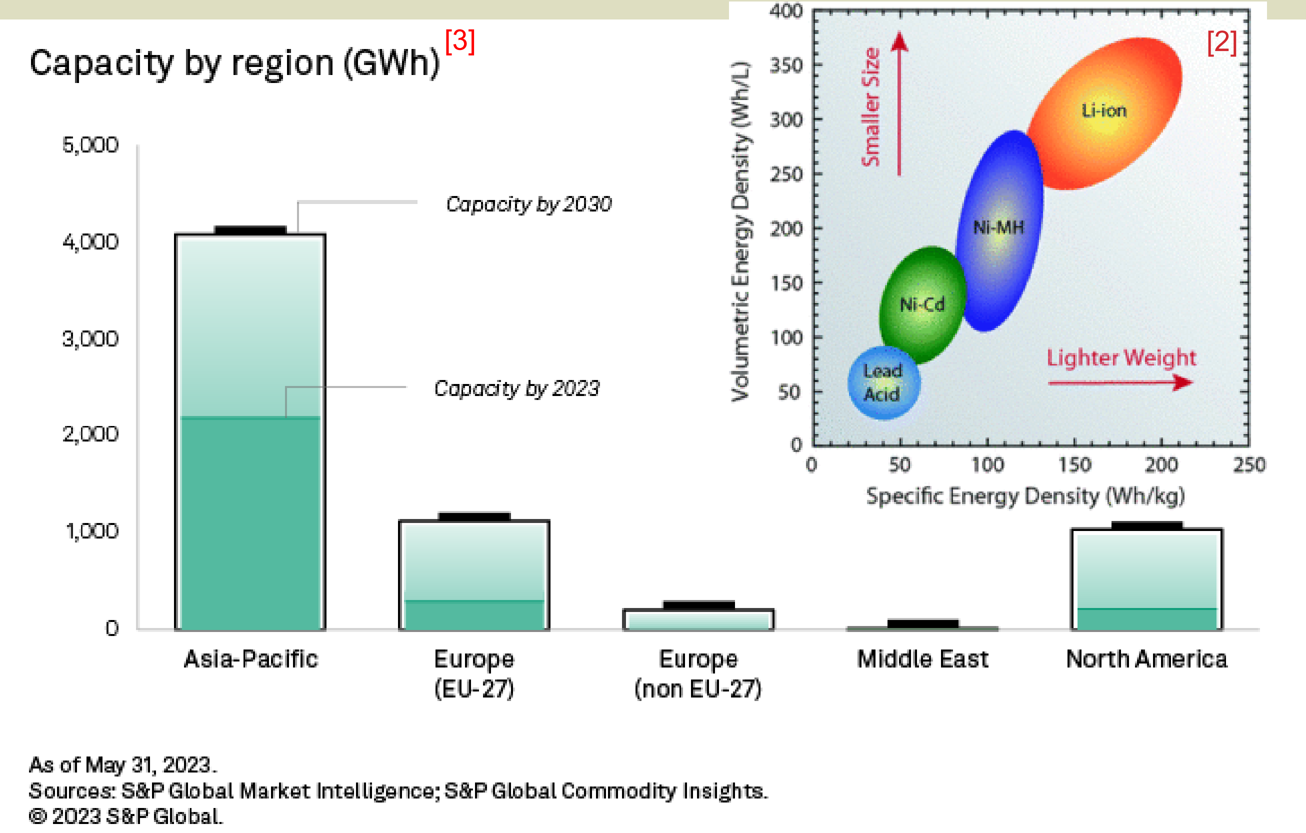
Agenda

- Battery capacity & test overview
- Current challenges, technology trends and possible solutions
  - Control loops for battery charging: More integration
  - Serial topology formation: Lower cost
  - High switching frequency: Smaller footprints
  - Impedance spectroscopy for battery test: Higher reliability
  - Battery self-discharge: Less test time
- Summary
  - Semiconductor devices drive the innovation and cost down [1].

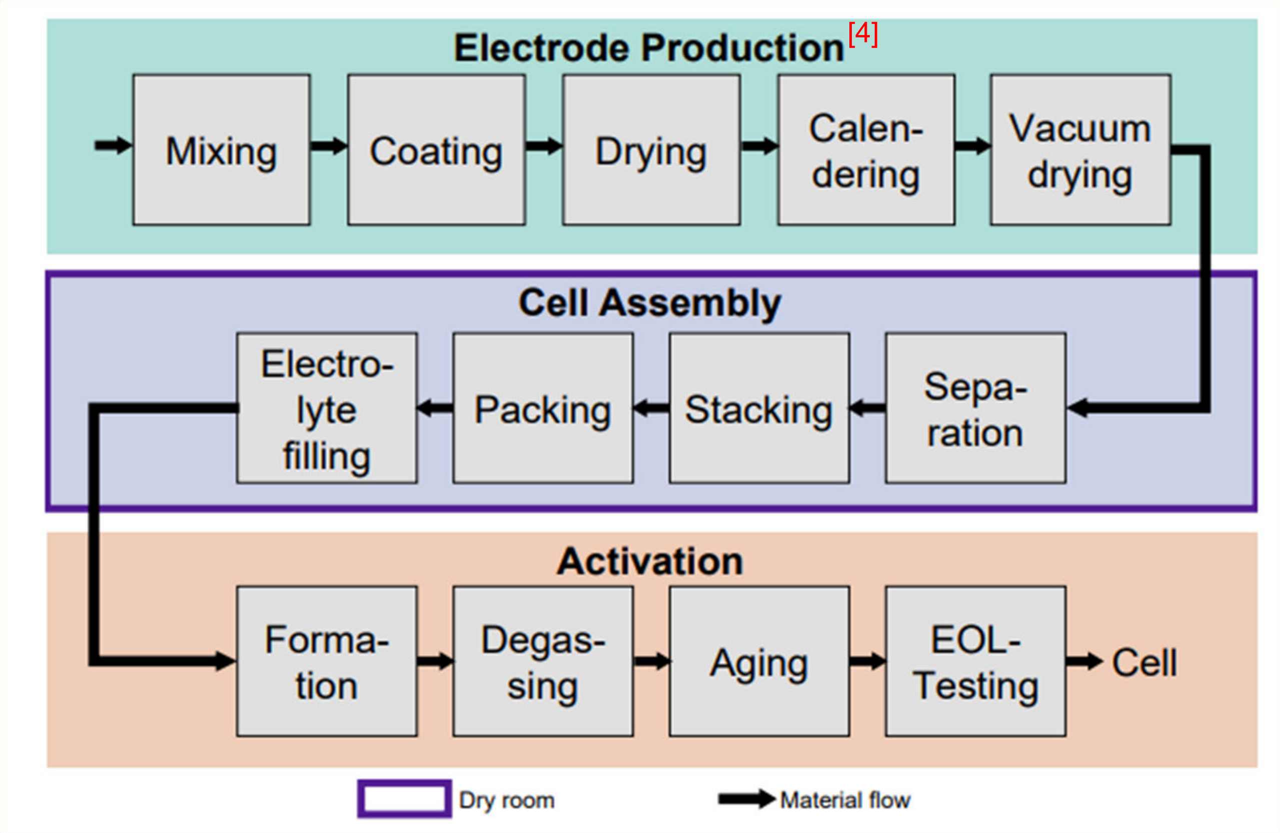
Battery Capacity Grows Rapidly

- Lithium-ion batteries still dominate and thrive
- LIBs are widely used in electronics, EVs, and grid storage



Battery Test Overview

- Test Flows
  - Formation, aging and test is important
    - High cost (30%) and time demand (95%)
    - Tight relationship with battery degradation and safety issues
  - Electronic components play critical roles



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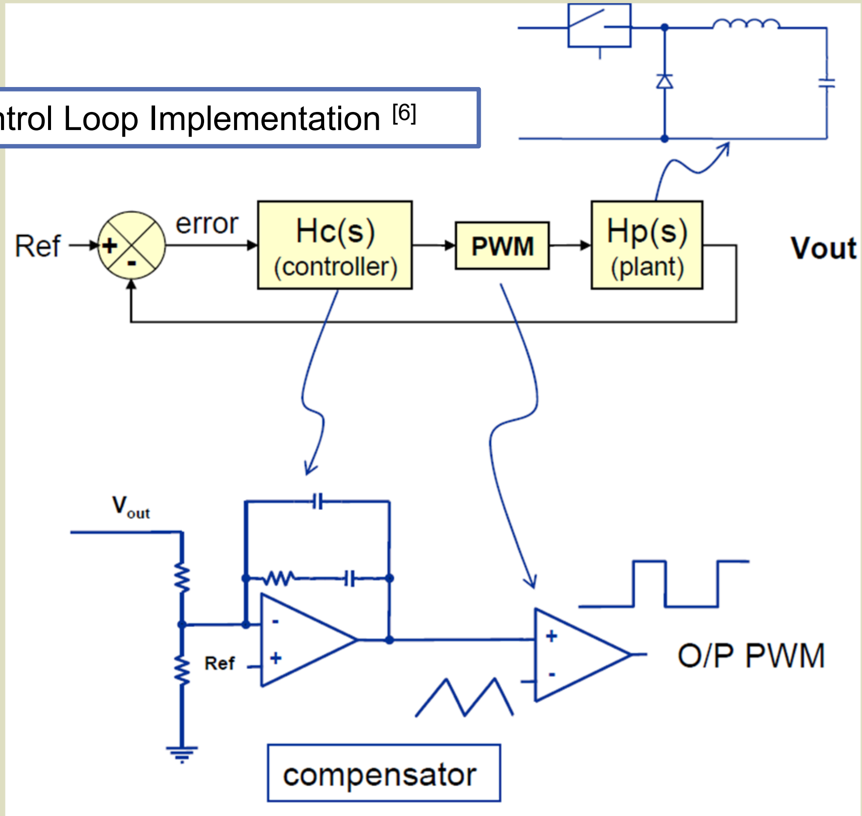
Control Loops for Battery Charging

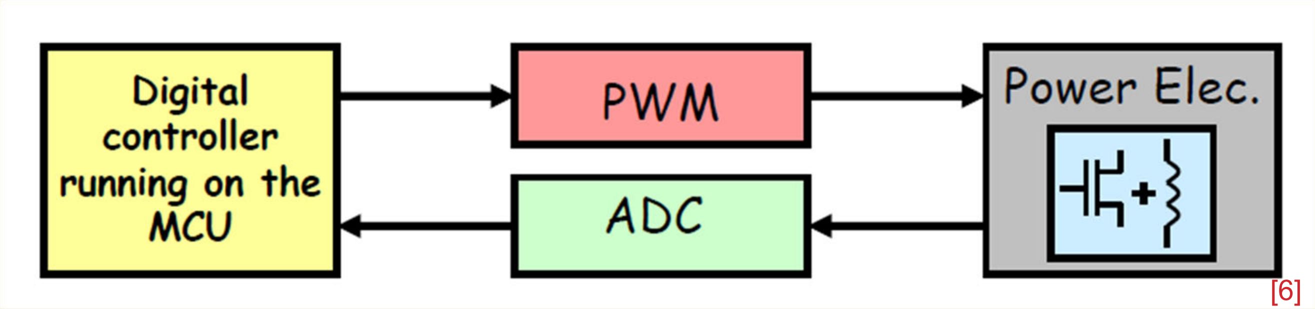
- Battery current & voltage must be precisely controlled [5]
  - During both formation & test cycles
- SMPS (switching mode power supply) control scheme is important for large current (>1 A)
  - Either analog or digital loop control works
- Analog control loop advantages
  - Fast response time (<1ms)
  - Challenges: individual designs, loop stability
  - High precision analog input ICs needed, like INA, ADC, DAC.

Analog Control Loop Implementation [6]



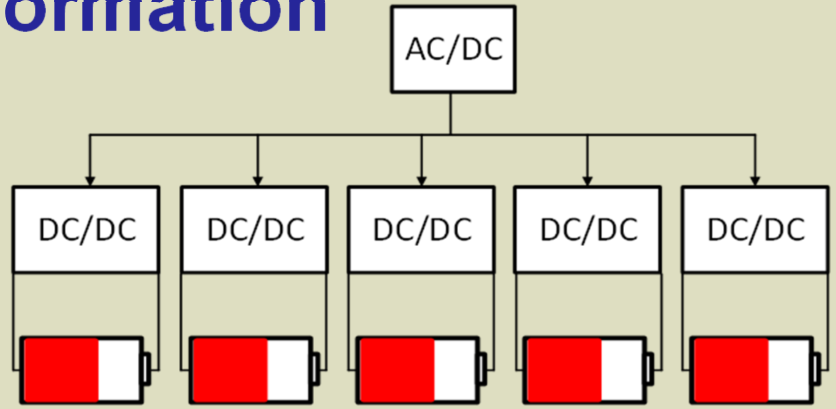
Control Loops for Battery Charging

- Digital control loops
  - Usually have lower cost (leverage the process power of modern microprocessors)
  - High precision external ADCs and DACs might be needed
  - Design Challenge: slow loop time, microprocessor limits on precision and speed

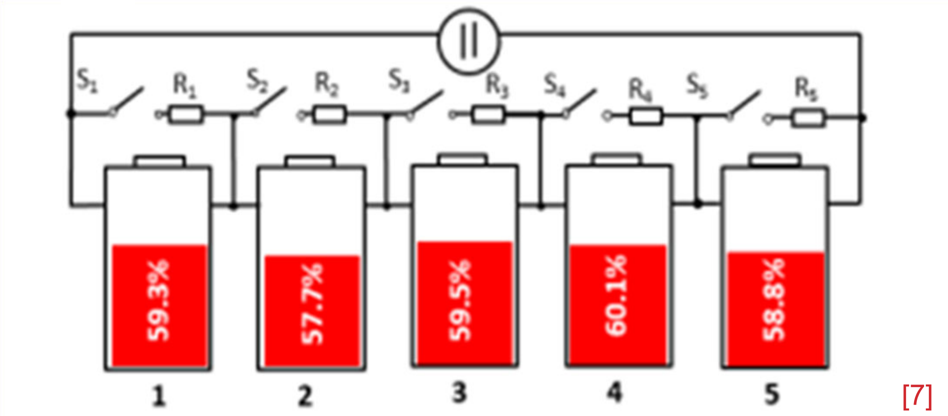


- Standalone ASSP could be the future solution
  - with proper function integration: analog input, ADC, PID controller, PWM generator

Serial Topology Formation



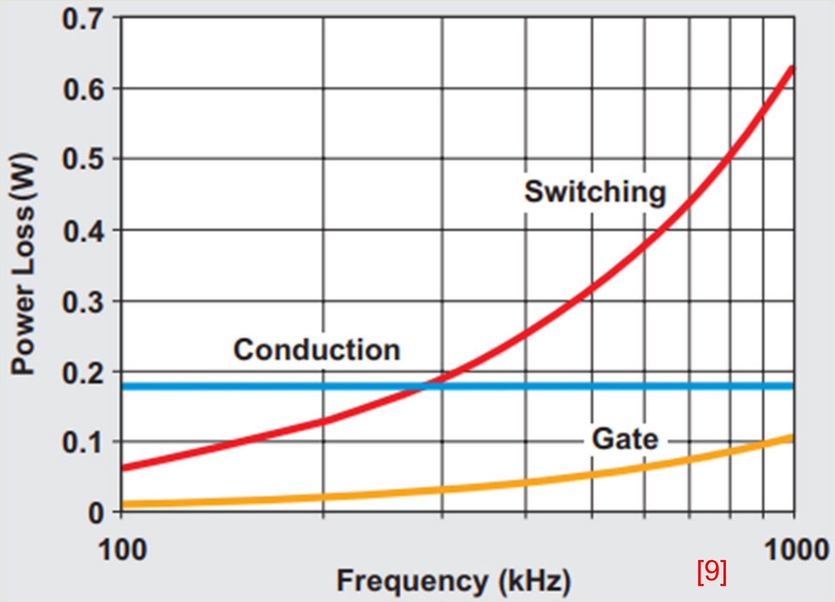
- Parallel charges each cell individually
- Serial charges multiple cells at once
  - Suits CC charging profile
  - Reduce cable costs
  - Active balancing or passive balancing
- Electrical components
  - Need smarter balancing scheme
  - Support high standoff voltage



[7]

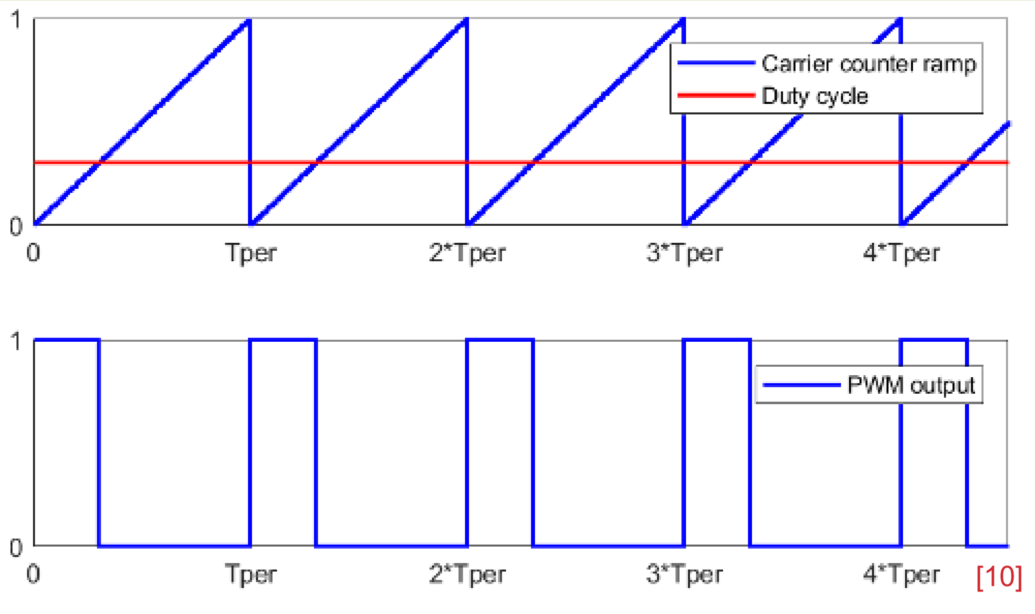
High Switching Frequency

- For miniaturizing SMPS, high switching frequency (SF) is generally adopted [8].
  - Reducing capacitance and inductance constants
- State of art: 100kHz or less.
  - Power MOSFET: low cost but large parasitics
  - Switch losses proportional to SF
- Better efficiency and higher channel density are achievable with the emergence of GaN technology (SF > 500kHz)



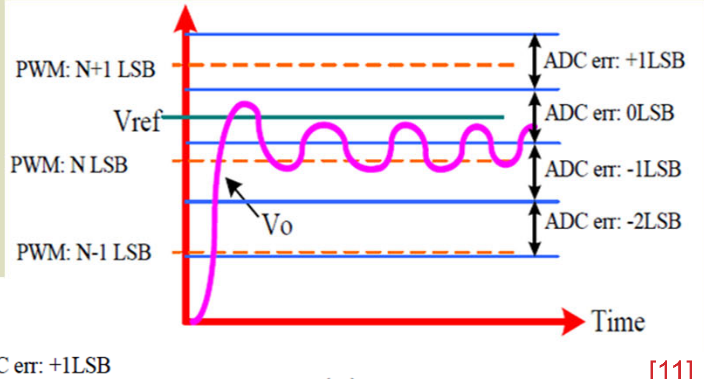
High Switching Frequency

- To generate PWM: a carrier counter ramp and duty cycle DC bias
  - microprocessor speed is limited by the minimum pulse (150 ps)
  - For example, an 18-bit DAC is needed for an 18-bit PWM



High Switching Frequency

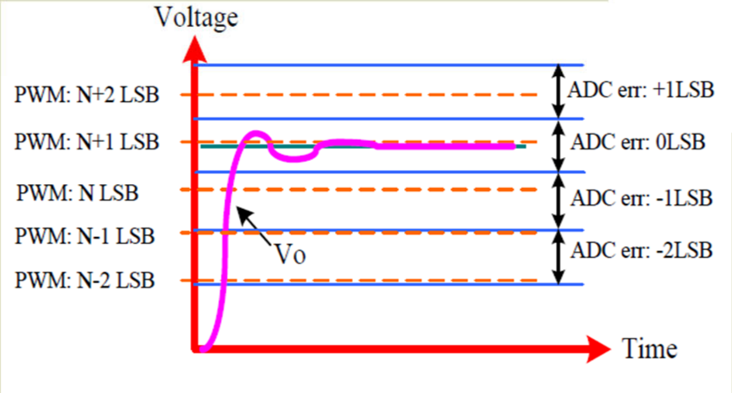
- For higher input voltage, higher resolution is also needed
  - 30 mΩ load resistance with 30 A charging current => 900 mV full scale voltage
  - 12-bit control resolution => 0.22 mV step
  - 12 V input voltage, 16-bit PWM needed
  - 48 V input voltage, 18-bit PWM needed
  - Limit cycle oscillation due to low PWM resolution



(a)

[11]

- For future products, both high switching frequency & high resolution PWM are desired

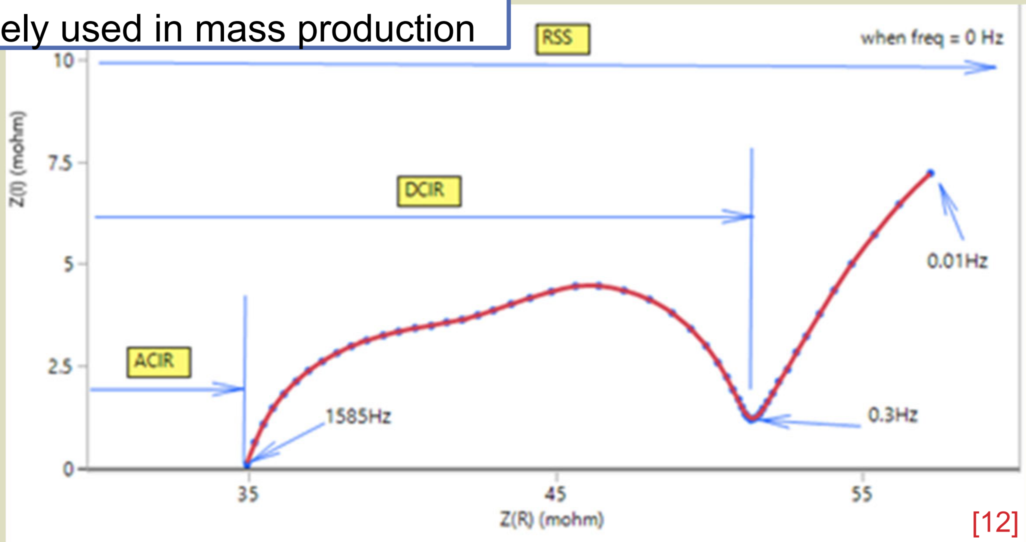


(b)

Impedance Spectroscopy for Battery Test

Battery impedance is an important parameter in production to reflect the quality of the battery

ACIR (Alternating Current Internal Res.)
- AC signal @ 1kHz
- Extensively used in mass production



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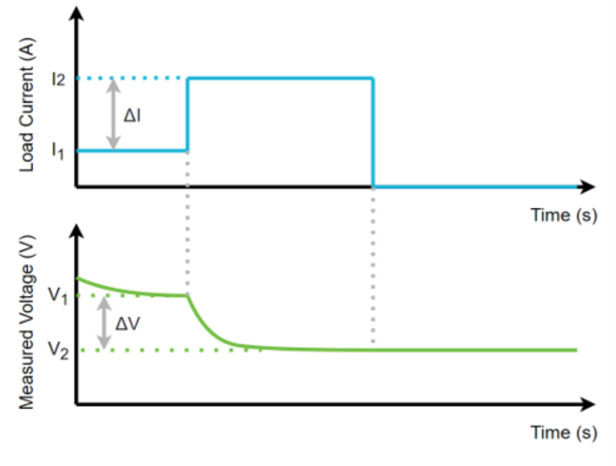
DCIR (Direct Current Internal Res.)
- Pulse discharge test, No extra hardware cost



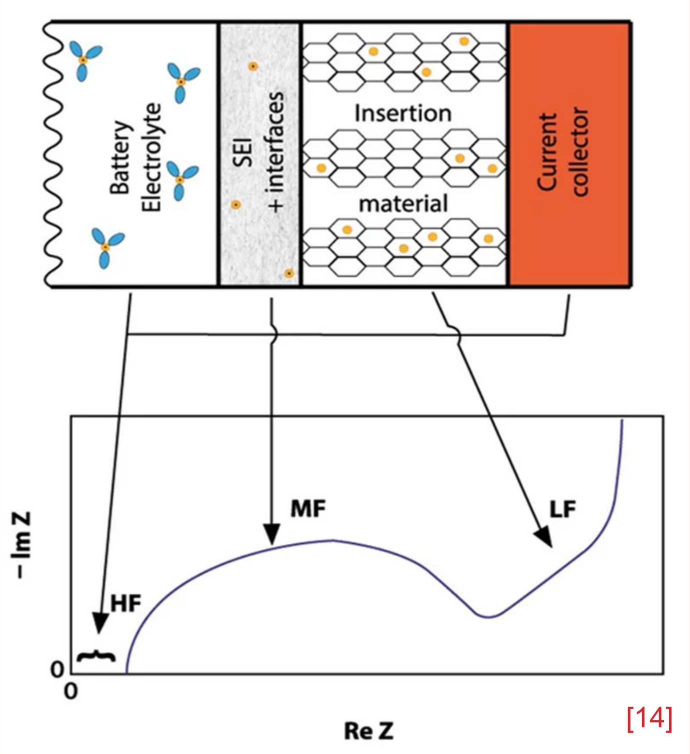
$$DCIR = \frac{\Delta V}{\Delta I} = \frac{V_1 - V_2}{I_2 - I_1}$$

[13]

Impedance Spectroscopy for Battery Test

- Electrochemical Impedance Spectroscopy (EIS) is gaining prominence over DCIR and ACIR
  - More data points across various frequencies
  - Enables the early detection of thermal runaway in batteries
  - Apply a sinusoidal current (galvanostatic, GEIS) or voltage (potentiostatic, PEIS) of a certain amplitude and frequency to measure the amplitude and phase shift of the output voltage or current

Nyquist plot of the impedance of the negative electrode of an LiB.



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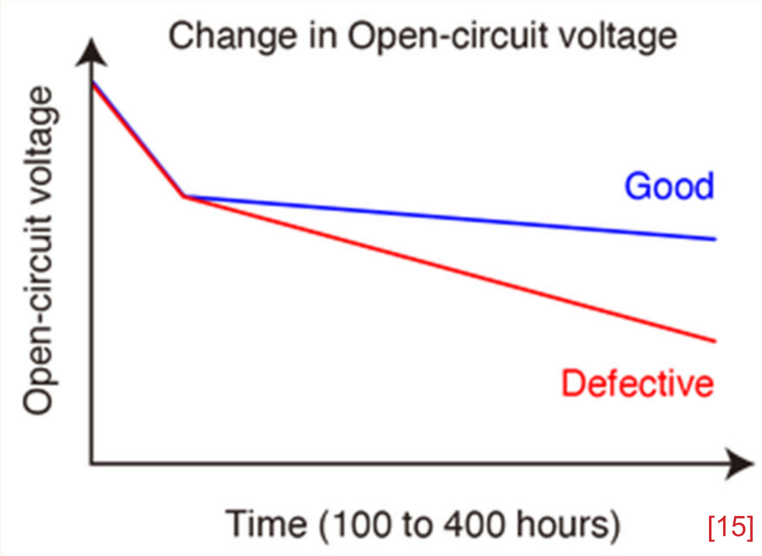
Impedance Spectroscopy for Battery Test

- The requirements of EIS measurement
  - Linearity and stationarity
  - Resolution
- Function integration in battery cycler
- IC level solutions show up lately
  - the device should be able to generate AC signals at various frequencies and measure real and imaginary impedance
  - Might be difficult to integrate the function in microprocessor due to heavy DFT and interface

Battery Self-discharge

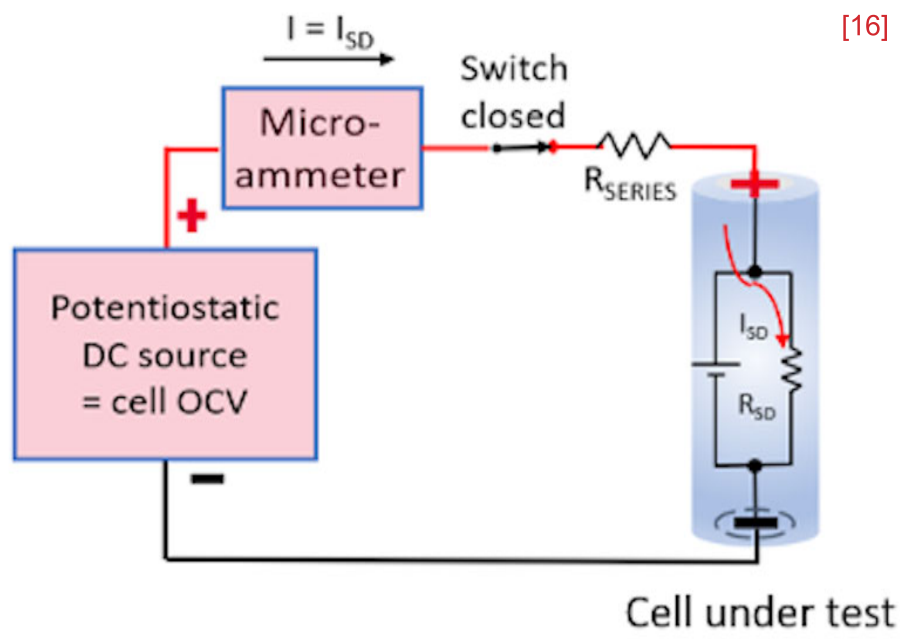
- Lithium-ion cells gradually discharge even when they are not connected to anything
  - Excess self-discharge indicates potentially catastrophic problems within the cell. Due to this, all cells are screened in manufacturing for self-discharge



- Traditional way – check delta OCV (open circuit voltage)
  - 6 ½ DMM (digital multimeters)
  - In the order of weeks

Battery Self-discharge

- Another way – directly measures internal self-discharge current
  - Potentiostatic
  - In the order of hours
- Future solution
  - Same function can be achieved by ICs
  - Integrate a switched regulator controller and a linear output
  - high-precision small current generation and measurement



Summary

- Formation, aging & test take the longest time and high cost in battery production. New ICs are critical for system solutions[2].
- While analog control loop has faster response time, digital control loop reduces cost of the battery test system. Having both wins.
- Serial topology can save more than 10% cost during formation.
- High switching frequency and high resolution PWM are needed for next generation battery test systems.
- EIS solutions are available with DFT processing capability.
- Integration of precision linear output enables battery's fast self-discharge check.

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