Battery Modeling in Electronic Design

Alberto Macii and Massimo Poncino

Politecnico di Torino

Outline

- Introduction & battery trends
- Battery non-idealities
- Battery models
- Automated Circuit-equivalent Model Identification
- Conclusions

Introduction

- Autonomous devices are ubiquitous!
  - How many devices we use is NOT battery-powered?

Cell phone charger

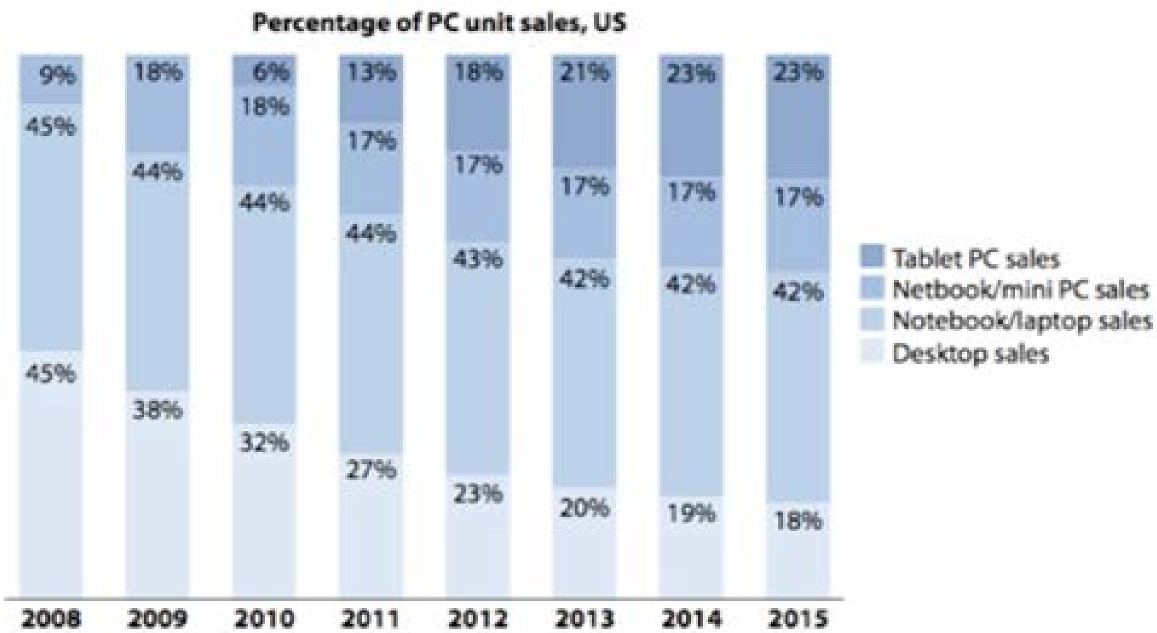
Wristwatch

Shaker Flashlight

Hearing aid

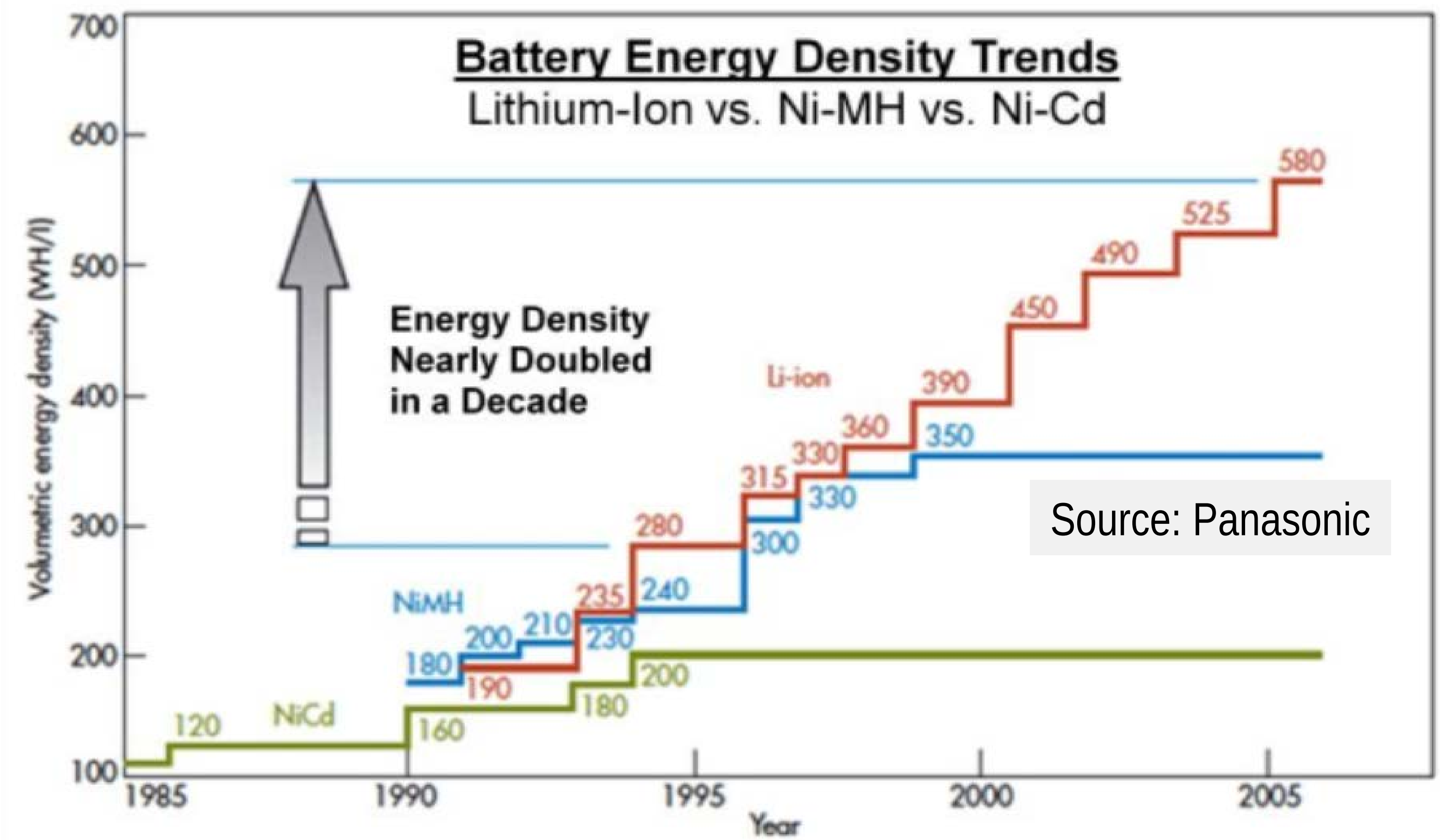
Cell phone

I-pod media player



Battery Trend

- Battery tech is improving
  - but no Moore's law in batteries…



Batteries have to be handled with care

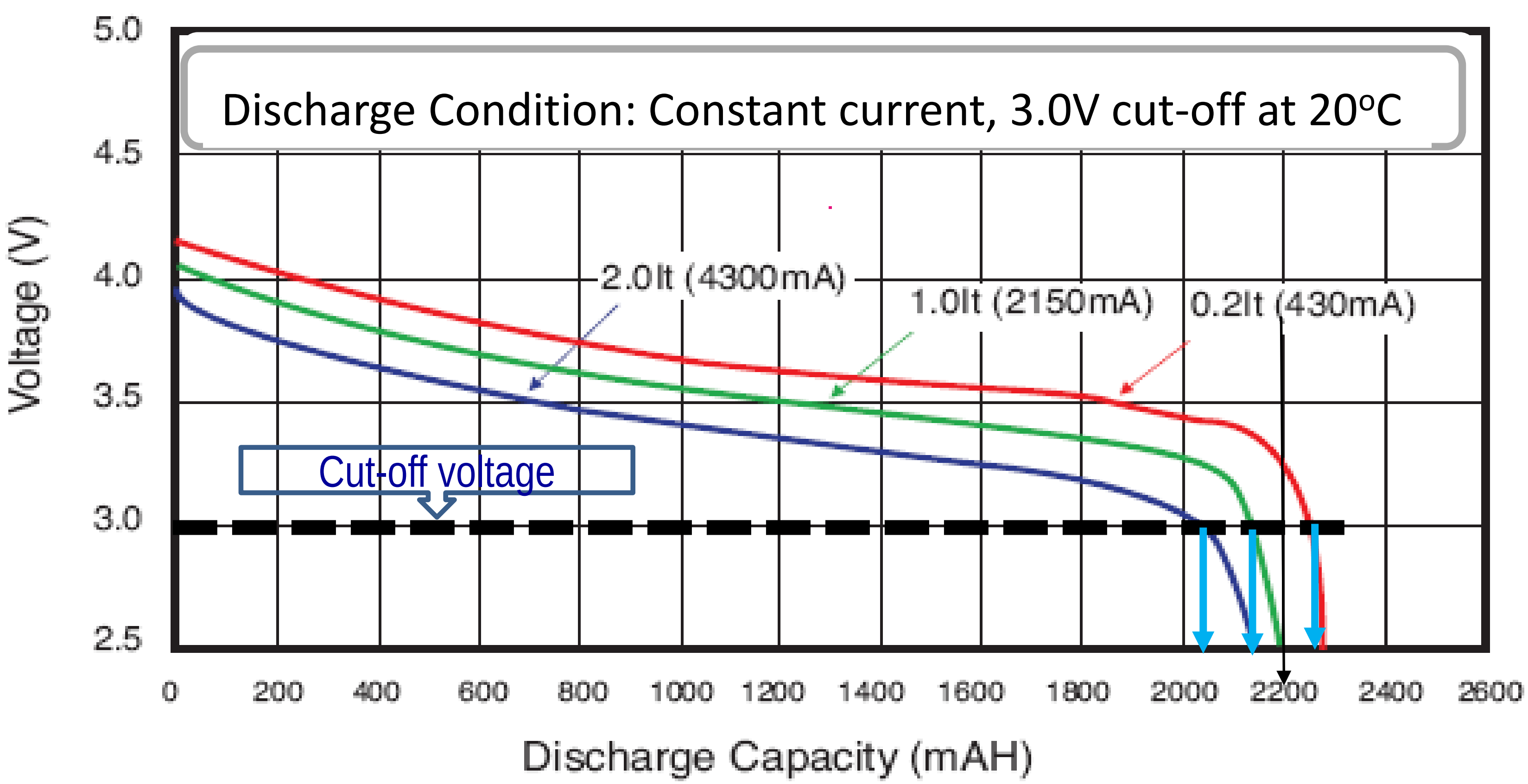
- Batteries are complex (and not ideal) devices…

- Traditional assumptions about the energy supply from the designer's perspective:
  1. **Any current can be drawn** from the energy supply at V_{dd}
  2. **Average power consumed** by the device is what matters

- Unfortunately, these are WRONG assumptions if we use a battery

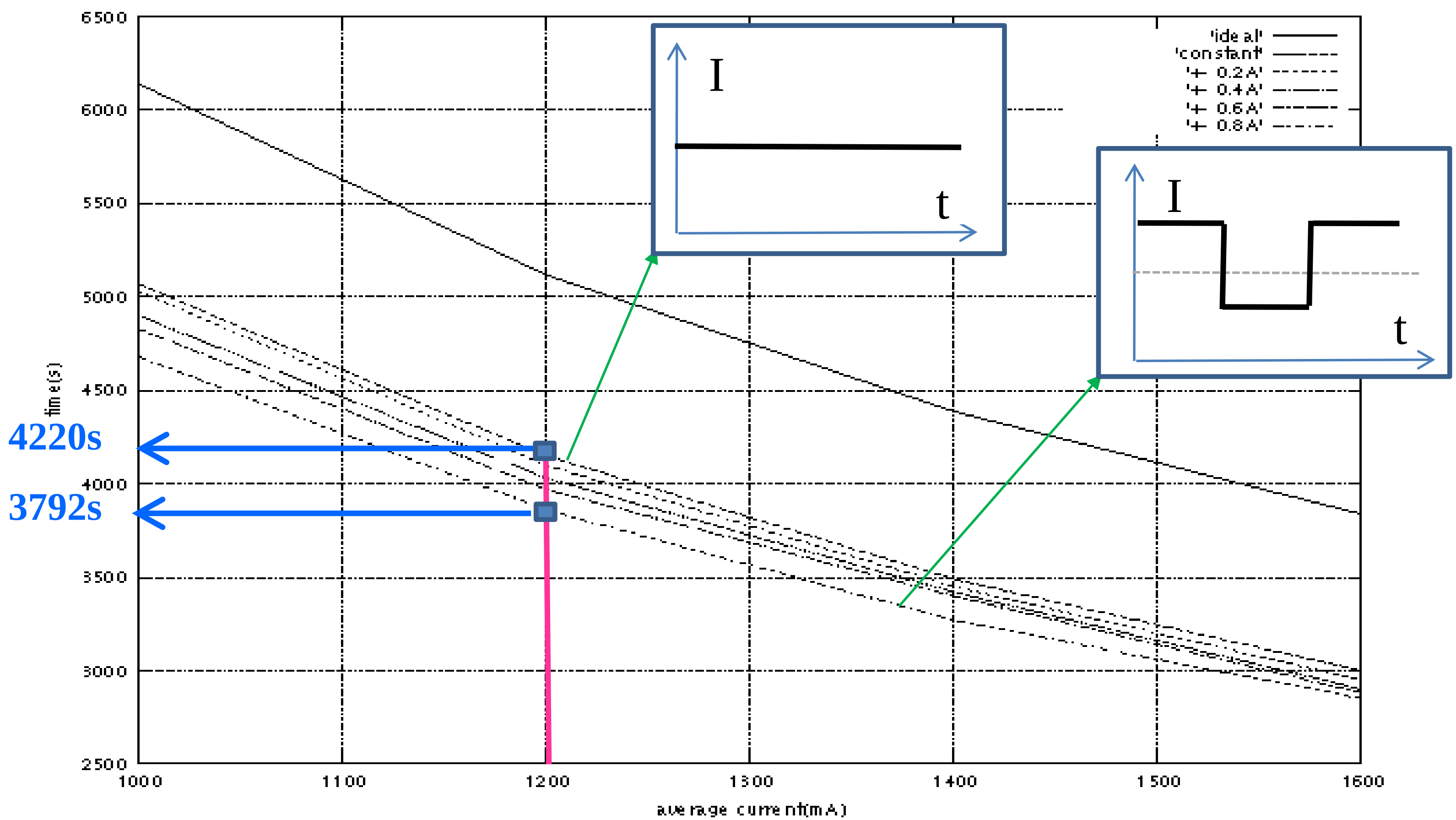
Battery non-idealities (1): Rated Capacity Effect

The amount of energy a battery can provide depends on the current drawn from the battery



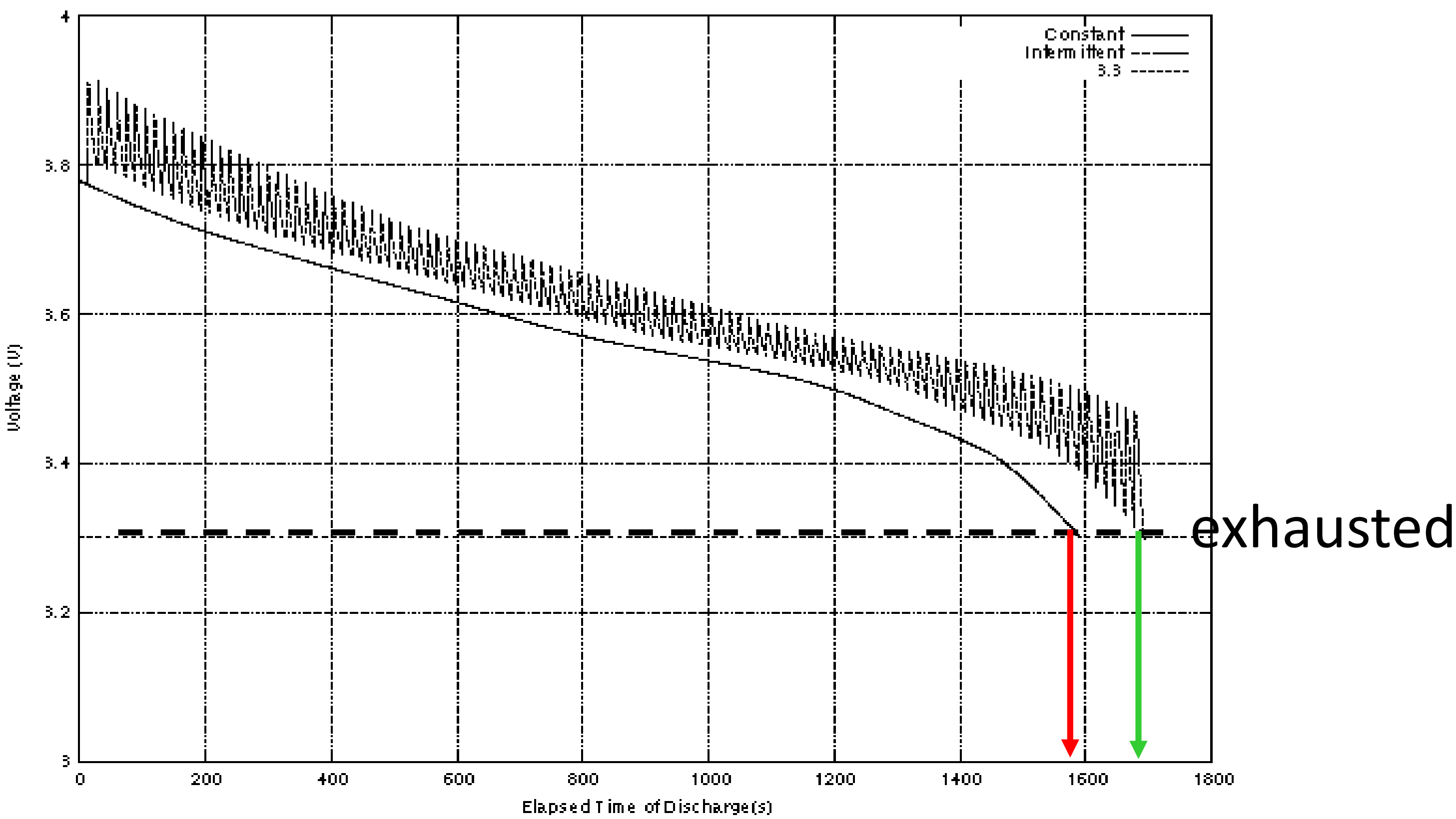
Battery non-idealities (2): Dependence on dynamics

The actual load profile matters, not just the average current load



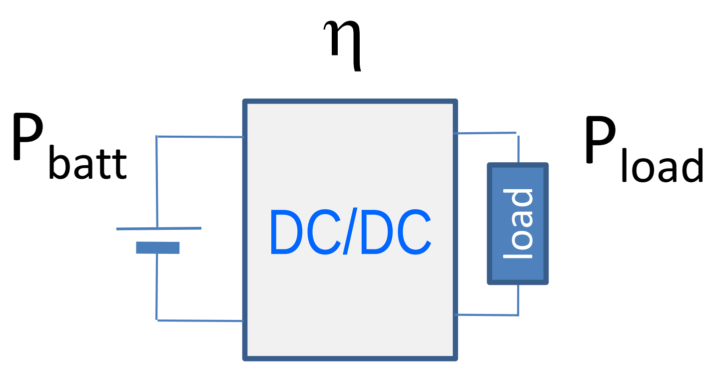
Battery non-idealities (3): recovery

A battery recovers some deliverable charge when it is given some rest.



Main impact of non-idealities

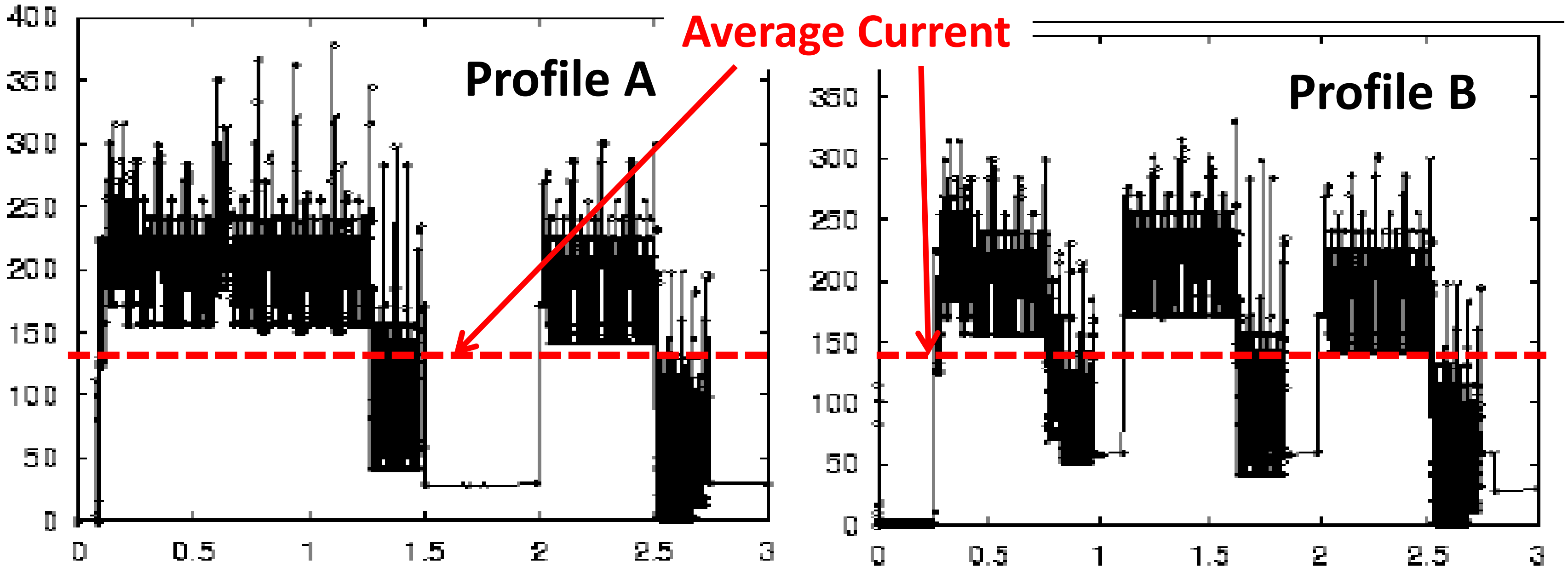
- **Current magnitude impacts battery efficiency**
  - Whenever possible use a smaller current
  - Consistent with "low-power design"!
  - But we have a converter in between…
    - A small load current can become a large battery current depending on the power levels and efficiency!
    - Recall: $I_{batt} = I_{load} * (V_{load}/V_{batt}) * 1/\eta$



Main impact of non-idealities (2)

- **Large current variations impact battery efficiency**
  - Smooth current profile as much as possible (filter?)
  - **Average current (power) is not a reliable metric for battery!**
- **Idle times can increase battery efficiency**
  - Contrast with smoothing of current variations…?
  - A minor effect, can neglect in electronic devices

Minimum avg. current ≠ max battery lifetime!



[Source: Intel]

Profile	Average Current(mA)	Battery Life (ms)	Specific Energy(Wh/Kg)
A	123.8	357053	15.12
B	124.2	536484	18.58

Battery Models

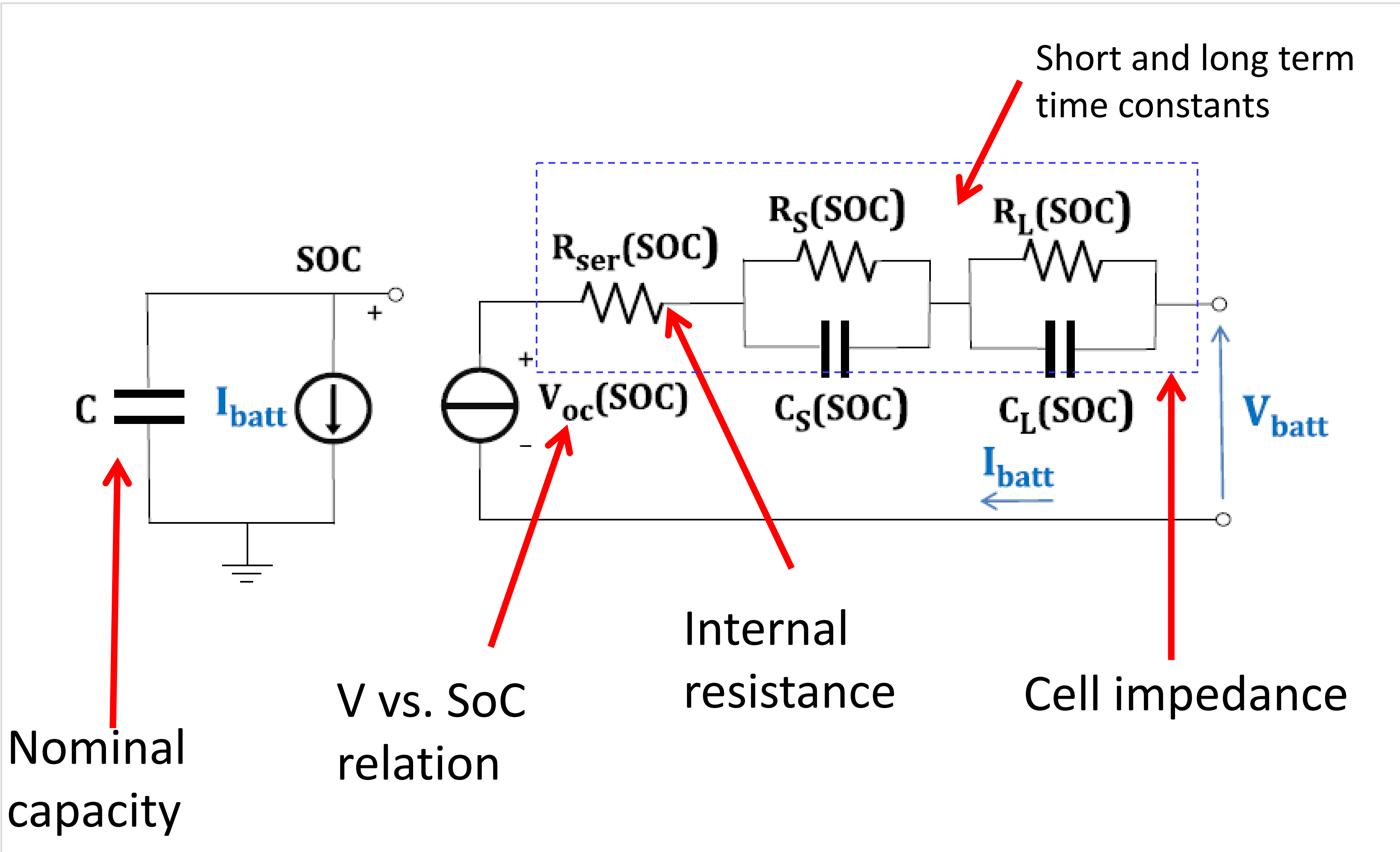
- Three main categories:
  - Electrochemical
    - Accurate, but unfriendly for electronic designers.
  - Analytical
    - The battery is described with equations relating relevant figures of merit (e.g., load).
  - Circuit-based
    - Suitable to be integrated in a simulation environment.

Analytical Models: Peukert's law

- Energy capacity: $\mathbf{C = I^n \times t}$
  - t = discharge time
  - I = discharge current
  - n = Peukert's coefficient
    - = 1 for ideal battery
    - 1.1-1.3 for real batteries
    - depends on chemistry and design

- Good first order approximation
  - does not capture **dynamics of discharge profile**
  - **Popular model in automotive!**

Circuit-Based Models



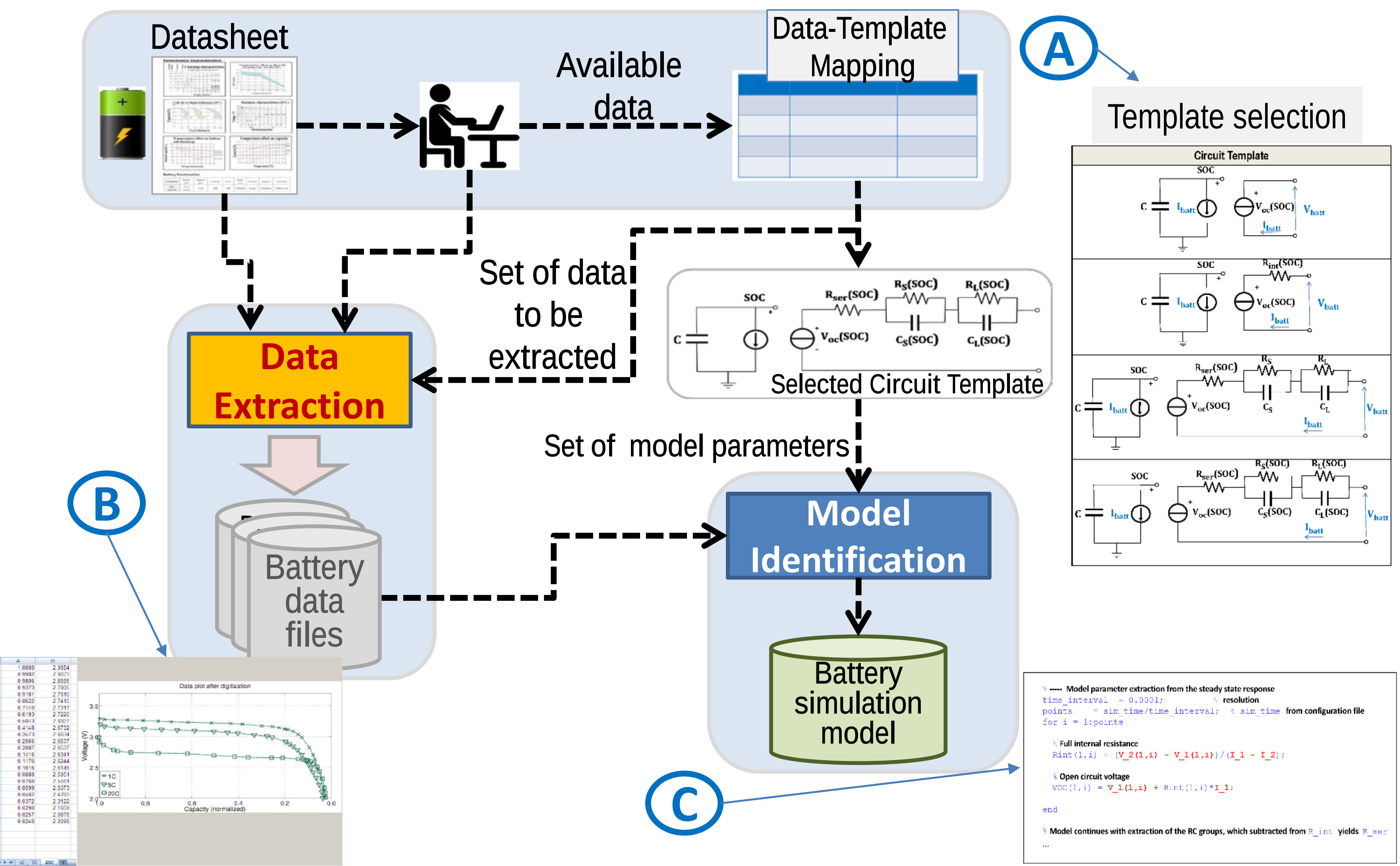
Identification of Model Parameters

- Model is very practical…

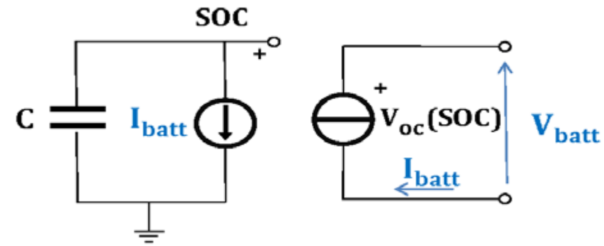
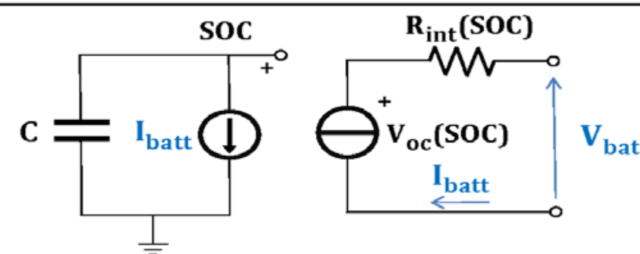
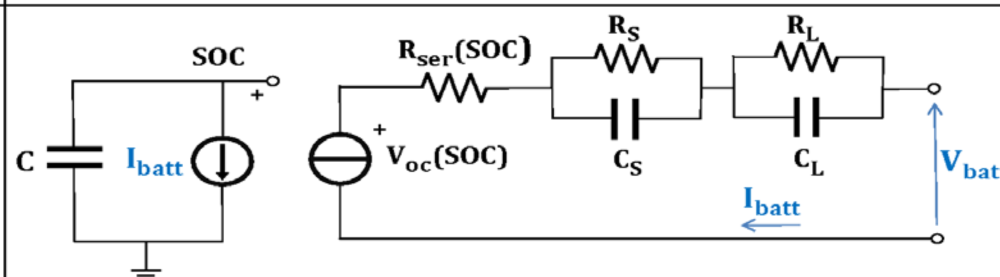
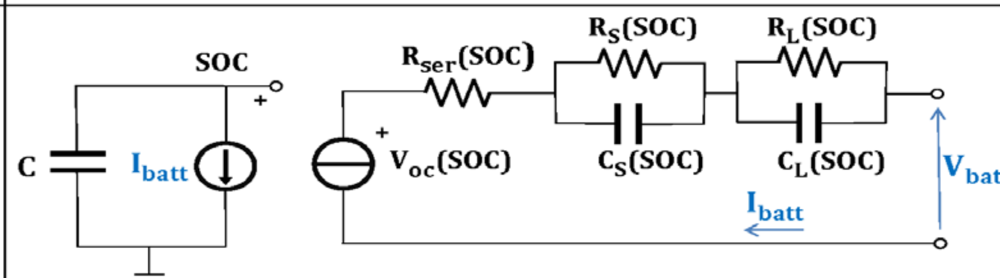
- …But what if I am a system designer and:
  - have no access to measurements (nor expertise)
  - want to explore different battery options?

- Here is where our approach works
  1. **Use only publicly available data**
  2. **These data DRIVE the degree of complexity of the resulting model**

Proposed Battery Modeling Flow

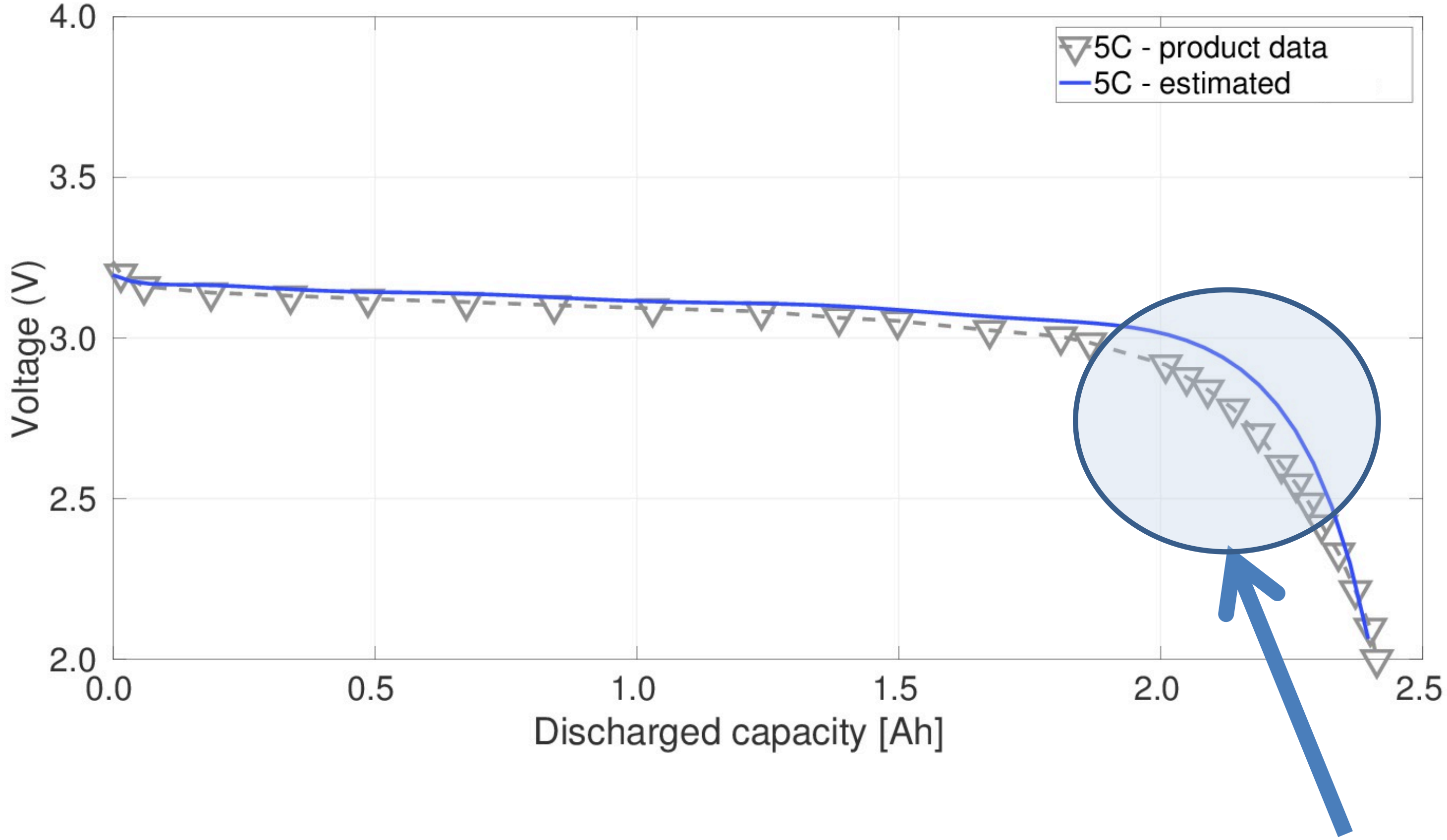


Data Template Mapping Table

Type	Available Data	Circuit Template
1	• 1 V vs. Capacity (or SOC) curve	
2	• >1 V vs. Capacity curves at different currents **OR** • 1 V vs. Capacity curve + internal resistance	
3	As for Type2, plus: • 1 V vs. t curve for a current pulse	
4	As for Type 2, plus: • 1 V vs. t curve for a set of current pulses	

Simulation Results

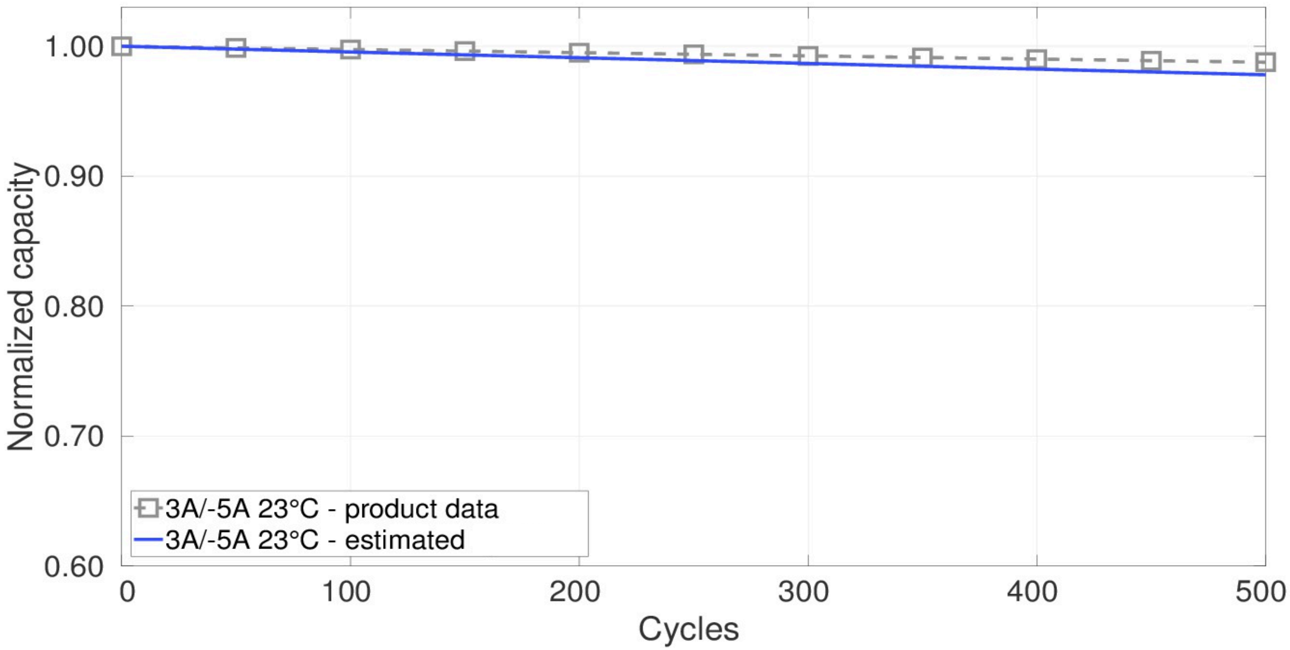
- Results for the steady-state response



- Avg. error: below 0.5% - Max error (knee region): 7%

Simulation Results (2)

- Results for the cycle life



- Operating temperature 23°C – charge current 3A – discharge current 5A

- Max error 0.98% after 500 cycles

Conclusion

- Battery modeling is essential for effective power/energy assessment of an electronic systems.
- Data availability may become an issue:
  - Measurements are costly and time consuming.
  - Public datasheets report limited information.
- Our methodology allows designers to:
  - Automatically generate different equivalent electrical circuit models by mean of a modular template
  - Accounts for 2^{nd} order battery effects like temperature and aging