Electric Vehicle (EE60082)

Lecture 15: BMS part5

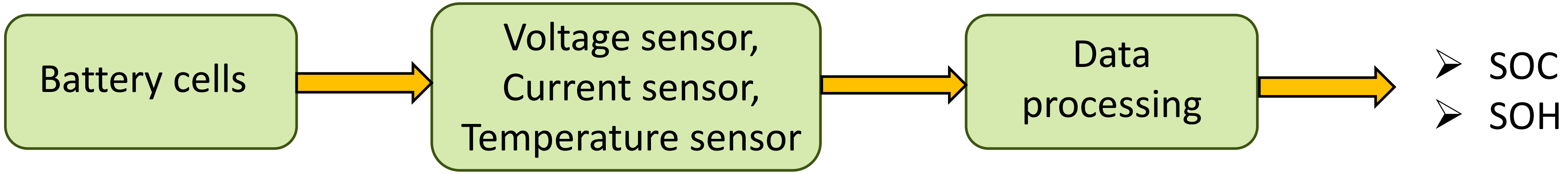
DR. SHIMUL K. DAM

ASSISTANT PROFESSOR,
DEPARTMENT OF ELECTRICAL ENGINEERING,
INDIAN INSTITUTE OF TECHNOLOGY (IIT), KHARAGPUR.

SOC Estimation (recap)

Accurate SOC estimation needed to-

- estimate available battery backup – reduce range anxiety



- SOC estimation methods,

1. OCV method;
2. Coulomb Counting method;
3. Other methods: model based, data driven, etc.

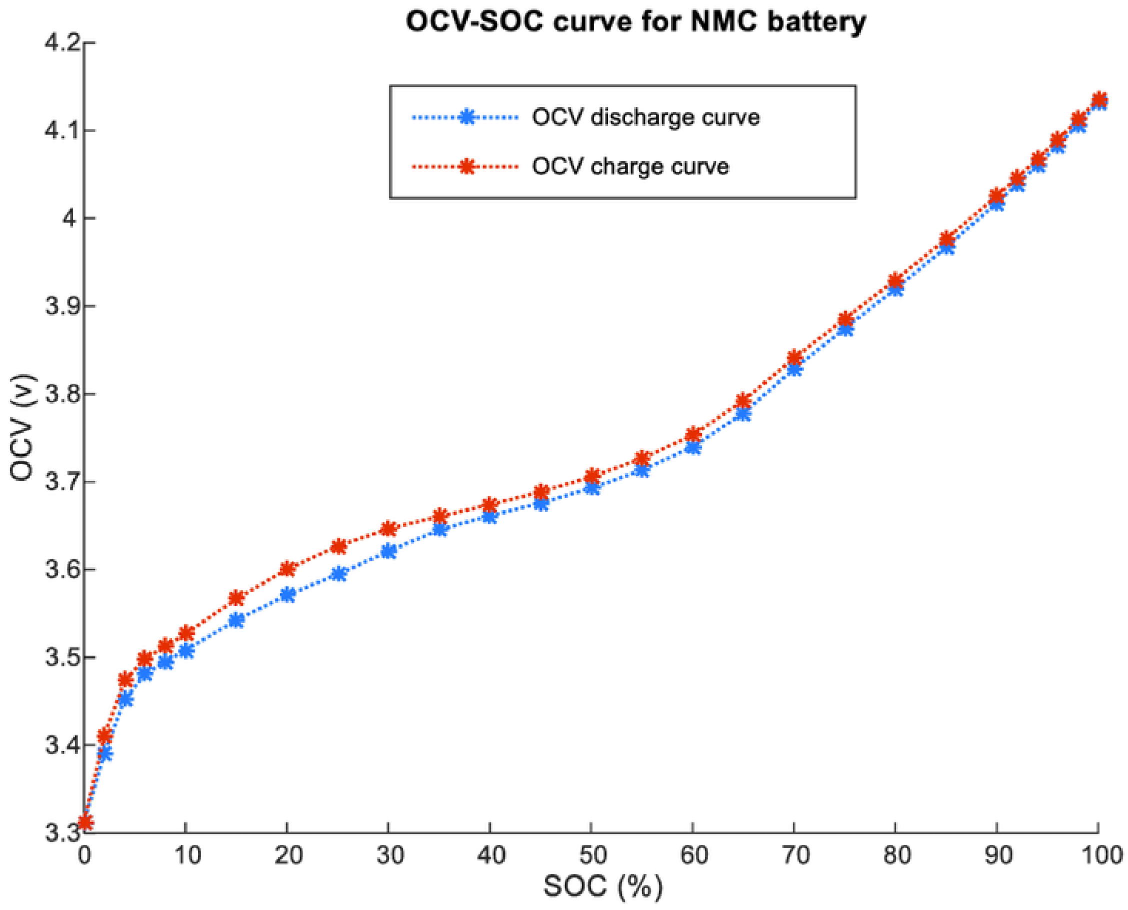
OCV Method (Look-up Table) (recap)

Pros:

- Most accurate method for new cell under rest condition;

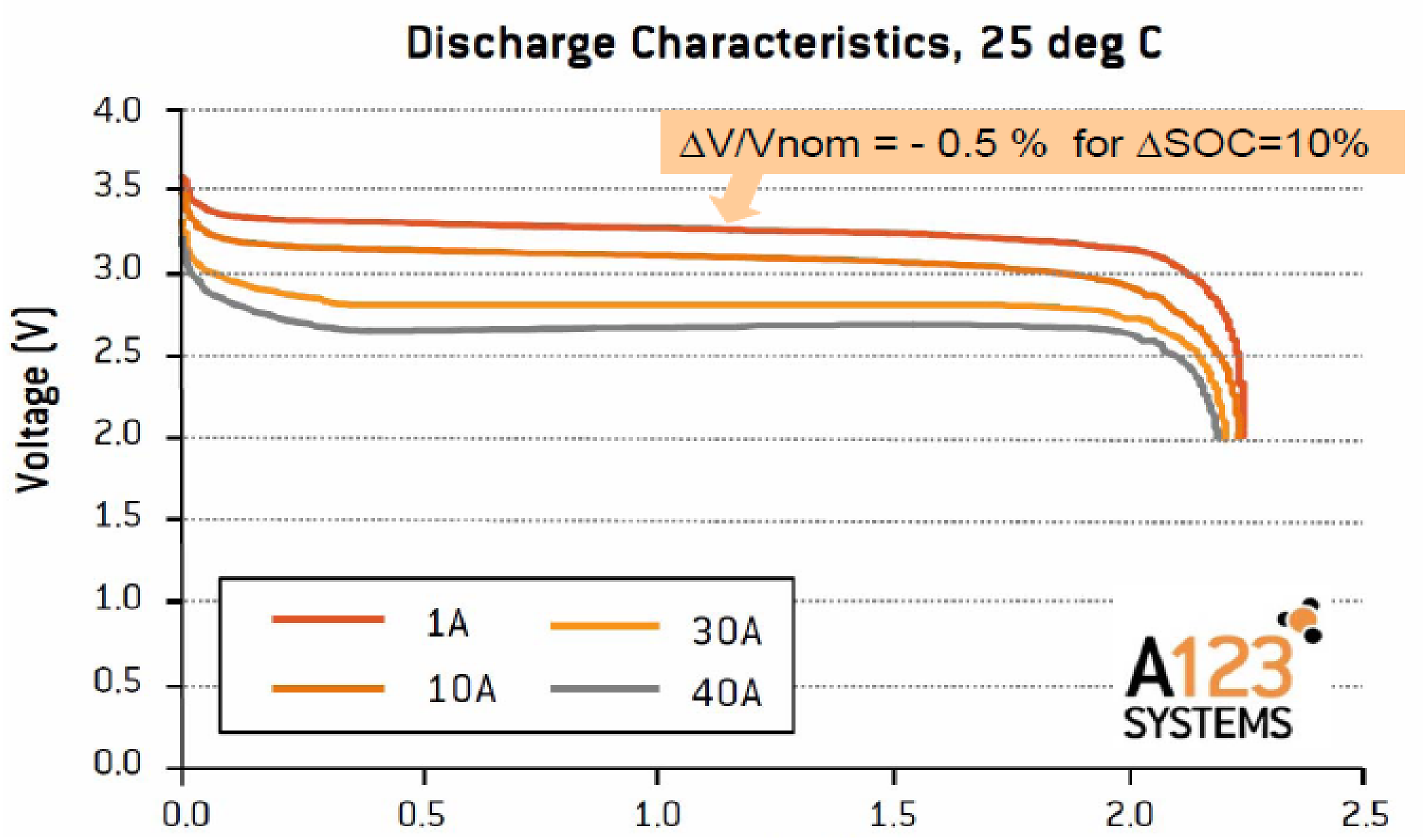
Cons:

- Not applicable in most applications;
- Not accurate for the aged cell;
- Can be difficult if the SOC curve is flat.



Case 2 (recap)

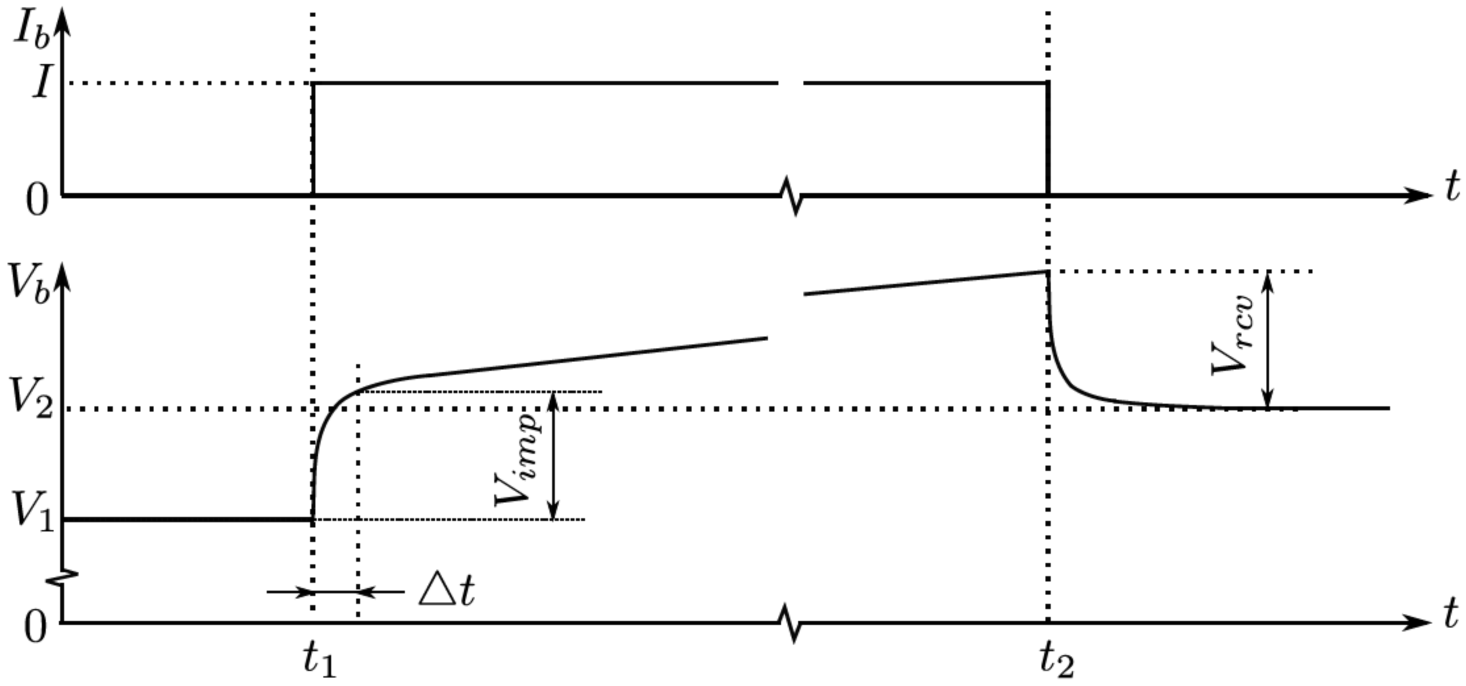
Example of a LFP lithium cell (Lithium Iron Phosphate)



DOD (Ah)

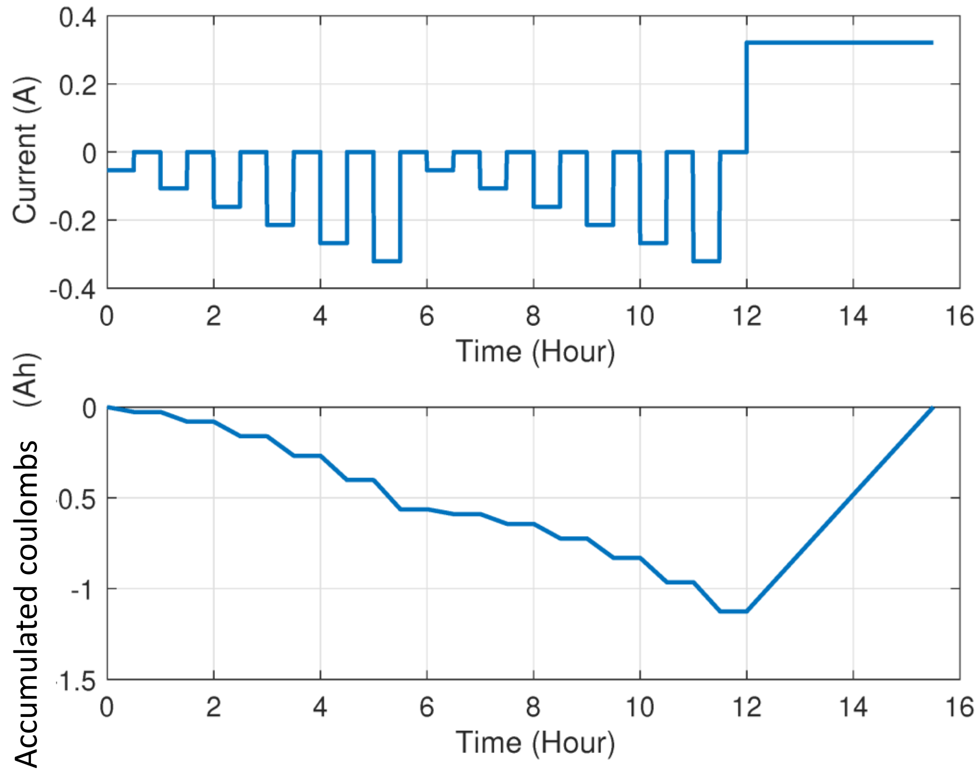
OCV Method: Limitations in practical conditions (recap)

- OCV measurement not possible when battery is in use
- Not feasible to use in EV application

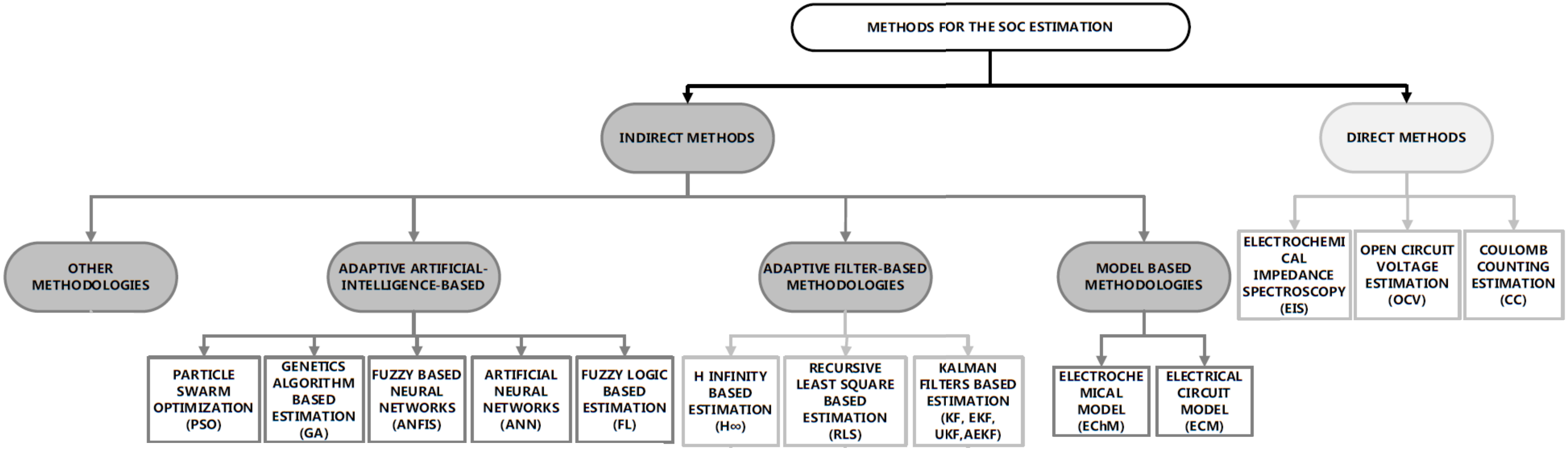


Coulomb Counting (recap)

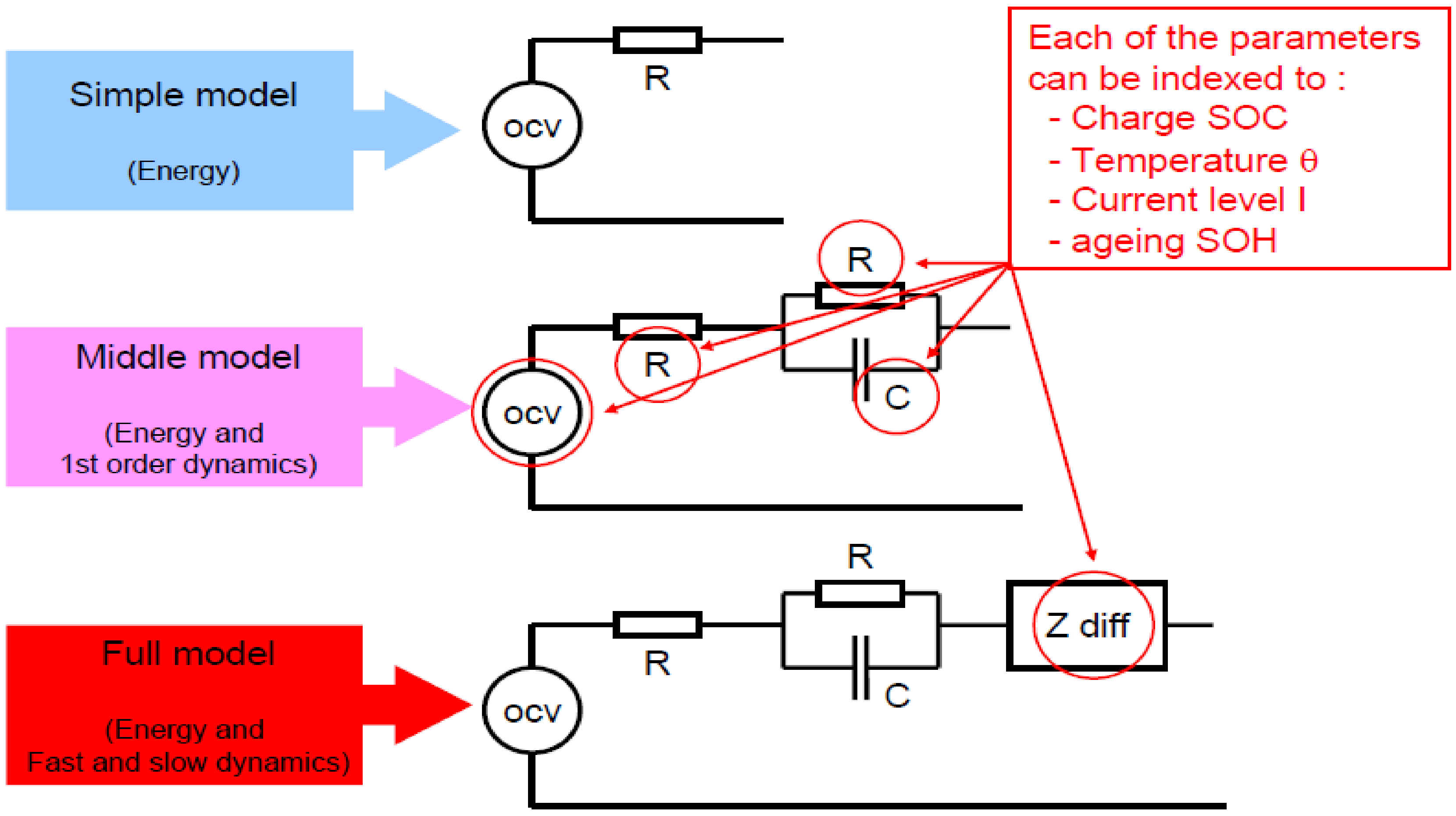
- Method:
  - Integrate battery current over time
  - Calculate total charge spent from the integration of current
  - Estimate total spent charge from fully charged condition
- Pros:
  - Simplest method among all.
- Cons:
  - Error accumulation if there is offset error in current sensor
  - Error accumulates over multiple cycles if battery is not fully charged
  - Can not accommodate for aging effect, temperature dependence, current dependance of SOC, etc.
  - Does not consider self-discharge



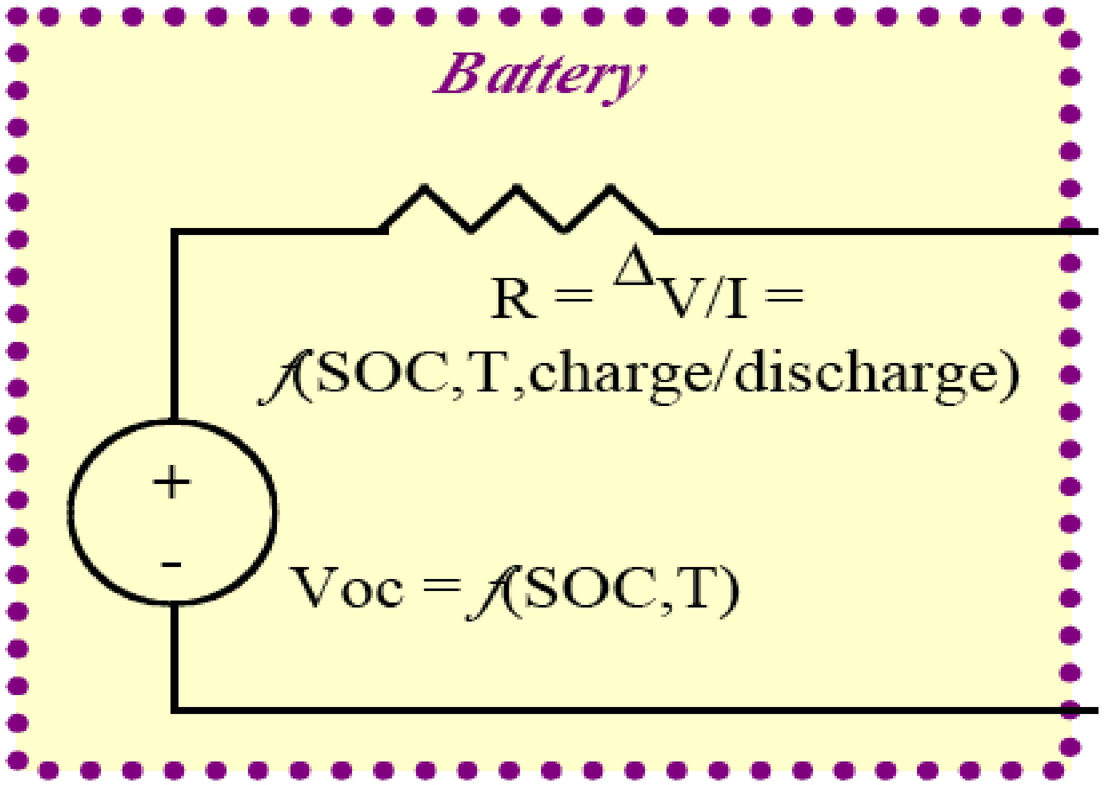
Other methods (recap)



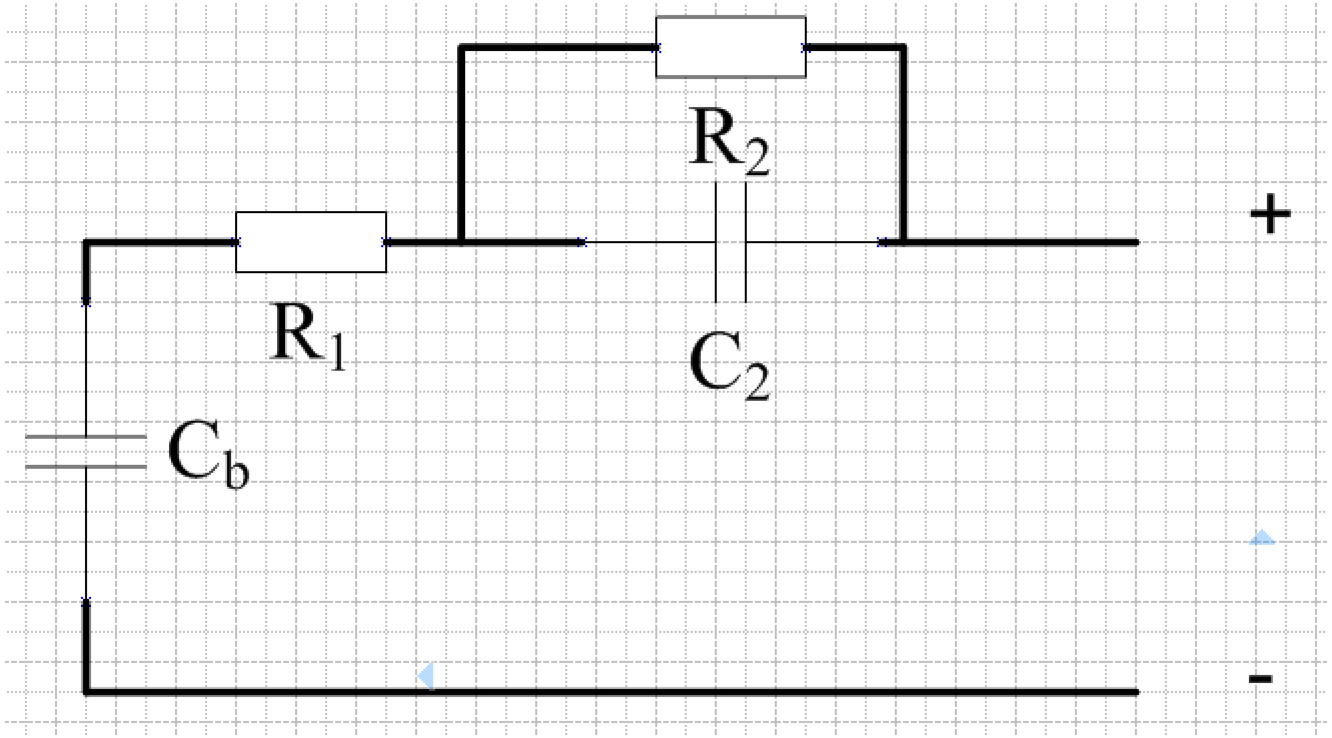
Electrical Circuit Model (ECM) (recap)



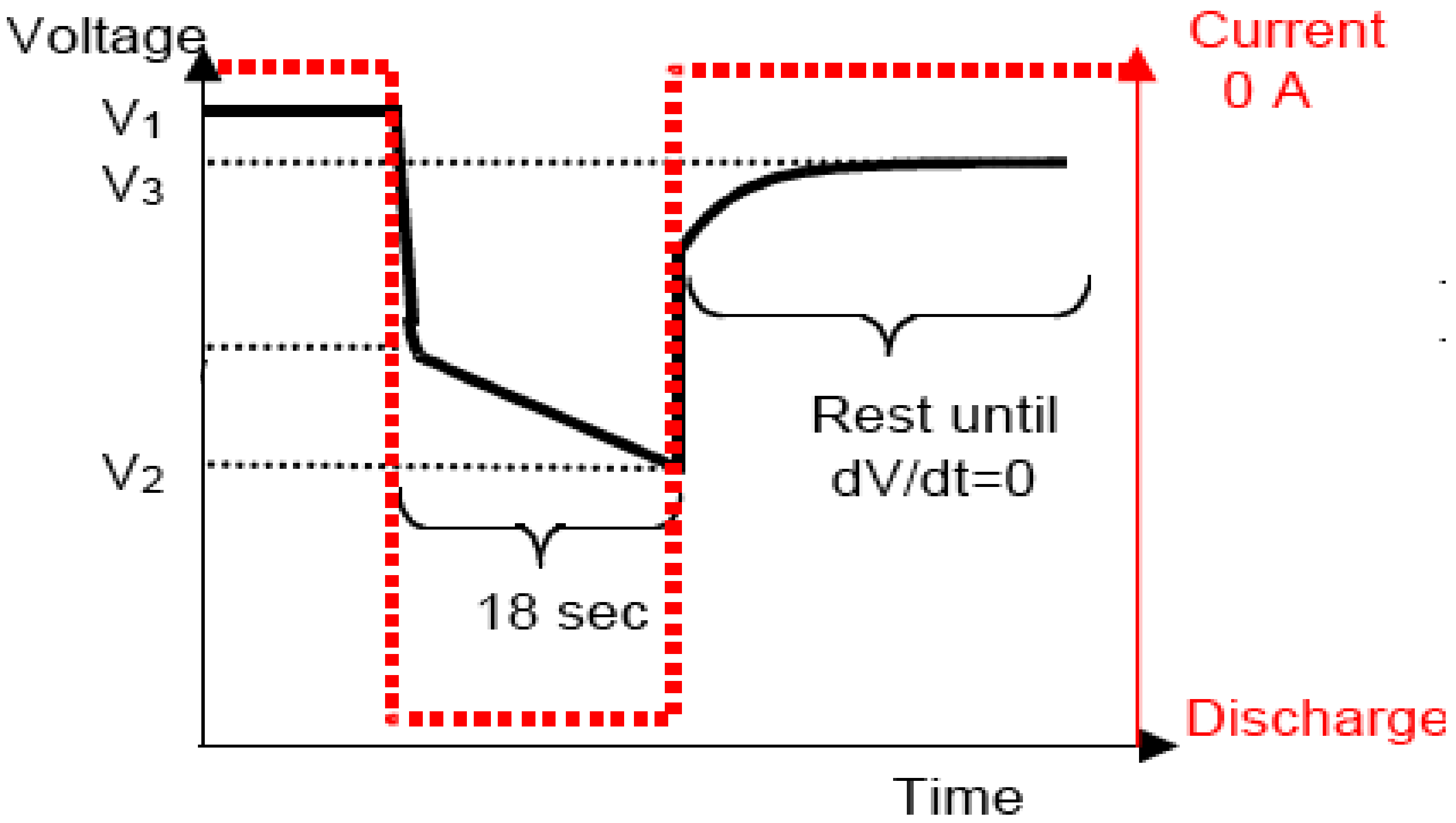
Simple Model (recap)



Middle Model (recap)



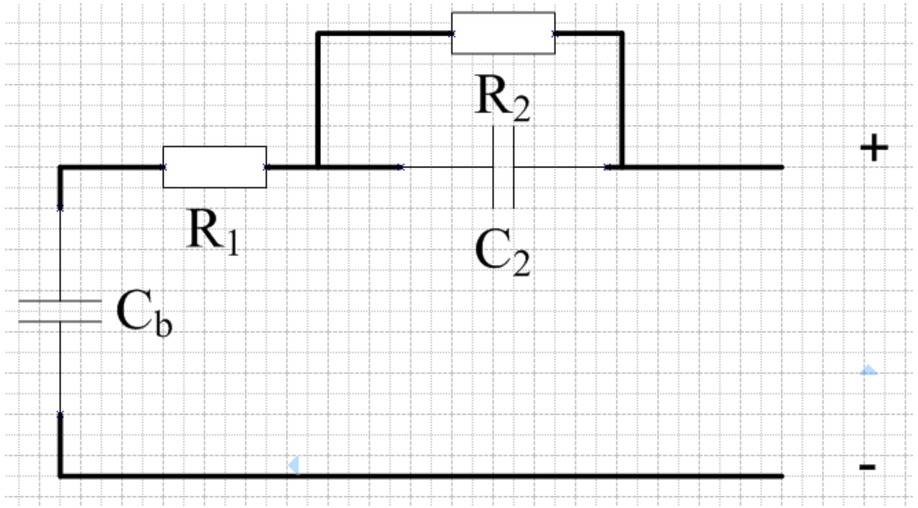
Pulse Testing for Middle Model (recap)

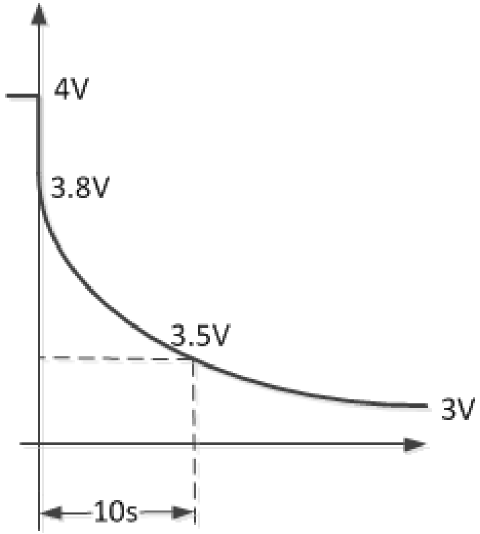


NREL / SAFT

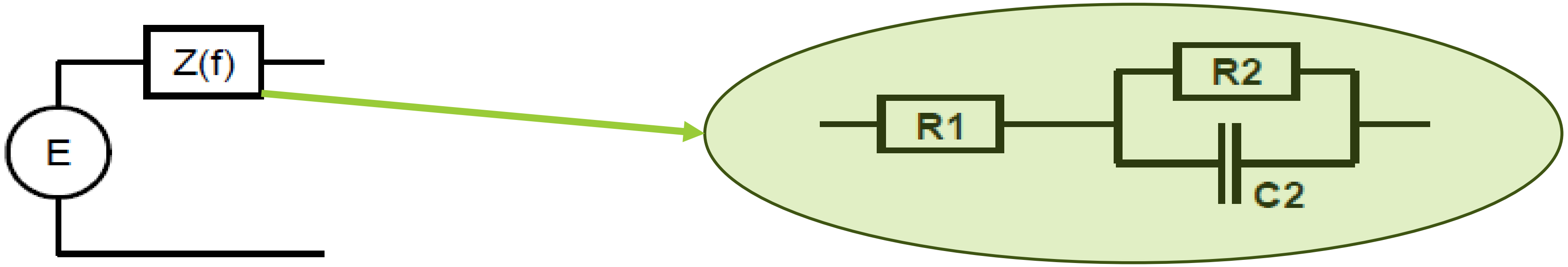
Practice (1) (recap)

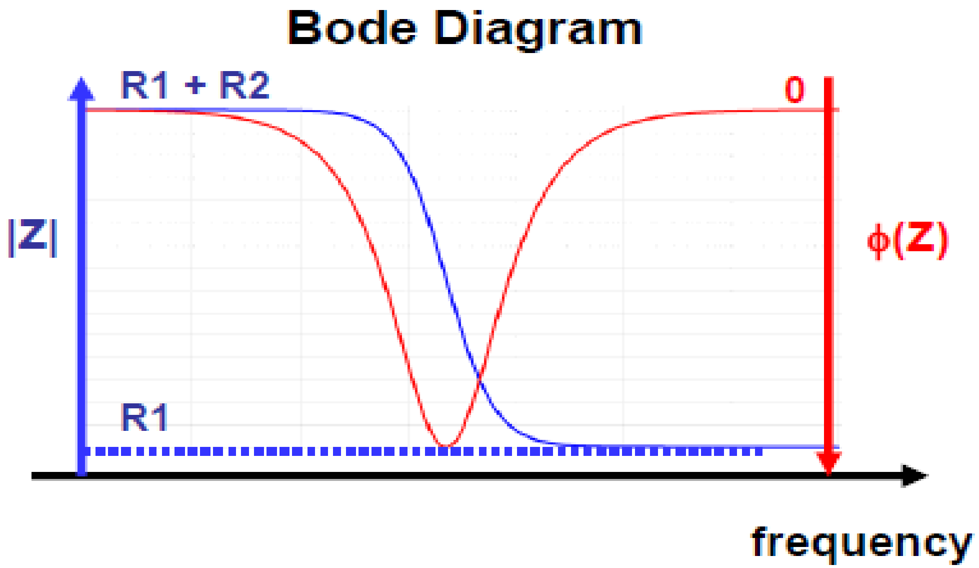
A battery is modeled as the left figure. At t=0 a 20A discharging current is imposed. The battery voltage sharply drops to 3.8V. After 10 seconds the battery voltage drops to 3.5V. At the end the battery terminal voltage settles at 3V. Calculate R_1, R_2 and C_2. Assume battery OCV does not change during this process.

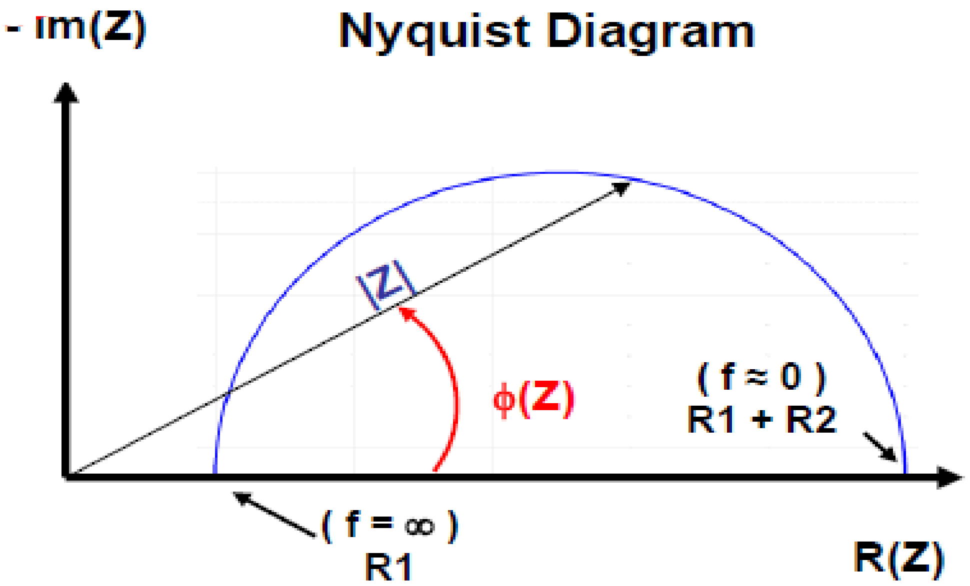




Battery Impedance

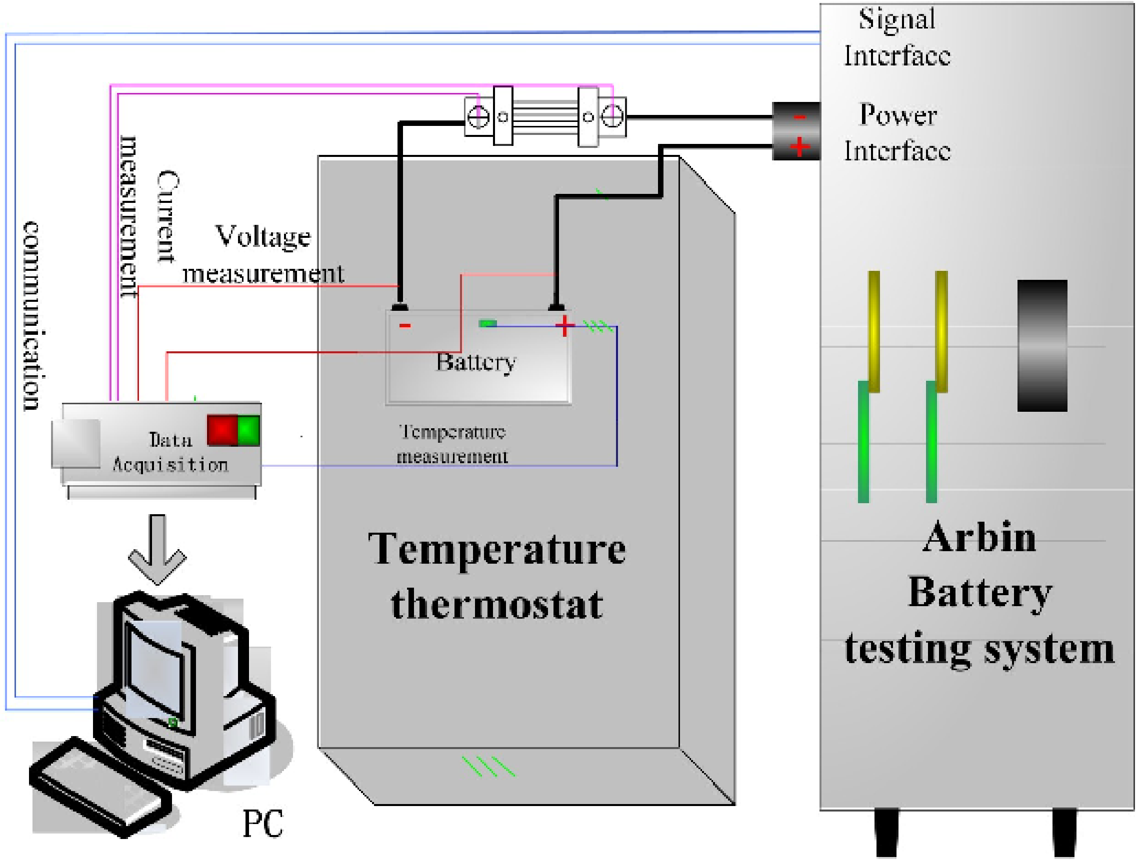






EIS Technology

- Electrochemical impedance spectroscopy (EIS):
  - Measurement of impedance of electrochemical cell over a frequency range
  - Small AC voltage applied on battery terminal
  - Resulting AC current is measured to calculate battery impedance
  - AC voltage can be
    - Single-sine
    - Multi-sine
    - Square-wave
- Requirements
  - Lower frequency range more useful (down to mHz or even µHz range)
  - No change in cell condition during measurements
  - Small amplitude of AC voltage



Why small amplitude?

Small amplitude perturbations bring two advantages:

- First, the effects of perturbations on the studied system will be small, which is beneficial to describe the system more accurately.

- Second, the response of the system will be linear, otherwise impedance can not be defined.

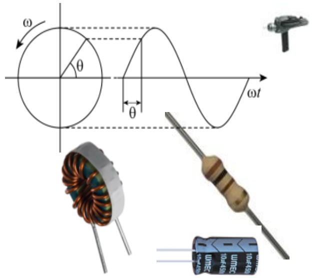
Applied perturbations

$$V_b = V_{b0} + V_{is}\sin(\omega_{is} t)$$
$$I_b = I_{b0} + I_{is}\sin(\omega_{is} t - \phi_{is})$$

Battery impedance

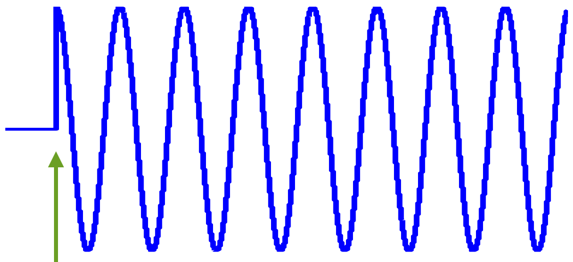
$$|Z_b(\omega_{is})| = \frac{V_{is}}{I_{is}}$$
$$\angle Z_b(\omega_{is}) = \phi_{is}$$

Sinusoidal Steady State Analysis

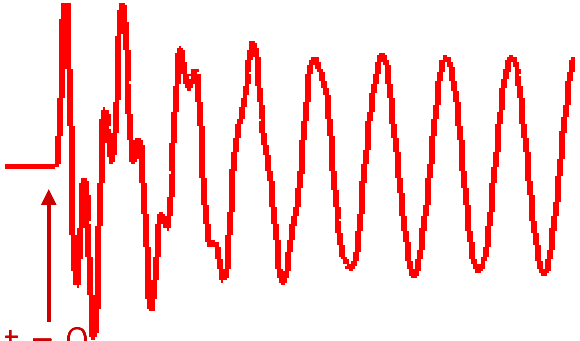


Apply a sinusoid input at t = 0

Input, *u(t)* → **Linear System** → **Output, *y(t)***



t = 0



t = 0

t → ∞

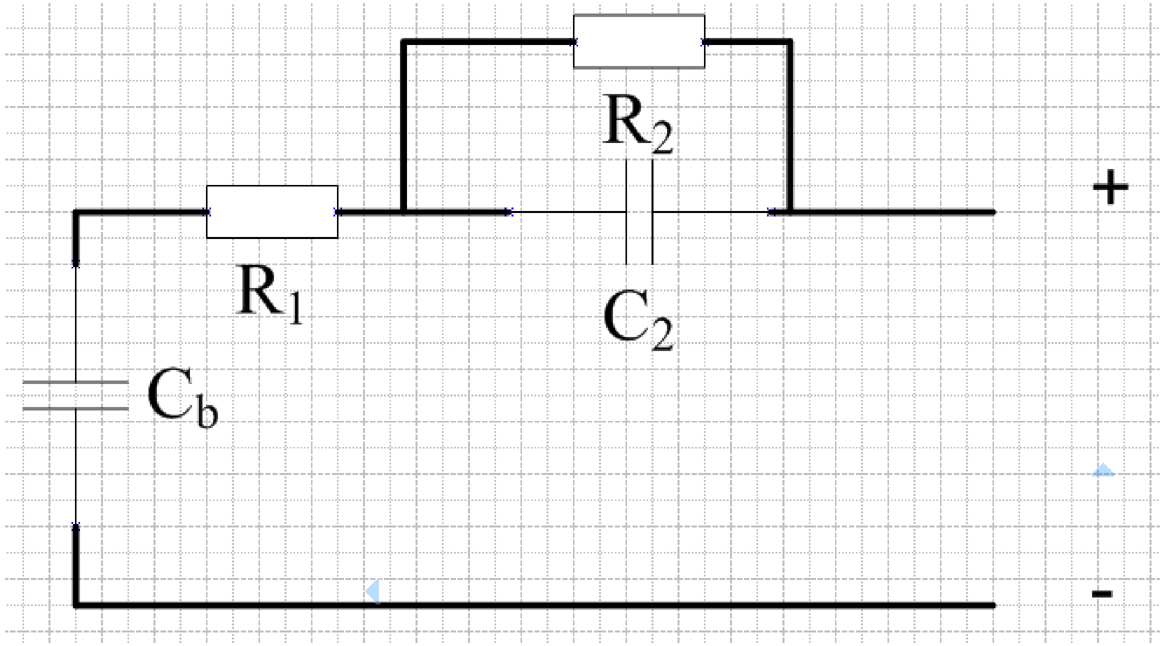
Transient response + Steady-state response

Dies out after some time…how long it takes to die out is a characteristic of the system.

Persists for as long as the system remains excited by the input.

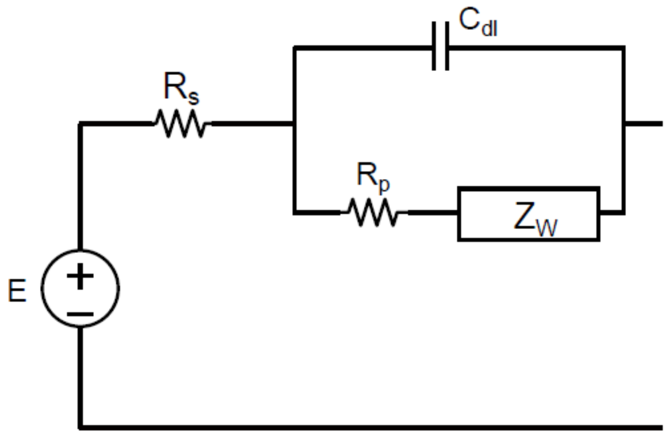
Practice

A battery with OCV=10V could be modeled as the follows. Assume R_1=R_2=0.1Ω, C_2=1F. Now EIS imposes a terminal voltage as 10+0.1sin(2π*50*t). Calculate the battery current.



EIS example

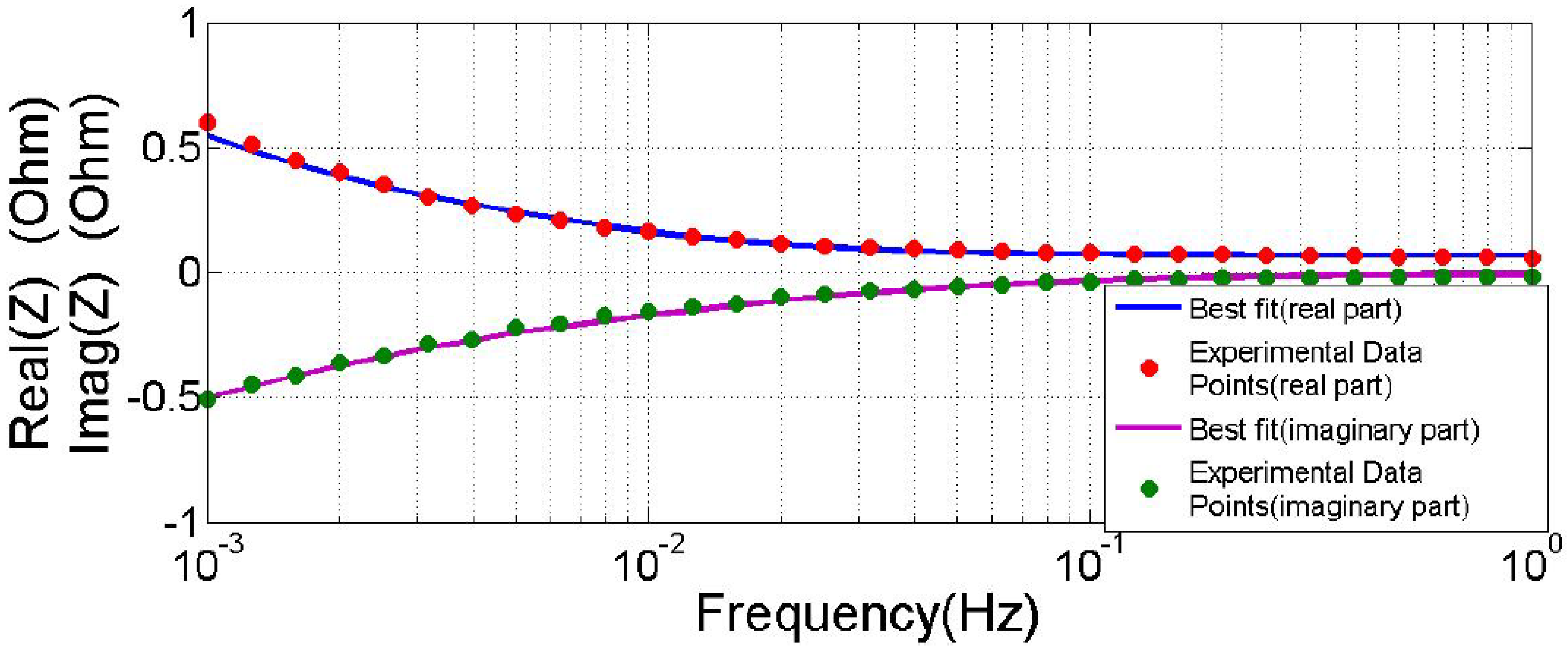
- a complex cell model
  - With Warburg impedance to account for slow dynamics



$$Z_W = W_b(1-j)\frac{\coth(W_c(1+j)\sqrt{\omega})}{\sqrt{\omega}}$$

- Five independent variables
- Many possible combinations of free variables for same value of impedance

Curve fitting for parameter estimation



$R_s = 0.074336\ \Omega$

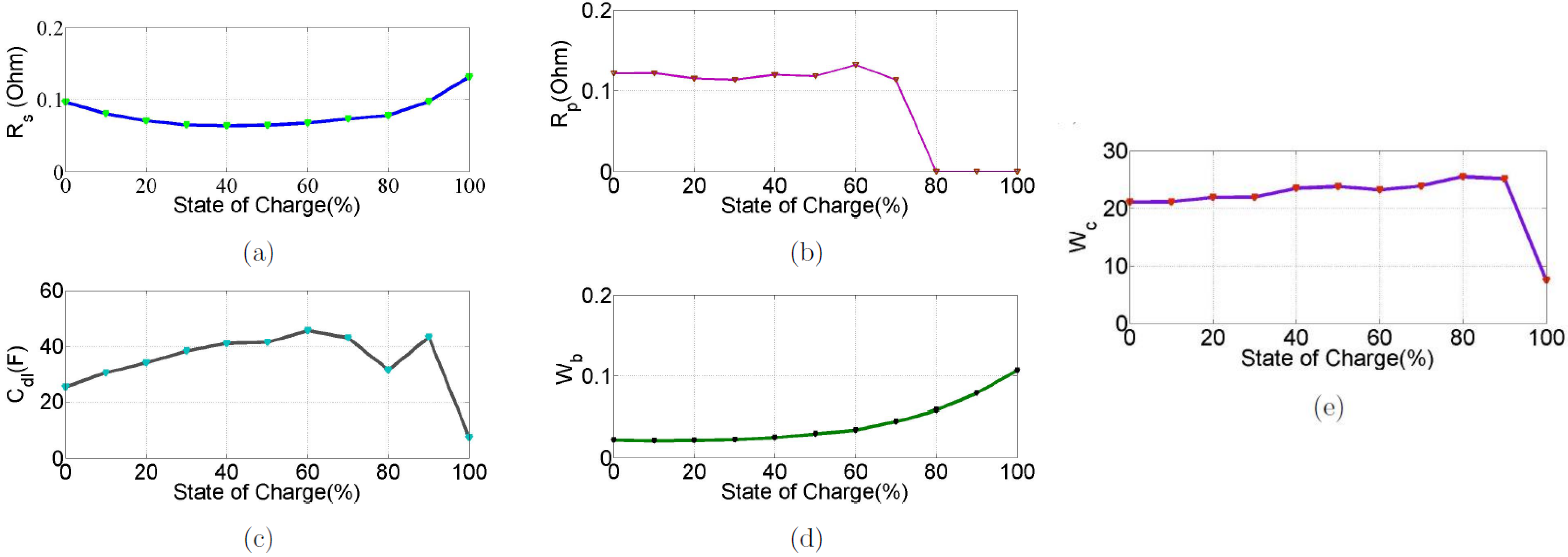
$R_p = 0.173972\ \Omega$

$C_{dl} = 53.848\ \mathrm{F}$

$Wb = 0.0385663\ \Omega(rad/s)^{0.5}$

$W_c = 26.5132.\ (rad/s)^{-0.5}$

Model parameter variation with SOC

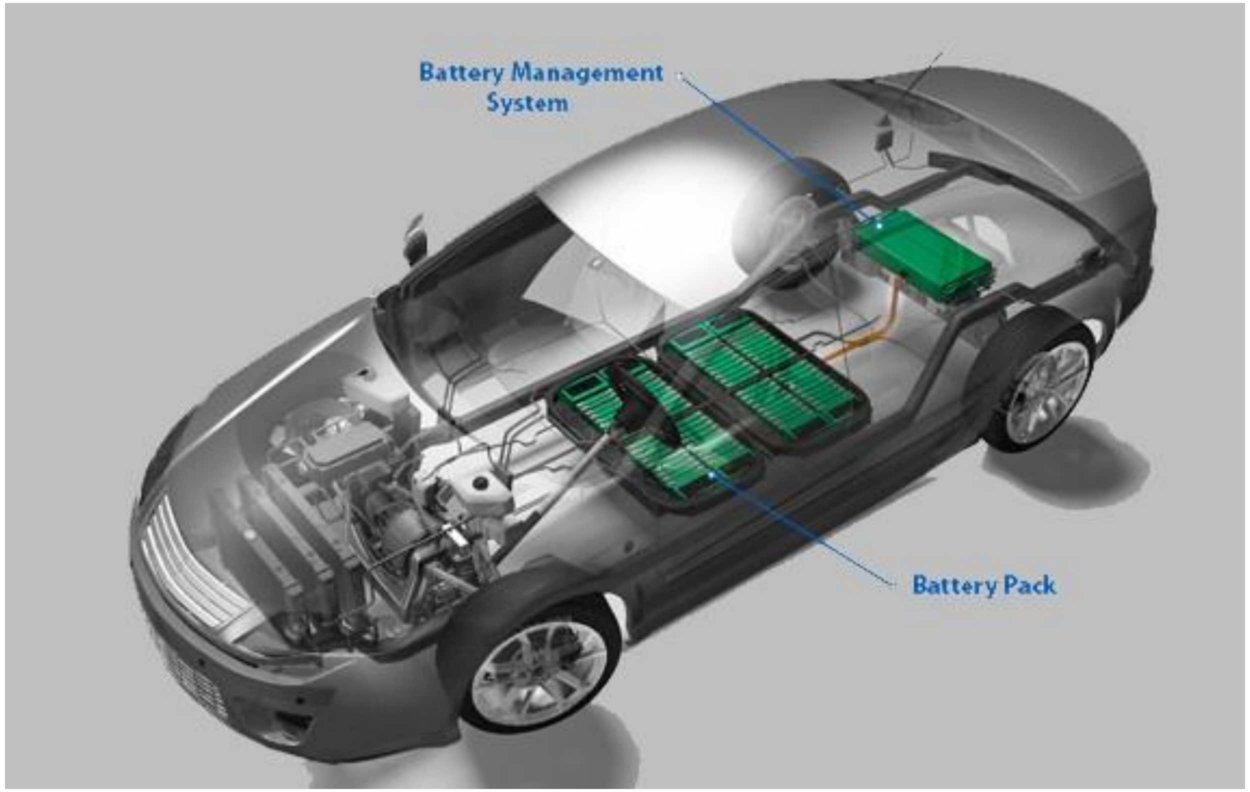


BMS

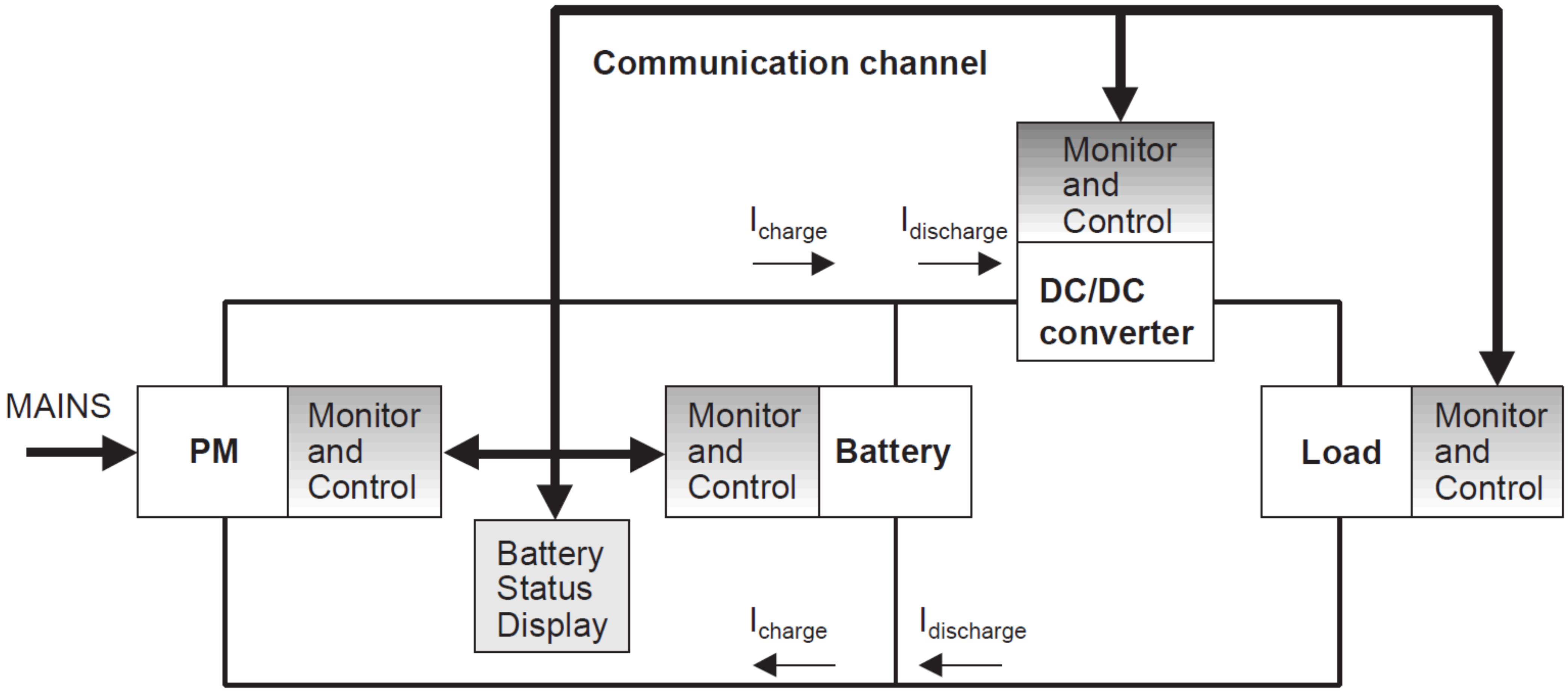
Battery Management System (BMS)

A generic definition of BMS:

- BMS is combination of all the parts of the system that performs one or more of the following functions for the battery pack,
  - Control
  - Monitor
  - Protect
  - Communicate



A generic BMS

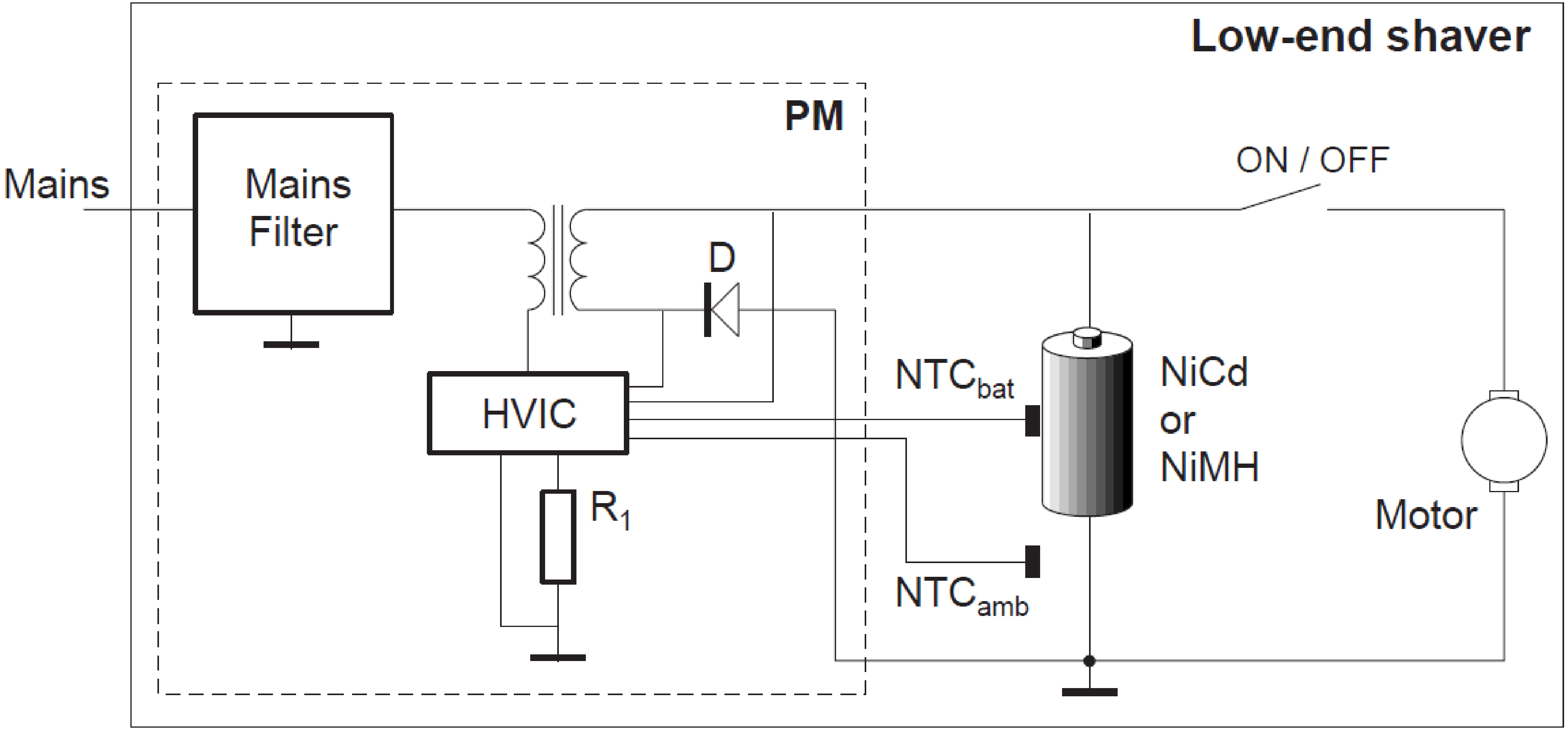


Functions of a BMS

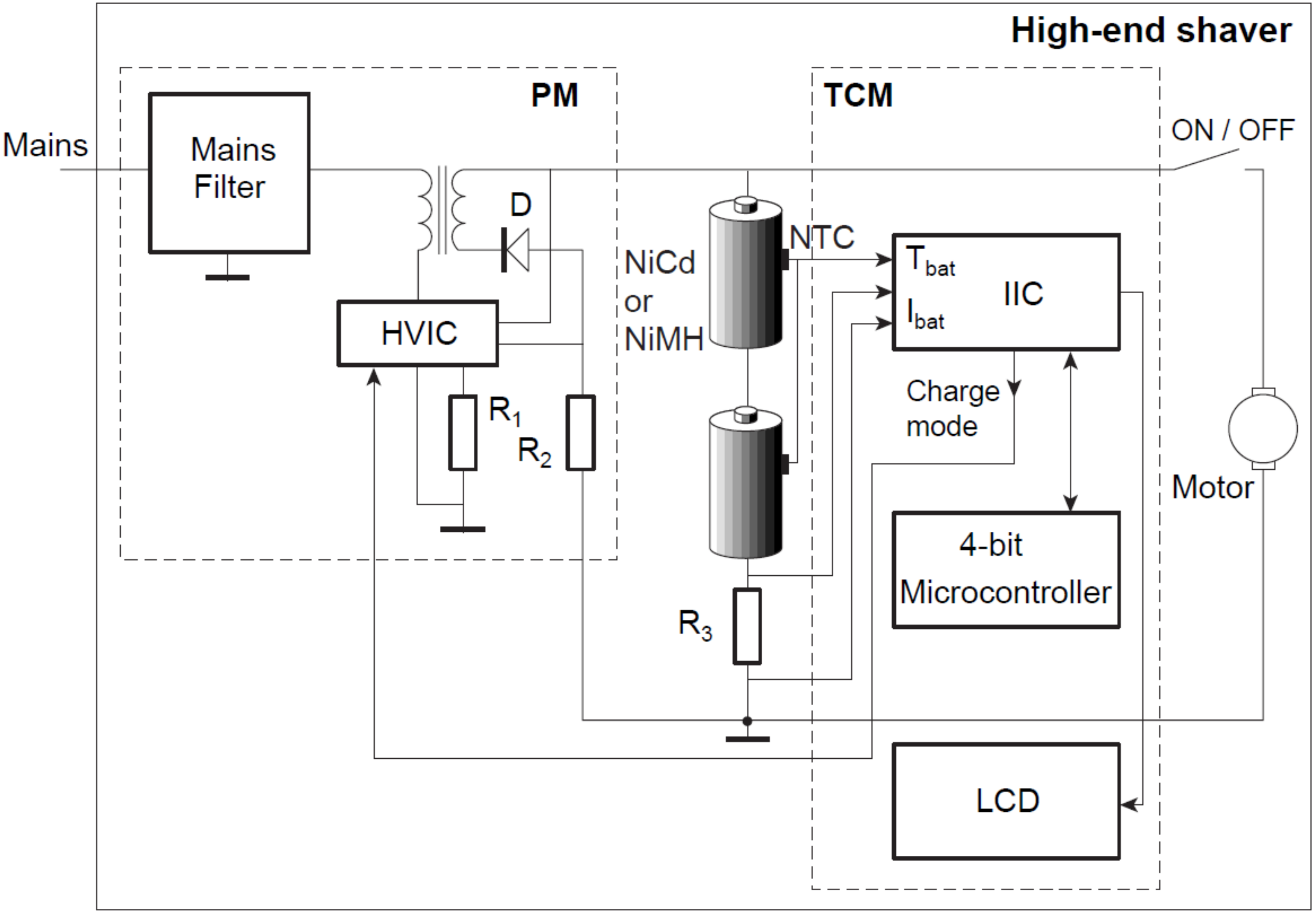
- Number of functions of a BMS depends on the application
- More functions mean higher cost

- BMS functions depend on the following factors
  - The cost of the portable product: cost of the BMS should be small compared to the product cost
  - The features of the portable product: high-end product has more features that need the BMS to be more sophisticated
  - Type of product: Products with high energy demand and frequent use needs more sophisticated BMS
  - Type of battery: some types of cell chemistries need more care and extra protection features

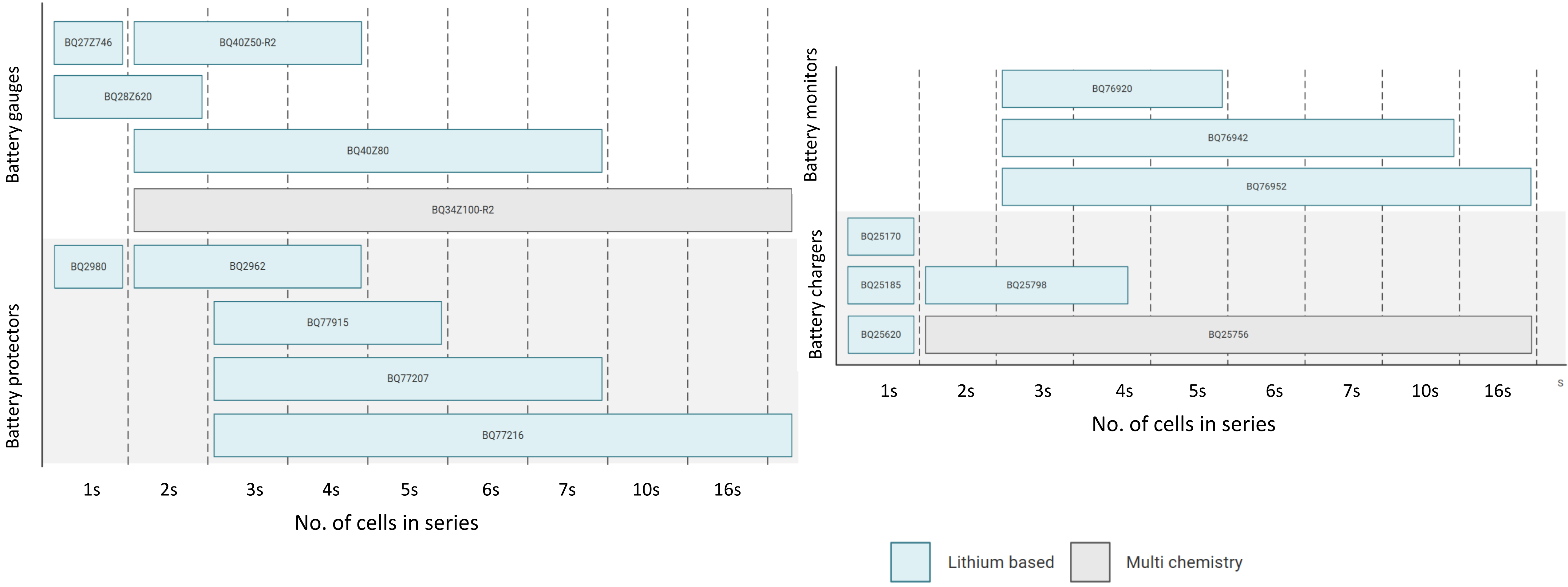
BMS example 1: low-end electric shaver



BMS example 2: high-end electric shaver

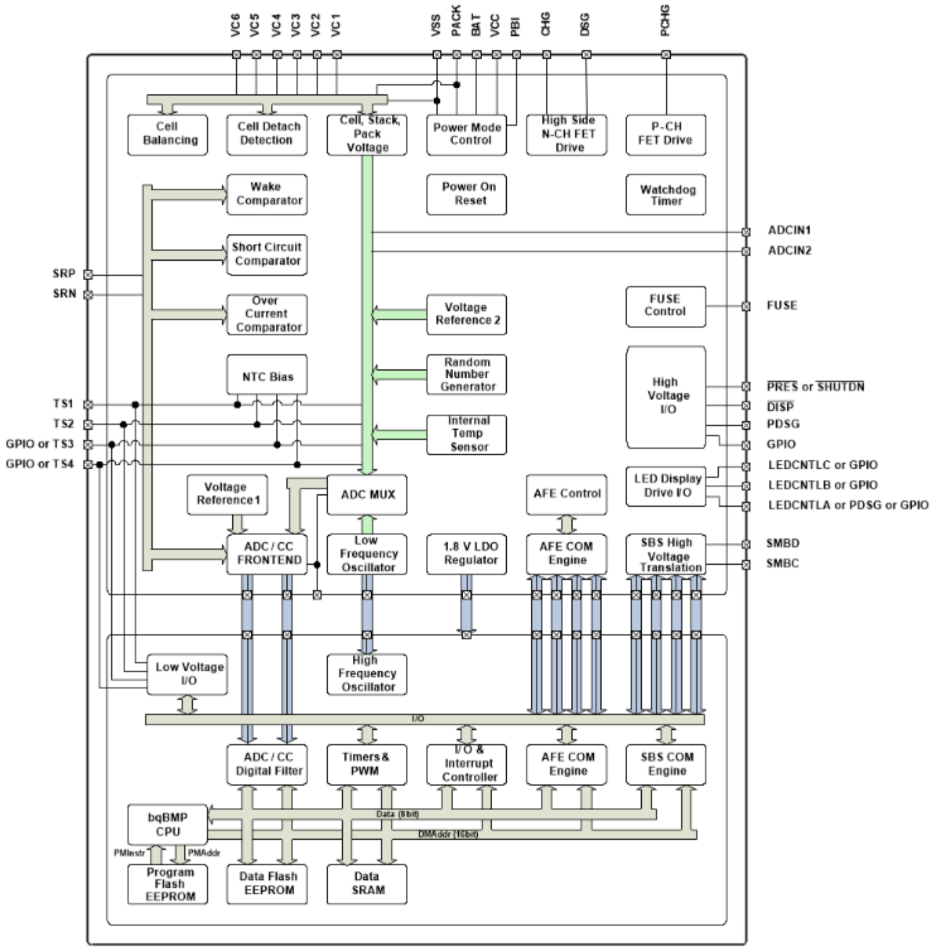


BMS ICs (from TI)



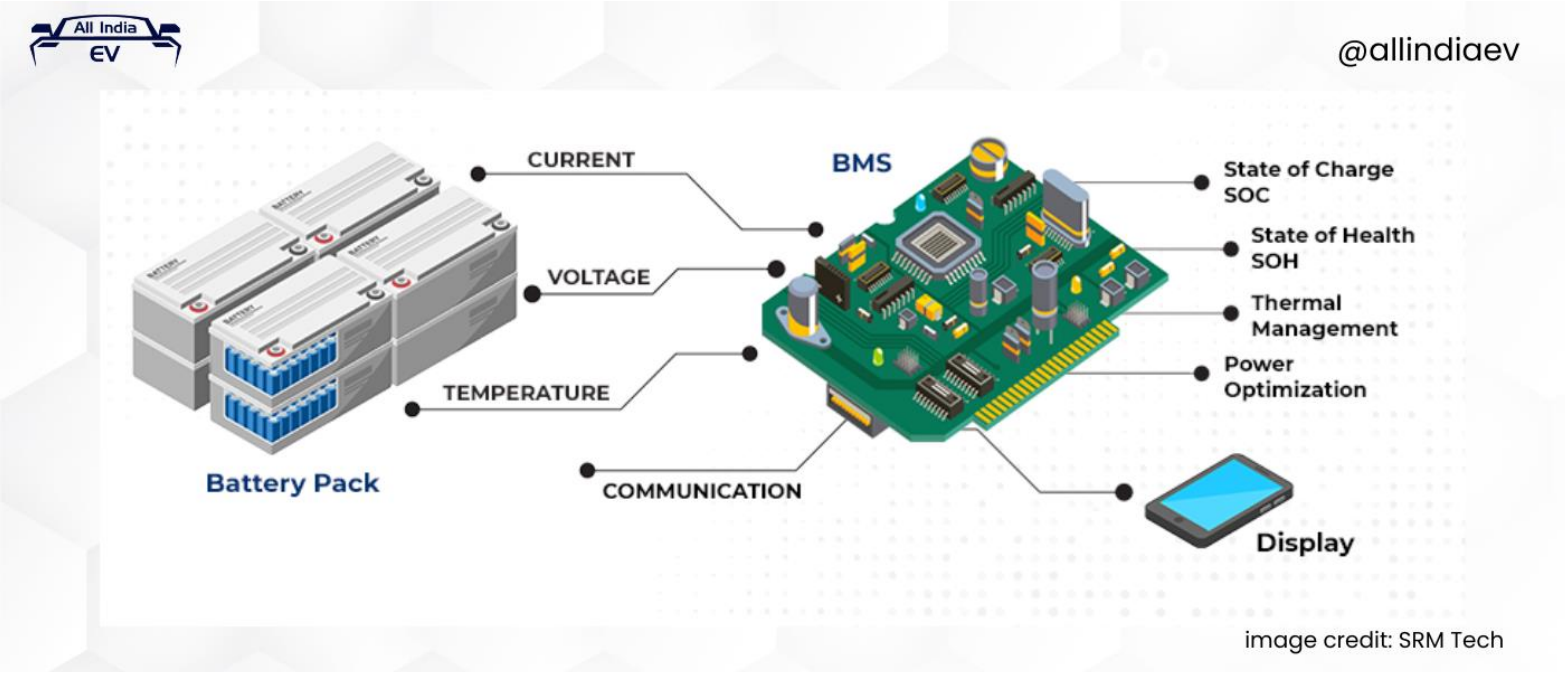
BMS IC example: BQ40Z80

- Fully integrated 2-series to 7-series Li-ion or Li-polymer cell battery pack manager and protection
- Next-generation patented Impedance Track® technology accurately measures available charge in Li-ion and Li-polymer batteries
- High-side N-CH protection FET drive
- Integrated cell balancing while charging or at rest
- Low Power Modes
  - LOW POWER
  - SLEEP
- Full array of programmable protection features
  - Voltage
  - Current
  - Temperature
  - Charge timeout
  - CHG/DSG FETs
  - Cell imbalance
- Sophisticated charge algorithms
  - JEITA
  - Advanced charging algorithm
- Diagnostic lifetime data monitor
- Black box event recorder
- Supports two-wire SMBus v1.1 interface
- Elliptic Curve Cryptography (ECC) authentication
- SHA-1 authentication
- Ultra-compact package: 32-Lead QFN



Functions of a BMS

- In EV, definition of BMS is relaxed to exclude power converters
- Thus, BMS only produces control commands for the charger and load converters in EV
- BMS has to depend on chargers and inverters for complete battery management



Functions of BMS for EV

Main goals of BMS

- Control battery charging and discharging
- Ensure safe operation
- Maximize battery utilization
- Prolong battery life

Challenges of fast charging for BMS

- Higher and faster voltage unbalance
- Higher power loss and cell temperature, leading to cell degradation
- Complicated thermal management

Charge/discharge Control

- Charge with desired profile
- High efficiency energy conversion

Measure and monitor

- Cell voltage, current, temperature
- Collect data for analysis, prediction, and decision making

Protect and bypass

- Detect over-current, over-voltage, over-temperature
- Detect faulty cell and bypass

Cell balancing

- Fast active cell balancing
- Multi-cell to multi-cell balancing with high efficiency

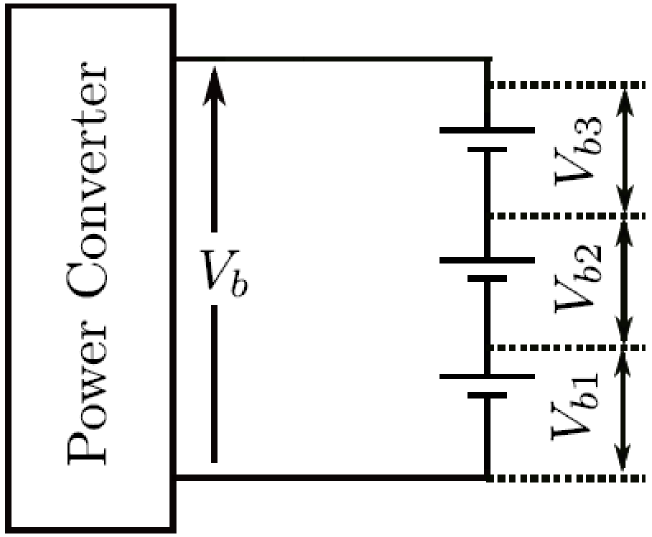
Communication

- Status report
- Data collection
- Charging control

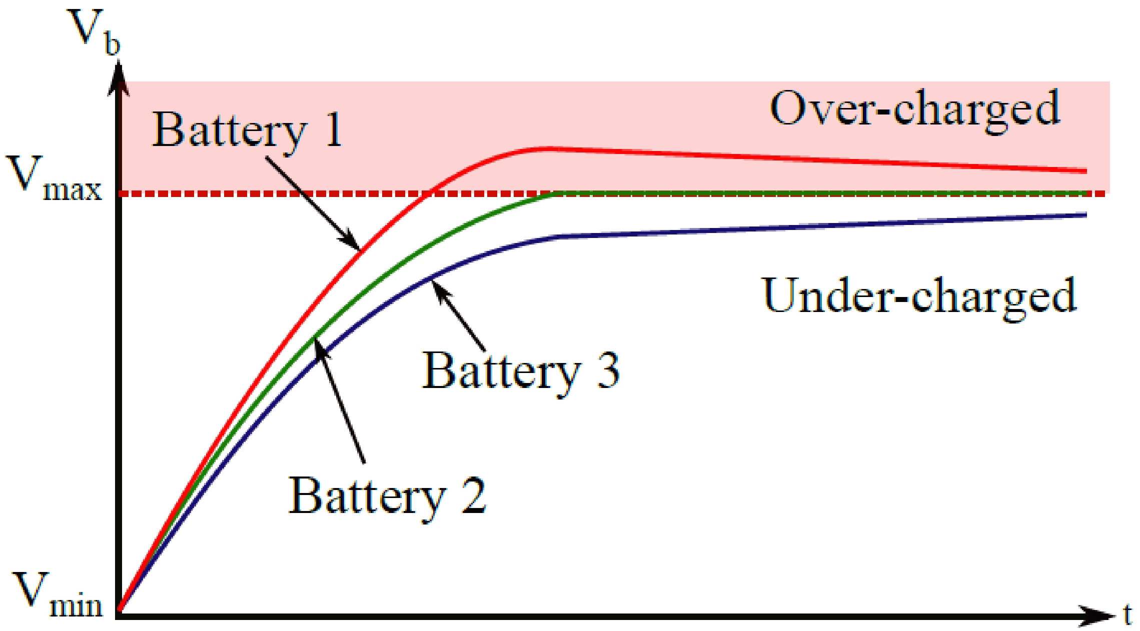
Thermal management

- Embedded cooling in battery pack
- Maintain safe temperature during fast charging

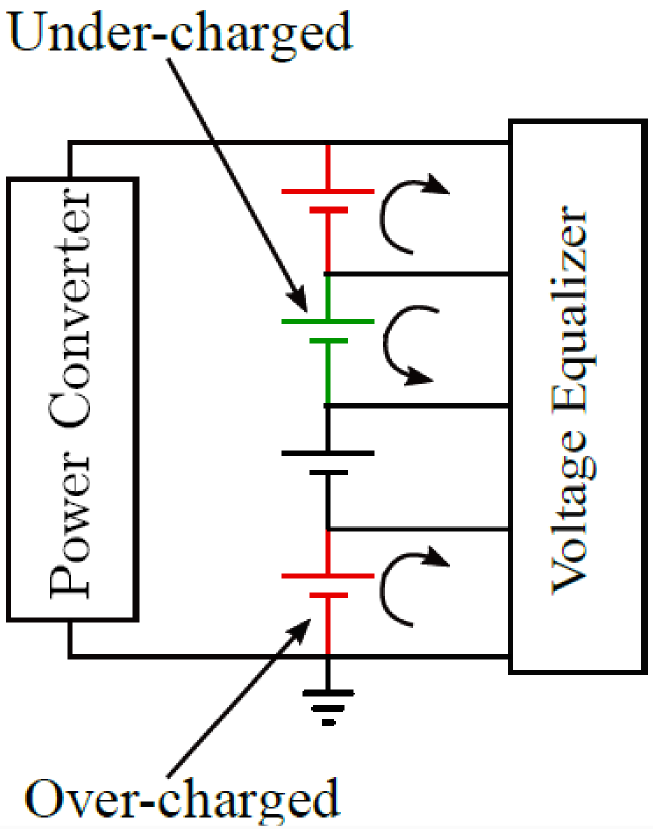
Cell balancing



Power Converter
V_b
V_{b3}
V_{b2}
V_{b1}



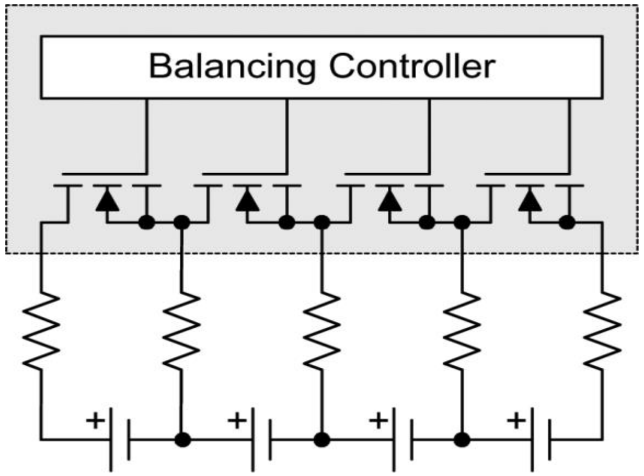
V_b
V_{max}
V_{min}
t
Battery 1
Over-charged
Under-charged
Battery 3
Battery 2



Voltage equalization:

- Voltage equalizer equalizes cell voltages
- Over-charged cells are discharged
- Under-charged cells are charged
- Over-charge and over-discharge of any cell is avoided.

Passive Resistor Balancing (Dissipative)



Energy of high-voltage cells is consumed by resistors

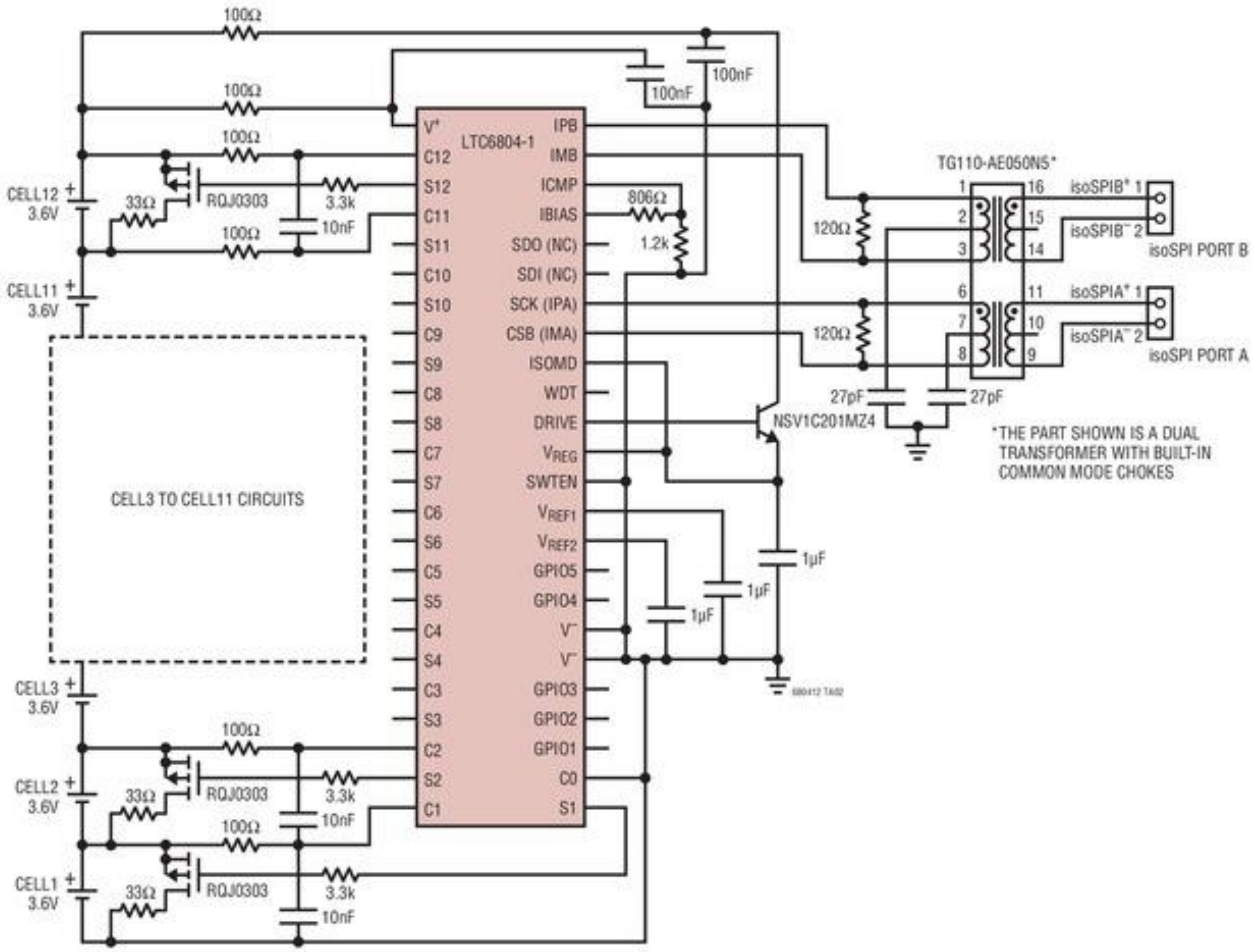
Loss of energy due to balance

Hard to manage heat

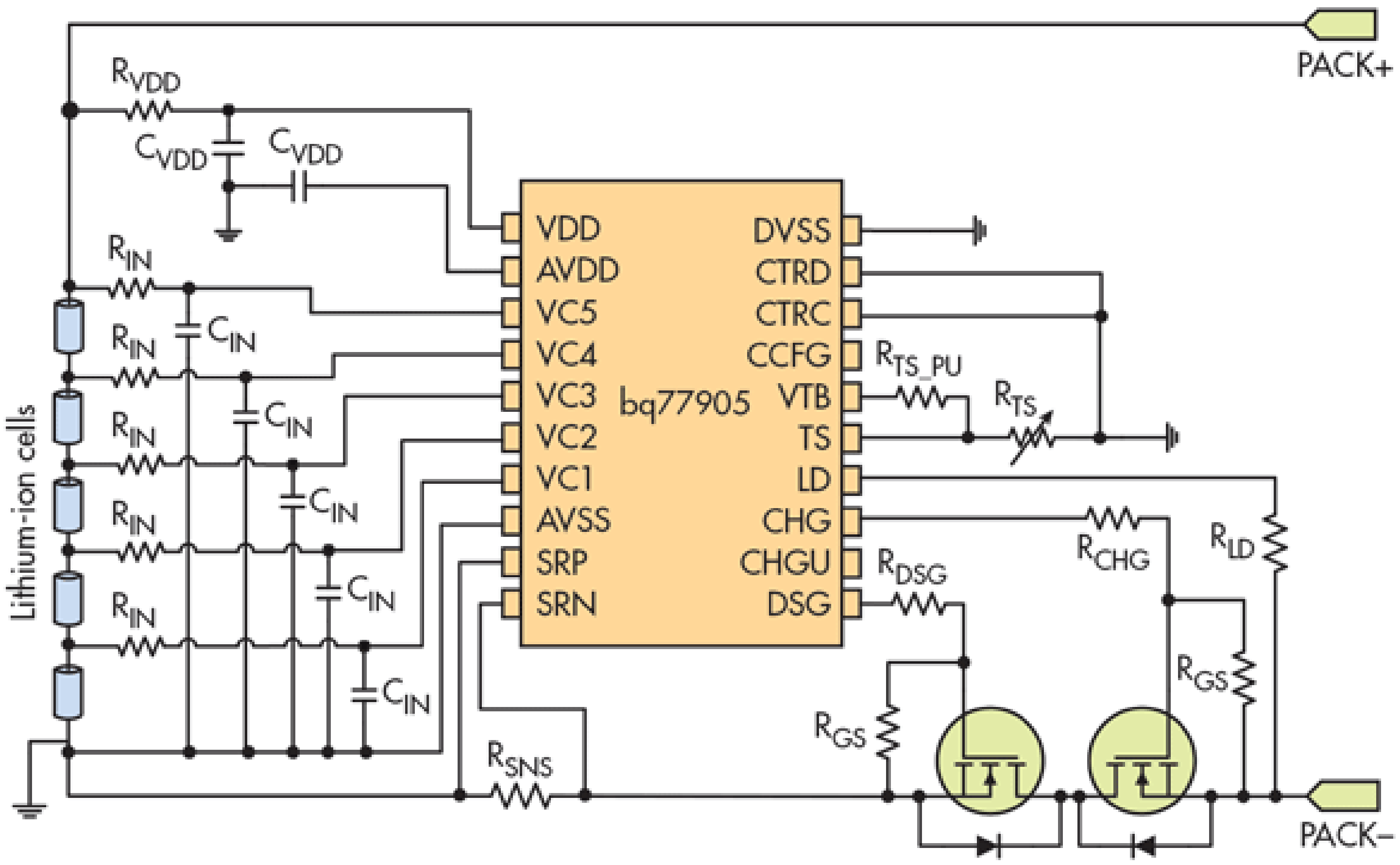
Can only balance the over-voltage cell

N. H. Kutkut, "Life cycle testing of series battery strings with individual battery equalizers," white paper, Power Designers, Inc., 2000. Available: http://t2rerc.buffalo.edu/products/2003_powercheq%20testing.pdf

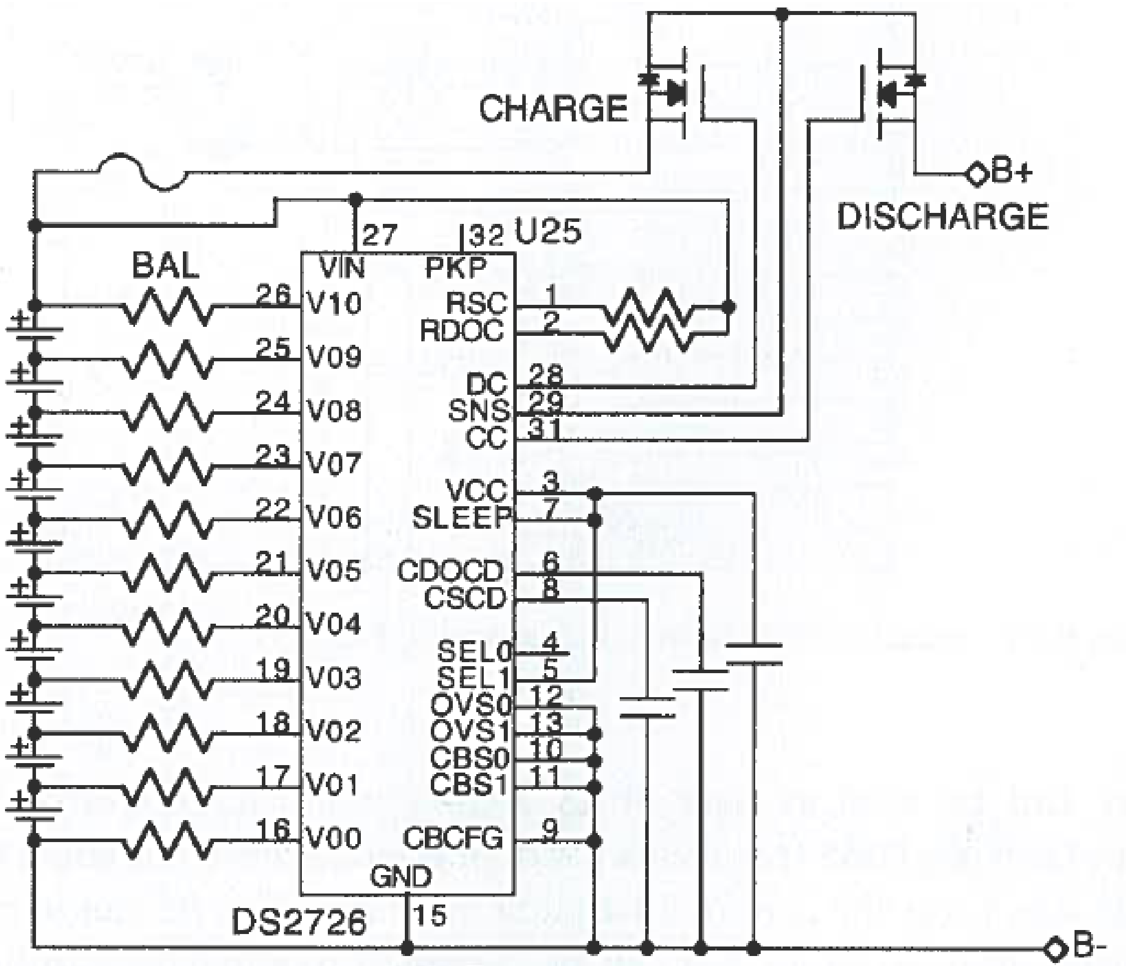
Example 1. LT Resistor Balancing



Example 2. TI Resistor Balancing

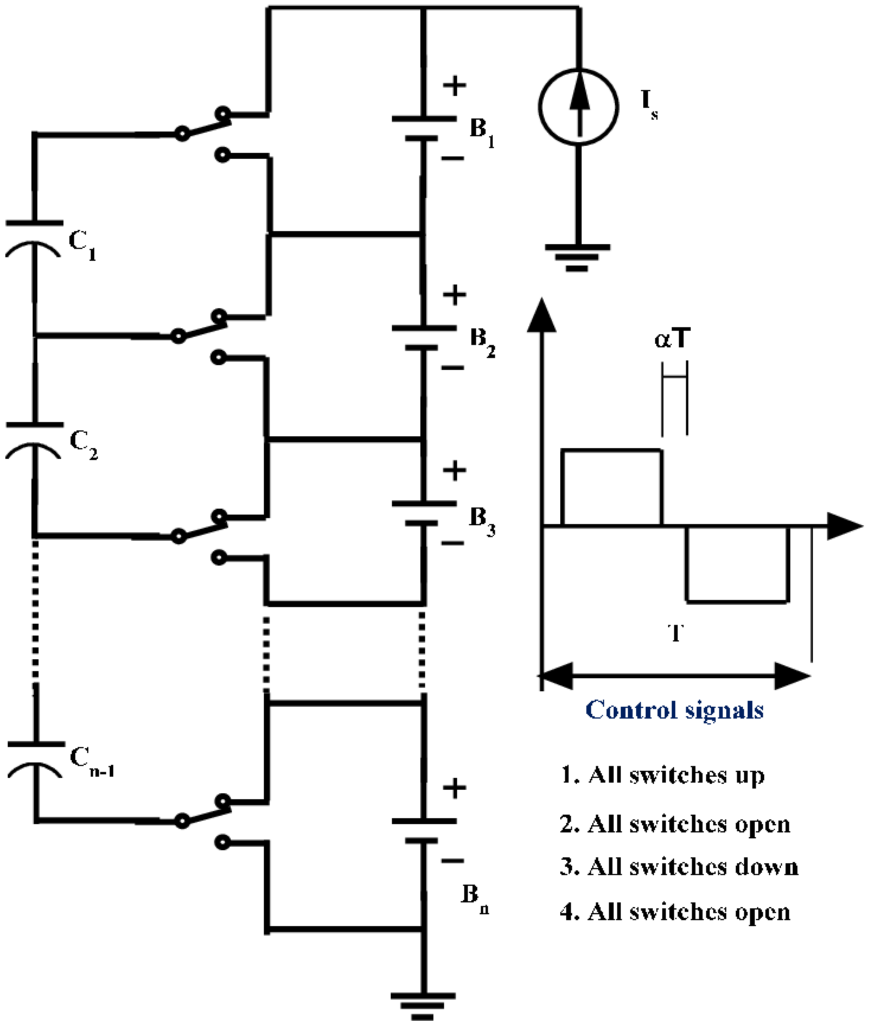


Example 3. Maxim Resistor Balancing



Maxim's DS2726 in a 10-cell analog protector.

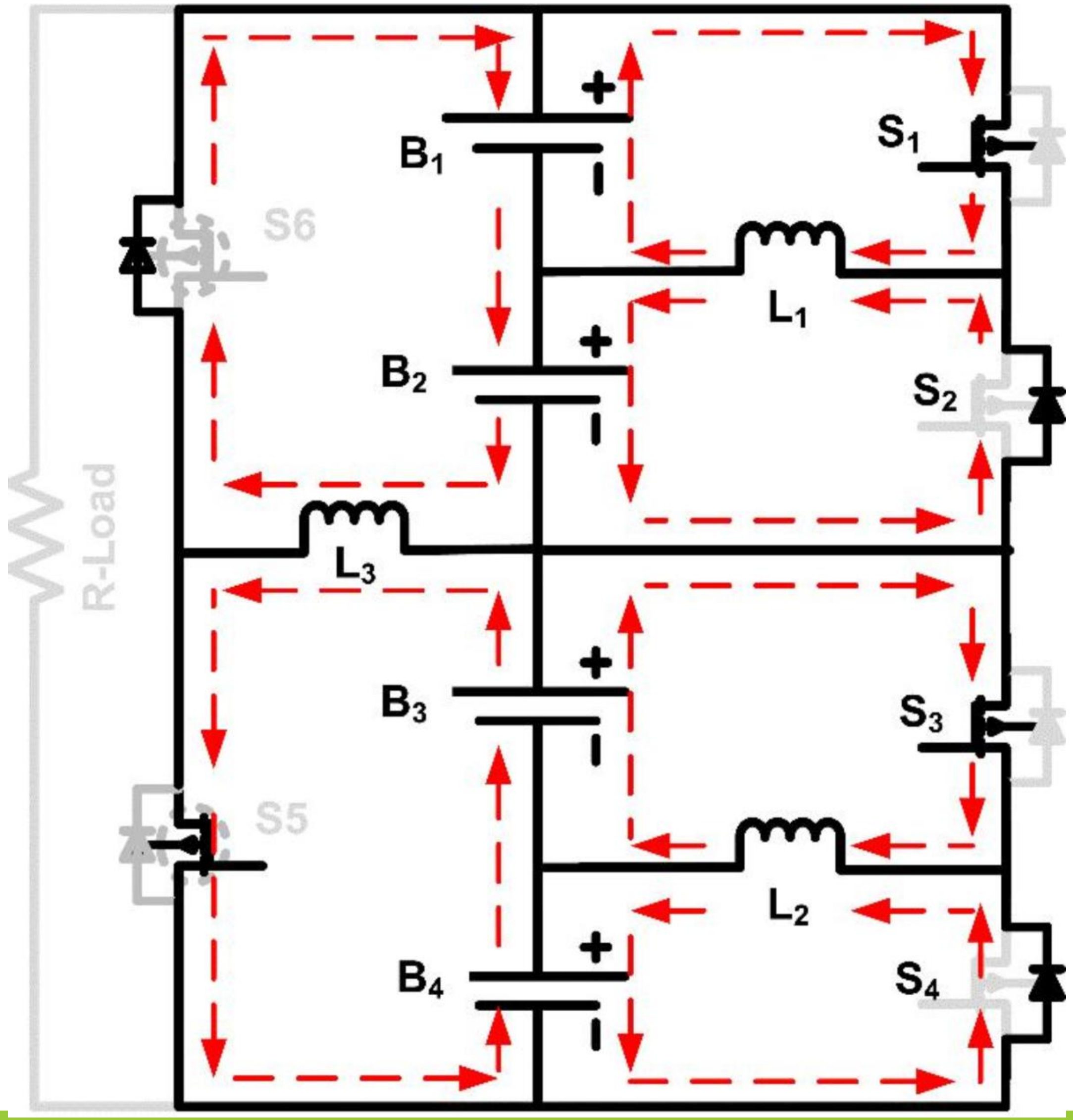
Active balancing: capacitive charge transfer



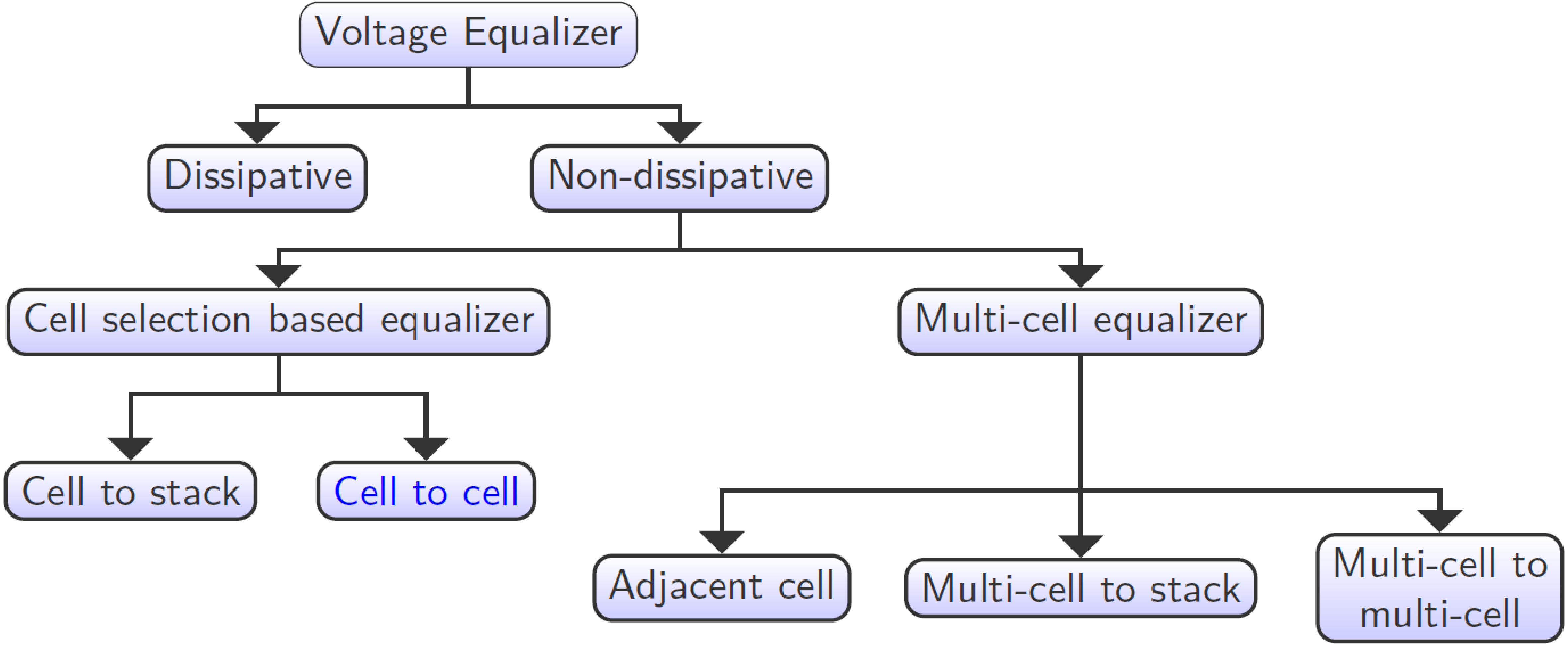
Control signals

1. All switches up
2. All switches open
3. All switches down
4. All switches open

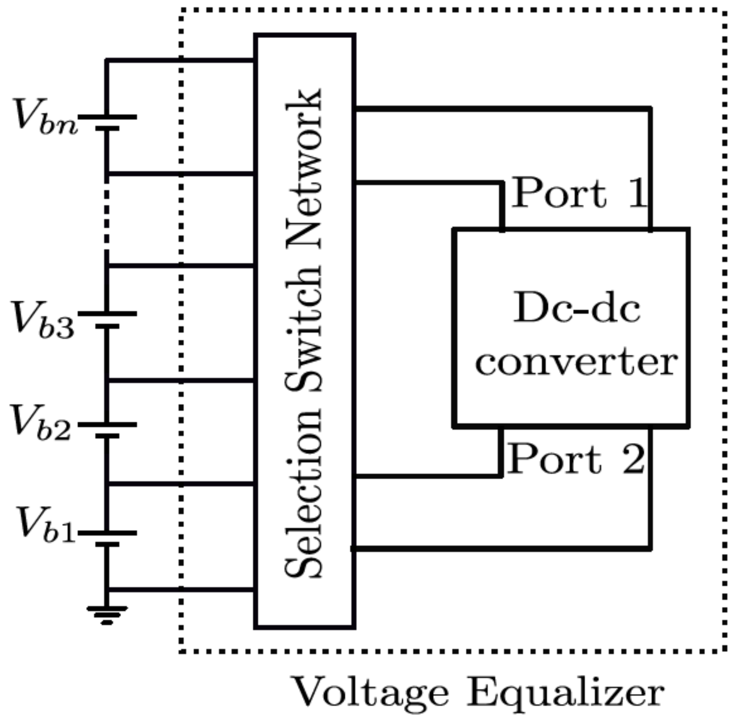
Active balancing: inductive charge transfer

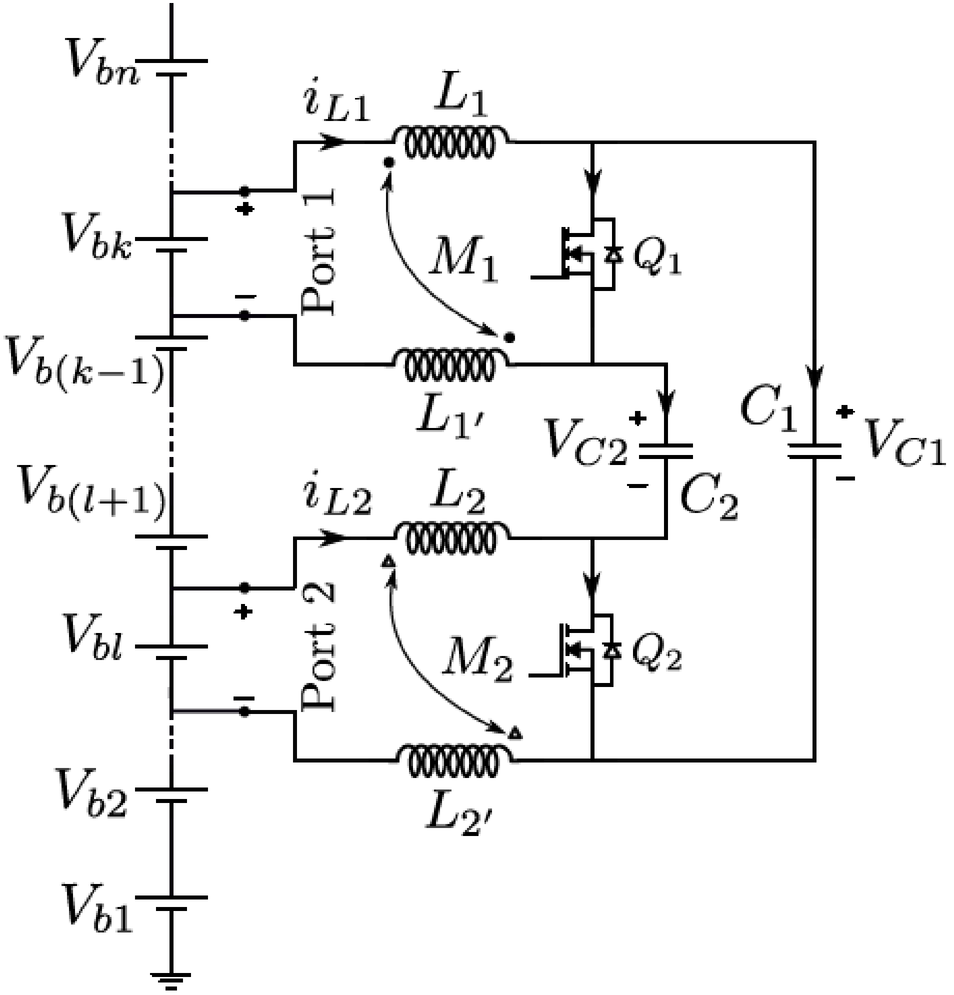


Classification of cell balancers: based on energy transfer paths

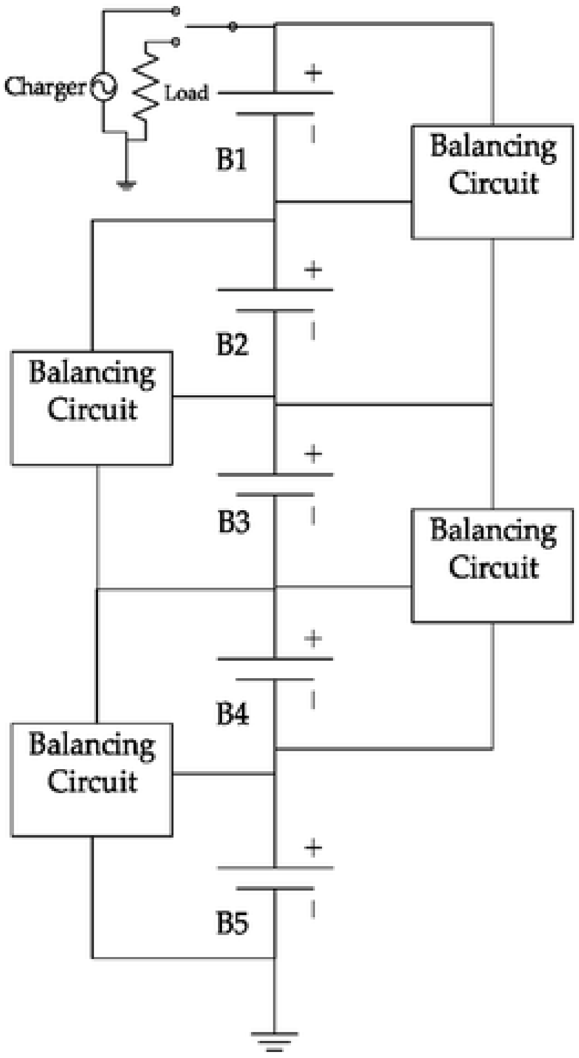


Cell selection based balancers

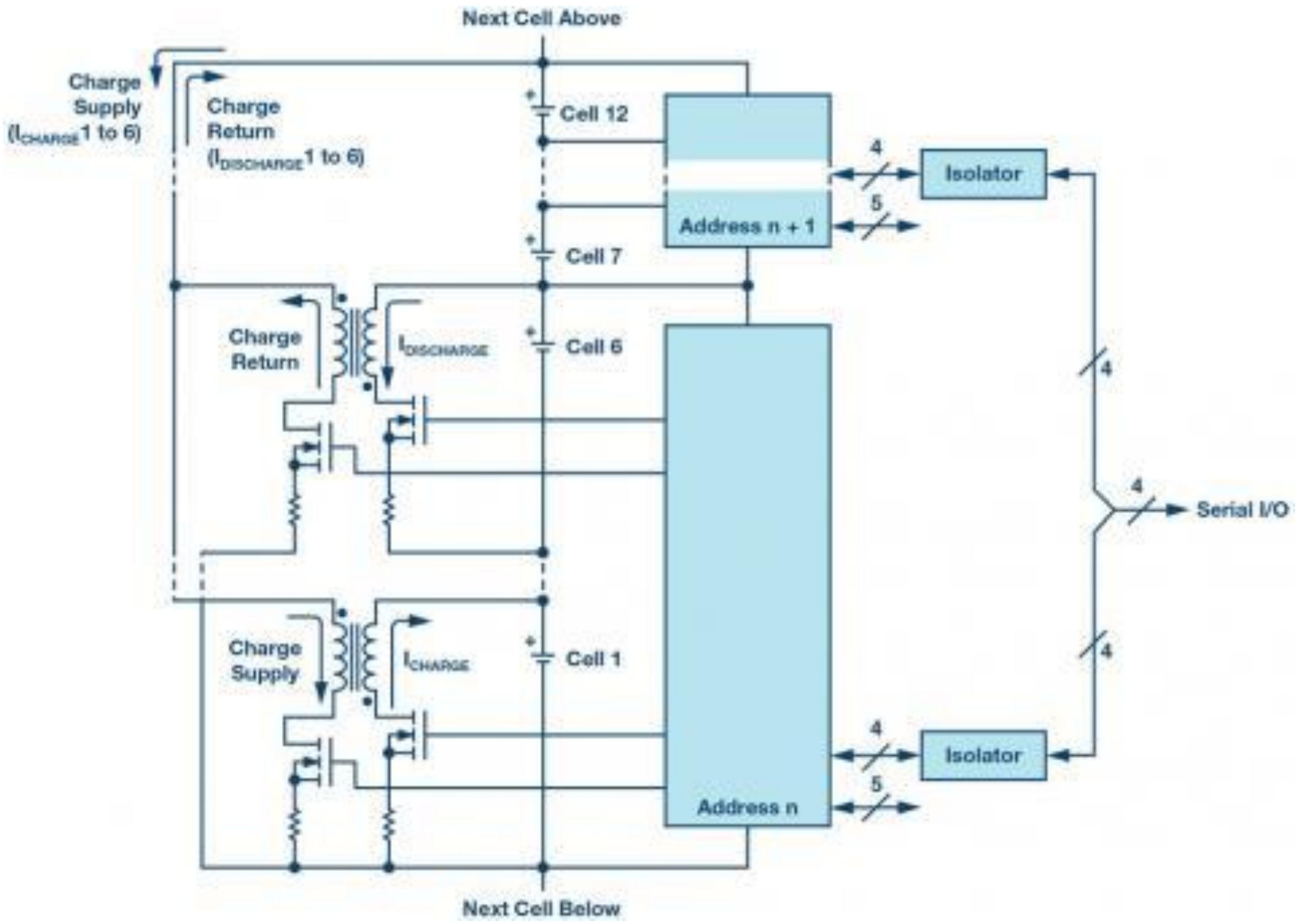




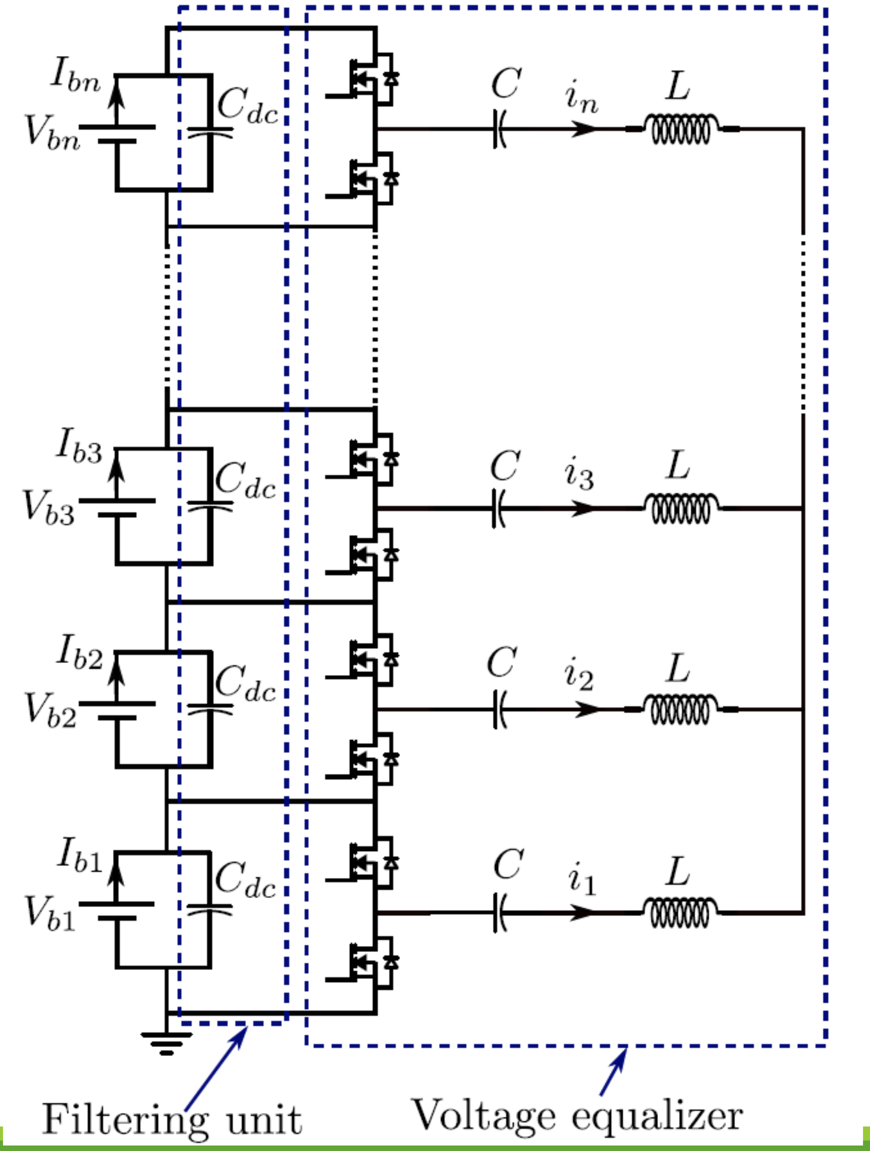
Adjacent cell balancer



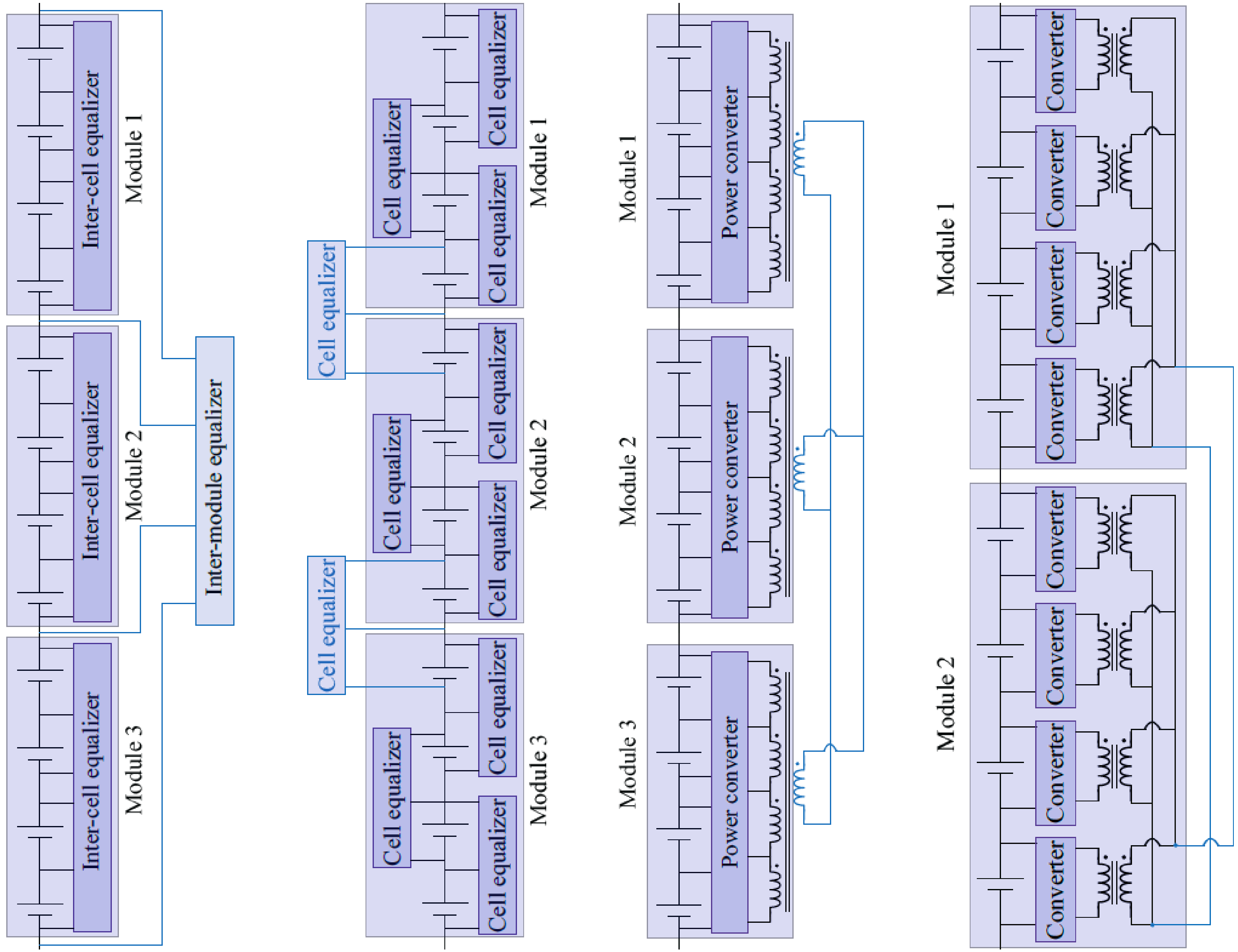
Multi-cell to stack balancing



Multi-cell to multi-cell balancing



Cell balancers: modularization methods



Thank you!