



Supercapacitor Applications Transportation

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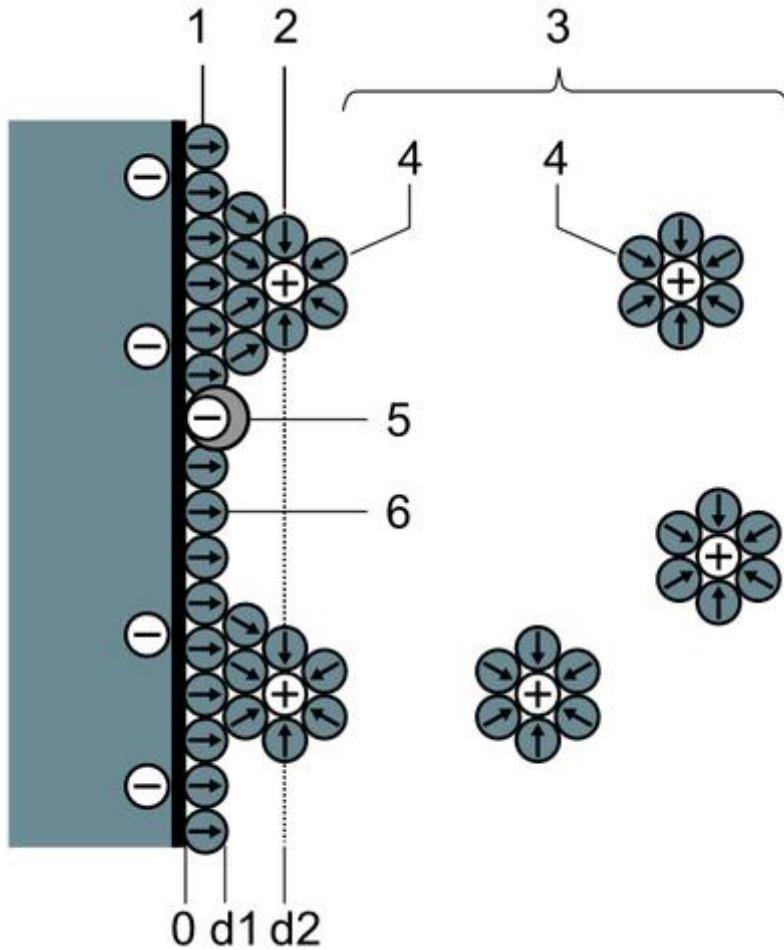
- Supercapacitor Basics
 - What is a Supercapacitor
 - Cell Design
 - Modules
- Typical Characteristics
- Cell Balancing
 - Active vs Passive
- Transportation Applications
 - Forklift Trucks
 - Diesel Starters
 - Locomotive Engines

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Design

(Electrical) Double Layers

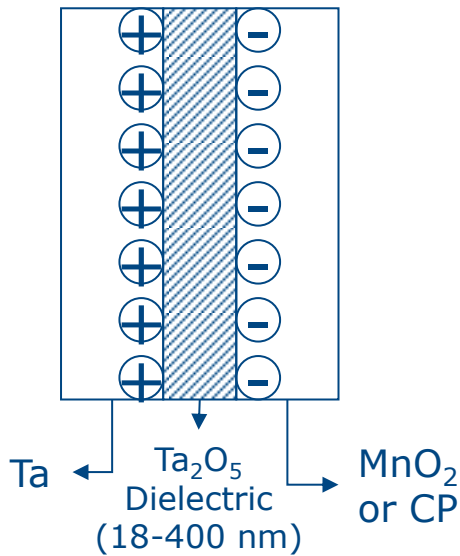


1. IHP Inner Helmholtz Layer
2. OHP Outer Helmholtz Layer
3. Diffuse layer
4. Solvated ions
5. Specifically adsorptive ions
6. Solvent molecule.

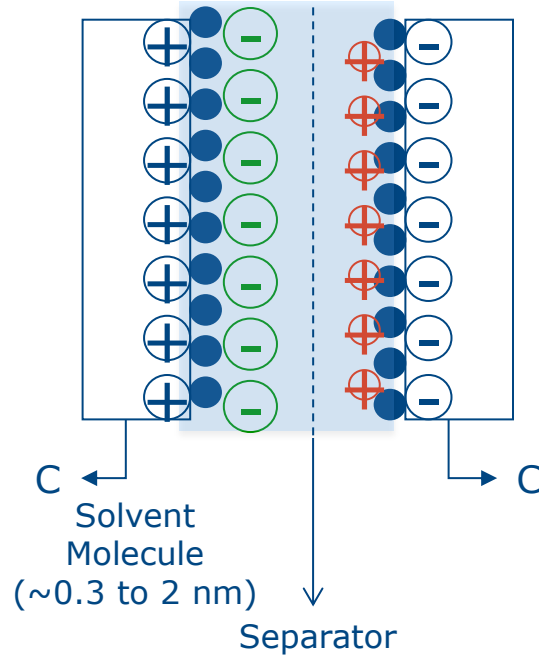
Traditional and EDLC

Comparison

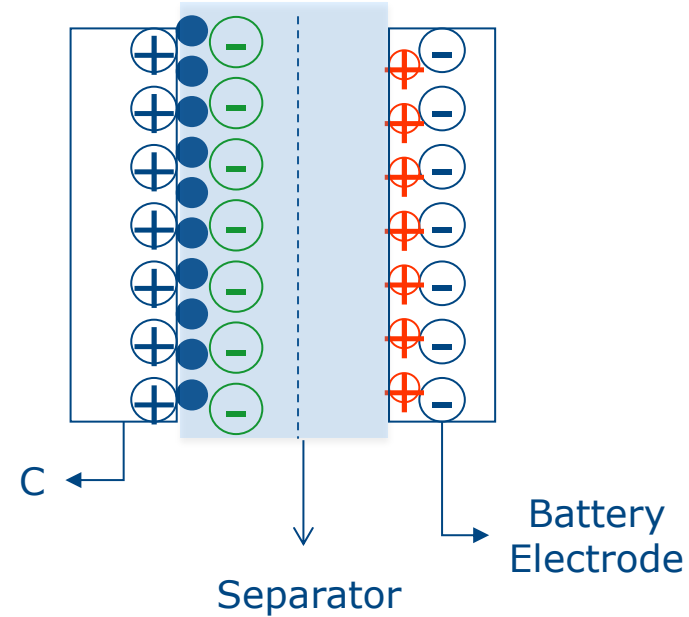
Tantalum Reference



Symmetric “Supercapacitor”



Asymmetric “Hybrid Capacitor”



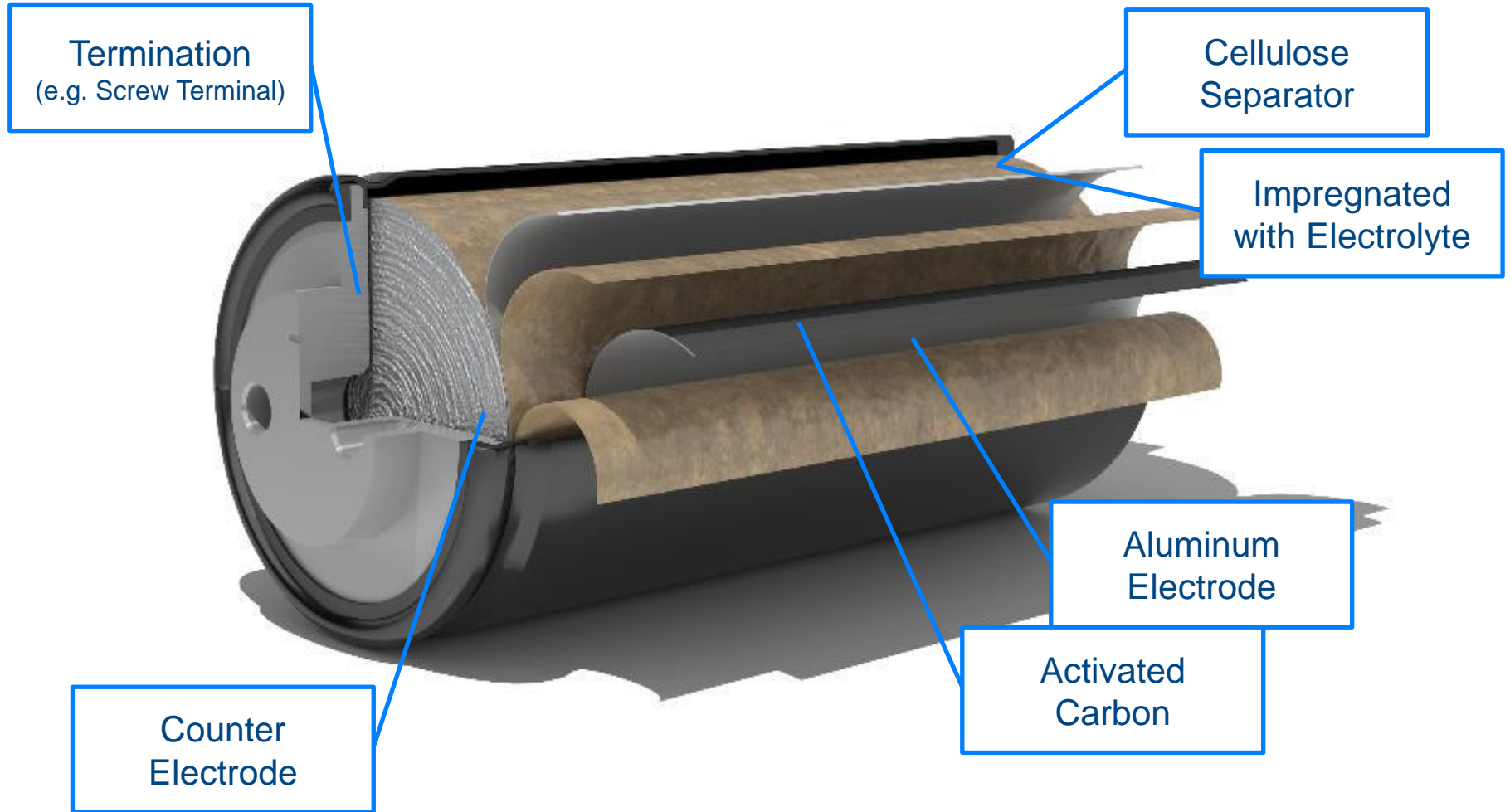
$$C = \frac{Q}{V}$$

$$C = \frac{e_0 K A}{d}$$

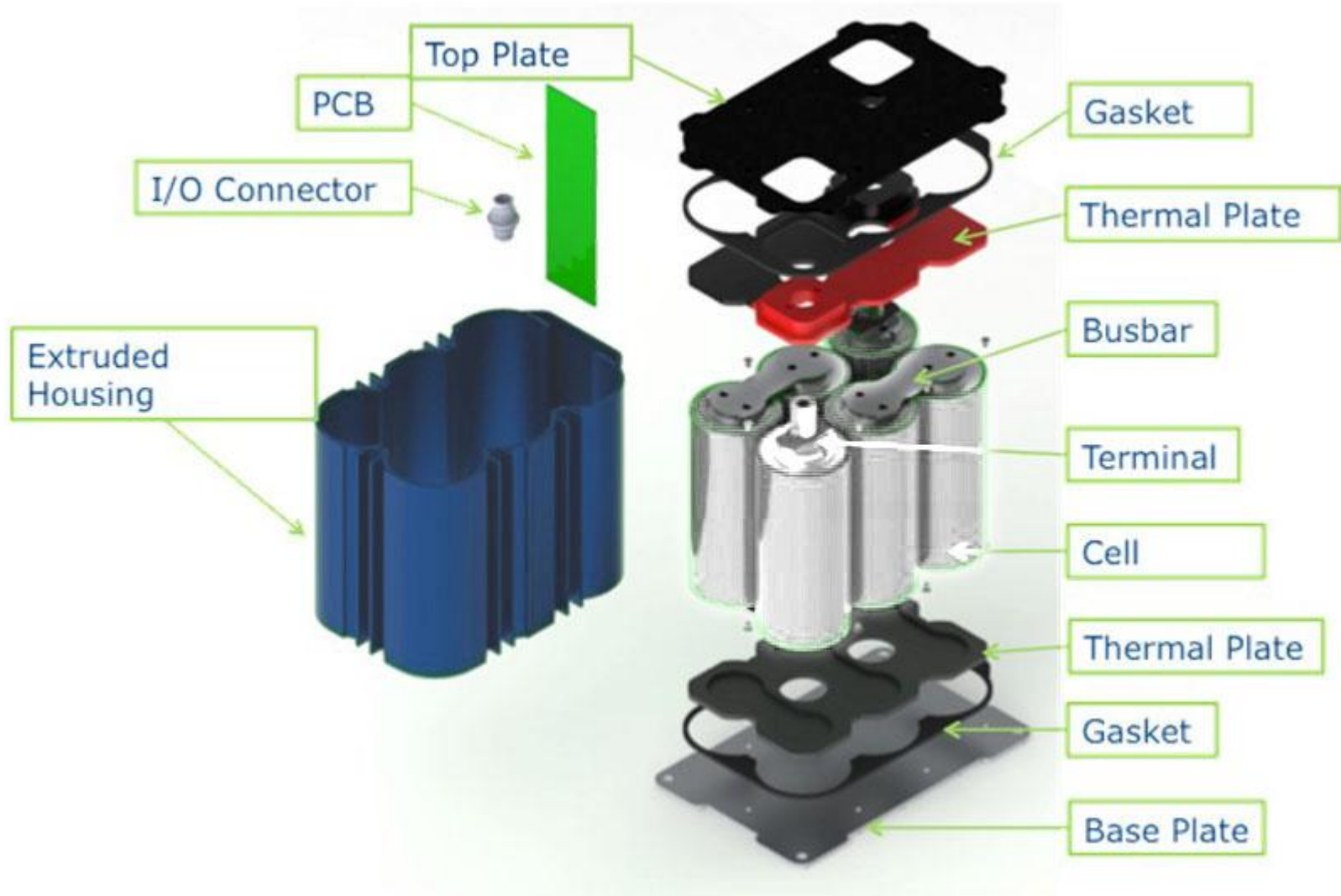
Surface area of carbon ←

Inner Helmholtz Layer ● ←

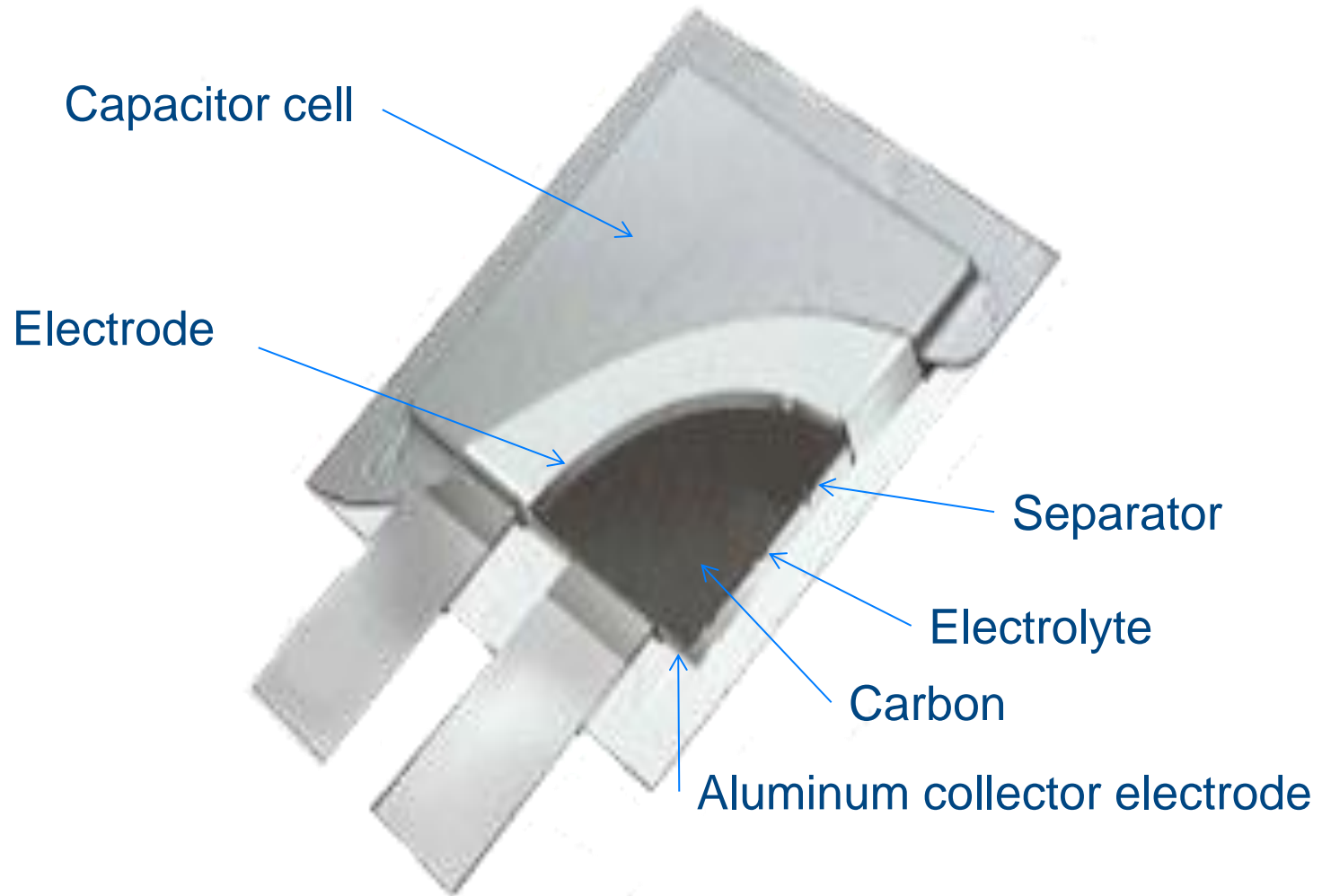
Structure of Large Cylindrical Cell



Supercapacitor Module Example



Structure of Laminated Flat Cell



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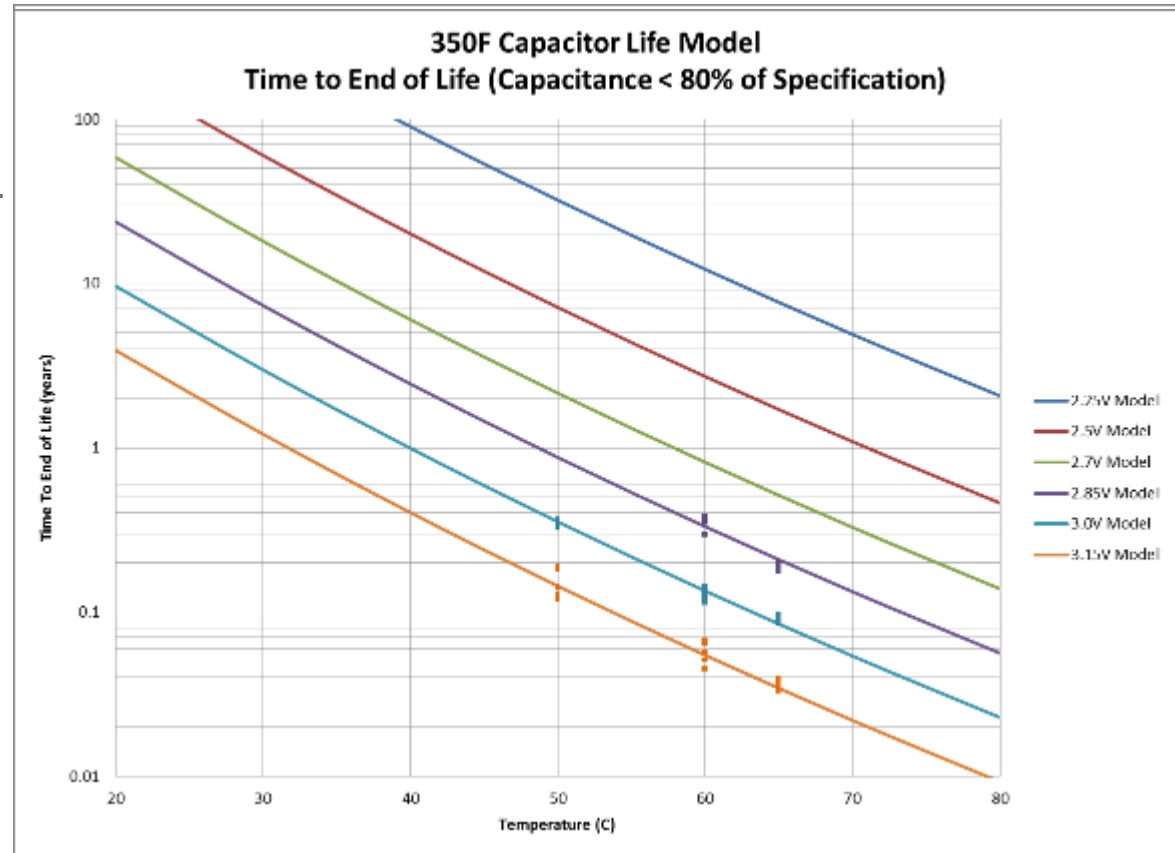
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Characteristics

Supercapacitor Life

Based on ESR and Capacitance

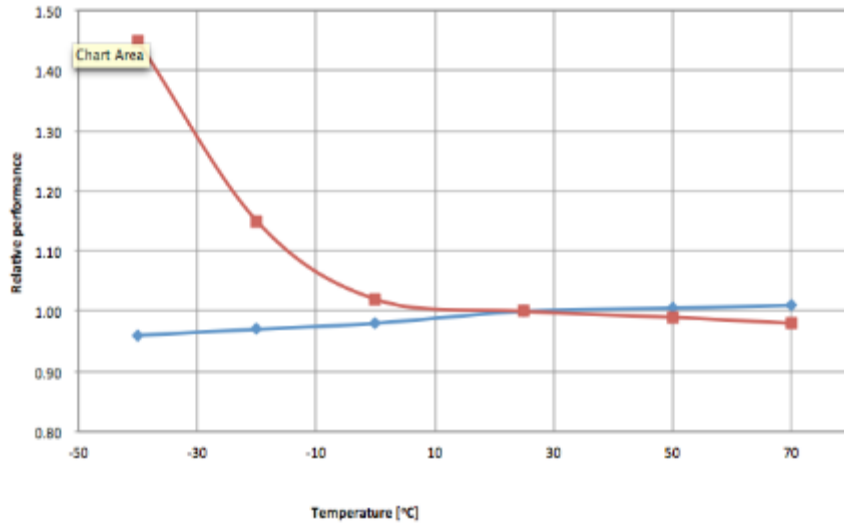
- End of Life:
 - Capacitance decrease of 20%
 - OR ESR increase of 100%
 - Typical lifetime limiting factor.
- Capacitance loss flattens over time
- No effect on life from
 - Discharge current rates
 - Depth of discharge
- Primary Lifetime Consideration:
 - Cell temperature and
 - Voltage



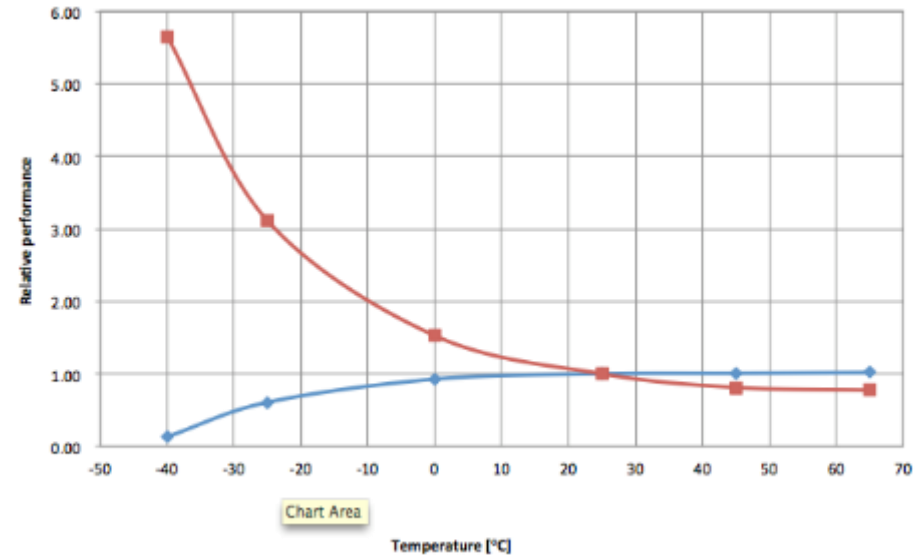
Temperature Performance

Supercapacitor versus Hybrid

Supercapacitor



Hybrid



◆ Capacitance
 ■ DC-ESR

	Operating Temp	Storage Temp
Supercapacitor	-40°C to +70°C (85°C)	-40°C to +70°C (85°C)
Hybrid	-30°C to +60°C	-40°C to +70°C

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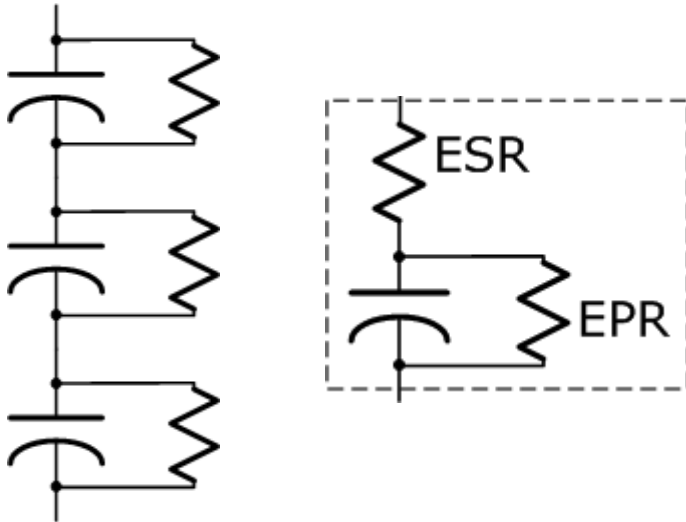
Cell Balancing

Voltage Balancing

Supercapacitor Options

Passive Balancing

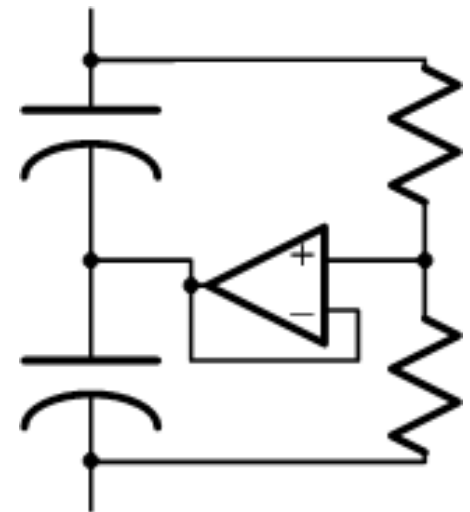
- Resistors force cells to balance
- Current higher through resistor than capacitor
- Balance resistor dictated by maximum temperature
- Lower efficiency



Active Balancing

- Distributes charge as necessary
- Implementations
 - Controlled Dissipation
 - Bleeds off excess charge
 - Charge Pump
 - Move excess charge

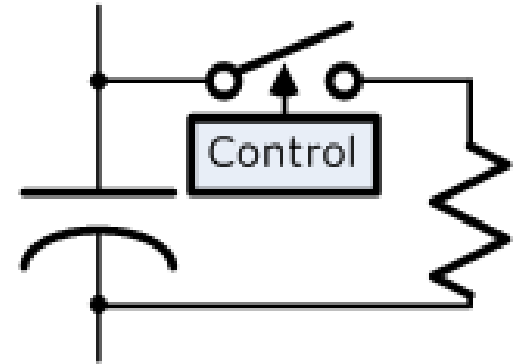
The resistors can be high in value because the amplifier does all the work.



Voltage Balancing

Hybrid Option

- Clamping is not real balancing
 - Voltage imbalance among the cells will persist
- Bleeds off charge when cell voltage is too high
- Clamping can be combined with either balancing approach
- Discontinue charging due clamp



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Applications

Forklift Trucks



Starting Batteries

Full Hybrids

- Gains in
 - Run-time
 - Reliability
 - Battery Life
- Refrigerated Warehouses



Figure 1: Basic Integration (built in battery)

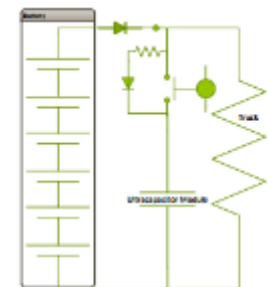


Figure 2: Improved regeneration capture (with controls)

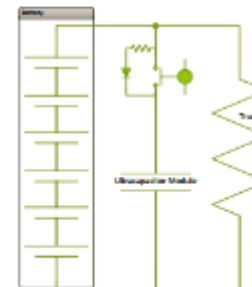


Figure 3: Controlled Integration (removable battery)



Figure 4: Optimized performance and cost

Diesel Engine / Locomotive

- Decreased diesel power of only 1200 hp instead of 3000 hp
- Increased energy storage of the supercapacitor set at 144 kJ instead of 90 kJ
- Critical state of the on-board battery (100 V, 450 Ah) with a charge level of only 30%
- Unfavorable starting conditions with an ambient temperature of +2°C

- Extends Starter Battery Power
- Moderate operating conditions
- Improved cold starting
- 200% longer operational life

Parameter Values:

- System Type SPD 2200/64 (96)
- Power of engines being started 1000 to 3200 h p.
- Nominal operating voltage 96/64 V
- Maximum operating voltage 110V
- Nominal discharge current 3500A
- Maximum discharge current 10000A
- Total energy store 135kJ
- Capacity 26/58F
- ESR < 0.010 Ohm
- Insulation resistance > 5 MOhm
- Service life (cycling) > 100,000
- Mass < 120kg
- Dimensions 426 x 420 x 545mm

Thank You!

For Application Notes and More Information:

<http://www.kemet.com/apec2015>





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