



---

## Supercapacitor Applications Transportation

---

JamesLewis@kemet.com  
Technical Marketing Director  
+1 512 961 6092  
@baldengineer

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

A large, stylized lightning bolt graphic in shades of blue and white, extending from the left side of the page towards the center. It has a bright, glowing core and jagged, branching edges.

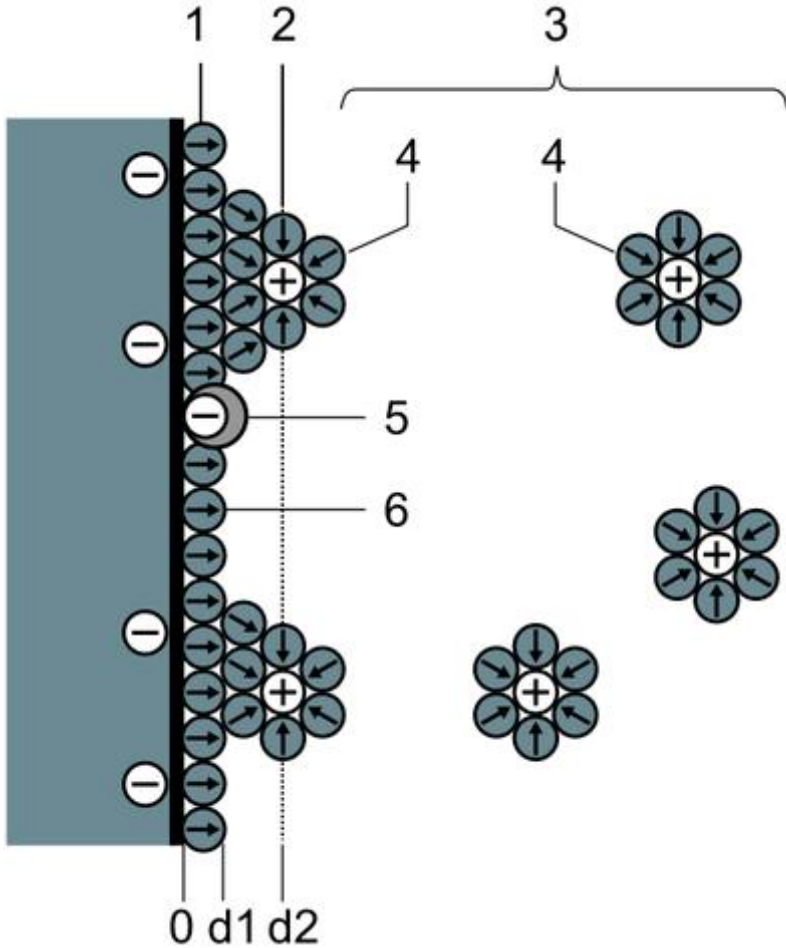
Electronic Components  
**KEMET**  
CHARGED.®

---

Design

---

# (Electrical) Double Layers

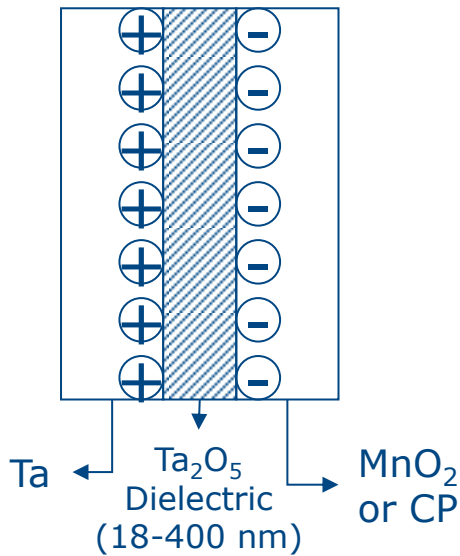


1. IHP Inner Helmholtz Layer
2. OHP Outer Helmholtz Layer
3. Diffuse layer
4. Solvated ions
5. Specifically adsorptive ions
6. Solvent molecule.

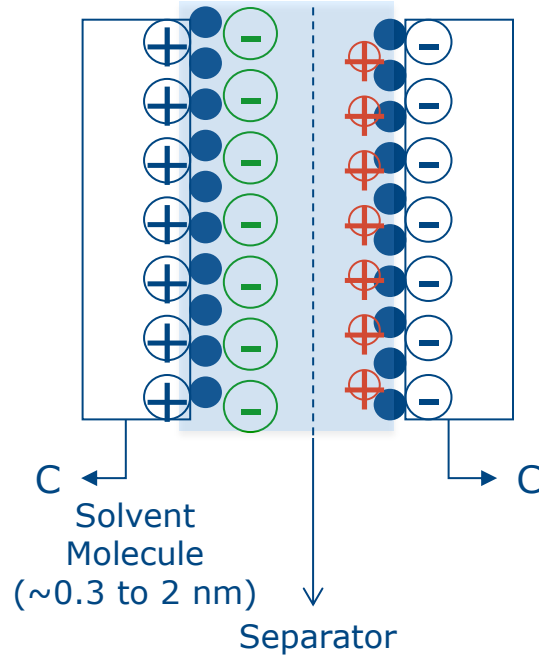
# Traditional and EDLC

## Comparison

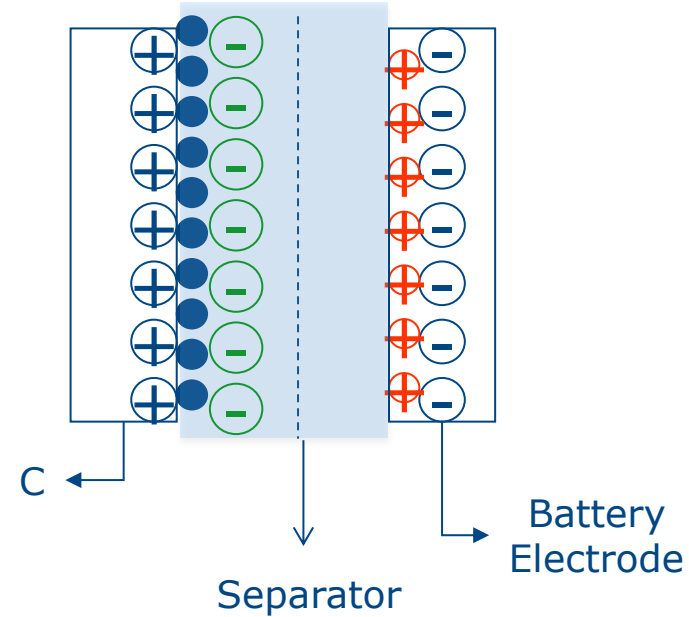
### Tantalum Reference



### Symmetric “Supercapacitor”



### Asymmetric “Hybrid Capacitor”



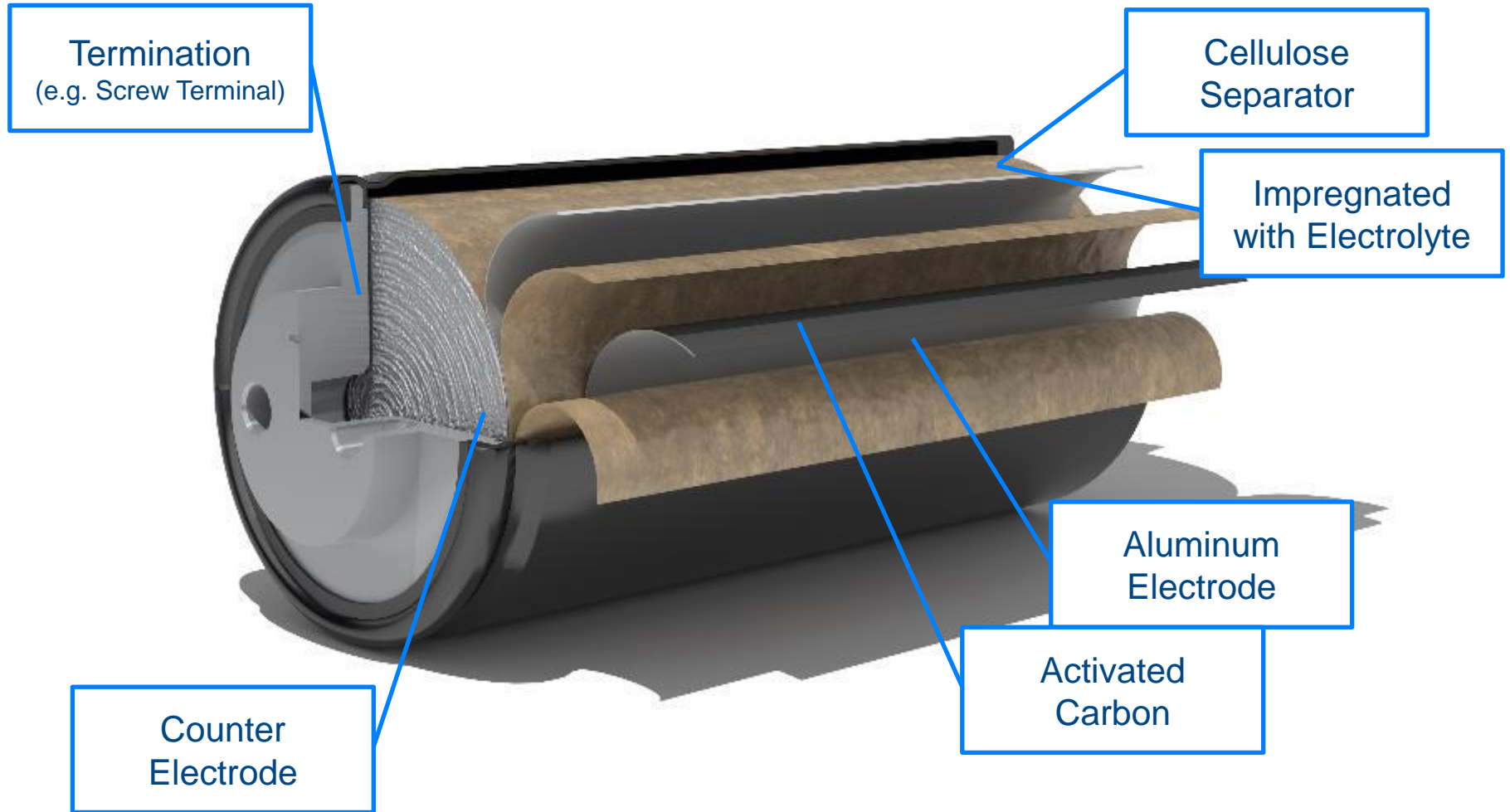
$$C = \frac{Q}{V}$$

$$C = \frac{\epsilon_0 K A}{d}$$

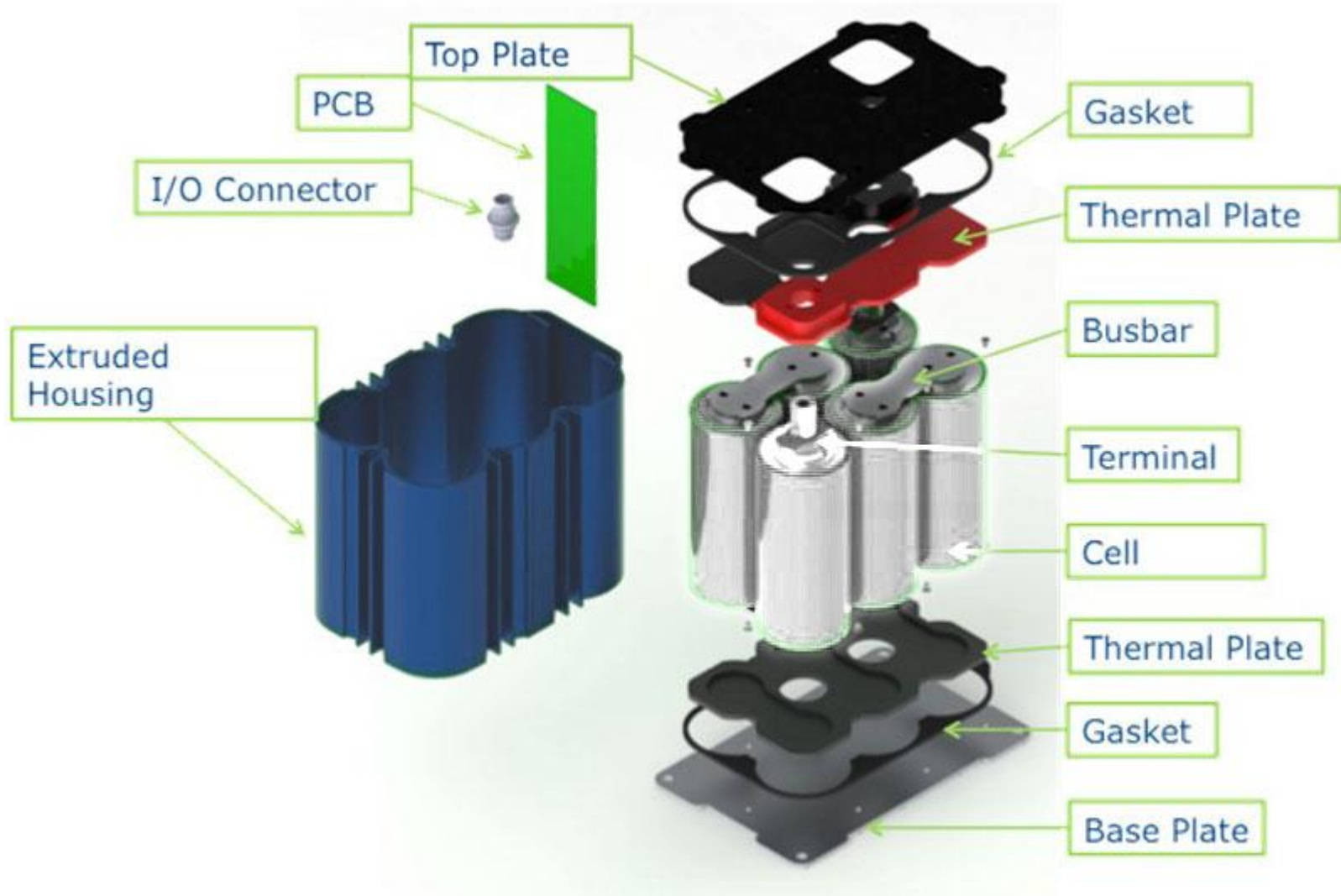
Surface area of carbon

Inner Helmholtz Layer ●

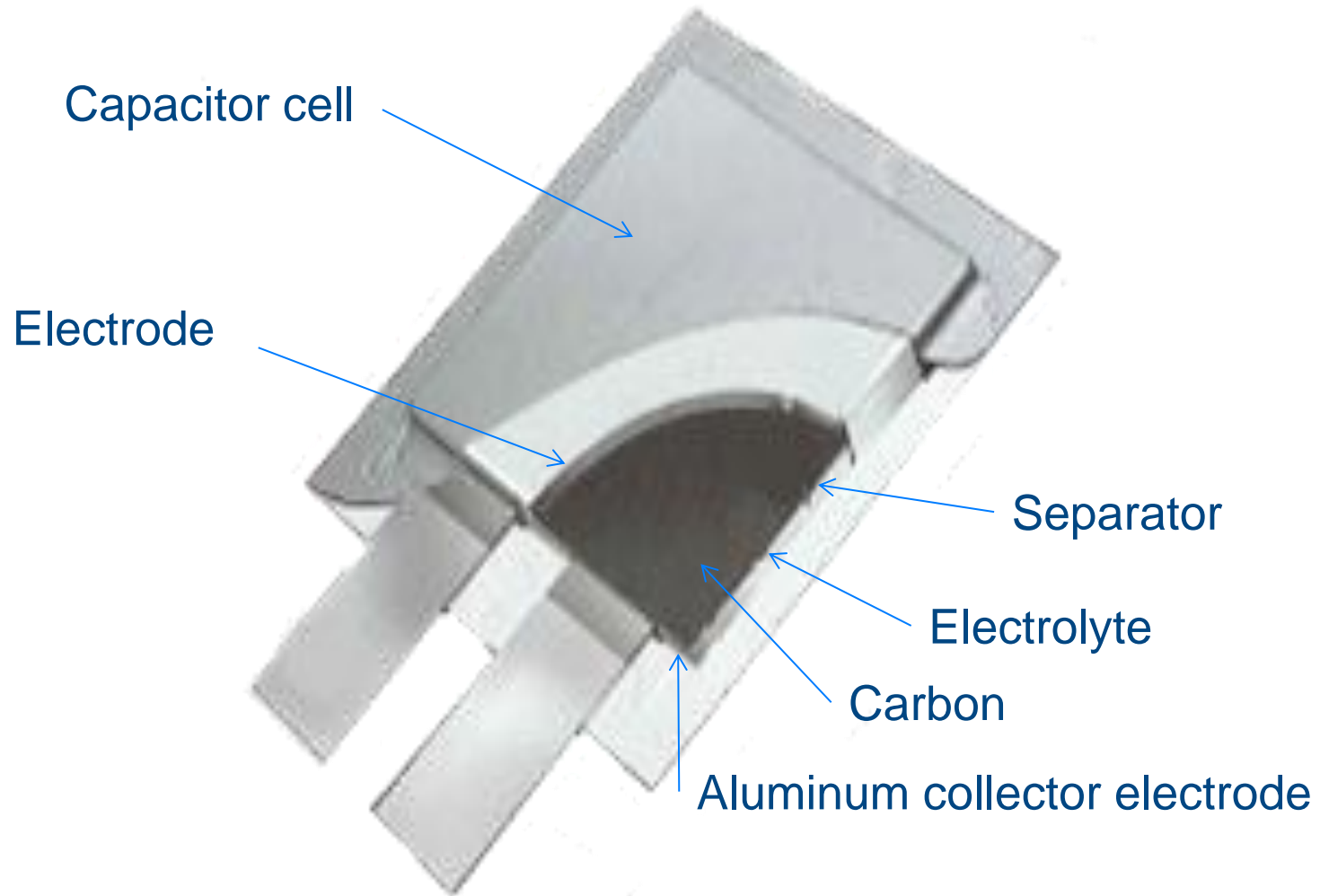
# Structure of Large Cylindrical Cell



# Supercapacitor Module Example



# Structure of Laminated Flat Cell





A large, stylized lightning bolt graphic in shades of blue and white, extending from the left side of the page towards the center. It has a bright, glowing core and jagged, branching edges.

Electronic Components  
**KEMET**  
CHARGED.®

---

Characteristics

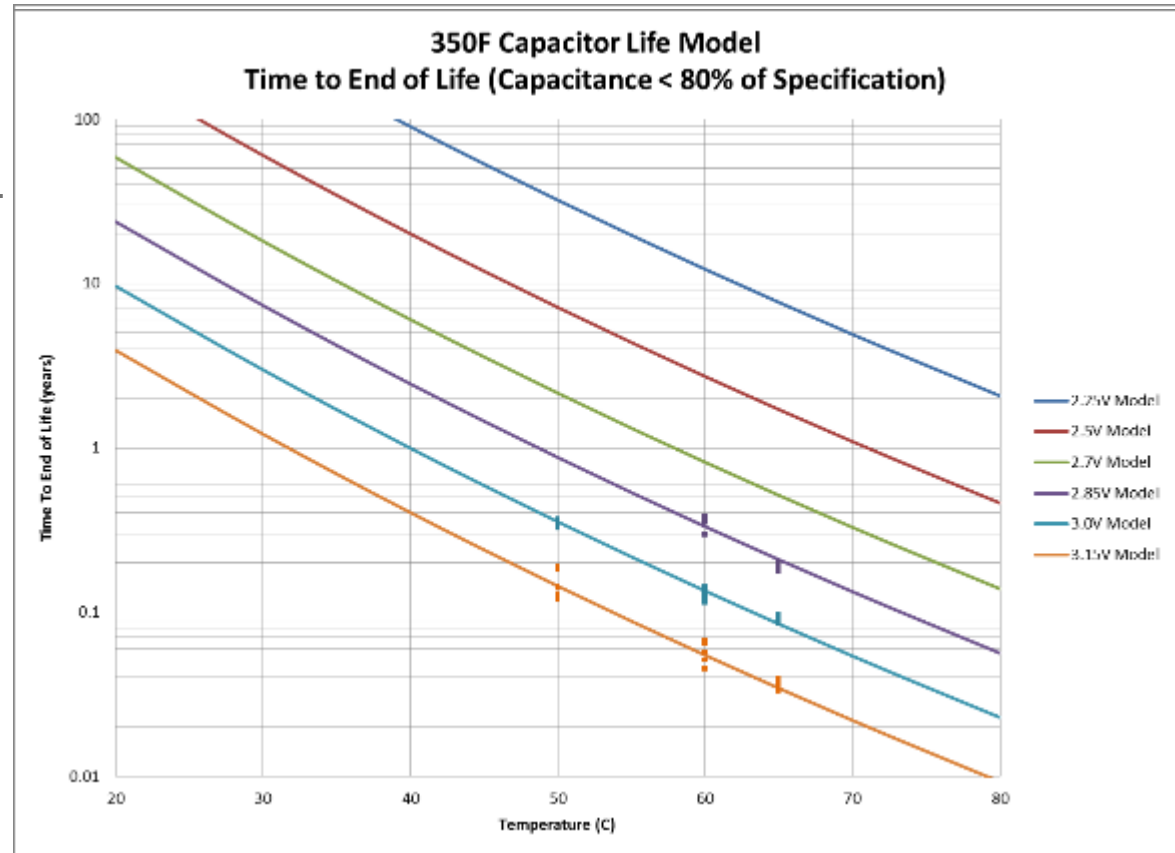
---



# Supercapacitor Life

## Based on ESR and Capacitance

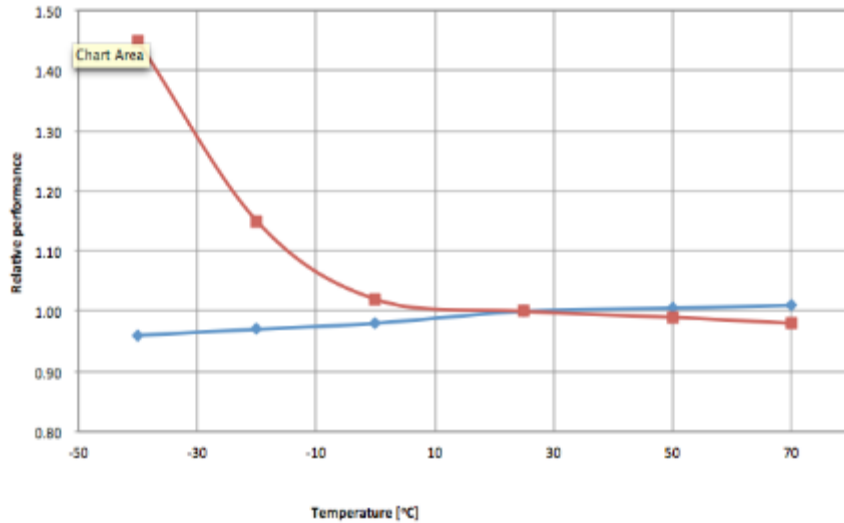
- End of Life:
  - Capacitance decrease of 20%
  - OR ESR increase of 100%
    - Typical lifetime limiting factor.
- Capacitance loss flattens over time
- No effect on life from
  - Discharge current rates
  - Depth of discharge
- Primary Lifetime Consideration:
  - Cell temperature and
  - Voltage



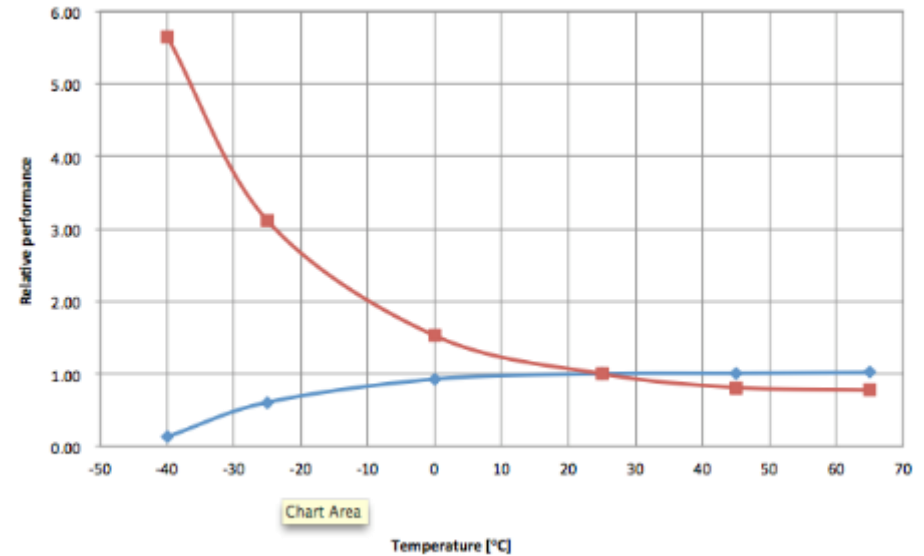
# Temperature Performance

## 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

A large, stylized lightning bolt graphic in shades of blue and white, extending from the left side of the slide towards the center. It has a bright, glowing core and jagged, branching edges.

Electronic Components  
**KEMET**  
CHARGED.®

---

Cell Balancing

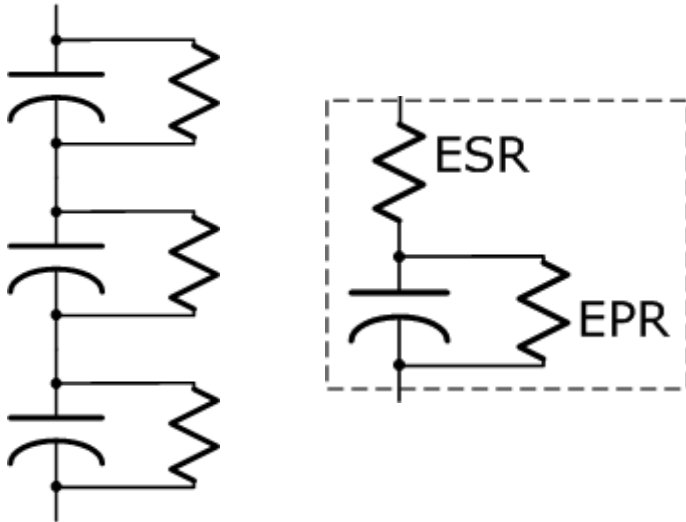
---

# Voltage Balancing

## Supercapacitor Options

### Passive Balancing

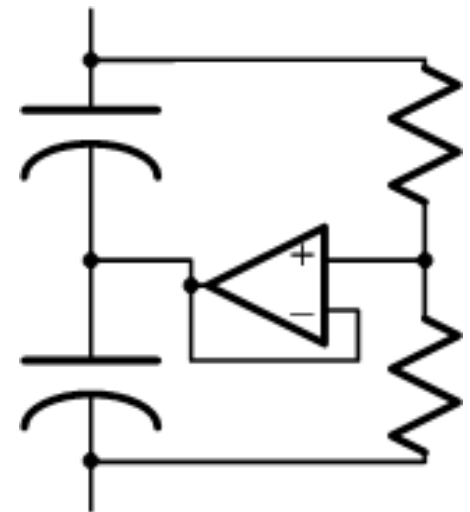
- Resistors force cells to balance
- Current higher through resistor than capacitor
- Balance resistor dictated by maximum temperature
- Lower efficiency



### Active Balancing

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

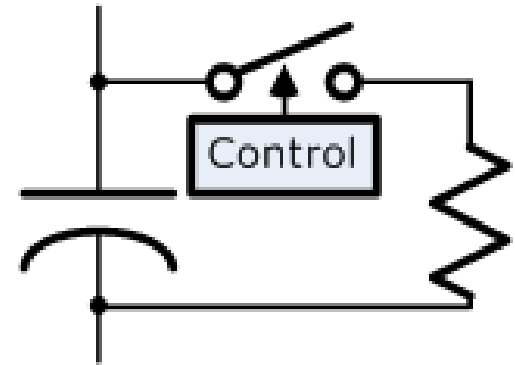
The resistors can be high in value because the amplifier does all the work.



# 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



A large, stylized lightning bolt graphic in shades of blue and white, extending from the left side of the page towards the center. It has a bright, glowing core and jagged, branching edges.

Electronic Components  
**KEMET**  
CHARGED.®

---

Applications

---



# Forklift Trucks



Starting Batteries

Full Hybrids

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



Figure 1: Basic Integration (built in battery)

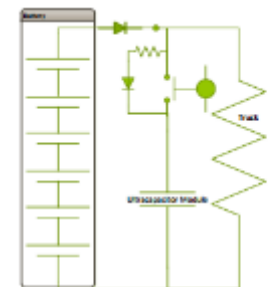


Figure 2: Improved regeneration capture (with controls)

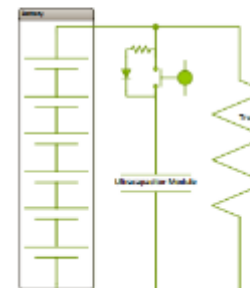


Figure 3: Controlled Integration (removable battery)



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>





---

## Supercapacitor Applications Transportation

---

JamesLewis@kemet.com  
Technical Marketing Director  
+1 512 961 6092  
@baldengineer