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Webinar Series

Choosing the Right Supercapacitor for Your Application

Roya Nikjoo

About the Speaker

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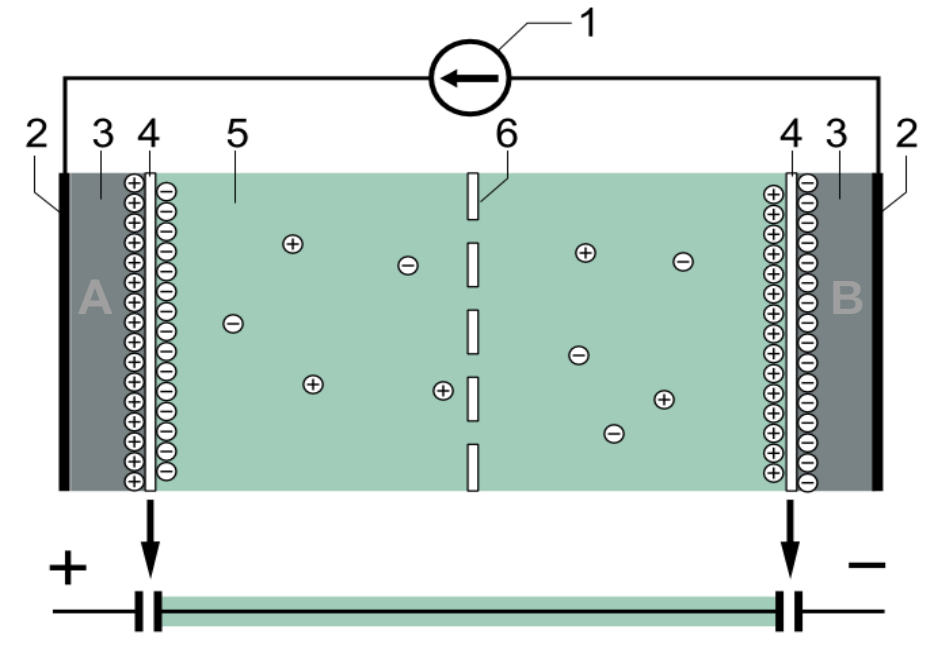
Today's Agenda

- Difference between supercapacitors and batteries
- How does a supercapacitor work?
- Structure of supercapacitors, different types of supercapacitors
- KEMET line-up
- Application examples
- How to calculate the correct capacitance for your application?
- Parasitic Effects
- Competitive advantage
- Automative grade supercap
- Summary

Supercapacitor vs. Coin Cell Battery

	Supercapacitor 	Lithium Coin Cell (Secondary battery) 	Coin Cell (Primary battery) Lithium , Manganese Lithium 
The principle of electric storage	Physical desorption of ion	Chemical reaction	Chemical reaction
Safety (Failure mode)	Safe (Open)	Outgassing, ignition, rupture (Short)	Outgassing, ignition, rupture (Short)
Charge/Discharge cycle	No limitation	Approx. 500 cycles	—
Charging time (Internal resistance)	Several seconds - (Low resistance)	10 minutes~several hours (High resistance)	— (High resistance)
Energy density (Wh/kg)	0.5 to 5	30 to 270	150 to 320
Operating temperature rage (deg-C)	-40 to +85	-20 to +60	-15 to +70 -40 to +125
Maintenance Free	Yes	No	No

How does a supercapacitor work?
Electrical double layer – Helmholtz layer



1. Source
2. Collector
3. Polarized electrode – solid carbon
4. Helmholtz- double layer
5. Electrolyte (diluted sulfuric acid)
6. Mechanical separator

- Solid carbon electrode towards a liquid electrolyte
- Charge separation distance ~1nm leads to very high capacitance

$$C = \frac{\varepsilon_0 K A}{d}$$

A ← Surface area of carbon

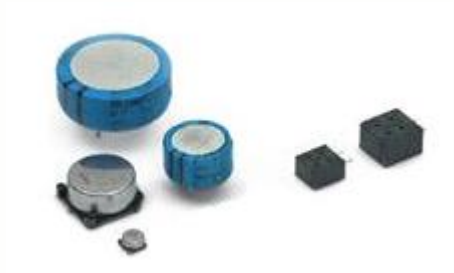
d ← Inner **Helmholtz** Layer

Result

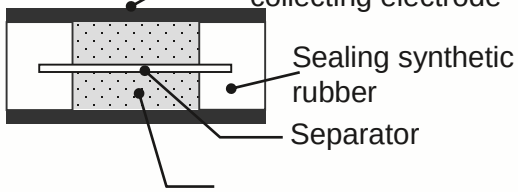
- Two double layers in series creating physical charge separation
- Electric Charges have been stored at the double layers

Supercapacitor Construction

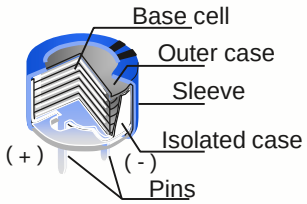
KEMET: Aqueous electrolyte



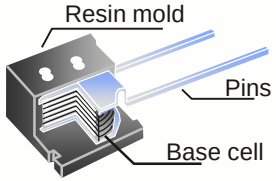
Base cell



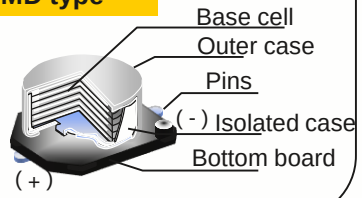
Can type



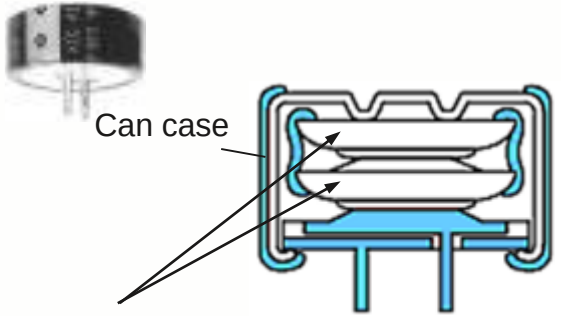
Resin mold type



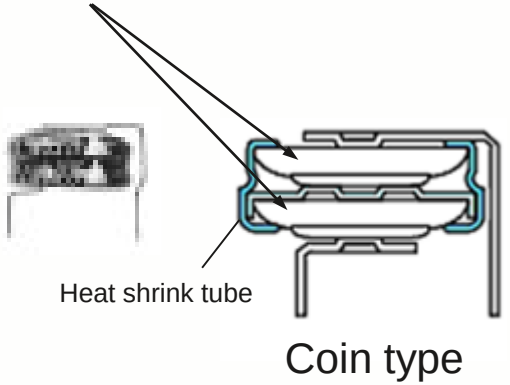
SMD type



Competitors: Organic electrolyte

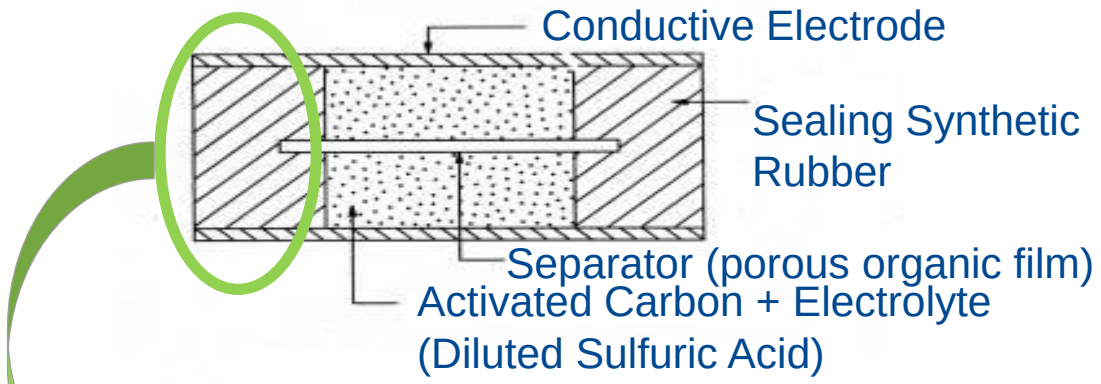


Coin cell



High Reliability Design
Cell Construction Difference, Aqueous Technology

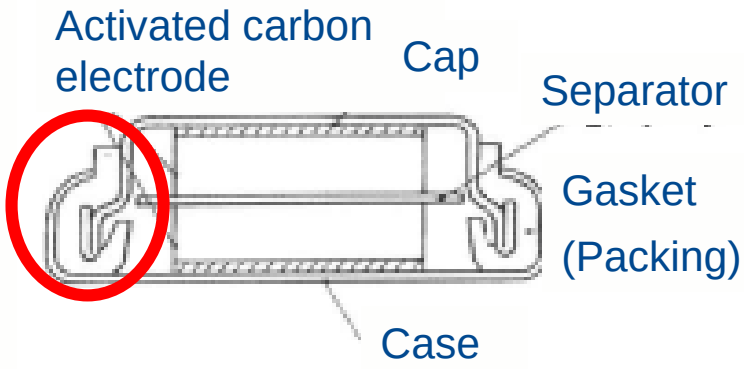
KEMET Base Cell



Cross-linking: Chemical Bond
Near Hermetic

- **Longer operational life (Cross-Link Sealing)**
- **High reliability for moisture (Aqueous Electrolyte)**
- **Strong shock resistance (Cross-Link Sealing)**

Competitive Base Cell

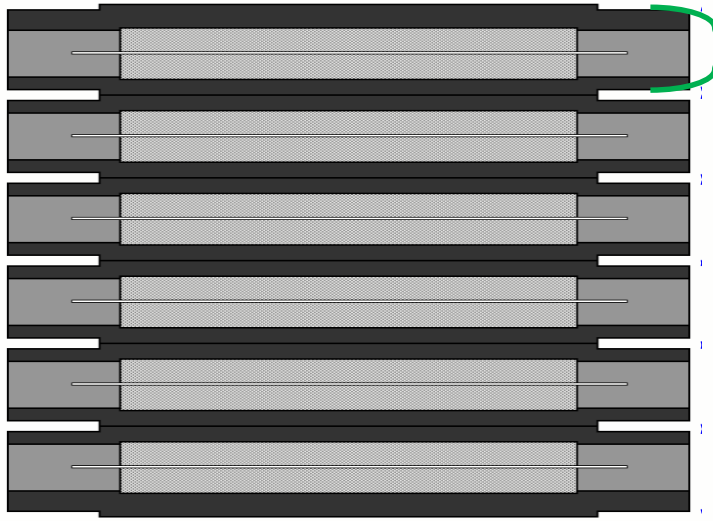


Gasket: Mechanical Compression
Leaks Electrolyte

- **Internal short on failure (Gasket Packing)**
- **Weak for moisture (Organic Electrolyte)**
- **Weak shock resistance (Gasket Packing)**

High Reliability Design
Voltage Margin Difference, Aqueous Technology

KEMET 5.5V Cell Stack



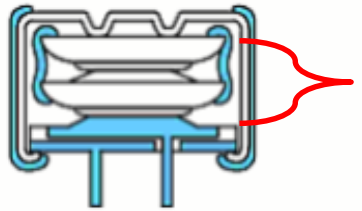
0.917v
Applied / cell

Max voltage of base cell is **1.2V/cell**

For 5.5v: 0.917v applied per cell

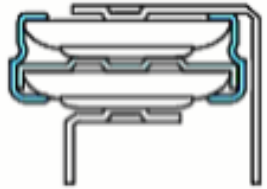
Gives 30% Margin

Competitive 5.5V Cell Stack



2.750v
Applied / cell

Can type



Coin type

Max voltage of base cell is **3.0V/cell**

For 5.5v: 2.750v applied per cell.

Leaves 8% Margin

Voltage stress causes the electrolyte to break down, reducing the life of the supercapacitor.

KEMET line-up, focus series

Surface Mount type

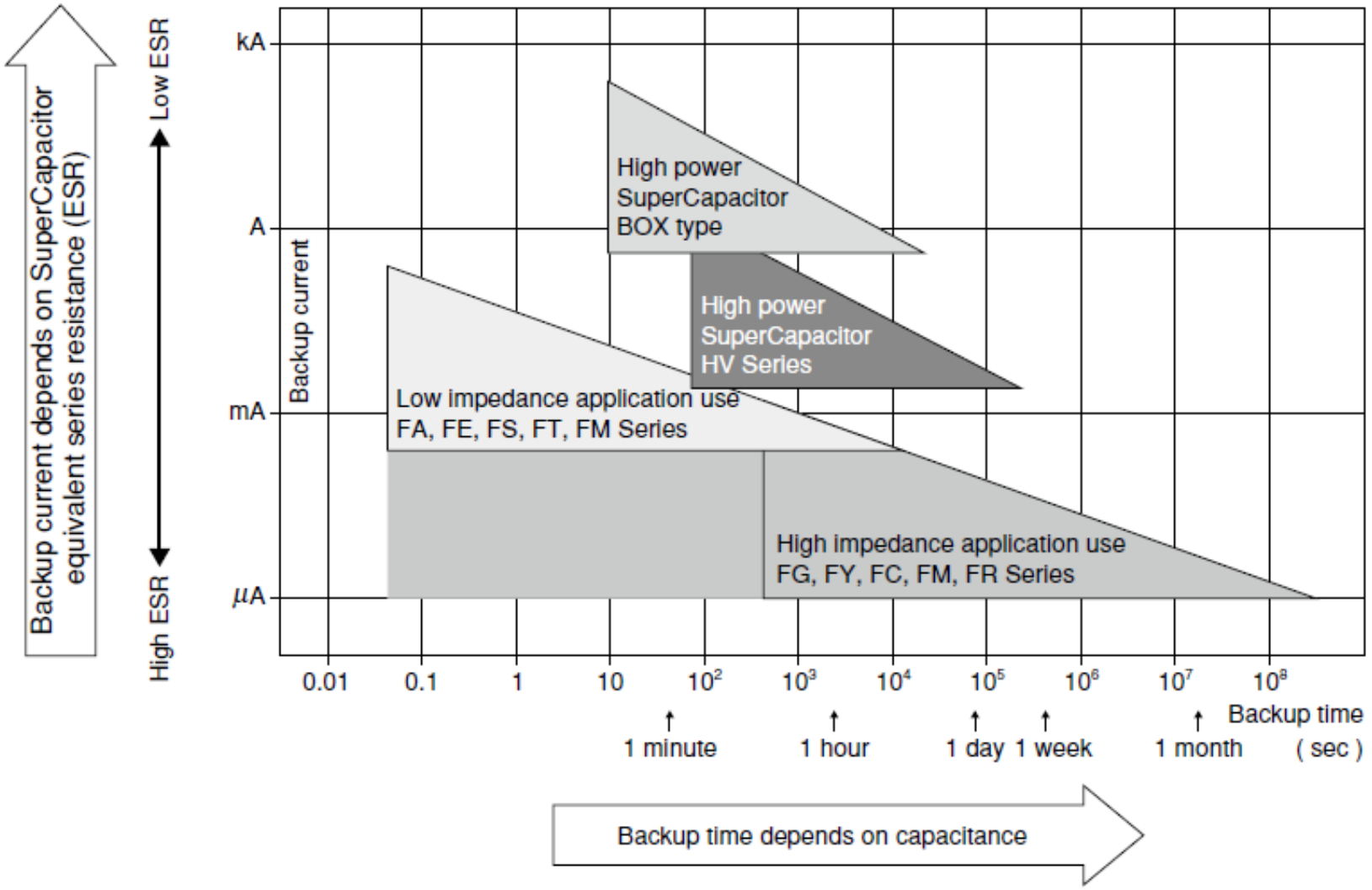
Resin Molded type

Can type

FM Series	FC Series	FG, FR, FY, FT, FS, FA, FE Series	HVZ Series
			
Capacitance range	**Capacitance range**	**Capacitance range**	**Capacitance range**
0.01 – 0.22 F	**0.047 – 1 F**	**0.01 – 5.6 F**	**1 – 200 F**
Voltage range	**Voltage range**	**Voltage range**	**Voltage range**
3.5 – 6.5 V	**3.5 – 5.5 V**	**3.5 – 12 V**	**2.7 V**
MaxTemp	**MaxTemp**	**MaxTemp**	**MaxTemp**
70°C/85°C	**70°C**	**70°C/85°C**	**70°C**

Series with temperature range (- 40 to +85): FT, FR, FM, FMR, FGR

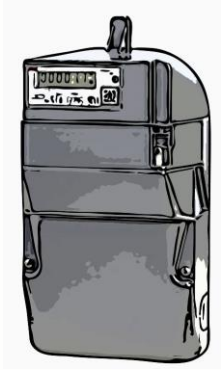
Performance for selection



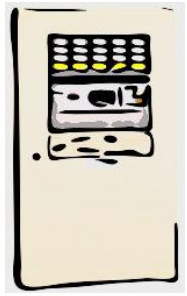
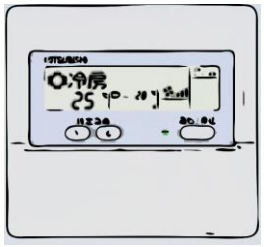
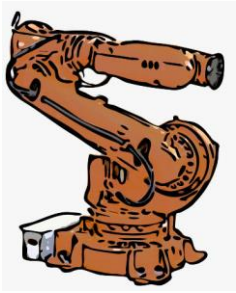
Application Examples of Supercapacitors

Intended use (guideline)	Power supply (guideline)	Application	Examples of equipments	Series
Long time back-up	500 μA and below	· CMOS RAM, IC for clocks	· Measuring device, Control equipment, Communication device, Automotive power source	· FR series (85℃ guaranteed)
		· CMOS micro computer, IC for clocks	· CMOS micro computer · Static RAM/DTS (digital tuning system)	· FC series · FG series · FY series · FM series
Back-up for 1 hour or less	50 mA and below	· Micro computer, RAM	· VCR, Microwave oven, · Micro computer · Memory equipped device	· FT series · FS series
		· Driving motor	· VCR, Printer, Projector · Video disk	
		· Subsidiary power supply for driving motor during voltage drop	· Camera	
Back-up for 10 seconds or less	1 A and below	· Power source of toys, LED, buzzer	· Toys, Display device, Alarm device	· FA series · FE series
		· High current supply for a short amount of time	· Actuator, Relay solenoid, Gas igniter	
Power assist	Up to several A	· Power supply, Subsidiary power supply	· Street sign, Display light , UPS	· HV series

Application Examples- 1

SET	Utility Meter	Automotive Infotainment	Flight Entertainment	Base Station For communication
				
Example MPN	FCS0H224ZF FM0H224ZF FGR0H105ZF	FM0H104ZF FMR0H104ZF FCS0H104ZF	FC0H105ZF-SS	FCS0H473ZF FCS0H104ZF
Note	Keep time information High temp/High humidity performance is important	Keep time information Car radio, Car navigation, Fish finder	Keep time information	Keep time information

Application Examples- 2

SET	Security / Fire alarm system	HVAC, Thermostat	Industrial Robot	Digital Network Camera
				
Example MPN	FM0H224ZF FG0H105ZF	FCS0H473ZF FCS0H104ZF	FCS0H104ZF FG0H473ZF	FM0H224ZF FMR0H224ZF FCS0V224ZF
Note	Keep time information	Keep time information	Keep time information, Keep location information	Keep time information

Application Examples-3

SET	Appliances with network function	POS terminal	Insulin pump, Other medical devices	Ultrasonic diagnostic equipment
				
Example MPN	FG0H105ZF FC0H105ZF-SS	FG0H104ZF FM0H104ZF FC0H104ZF	**FG0H104ZF** **FG0H224ZF**	**FCS0H473ZF** **FCS0H104ZF**
Note	Keep time information	Keep transaction data	Sustaining corrected data and setting. Keep setting information.	Keep time information

How to calculate the correct capacitance for the application?

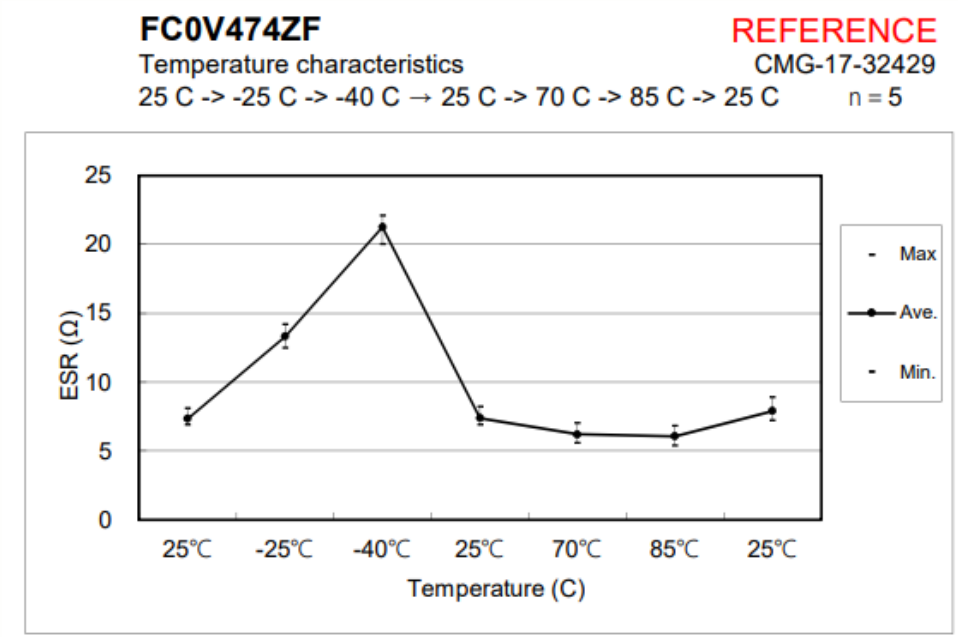
Application information parameters:

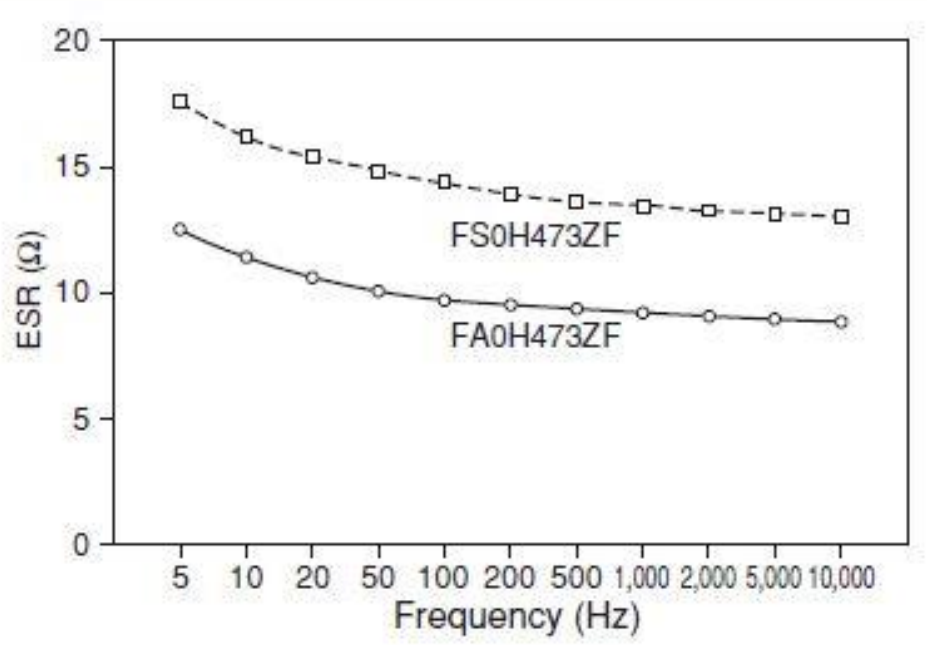
- $\boldsymbol{t}\ [\mathrm{s}]$ – required back up time
- $\boldsymbol{I_{backup}}$ – required back up current
- $\boldsymbol{V_{min}, V_{max}}$ – minimum and maximum operating voltage
- operating ambient temperature
- required dimensions
- mounting type (surface mount or through-hole)

$$\boldsymbol{C} = \frac{(\boldsymbol{I_{backup}})[A] \times \boldsymbol{t}\ [s]}{(\boldsymbol{V_{max}} - \boldsymbol{V_{min}})[V]}$$

Parasitic effects
R_{series} - DC Resistance and ESR

- Resistance of the capacitor's terminals and electrodes
- Ohmic losses within a capacitor during the movement of charge carriers
- RC value impacts the charge and discharge time
- ESR is considered as AC resistance which has a frequency dependent characteristic





Additional parameters needed for the calculation

- The voltage drop of the supercapacitor is determined by the DC resistance and the back-up current.
- The DC resistance values of each part number are given in our datasheets.

Additional parameters:

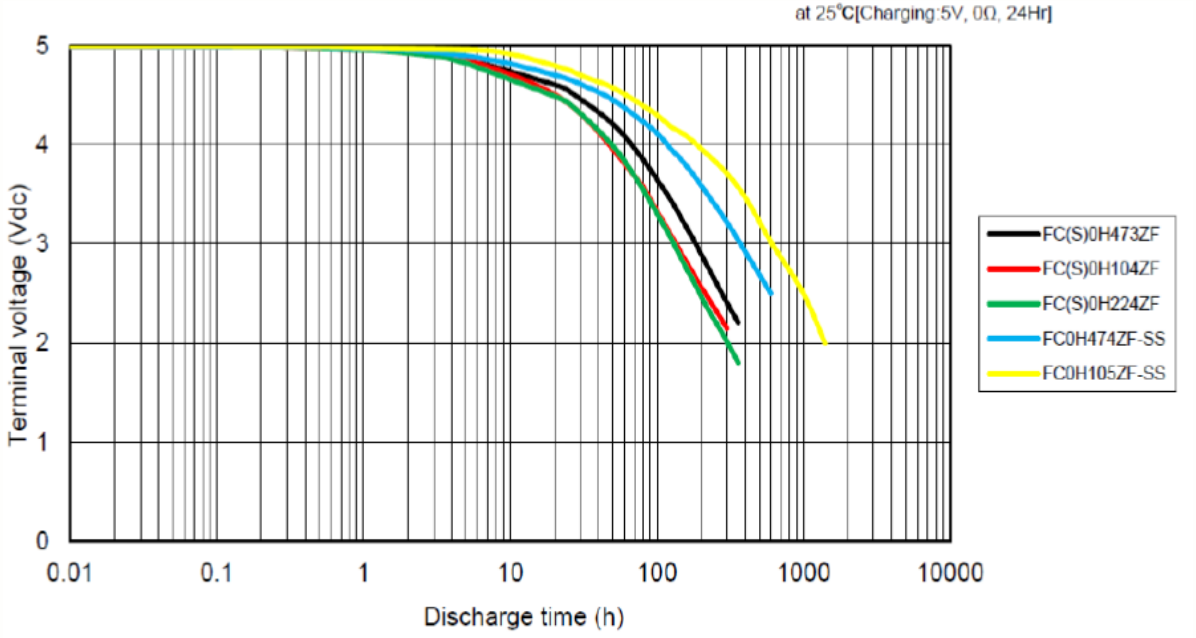
- V_{drop} – voltage drop by DC resistance
  when back up current is 1mA or below – we disregard the drop
- R_{series} – DC resistance

$$V_{drop} = R_{series}[\Omega] * Ibackup[A]$$

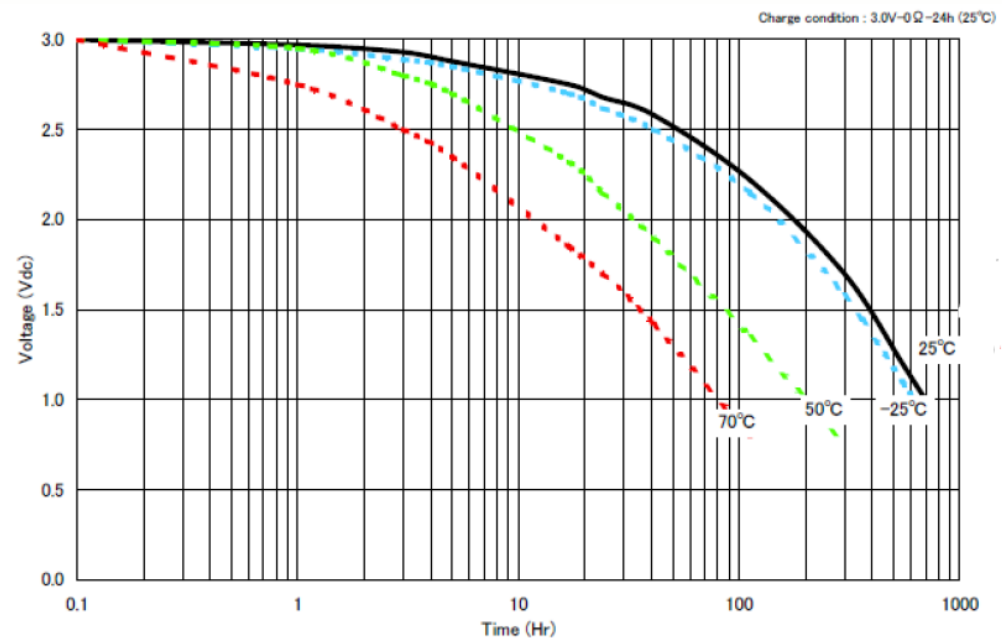
$$\boldsymbol{C = \frac{\left(I_{backup}\right)[A] \times t\,[s]}{\left(V_{max} - V_{min} - V_{drop}\right)[V]}}$$

Parasitic effects
Self-discharge characteristic

- SD characteristic - measured when the main charging source is disconnected from the supercapacitor
- Self-discharge characteristic (SD) – important characteristics to determine the backup time – needs to be taken in consideration

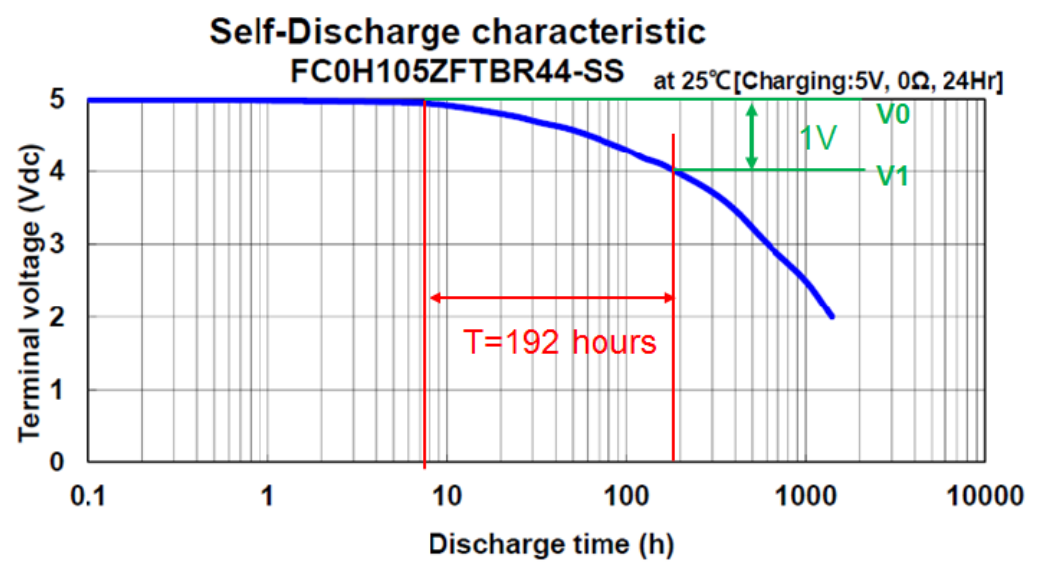


Self-discharge characteristics of the FC series supercapacitor



Self-discharge characteristics of the FC0V474ZF at different temperatures

Additional parameters needed for the calculation



Additional parameters:

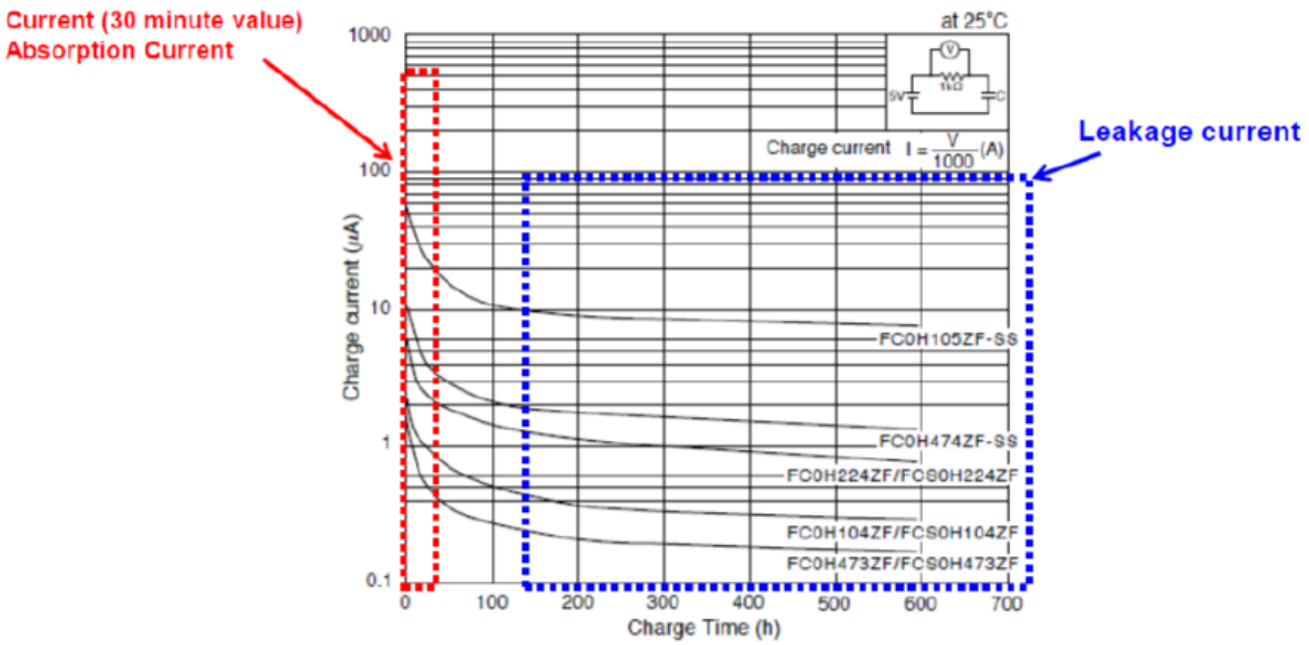
- V_{drop} – voltage drop by DC resistance
  when back up current is 1mA or below – we disregard the drop, negligible for RTC backup application
- $I_{self.discharge}$ – self discharge characteristic
- R_{series} – DC resistance

$$I_{self.discharge} = \frac{C[F] * (V_0 - V_1 - V_{drop})[V]}{T[s]}$$

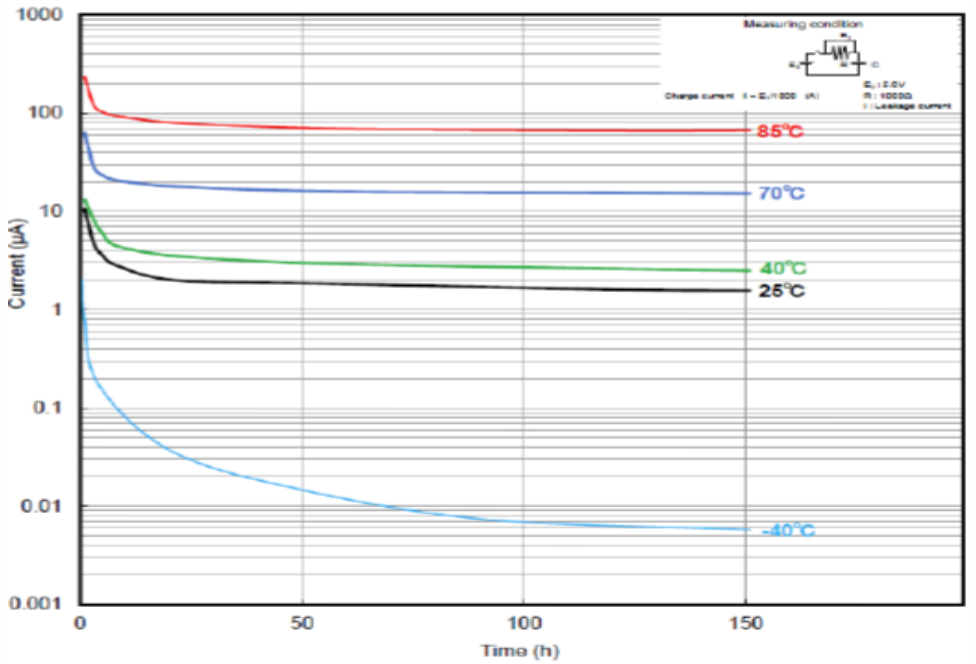
$$t\ (back\ up\ time\ estimation) = \frac{C[F] * (V_{max} - V_{min} - V_{drop})[V]}{(I_{self.discharge} + I_{backup})\ [A]}$$

Parasitic Effects
Leakage current

- Leakage current “LC” is a charge current measured from the pin-to-pin voltage across a charge resistor when the supercapacitor is charged for many hours and while the supercapacitor is on charge.
- Supercapacitor has a high internal resistance → small current is needed to keep the charge on the supercapacitor



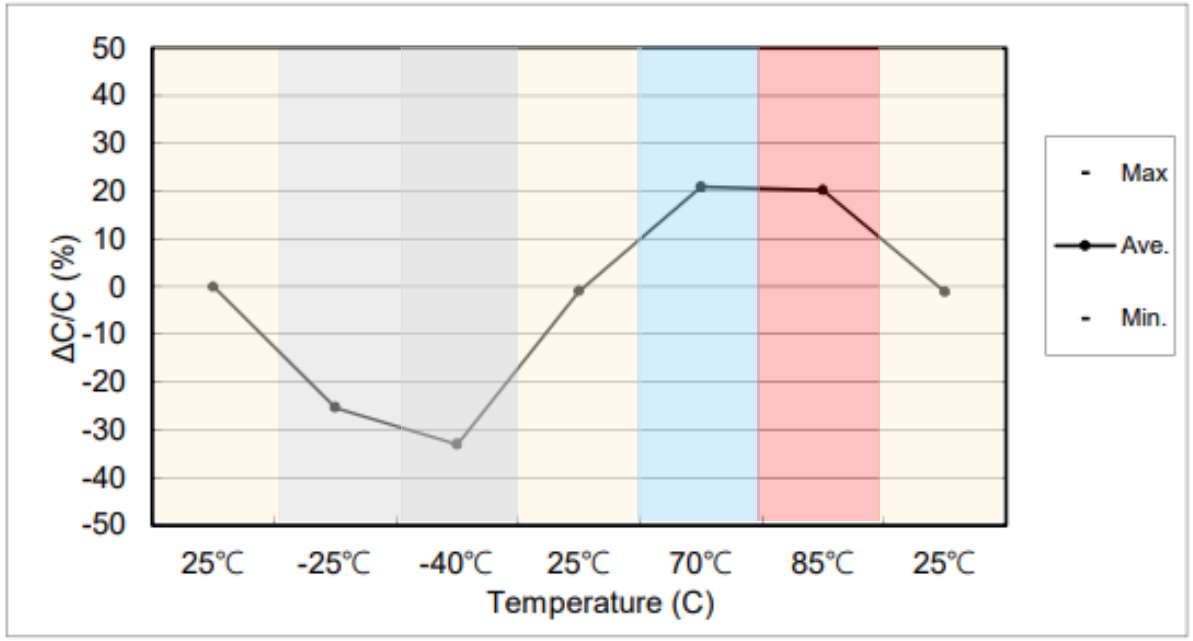
LC characteristics at room temperature and measurement circuit



LC characteristics of the FC0H224ZF at different temperatures

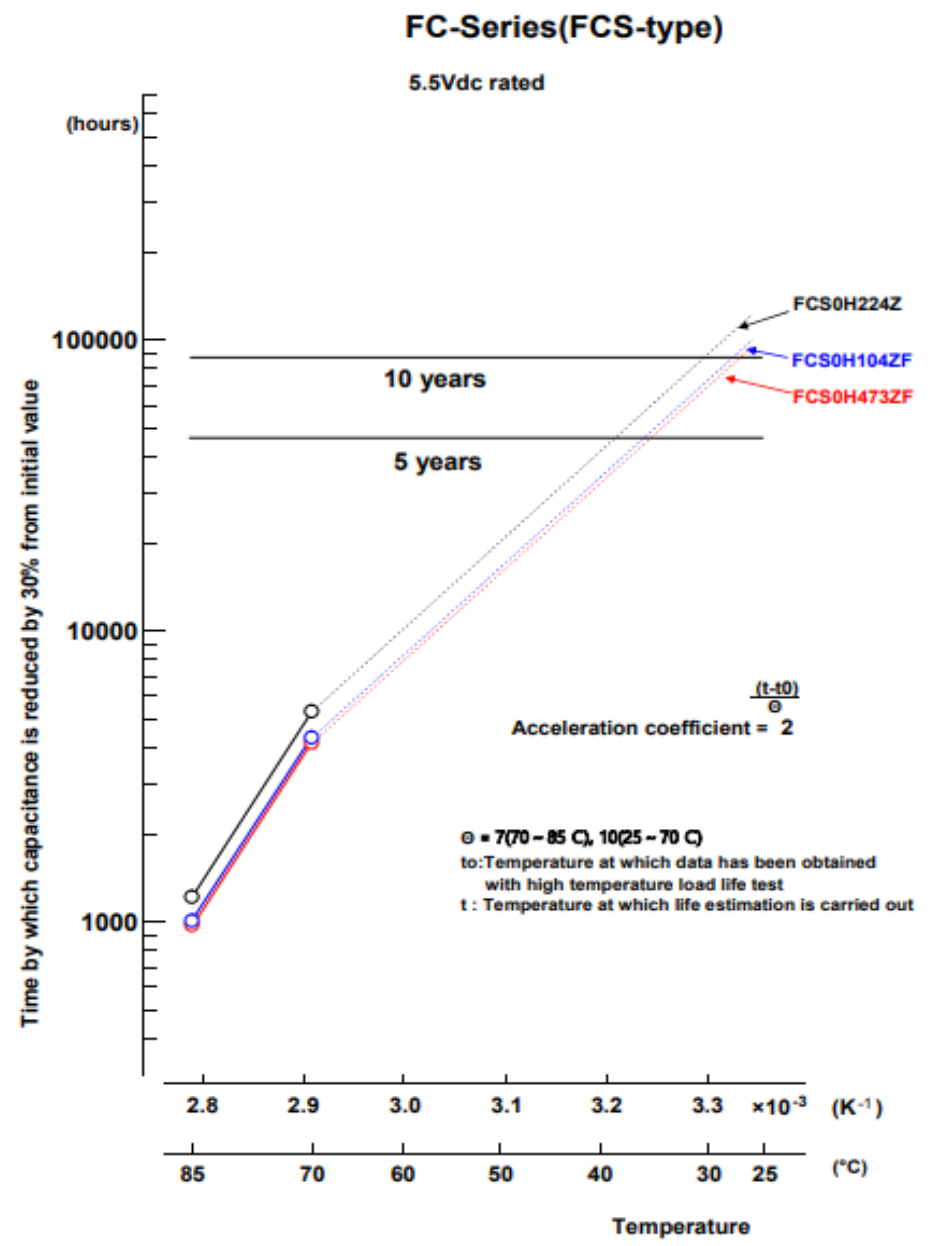
Parasitic effects
Ambient tempeture

- The operating temperature as one of the main factors for choosing the right supercapacitors
- Parameters that depend on the temperature:
  - Lifetime of the supercapacitor
  - Self discharge characteristic / discharge time
  - Leakage current
  - Capacitance
  - DC resistance

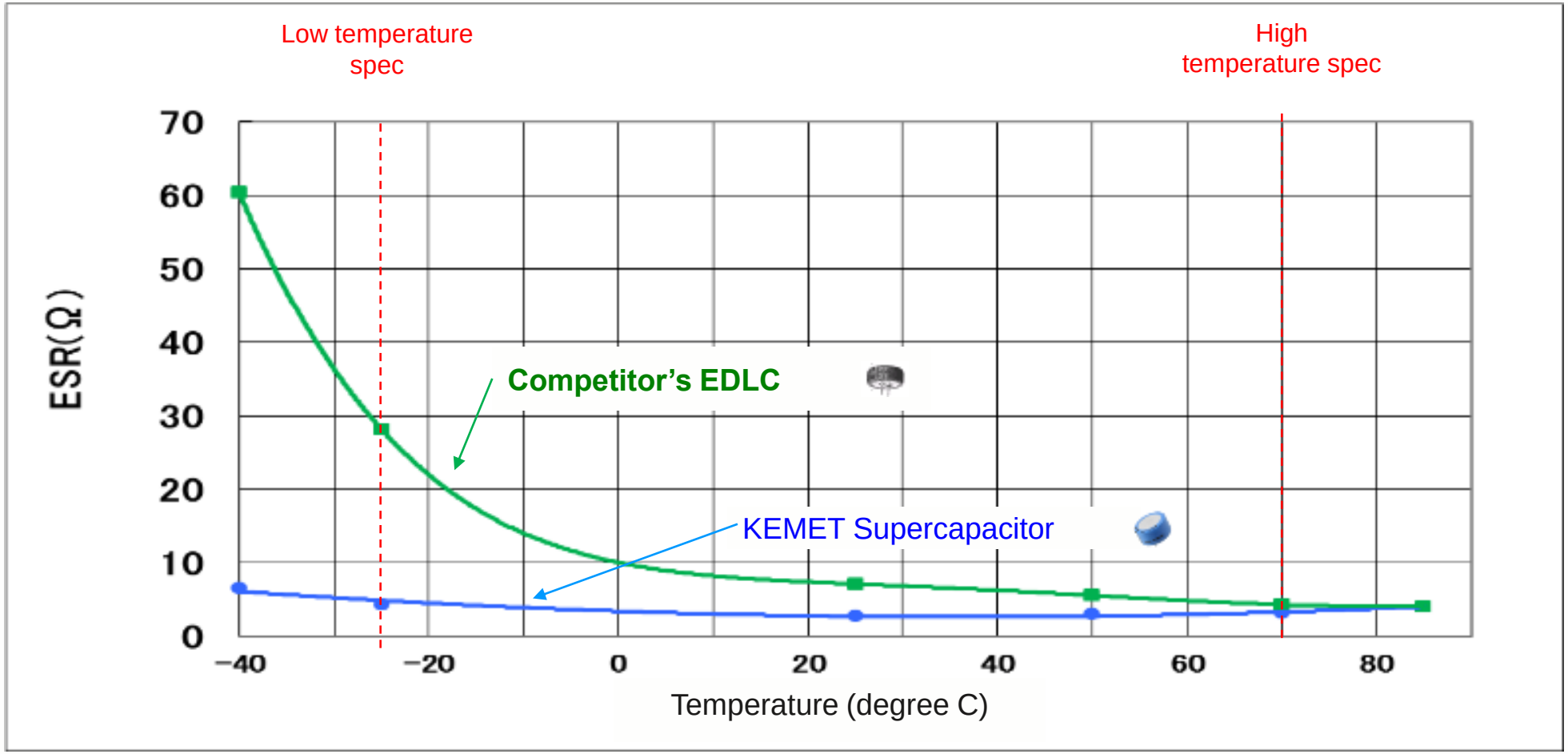


Lifetime of the supercapacitors

- Defined as the point at which capacitance is reduced to 70% of the initial value
- High temperature load life tests -> the life is reduced by half with an increase of 10°C temperature
- Lifetime of the supercapacitors – 10 years and more at ambient temperature 25°C



Supercapacitor ESR
KEMET vs. Competitor

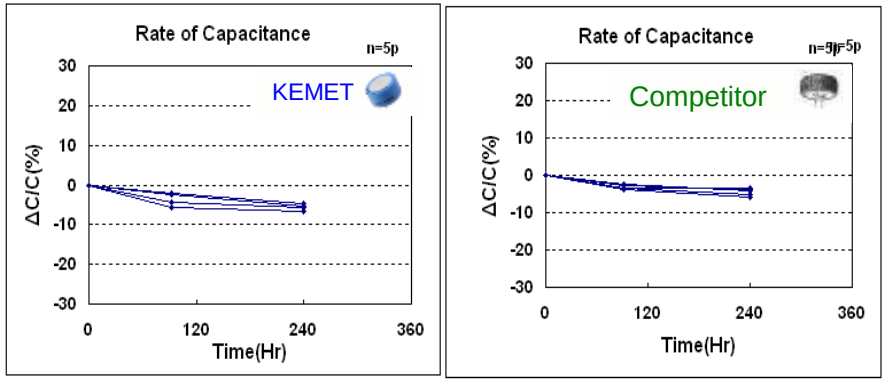


KEMET Supercapacitor: Better ESR stability over temperature.

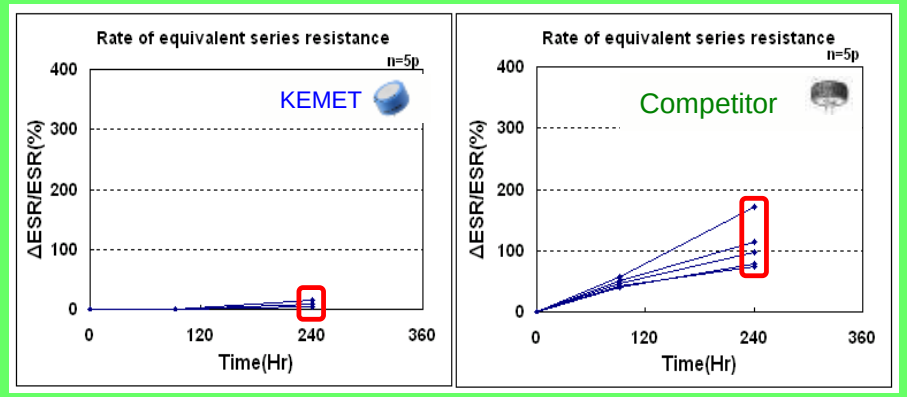
High Temperature, High Humidity Test

Test Condition: 85℃, 85% RH, no load, 240 hours

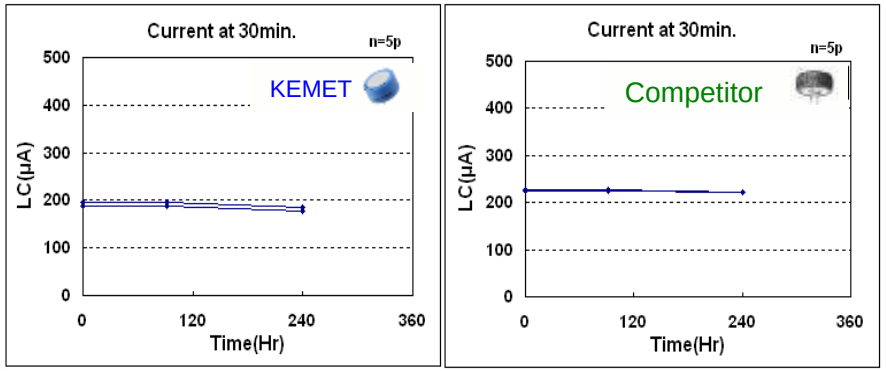
Capacitance changing rate



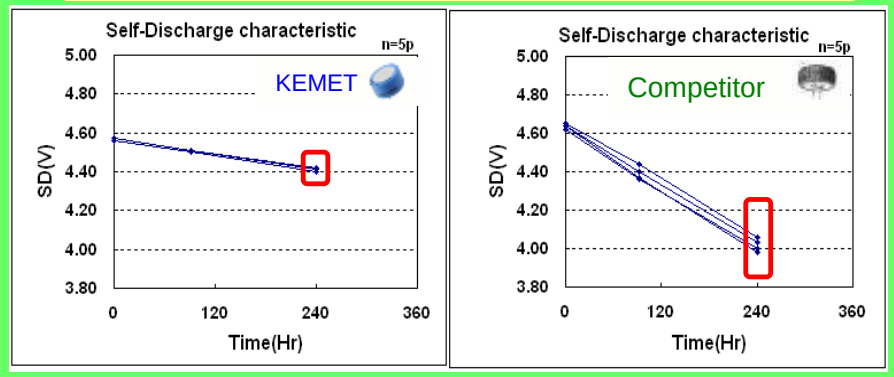
ESR changing rate *(@1kHz)*



LC characteristic *(30min value)*



Self discharge characteristic *(24Hr value)*



Competitor part: Poor ESR performance, Poor Self Discharge performance

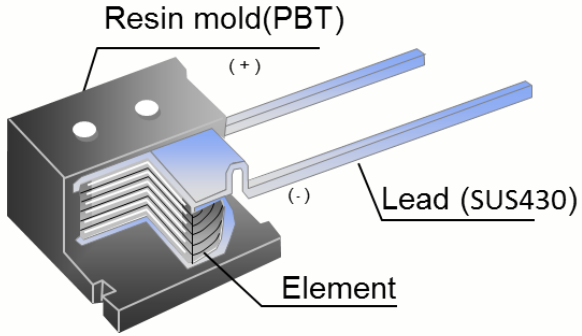
New Supercapacitor AEC-Q200 Compliant Products

High Reliability for Automotive market

AEC-Q200 Grade3* Compliant Product, FM series

***Grade3: Using Aluminum Capacitor's Standards.**
For most passenger compartment
(-40ºC~+85ºC)

Mold type



Outline	Development Status
Mold type *** High reliability.** *** Automatic mounting compatible.**	**Development Completed.** **Mass production Q4 CY2020**

Recap

- Supercapacitors have no limit for charge/discharge cycles
- Quick charge and discharge possible since no chemical charge is involved
- Open failure mode
- Simple installation – SMD and automatic mounting series available
- Wide operating temperature range – up to 85°C
- High reliability in humid environments
- Maintenance free
- Every application that needs a ”small power” backup solution is a potential for supercapacitors

Q&A

- Submit question via the Q&A window
- Note that the speaker will try to answer as many as time allots
- Ask attendees to submit unanswered or late questions via this link: https://go.kemet.com/contact-us

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- Automotive Series: Advanced Driver-Assistance Systems
- Automotive Series: Powertrain
- Automotive Series: 48V Systems

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