Cellergy

Super Capacitors Improve Power Performance

Supercapacitors for Pulse Applications

Eli Alon, CTO

Supercapacitors USA 2012 conference

Cellergy a Subsidiary of **PCB** TECHNOLOGIES

Get Power – Run Longer

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Agenda

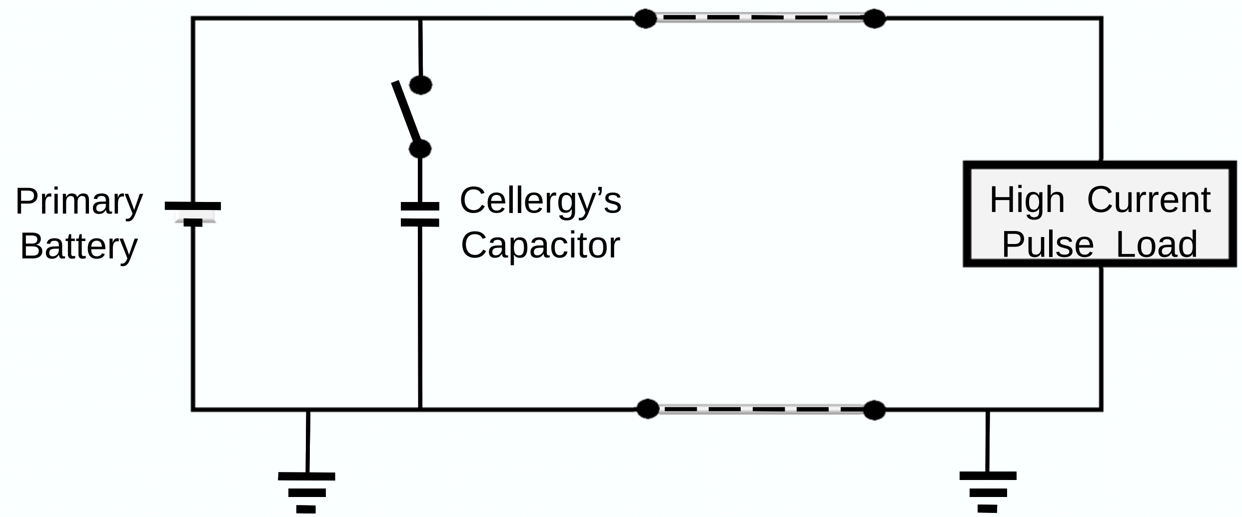
- Company Profile
- Core Competency
- Automated Production Line & technology highlights
- Applications
- Which data should an engineer know when selecting a SC for a specific application?
  - Performances of Cellergy SCs
  - Accelerated testing, cycle life and life time of supercapacitors
- SCs for Energy Harvesting (in Appendix)
- Why select Cellergy products?

Supercapacitors can do it…

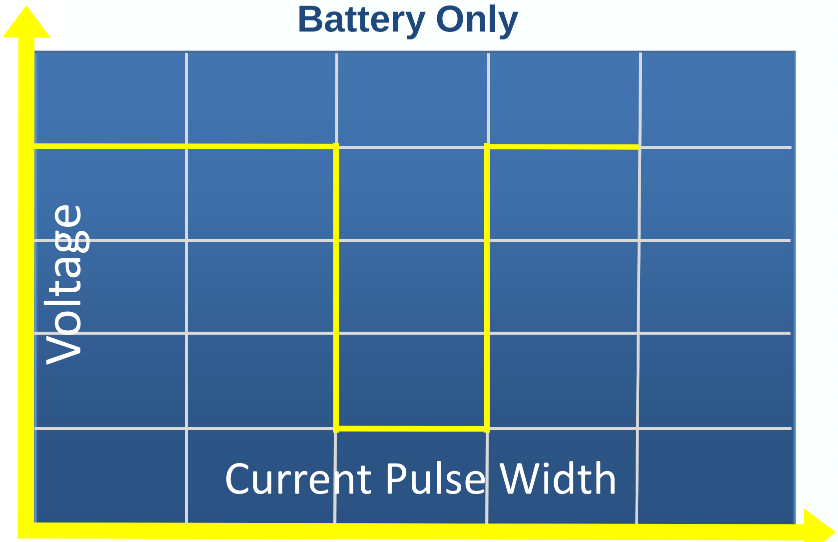
- In certain applications electronic devices need to deliver high current pulses
- In most battery operated devices - using primary batteries - driving such currents is many times impossible.
- In Energy Harvesting (EH) systems -supercapacitors are used for energy storage, mostly eliminating the need for batteries and batteries replacement.
  - SCs buffer the high power load from the low power source in a small form factor.

EDLC & Battery Coupling

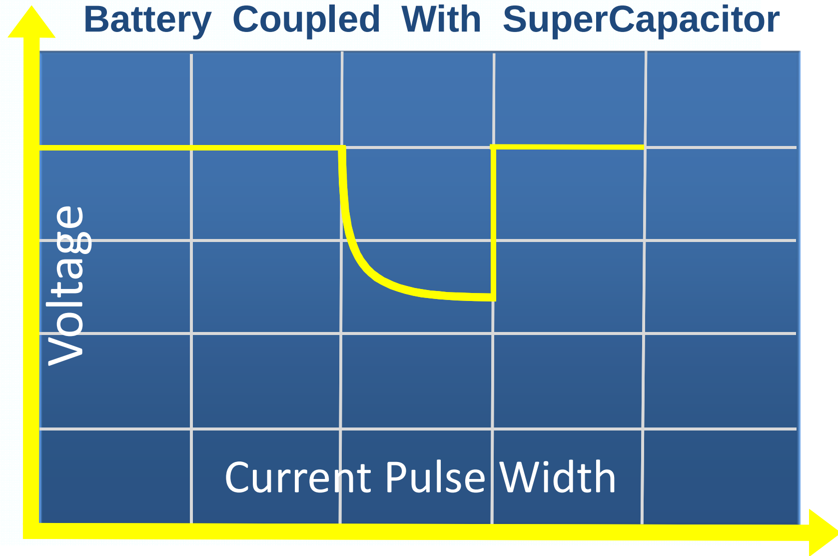
*Voltage Drop **with** and **without** SC*



Battery Only



Battery Coupled With SuperCapacitor



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- ✓ Cellergy develops & manufactures flat, thin, bi-polar low ESR Pulse Super Capacitors based on it's own IP.
- ✓ Automated Line developed by Cellergy specific for its products is implemented for volume manufacturing.
- ✓ Current product lines are for the industrial & consumer electronics industry (mainly for battery operated devices).
- ✓ 4 form factor groups are manufactured (different size).

Cellergy

About us

- Founded in 2002, privately held
- Acquired by PCB Technologies in 2007
- R&D and manufacturing site in Migdal Ha'emek, Israel
- Patented wafer-printing technology
- Production floor area - 1,200m^2
- Production capacity (current) – 15M pcs/year
- Quality system – ISO 9001:2000
- Products – RoHS and REACH certified
- **Frost & Sullivan award for Super-Capacitors technology innovation in 2010**

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Core Competency

Patented Screen Printing Technology and automated manufacturing line of Super-Capacitors (EDLCs):

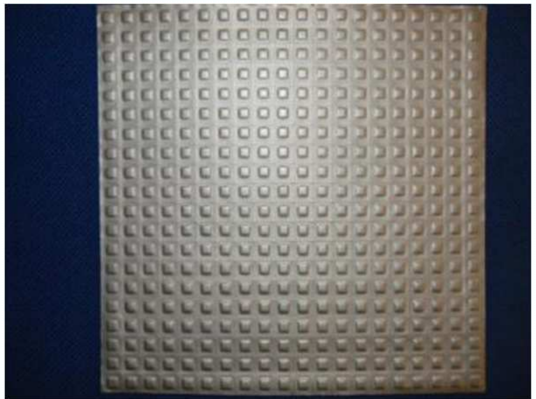
- High capacitance
- Low ESR
- High power density
- Low leakage current
- Small footprint (from 12x12.5mm and 10x15 mm)
- Environmental friendly (no harmful solvents)
- Robust construction
- Cost effective
- Tailor made

Wafer – inside view during production stage

Automated Production Line

Production line

Wafer – inside view during production stage



Wafer of 12x12.5 mm cells
(400 cells)

Wafer of 28x17 mm cells
(144 cells)

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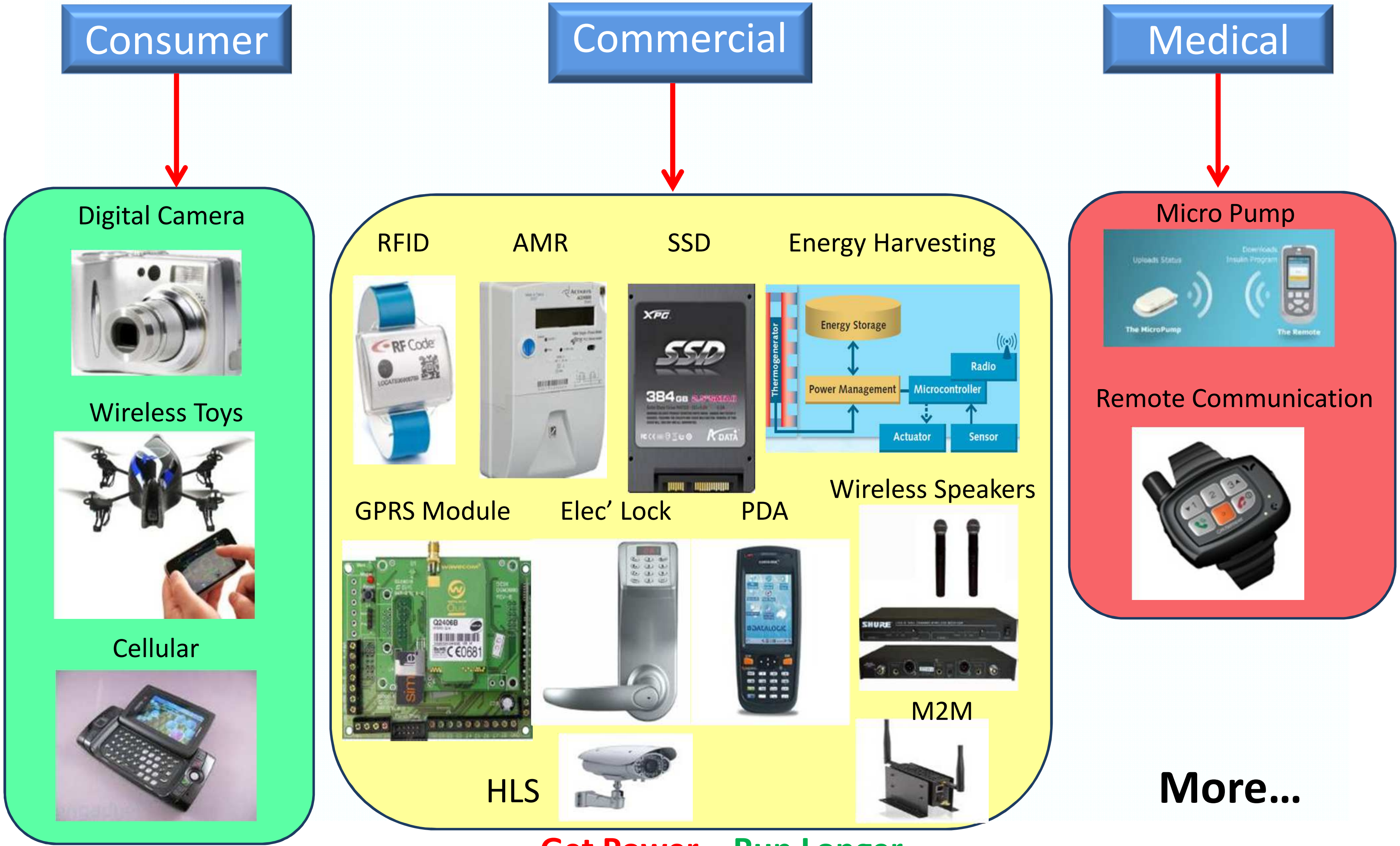
Applications



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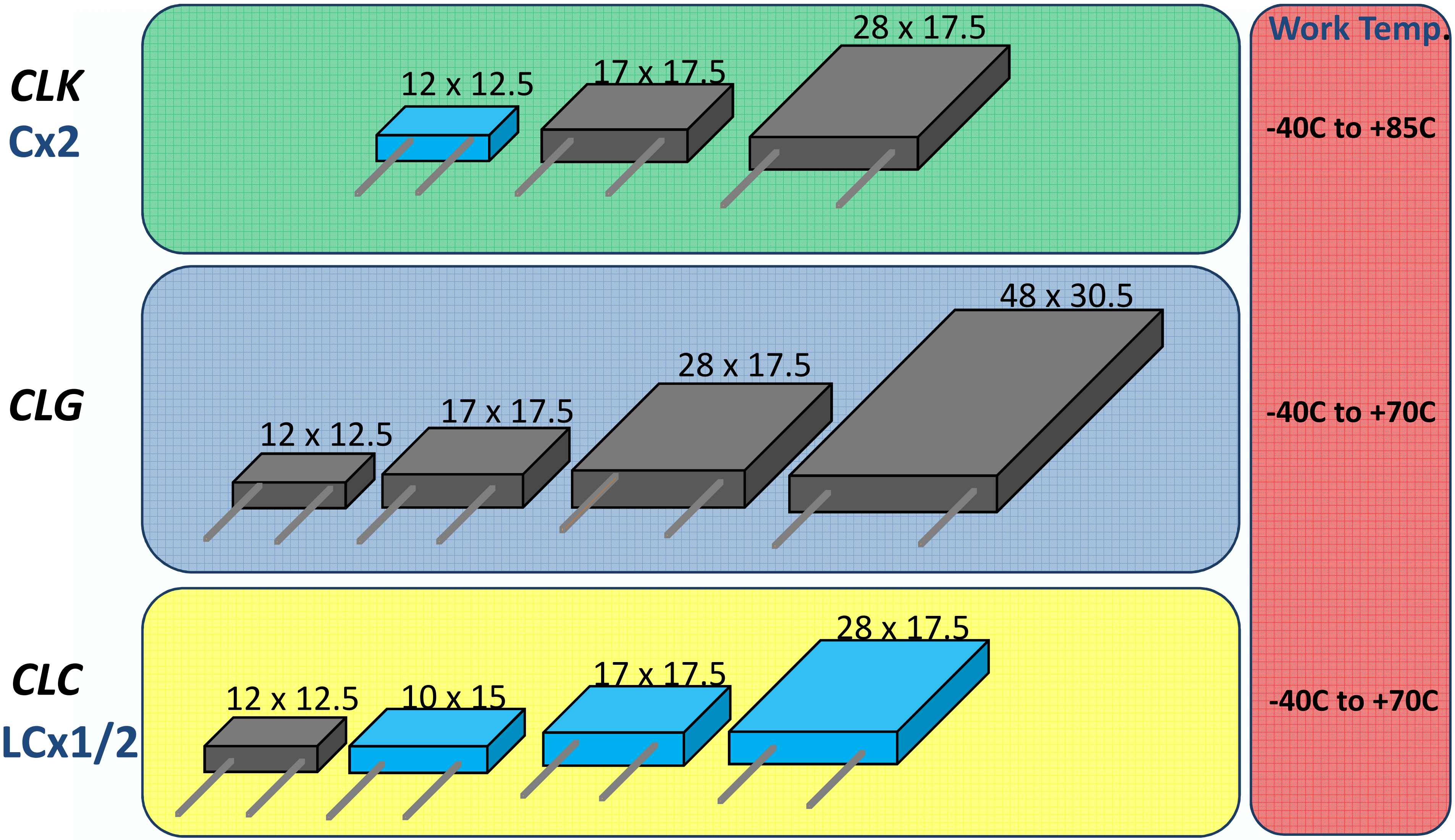
Cellergy's Product Lines



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Which data should an engineer know when selecting a SC for a specific application?

- Voltage
- Capacitance, ESR
- Max Leakage current
- Thickness/Size
- Working (storage) temperature range
- Life (cycle) time
- Environment
- Vibration & shock conditions
- Permitted voltage Drop
- Battery data
- Pulse characteristics (current, pulse width, duty cycle)

Products range - Line Card of 12x12.5 products

CLG : Standard

	P/N	Nominal Voltage (Volt)	ESR (mΩ)	Capacitance (mF)	Max Allowed LC (μA)	Length (mm)	Width (mm)	Height (mm)	Pitch (mm)	Weight (gram)
12x12.5 Single	CLG03P012L12 *	3.5	600	12	3	12	12.5	2.4	8.0 **	1.3
	CLG04P010L12	4.2	720	10	3	12	12.5	2.6	8.0	1.4
	CLG05P008L12	5.5	1000	8	3	12	12.5	3.1	8.0	1.5
	CLG06P007L12	6.3	1200	7	3	12	12.5	3.4	8.0	1.6
12x12.5 Double ***	CLG03P025L12	3.5	300	25	6	12	12.5	3.4	8.0	1.6
	CLG04P020L12	4.2	360	20	6	12	12.5	3.9	8.0	1.7
	CLG05P016L12	5.5	500	16	6	12	12	4.8	8.0	1.8
	CLG06P012L12	6.3	600	12	6	12	12.5	5.3	8.0	1.9

CLC : Low Leakage

	P/N	Nominal Voltage (Volt)	ESR (mΩ)	Capacitance (mF)	Max Allowed LC (μA)	Length (mm)	Width (mm)	Height (mm)	Pitch (mm)	Weight (gram)
12x12.5 Single	CLC03P012L12 *	3.5	600	12	1.5	12	12.5	2.4	8.0 **	1.3
	CLC04P010L12	4.2	720	10	1.5	12	12.5	2.6	8.0	1.4
12x12.5 Double ***	CLC03P025L12	3.5	300	25	3	12	12.5	3.4	8.0	1.6
	CLC04P020L12	4.2	360	20	3	12	12.5	3.9	8.0	1.7

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Products Range

Line card of 12 x 12.5mm

CLG: Standard

	P/N	Nominal Voltage (Volt)	ESR (mΩ)	Capacitance (mF)	Max LC (µA)	Length (mm)	Width (mm)	Height (mm)	Pitch (mm)	Weight (Gram)
12 x 12.5 Single	CLGXX12	3.5	600	12	3	12	12.5	2.4	8.0	1.3
12 x 12.5 Single	CLGXX12	4.2	720	10	3	12	12.5	2.6	8.0	1.4
12 x 12.5 Double	CLGXX12	3.5	500	16	6	12	12.5	4.8	8.0	1.8
12 x 12.5 Double	CLGXX12	4.2	600	12	6	12	12.5	5.3	8.0	1.9

CLG: Low Leakage

	P/N	Nominal Voltage (Volt)	ESR (mΩ)	Capacitance (mF)	Max LC (µA)	Length (mm)	Width (mm)	Height (mm)	Pitch (mm)	Weight (Gram)
12 x 12.5 Single	CLGXX12	3.5	600	12	**1.5**	12	12.5	2.4	8.0	1.3
12 x 12.5 Single	CLGXX12	4.2	720	10	**1.5**	12	12.5	2.6	8.0	1.4
12 x 12.5 Double	CLGXX12	3.5	300	25	**3**	12	12.5	3.4	8.0	1.6
12 x 12.5 Double	CLGXX12	4.2	360	20	**3**	12	12.5	3.9	8.0	1.7

Products range - Line Card of 28x17.5

CLG : Standard

	P/N	Nominal Voltage (Volt)	ESR (mΩ)	Capacitance (mF)	Max Allowed LC (μA)	Length (mm)	Width (mm)	Height (mm)	Pitch (mm)	Weight (gram)
28x17.5 Single	CLG03P060L28*	3.5	130	60	10	28	17.5	2.4	11.0	4.3
	CLG04P050L28	4.2	150	50	10	28	17.5	2.6	11.0	4.5
	CLG05P040L28	5.5	200	40	10	28	17.5	3.1	11.0	4.8
	CLG06P035L28	6.3	230	35	10	28	17.5	3.4	11.0	5.3
	CLG12P015L28	12	445	15	10	28	17.5	5.4	11.0	6.4
28x17.5 Double **	CLG03P120L28	3.5	65	120	20	28	17.5	3.4	11.0	5.3
	CLG04P100L28	4.2	75	100	20	28	17.5	3.9	11.0	5.4
	CLG05P080L28	5.5	100	80	20	28	17.5	4.8	11.0	5.7
	CLG06P070L28	6.3	115	70	20	28	17.5	5.4	11.0	6.3
	CLG12P030L28	12	225	30	20	28	17.5	9.0	11.0	6.4

CLK : Extra Capacitance

	P/N	Nominal Voltage (Volt)	ESR (mΩ)	Capacitance (mF)	Max Allowed LC (μA)	Length (mm)	Width (mm)	Height (mm)	Pitch (mm)	Weight (gram)
28x17.5 Single	CLK03P120L28*	3.5	160	120	10	28	17.5	3.0	11.0	4.3
	CLK04P100L28	4.2	180	100	10	28	17.5	3.2	11.0	4.5
	CLK05P075L28	5.5	230	80	10	28	17.5	3.5	11.0	4.8
28x17.5 Double **	CLK03P240L28	3.5	80	240	20	28	17.5	4.5	11.0	5.3
	CLK04P200L28	4.2	90	200	20	28	17.5	4.9	11.0	5.4
	CLK05P160L28	5.5	115	160	20	28	17.5	6.0	11.0	5.7

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Products Range

Line card of 28 x 17.5mm

CLG: Standard

	P/N	Nominal Voltage	ESR	Capacitance	Max LC	Length	Width	Height	Pitch	Weight
		(Volt)	(mΩ)	(mF)	(µA)	(mm)	(mm)	(mm)	(mm)	(Gram)
28 x 17.5 Single	CLGXX28	3.5	130	60	10	28	17.5	2.4	11.0	4.3
	CLGXX28	4.2	150	50	10	28	17.5	2.6	11.0	4.5
27 x 17.5 Double	CLGXX28	3.5	65	120	20	28	17.5	3.4	11.0	5.3
	CLGXX28	4.2	75	100	20	28	17.5	3.9	11.0	5.4

CLK: High Capacitance

	P/N	Nominal Voltage	ESR	Capacitance	Max LC	Length	Width	Height	Pitch	Weight
		(Volt)	(mΩ)	(mF)	(µA)	(mm)	(mm)	(mm)	(mm)	(Gram)
28 x 17.5 Single	CLGXX28	3.5	160	**120**	10	28	17.5	3.0	11.0	4.3
	CLGXX28	4.2	180	**100**	10	28	17.5	3.2	11.0	4.5
27 x 17.5 Double	CLGXX28	3.5	80	**240**	20	28	17.5	4.5	11.0	5.3
	CLGXX28	4.2	90	**200**	20	28	17.5	4.9	11.0	5.4

Qualification Test Summary

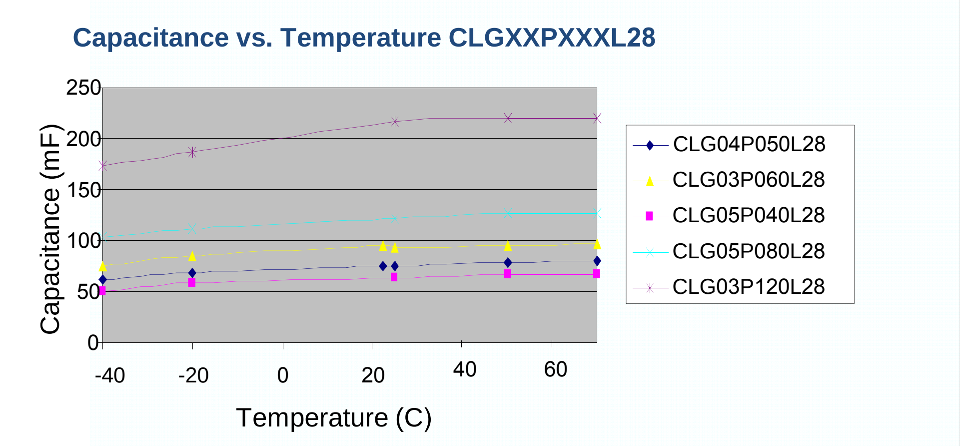
No.	Item	Test Method	Limits
1	Initial capacitance	Charge to rated voltage for 10min. discharge at constant current. C=Idt/dv (details in the page 19)	+80% / -20% of rated value
2	Initial leakage current	Charge to rated voltage 12 hr measure current (details in the page 19)	Within Limits (refer to max. LC values in line card table)
3	Initial ESR	Measure @ 1 KHz, Voltage 20mV amplitude, (details in the page 19)	+20% / -50% of rated value
4	Endurance	1000 hrs at 70°C at rated voltage (500 hrs at 70°C for 12x12 foot print products) Cool to RT measure: ESR,LC,C	LC < 3.0x rated value Cap > 0.7x rated value ESR < 3.0x rated value
5	Humidity life	1000 hrs at 40°C 90-95% humidity no voltage Cool to RT measure: ESR,LC,C	LC < 1.5x rated value Cap > 0.9x rated value ESR < 1.5x rated value
6	Lead pull strength	In accordance with JIS-C5102,8.1	LC : rated value Cap : rated value ESR : rated value
7	Surge voltage	Apply 15% voltage above rated voltage for 10 sec short cells 10 seconds repeat procedure 1000 times measure ESR,LC,C	LC : < 2.0x rated value Cap : > 0.7x rated value ESR: < 2.0x rated value
8	Temperature cycling	Each cycle consist of following steps: 1) Place supercapacitor in cold chamber (–40C) hold for 30 min 2) Transfer supercapacitor to hot chamber (+70C) in 2 to 3 minutes. 3) Hold supercapacitor in hot chamber for 30 min Number of cycles: 5	LC : < 1.5x rated value Cap: > 0.9x rated value ESR: < 1.5x rated value
9	Vibration	Frequency = 10 to 55 Hz Amplitude of vibration: 0.75 mm 2 hours each in three directions. (Total 6 hours)	LC : rated value Cap : rated value ESR : rated value No visual damage

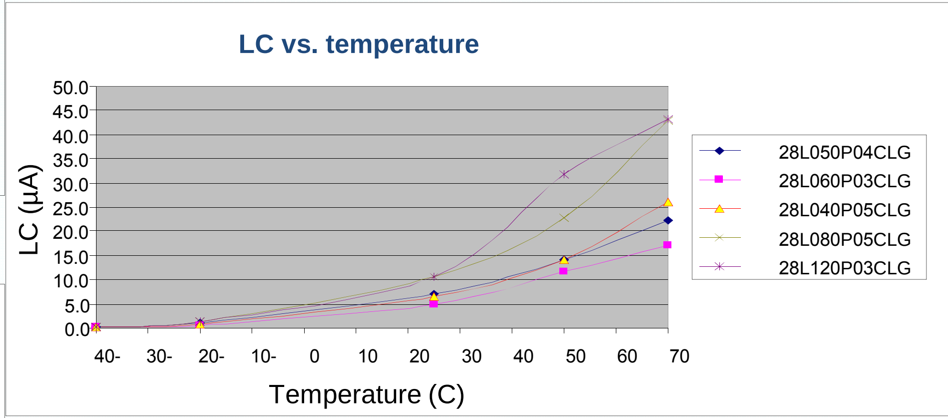
Qualification Test Summary

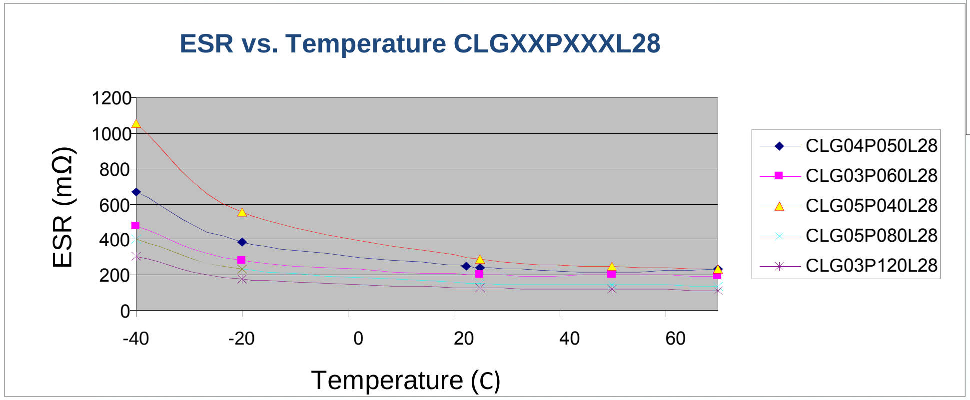
No.	Item	Test Method	Limits
1	Initial Capacitance	Charge to rated voltage for 10min. Discharge at constant current, C=Idt/dv	+80% / -20% of rated value
2	Initial Leakage Current	Charge to rated voltage 12hr. Measure current	Within limits
3	Initial ESR	Measure @ 1KHz, Voltage 20mV amplitude	+20% / -50% of rated value
4	Endurance	1000hrs at 70^{o}C at rated voltage 500hrs at 85^{o}C at rated voltage (CLK)	LC < 3.0x , Cap > 0.7x ESR < 3.0x
5	Humidity life	1000hrs at 40^{o}C, 90-95% humidity no voltage. Cool to RT, measure ESR, LC, C	LC < 1.5x , Cap > 0.9x ESR < 1.5x
6	Robustness of Termination	In accordance with IEC 62391-1 and subject to test Ub: Bending of IEC 60068-2-21, method 2: two or more bends in an angle of 90^{o} in the same direction	LC < 2.0x , Cap > 0.7x ESR < 2.0x No visual damage
7	Surge Voltage	Apply 15% voltage above rated voltage for 10sec, short cells 10sec, repeat procedures 1000 times measure	LC < 2.0x , Cap > 0.7x ESR < 2.0x
8	Temperature cycling	Each cycle consist of the following steps: 1. Place SC in cold chamber (-40^{o}C) and hold for 10min 2. Transfer SC to hot chamber (+70^{o}) in 2-3min 3. Hold SC in hot chamber for 30min (repeat cycle 5 times)	LC < 1.5x, Cap > 0.9x, ESR 1.5x
9	Vibration	Frequency = 10 to 55Hz Amplitude of vibration = 0.75mm 2 hours each in three directions (total 6 hours)	LC < 2.0x , Cap > 0.7x ESR < 2.0x No visual damage

Temperature Characteristics

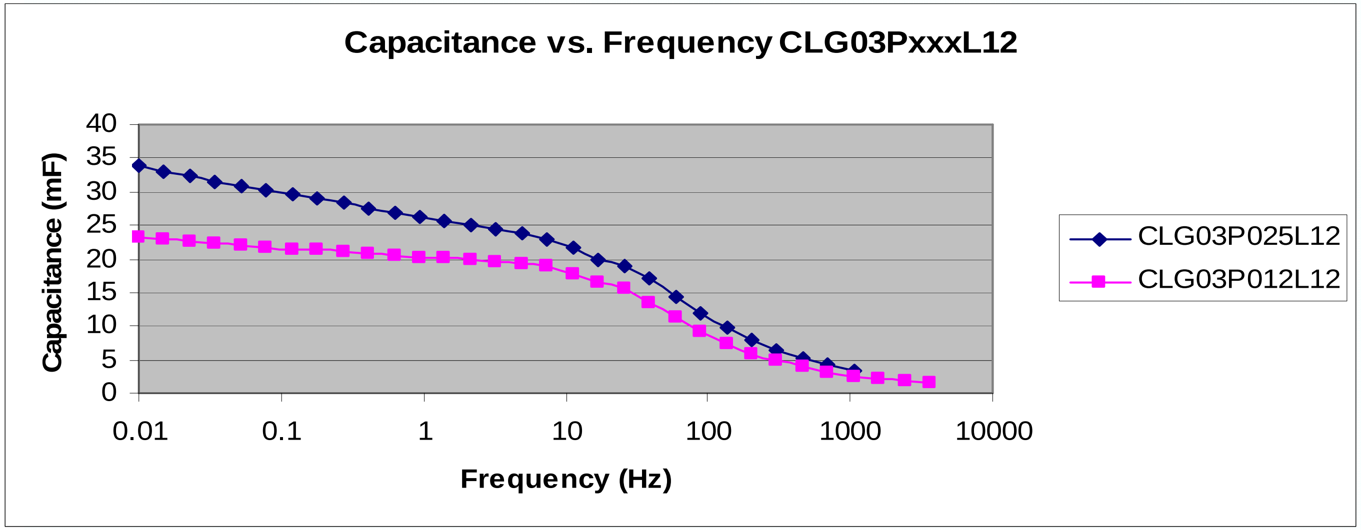
ESR, Capacitance & LC vs. Temperature

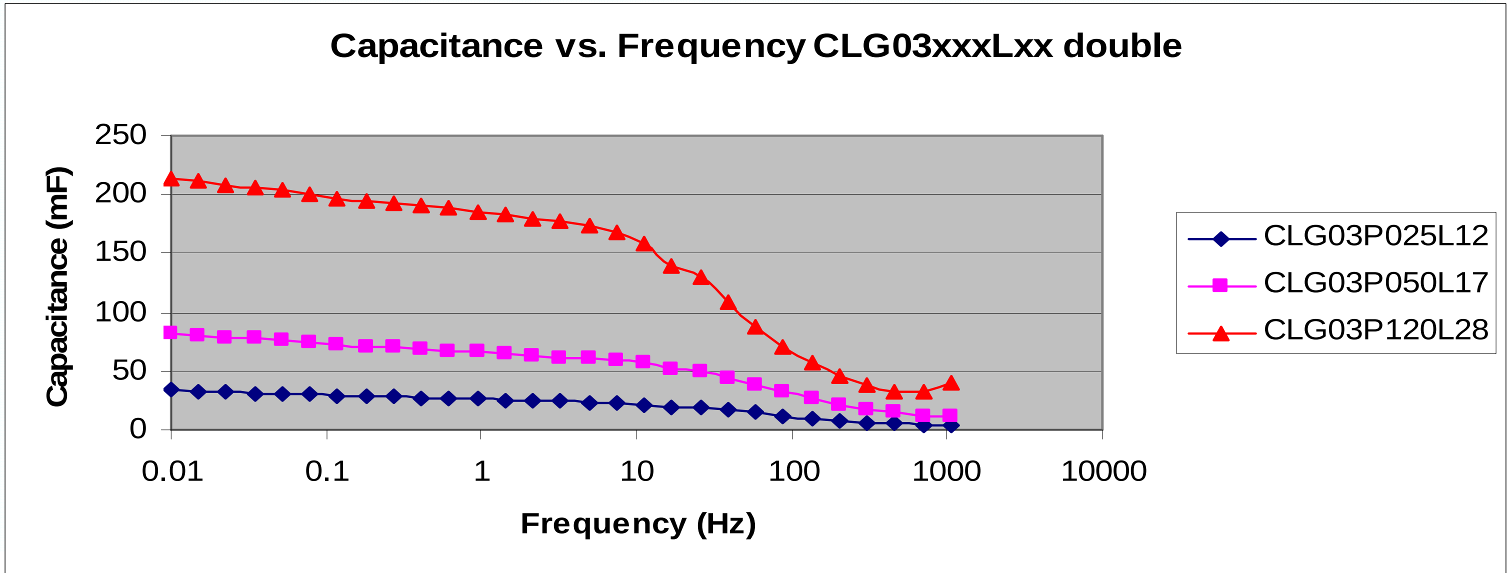






Capacitance vs. Frequency





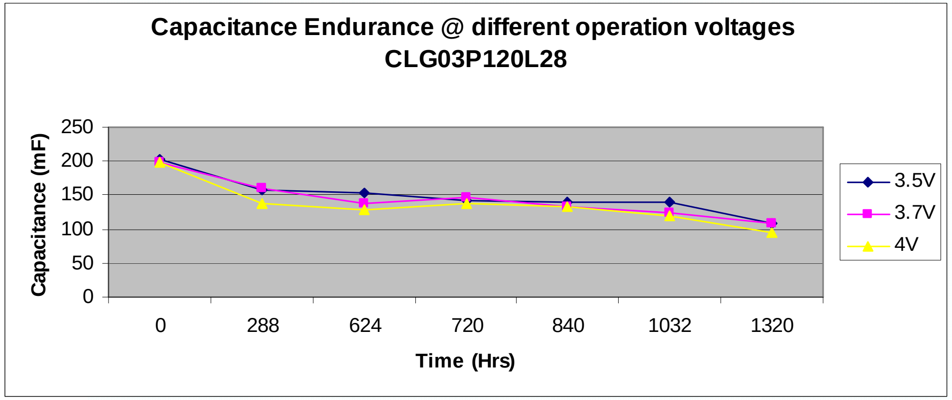
Reliability

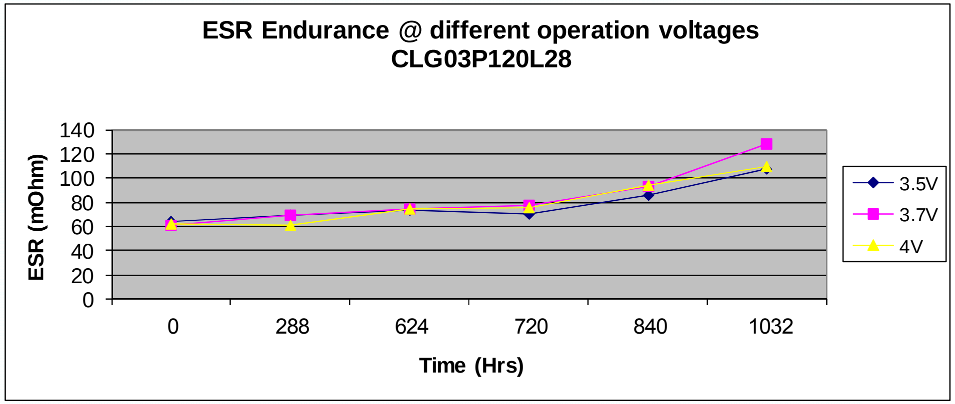
- Life time
- Cycle life
- Accelerated testing
- Endurance test
- Models for correlation
- Promises vs. reality

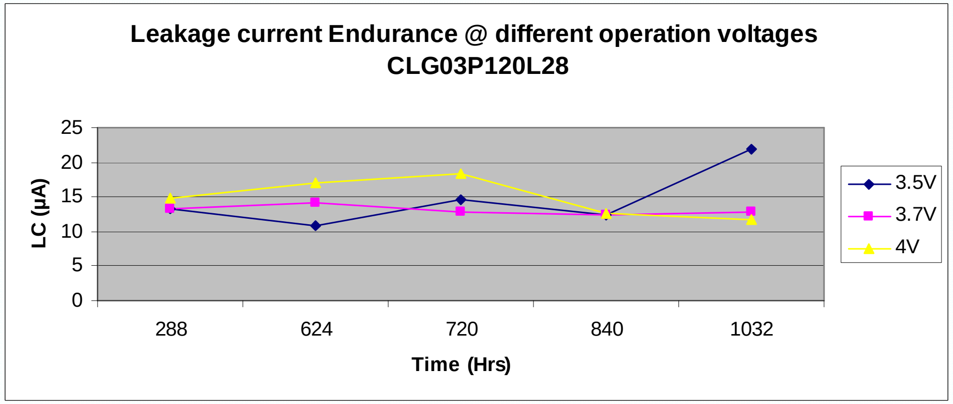
Endurance tests

Includes voltage enhancement

ESR – 65mΩ	Capacitance – 120mF	LC - 20µA







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Why life time of SC is not indefinite ?

- Virtually unlimited cycle life of supercapacitors (>100,000's of cycles)
- Supercapacitors should have an almost indefinite life, because the EDLC is charged and discharged by electrostatic adsorption and desorption of ions on the electrodes whose process involves mass transfer without a chemical reaction.
- However, the actual life of an EDLC is finite, such that its performance begins to slowly degrade and is significantly deteriorated at some point.
- **Aging is visible mainly by increase in ESR and by capacitance loss**

Life time Definitions

The time until the capacitor exhibits an explicit failure such as:

- package rupture with electrolyte leakage
- time to development of internal short
- the time until reaching poor performance that is defined as a failure

Voltage and temperature, not charge/discharge cycling, are the two major factors that affect SC life

Reason for deterioration of SC

- Side reactions during charge/discharge (Faradic process)
  - Between electrolyte ions and Carbon
  - Of electrolyte ions with different impurities
- Cells depletion (electrolyte drying) – by diffusion mechanism
- Electrochemical decomposition of the electrolyte
  - May generate gas evolution (over-pressure in the cell)
- Closing of the pores access (clogging of pores)
- Oxidation of the carbon surface
- Delamination due to temperature cycling causing increase in ESR and eventually failure
- Enhanced aging at high temperatures or voltage

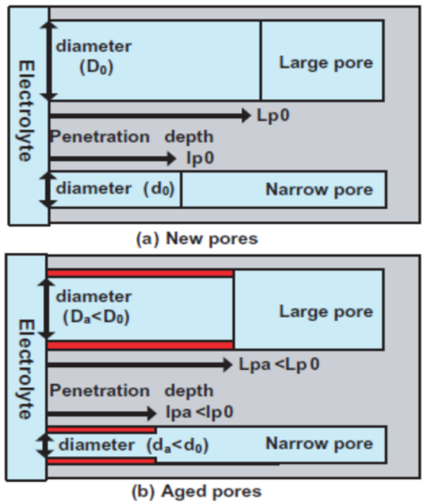
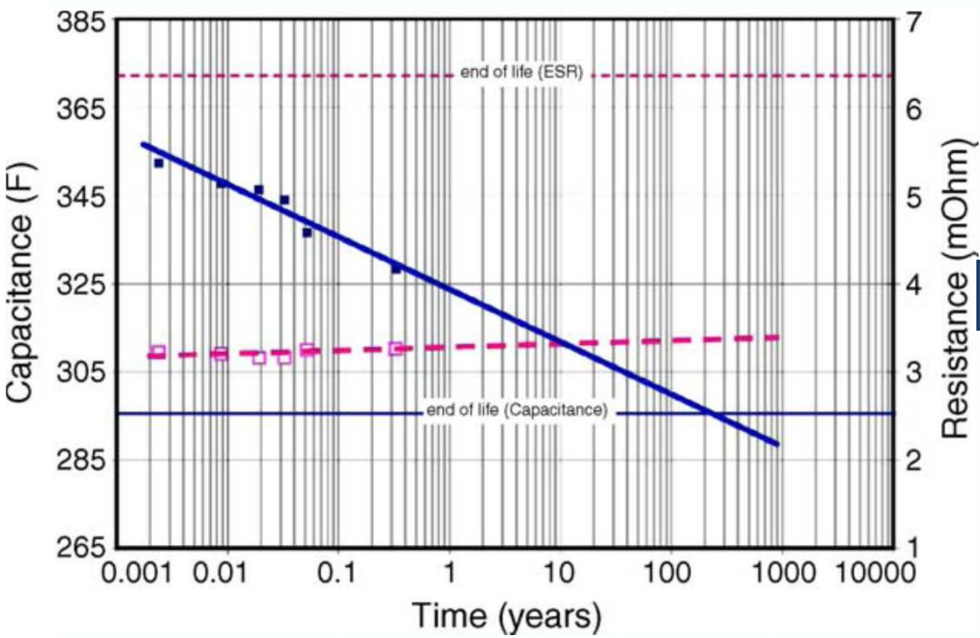


Illustration of the dispersion of pore size and it's consequence on

Life time models & accelerated testing

***Model I**: Constant load test extrapolation (Kutz et. Al 2006)*

Assuming same degradation process at short time and extrapolated time (no accelerated testing used)



Expected life time at RT
From extrapolation > 300 years

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Life time models & accelerated testing

***Model II**: Arrhenius – Eyring life relationship (Miller et al.2006)*

τ = A·exp(B/T)expD·V = A·exp(B/T + D·V)

where

- τ is the component's life
- T is the absolute temperature in Kelvin
- V is the applied voltage
- A, B, and D are constants.

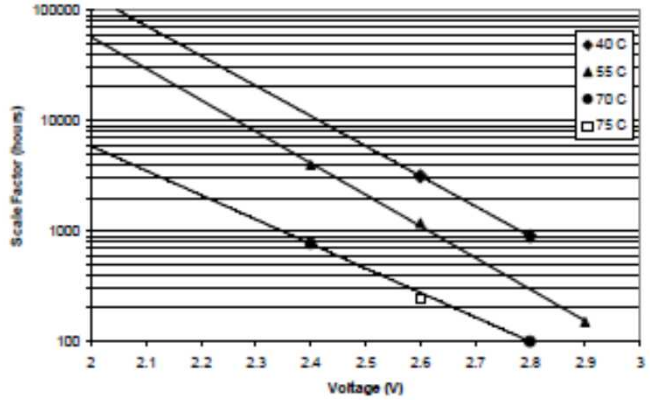

Figure 3. Capacitor characteristic life versus operating voltage.

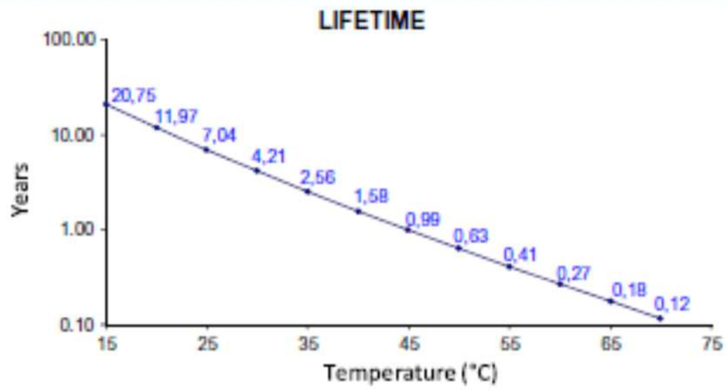

Fig. 9. Lifetime of supercapacitor according to the temperature for an ageing at 2.7 V.

(Gualous et al. 2010)

Expected life time at RT
From extrapolation ~7 years

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Life time models & accelerated testing

***Model III**: The ten-degree rule*

A 10^{o}C decrease in temperature will double the life of a cell

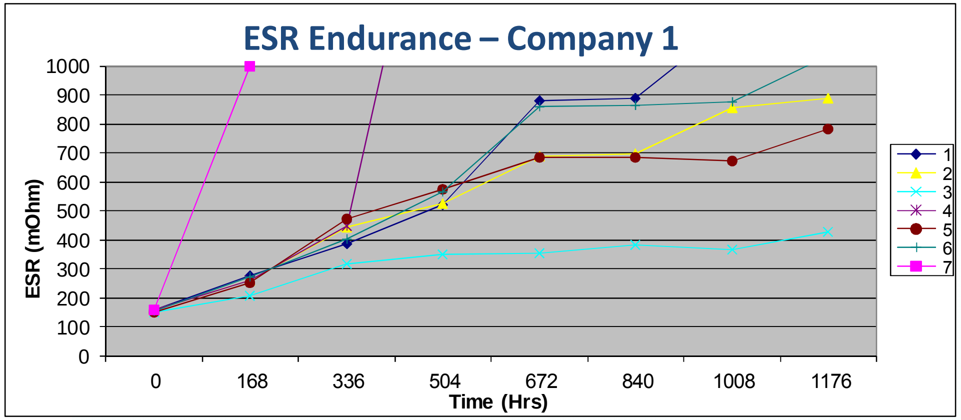
A 0.1V decrease in voltage will double the life of a cell

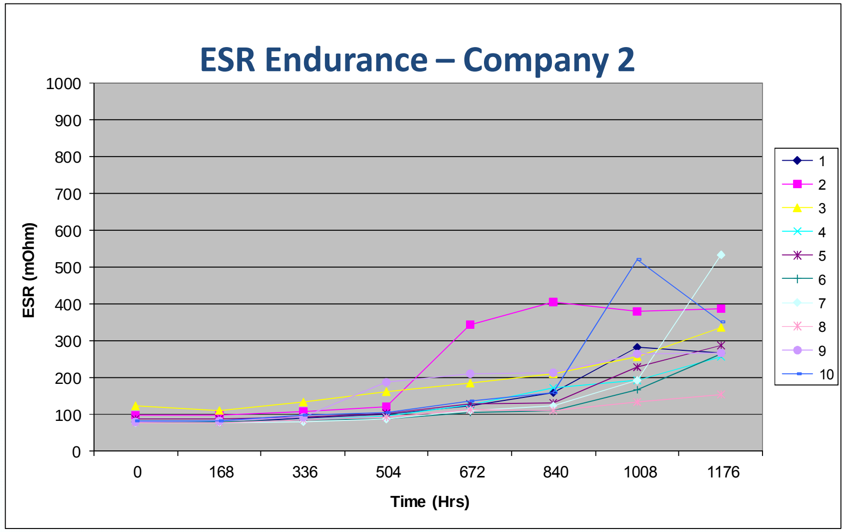
$$\tau_T(V)/\tau_{T_o}(V_o) = 2^{[(T_o-T)/10]} * 2^{[(V_o-V)/0.1]}$$

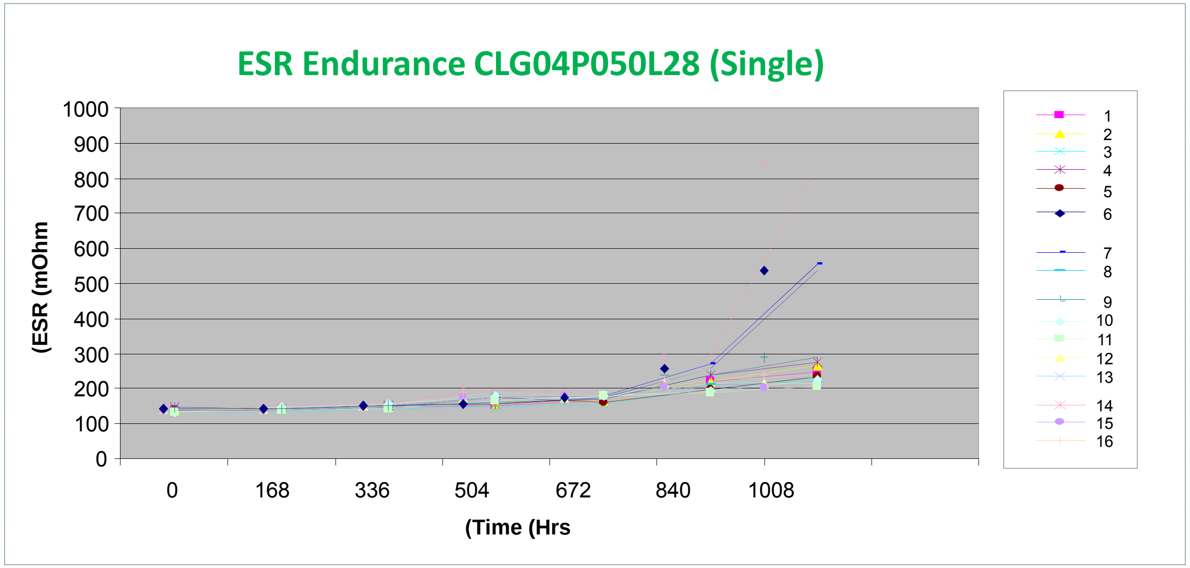
1000 Hrs. at 70C correlates to 2.6 Year (at constant voltage)

Comparison of **ESR** Endurance test

CLG04P050L28 vs. Other companies products







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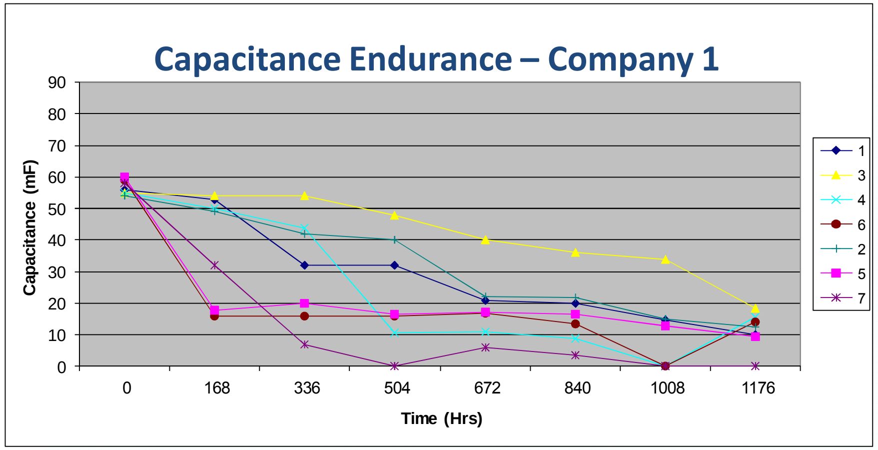
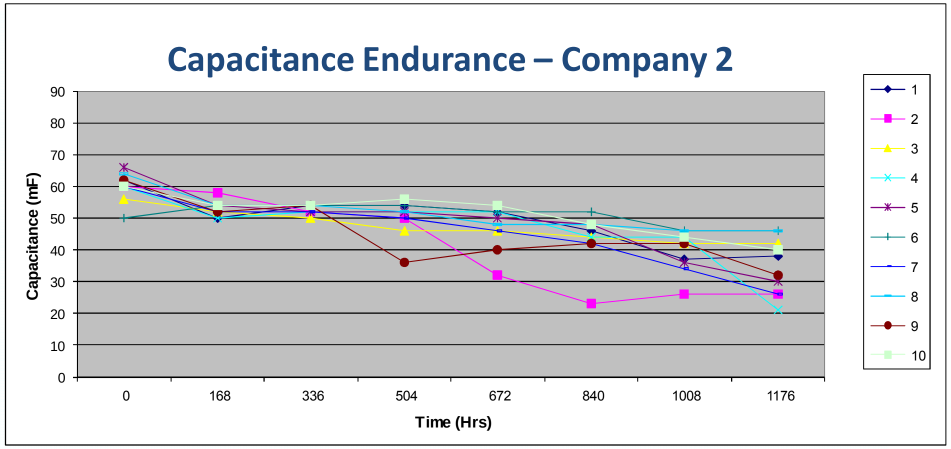
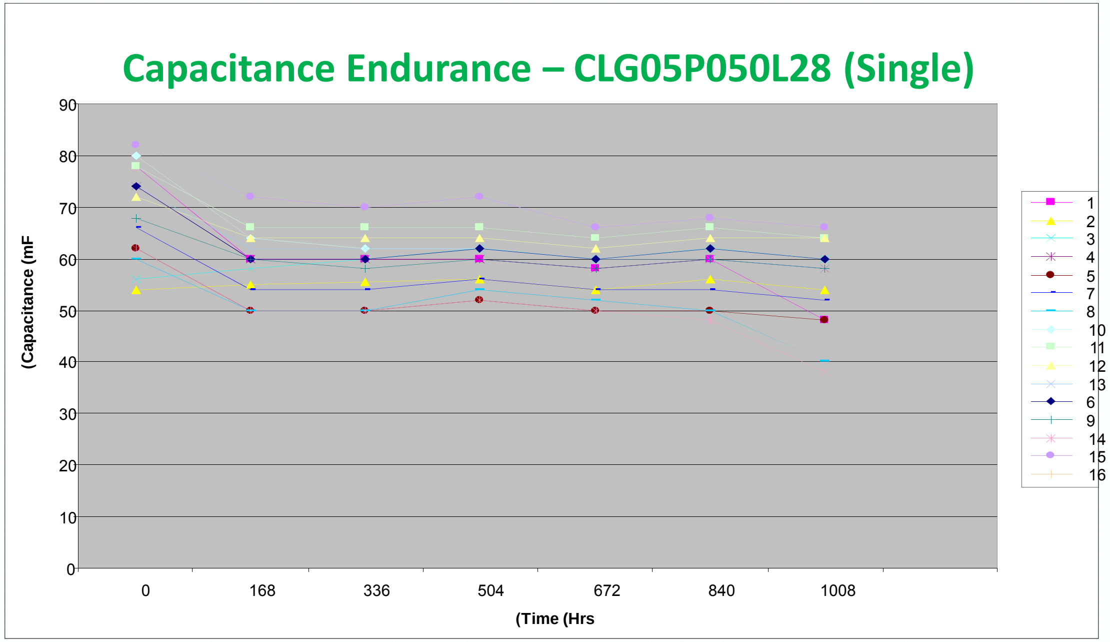
Comparison of **Capacitance** Endurance test

CLG04P050L28 vs. Other companies products







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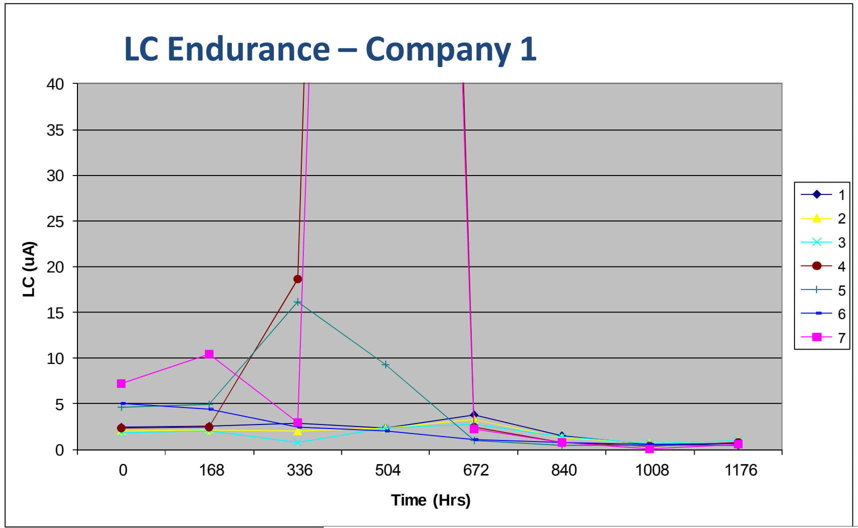
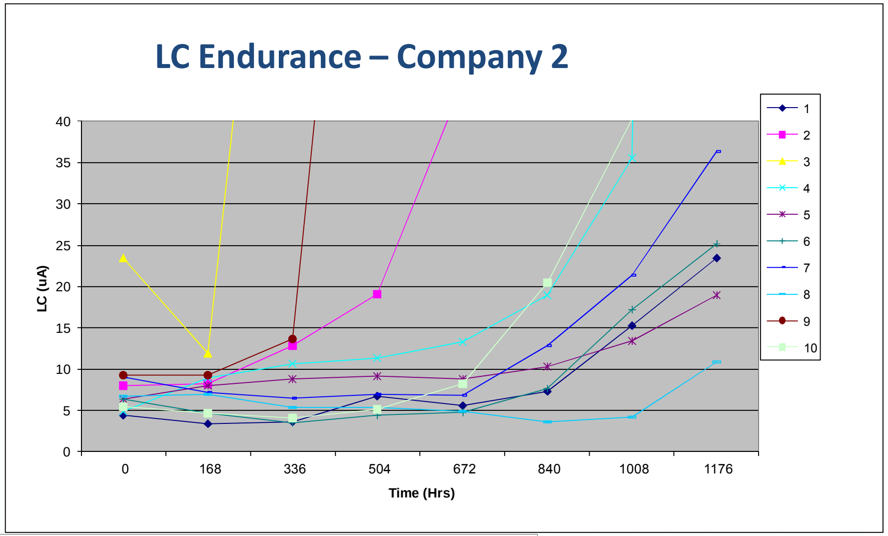
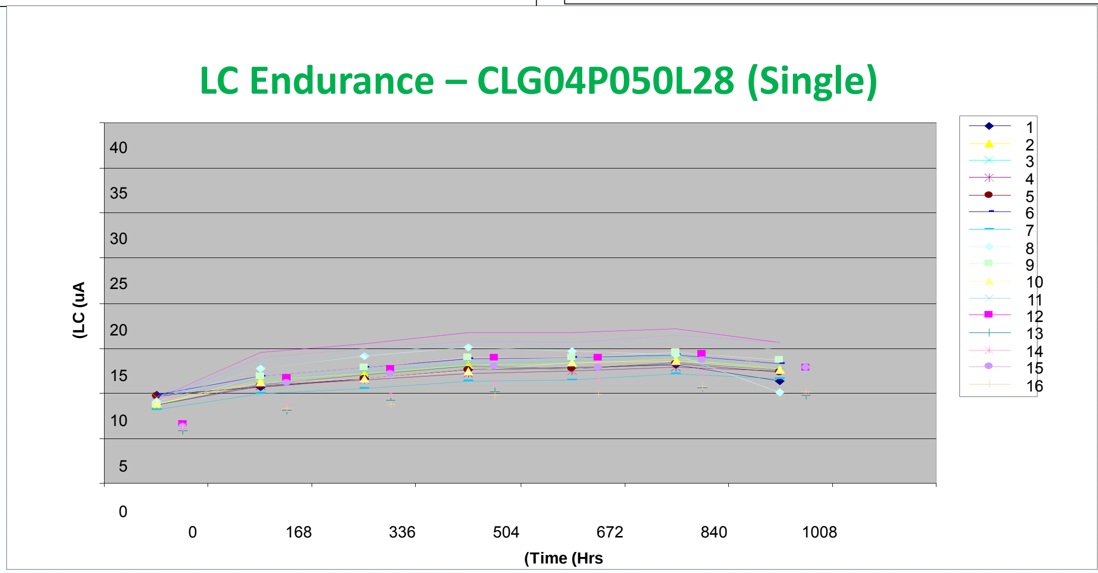
Comparison of **LC** Endurance test

CLG04P050L28 vs. Other companies products







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Endurance test

Is it really an accelerated test for life time ?

An accelerated test is useful only if **no different failure mechanism appears** in both; the item under the accelerated condition and similar item in normal use

But what we see is:

- Different capacitance decrease "patterns"
  RT vs. elevated temperature (70C) – not shown in the presentation
- Endurance test usually is done at upper level of allowed temperature, where different phenomena may happen compared to normal use temperature
  - High vapor pressure
  - Swelling and de-swelling >> may cause mechanical delamination
- Results don't follow the model…

Life time and Endurance – Summary & Conclusions

No valid model for life time of low energy supercapacitors exists (in capacitance range up to 1F). Correlation between endurance tests and life time not proved

- Endurance tests can be used for measuring the performance at elevated temperature or as comparison between different SCs:
  - **higher robustness >> Better endurance performance >> longer life time (probably)**

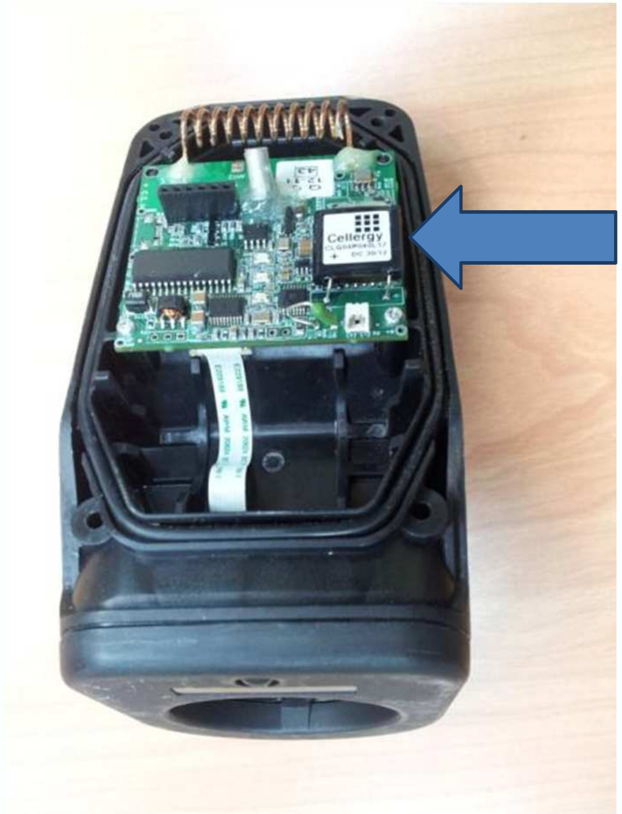
- For Life time predictions >> need a new model

Why select Cellergy Super-Capacitors

- Very wide product offering enables perfect-fit to various applications
- Patented automated line enables high flexibility in tailor-made products and shorten delivery lead time
- Better Endurance performance of Cellergy Supercapacitors than of some of its competitors
- Very fast response time
- **Green** products – no harmful substances
- No need for balancing resistors Vs. Organic Super capacitors
- Cost effective

Cellergy

Thank You



Get Power – Run Longer