CAP-XX

Supercapacitors support low power Energy Harvesters & Coin Cells

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Pierre Mars

VP Quality & Applications Engineering

Outline

- When to use supercapacitors
- Low power energy sources & the IoT
- Key supercapacitor properties
- Supercapacitor design considerations
- Case study: Powering peak loads (BLE) with a small solar cell indoors & a single cell supercapacitor
- What’s new? 3V thin prismatic cells

About CAP-XX

- Export-driven supercapacitor manufacturer founded in 1996
- Leader in design & development of thin, prismatic, high power supercapacitors for portable & space-constrained devices
- Applications in multiple high growth markets, including IoT, wearable technology & automotive applications (large capacity devices)
- Unique technology built on in-house R&D
- >23 million cells sold, including to global, brand name customers
- Strong IP platform. Licenced to Murata, Japan and AVX, USA
- Headquartered in Sydney, global network of distributors
- Admitted to the LSE AIM in 2006

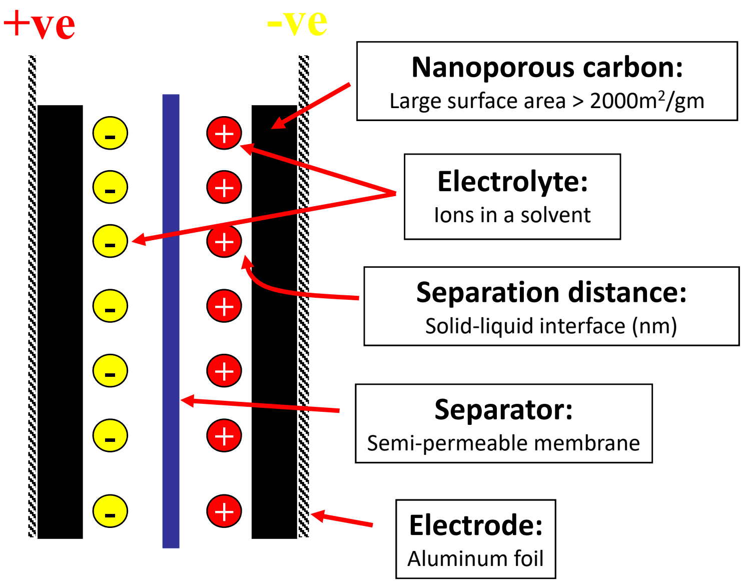
What makes a Supercap “Super”?

A supercapacitor is an energy storage device which utilizes high surface area carbon to deliver much higher energy density than conventional capacitors

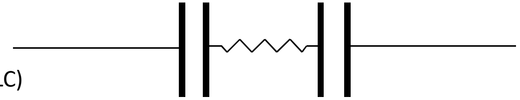
Basic Theory:
Capacitance is proportional to the charge storage area, divided by the charge separation distance (C α A / d)

As area (A) ↑, and
charge distance (d) ↓
capacitance (C) ↑↑↑↑

No dielectric, working voltage determined by electrolyte



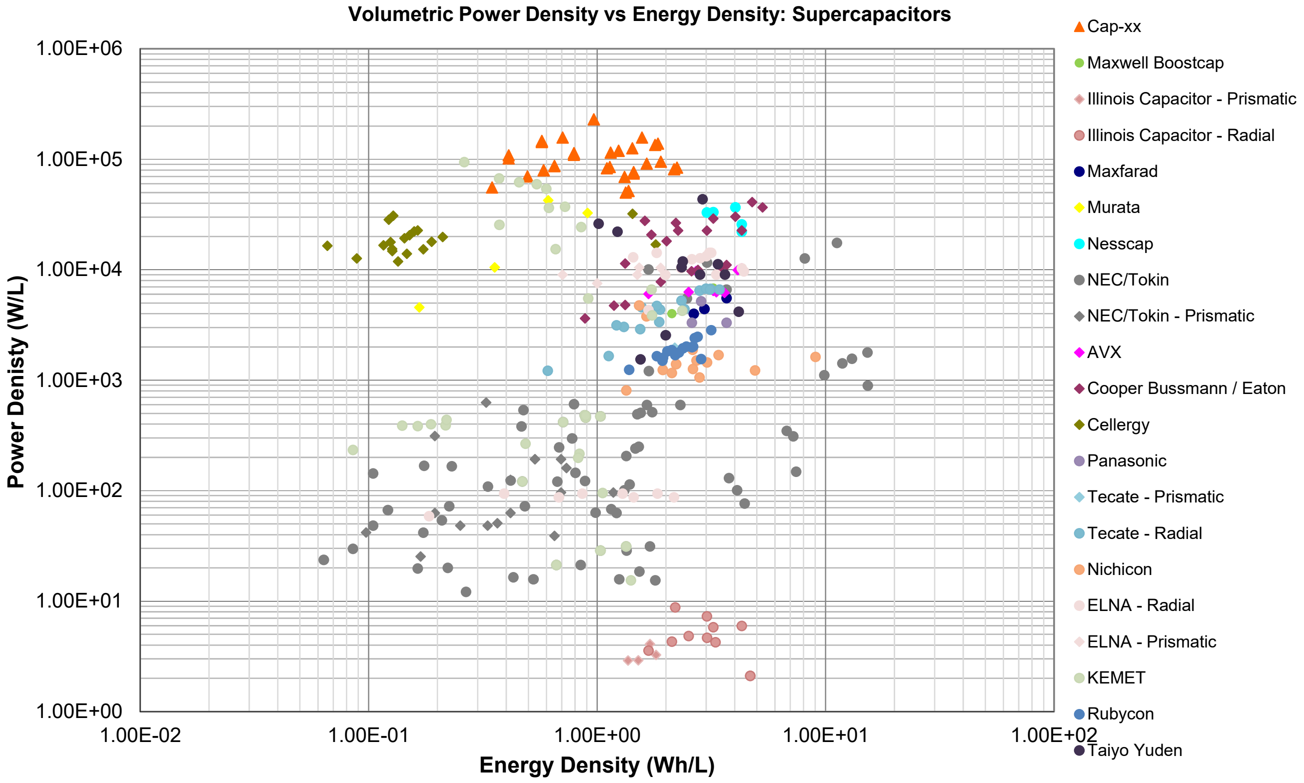
Basic Electrical Model:
Electric Double Layer Capacitor (EDLC)



What makes CAP-XX “Super”?

- Very small, very thin form factors
- Ultra-low impedance (ESR)
  - High power delivery (CAP-XX has world’s highest power density)
- Very high capacitance (C)
  - Provides the energy needed to keep delivering the power
- Easy to charge
  - Just need a charge current (from 20uA) & over-voltage protection
- Very low leakage current (<1µA)
- Unlimited cycle life (physical charge storage, no chemical reactions)
- Excellent low temperature performance
- Good frequency response

High Power & Energy Density



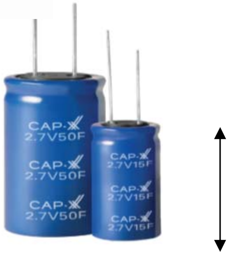
CAP-XX has 3 ranges of supercapacitor products:

- Large Prismatic cells & Modules
  - 100F – 6000F, cells ESR as low as 0.1mΩ
  - Standard or custom modules, e.g. 1000F, 16V, 1mΩ, 2000A
  - Extreme power, 6KW/cell

1000F, 16V, truck battery size

- Small thin prismatic cells
  - Unparalleled high performance
  - ESR as low as 12mΩ
  - From 0.1F – 3.6F single cells, 2.7V
  - 0.075F – 1.2F dual cells, 5.5V

- Small Cylindrical cells
  - High performance at excellent value
  - Cylindrical cells from 1F – 400F, 2.7V
  - Dual cell modules, 5.4V



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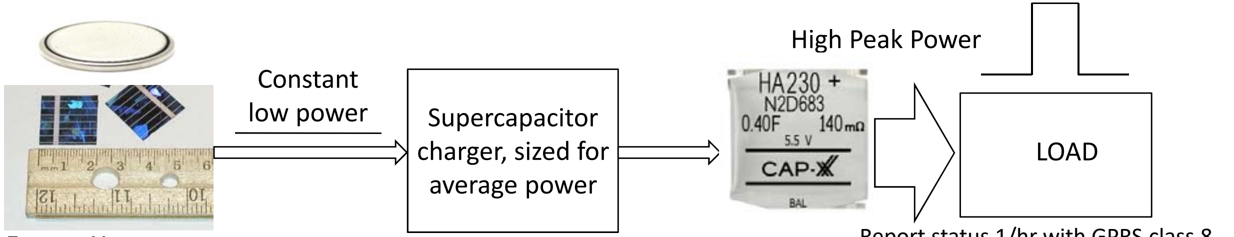
When to use Supercapacitors

- Supercapacitors offer peak load support (acting as a power buffer) & back-up power (acting as an energy reservoir)
- In both cases, the load sees a low impedance source (the supercapacitor) that delivers peak power & backup power for the required duration, while the source provides a constant, low power charge current at peak efficiency
  - Low ESR = high power, minimum voltage ripple
  - High C = long hold-up times, minimum voltage ripple
- Power budget for peak load applications:
  The average load power must be < the average source power available



Energy Harvester or Low Power Battery

If 75% efficient, only needs 1mW at input

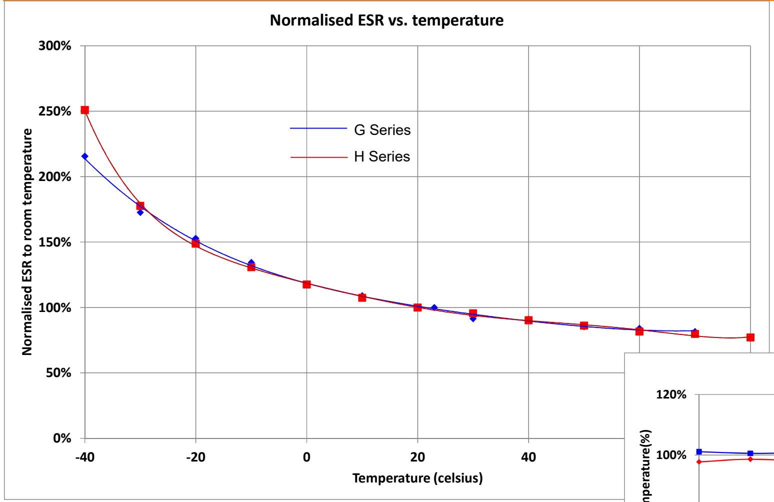
Report status 1/hr with GPRS class 8
3 sec SMS = 2A @ 3.6V/8 x 3/3600 =
0.75mW average pwr 7.2W peak pwr

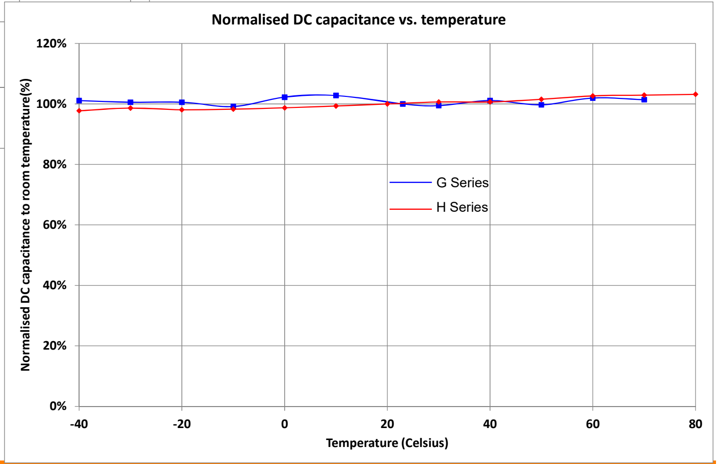
Supercapacitors are ideal power buffers

- The environment has abundant energy to be harvested
  but at very low power
- Many applications need burst power to acquire & transmit data
- A supercapacitor is an ideal power buffer:
  - Simply charged at very low power from energy source
  - Physical charge storage, “unlimited” cycle life
  - Very low ESR, high power delivery
  - Wide temperature range
  - Good energy storage, support the peak power burst for its duration
  - Very low leakage current (~1uA)
  - Efficient charge / discharge
  - SVHC, RoHS compliant: Al, C, electrolyte: no disposal issues
- Average o/p power $\leq$ input power x η

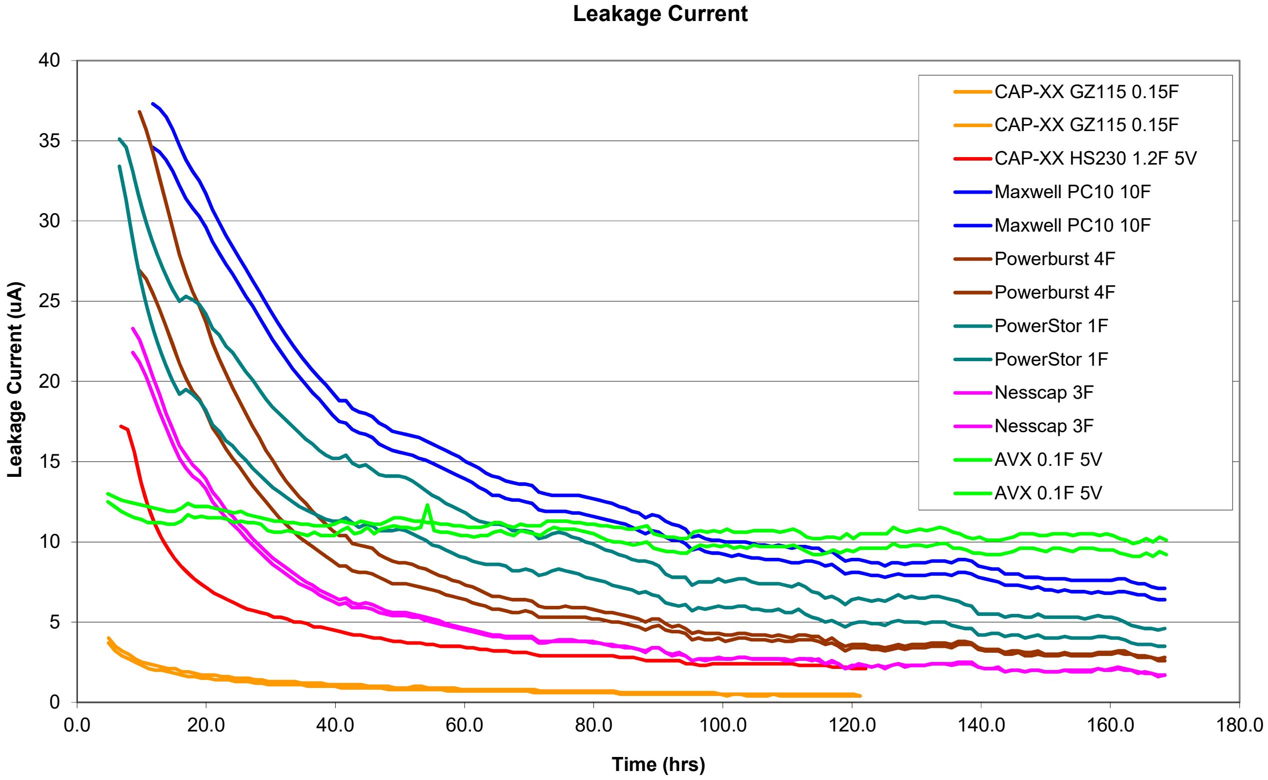
SUPERCAPACITOR PROPERTIES

High C and Low ESR across a wide Temperature Range

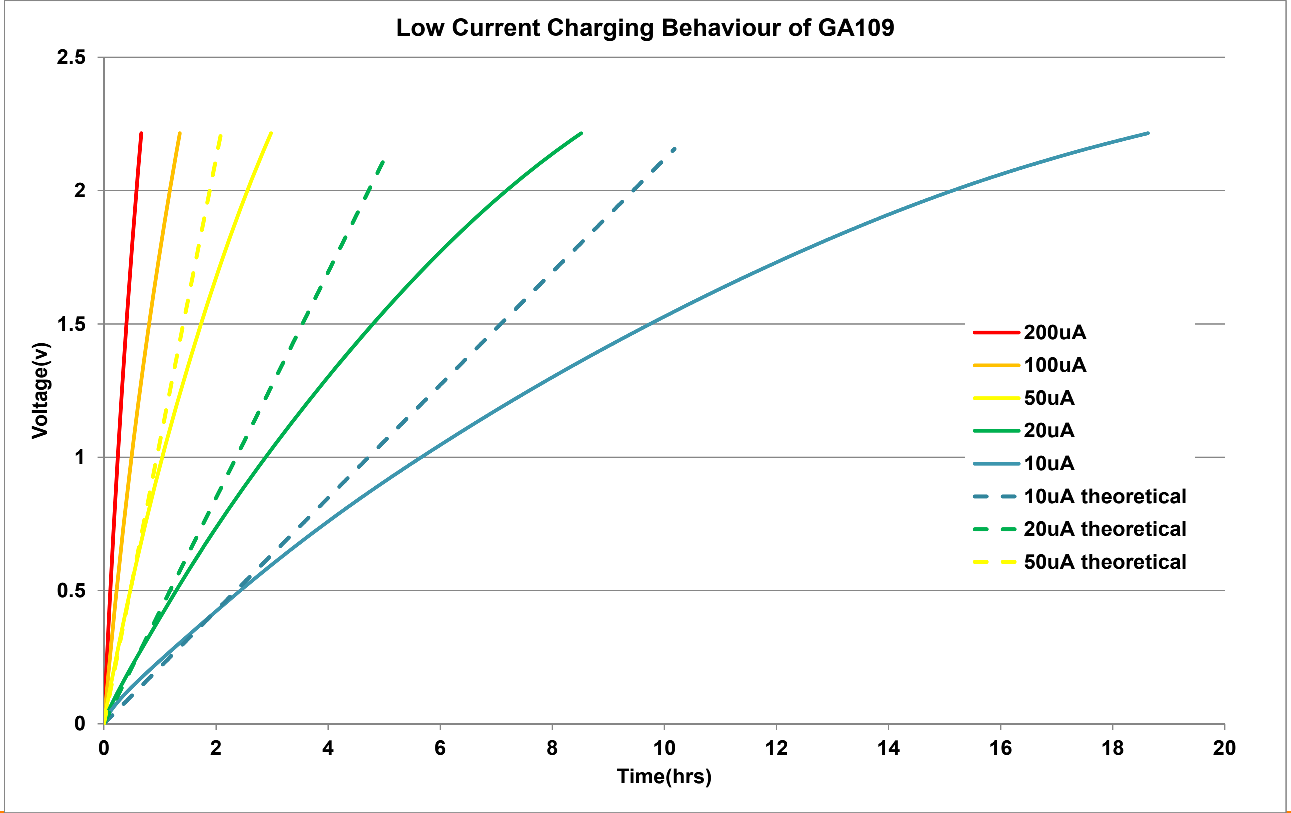




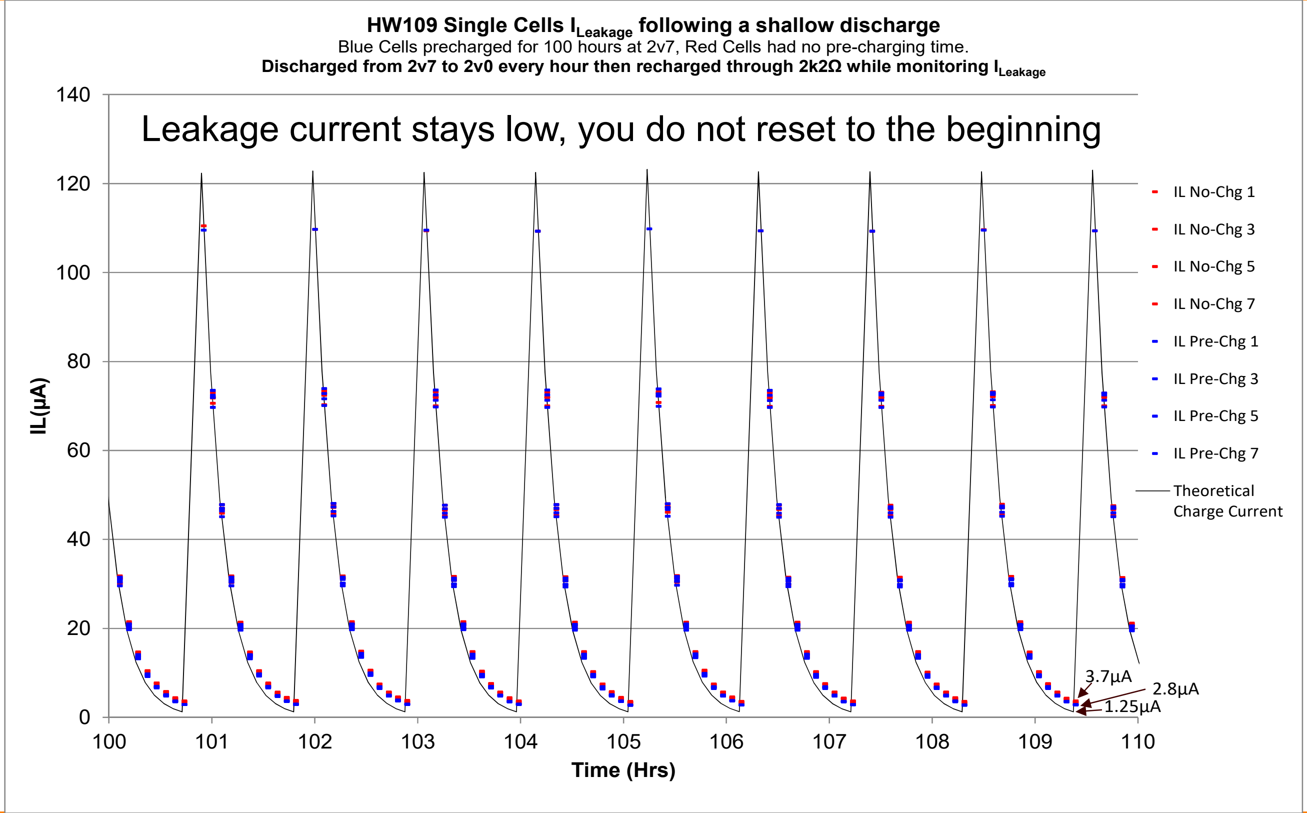
Low Leakage Current…



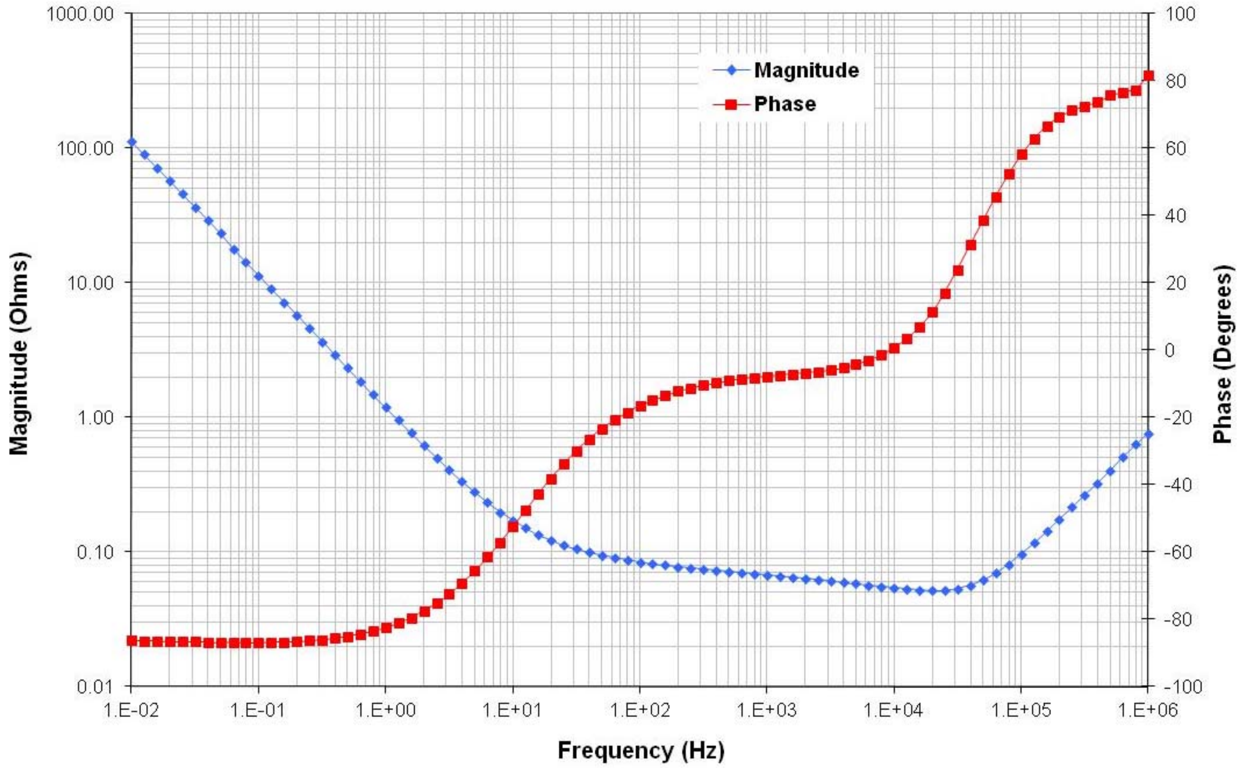
CAP-XX ...translates to Low Charge Current



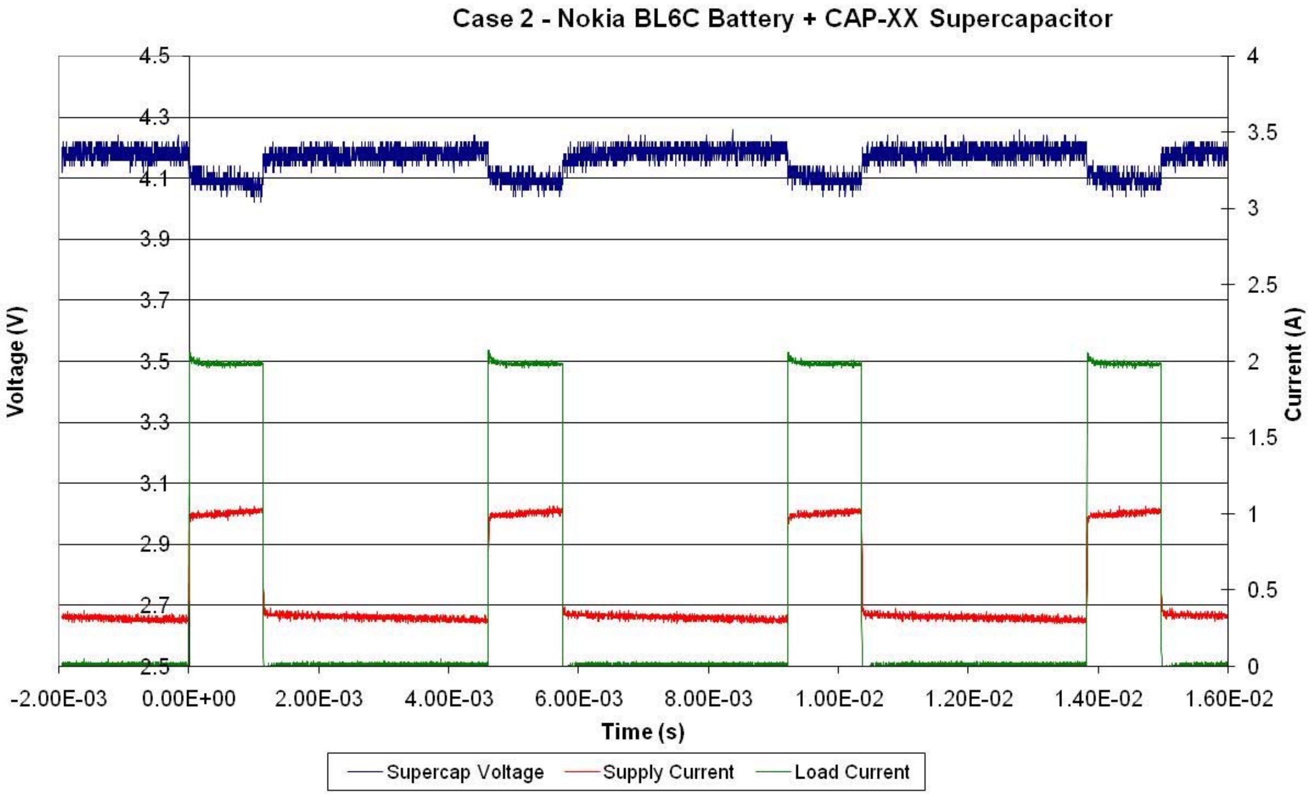
Shallow discharge steady state



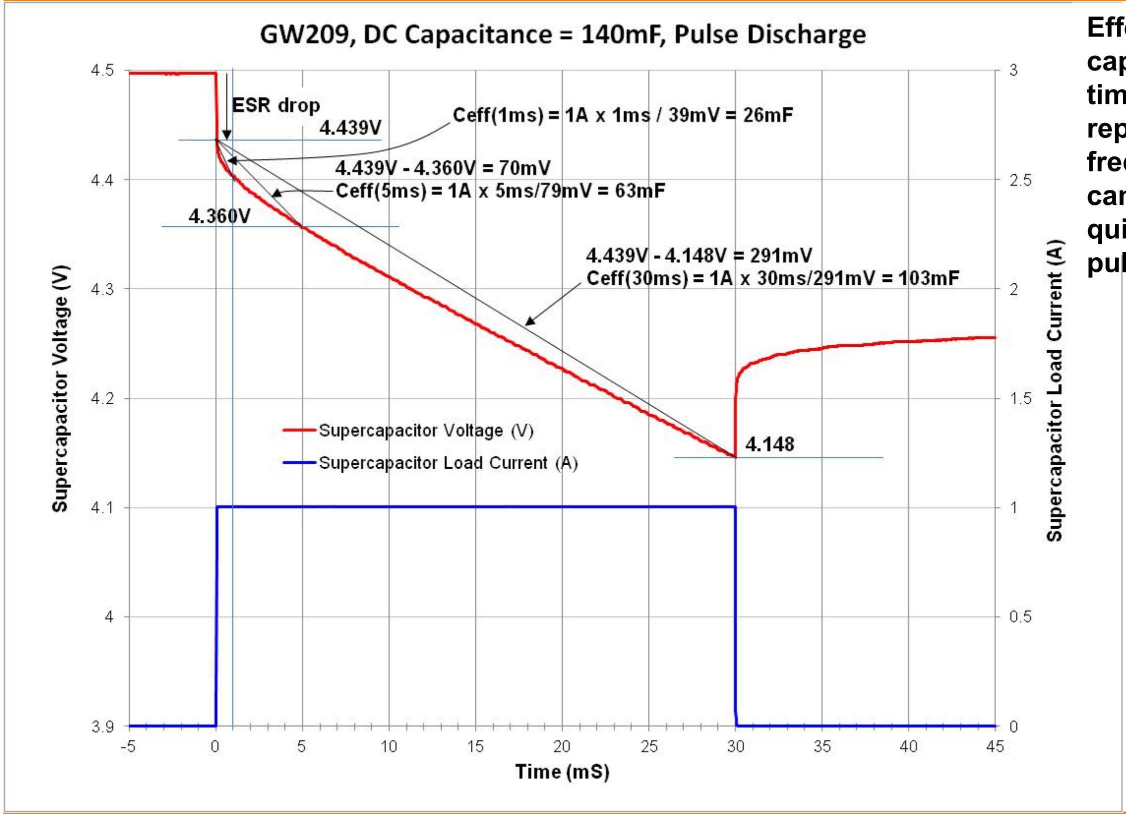
Poor Frequency Response ...



... But excellent pulse response

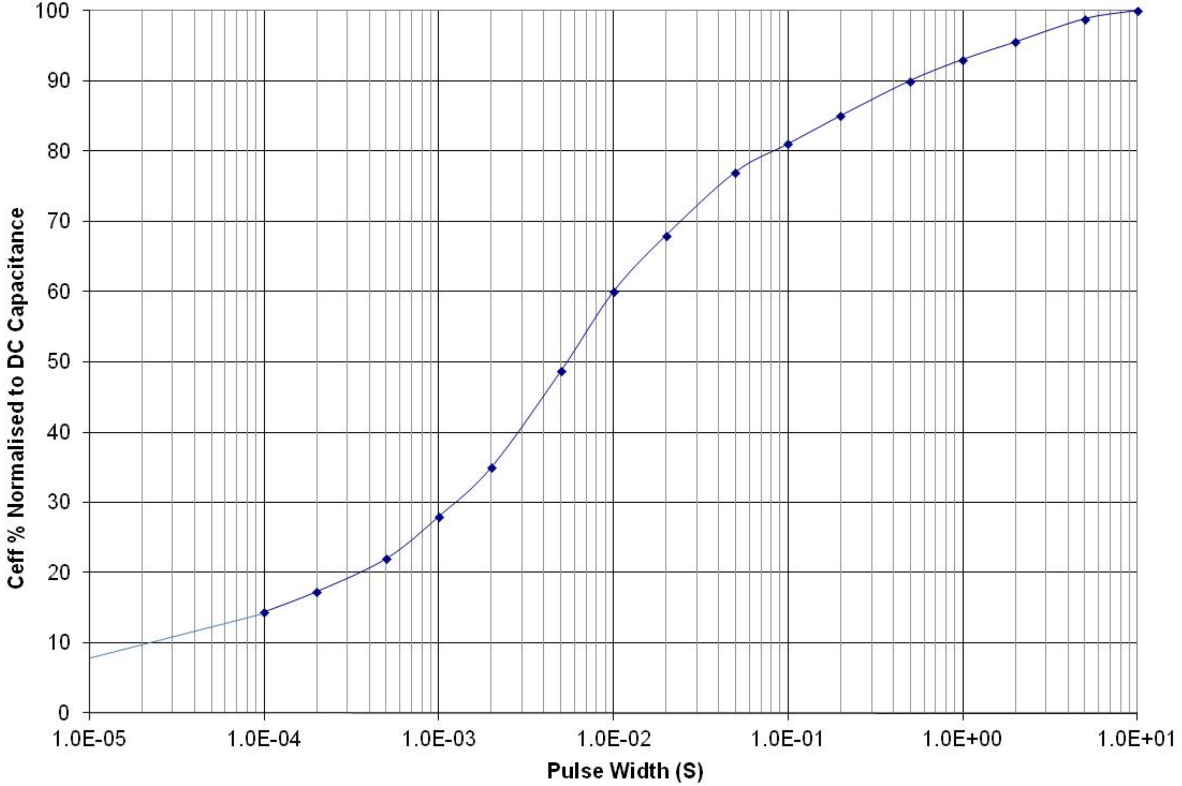


What is effective capacitance?



Effective capacitance is a time domain representation of freq response that can be used for a quick estimate of pulse response

Effective Capacitance (GW209)



Efficient Charge / Discharge Cycle

- Losses = I^2R x duration during charge, discharge
- Energy in/out = 2 x ½ C ($V^2_{MAX} - V^2_{MIN}$)
- Efficiency = $\dfrac{\text{Energy in/out}}{\text{Energy in/out + Losses}} = \dfrac{\text{Energy in/out}}{\text{Energy in/out} + i^2.\text{ESR.t}}$

$$= \frac{\frac{1}{2}C(V_2^2 - V_1^2)}{\frac{1}{2}C(V_2^2 - V_1^2) + i^2.ESR.C\frac{(V_2 - V_1)}{I}}$$

$$= \frac{V_2 + V_1}{V_2 + V_1 + 2.I.ESR}$$

- Ex 1: GPRS 2A disch from 3.8V to 3.2V, ESR = 50mΩ, →η = 97.2%
- Ex 2: Charge @ 50mA from 3.2V to 3.8V, →η = 99.9%

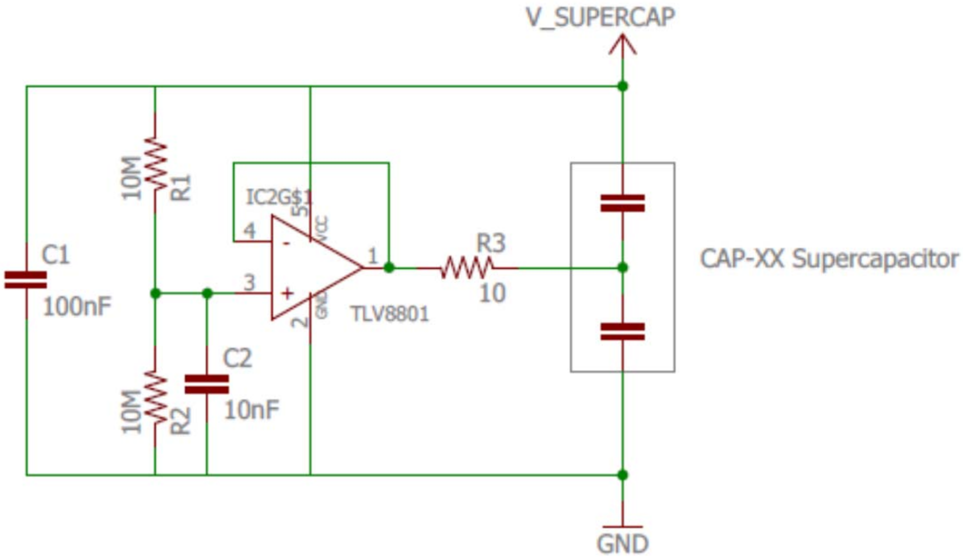
SUPERCAPACITOR DESIGN CONSIDERATIONS

Cell Voltage Balancing

- Supercapacitors are low voltage devices
- Modules containing 2 or more supercapacitors in series are needed to achieve higher operating voltages
- Multi-cell modules need voltage balancing to ensure that slight differences in leakage current do not cause voltage imbalances between the cells
- Without adequate voltage balancing, one cell may go over-voltage, leading to accelerated ageing & premature failure
- Balancing can be:
  - Passive (simple, but costly in terms of energy lost), or
  - Active (to achieve the minimum possible leakage current)

Active Balancing with an Op Amp

- Low current rail-rail op amp, ~500nA
- Can source or sink current, 4.7mA
- Supplies or sinks the difference in leakage current between the 2 cells to maintain balance
- Total current, supercapacitor leakage + balancing circuit ~2µA
- Low cost op amp



Or Use a Single Cell

- If your circuit can run at 2.7V or less, use a single cell
  - Simpler (no balancing required)
  - Cheaper
  - Thinner
- If not, consider a low power boost from the supercapacitor to the load
  - Load V > 2.7V
  - Load power < 1.0W
  - Use a small boost on the output of the supercapacitor
- Depends on energy / power required
- It’s a cost / size trade-off

Sizing the Supercapacitor

- Energy balance approach often used:

  Avg Load Power x Time = E = ½ $C(V_{init}^2 – V_{final}^2)$,

  $\therefore C = 2E/(V_{init}^2 – V_{final}^2)$
- But this implicitly assumes ESR = 0!
- This may lead to undersizing the supercapacitor.
- For constant current pulse of duration T:

  Vdrop = I_{LOAD} x [ESR + T/Ceff(T)]
- For constant power it will be worse as I_{LOAD} increases as Vsupercap decreases to keep V x I = const. See CAP-XX website for tools that solve this problem.

Supercapacitor Charging

A supercapacitor charging circuit must:

1. behave gracefully into a short circuit since a discharged supercapacitor will look like a short, or the in-rush current will have to be limited
2. be able to charge from 0V
3. provide over voltage protection for the supercapacitor
4. prevent the supercapacitor from discharging into the source when $V_{SOURCE} < V_{SUPERCAP}$

and

5. should be designed for maximum efficiency

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Small Solar Cells

Note:

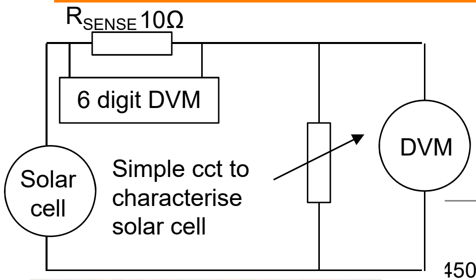
- Power output for solar cells is typically defined at 50,000 lux (bright sunlight) or 100,000 lux (1kW/m2)
- If used indoors, light levels are MUCH lower: Typically between 300 lux (minimum for easy reading) & 500 lux (well it office) AND with different spectrum (LED/CCFL)
- Select & characterise your solar cell for the conditions in which it will be used!

LUX	DESCRIPTION
50,000	British summer sunshine
5,000	Overcast sky
500	Well-lit office
300	Minimum for easy reading
50	Passageway/outside working area
15	Good main road lighting
10	Sunset

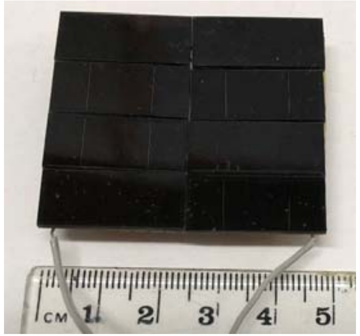
Source: www.use-ip.co.uk

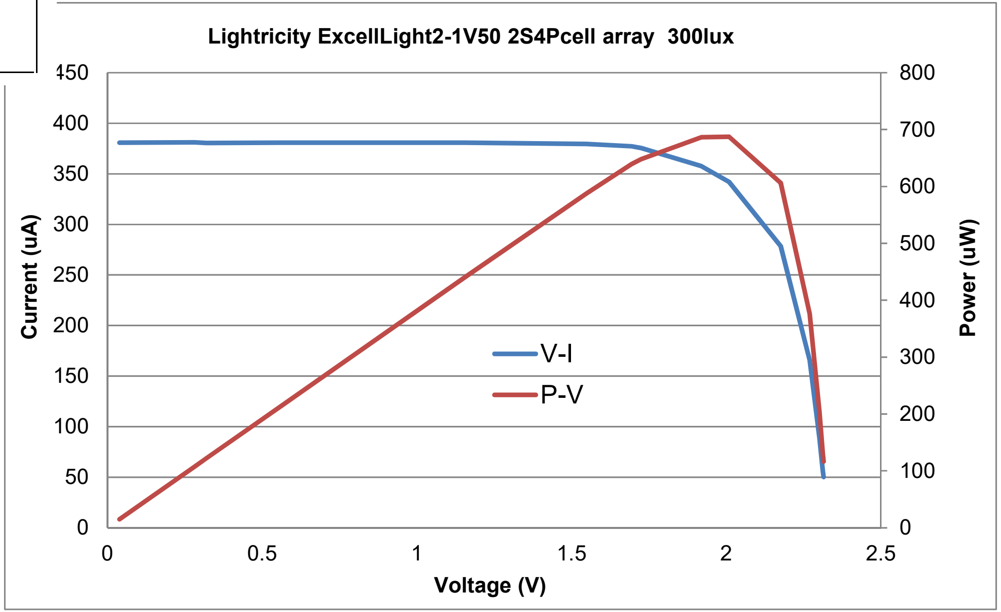
Indoor use: LED/CCFL spectrum, typically 200 – 400 lux. Silicon cells will not do well!

Characterise your Solar Cell



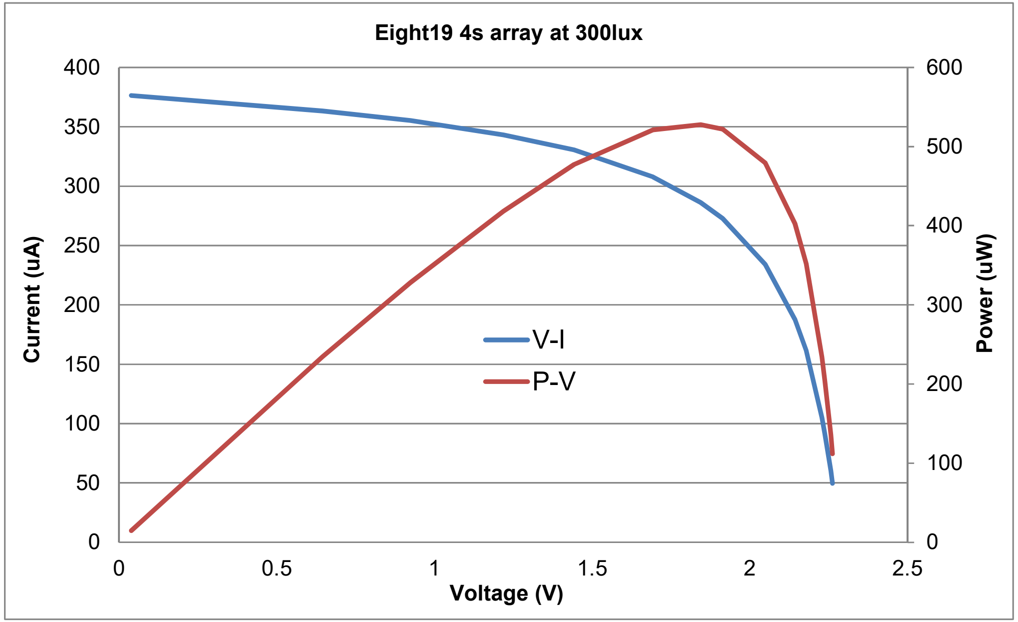
Lightricity: Crystalline: efficient, 22.1μW/cm^2 @ 200 lux LED spectrum, but expensive.
2s4p array of ExcellLight2-1V50 cells. 47mm x 41mm





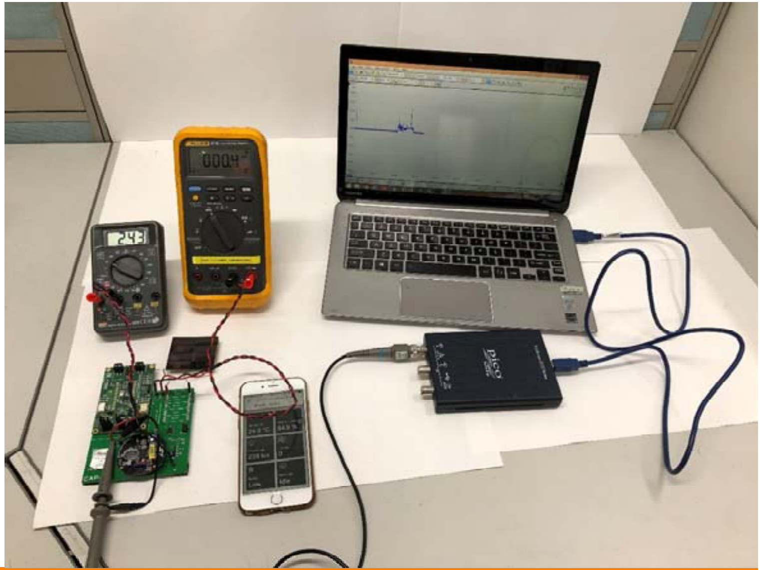
Characterise your Solar Cell

Eight19: Printable Organic Solar Cell: Low cost but less efficient,3µW/cm^2. 4s array of cells customised to length. 162mm x 19mm.



Small Solar Cell + Supercap

- We used either the Lightricity or Eight19 solar cell arrays to provide ~0.7mW in indoor LED lighting to a boost converter with MPPT to charge a supercapacitor to 2.65V
- The supercapacitor supplies a blue tooth sensor reporting 1/sec with ~50mW peak power.



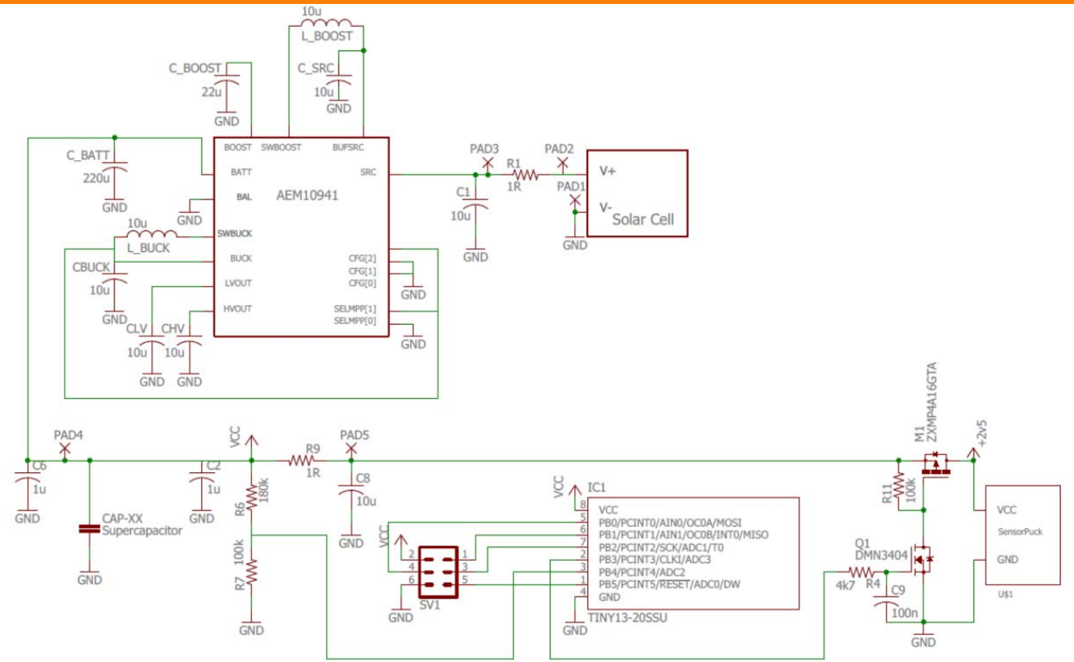
Selecting your charging IC

Attribute	AEM10941	Comment
Min cold start voltage	380mV	Must be > Voc at lowest light level you wish to operate at.
Cold start charge	Rapid. Boost charges 22μF (typ) cap.	How the IC boosts the input voltage during cold start to reach the internal voltage required to run as a boost.
Cold start power	3μW	The lower the better, but must be < power available from the solar cell at min light levels at which the unit must charge.
Cold start threshold	380mV	Voltage at which the IC starts operating as a boost converter, the lower the better
Vin min after start up	50mV	Min i/p voltage for the boost to keep operating once it has started
Quiescent current	< 1μA	Current drawn by the IC while operating as a boost. Vbatt ≥ 2.5VThis is reflected in the low power efficiency.
Max Peak Power Tracking	Samples Vsolar_oc every 5s. Can set MPPT at 70%, 75%, 85%, 90% of Voc	Periodically disconnecting the i/p to sample Voc is the preferred method. MPPT then set as % of Voc. Some ICs set this as a fixed value which only works in constant light.
Efficiency	~90% at Peak Pwr Pt	90% is excellent efficiency at such low power. Vscap > Vsolar
Hysteric operation	Yes	The boost converter turns off when Vcap reaches its desired voltage and turns on again when Vcap has discharged to a lower threshold. Saves power.
Max current	100mA	From energy harvester to boost converter

Configuring solar cell array and selecting charging IC should be done together as a system design.

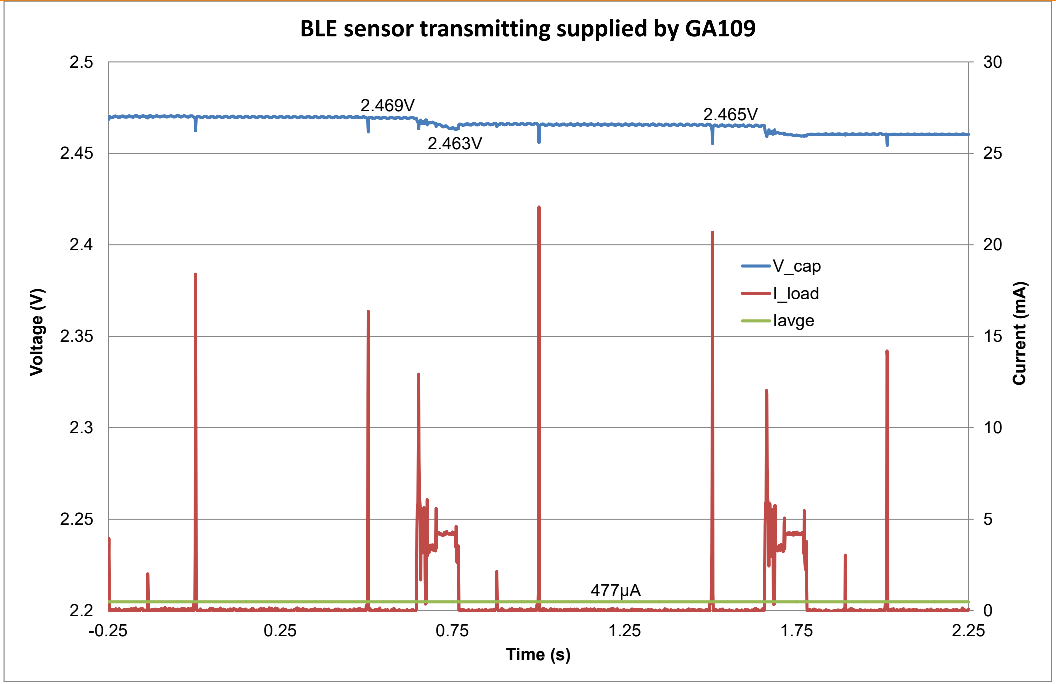
- E.g Vsolar_oc < Vload, so boost always, no need for buck-boost
- Vsolar_oc in low light > min cold start voltage, + sufficient power to start (no. of cells in series)
- Average solar power in x η ≥ average load power = Peak power x duty cycle (no. of cells in //)

Solar cell + Boost in low light



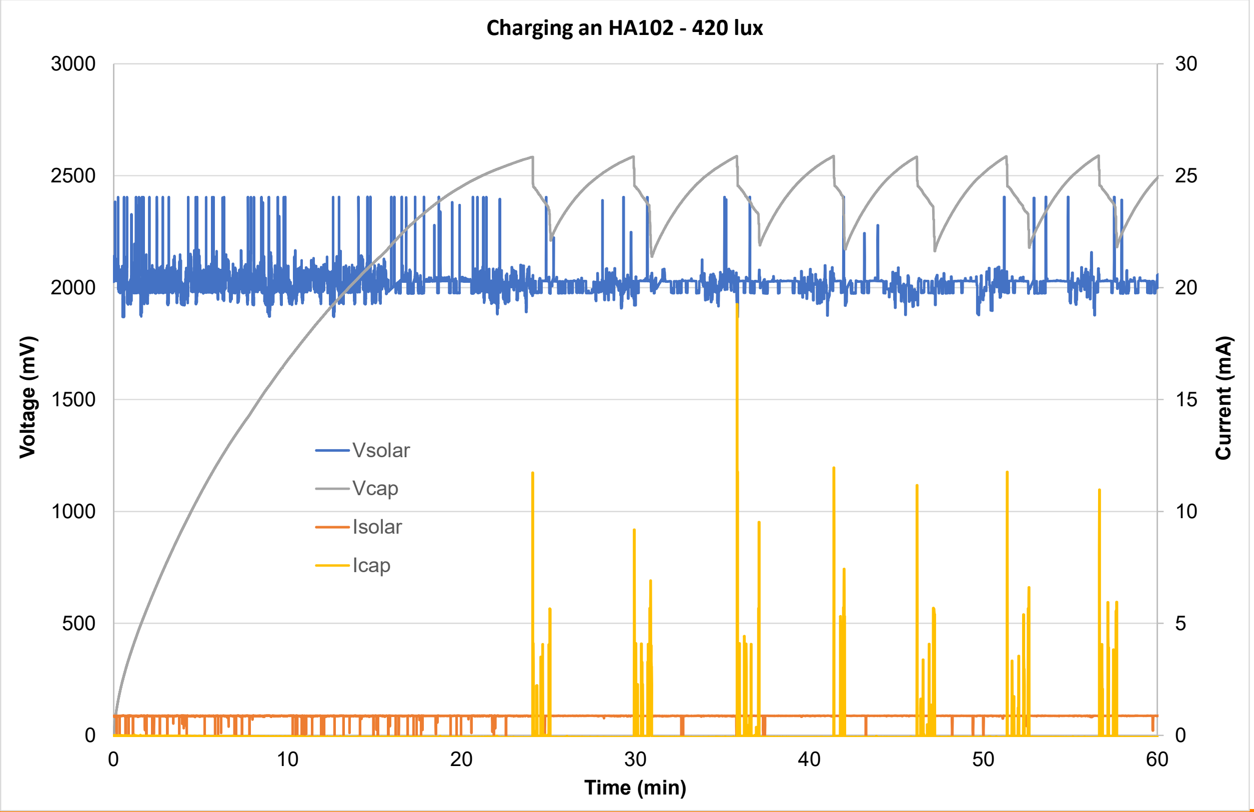
Single cell solution. No voltage balancing required.
E-peas AEM10941 with indoor solar cell charges in very low light
Sensor reports 1/sec when free running. IC1 & M1 set avge load pwr = avge input pwr x η

BLE Load Current



- Supercapacitor can maintain 1s reporting interval if charged at 477µA
- Declining V_cap shows insufficient current, so U1, M1 cuts load to keep power balance
- But will now need to re-initialise BLE sensor every time power is re-connected

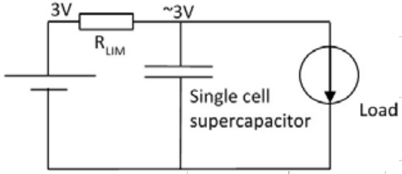
Supplying BLE @ ~400 lux LED

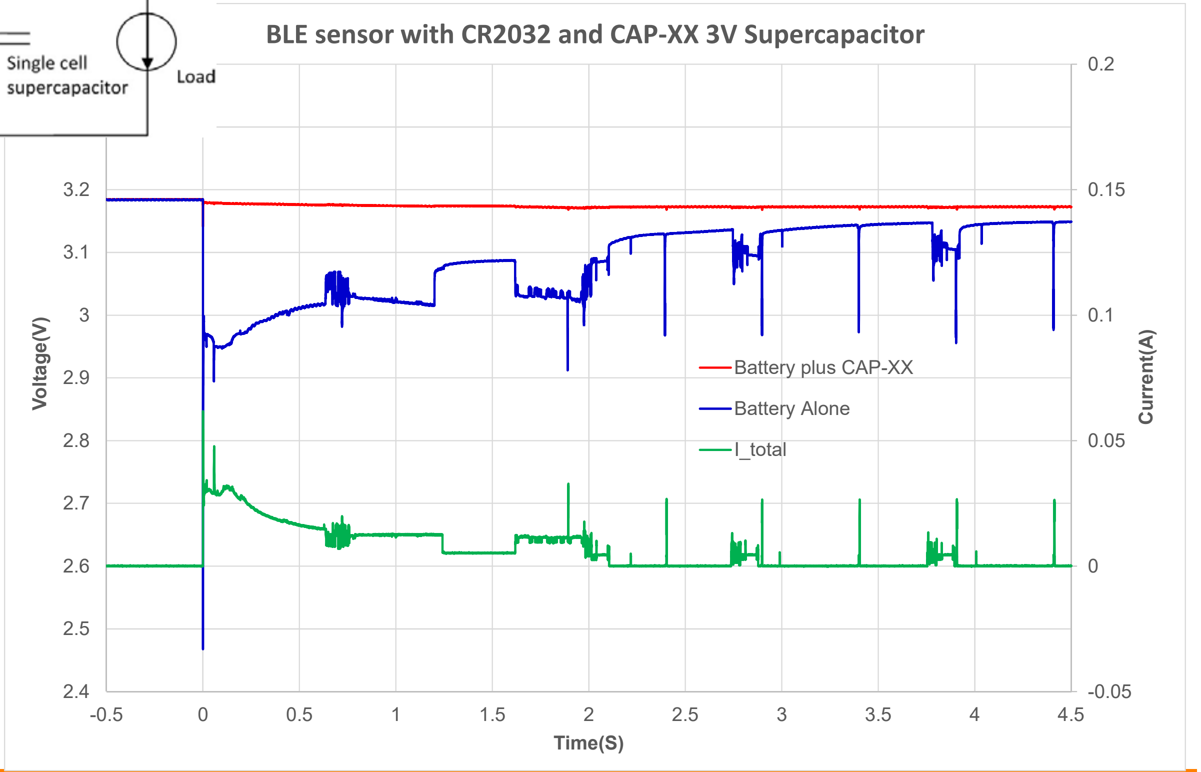


What’s New

3V Prismatic Cell

3V cell across a coin cell supporting BLE



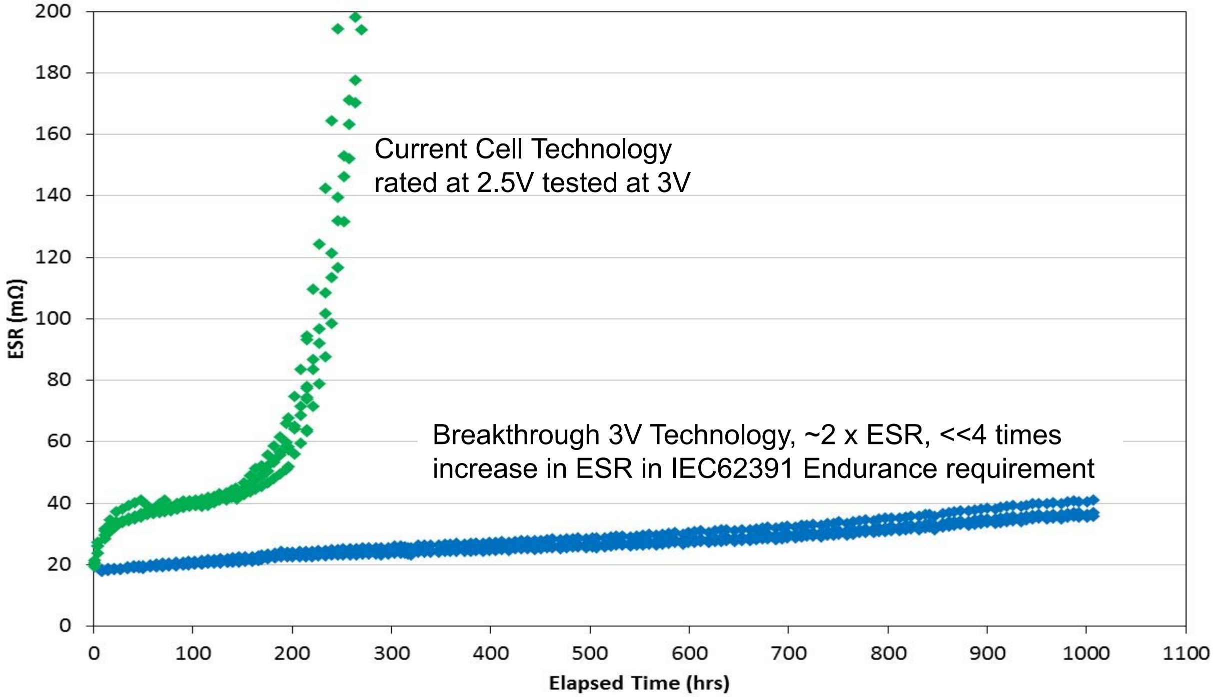


3V Prismatic cell advantages

- Cost and size savings, no need for an LDO between supercapacitor & battery.
- Saving battery energy. If load is constant power then an LDO dropping the battery voltage from 3V to 2.7V is 90% efficient. 10% of the battery energy is lost. If the LDO draws 1μA then that drains 8.8mAh/yr from the battery. After 3 years, the 3V cell would save 22% of battery energy.
- CAP-XX's unique thin prismatic 3V cell does not compromise the industrial design for wearables, key FOBs and unobtrusive thin, flat sensors.
- Low leakage current that does not excessively drain battery energy, ~1.5μA for a 500mF cell
- If the application runs down to 1.8V then a 3V supercap stores 42% more energy than a 2.7V one.
- Very long life at lower voltages, e.g. 1.8V/cell – dual cell supercapacitor supporting a $LiSOCl_2$ battery

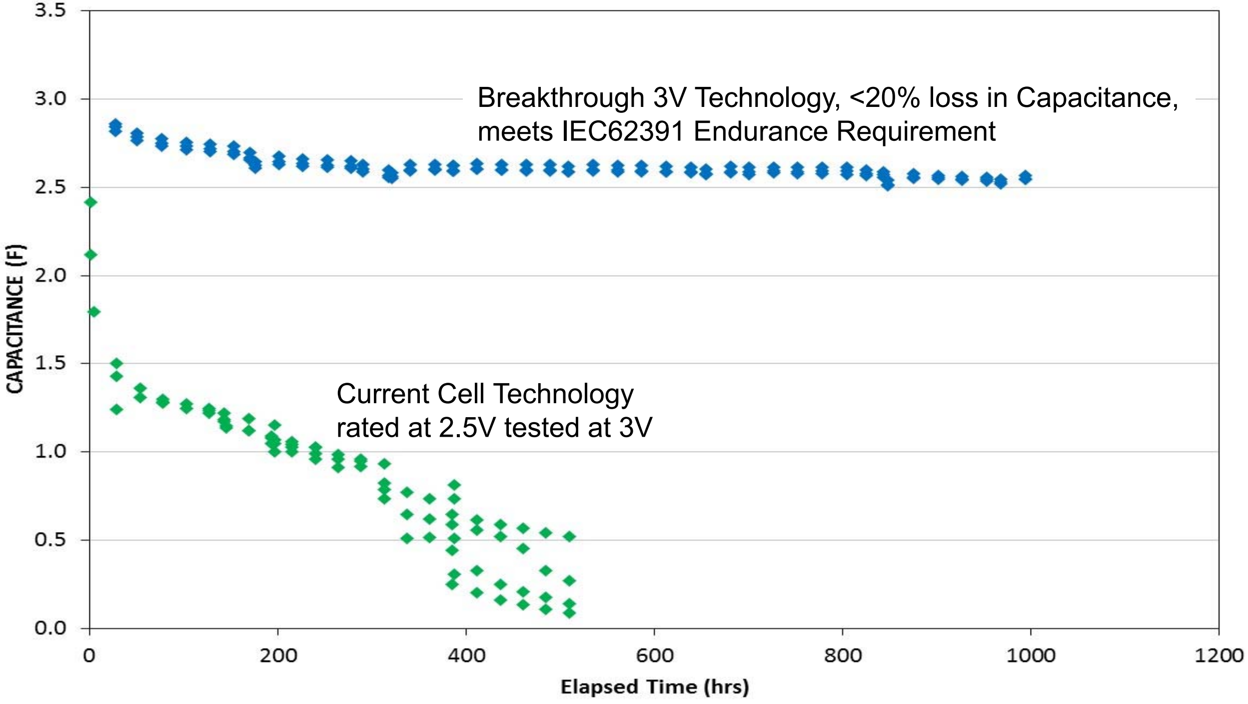
3V Device : ESR Rise Rate

Life testing at 3V and 70°C shows improvements during development of 3V technology : Breakthrough << 4 times increase in ESR after 1000hrs testing



3V Device : Capacitance Loss

Life testing at 3V and 70°C shows improvements during development of 3V technology. Breakthrough: <20% loss in capacitance after 1000hrs of testing.



Recap

- Supercapacitors are an ideal power buffer between a low power source and a load with low average power but high peak power.
- They operate well over a wide temperature range, will decay to a low leakage current, and can be charged from a very low/fluctuating charge current with very high efficiency.
- Dual cell modules must be balanced.
- Reviewed principles of supercapacitor charging circuits, sizing the supercap - remember ESR, effective capacitance.
- Looked at a case study using a small solar cell to charge a supercapacitor supplying a peak load power >> max i/p power.
- 3V thin prismatic cells are in development and are ideal with coin cell applications needing burst power or very long life applications at lower voltages.

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For more information, contact:

[name, title]

[email address]

or visit us at:

www.cap-xx.com