CAP-XX

Using a Supercapacitor to Power Wireless Nodes from a 3V Button Battery

Dave McIntosh, Pierre Mars

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1. The Problem

Source max power < load peak power

Source & Load power

- Wireless sensors are becoming ubiquitous:
  - Security
  - Fire
  - Condition monitoring
  - Location tracking
  - etc.
- Many of these applications require small, unobtrusive sensors, powered by small high energy batteries with long life but low rate capability: e.g. $LiSOCl_2$
- But the load requires burst power for data collection and transmission and that exceeds the power the battery can deliver
- Even though the average load power < average power the source can deliver, due to the intermittent nature of the load

2. The Solution

Charge a supercapacitor at average power
Provide peak power to the load from the supercapacitor

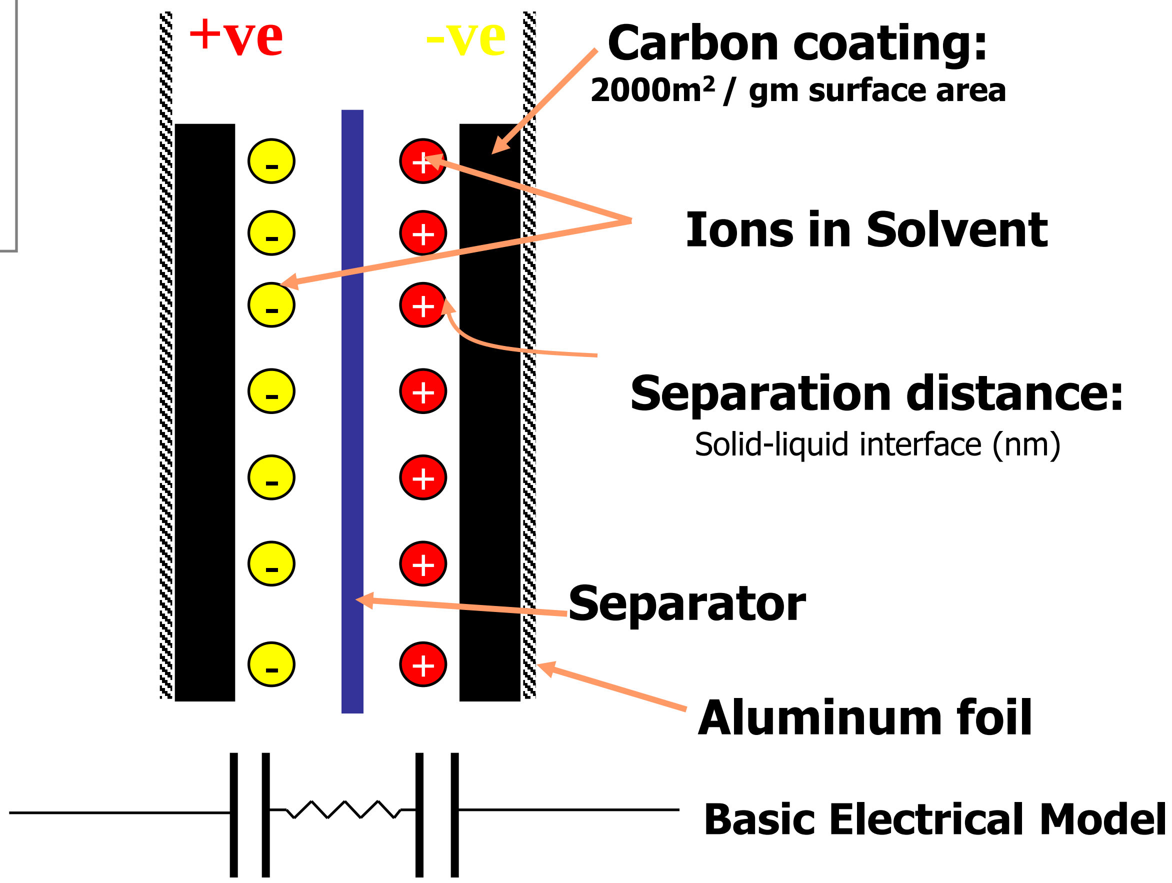
3. Organic vs Aqueous Supercapacitors

What is a Supercapacitor?

A supercapacitor is a high performance “green” electronic component

C α A / d
A ↑↑, d ↓↓ = C↑↑↑↑
Physical charge storage,
Not electrochemical

- **No dielectric, max voltage limited by electrolyte breakdown voltage**
- **ESR α 1/Electrode area**
- **Cα Carbon volume**



Organic or Aqueous?

- Two possible electrolyte types:
  - Organic: Max voltage up to 2.7V/cell & higher energy density, but difficult to make
  - Aqueous: Max voltage ~1V/cell but simple to make

- Need to cascade cells in series to achieve working voltage
- An aqueous supercap will need 3 cells in series to attain the same working voltage as a single organic supercap cell

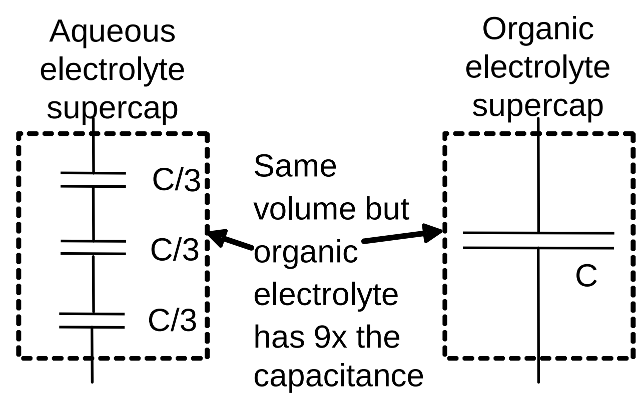


Figure 1. Comparison of energy density for aqueous & organic electrolyte supercapacitors rated at 2.7V

- For an equivalent carbon volume, the aqueous supercap will have 1/9 the C of an organic supercap

Use a supercap to buffer power

- Small form factor, single cell supercapacitors are available with high C (up to 2.4F) & low ESR (down to ~14mΩ)
- They can be charged at low currents from a low power source
- Have low enough ESR to deliver the load power required, even for GSM transmission (~8W),
- And high enough C to deliver that power for the duration needed: sufficient energy storage
- A supercapacitor looks like a low power load to the source & a low impedance source to the load

4. Solution using a single cell organic supercapacitor

Solution

- Max supercapacitor voltage = 2.7V, but max source voltage is typically 3V, e.g. CR2032
- Need over-voltage protection
- Load can operate at <2.7V (down to 0.7V for a well designed boost converter)
- Circuit below can be designed with quiescent current of <3μA

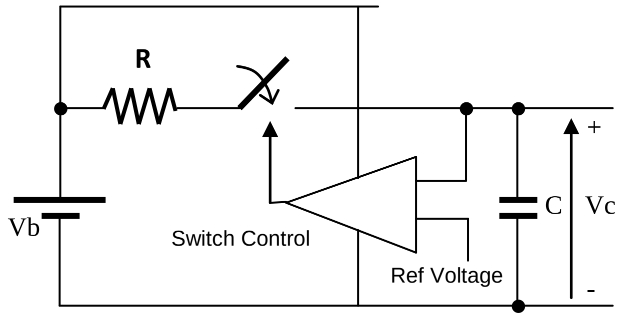


Figure 2. Button battery supercap trickle charger

- R is chosen to optimise supercapacitor charge time while limiting the high current stress on the battery to an acceptable level. Energy loss is independent of R

5. Losses independent of current limit R

Losses independent of R

- Analysis in the paper shows losses are independent of R:
  - For higher values of R, current is less, but time to charge is longer
  - For lower values of R, higher current and shorter charge time
  - So the energy lost

$$\int_0^{charge\_time} i_{charge}^2 \bullet R(dt)$$

  - Depends on the supercapacitor C, and the voltages the supercapacitor is charged from and to.

$$= C\left[V_b (V_{C2} - V_{C1}) + \frac{{V_{C1}}^2 - {V_{C2}}^2}{2} \right]$$

6. Circuit implementation of the button battery supercapacitor charger

Charger Circuit

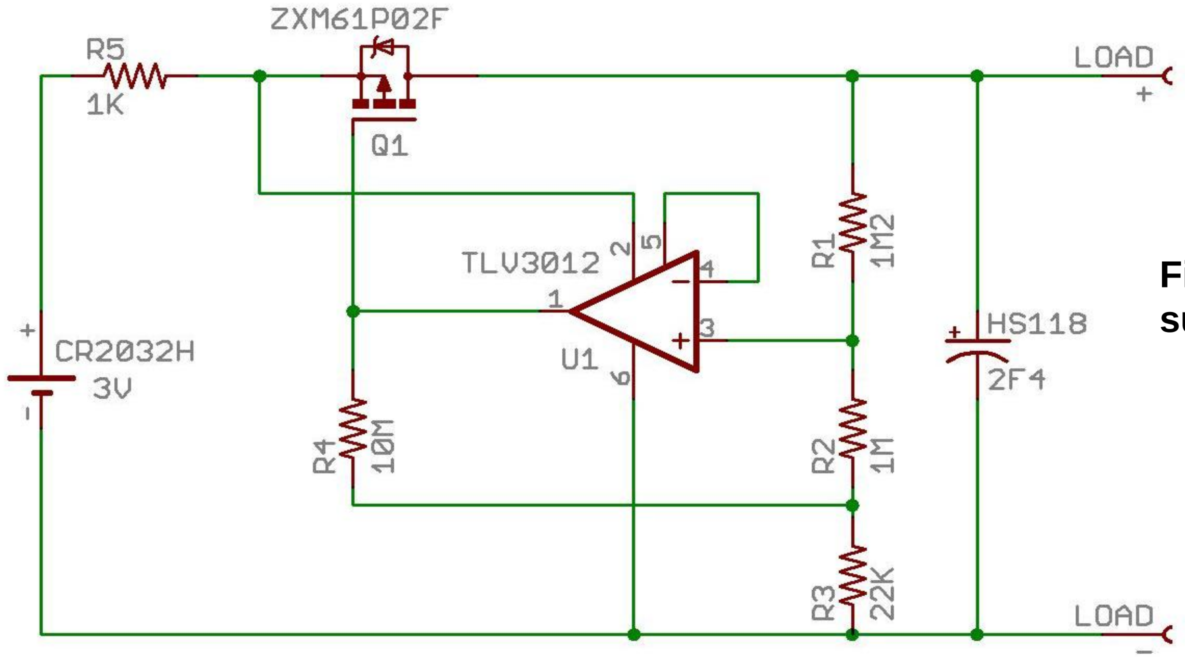


Fig 4: Button battery supercap charger circuit

- Hysteresis: Q1 OFF when Vscap > 2.696V, Q1 ON when Vscap < 2.688V
- Quiescent current when supercapacitor fully charged ~3μA – 5μA
- R determined so Trecharge < 5RC, supercap charged to 99% of Vbatt. In the circuit of Fig 4, this would be 5 x 2400 = 3hrs 20 mins

7. Design considerations

Min voltage the battery must supply

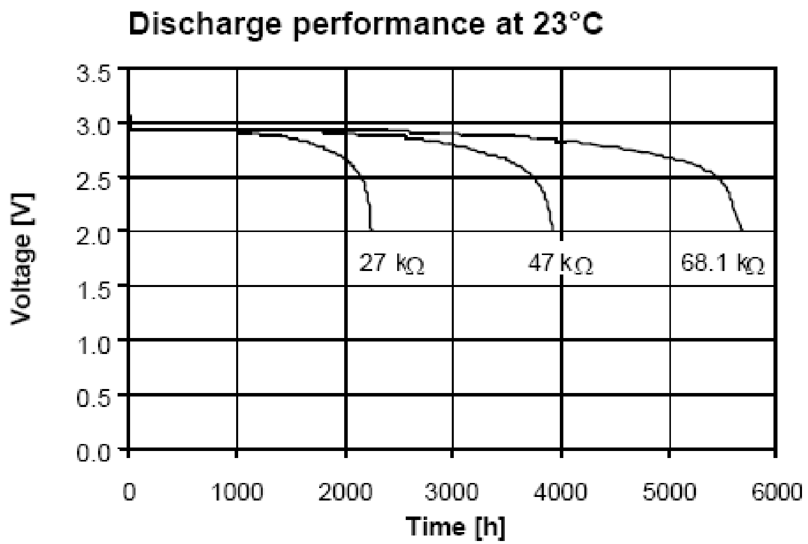


Fig 5. CR2032 discharge performance

Discharge curves from the manufacturer are typically time vs constant resistive load ….

… which can be used to calculate mAh vs min battery voltage at which the system operates. The curve above shows if the system is designed to operate at ≤ 2.6V, then max battery energy will be extracted. Cct in 6. will run down to 1.8V

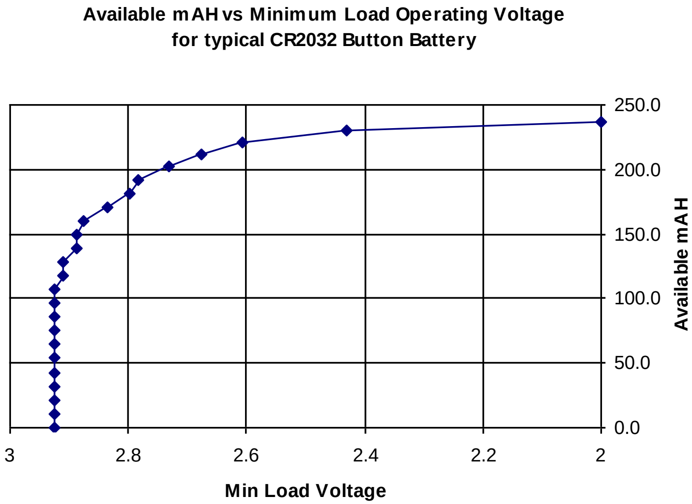


Fig 6: CR2032 Capacity vs Minimum Load Voltage

Keep Supercapacitor on charge, or Charge when needed?

Key design decision to minimise energy loss:

- Always keep the supercapacitor on charge and lose the energy from circuit quiescent current and supercapacitor leakage current

Or

- Let the supercapacitor discharge after use

Factors affecting the decision:

- Time between burst load intervals
- Supercapacitor self discharge characteristic
- C value

Keep Supercapacitor on charge, or Charge when needed?

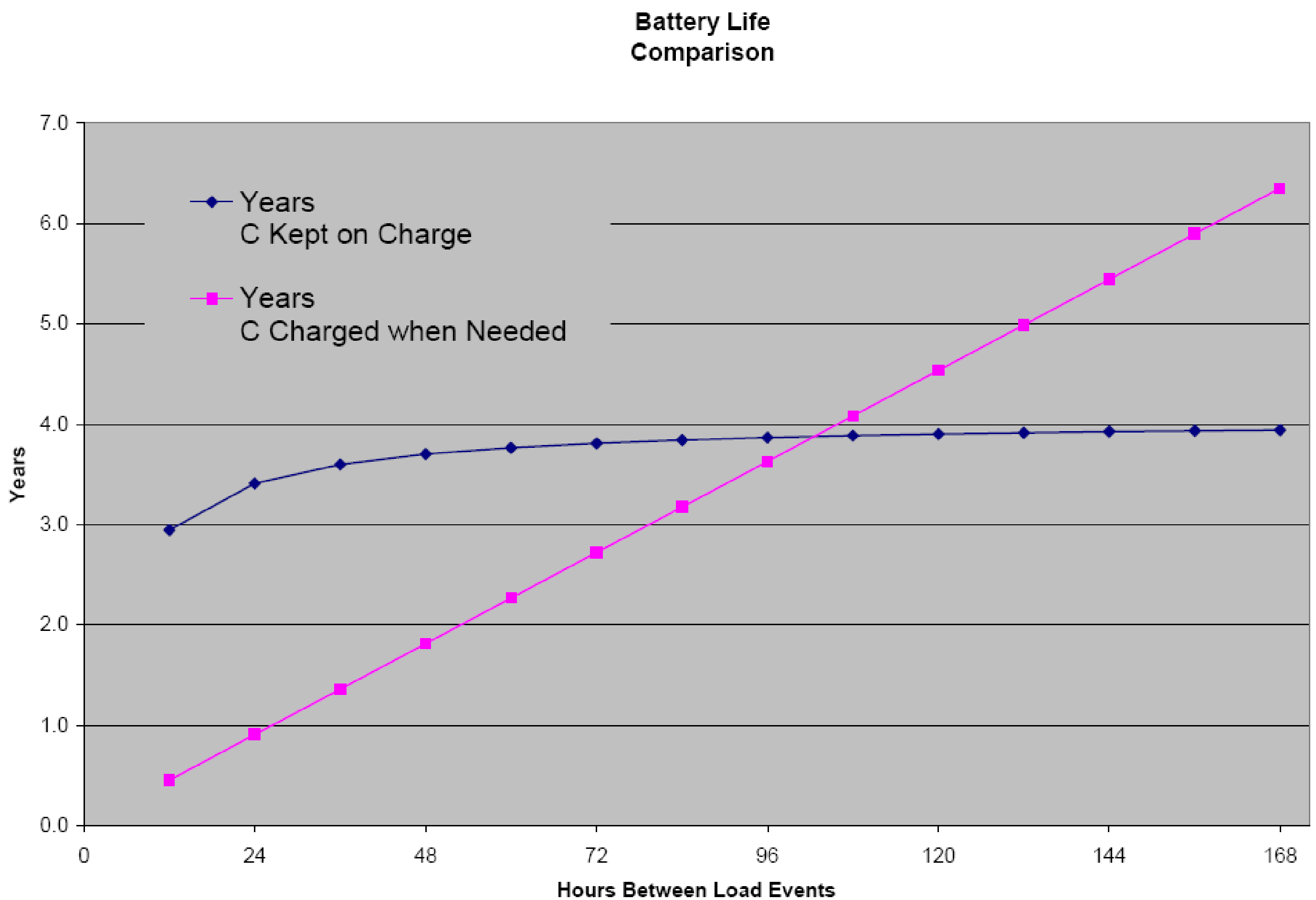


Figure 7: Battery Life depending on whether supercapacitor is always on charge or only charged prior to each load event.

Supercapacitors do not behave like classical capacitors

They need a minimum charge current

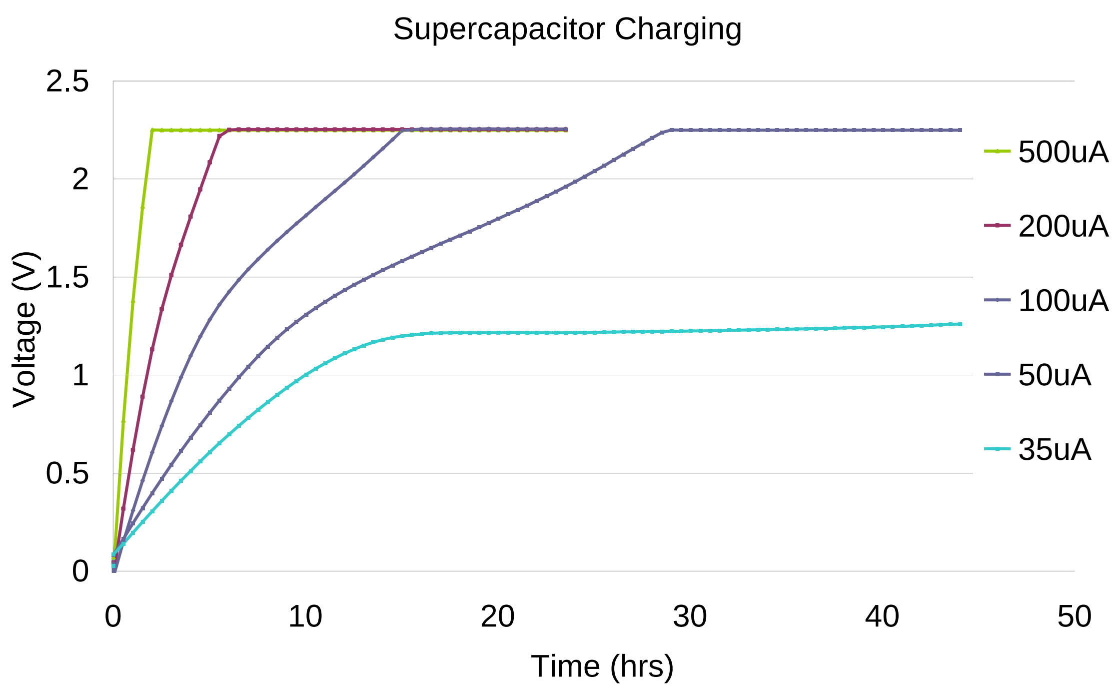


Figure 10: Supercapacitor charging at low levels of constant current.

Supercapacitors do not behave like classical capacitors

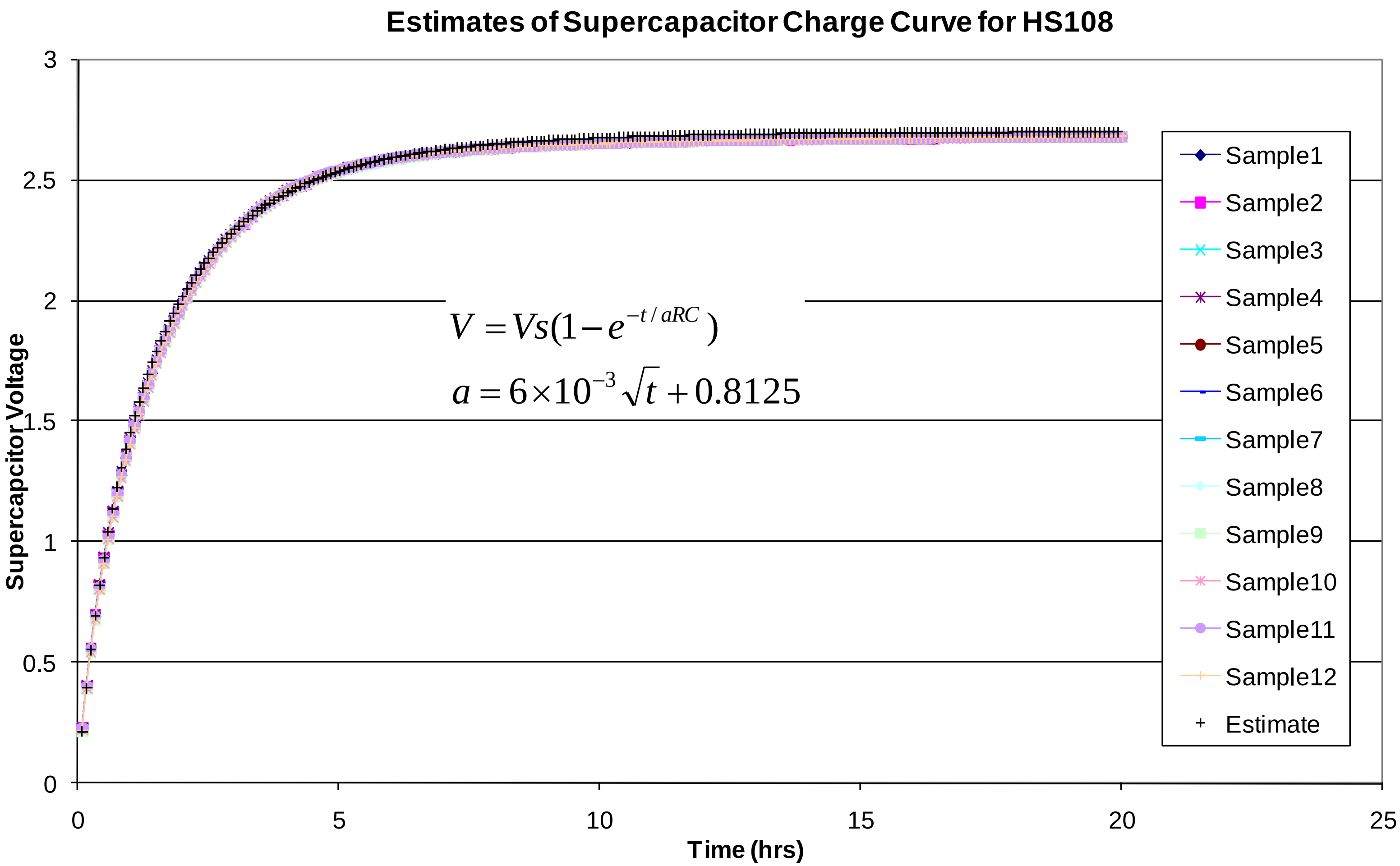


Figure 11. Supercapacitor charging does not follow the classical model

Self discharge characteristic empirically determined

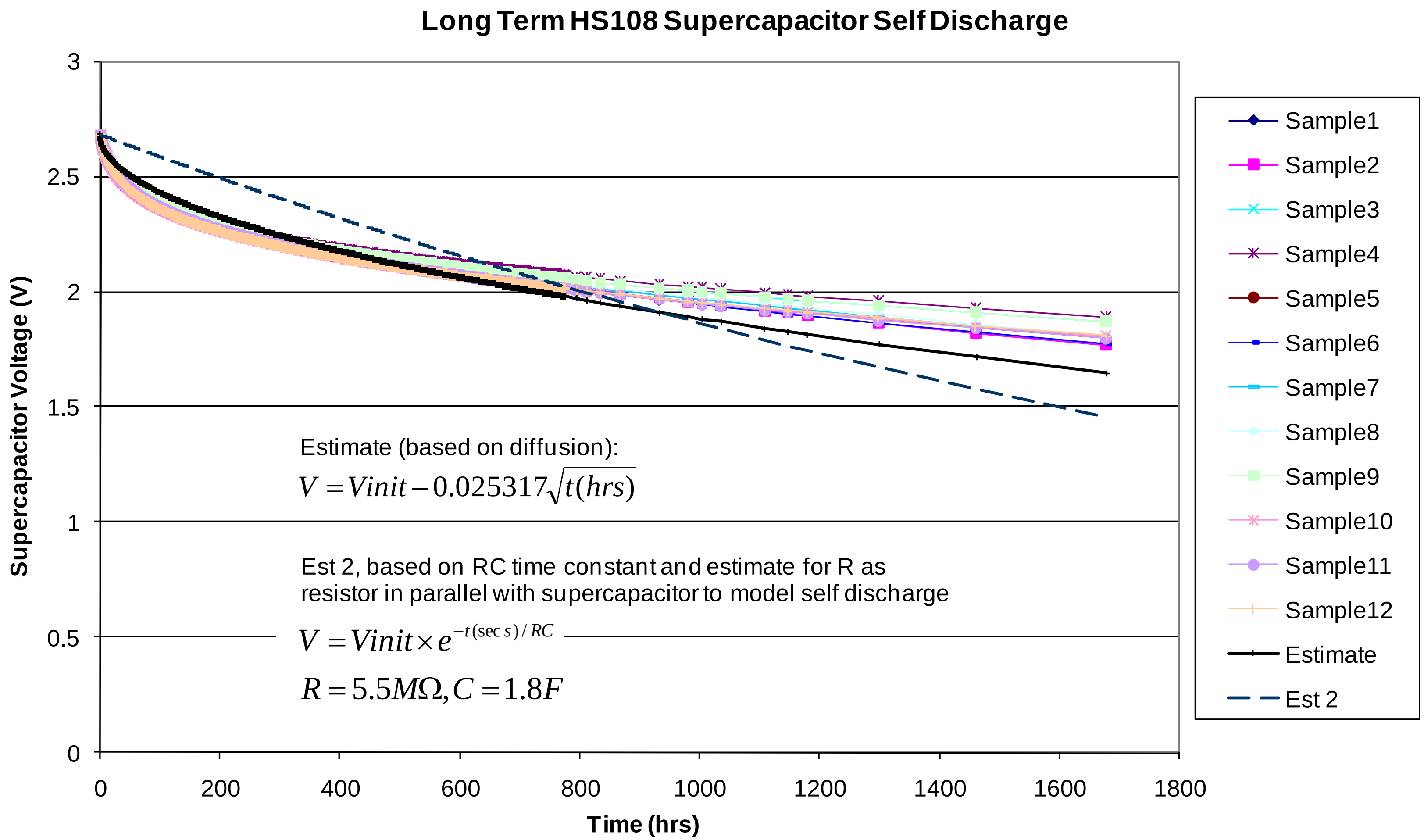


Figure 12: Supercapacitor self discharge characteristic

8. Case Study

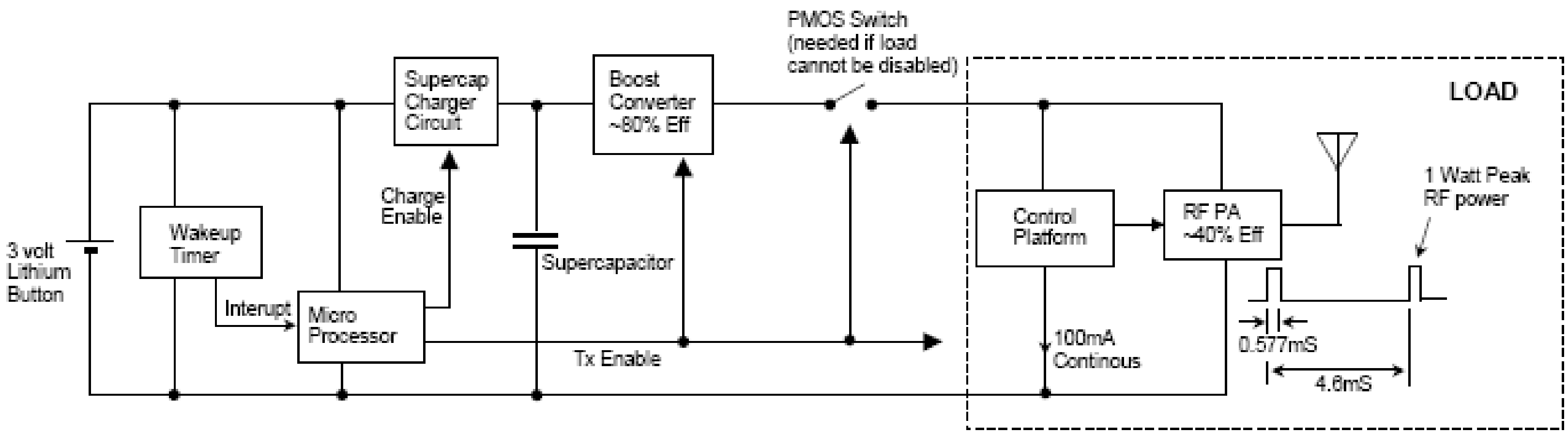


Figure 9: System Architecture: Single 3 Volt Lithium Cell Driving a 1 Watt Class 8 GPRS Load.

- GSM transmitter, 1W @ 1/8 duty cycle, RF PA is 40% efficient
- 3 sec burst. 100mA continuous current while module is on.
- Data collection & transmission 1/week
- Boost converter Vo = 3.6V, min boost converter Vin = 0.9V
- Boost converter efficiency = 80%

Sizing the supercapacitor

- Two constraints: Min C & Max ESR, they are interdependent
- Need to determine peak load current and total load energy to size C & ESR
- $C \geq 2 \times E_{LOAD}/[V_{BATT\ MIN}{}^2 - (V_{LOAD\ MIN} + I_{PEAK} \times ESR)^2]$
- Load energy delivered by the supercapacitor

  = [(1W/40%x1/8 + 3.6V x 0.1A)/80%] x 3 secs

  = 2.52J
- Peak boost converter i/p power

  = [1W/40% + 3.6V x 0.1A]/80%

  = 3.58W
- Peak current = 3.58W/min boost Vin = 3.58W/0.9V = 4A

  $\therefore V_{LOAD\ MIN} + I_{PEAK} \times ESR) = 0.9V + 4A \times 0.1A = 1.3V$
- Assume ESR = 100mΩ

  $\therefore C \geq 2 \times 2.52J/(2.6^2 - 1.3^2) = 0.995F$
- Select HS108. 1.8F±20%, 28mΩ±20%

9. Conclusions & Next Steps

Conclusions & Next Steps

1. A supercapacitor can be used to buffer a high peak power load so a low power high energy source can be used (eg, a 3V button battery)
2. A single cell organic electrolyte supercapacitor is best suited for such applications due to its:
   - Superior energy density
   - Low ESR
   - Low leakage current and no need for cell balancing
3. We have presented design considerations to optimise such a system, most notably whether to leave the supercapacitor on charge or to charge as needed
4. We have shown that supercapacitors do not behave as classical supercapacitors
5. We have presented a case study
6. Further work is required to characterise the charge & self discharge behaviour. These are crucial to choosing the best charging strategy. Currently, the best course of action is to empirically characterise the charge/discharge behaviour of the supercapacitors of interest

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For more information, please contact

Pierre Mars

V.P. Applications Engineering

Email: pierre.mars@cap-xx.com

Web: www.cap-xx.com