FEDERAZIONE NAZIONALE IMPRESE ELETTROTECNICHE ED ELETTRONICHE

ANIE COMPONENTI ELETTRONICI

L'energia dell'IoT: componenti elettronici passivi su misura per edifici intelligenti (smart building)

Hybrid (HS) & Supercapacitor (SC) Application

Agenda

1. Motivation for Smart Powering Smart Devices
2. Powering Smart Building Applications
3. Indoor Energy Harvesting
4. Energy Storage Mediums for Harvested Energy
5. Hybrid Supercapacitors aka. LiC – an Emerging New Technology
6. Super- and Hybrid-Capacitors Applications in Smart Buildings
   - Considerations for design – Smart Meters & Thermostats
   - Additional Application Examples

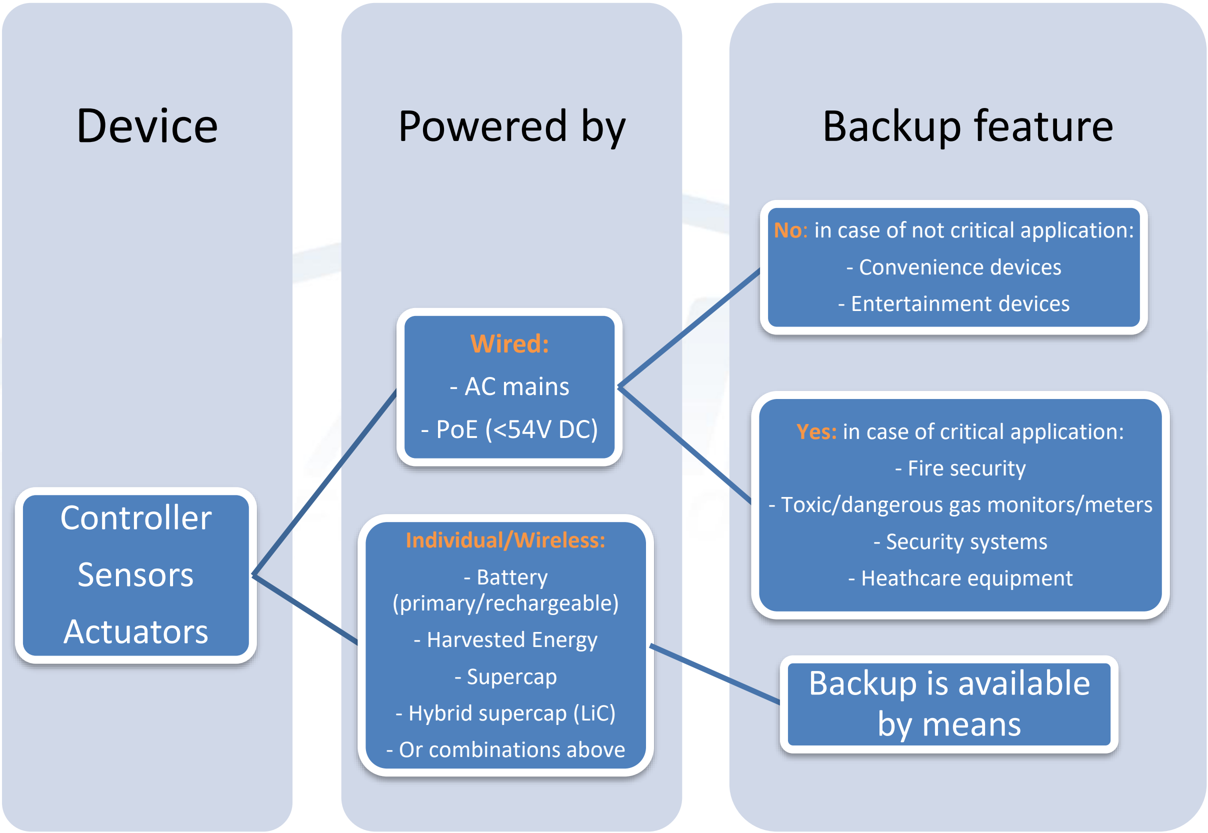
SC=SuperCapacitor
HS=Hybrid Supercapacitor

Motivation For Smart Powering Smart Devices

1. Reducing battery waste
2. Improving user comfort
3. Improving energy efficiency
4. Improving reliability

Powering Smart Building Applications

Powering Smart Buildings/Factories



Indoor Energy Harvesting

Indoor Energy Harvesting Options

Method	Source	Efficiency	Typical Power Output	Cost	Best Use Cases	Typical Generated Voltage Range
Indoor Solar (PV)	Ambient light (LEDs, bulbs)	Moderate (10–20%)	µW–mW	Low–Moderate	Clocks, sensors, remote controls	1–12 V
Thermal (TEG)	Temperature gradients	Low (5–8%)	µW–mW	Moderate	Wearables, industrial monitoring	10–100 mV -> boost
RF Harvesting	Wi-Fi, Bluetooth, cellular	Low (<1%)	nW–µW	Low	Passive RFID, low-power IoT	0.1–0.5 V - > boost
Piezoelectric	Vibrations, motion	Moderate (10–20%)	µW–mW	Moderate	Keyboards, wearables, floor sensors	1–10 V
Electromagnetic (Inductive)	Magnetic fields near electronics	Moderate (10–30%)	µW–mW	Moderate	Wireless charging, motor-adjacent devices	0.1–5 V
Capacitive (Electrostatic)	Motion, vibration	Low–Moderate	nW–µW	Low–Moderate	MEMS sensors, micro-devices	0.1–1 V -> boost
Triboelectric	Friction, contact between surfaces	Moderate (10–20%)	µW–mW	Low–Moderate	Wearables, touch interfaces	1–100 V

Energy Storage Mediums/Options for Harvested Energy Storage

Energy Storage Medium Options – By Performance

Battery Type	Energy Density	Power Density	Coulometric Efficiency	Notes
NiMH (Nickel-Metal Hydride)	High	Low	66% – 92%	Efficiency drops significantly after ~70% SoC due to heat loss.
Li-ion (Lithium-Ion)	Highest	High	95% – 99%	Very high efficiency; minimal energy loss during charge/discharge cycles.
Lead-Acid	Moderate	Medium	70% – 85%	Lower efficiency due to gassing and internal resistance.
NiCd (Nickel-Cadmium)	Moderate	Medium	70% – 90%	Good efficiency, but environmental concerns limit usage.
Alkaline Battery	High	Low	0%	Not rechargeable
Supercapacitor	Lowest	Highest	99+%	Greenest, safest, very high current capability
Hybrid Supercapacitor	Moderate	High	98+%	Green, safe, low self discharge

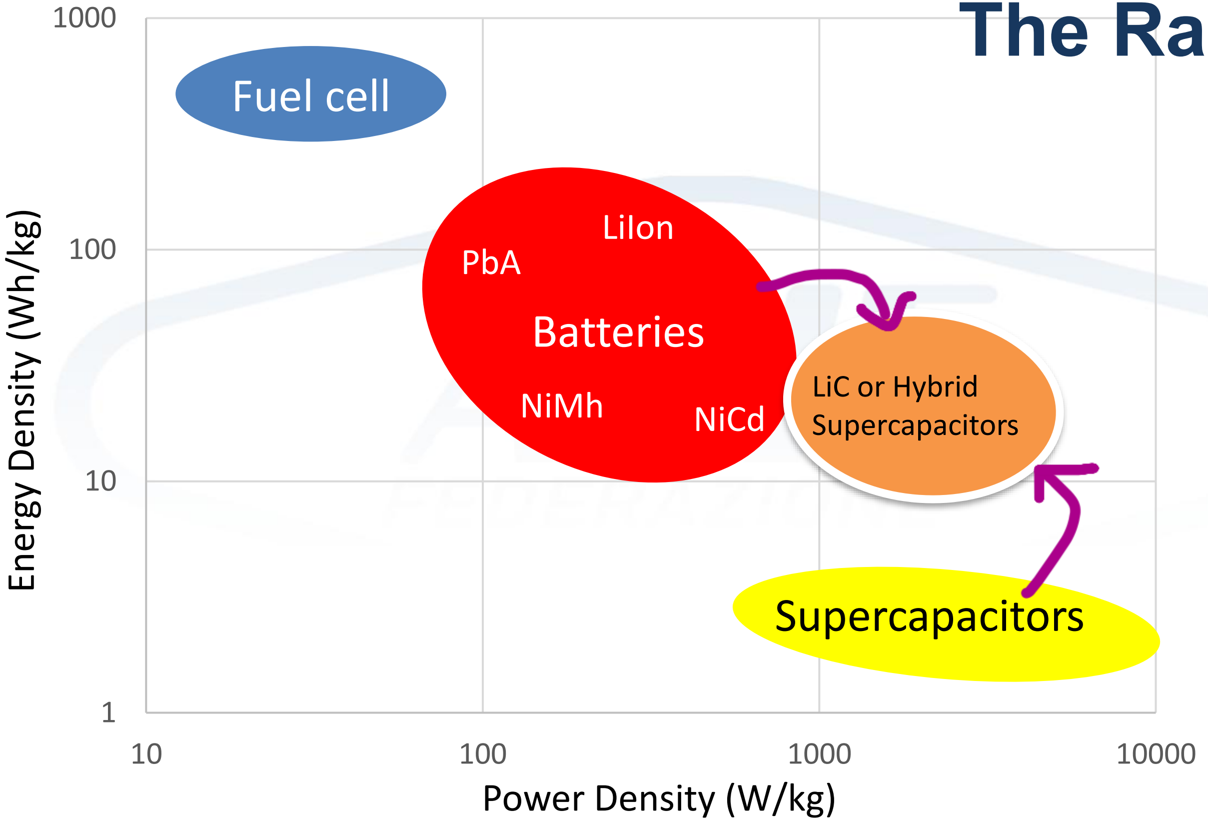
Energy Storage Medium Options – By Environmental Impact

Battery Type	User Safety	Toxicity	Recyclability	Environmental Impact Level
Lithium-Ion (Li-ion)	High explosion, thermal runaway risk	High (Cobalt, Nickel)	Low (~5%)	High
Lead-Acid	Moderate explosion risk, gas buildup	High (Lead)	High (~99%)	High
Nickel-Cadmium (NiCd)	Moderate thermal runaway risk if abused	High (Cadmium)	Moderate	High
Alkaline (Single-Use)	Very low risk	Moderate (Zinc, Manganese)	Low	Moderate
Nickel-Metal Hydride (NiMH)	Low risk, only heating by overcharge or undercharged	Lower	Moderate	Lower
Supercapacitor	No risk even by short circuiting or abusing (besides high power release)	No or Very low (irritation in case of acetonitrile electrolyte)	High (40% aluminum, rest is carbon and paper)	Very low
Hybrid Supercapacitor	Very low risk, heating if short circuited or abused	Very low (electrolyte may cause irritation)	Moderate (Al and Cu + carbon)	Very low

Hybrid Supercapacitors aka. LiC – an emerging new technology

Energy Storage Mediums:

The Ragone-Plot



EDLC aka. Supercaps

Construction

Supercaps are symetrical devices comprised by activated carbon electrodes at both anode and cathode sides

Charge & Discharge

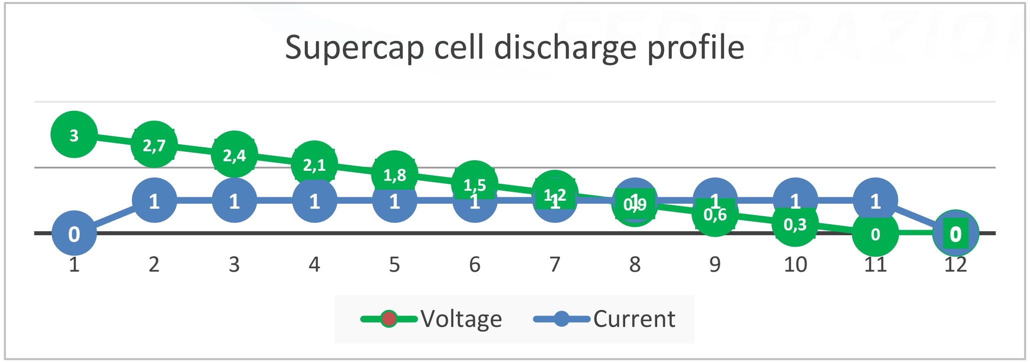
No chemical reactions in electrostatic processes
Can be done at the same speed and fashion in seconds

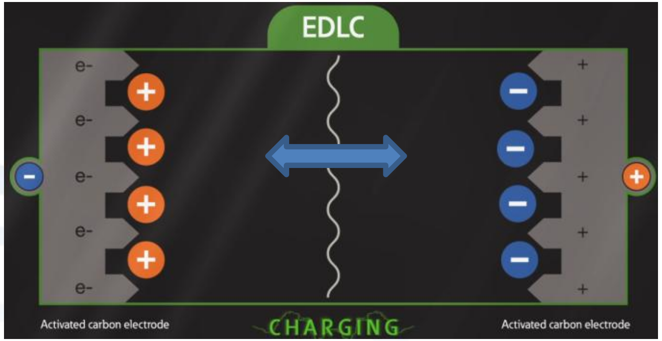
Cycle life

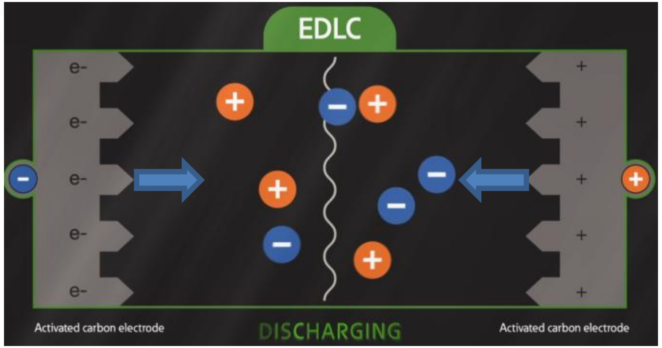
Practically unlimited

Voltage

Voltage drops linerarly by the energy delivered







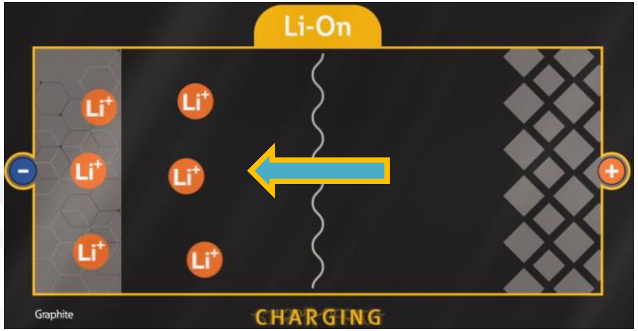
Lilon batteries

Construction

Lilon batteries are asymmetric devices comprising of graphite anodes and metal oxide cathodes (Co, Mn, PO4, Fe, Ni combinations)

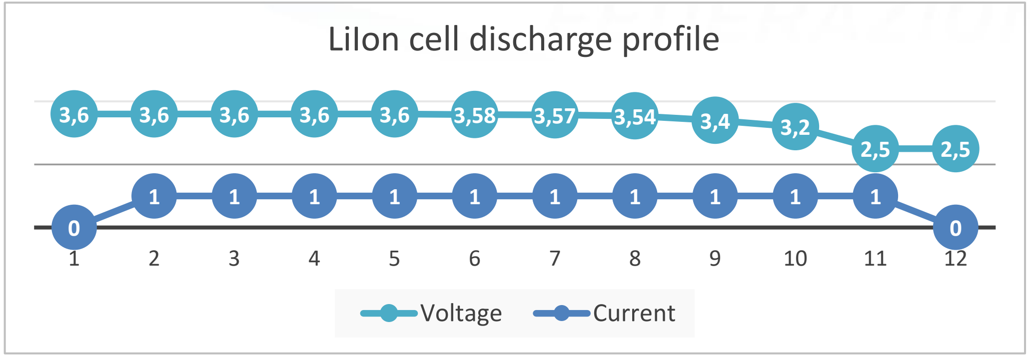
Charge & Discharge

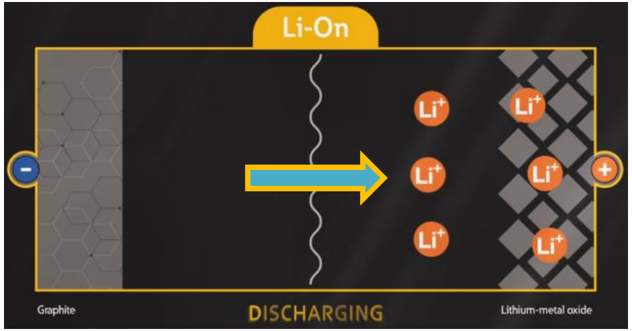
- Charge and discharge are electrochemical processes
- Discharge profile is flat, delivering quasi constant voltage



Cycle life

Cycle life is limited due to degradation (electrolyte oxidation, Li oxide buildup on anode and cathode surface, structural damage etc.)





LiC aka. Hybrid Supercaps

Construction

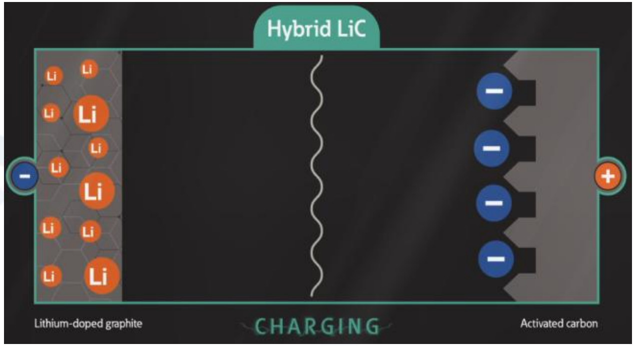
Hybrid supercaps are asymmetric devices comprise of a Li doped graphite anode and activated carbon cathode

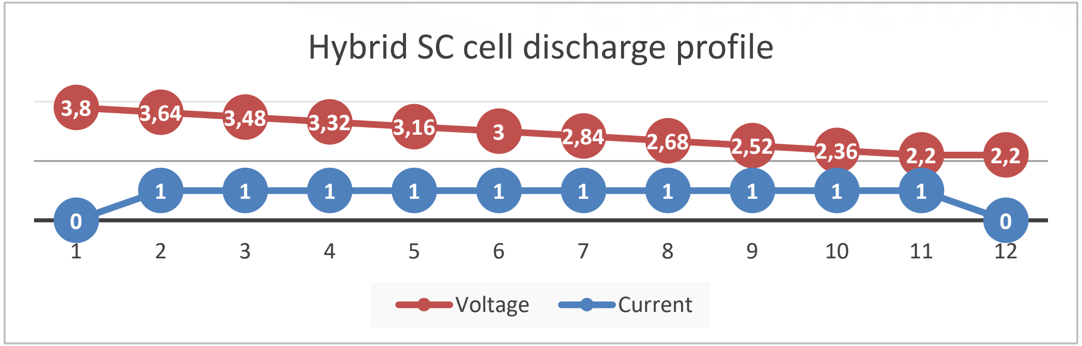
Thermal runaway

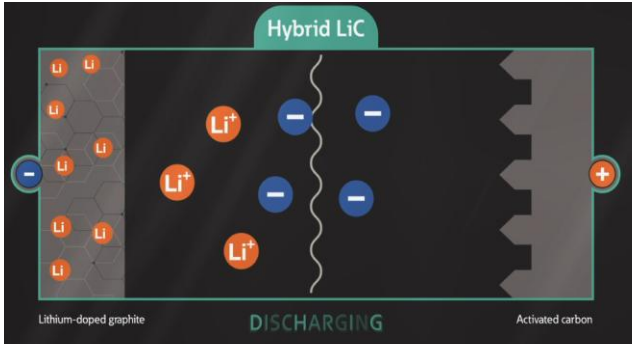
As there are no metal oxides used the hybrid supercaps are not posing any risk of fire or thermal runaway

Charge & Discharge

The charge movement is done electrochemically mainly but in significantly lower depth as in case of the LiIon battery. This results a very high ~500.000x cycle life and very fast responsiveness to high current rate discharges







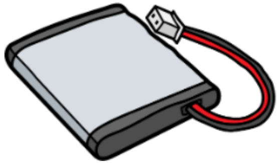
Technology Comparison

Traditional supercapacitor	Hybrid supercapacitor
+ Long calendar life, up to 20 years*	+ High energy density provides longer back up times
+ Ultra low resistance (ESR) for higher power	+ Low leakage current provides long life when used with a primary battery
+ Higher efficiency in high current discharges	+ Low self discharge maintains voltage over long periods with no charge source
+ Lower self heating for long life in high current use	• Minimum voltage required; cannot be short circuited
+ Discharge to zero volts for safety	+ High voltage single cell better match to battery voltages
+ Broad temperature range -40 to +85 ^{o}C	+ High voltage can require fewer cells to meet system voltage
+ Environmentally friendly; no heavy metals, no rare metals, easily recycled	+ Long lifetime: 10 years at 20 ^{o}C
• Longest lifetime	+ Long cycle life: 500k (HS), 250k (HSL)
• Long cycle life: 500k – 1M+	

Technology Comparison

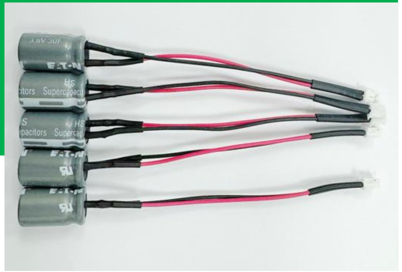
Li-ion battery

- \+ Highest energy density: discharge times 3 min. to hours
- \+ Lower self discharge
- \- High current recharge shortens life
- \- Higher internal resistance limits power
- \- Must manage thermal load
- \- Operating temperature range -10 to +40 ºC
- \- Require sophisticated battery management system
- \- Must oversize to reach longer lifetimes >5 years
- \- Cycle life: 3k-10k

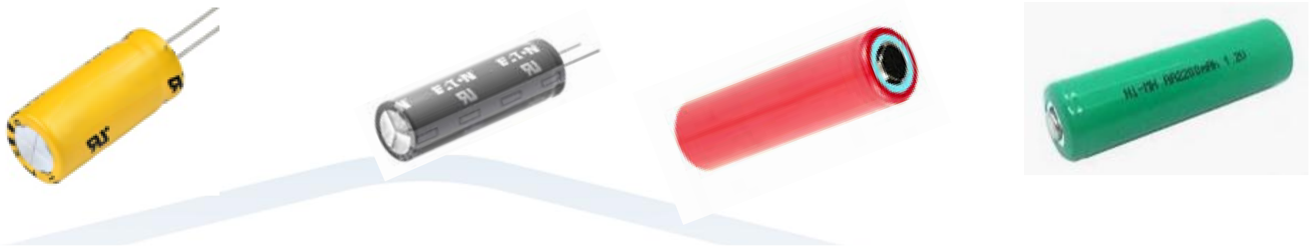


Hybrid supercapacitor

- \+ High energy density provides longer back up times minutes
- • Low self discharge for longer life when paired to primary batteries
- \+ Long lifetime: 10 years at 20 ºC
- \+ Long cycle life: 500k (HS), 250k (HSL)
- \+ Safety: no thermal runaway, short circuit does not cause fire



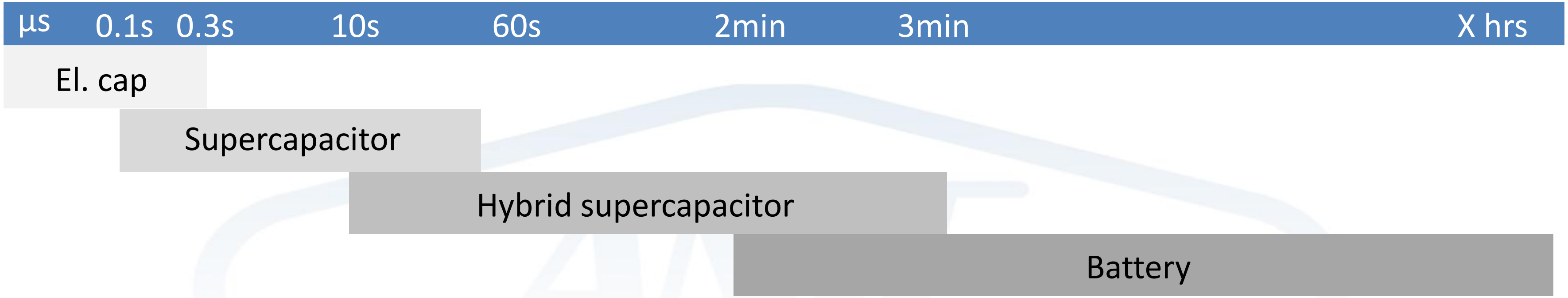
SC vs. HS vs. Batteries Performance



	~AA size SuperCap (34F/3V/5.5ccm)	~AA size Hybrid SC (400F/3.8V/5.5ccm)	AA size LiIon (3.7V, 1Ah, 8.5ccm)	AA size NiMh (1.2V, 2.45Ah, 8.3ccm)
Total stored energy	8 mWh/ccm	82 mWh/ccm	423 mWh/ccm max (load and temp dependent)	339 mWh/ccm max (load and temp dependant)
Peak power	141W	45W	10W	3W
Cylcle life	1M (unlimited)	500k	1k	500
Energy transfer life	34kWh	125kWh	3.6kWh	1.5kWh
Operating temp range	-40C/+65C (+85C with derating)	-25C/+70C (+85C with derating)	0C/+60C (discharge possible up to -20C with limited current)	(-4C/+50C)

Different performance aspects for different applications

Energy Storage On The Scale Of Economy



The optimal solution depends on:

- Duty cycle of charge/discharge
- Number of cycles
- Ambient temperature level
- Discharge current
- Lifetime requirements

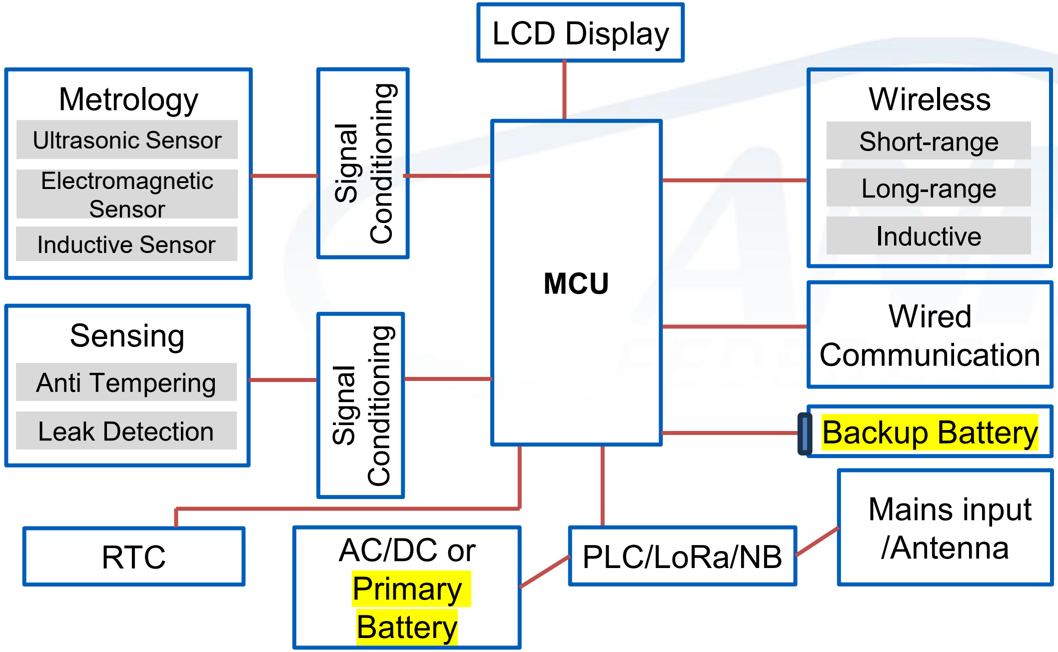
Super and Hybrid Capacitors Application In Smart Buildings

Smart Metering

Application:

- Electricity:
  - RTC backup/Anti Tampering (SC: 0.22-1F)
  - Brownout/Last Gasp (SC: 3-4s 10-100F)
- Water:
  - Wireless boost (SC: 2s 2-5F)
- Gas:
  - Wireless boost/safety closure (SC/HS: 1-2s 25-100F)

Mains or Primary Powered Example: Smart Meters (Electricity, Water and Gas)



Battery devices needed for:

- Brown-out/black-out power backup (electricity)
- Boost power (gas and water, communication and safety valves)
- Anti tampering or leak detection (electricity)
- Real time clock backup (electricity)

IoT Communication Options

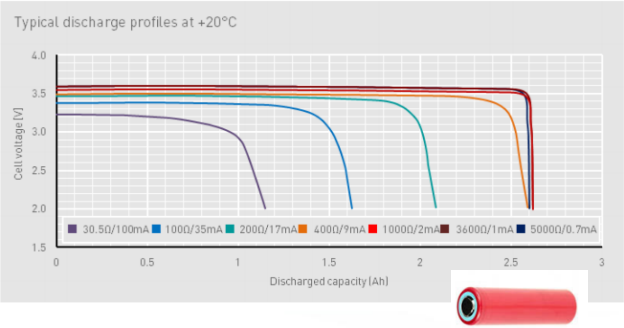
Communication channel	Max current consumption during TX/RX	Typical power source	Applications
Bluetooth 5.0 – very short range ~10m (Microchip RN2483)	10mA @ 3.6V, typically 2-3mA continously	• LiIon battery, • NiMh battery sized as per autonony requirements	Indoor consumer applications, audio, smart home applicances
WIFI – short range 10-100m, heavy data traffic (– Atmel LowPower WIFI)	200-300mA TX, 50-100mA RX @ 3.6V	• Larger LiIon battery • Larger NiMh battery Optional with supercaps to extend battery life and temp range	Security systems, smart city applications, sensors, monitoring systems
Zigbee/Z-wave/Thread – short range 10-30m	25-45mA @ 3V, 5mA in idle mode	• LiIon battery • NiMh battery • **Hybrid supercap** – if energy harvested	Smart home applications/appliances
LORA – mid range 5-20km (Microchip RN2483)	40mA @ 3.6V during time of transmission, 50uA continous	• LiIon battery • NiMh battery • **Hybrid supercap** Parallel **supercap optional** to extend transmission range or operating temperature	Outdoor security systems, smart city applications, EV chargers, industrial sensing
NB IoT with GSM/GPRS module – long range	200mA-2A @ 3.6V range dependent, <100uA in sleep mode	Primary Lithium cells (LiSocl2) + secondary battery (**supercap or hybrid cap**/battery)	Asset tracking, smart metering, eCall, bikes tracking, agricultural monitoring

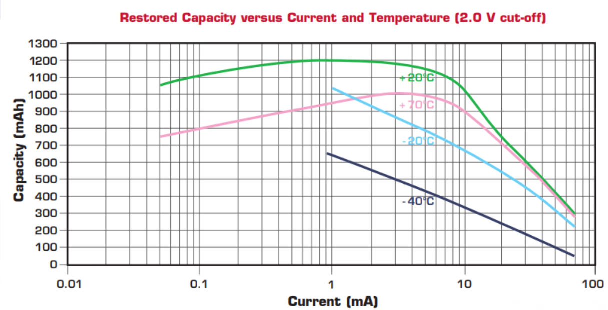
ANIE
FEDERAZIONE NAZIONALE IMPRESE ELETTROTECNICHE ED ELETTRONICHE

ANIE COMPONENTI ELETTRONICI

LoRA Design Example

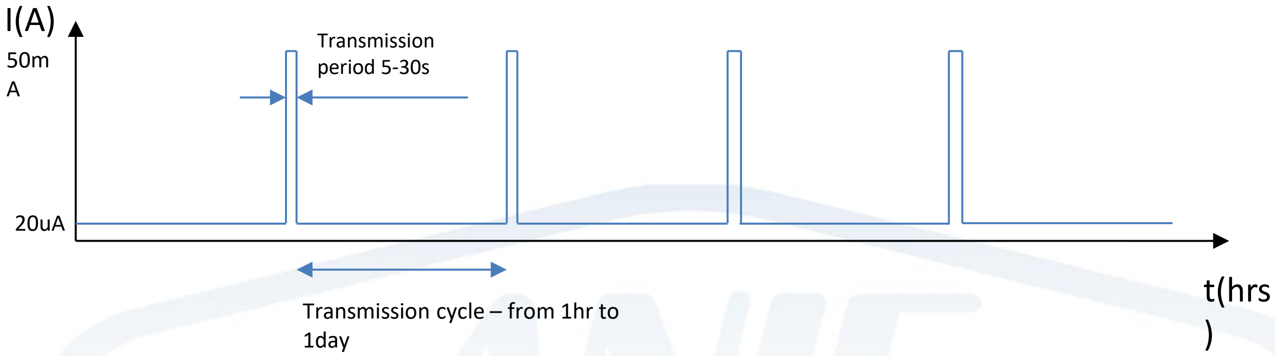
- Application: Water meter
- Power source: 1/2AA-size LiSocl2 primary battery
- Power during transmission: 50mA for 10s…daily 1x transmission





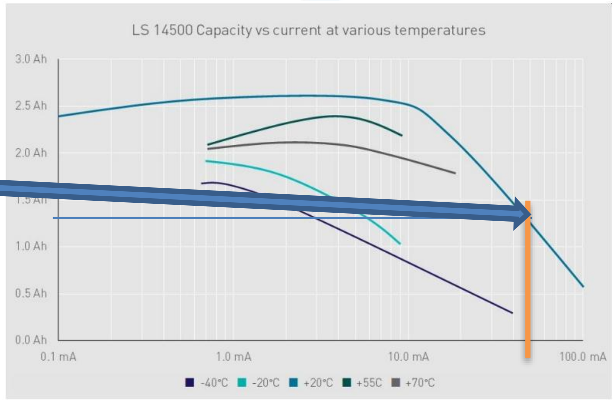
Solution #1	Solution #2
AA size LiSocl2 (3.6V/2.6Ah)	AA size LiSocl2 (3.6V/2.6Ah) + 2xsupercaps (2.7V/1F)
With 1x daily transmission 20% extra of total capacity will be consumed by the pulses	Supercaps are sized to take care of the current pulses, but consume ~2uA depending on the balancing => consumes ~10% extra of the total capacity

LoRA Design Example



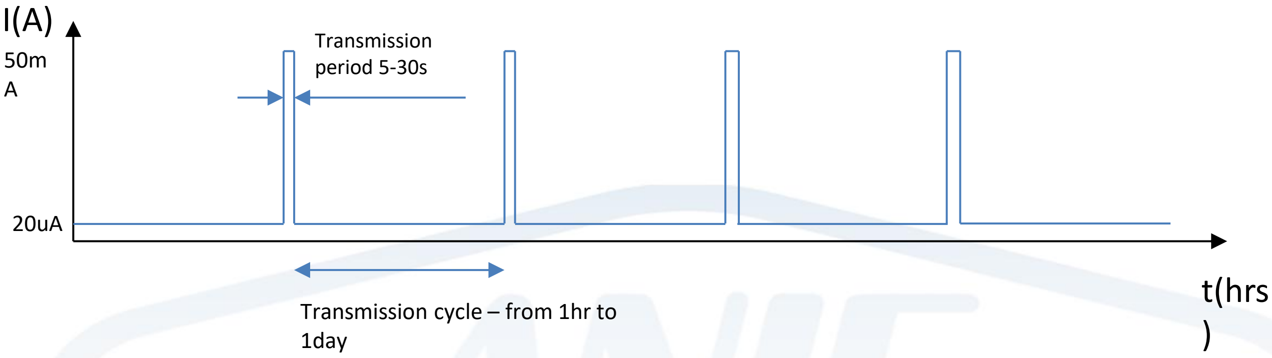
- Required energy for operation = 10years x 20uA => 1.75Ah
- Required energy for communication = 0.5Ah for 1xday with 10s transmission period, BUT this level of discharge current will consume ~35% of the battery capacitance ~ 0.85Ah
- Total energy consumption = 1.75A + 0.85A = 2.6Ah

AA LiSocl2 battery selected with 2.6Ah capacity seems to provide the required energy if 1x per day transmission period is required. If considered -20C temperatures it requires additional oversizing.



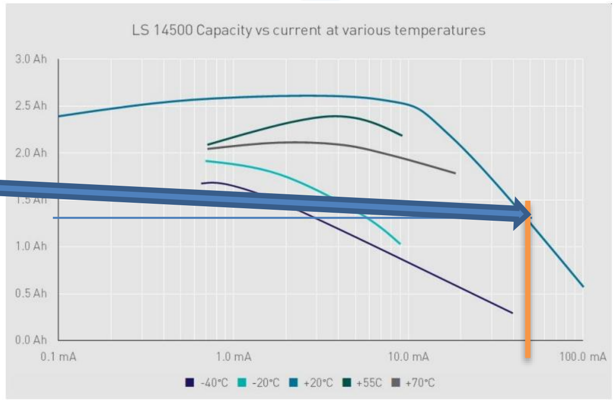
Source: Saft Batteries

LoRA Design Example



- Required energy for operation = 10years x 20uA => 1.75Ah
- Required energy for communication = 1Ah for with 2x10s transmission period, BUT this level of discharge current will consume ~75% of the battery capacitance ~ 1.92Ah
- Total energy consumption = 1.75A + 1.92A = 3.67Ah

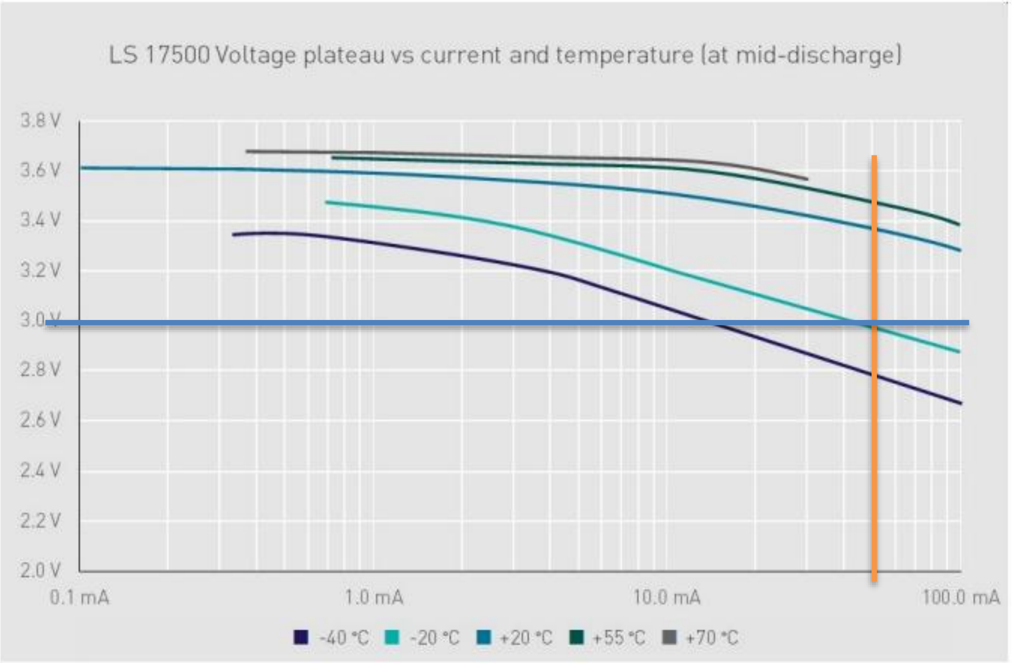
„A size" LiSocl2 battery would be required with 3.7Ah capacity to provide the required energy if 2x per day transmission period is required. If we consider -20C



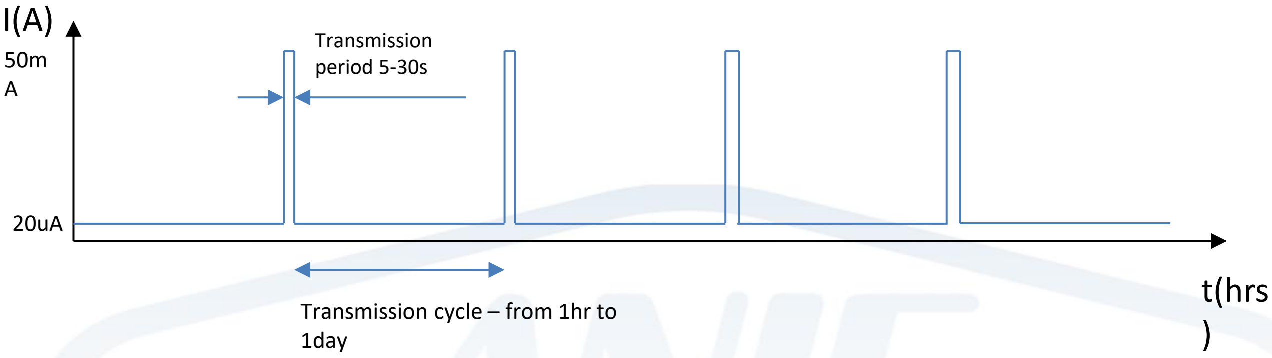
Source: Saft Batteries

LoRA Design Example

- In cold temperatures the battery voltage + available capacity is dropping.
- @ -20C the battery voltage is 3V instead of 3.6V
- Normally the transmission circuit works between 2.5-4V => the battery needs to provide higher currents even in cold temperature or provide the 50mA current longer than at 25C => this puts heavier stress on the battery => one size larger battery is needed to provide power in case cold temperature operation is required

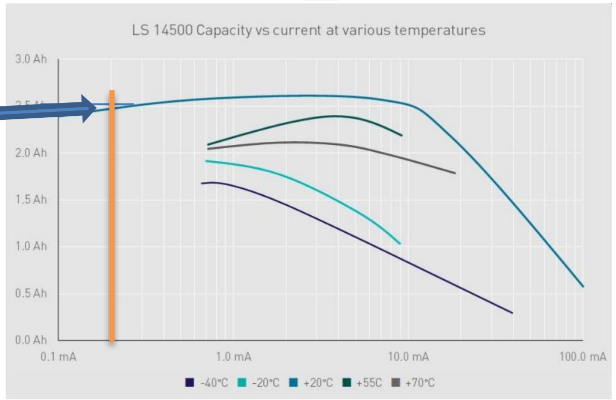


LoRA Design Example

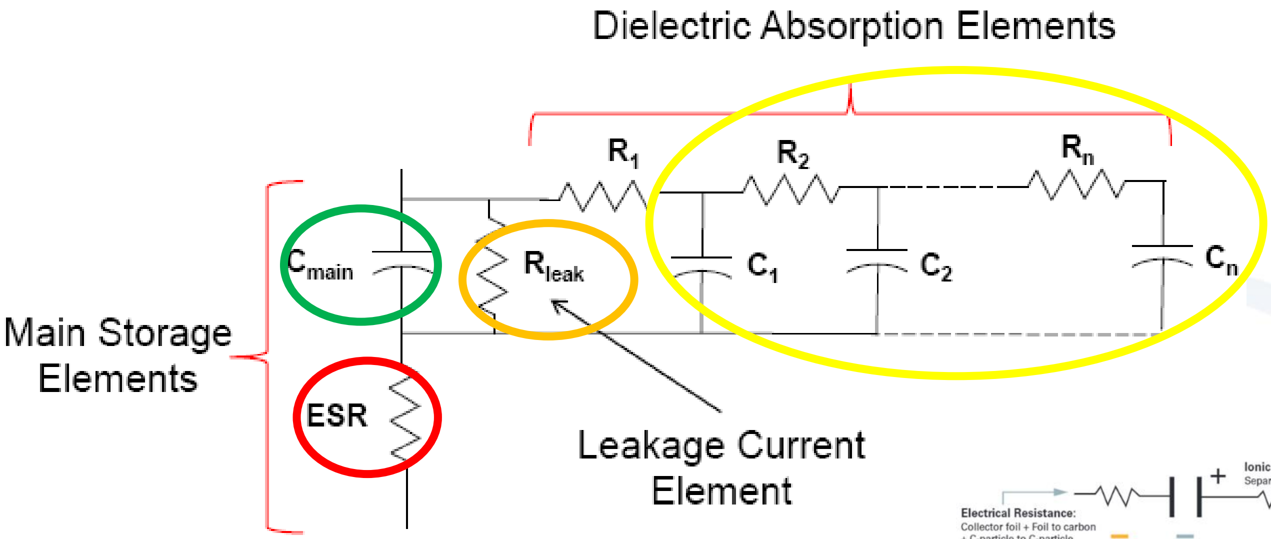


- Required energy for operation = 10years x 20uA => 1.75Ah
- Required energy for communication = 1Ah for with 2x10s transmission period. Regular consumption can be considered as the supercaps will deliver the transmission power.
- Supercap energy consumption to be considered!!!
- Total energy consumption = 1.75Ah + 1Ah = 2.75Ah

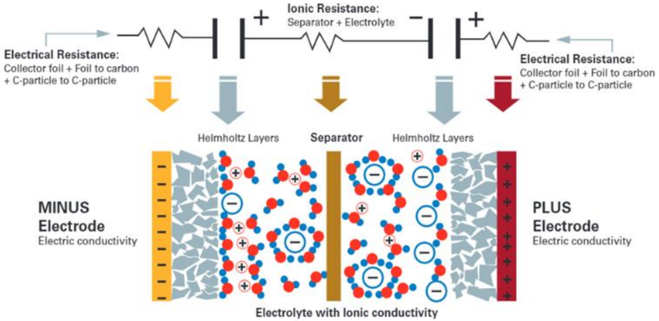
„AA size" LiSocl2 battery would be required with 2.7Ah capacity to provide the required energy if 2x per day transmission period is required.



Basic SC Model



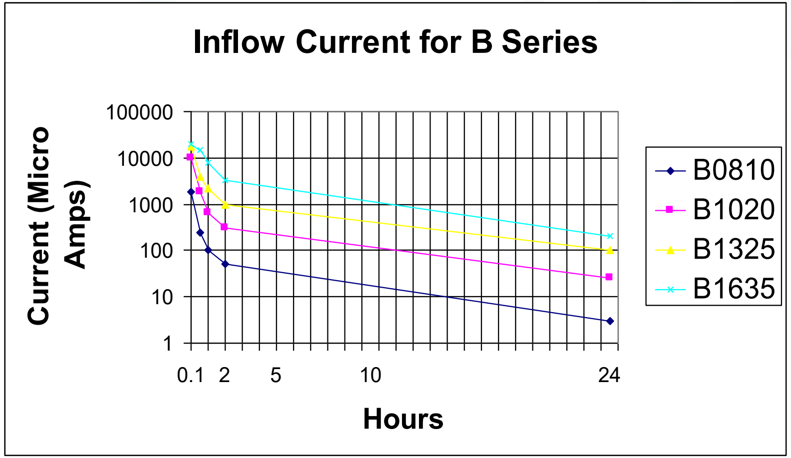
$C_{main} >>> C_1, C_2 \ \& \ C_n$

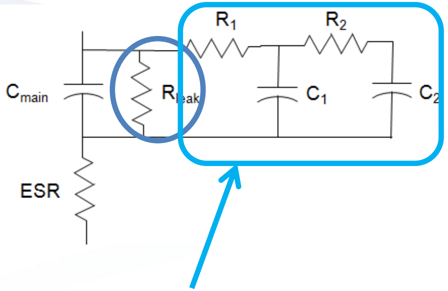


Supercaps energy consumption – the leakage current

Leakage Current – Leakage arises because the materials separating the electrodes are not perfect insulators. This is modeled as a resistor across the capacitor.
Inflow Current – True leakage current to measure takes 100-1000Hrs charge. Inflow current is a more suitable way to get indication of the capacitor's leakage current value.

Leakage/inflow current increases by size and capacitance.



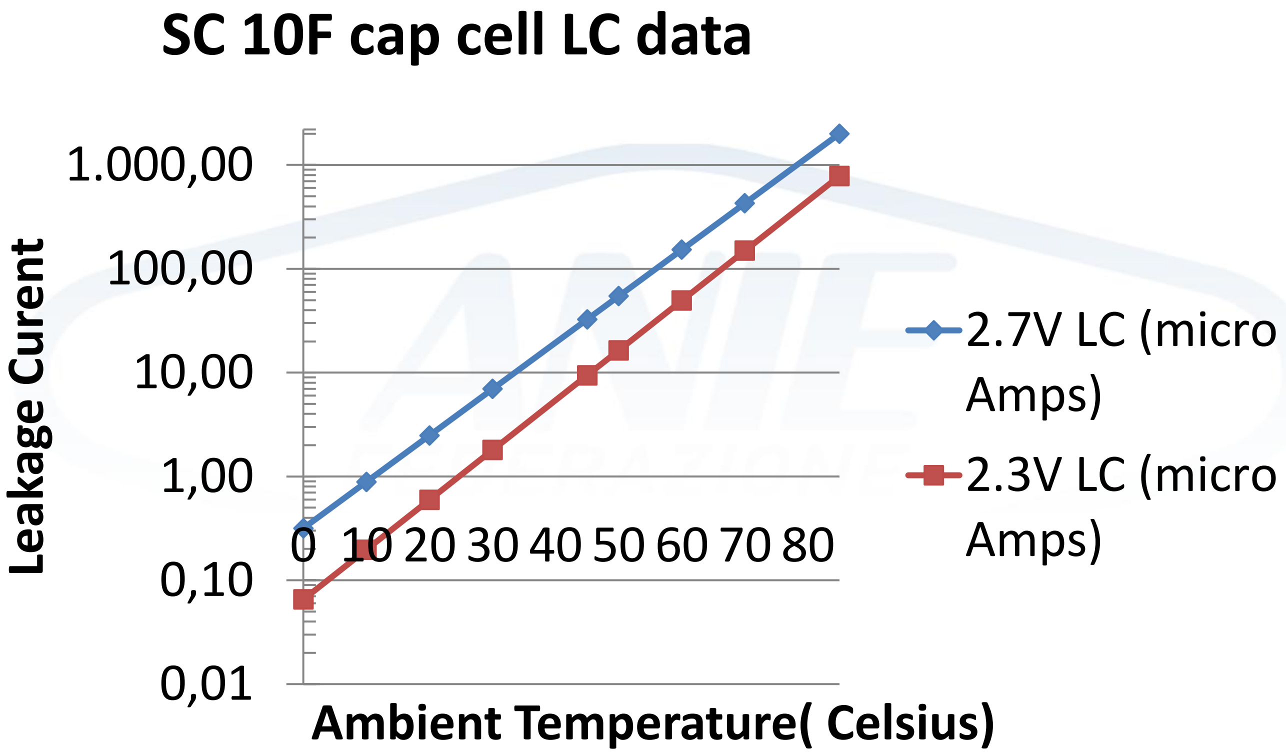


Need to charge parasitic RC elements before inflow current falls to true leakage current level. Once charged these parasitic elements will be slowest to discharge so leakage current levels will be reached more rapidly following a partial discharge.

Supercaps energy consumption – the leakage current

- Leakage and inflow current are highly dependent of temperature and voltage level
- With every 10C temp increase the LC increases with 2-3x
- With every 0.2V charge decrease the LC is getting halved
- LC is proportional to the size of the capacitor, typically linear conversion
- LC is dependant of the electrolyte type: using ACN results slightly higher LC than PC caps
- P (pack) series LC is mainly dominated by the balancing resitor discharge effect except the PHVL series
- Lowest leakage current can be achieved by using single cells with active balancing or using PHVL series
- Eaton can provide accurate LC data based on measurement results

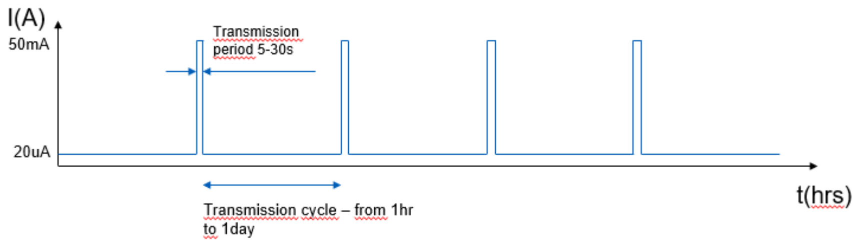
Supercaps energy consumption – LC vs. temp



LORA example – supercap sizing

- 50mA for 10s considered – supercap delivers fully the transmission power
- 3.1V charge voltage considered for the low temp battery effect – supercap will follow the battery voltage with some delay
- 2.5V cutoff voltage was considered for TX circuit
- -10% potential initial tolerance for the capacitor
- -30% capacitance loss over the lifetime in 15yrs
- 100% ESR increase over the lifetime in 15yrs

Result= 2pcs 3F supercap are required



1. Enter System/Customer Requirements

Select Discharge Type	Constant Cur	
Power or Current	5,00E-02	Amps
Discharge Time	10	seconds
System Max. Voltage	3,1	Volts
Operating Voltage	3,1	Volts
System Min. Voltage	2,5	Volts

2. Select Product

- HS1020-3R8506-R
- HS1025-3R8706-R
- HS1225-3R8127-R
- HS1625-3R8227-R
- HV0810-2R7105-AP
- HV0810-2R7105-R
- HV0820-2R7305-AP
- HV0820-2R7305-R
- HV0830-2R7605-R
- HV1020-2R7505-R
- HV1030-2R7106-R
- HV1245-2R7356-R
- HV1325-2R7156-R
- HV1625-2R7256-R

Calculated Requirements

Energy	1,4	J
	0	Wh
Max Power	0,155	W
Max Current	0,05	Amps

Go To Life Estimator

See the Discharge Curve

Design Capability

Cell Capacitance @EOL	1,89	F
Capacitance per string	0,945	F
Cell ESR @EOL	0,16	ohms
String Resistance	0,32012	ohms
Power per string	7,505	W
Energy per string	1,588	J
Total Energy	1,588	J
Total Power	7,505	W
Vmin, Energy	2,58	V
ESR Drop	0,02	V
Vmin, Dishcarged	2,55	V

3. Supercap Design

	User Input	Recommended Value
Cells in Series	2	2
Cap Derating	0,63	0,63
ESR Derating	2	2
Contact Resistance per	6,00E-05 ohms	
Strings in Parallel	1	1

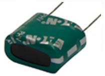
Total # Cells/Packs/Mo 2

2 series x 1 parallel HV0820-2R7305-R

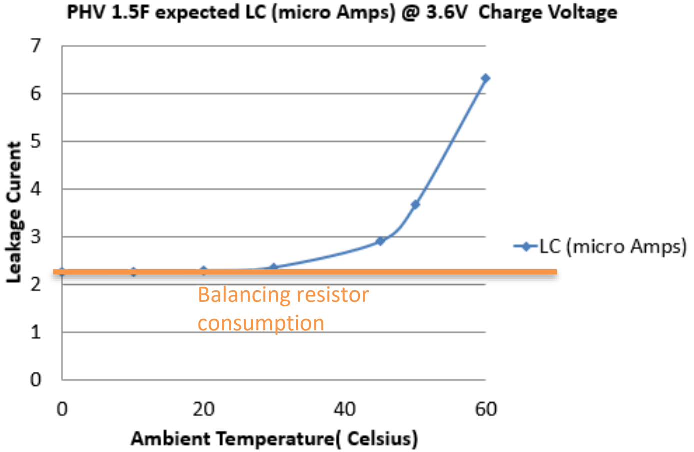
LORA example – supercap energy consumption

Supercap options	Expected continous consumption @ 25C/3.6V	Total consumptio n in 10yrs	Size
2x SC 3F caps with passive balancing	~2mA	175.2Ah	9x17x22mm
2x SC 3F caps with active balancing (opamp comparator)	~3-5uA – depending on the voltage divire and opamp consumption	0.35Ah	9x17x22mm
1x SC 1.5F pack with matched cells and integrated balancing	~2.3uA	0.2Ah	9x17x22mm
1x SC 1.5F low self discharge pack	<1uA	0.088Ah	9x17x22mm
1pc HS 10F hybrid cell	<0.1uA	0.0088Ah	8x14mm





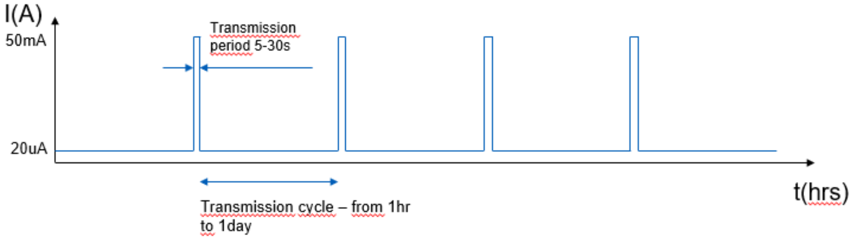
cost



LoRa™

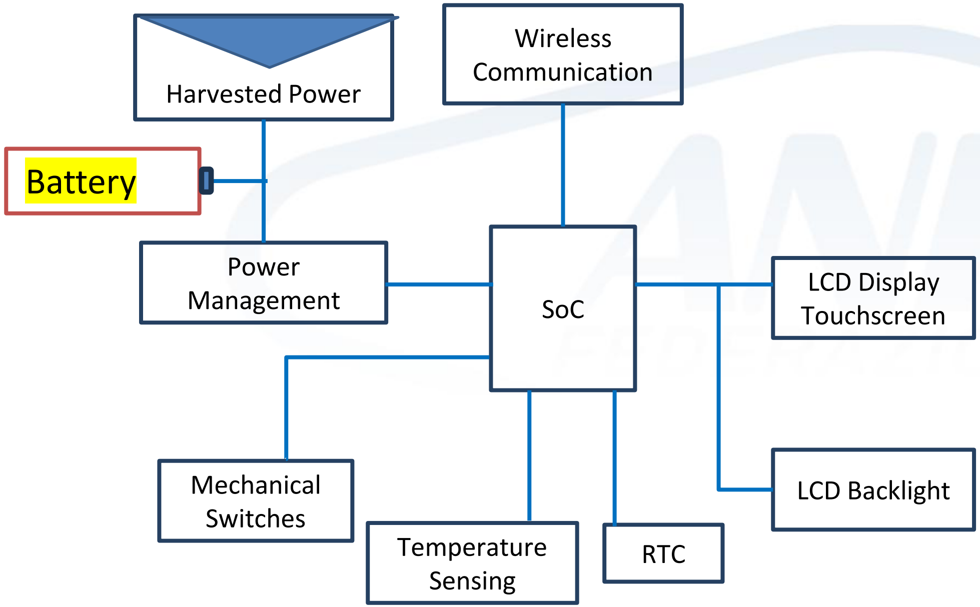
LORA example – 2x per day transmission

Conclusion: in case cold temperatures or higher than 1x daily transmission is required then supercaps provide a cost efficient adder to improve battery lifetime



Transmission frequency + temperature	Required energy storage	Cost
Daily 1x transmission no subzero temperature	1x AA LiSocl 2.6Ah	++
Daily 2x transmission with battery only no subzero temperature	1x A LiSocl 3.7Ah	++++
Daily 2x transmission battery only up to -20C battery only	1x C size 7.7Ah	++++++
Daily 2x transmission battery + supercaps up to -20C (even -40C)	1x AA LiSocl 2.6Ah + SC 1.5F low self discharge or HS 10F hybrid supercap	+++

Harvested Energy Powered Example: Thermostat



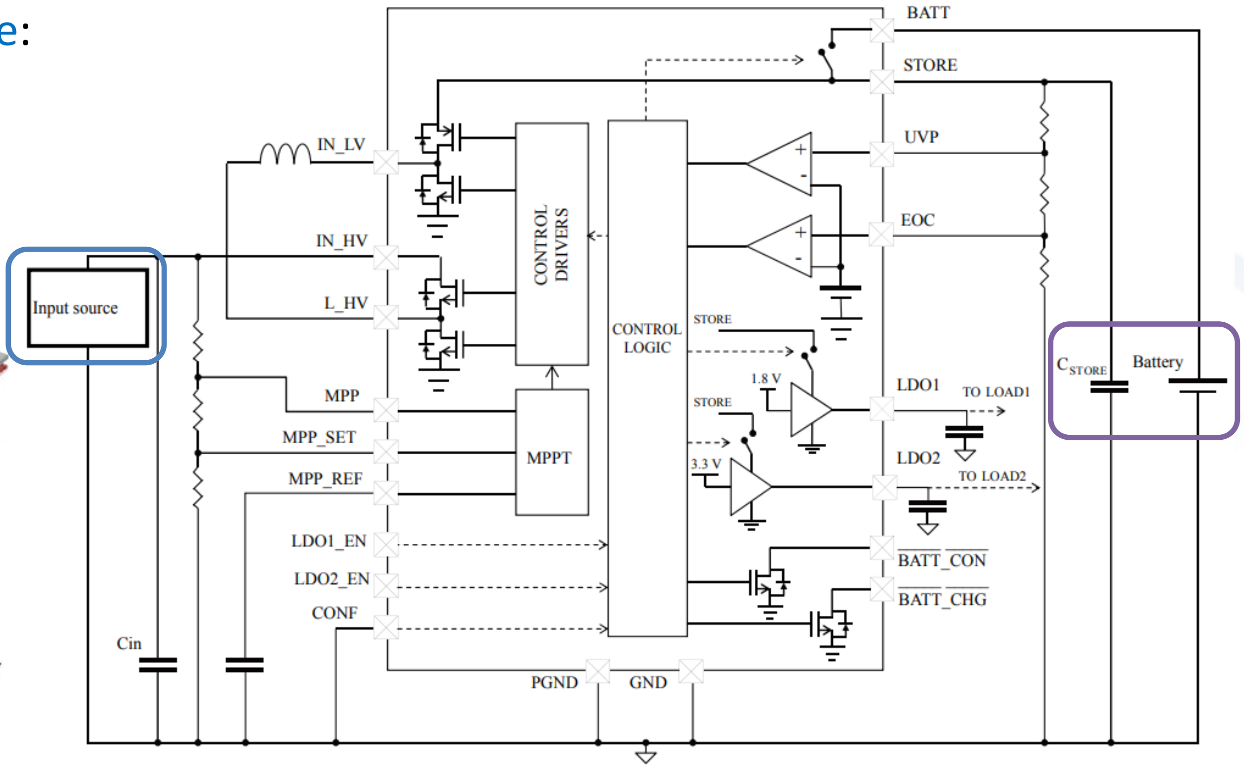
Battery devices needed for:

- Harvested energy storage for overnight power backup
- Boost for mechanical switches, actuators, valves
- RTC/memory backup during off-season/maintanace

IoT Power Circuit With Harvested Energy

Input source:

- Thermal (TEG)
- Thin Film Solar



Storage medium(s):

- Battery
- Supercap
- Or Hybrid Supercap

Considerations For The Storage Medium Selection

1. Energy needed to gap operational/non-operational periods:
   - Factory to installation timing – may be 12months+ requires a full charge (RTC, settings)
   - Off-season (no heating) period – may need to keep RTC and settings for 6months
2. Necessary power for actuators/communication channels:
   - Valves may require Amperes range currents
   - Communication may be only 10mA range
3. Setting the right harvester voltage:
   - Batteries needs higher charge voltages
   - Supercaps and Hybrid SC floats with the voltage
   - Aging to consider especially by TEG
4. Self-discharge of the storage medium:
   - Deep discharge protection may be needed

Emergency Exit Lighting

Application:

- Backup power for exit lights

Power needs:

- 3-10W for 1-3hrs

Battery types:

- NiCd (7.2-14-4V 1-2Ah) – periodic replacement needed (3-5yrs)
- HS (2-4s 400-800F) – maintanance free solution

Fire and Security

Application:

- Smoke/CO/Heat detectors
  - SC: (2s 5-10F) in case of backup
  - HS: (2s 10-30F) in case of harvested
- Call point
  - SC: (2s 10-25F) in case of backup
- Sounder
  - HS: (2s 50-100F) in case of backup
- Central units
  - Normally backed by UPS or own larger battery (PbA)
- Surveillance cameras/system:
  - HS: (2s 200-400F) for backup/overnight power

Access Control

Application:

- eDoor locks main (HS: 20-30F) or boost power (SC: 1-5F)
- Driveline gate openers backup power (SC: 6-12s 400F cells)
- Personal access gates backup (SC: 4-6s 10-25F)

Remote Controls

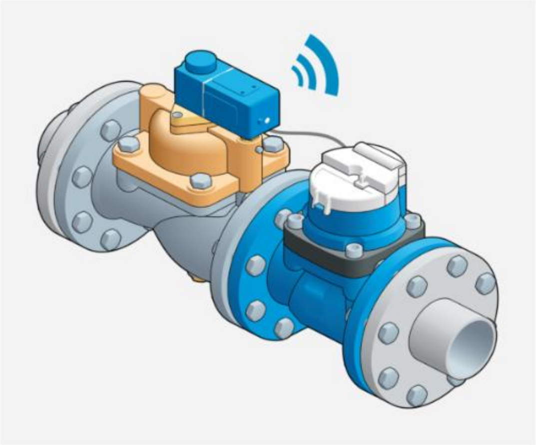
Application:

- TV remote with RF harvesting(HS: 2s 100-200F)
- Window blinds:
    - Remote controller solar (HS: 10-30F)
    - Blind motors mains by solar generation (SC: 6-12s 60-100F, or HS: 4-8s 200F)
- Access remote controllers power while off charger (HS: 50-100F)

Remote Safety Valves/Felts

Application:

- Smart valves/fluid control communication mains/boost power (HS: 10-30F)
- Safety gas valves backup (SC: 4-6s 25-60F)
- Ventillation felts (SC: 4-6s 10-25F)



Summary

Hybrid supercapacitors combine advantages of batteries and supercapacitors in one cell

Backup power and pulse power applications which require discharge times ~1-3 minutes are an ideal fit for the technology

Higher operating voltage reduces system size, in many cases to 1 cell

Capacitance and energy density up to 10 times a traditional supercapacitor

HS and HSL families optimize for different temperature ranges and HSH for higher energy densities

Cycle life continues to be a significant differentiator to batteries