Energy Storage Options

By Tom Davis - KB7HTA

Objective

- To provide a better understanding of energy storage systems and their applications

Energy Density

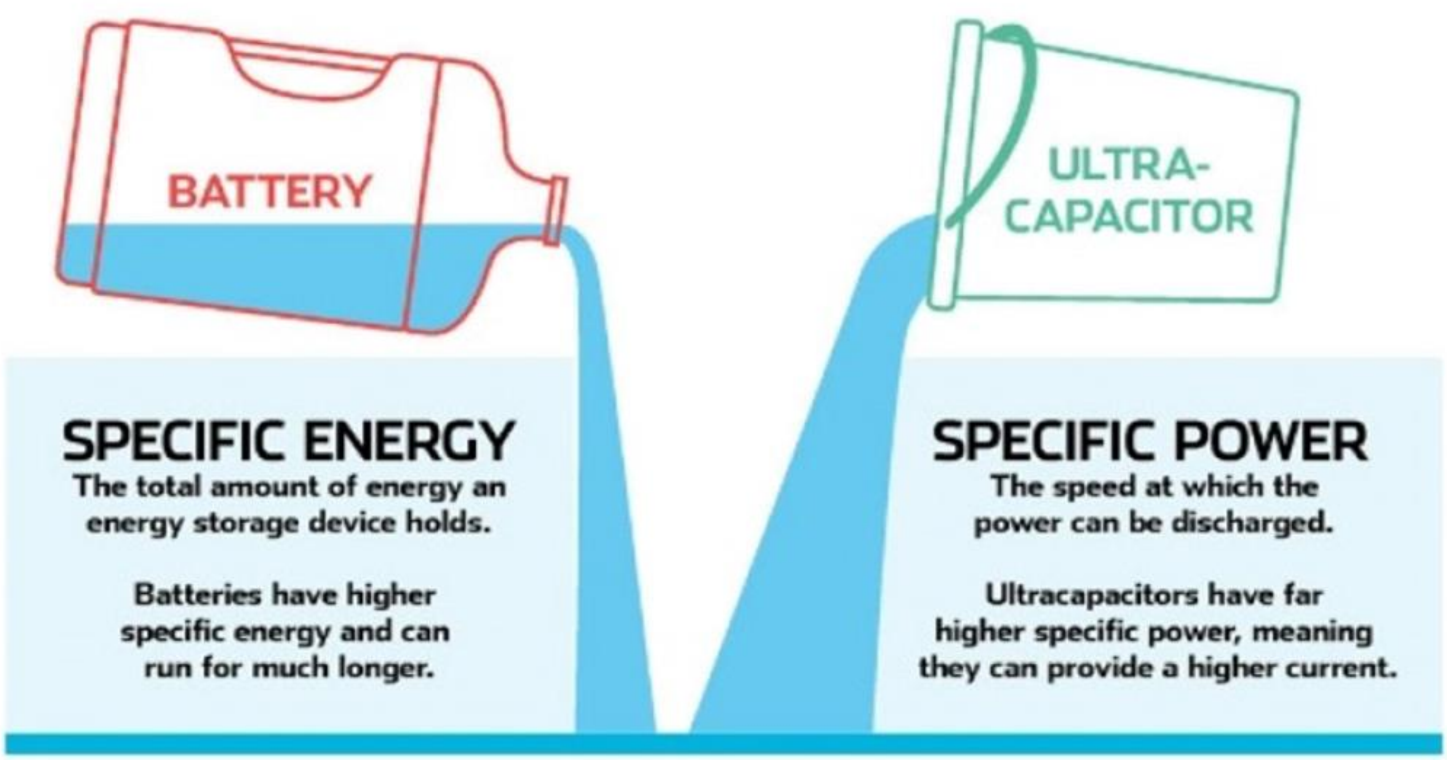
- **Energy density** is the amount of energy that can be stored in a given system, substance, or region of space. Energy density can be measured in energy (Joules) per volume or per mass (Kilogram).

Power Density

- **Power density** is the amount of power (Watts) per unit volume or mass (Kilogram).

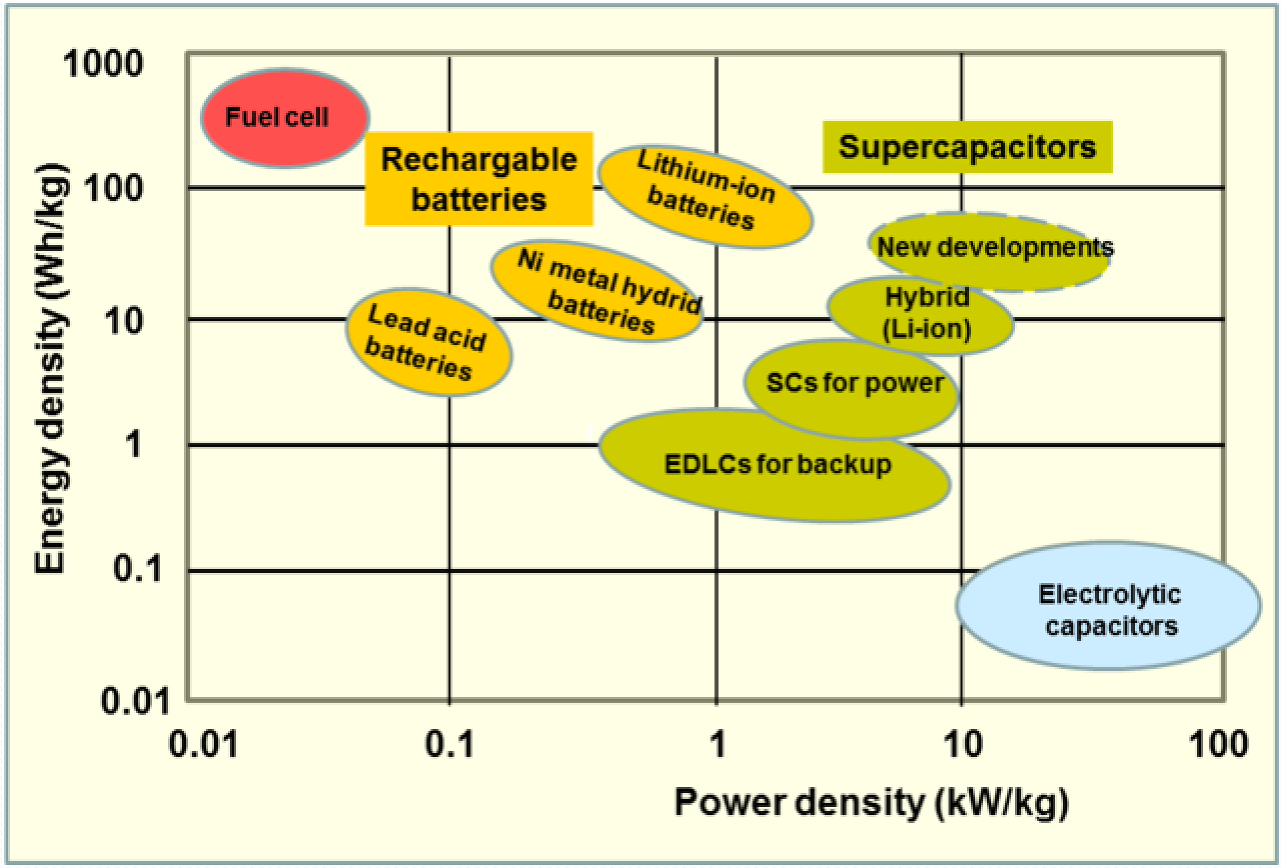
Power Density vs Energy Density

EXHIBIT 3: ‘Energy’ density and Power density comparison between a battery and a Supercapacitor



Source: Skeletontech

Energy Storage Overview



Fuel Cell Battery

Fuel Cell Battery

Advantages

- High energy density improves productivity
- Good reliability- quality of power provided does not degrade over time
- Size reduction- fuel cells are significantly lighter and more compact

Disadvantages

- Expensive to manufacture due the high cost of catalysts (platinum)
- Hydrogen storage, transportation and expense
- Fuel cell efficiency
- Low power density

Nickel Cadmium Battery

Nickel Cadmium Battery

Advantages

- NiCd is relatively inexpensive when compared to newer chemistries.
- NiCd has good specific energy compared to technologies such as lead-acid.
- Good pulse power performance made it the initial chemistry of choice for power tools.

Disadvantages

- Mature technology with little tolerance for overcharging.
- Cadmium is environmentally troublesome.
- Noticeable charging memory effect.

Nickel Metal Hydride Battery

Nickel Metal Hydride Battery

Advantages

- 30 - 40 % higher capacity over a standard Ni-Cd.
- The Nickel Metal Hydride Battery has potential for yet higher energy densities.
- Less prone to memory than the Ni-Cd.
- Periodic exercise cycles are required less often.

Disadvantages

- NiMH generates more heat during charge and requires a longer charge time than the NiCd
- The trickle charge is critical and must be controlled carefully
- High self-discharge — the NiMH has about 50 percent higher self-discharge compared to the NiCd.

Lead Acid Battery

Lead Acid Battery

Advantages

- Mature technology
- Relatively cheap to manufacture and buy
- Large current capability
- Can be made for a variety of applications
- Tolerant to abuse
- Tolerant of overcharging

Disadvantages

- Fails after a few years use lifespan typically 300 - 500 cycles
- Cannot always be used in a variety of orientations
- Corrosive electrolyte
- Lead is not environmentally friendly

Lithium Iron Phosphate

Lithium Iron Phosphate Battery

Advantages

- Less degradation and long life
- No harm to the environment
- Compact size and lightweight
- High safety and efficiency

Disadvantages

- These batteries have a low nominal voltage that reduces energy
- You have to face balancing issues with aging, and they are a high self-discharging rate compared to other batteries
- Lithium iron phosphate/ LFP batteries have a low energy density compared to Li Ion, and more protection is required
- These batteries don’t perform well at low temperatures and need more protection and care

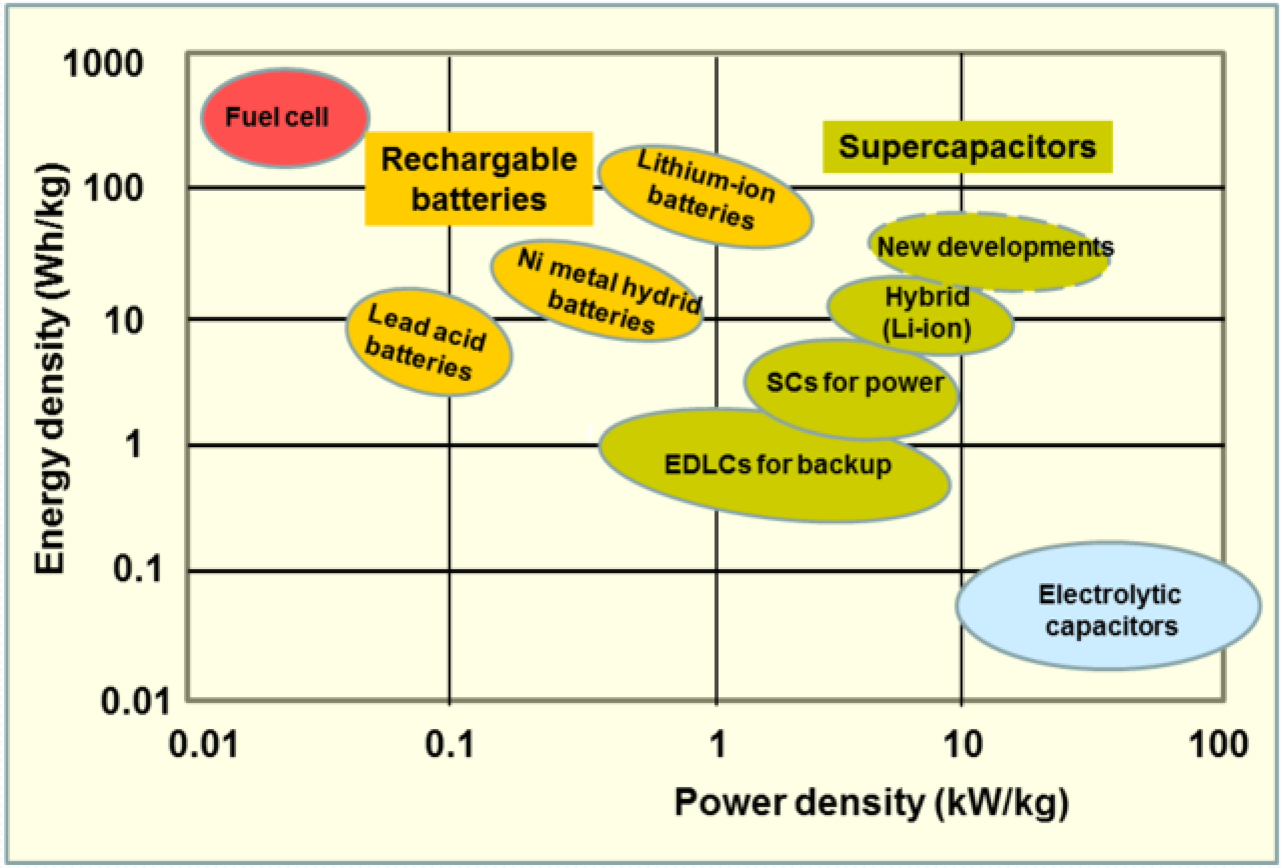
Super Capacitor Battery

Supercapacitor Battery

Advantages

- High power density
- Extremely long cycle life – 20,000 to 1,000,000+
- Fast charge and discharge
- Good safety performance, no pollution, and no memory effect
- **Disadvantages**
- Need over-charge, over-discharge and balance protection
- Amount of energy stored per unit mass is lower compared to electrochemical battery
- Individual cells have low voltages. Hence series connections are required in order to achieve higher voltages

Energy Storage Discussion



Energy Storage Discussion

Supercapacitor vs Lithium Ion

Experimentation with Supercapacitors – The above is a comparison between a 3.8 V Lithium Ion 18650 battery and a 4000 Farad, 4.2 V Super Capacitor.

Lead Acid Battery Go-Box

LithiumFePO4 Battery Go-Box

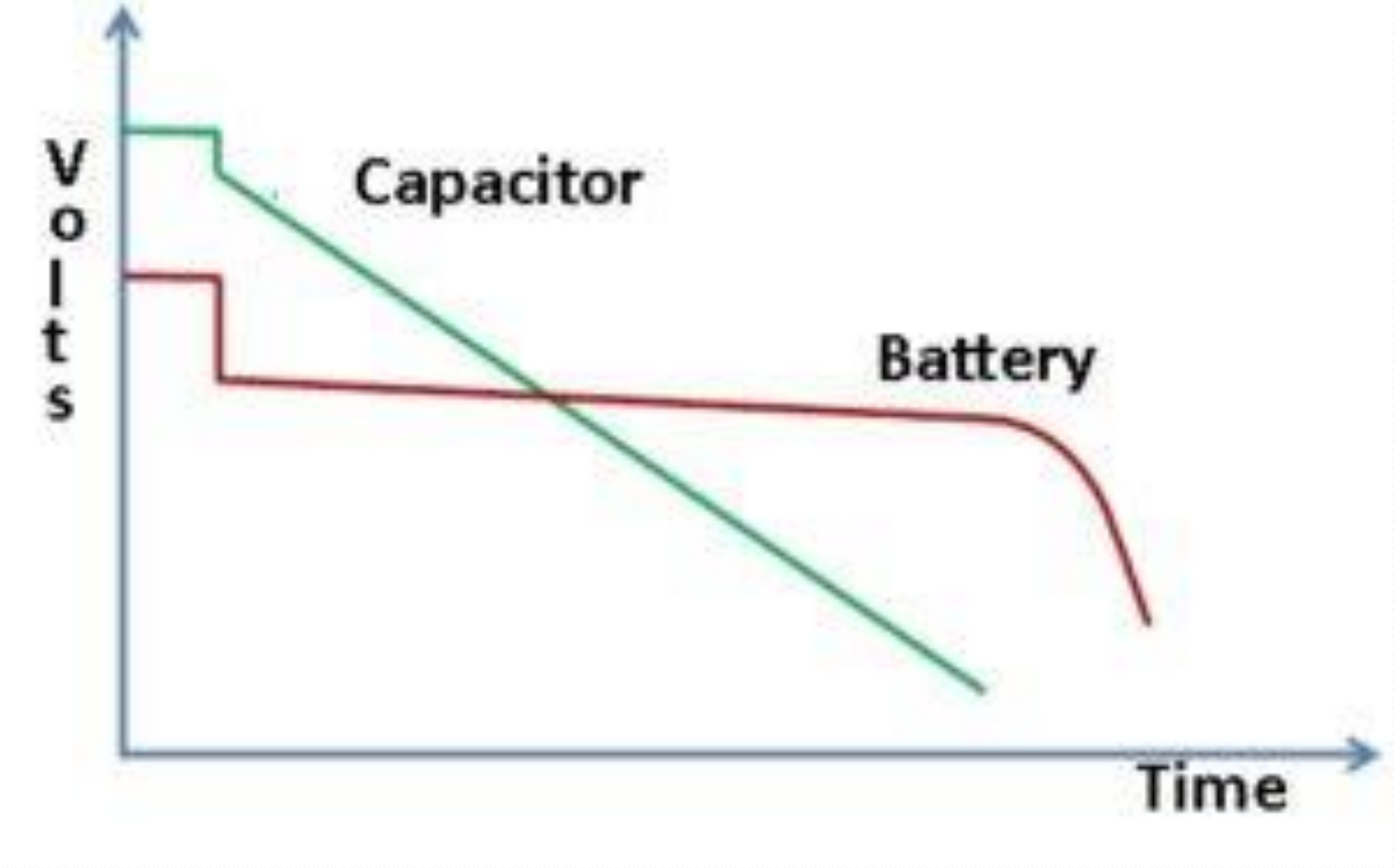
Super Capacitor Battery Go-Box

LithiumFePO4 vs. Supercapacitor

Function	Typical Lithium-ion battery	Supercapacitor	Comments
Charge time	Minutes (Double digits)	Seconds	Supercapacitors charge and discharge faster
Lifetime	Short	Long	Supercapacitors can be used many times and have a longer life
Reliability	Some maintenance required	Maintenance free and reliable	Supercapacitors are more reliable
Specific Energy (Wh/kg)	Very high	Low	Batteries can hold more charge and energy over a longer period
Specific Power (W/kg)	Low	High	Supercapacitors can provide a lot of power quickly
Current cost per kWh	Low	High	Batteries lower cost at this time
Range of charge/discharge temperatures	Poor/Limited	Good/Wide Range	Supercapacitors will work in a wider range of temperatures, including very cold climates
Over-charging and safety issues	Potential issues	Draws charge only as needed.	Supercapacitors potentially safer with a lower risk of issues such as thermal runaway
Environmental impact	Often contain lithium, cobalt and other materials	Often carbon-based materials and non-toxic	Supercapacitors said to be greener in terms of disposal

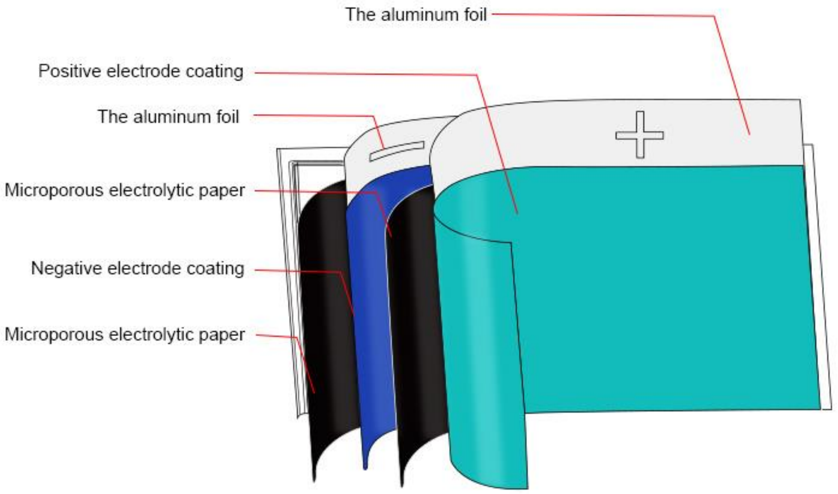
Basic comparison of batteries vs supercapacitors

LithiumFePO4 vs. Supercapacitor

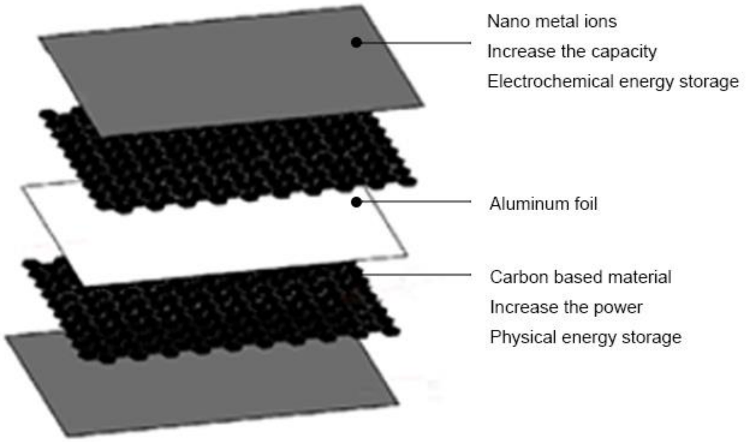


Supercapacitor Construction

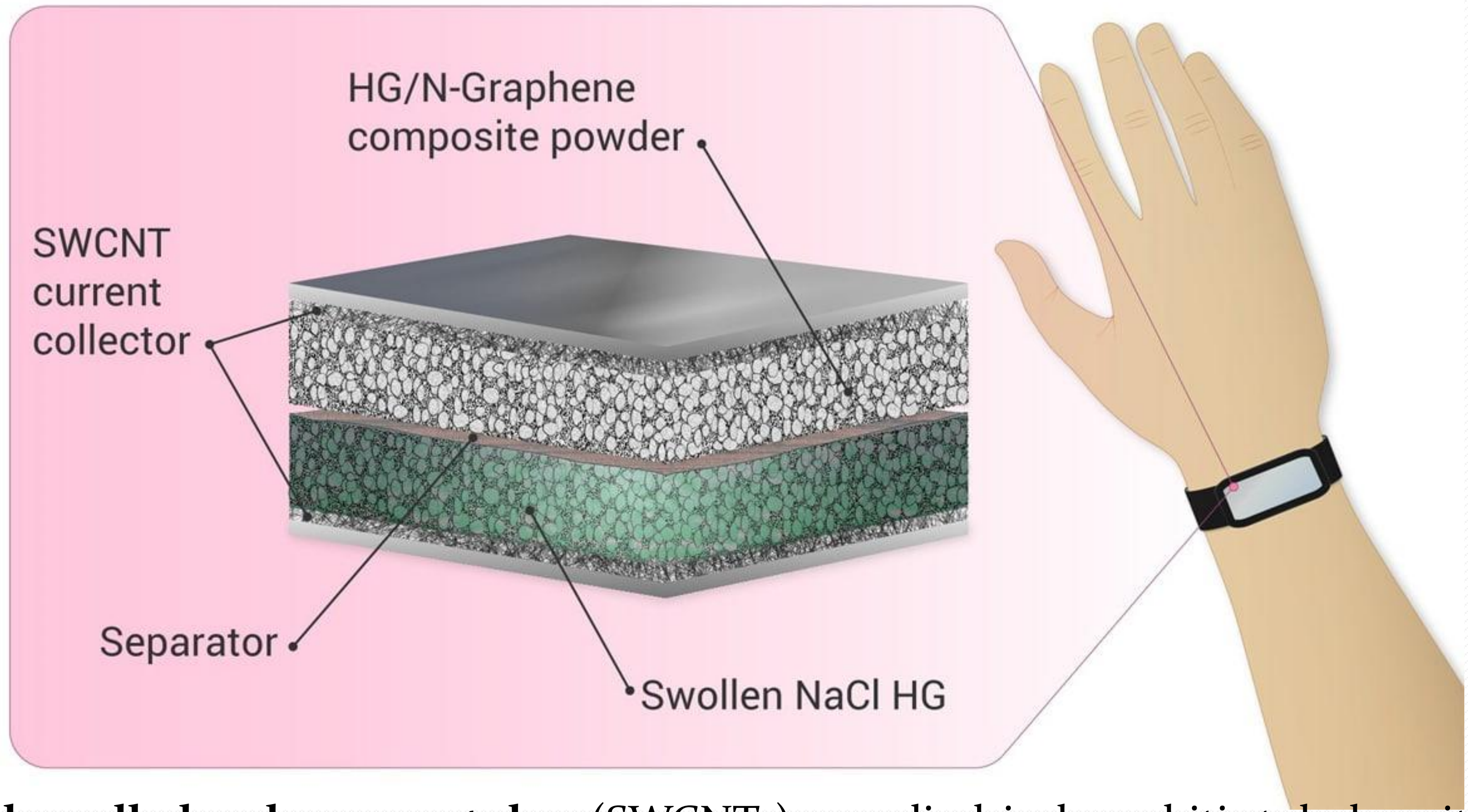
Schematic diagram of ultracapacitor principle



Polar decomposition diagram

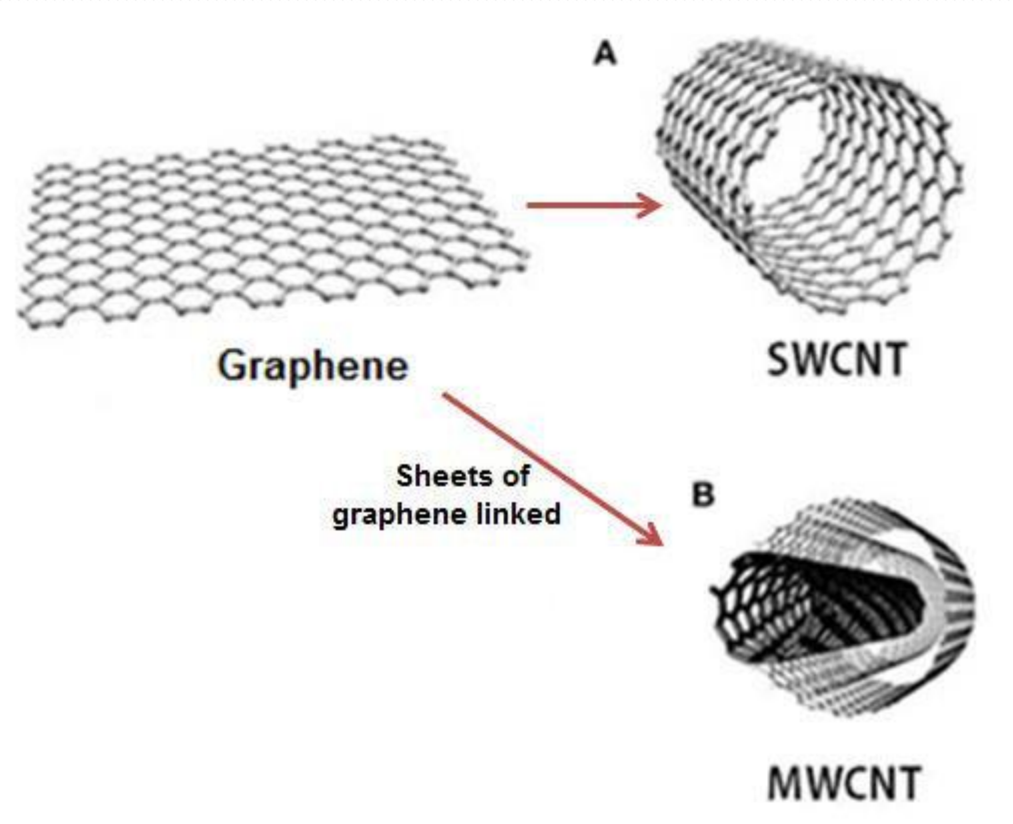


Supercapacitor Construction



Single-walled carbon nanotubes (SWCNTs) are cylindrical graphitic tubules with diameters of approximately 1.0 nm, and they have a variety of electronic properties that depend on how the graphene sheet is rolled, which is referred to as chirality

Supercapacitor Construction



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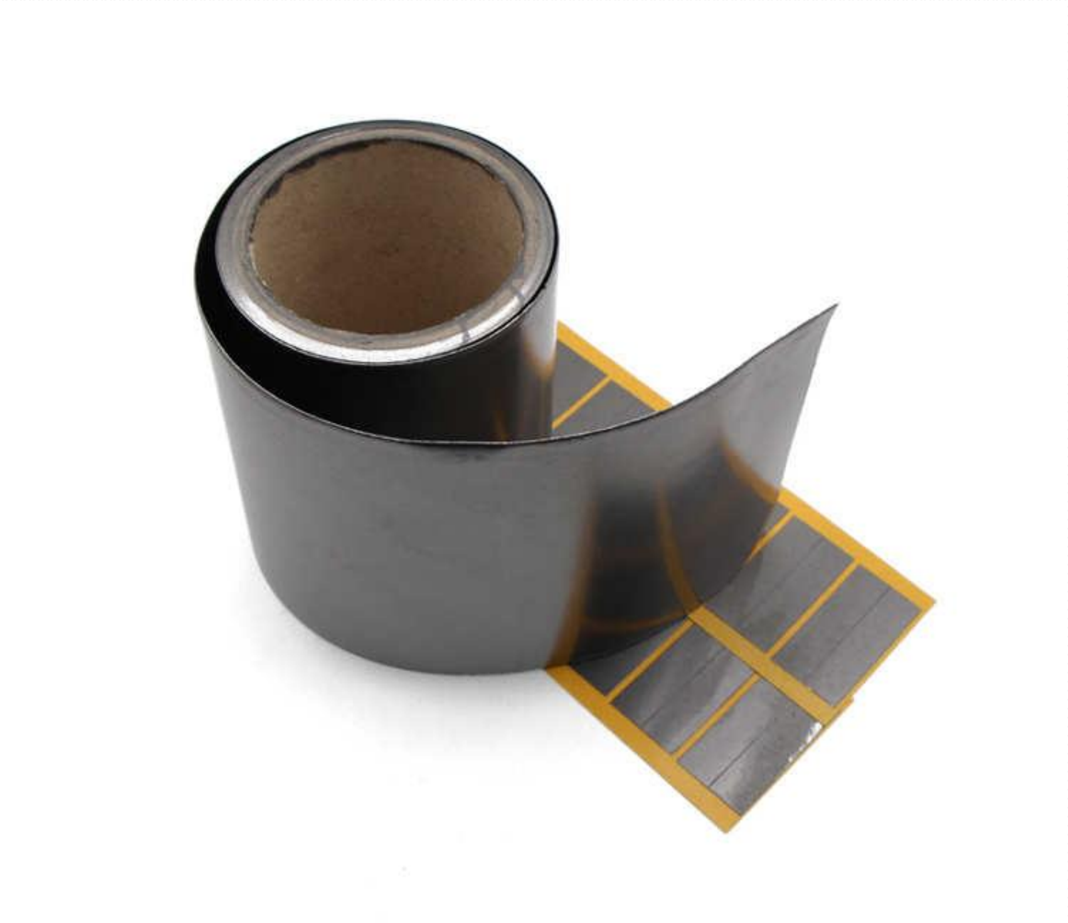
Supercapacitor Construction



Graphene Sheet – Highly conductive with a thickness of 35 um.

Supercapacitor Construction

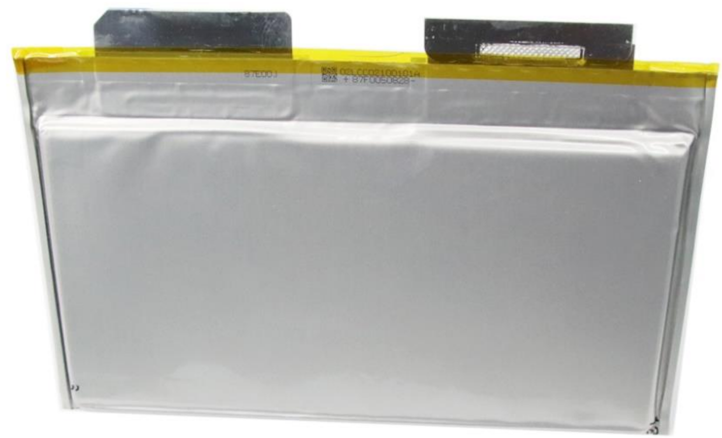
Graphene Powder – Highly conductive powder.

Supercapacitor Examples

Demonstration

Examples of Supercapacitors – On the left is an example of older supercapacitors, 500 Farad at 2.7 V and on the right is a newer ultra-capacitor, 5000 Farad at 2.7 V.

Supercapacitor Examples



Size: 60 x 138 mm   Mass: 810 g

Size: 220 x 128 x 7.5 mm
Mass: 980 g

Examples of Ultracapacitors – On the left is an example of an Ultracapacitor 100,000 Farad at 2.7 V and on the right is a 120,000 Farad at 2.7 V capacitor. These have a typical ESR of ~1 mOhm and a continuous current of 28 A with a stored energy of ~ 60 - 75 WH. They have a working temperature of -40° to 70° C

Supercapacitor Examples

Advantages

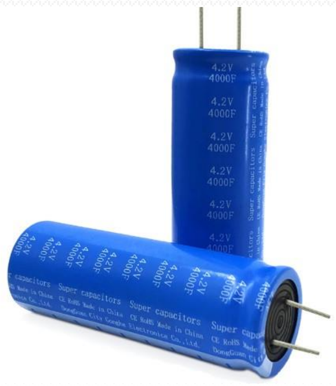
- 3.8 V operating voltage
- Low ESR for high power density
- Up to 8 times energy vs supercapacitors
- Low self-discharge to use with batteries

Applications

- Industrial backup/ride through
- Backup for storage servers
- Water and gas smart meters
- IoT energy storage
- Medical backup power/alarm
- Commercial trucks/containers asset tracking

Hybrid Cylindrical Cells (Eaton) – These are 220 Farad at 3.8 V, which makes them work well in tandem with LiFePO4 batteries like a 18650 cell. They have a maximum Voltage of 4.0 V and a minimum voltage of 2.2 V.

Supercapacitor Examples



MODEL NUMBER:	C424000R
PLACE OF ORIGIN:	GUANGDONG,CN
TERMINAL:	RADIAL/PIN
WORKING TEMPERATURE:	FROM -40 TO +70
ESR:	45mΩ
LEAKAGE CURRENT:	≤0.5 mA
CHARGING AND DISCHARGING TIME:	MORE THAN 20,000 TIMES
NORMAL CURRENT:	3 A
STORED ENERGY:	15 WH
MAXIMUM CONTINUOUS CURRENT:	6 A
MAXIMUM PEAK CURRENT:	30 A
MOQ:	24PCS
SPECIFICATION:	4.2V4000F
SIZE:	D24*69MM
WEIGHT:	70 G
WARRANTY TIME:	3 YEARS
COLOUR:	BLUE OR As Customized
APPLICATION:	Heavy industry equipment Vehicle system Fan pitch system hybrid car Rail UPS and telecommunication systems High impact and vibration environment

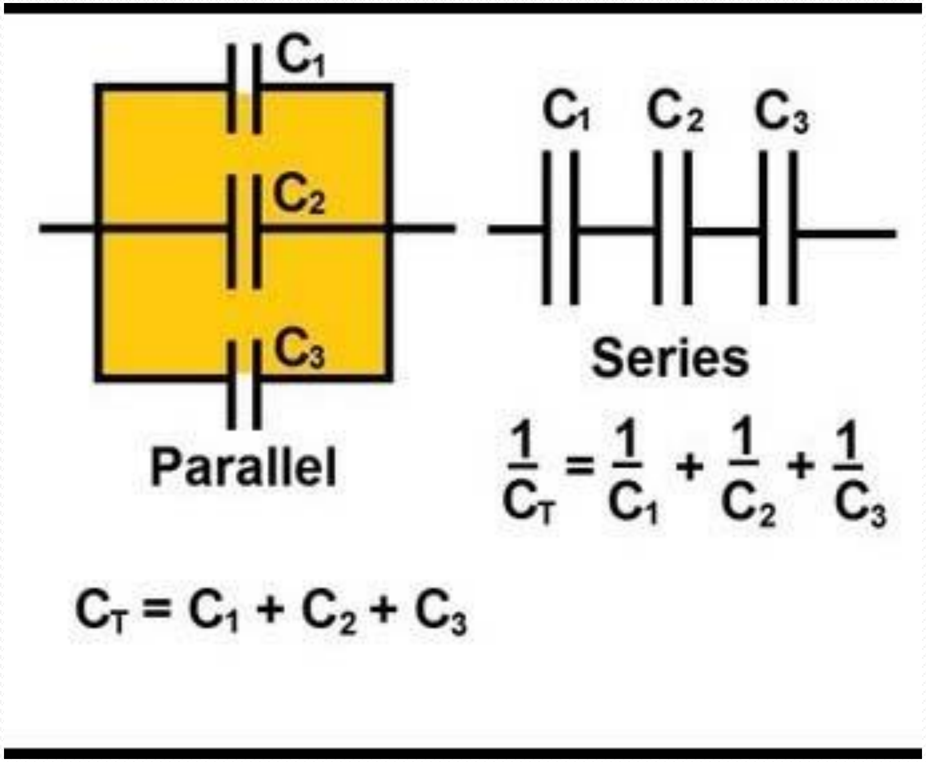
Reading the Specifications – Even though the voltage (4.2 V) and capacitance (4000 F) are important, check the remaining specifications to see if it meets your requirements.

Supercapacitor Examples

Product Name	GH 16V 16800F Moudle
Rated Capacitance	16800F
Energy Storage	360Wh
Capacitance Range	16000F-18000F
Rated Voltage	16V
Surge Voltage	17.1V
Internal Resistance(AC)	≤ 0.6 mOhm
Maximum Continous Current	150A
25℃ Leakage Current	15mA
Maximum Peak Current	1000A
Operating Temperature Range	minus 40 to plus 65 ℃
Storage Temperature Range	minus 40 to plus 70 ℃
Cycle Life	≥100,000
Product Weight:	IP65
PRODUCT WEIGHT:	7.5kg
Product Size ±5mm	220*132*185mm
Warranty Time	5 years

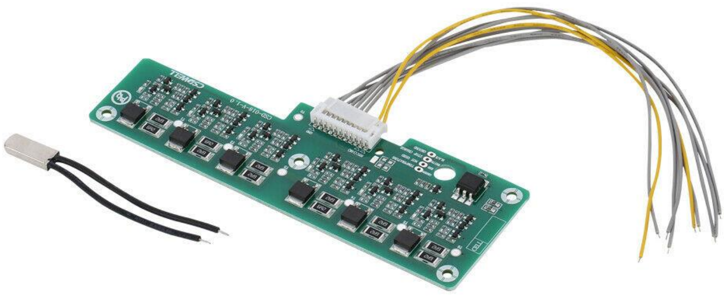
Supercapacitor Battery Specifications– The battery is rated at 16 Volts and a maximum continuous current of 150 Amps. Some calculations give this battery a Energy density of ~50-80 Wh/Kg that places it at the lower end of the Lithium range.

Supercapacitor Math



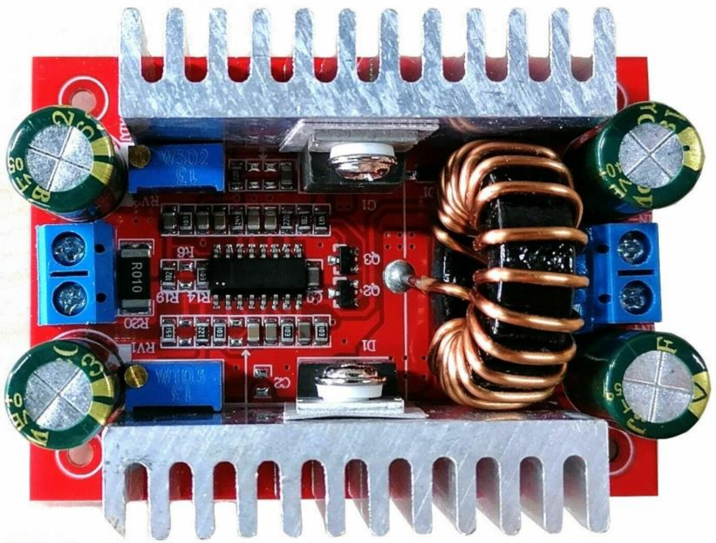
OK, so you want higher voltages for your battery pack – To get higher voltages, you will need to put multiple supercapacitors in series. For example, if you want a 12 Volt battery you will need to have at least 5, with 6 being the most common choice to give 16.2 Volts. This makes the capacitor battery compatible with Lithium batteries and allows it to be well below capacitor specifications. Example: 1/C = 1/500 + 1/500 + 1/500 + 1/500 = 125F at a voltage of, 4 x 2.7 = 10.8 V.

Supercapacitor Protection



Protection and balancing circuit for supercapacitors – These are used, when placing multiple capacitors in series. Protection board Reverse Engineering Part 1 and Reverse Engineering Part 2

Supercapacitor Linear Output

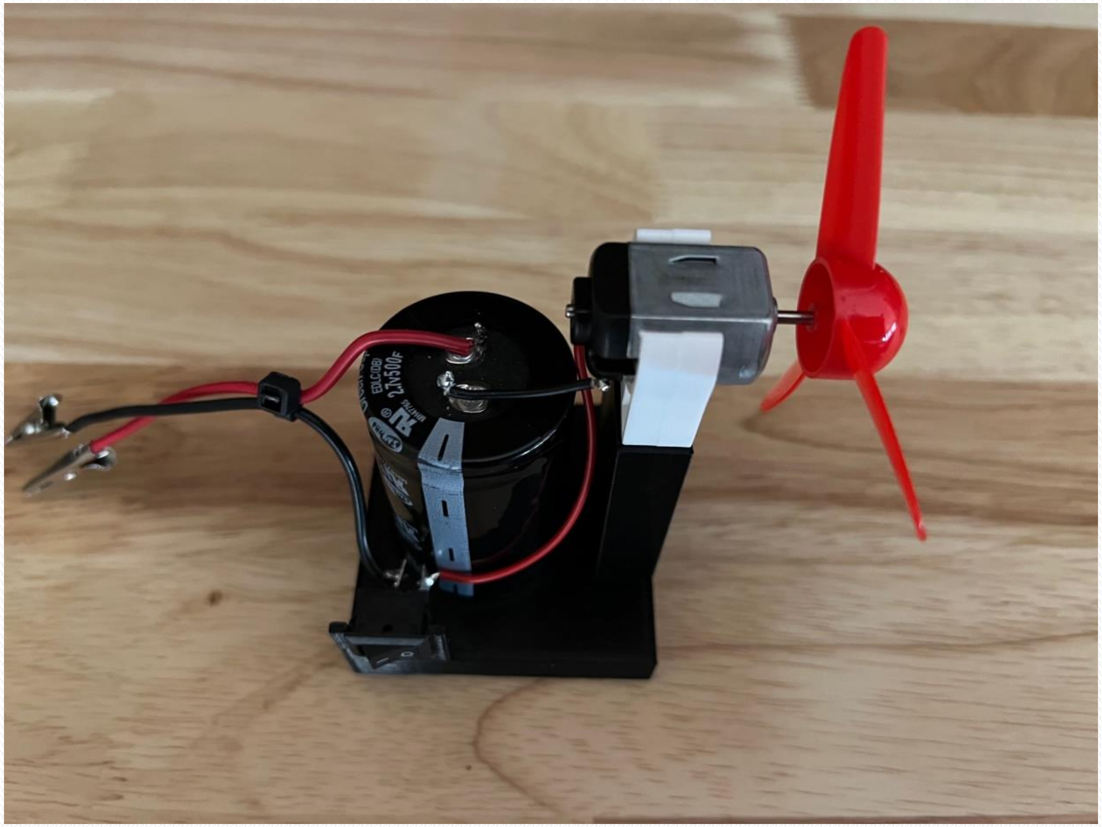


DC to DC Boost Converters for supercapacitors – These are used, when a constant output voltage and/or current is required.

Supercapacitor Math

Capacitor Discharge Time Calculator			
Enter Initial Values	Supercapacitor discharge time calculator		
Vcapmax:	2.7000	Volts	
Vcapmin	1.0000	Volts	
Capacitor Size	500.0000	Farads	
Capacitor ESR	0.1000	Ohms	
Imax	0.6000	Amps	
Calculated			
Resistive Load	4.5000	Ohms	= Vo/Imax
Time - Resistive Load	2284.4791	Seconds	= ln(Vo/V)*(Resr + R)*C
Time - Constant Current	1416.6667	Seconds	= (Vo - V)*C/Imax
Stored Energy	0.4368	W/Hours	= 0.5*(Vo^2 - V^2)*C/3600
Peak Power	18.2250	Watts	= Vo^2/4*ESR
Peak Current	16.6667	Amps	= (Vo-V)*C/(1+ESR*C)

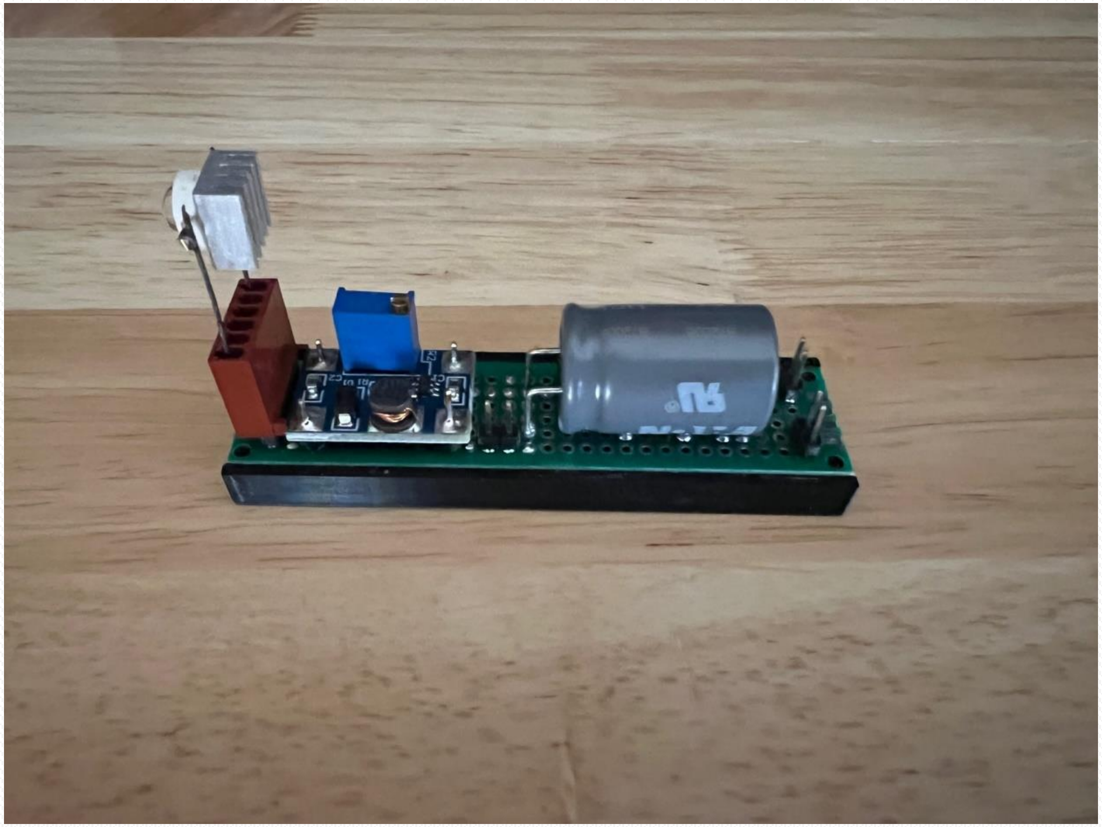
Supercapacitor Experiments



<u>Demonstration</u>

Experimentation with Supercapacitors – This is a test of a 500 Farad, 2.7 V supercapacitor connected to a toy motor with a propeller.

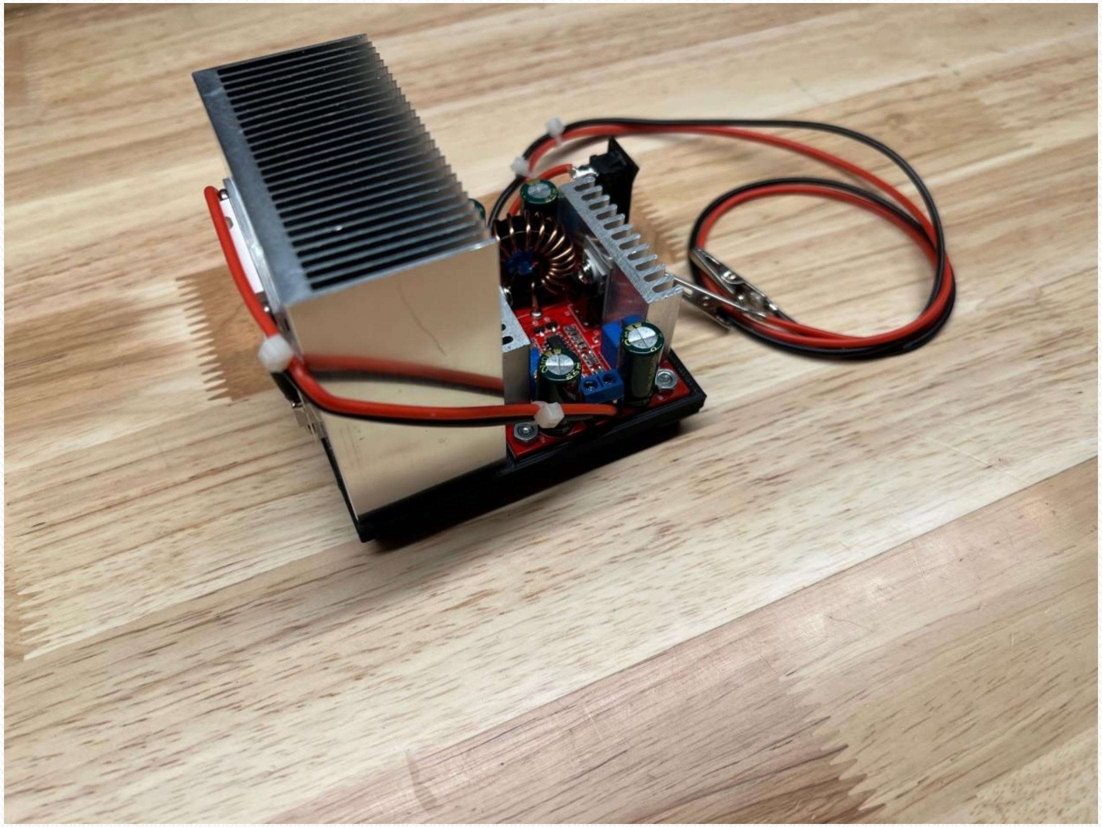
Supercapacitor Experiments



Demonstration

Experimentation with Supercapacitors – This is a test of a 220 Farad, 3.8 V hybrid supercapacitor. The circuit board contains a hybrid capacitor, DC-DC Boost converter and a 3 W LED.

Supercapacitor Experiments



Demonstration

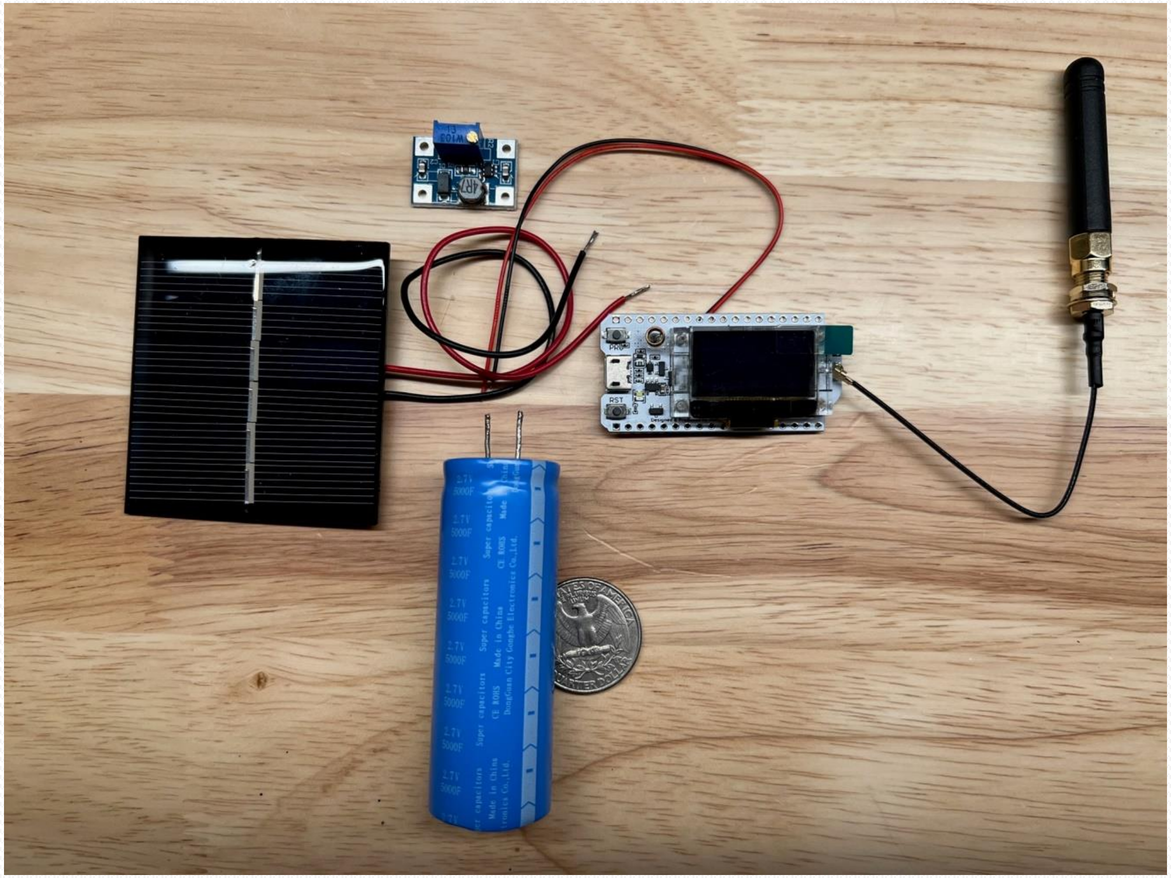
Experimentation with Supercapacitors – This is a test of a 583 Farad, 16 V Ultracapacitor battery. The circuit board contains a 20 watt LED and a DC-DC boost converter. The DC-DC(8-50V)converter is a solution for the linear discharge of a battery.

Supercapacitor Experiments

<u>Demonstration</u>

Experimentation with Supercapacitors – This is a test of a 583 Farad, 16.2 V Supercapacitor and 2P3S Lithium 18650 battery pack.

Supercapacitor Powered Equipment



Experimentation with Supercapacitors – The above components in conjunction with Meshtastic firmware could be used as a remote LoRa node for the relay of text traffic, GPS information and/or sensor data.

Supercapacitor Powered Equipment

Experimentation with Supercapacitors – With the above components you can construct your own Energy Storage Module.

Supercapacitor Powered Equipment

Description	Cost
Super Capacitor – 4000 Farad @ 4.2 Volts	$14.00
USB Lithium Ion 18650 Battery Charger PCB	$3.00
DC – DC Boost Converter PCB	$4.00
Type A Female USB to DIP 2.54mm PCB Board Adapter	$1.50
650nm 6mm 5V 5mW Red Laser Dot Diode Module Brass Head	$1.50
DC Power Pigtail Wire w/Plug 18AWG 2.1mm x 5.5mm Male/Female	$2.50
3D Printed Case(s)	$15.00
Total	$41.50
Cost per Kit	$40.00

Experimentation with Supercapacitors – The above table lists the components and cost to build a small scale Energy Storage Module with accessories.

Links

- Supercapacitor discharge time calculator
- KB7HTA Supercapacitor discharge time calculator
- Energy storage by the Farad, Part 1
- Energy storage by the Farad, Part 2
- Make Your Own Supercapacitor
- How to use supercapacitors

Energy Storage Options Presentation