TAS Astro
Energy Storage

Marc Sabathé

December 2021

DEFENCE AND SPACE

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Agenda

8:30 – 9:00	**Energy Storage** – Different Energy storage mode
9:30 – 9:45:	**Coffee break**
9:45 – 10:45:	**Storage Cell** – Kind of cells – Li-Ion Cells
10:45 – 11:00:	**Coffee break**
11:00 – 12:00:	**Batteries** – Cells in batteries – Management

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About the presenter

- **Marc Sabathé**
  Responsible of Battery Assembly Line

- **Experience:**
  - Chloride energy
  - Realix
  - Airbus Defence & Space
    - Electrical Lab Test
    - Batteries Tests
    - Batteries Design & Qualification

- **Education:**
  - DESS Electronique de Puissance (ENSEEIHT)

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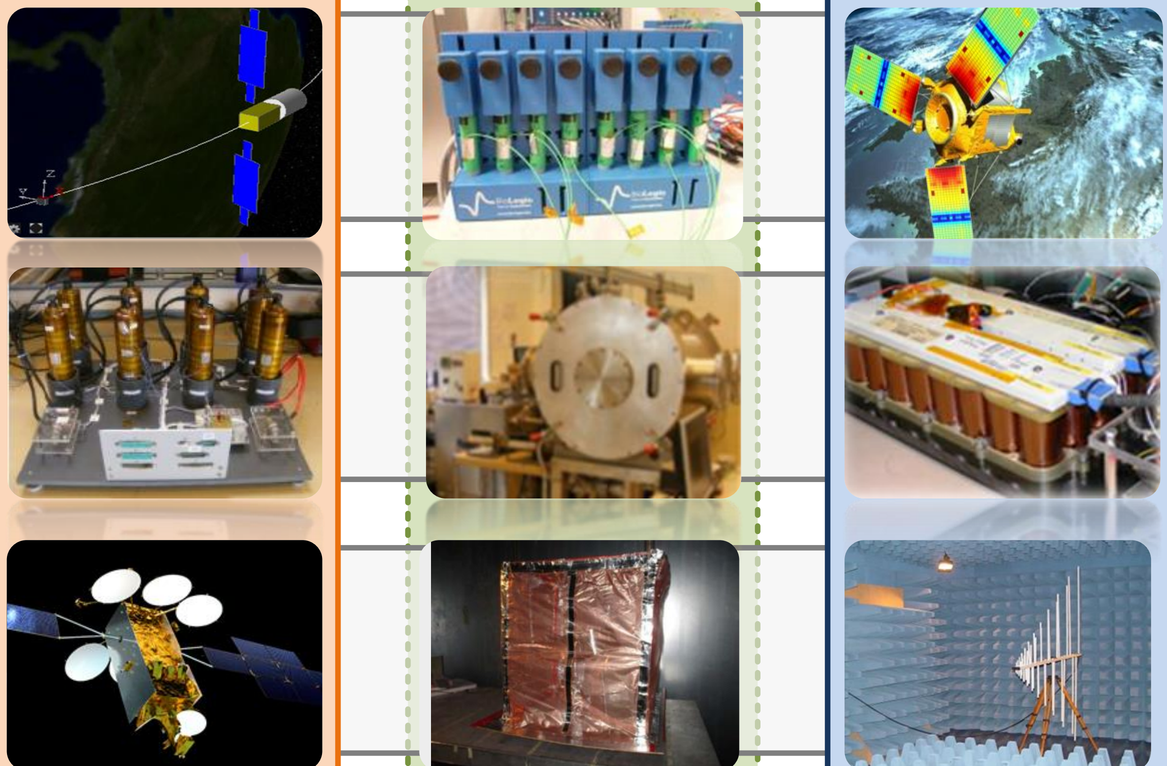
Electrical Engineering Department presentation

ELECTRICAL ENGINEERING DEPARTMENT

	TELECOM & SS	R&T	ENS & Intruments
Electrical, Power & Harness			
Electrical Laboratory			
Radio Frequency & Electro Magnetic Compatibiity			



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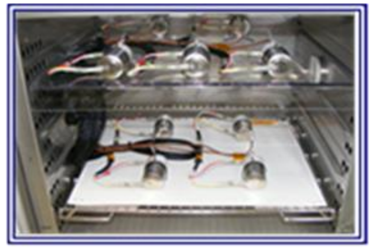
Electrical Engineering Department presentation

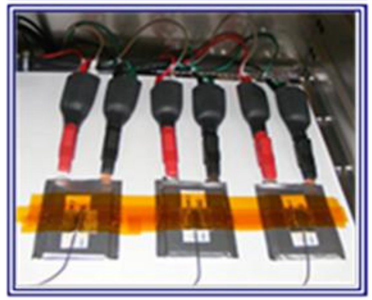
What do we do?

- Batteries and Solar Cells benchmarking
- New technologies characterisation and tests
- Electrical Analysis and tests (PPS, LCL…)
- Power and Energy Simulations and tests
- EMC analysis and tests
- RF Link budgets

What tools do we use?

- Laboratory Test
- Power Systema
- Pspice
- Matlab
- Engineering Base
- CST
- SPIS
- Systema GTD
- Spaceclaim





Accronyms

AC	Alternating Current	GEO	Geostationary Earth Orbit
AM	Air Mass	GTO	Geostationary Transfer Orbit
ANLH	Ascending Node Local Hour	HiEta	High Efficiency
AOCS	Attitude and Orbit Control System	Im	Current at maximum power
APU	Auxiliary Power Unit	Isc	Short Circuit Current
ARC	Anti-Reflective Coating	ISS	International Space Station
aSi	Amorphous Silicon	JPL	Jet Propulsion Laboratory
AU	Astronomical Unit	LEO	Low Earh Orbit
BCR	Battery Charge Regulator	Li-ion	Lithium Ion
BDR	Battery Discharge Regulator	LILT	Low Intensity Low Temperature
BOE	Beginning Of Eclipse	LISN	Line Impedance Simulation Network
BOL	Beginning Of Life	MEO	Medium Earth Orbit
BSF	Back Surface Field	NiCd	Nickel Cadmium
BSFR	Back Surface Field and Reflector	NiH2	Nickel Hydrogen
BSR	Back Surface Reflector	PCB	Printed Circuit Board
CE	Conducted Emission	Pmax	Maximum Power
CFRP	Carbon Fibre Reinforced Plastic	PSA	Part Stress Analysis
CS	Conducted Susceptibility	PWM	Pulse Width Modulation
CV	Converter	RTG	Radioisotopic Thermal Generator
DC	Direct Current	S3R	Sequential Switching Shunt (or Series) Regulator
DJ	Double Junction	SA	Solar Array
DOD	Depth Of Discharge	SADM	Solar Array Drive Mechanism
EMC	ElectroMgnatic Compatibility	SCA	Solar Cell Assembly
EOC	End Of Charge	Si	Silicon
EOD	End Of Discharge	SOA	Safe Operating Area
EOE	End Of Eclipse	SOC	State Of Charge
EOL	End Of Life	SSO	Sun Synchronous Orbit
EPS	Electrical Power System	SSPC	Solid State Power Controler
ESD	ElectroStatic Discharge	TJ	Triple Junction
FET	Field Effect Transistor	UVD	Under Voltage Detection
FF	Fill Factor	Vm	Voltage at maximum power
GaAs	Gallium Arsenide	Voc	Open Circuit Voltage

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Storage Energy Types

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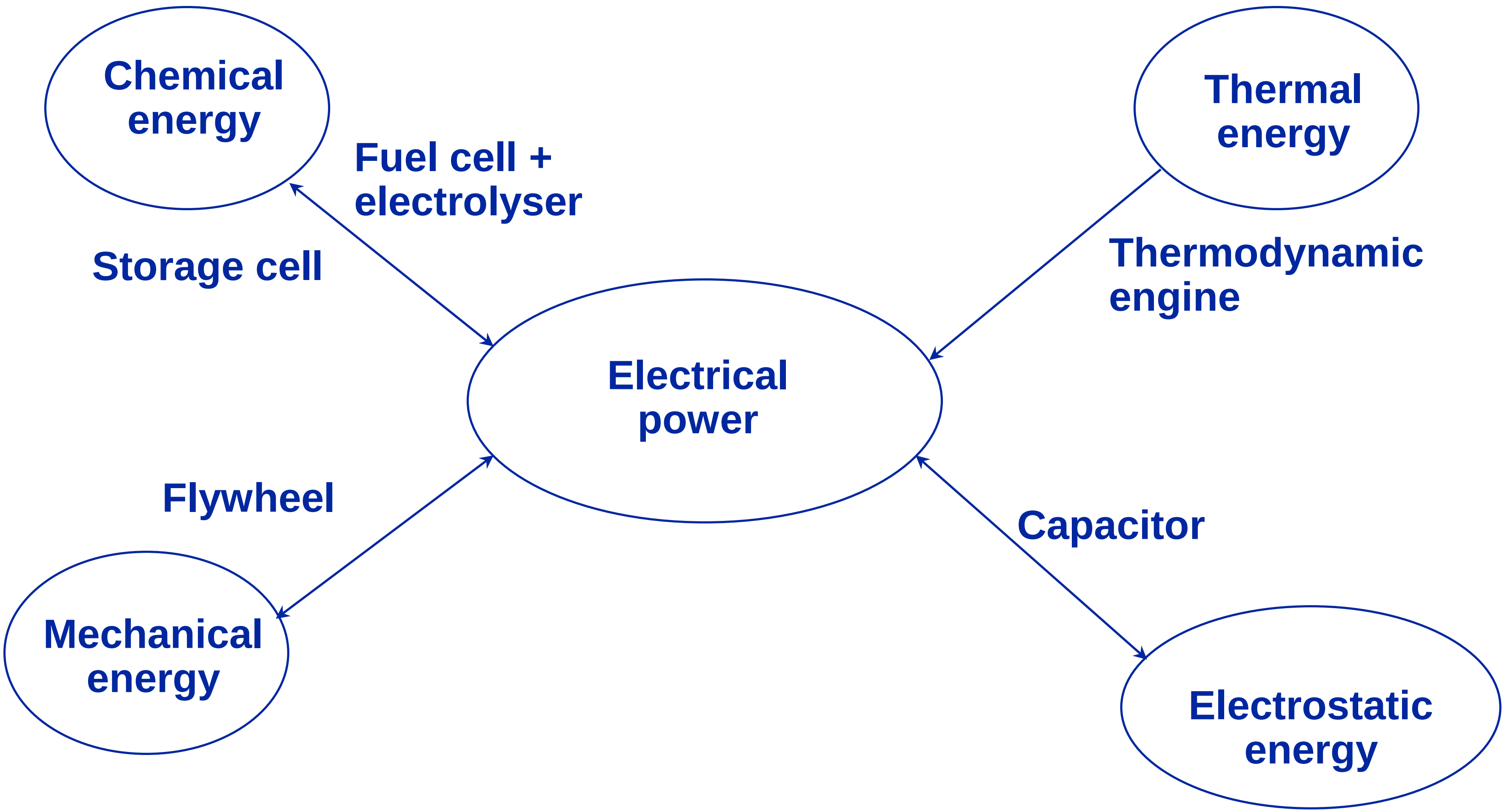
ENERGY STORAGE (1)

Storage energy types



Thermal Energy storage

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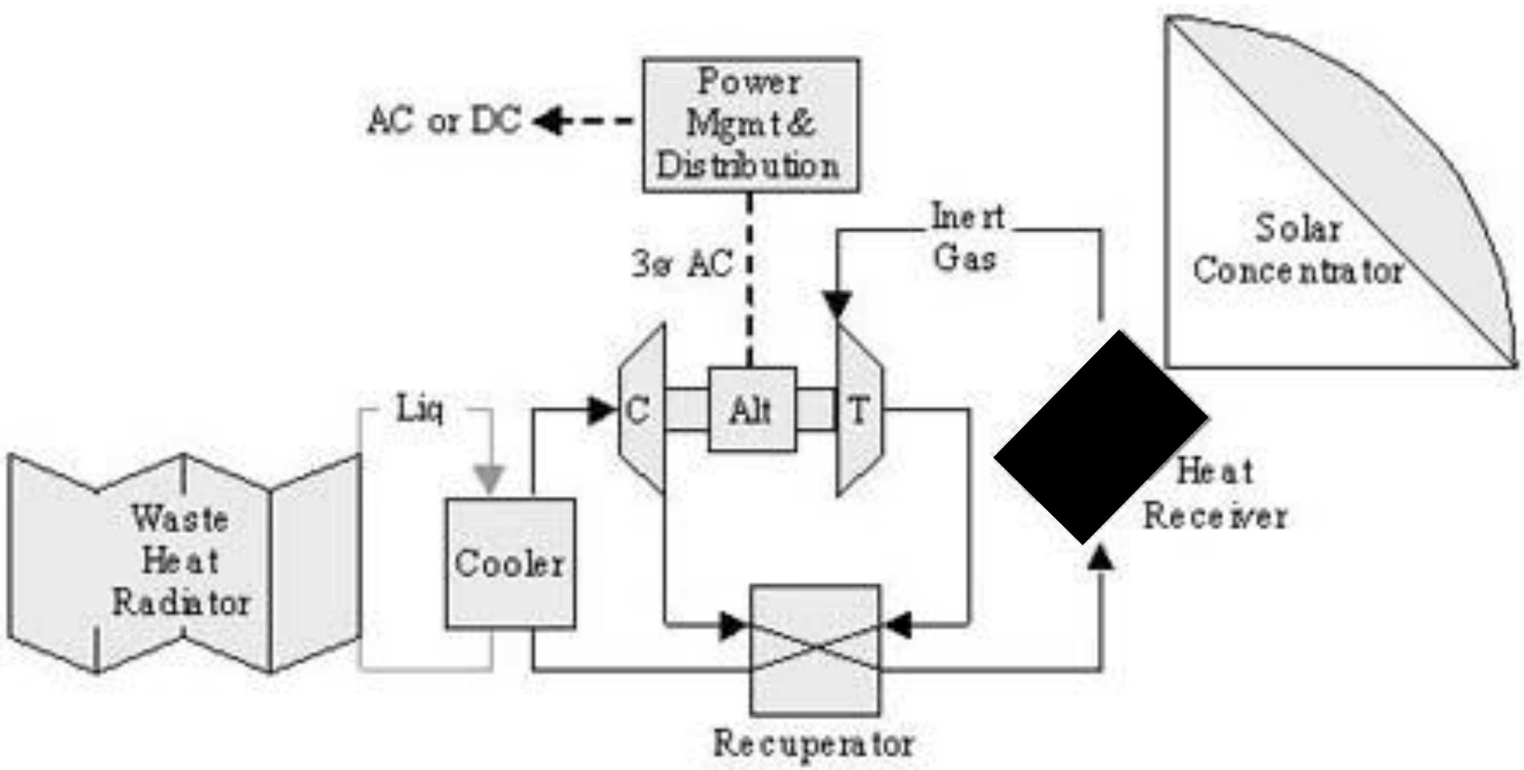
ENERGY STORAGE (2)

Thermal energy (thermodynamic engine)

- Energy is stored under the form of latent heat inside the hot source and is converted by the thermodynamic engine when needed



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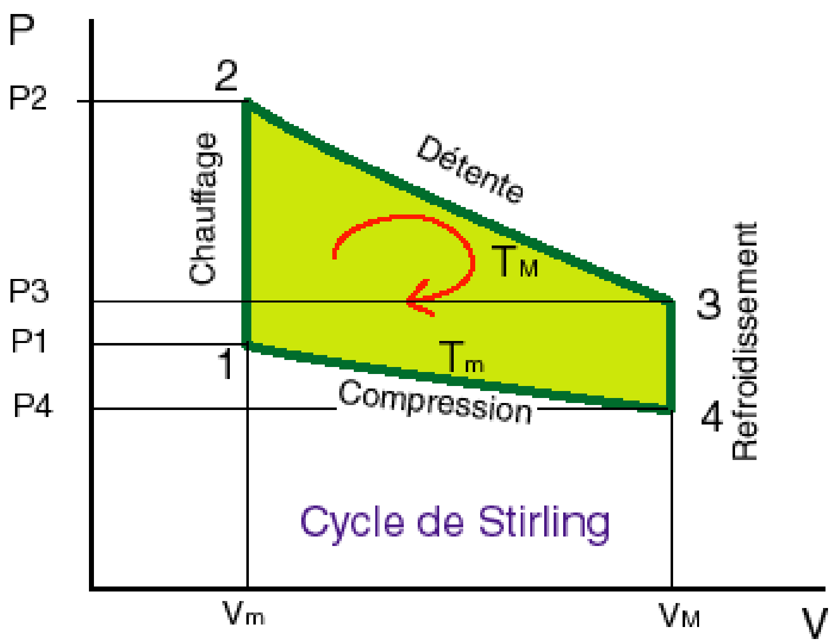
ENERGY STORAGE (3)

Thermal energy (thermodynamic engine)



see
http://www.moteurstirling.com

Earth application : 3 kW AC
www.infiniacorp.com

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ENERGY STORAGE (4)

Thermal energy (thermodynamic engine)

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ENERGY STORAGE (5)

350 W Free Piston Stirling convertor developped by Stirling Technology Compagny (US)

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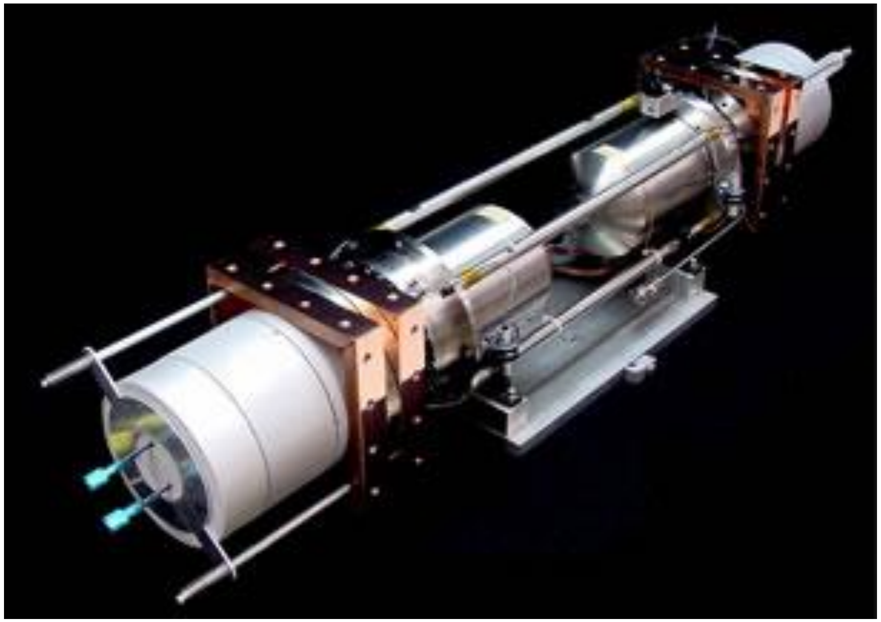
ENERGY STORAGE (6)



SRG 110

With Lockheed Martin, the United States Department of Energy (DOE), and NASA, Infinia developed and tested the Stirling Convertor Assemblies used in the first Stirling Radioisotope Generator (SRG) systems planned for use in deep space exploration missions. **Voir www.infiniacorp.com**

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Electrostatic Energy storage

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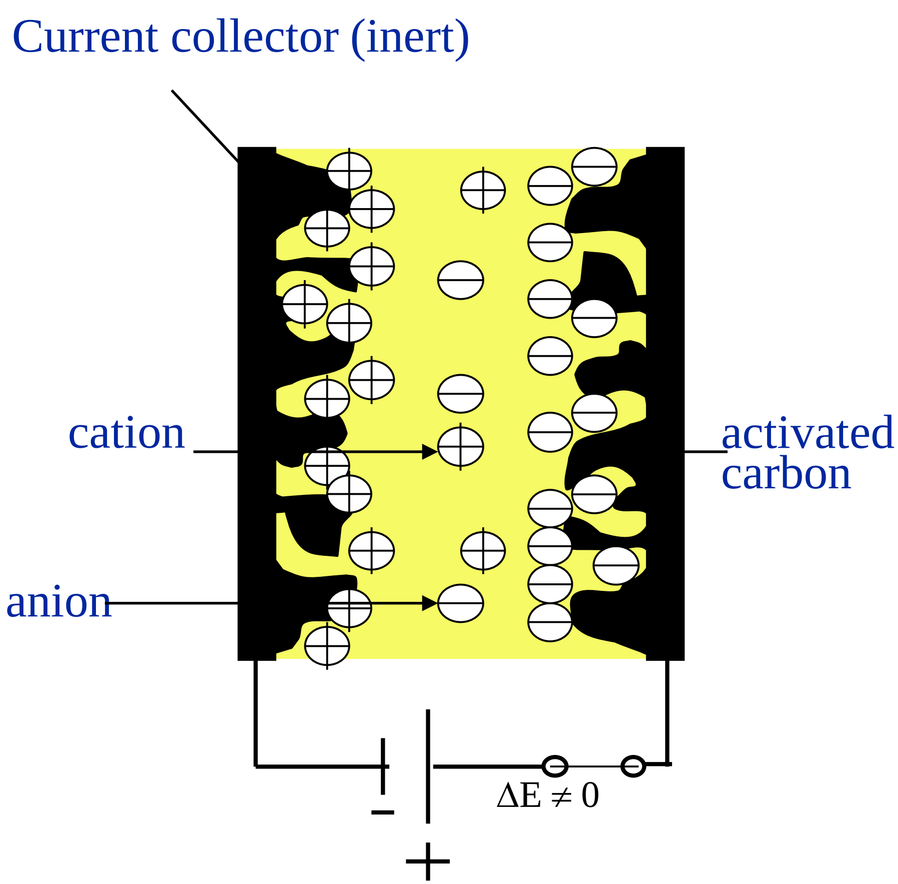
ENERGY STORAGE (7)

Electrostatic energy(Supercapacitor or Dual Layer Capacitor - DLC)



Polarized System :

$\Rightarrow$ absorption of the ions on the activated carbon

$\Rightarrow$ load of the dual layer capacity

- If Cdl = 10 µF/cm², with S = 2000 m²/g

  $\Rightarrow$ C = 200 F/g of CA

- In aqueous area :

ΔEmax= 1,2 V ; W = 1/2C(1,2)²

- In organic area :

ΔEmax = 2,5 V ; W=1/2C(2,5)²

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ENERGY STORAGE (8)

- Supercapacitors associate two electrically conductive electrodes and a ionic conductor electrolyte

- Very large capacities, up to several kFarads, thanks to :
  - large electrodes developped area by use od ultra-porous materials (activated carbon, 1000 to 3000 m^2/g)
  - distance between charges in the nanometer range

- Very active R&D oriented towards terrestrial applications, such as electrical vehicle, wireless tramway, uninterruptible supplies, toys, ...

- Numerous manufacturers worldwide [MAXWELL, EVANS (USA), PANASONIC, ELNA (Japan), BOLLORE (France), EPCOS (Germany, a common subsidiary of Siemens and Matsushita), MONTENA (Switzerland, now a subsidiary of Maxwell)...]

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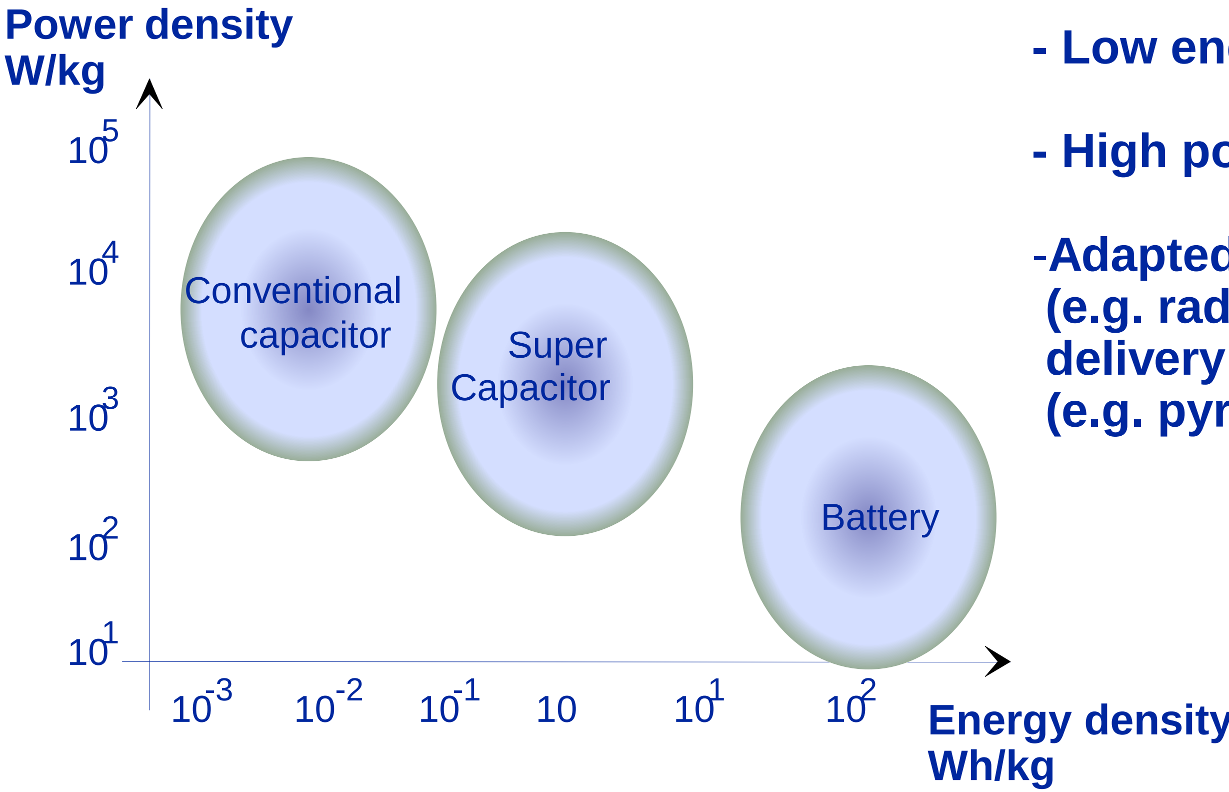
ENERGY STORAGE (9)



- Low energy density

- High power density

-Adapted to power levelling (e.g. radar payload) or to the delivery of high power pulse (e.g. pyro devices actuation)

ENERGY STORAGE (10)

Cordless tools

Monitoring systems

Power Electronics

Supercapacitor < 100 F

2 Ultracaps offer more freedom of movement for Rollei´s Lens Control as well.

UltraCaps from EPCOS support fast shutter release.

- **Consumer Electronics**
- **System of storage**

Existing market with important volume

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ENERGY STORAGE (11)

Applications

Supercapacitor > 100 F

- **Power system**

Lot of programs for
“clean vehicles” development

1 UltraCap module

1 Customer-specific UltraCap modules can be produced for a wide range of voltages and capacitances.

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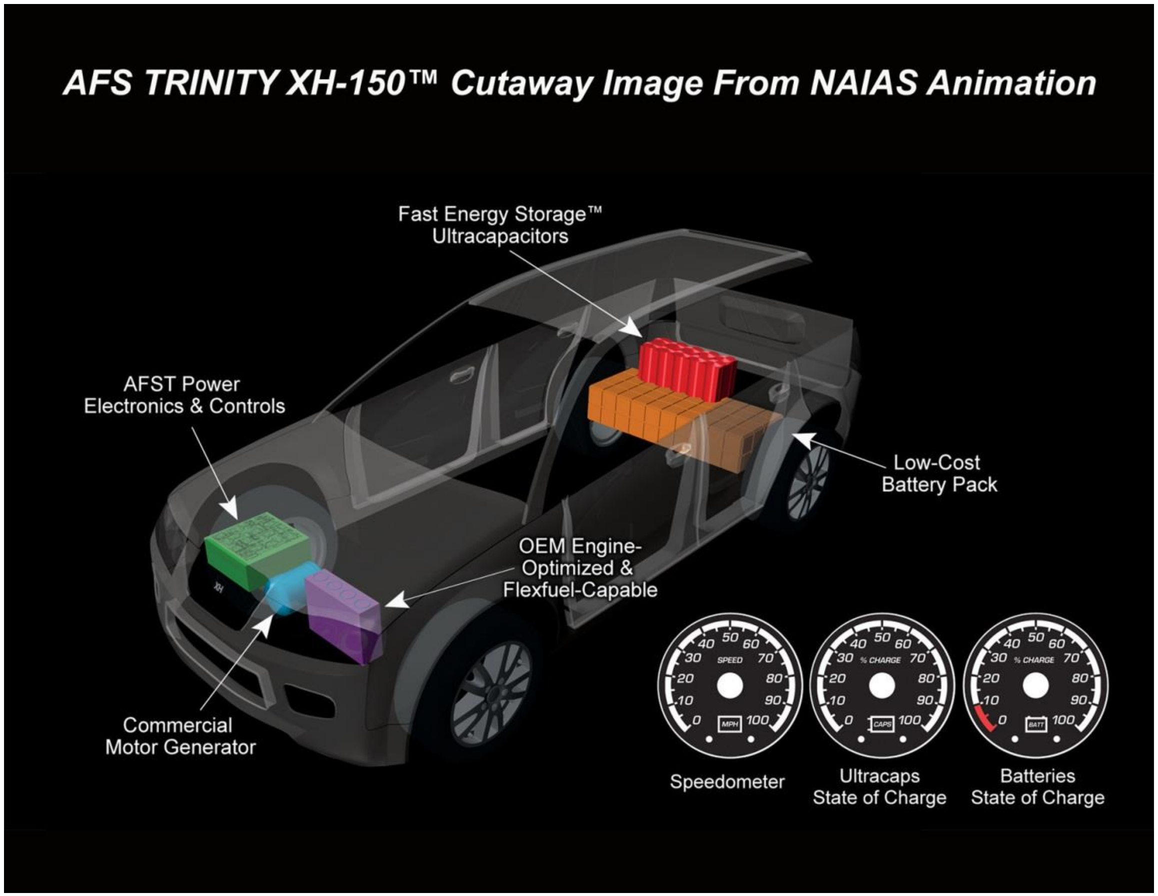
ENERGY STORAGE (12)

Applications : hybrid systems



Video

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ENERGY STORAGE (13)

Applications

Power delivery

Emergency door opening

Energy harvesting

Tramway (Mitrac)

Energy harvesting

Harbor Grantry Crane

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ENERGY STORAGE (14)

Space applications

All need of pulse power system

- Save memory system
- Repeat and fast actuation system
- Pyrotechnical system
- Radar

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ENERGY STORAGE (15)

AVANTAGES	DRAWBACKS
High power density	Low energy density
Excellent resistance to cycling (no electrochemical reactions)	Significant self discharge (improving)
Low thermal dissipation	Care to be exercised when series connecting
Very high charge and discharge rates are possible	No space qualified part available yet
Voltage is a direct indication of state of charge	
Potentially low cost (but not the case yet !)	

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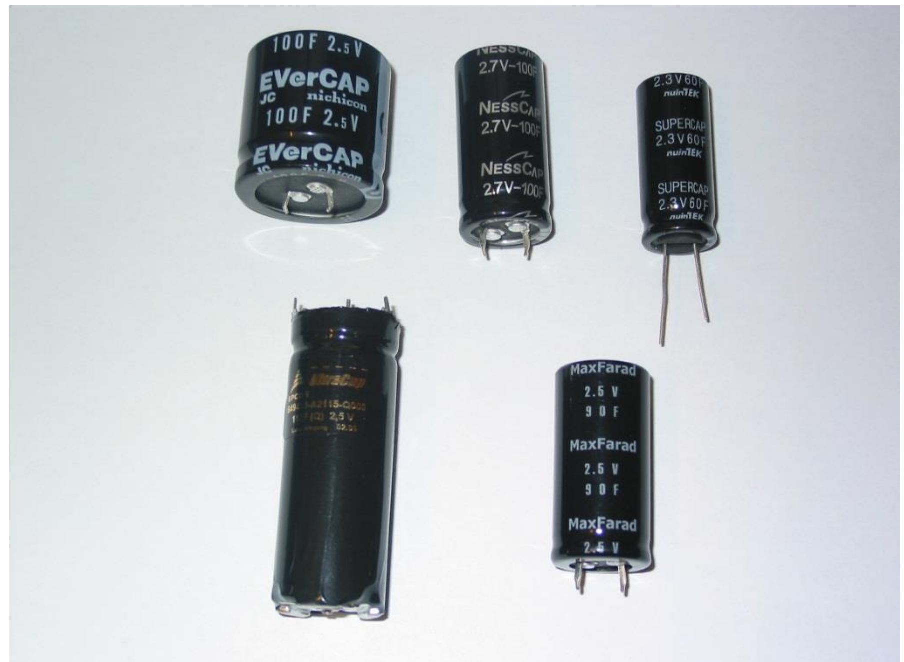
ENERGY STORAGE (16)

Supercapacitor carbon /carbon

Maxwell-Montena

Panasonic



Supercapacitor 60 F 110 F

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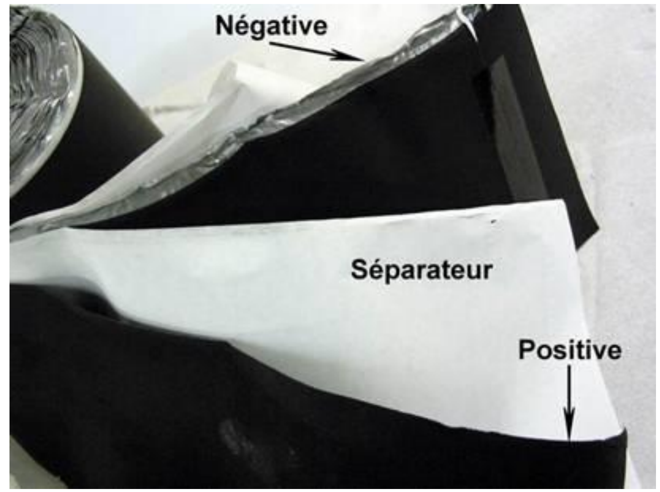
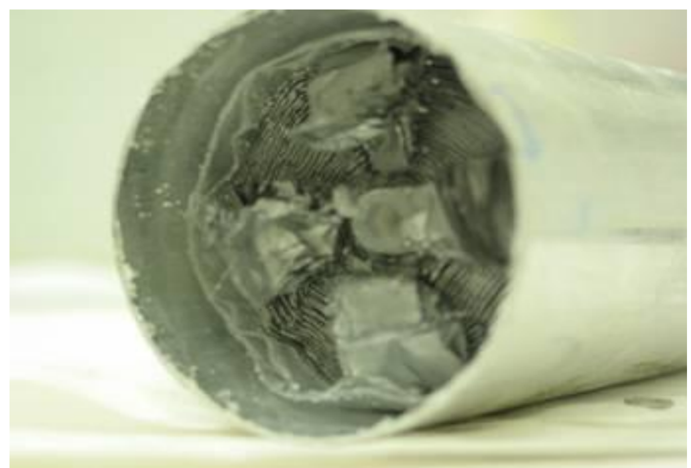
ENERGY STORAGE (17)

Design supercapacitor carbon/carbon





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Mechanical Energy storage

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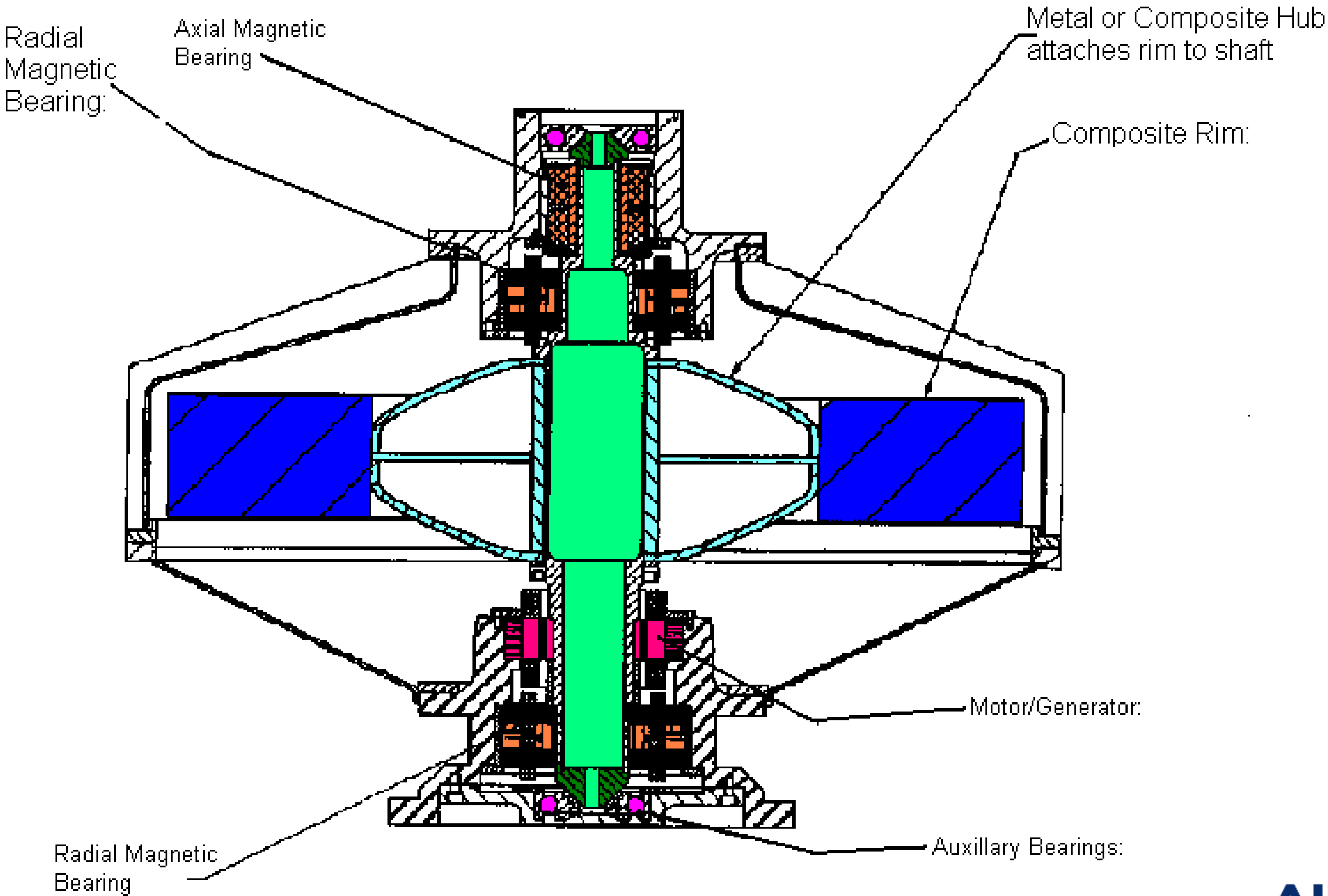
ENERGY STORAGE (18)

Mechanical energy (flywheel)



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ENERGY STORAGE (19)

- Flywheel
  - The theoretical energy density with best available performance is close to 500 Wh/kg
  - Larger and more predictible lifetime than for electrochemical batteries
  - Larger acceptable depth of discharge for LEO missions
  - Must be part of an integrated assembly with the attitude control subsystem
  - In the USA, some developments have reached the EM/QM level (ISSA)

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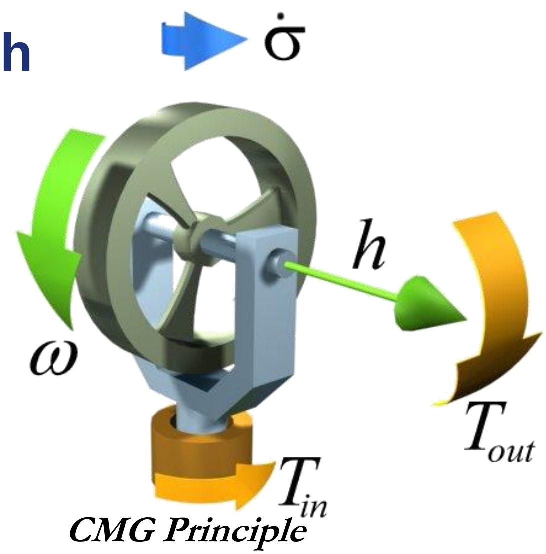
ENERGY STORAGE (20)

CMG 15-45 S principle (1)

CMG 15-45S principle :
A low torque high-precision articulation orientating a 15Nms wheel, producing an <u>output torque of up to 45 Nm</u>

CMGs use gyroscopic effect to produce a high output torque by rotating the spin axis of a momentum wheel :

$$\vec{T}_{out}(t)=\vec{h}_{wheel}\wedge\dot{\vec{\sigma}}_{gimbal}$$

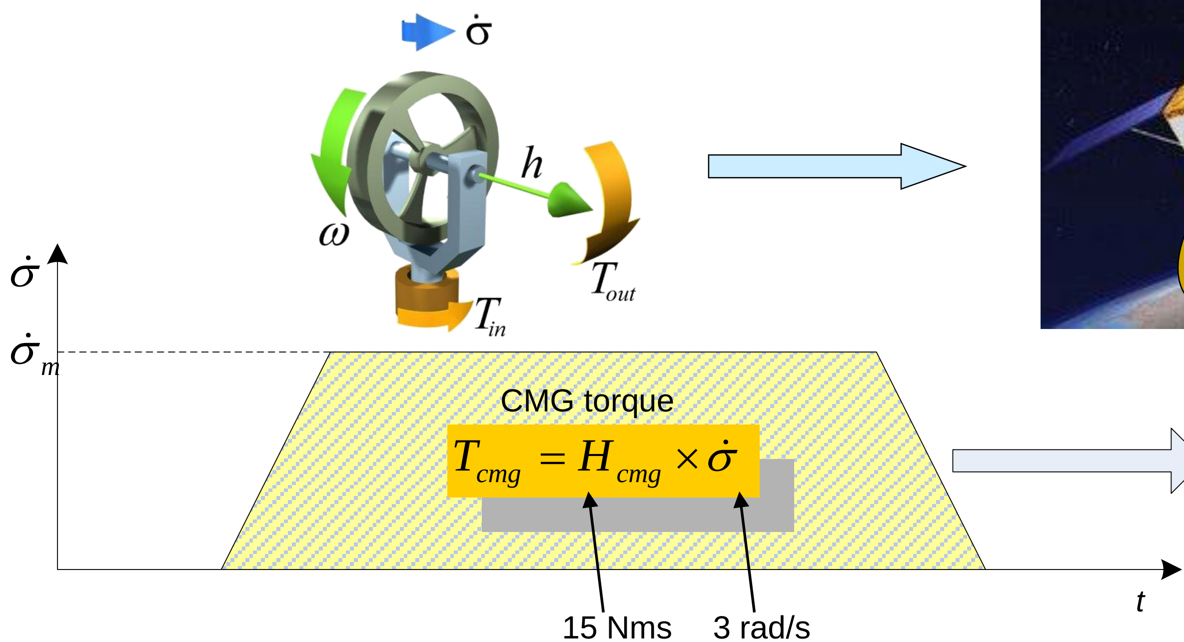


- The CMG 15-45 S developed by AIRBUS provides an outstanding amplification ratio : with a low torque motor rotating a 15Nms wheel up to 3 rad/s, the output torque is 45 Nm

Peak output torque = 45 Nm
Momentum = 15 Nms

ENERGY STORAGE (20)

CMG 15-45 S principle (2)



$$T_{cmg} = H_{cmg} \times \dot{\sigma}$$

S/L acceleration

$$\dot{\omega}_{sat} = \frac{T_{cmg}}{I_{sat}}$$

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ENERGY STORAGE (20)

CMG 15-45 S product

Key features :

- Very high performances
- Simple accommodation in satellites
- Proven technologies

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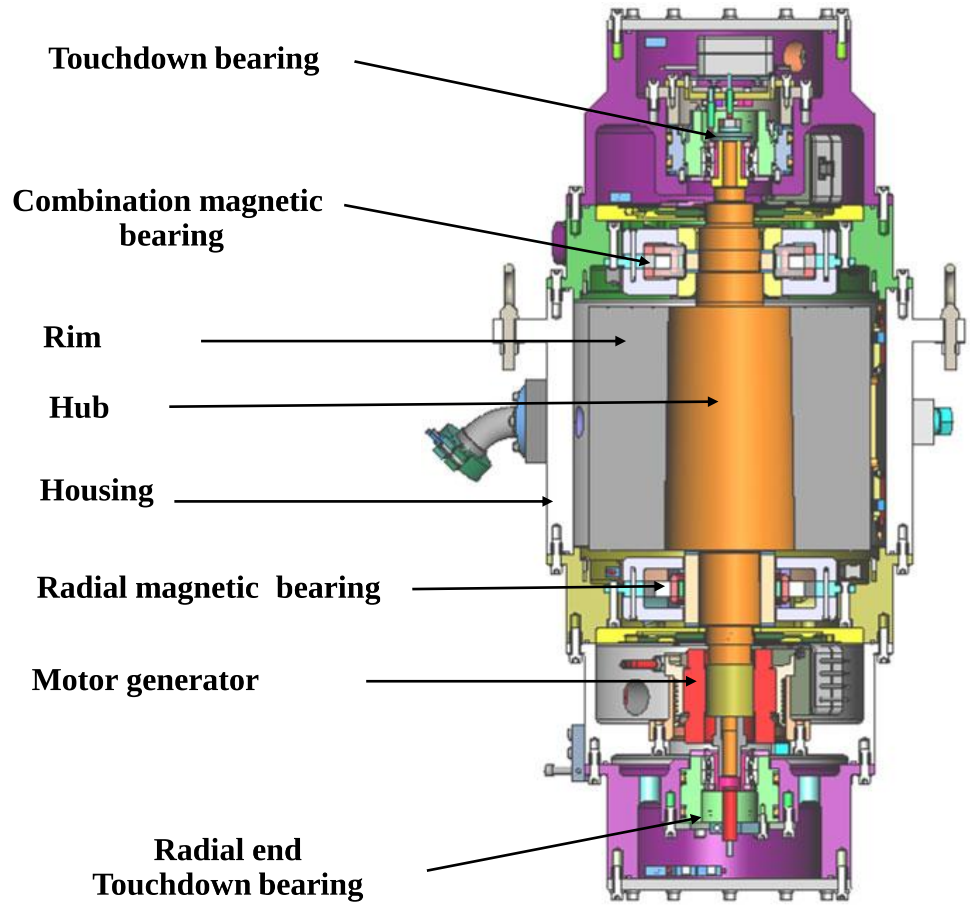
ENERGY STORAGE (20)

NASA GRC G2 Flywheel module : 3 kW

20 to 60 krpm



Chimical Energy (Fuell Cell)

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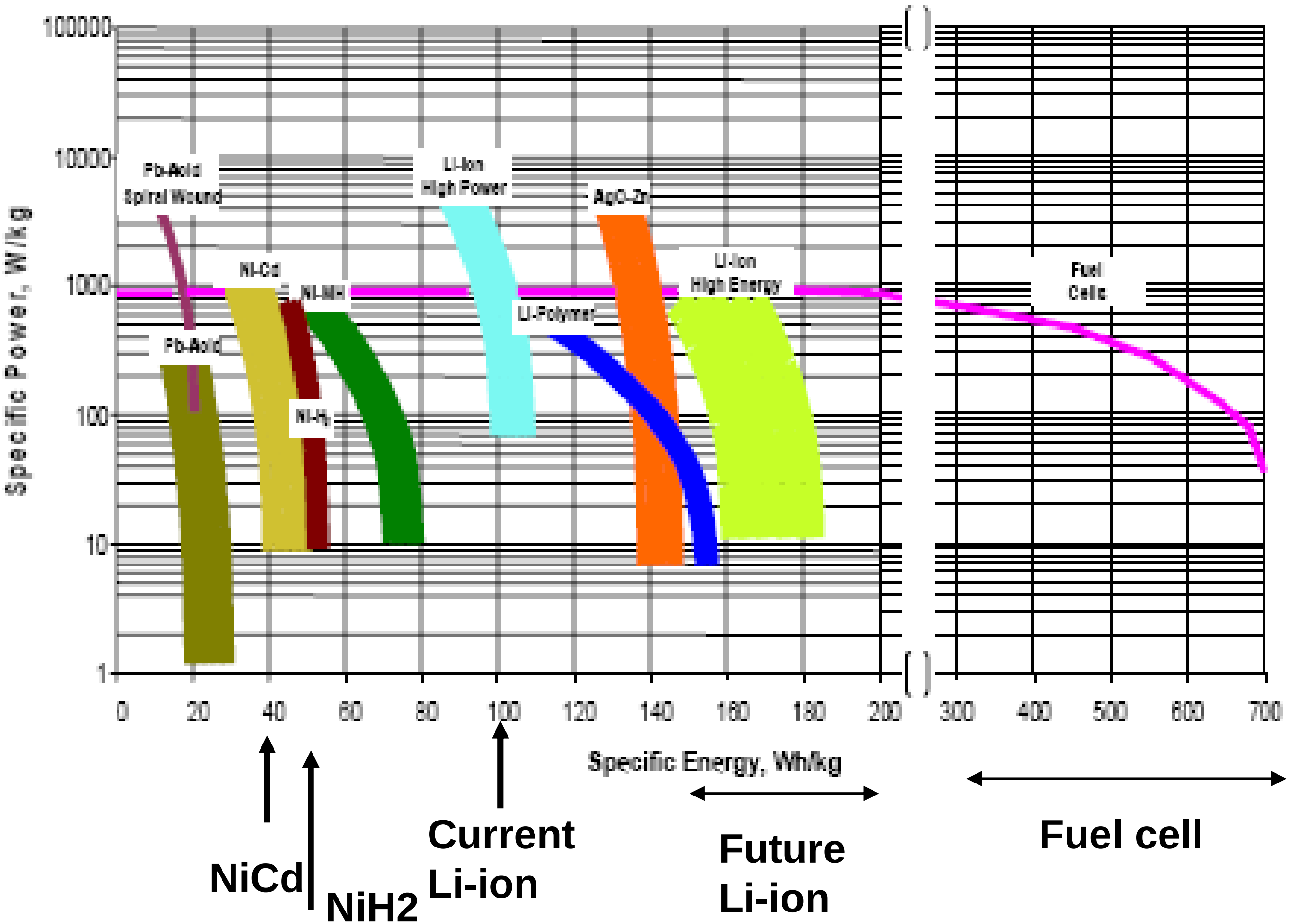
ENERGY STORAGE (21)

Chimical Energy

Regenerative Fuel Cell system (RFCS)

Ragone plots



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ENERGY STORAGE (22)

Chimical Energy

Fuel Cell system (FCS)

basic principle of a fuel cell

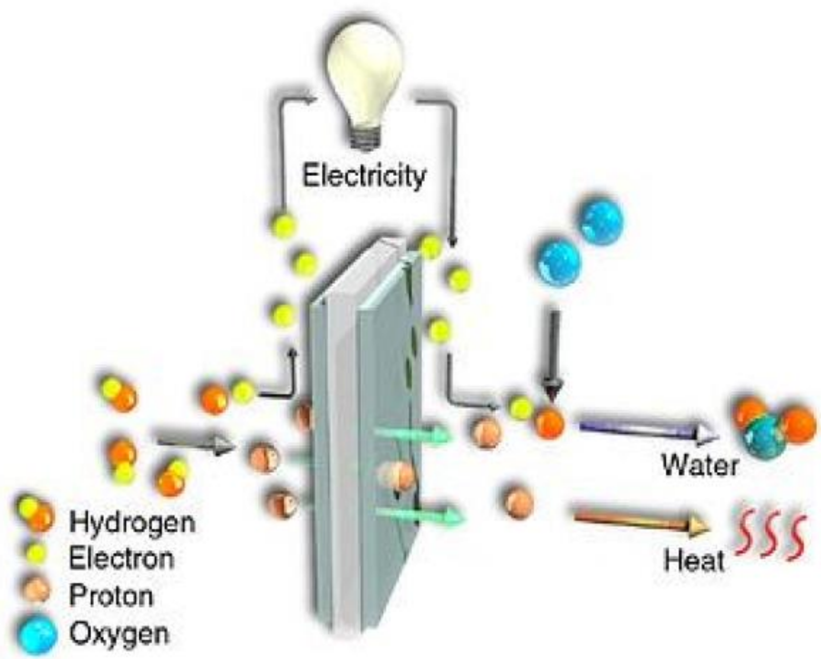

Figure 4: 10-cell URFC

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ENERGY STORAGE (23)

Chimical Energy

Fuel Cell system (RFCS)

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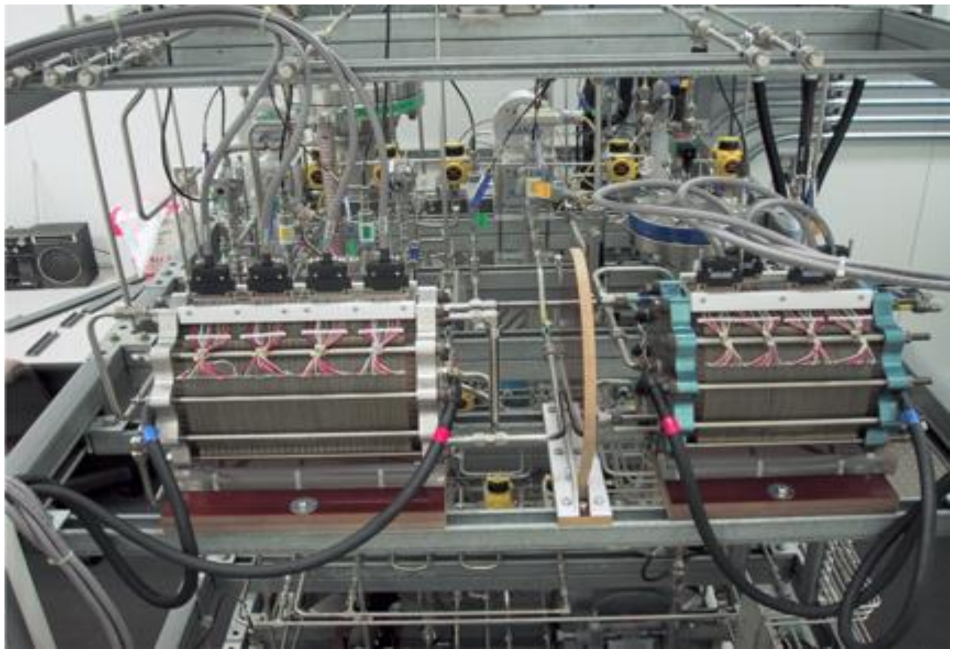
ENERGY STORAGE (26)

Chimical Energy

Regenerative Fuel Cell system (RFCS)



NASA prototype

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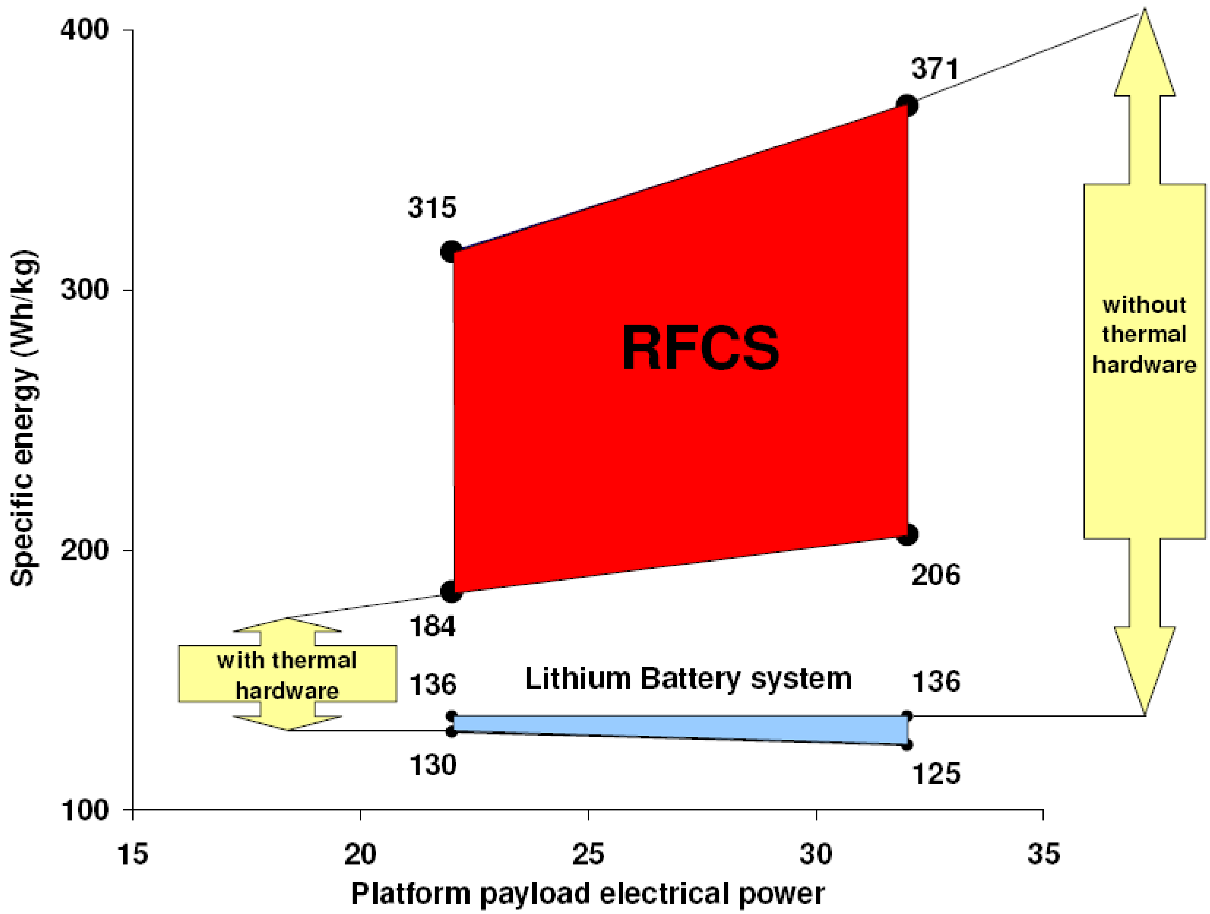
ENERGY STORAGE (27)

Chimical Energy

Regenerative Fuel Cell system (RFCS)



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Chimical Energy (storage cell)

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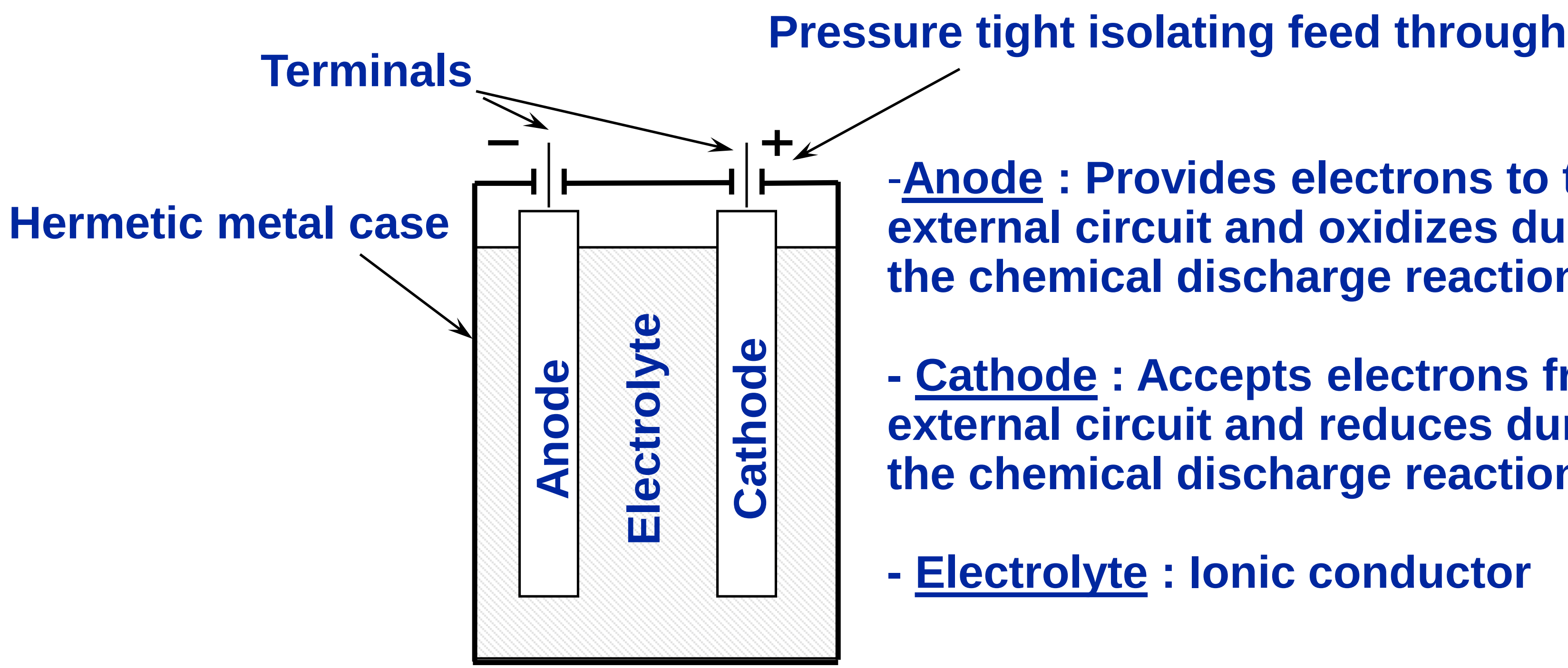
ENERGY STORAGE

Storage Cell

Chemical energy : Storage Cell

- A storage cell is made of two electrodes immersed into an electrolyte



-**Anode** : Provides electrons to the external circuit and oxidizes during the chemical discharge reaction.

- **Cathode** : Accepts electrons from the external circuit and reduces during the chemical discharge reaction.

- **Electrolyte** : Ionic conductor

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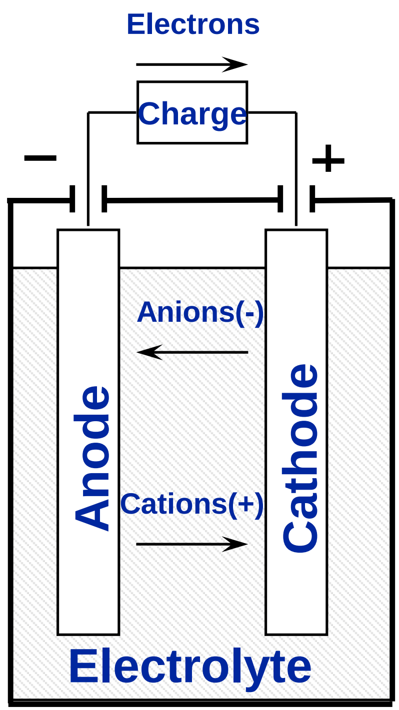
ENERGY STORAGE

Storage Cell

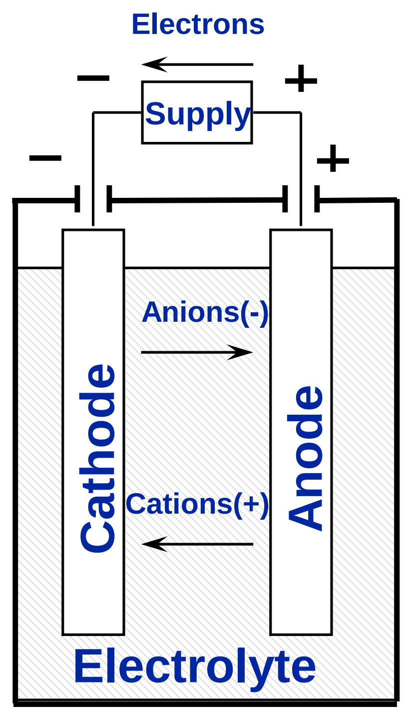
OPERATING PRINCIPLE

Negative electrode:
Oxidation, i.e. loss of electrons
$Zn \rightarrow Zn^{2+} + 2e$

Positive electrode :
Reduction, i.e. gain of electrons
$Cl_2 + 2e \rightarrow 2Cl^-$



Discharge phase



Charging phase

Negative electrode :
Reduction, i.e. gain of electrons
$Zn^{2+} + 2e \rightarrow Zn$

Positive electrode :
Oxidation, i.e. loss of electrons
$2Cl^- \rightarrow Cl_2 + 2e$

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ENERGY STORAGE

Storage Cell

TECHNOLOGIES USED IN SPACE

Techno	Anode	Cathode	Electrolyte	Specific energy
NiCd	Ni	Cd	KOH	25 Wh/kg
NiH2	Ni	Pt	KOH	45 Wh/kg
Li-ion	Co, Ni, Mg	C	Organic	> 110 Wh/kg

ENERGY STORAGE

Storage Cell

NiCd

Eagle Picher

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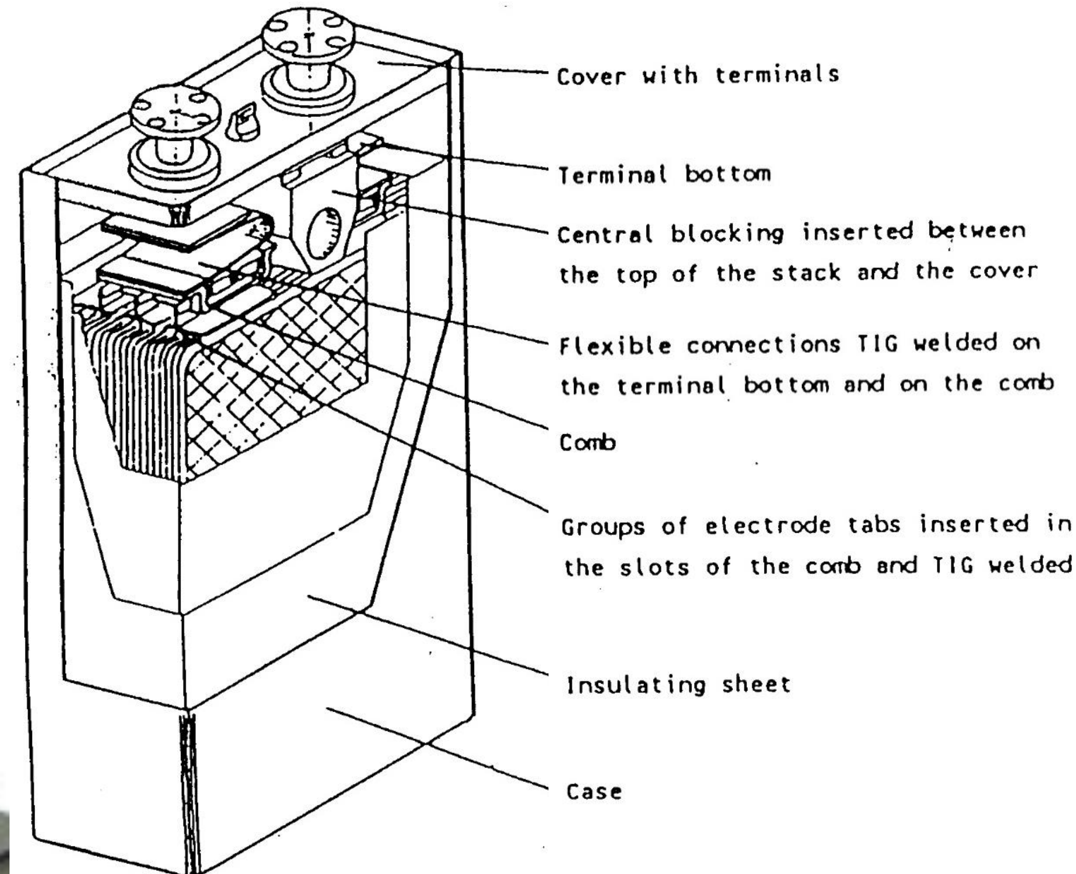

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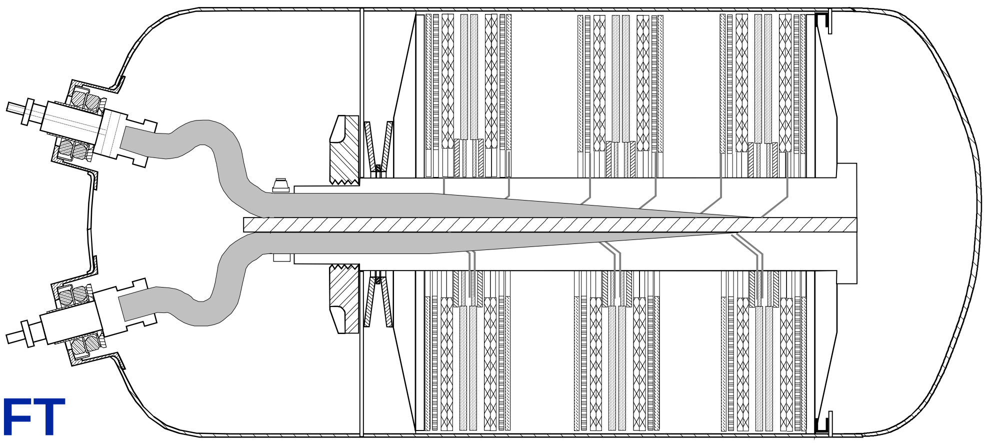
ENERGY STORAGE

Storage Cell

NiH_2



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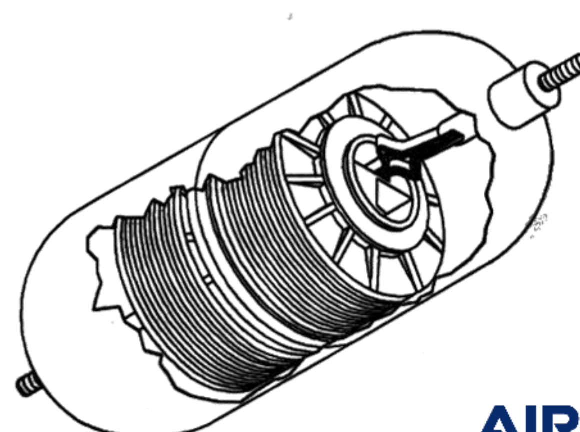
Eagle Picher



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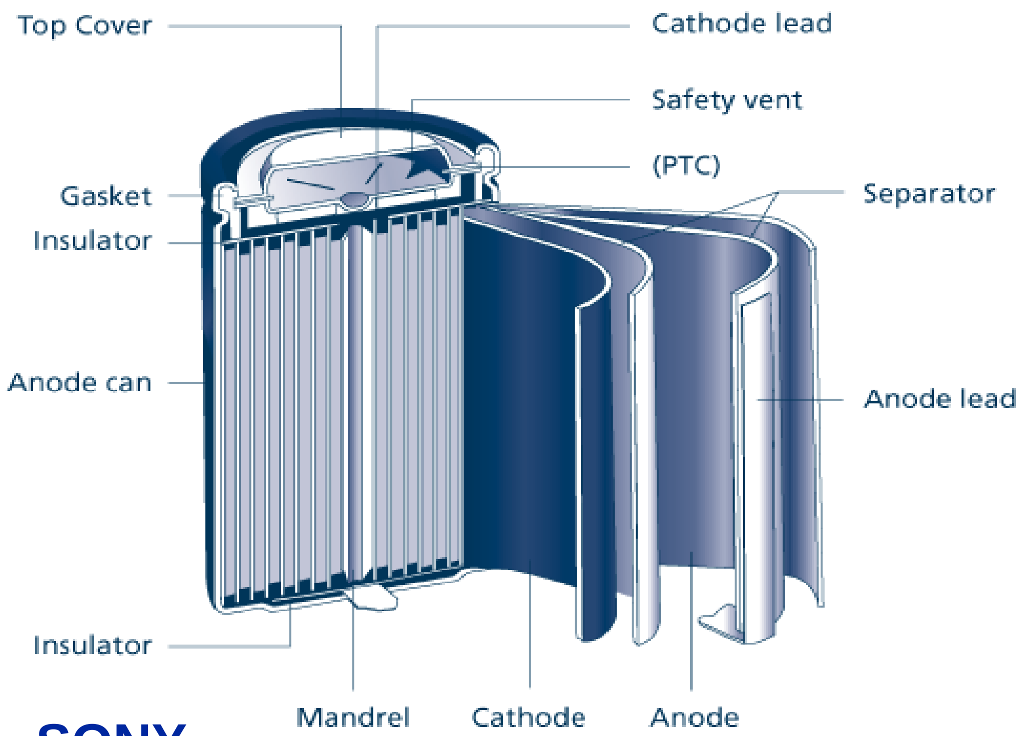
ENERGY STORAGE

Storage Cell

Li-ion



SONY

GS-YUASA

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ENERGY STORAGE

Storage Cell

A little vocabulary

- Nameplate or nominal capacity (Ah) : Qnom or C or Cnom, is the number of Ah stated by the manufacturer. This capacity may or may not represent the amount of Ah available upon discharge down to a technology dependent EOD voltage.

225 AH IPV $Ni\text{-}H_2$ Battery Cell Design

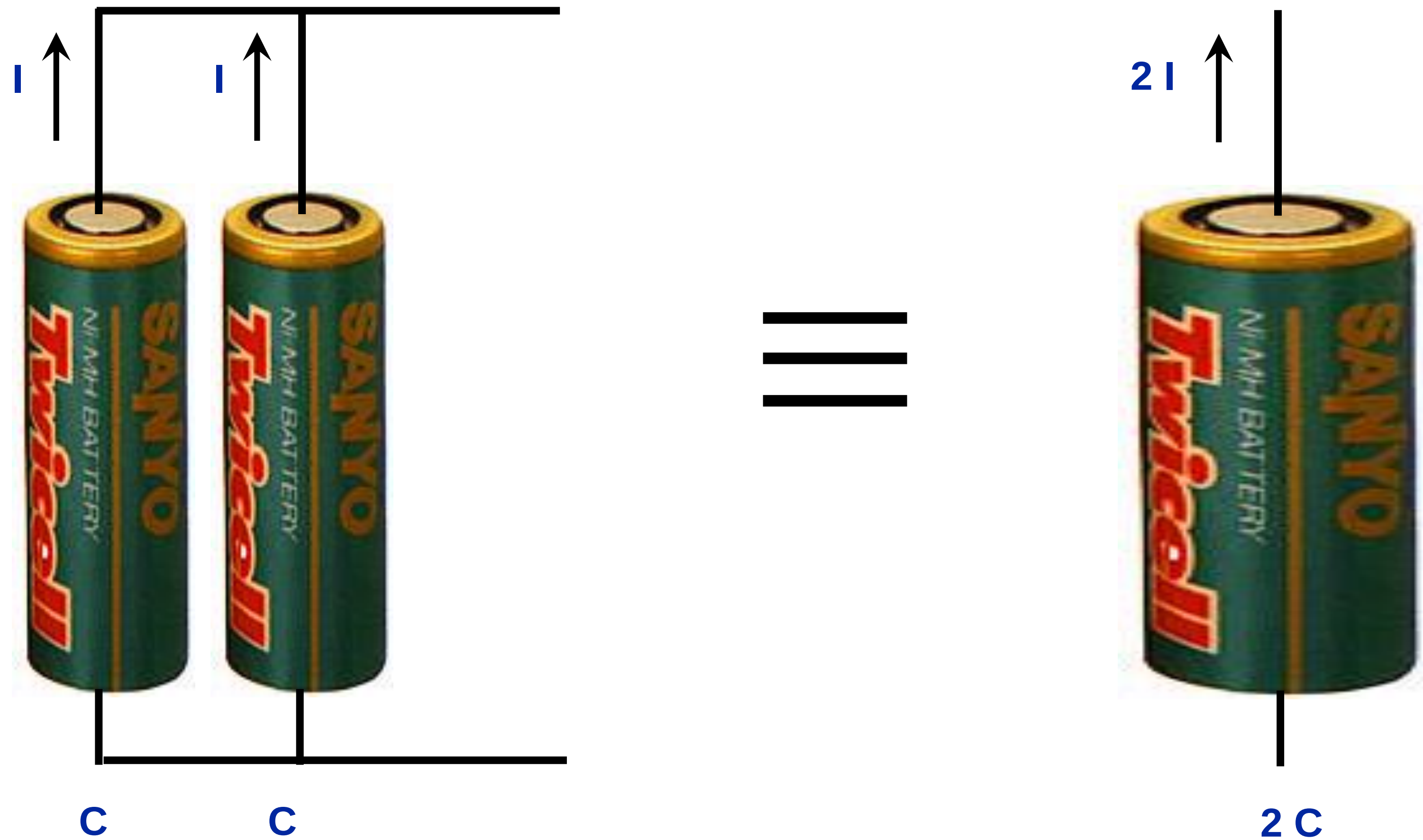
Voltage	1.25	Volts
Nameplate Capacity	225	AH
Nominal Capacity	238	AH
Length (Terminals)	39.2	cm
Diameter	14.5	cm
Specific-Energy	50.0	Whr/Kg
Cell Weight	5917	gm

o Nominal Capacity	**256**	**Ah**
o Average Lot Capacity @ C/2	230.4	Ah
o Minimum Cell Capacity @ C/2	221.2	Ah
o Midpoint Voltage @ C/2	1.260	V
o Voltage Drop at C rate	43	mV
o Charge Retention, minimum	84	%

ENERGY STORAGE

Storage Cell

- Charge and discharge currents are expressed as a fraction of the nameplate capacity (0.33 C, C/10, C/2, C/100)



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ENERGY STORAGE

Storage Cell

- **Capacity** : Current provided during a time , expressed in Ah symbol Q (Ah) but in b attery language : C
- **Energy** : Power provided during a time, expressed in Wh
- Depth Of Discharge (%) : **DOD**, the number of discharged Ah divided by the nameplate capacity.
- State Of Charge (%) : **SOC**, the amount of remaining Ah divided by the nameplate capacity. **SOC = 1 – DOD**
- **Taper Charge** : a constant voltage charging to guarantee the battery to full SOC (Li-ion).

ENERGY STORAGE
Li-Ion Cell

SAFT VES140S Li-Ion
38.5 Ah

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ENERGY STORAGE

Li-Ion Cell

SAFT VES140S Li-Ion

Cell electrical characteristics

Nominal voltage	3.6 V
Nominal capacity at C/1.5 rate at 4.1 V/3 V & 20°C	39 Ah
Maximum discharge current at 25°C	100 A (Continuous ~2 s pulse)
Specific energy (minimum)	126 Wh/Kg
Energy density	140 Wh/l

Cell mechanical characteristics

Diameter	53 mm
Height	250 mm
Mass	1.13 kg
Mechanical environment Leak rate	Qualified all launchers 10^{-8} dm^3 atm s^{-1}

Cell operating conditions

Lower voltage limit for discharge	Continuous (0°C to +45°C) 2.7 V
Charging method	Constant current/constant voltage (CCCV)
Charging voltage (max)	4.1 V
Recommended continuous charge current	GEO/MEO C/10 LEO (20 % DOD) C/5
Operating temperature	Charge +10°C to +35°C Discharge 0°C to +40°C
Storage and transportation temperature	- 40°C to +65°C

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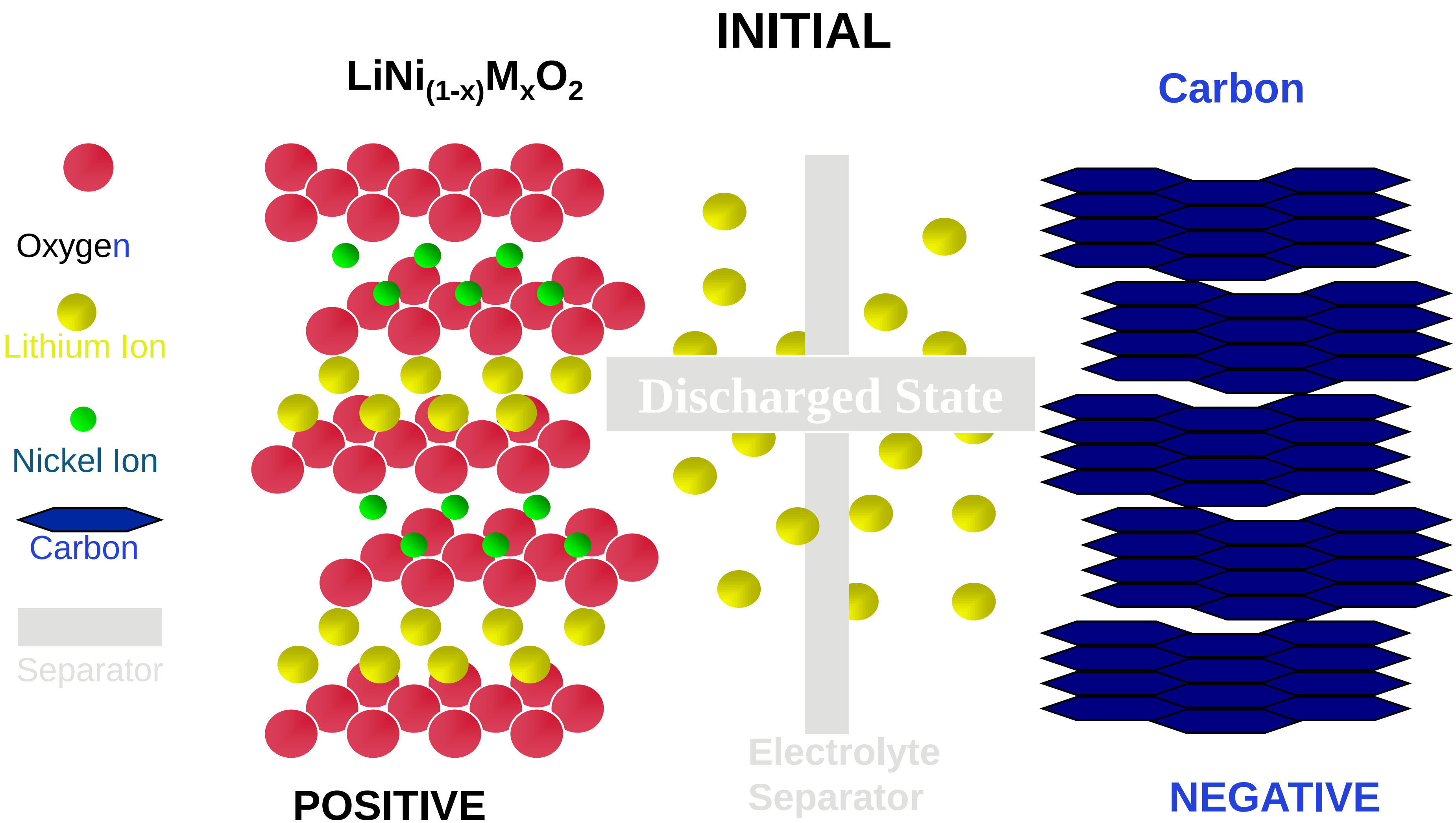
ENERGY STORAGE

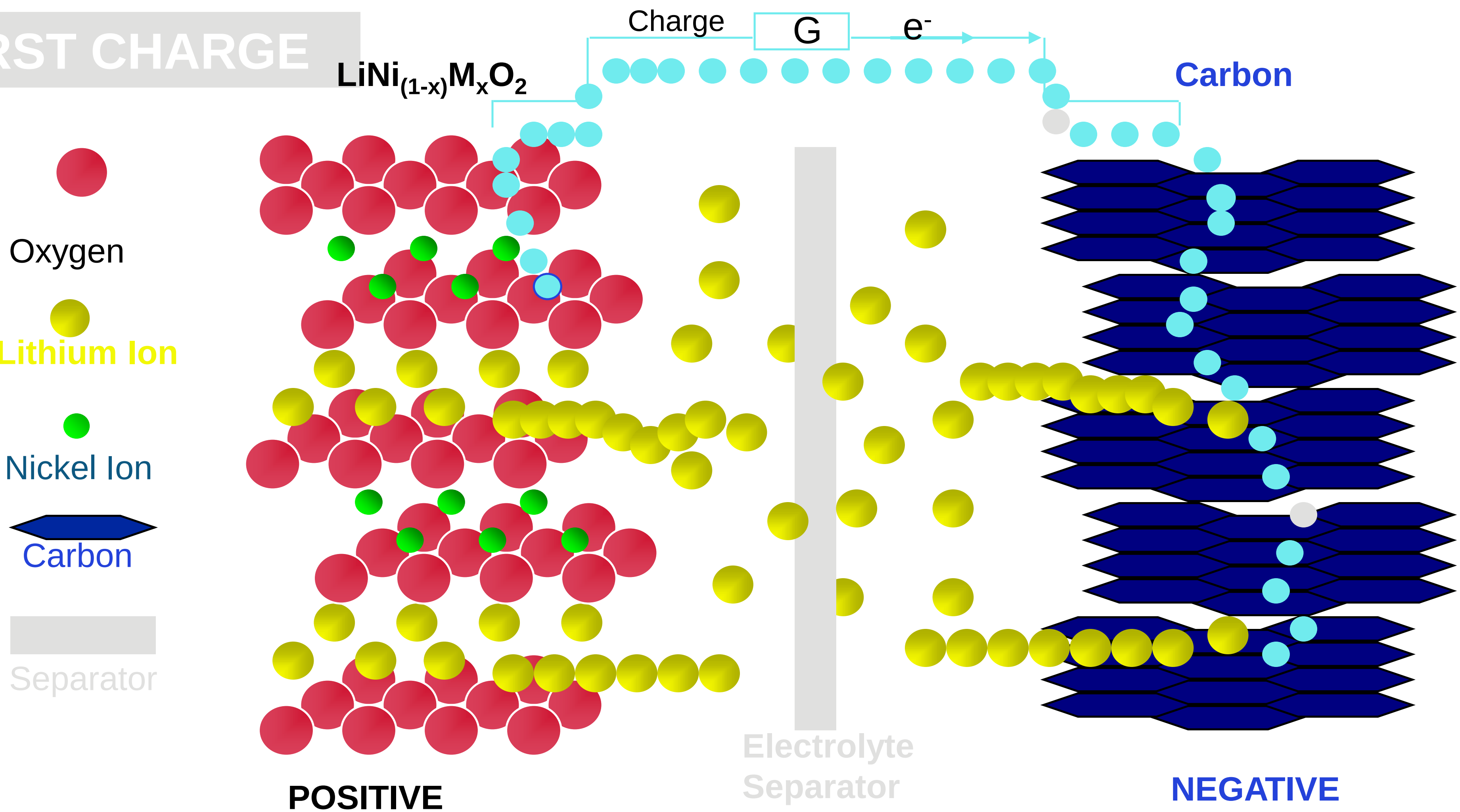
Li-Ion Cell



ENERGY STORAGE

Li-Ion Cell

FIRST CHARGE



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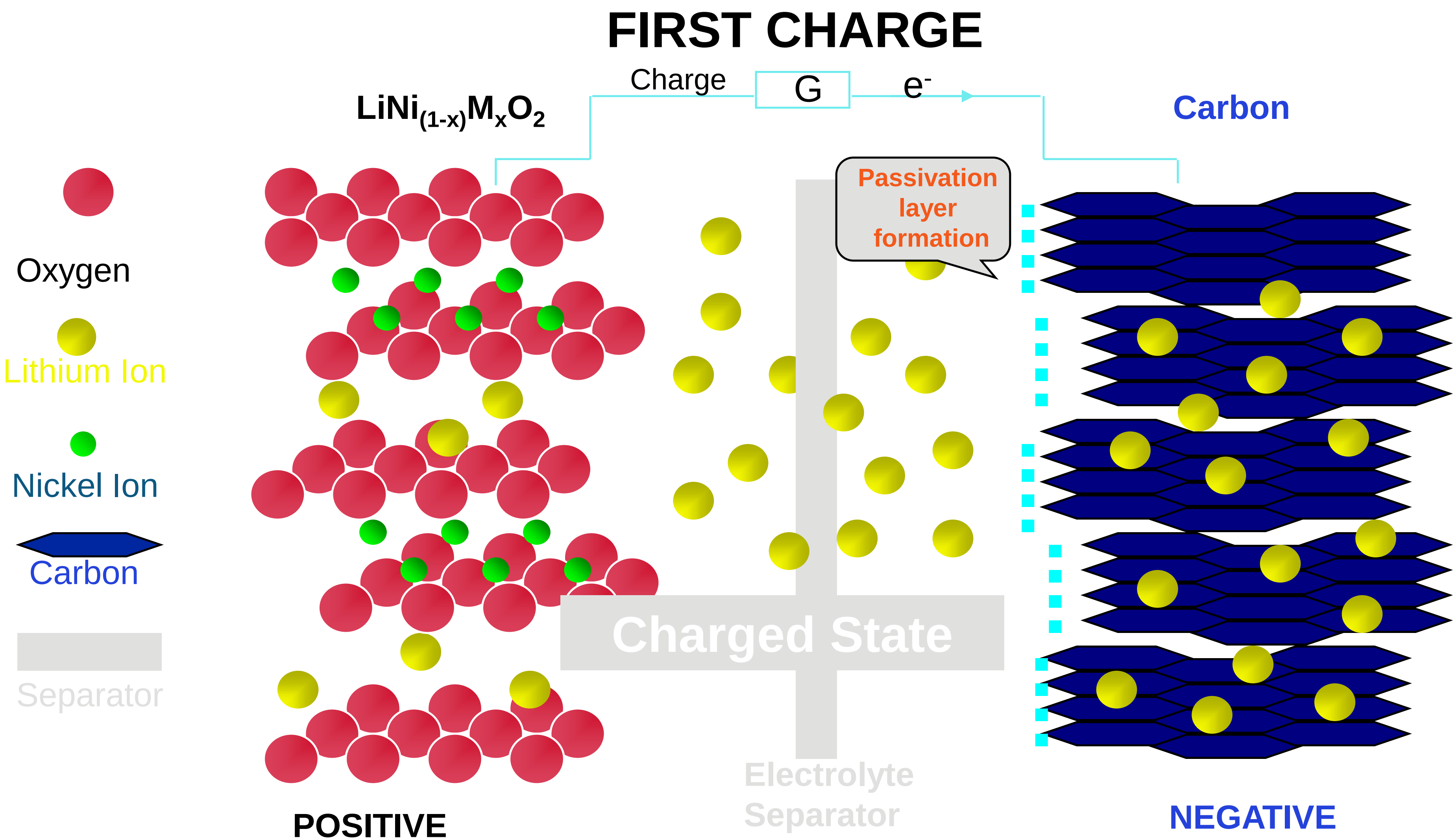
ENERGY STORAGE

Li-Ion Cell



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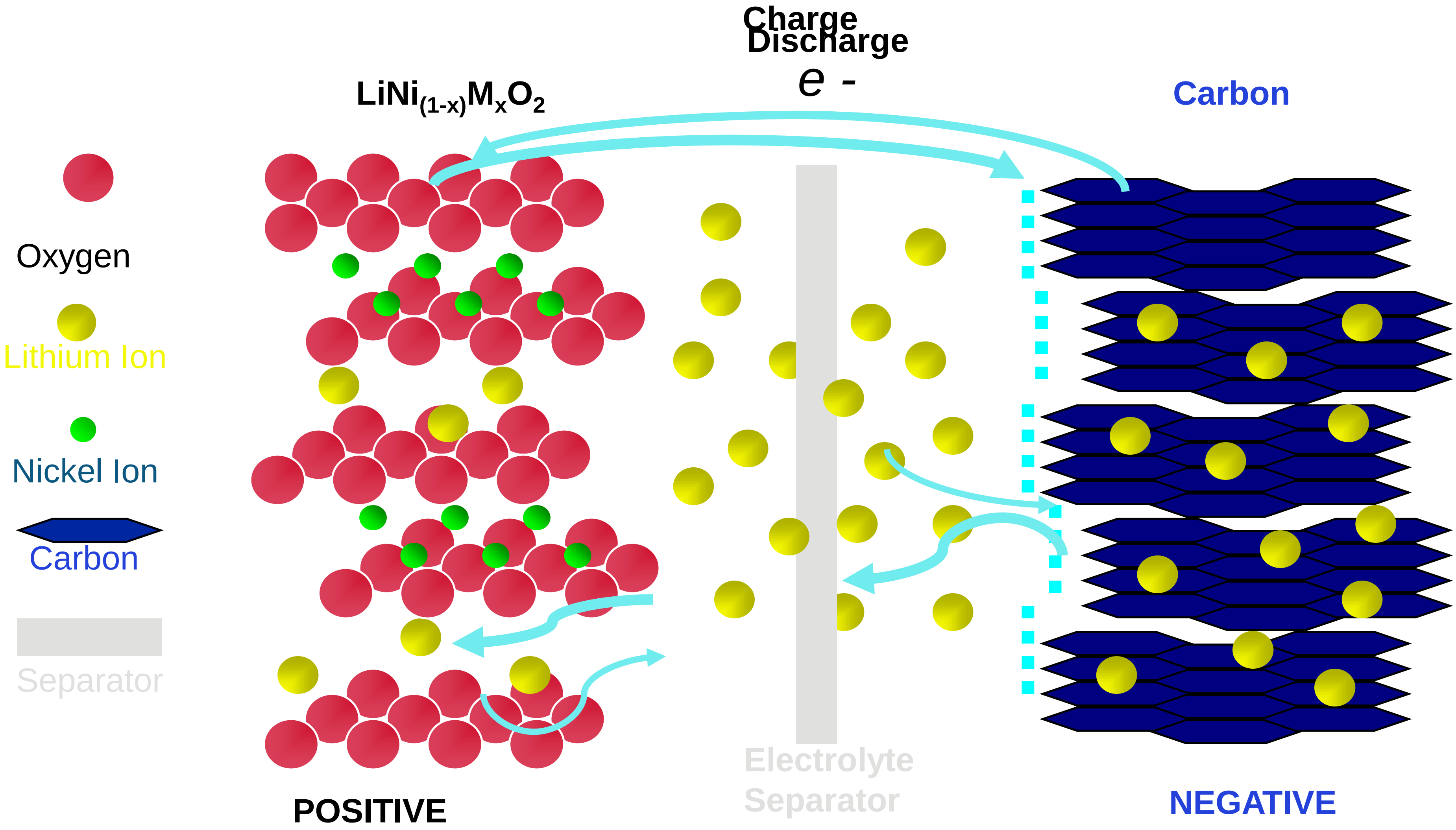
DEFENCE AND SPACE

ENERGY STORAGE

Li-Ion Cell



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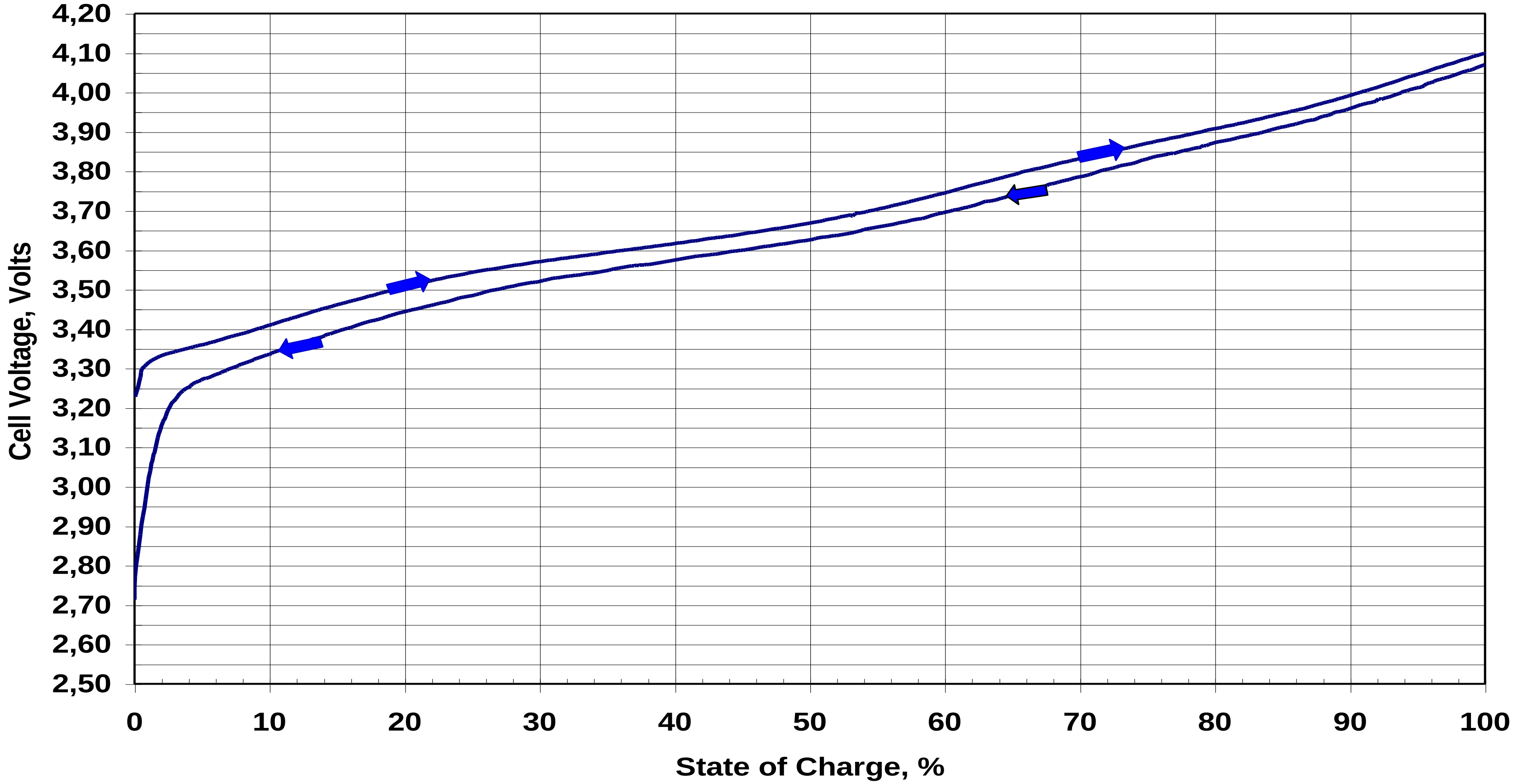
ENERGY STORAGE

Li-Ion Cell

Voltage typical behaviour in open circuit



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ENERGY STORAGE

Cell advantage and drawback

	NiCd / NiH2	Li-Ion
Specific Energy	25 to 45 Wh/kg	> 100 Wh/kg
Charge	Can accept overcharge	Irreversible damage in case of overcharge. Risk of explosion
Discharge	Discharge down to 0V	Irreversible damage in case of overdischarge
Leakage current	High leakage current up to 10%/day	Low leakage current about 2% a year
Operating temperature	Low temperature About 5°C Not accept operating over 30°C	High temperature 15°C in flight but accept 30°C (up to 45°C)
Thermal dissipation	Important thermal dissipation	Low thermal dissipation
Needed system	Trickkle charge to maintain cell charged Cell dissipation control	Protection to avoid overcharge and overdischarge

Storage Cells – set in batteries and management

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ENERGY STORAGE

Li-Ion Battery

Set in Battery (Li-Ion Cells)

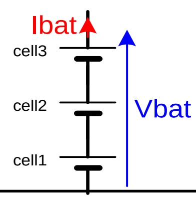
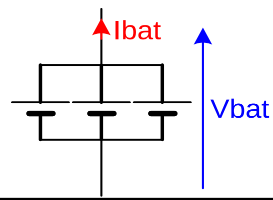
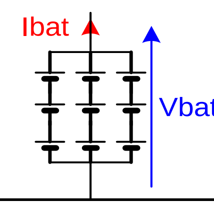
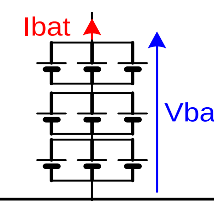
- In order to increase voltage and/or capacity/Energy, cells are set in serial and/or parallel association
  - Serial
  - Parallel
  - Serial – Parallel : EOS Battery approach
  - Parallel - Serial : Telecom battery approach

ENERGY STORAGE

Li-Ion Battery

Different battery configuration

- In order to increase voltage and/or Capacity/Energy, cells are set in serial and/or parallel association

	Serial	//	Serial-//	//-Serial
S/C application			EOS	Telecom
				
Battery voltage	Vbat=3Vcell	Vbat=Vcell	Vbat=3Vcell	Vbat=3Vcell
Battery current	Ibat=Icell	Ibat=3Icell	Ibat=3Icell	Ibat=3Icell
Capacity	Q bat=Q cell	X 3	X 3	X 3
Energy	X 3	X3	X 9	X 9
Failure if Cell in Open	Battery lost	Capacity lower	Capacity lower	Voltage/NRJ lower
Failure if Cell in Short	Voltage/NRJ lower	Battery lost	Capacity lower	Voltage/NRJ lower
Protection need	Bypass	Cell open system	Cell open system	Bypass

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ENERGY STORAGE

Li-Ion Battery management

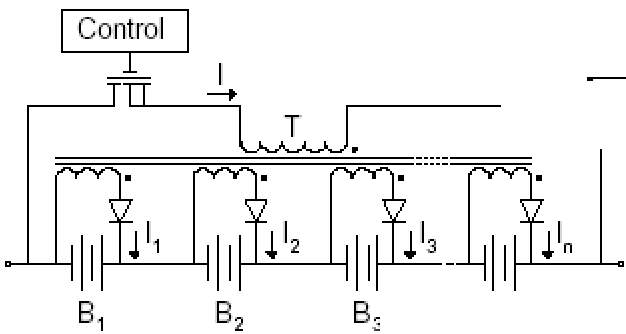
CELL MANAGEMENT

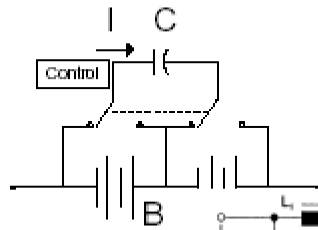
- Cell management shall be performed on batteries
  - All technologies do not offer the same robustness to overcharge and overdischarge
  - NiCd & NiH2 are intrinsically able to accept charging above maximum SOC, at the expense of gas generation/recombination resulting into thermal dissipation
  - This is not true for Li-ion : a prolonged overcharge results into cell destruction and a deep discharge may alter its performance considerably
  - Consequently the individual management of cell voltage inside a battery may be necessary in order to avoid such situations
  - Many devices have been designed to this end, from the most complicated...

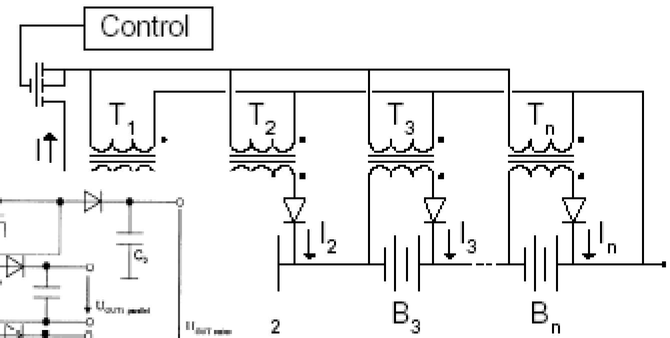
ENERGY STORAGE

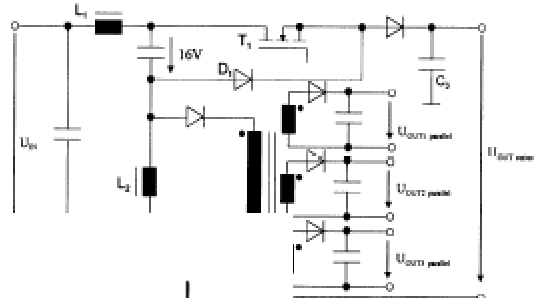
Li-Ion Battery management

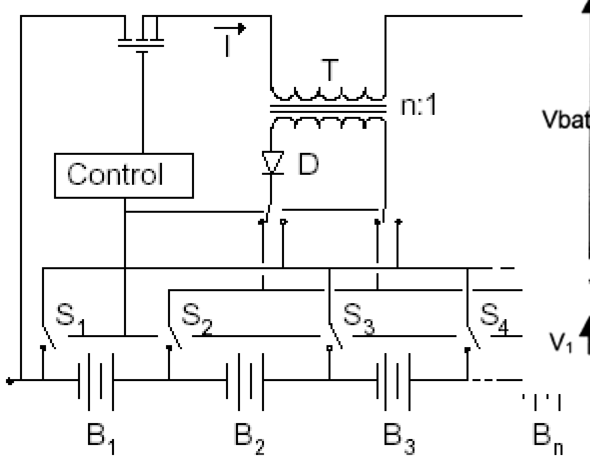
- ...to the less simples !

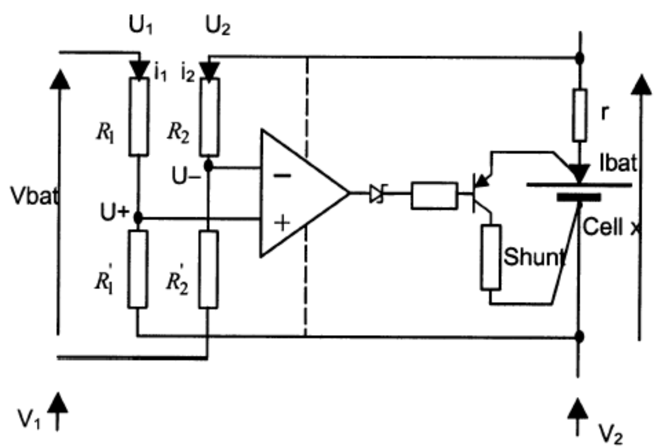


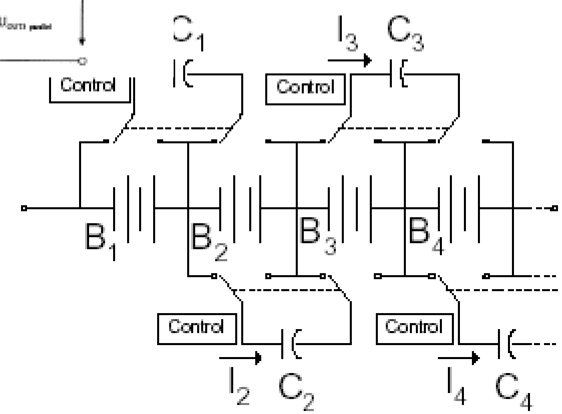












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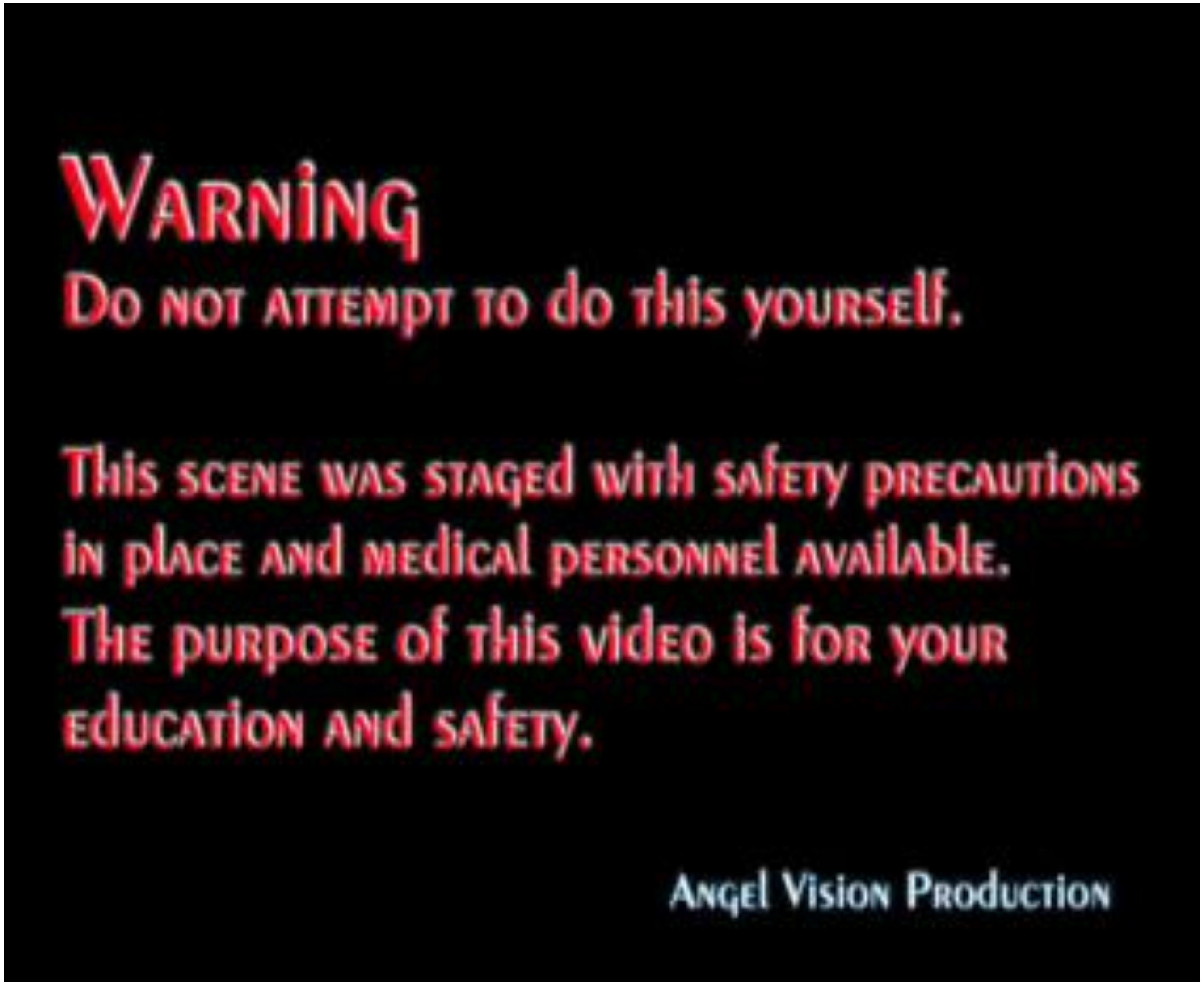
ENERGY STORAGE

Li-Ion Battery management



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ENERGY STORAGE

Li-Ion Battery management

Telecom Li-Ion Battery management (//-Serial association battery)

- ❑ Charge : Taper charge is used at battery voltage level
  - Charge current decreased when voltage reached
    - Avoid overcharge
    - Perform a fully battery charge
    - Cell voltage balancing need to be performed for a fully charge

- ❑ Discharge
  - Discharge is stopped when one cell reach low voltage thresold
    - Allow to avoid overdischarge

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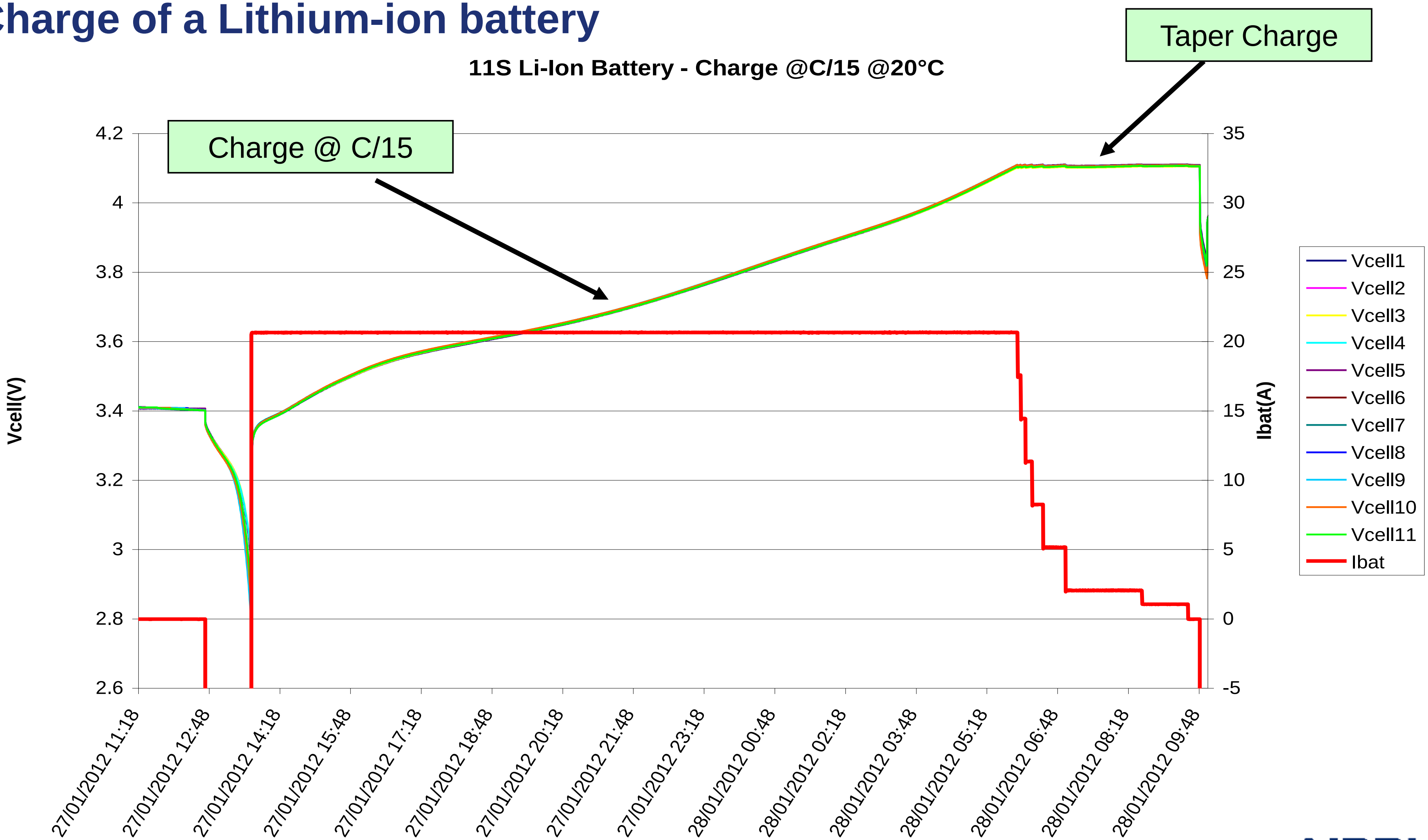
ENERGY STORAGE

Li-Ion Battery management

Charge of a Lithium-ion battery



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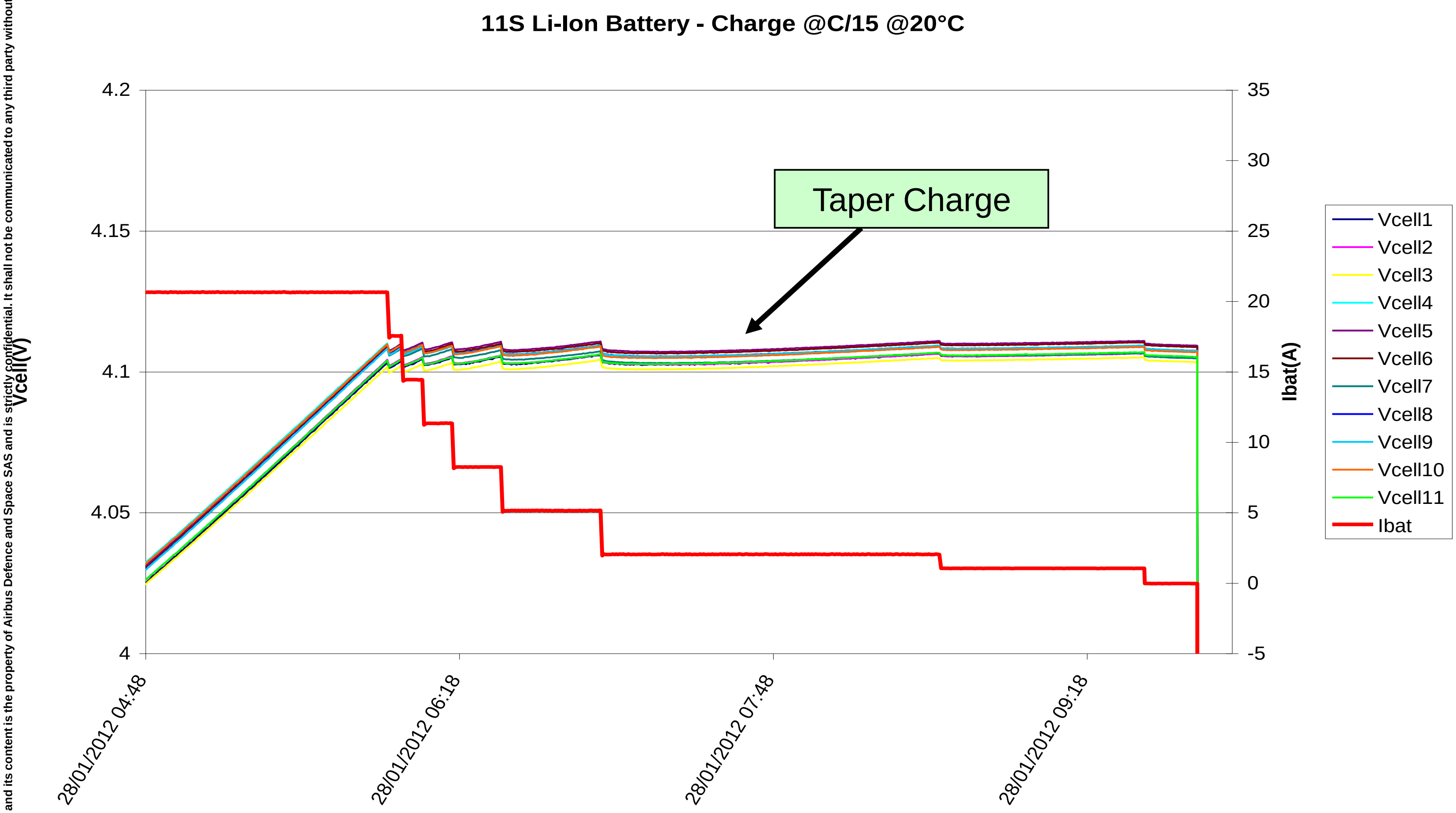
Charge of a Lithium-ion battery



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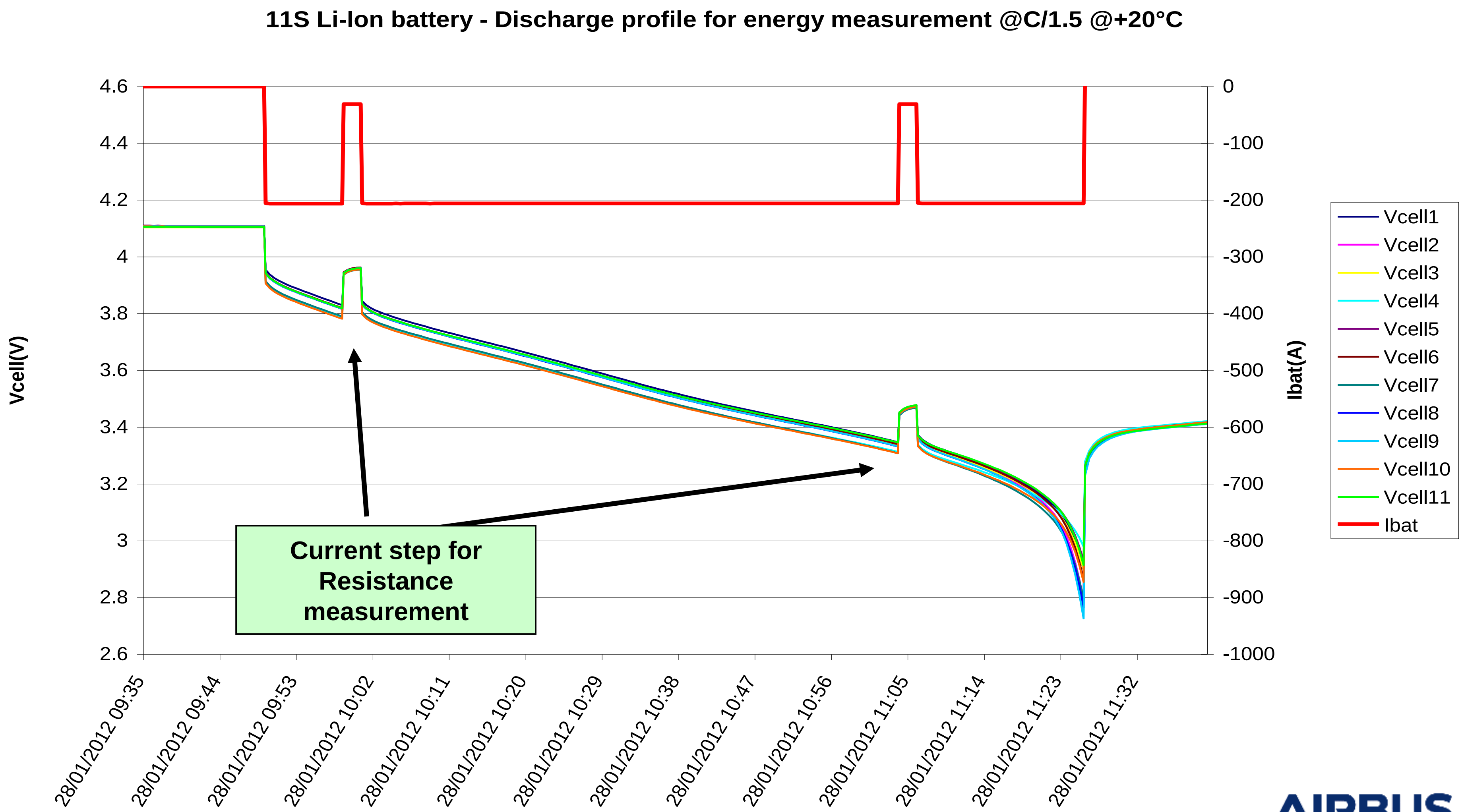
Li-Ion Battery management

Discharge of a Lithium-ion battery



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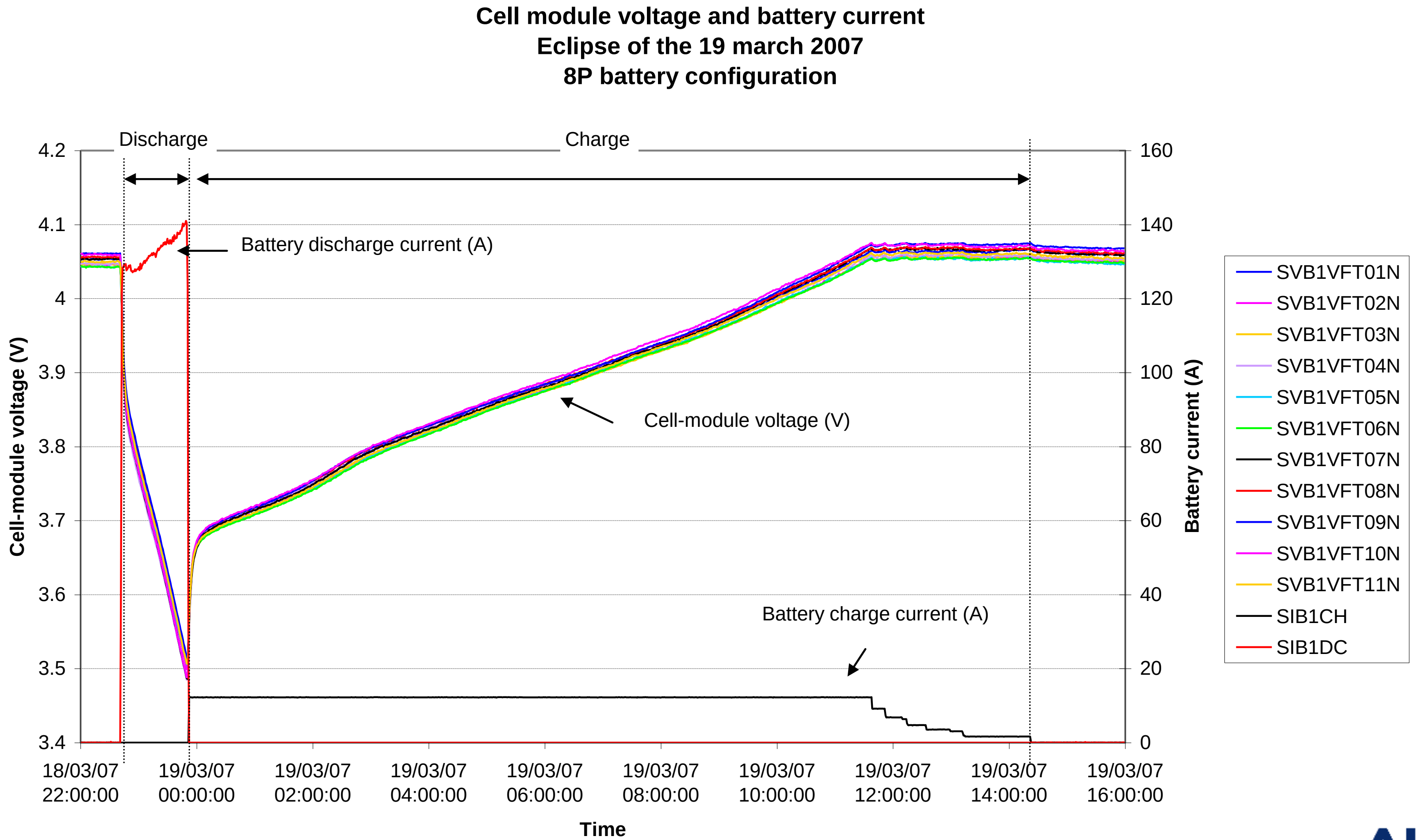
Charge and discharge voltage behaviour on Li-Ion Cell



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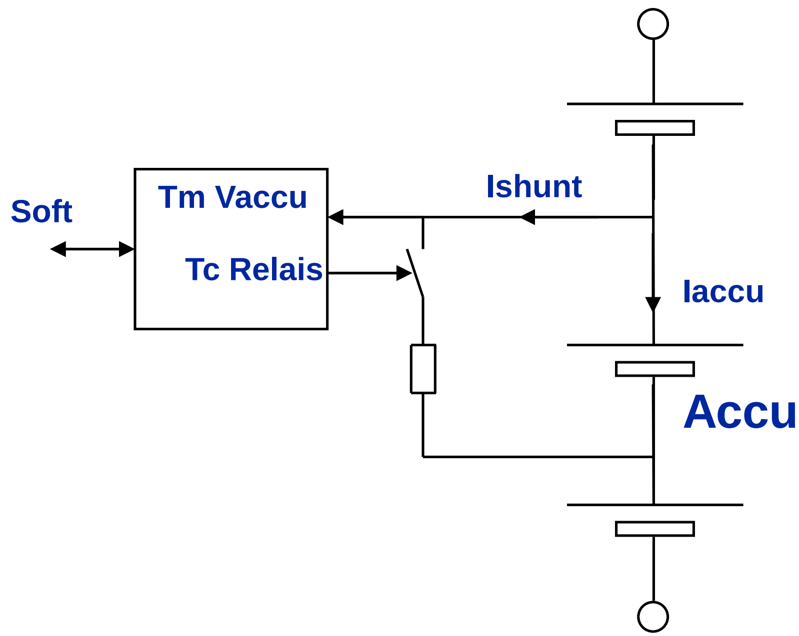
ENERGY STORAGE

Li-Ion Battery management

Li-ion CELL balancing

Each cell voltage is monitored by the on board software.
The cell SOC is derived from this measurement.
The on board S/W drives the relays in order to remove some capacity from the most charged cells and bring their voltage down.
The maximum discharge current is close to C/200.

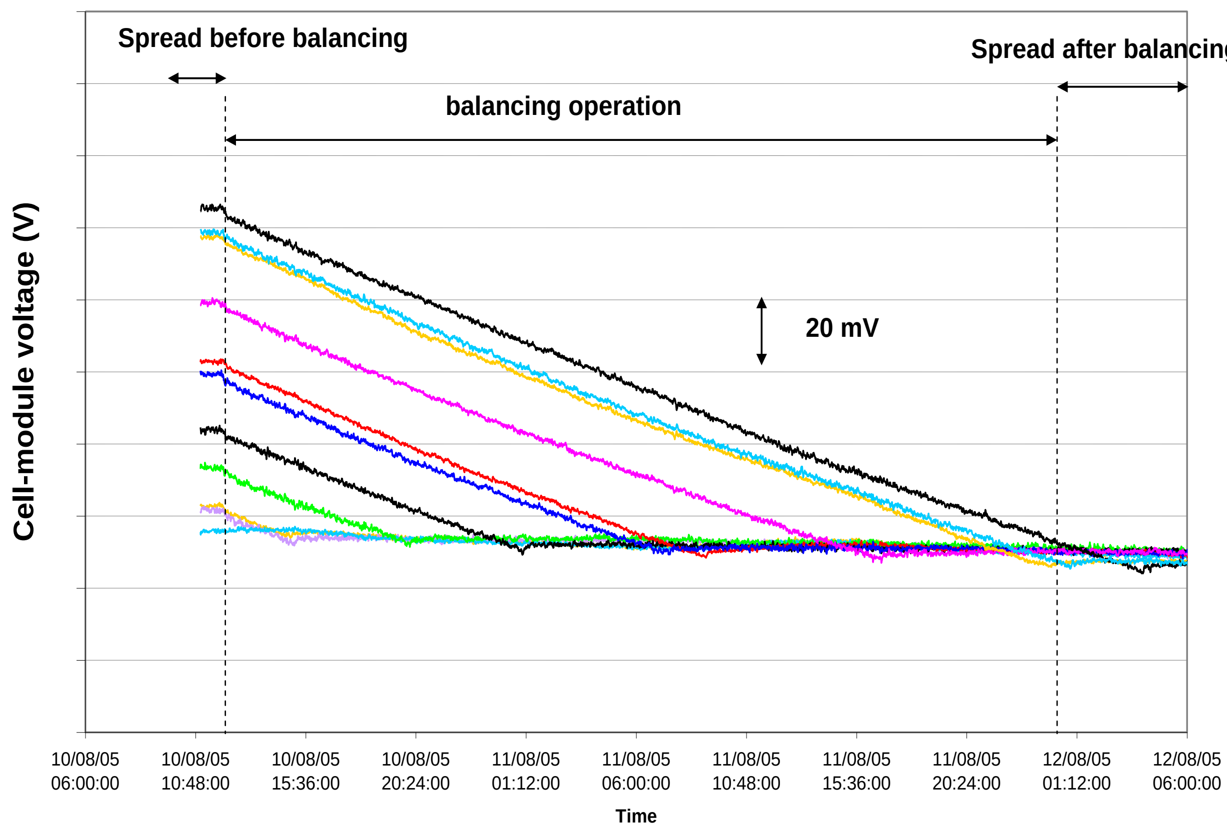


DEFENCE AND SPACE

ENERGY STORAGE

Li-Ion Battery management

And it works !



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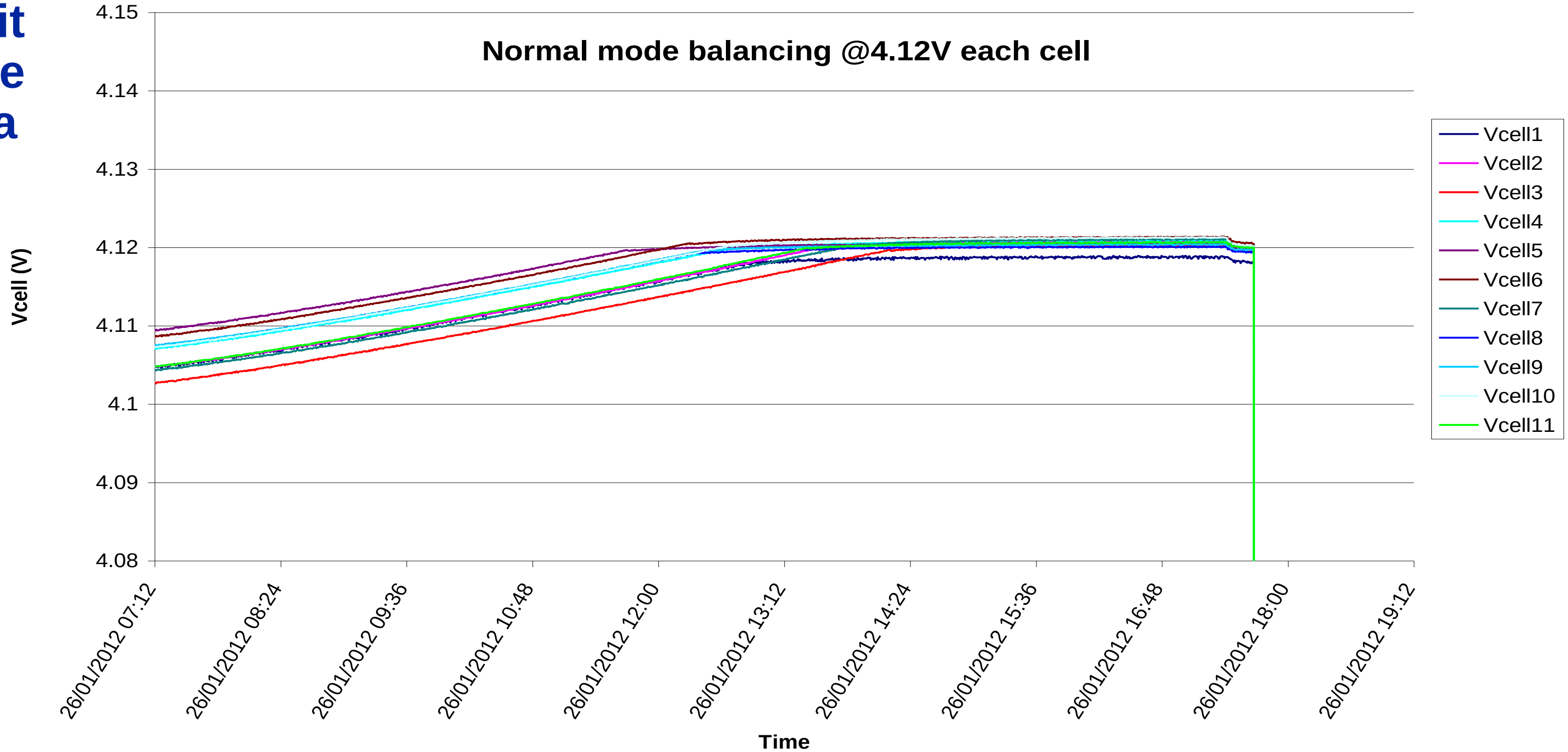
ENERGY STORAGE

Li-Ion Battery management

Li-ion CELL MANAGEMENT

Solution applied for EUROSTAR 3000 MK2

The system limit autimatically the cell voltage to a threshold



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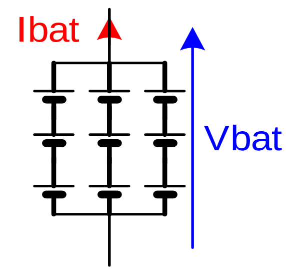
ENERGY STORAGE

Li-Ion Battery management

EOS Li-Ion Battery management (Serial-// association battery)

- ❑ Charge : Taper charge is used at battery voltage level
  - Charge current decreased when voltage reached
    - Avoid overcharge
    - Perform a fully battery charge
    - Cell voltage balancing
      - No need because several serial cells are set in // and allows to guarantee a good natural balance



- ❑ Discharge
  - Discharge is stopped when battery low voltage thresold reached
    - Allow to avoid overdischarge

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ENERGY STORAGE

Li-Ion Battery management

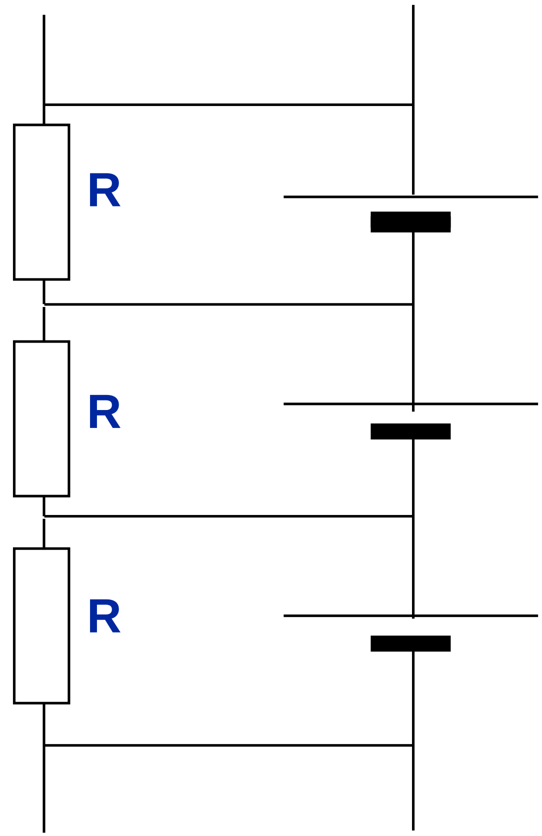
Possible solution for LEO spacecraft

On LEO the battery is never at rest, precluding the measurement of cell e.m.f.

Therefore the E3000 solution is not applicable.

The alternative is to permanently connect a fixed resistor across each cell. These resistors impose almost identical cell voltages by deriving a currrent that is large versus the cell self discharge one.

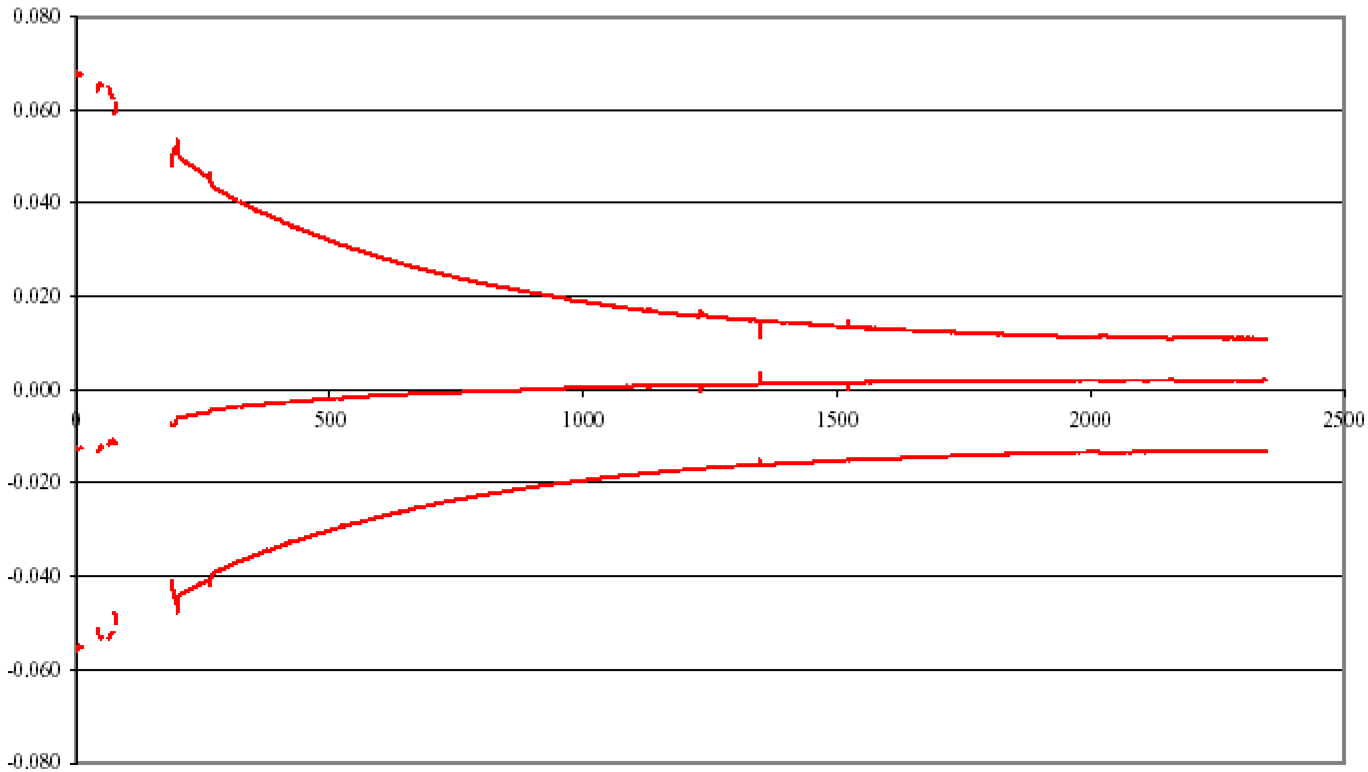
This current is also close to C/200, but is drained constantly, impacting both the energy budget and the battery thermal control.



ENERGY STORAGE

Li-Ion Battery management

And it works :



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ENERGY STORAGE

Failure mode

CELL Failure Mode in battery association

Technology	Failure mode	Root cause
NiCd	Short-circuit	Cd migration
	Open circuit	Electrolyte leakage
NiH2	Short-circuit	Unlikely
	Open circuit	H2 leakage
Li-ion	Short-circuit	Li dendrites
	Open circuit	Electrolyte leakage

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ENERGY STORAGE

Failure mode

CONSEQUENCES OF A FAILURE AT BATTERY LEVEL

- Short circuit
  - voltage drop due to the loss of the failed cell
  - possibly, disconnection of the battery under concern
- Open circuit
  - loss of the complete battery if made of a single string of cells
    - catastrophic in case of a single battery

Therefore the battery must be made immune to a cell open circuit failure

- Prompt the need for a bypass
- The open circuit failure mode is the sizing one and covers the short circuit case
  - the battery voltage is reduced by the failed cell one plus possibly the bypass drop

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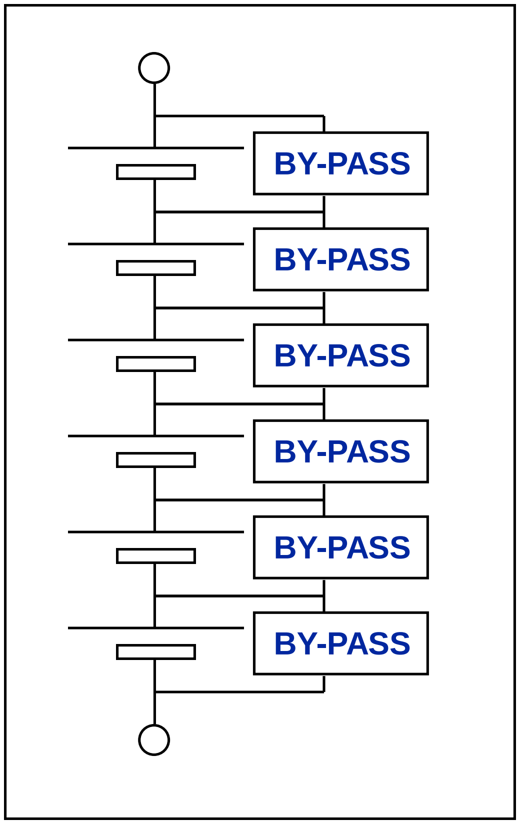
ENERGY STORAGE

Bypass system

BASIC PRINCIPLES



OBJECTIVE : to avoid the loss of a complete battery upon cell open circuit.

CONSTRAINTS :

- stay inactive as long as the cell operates normally (on charge and discharge)
- operate reliably upon cell failure.
- avoid currrent interruption during discharge
- have low insertion loss
- be as autonomous as possible
- be as lightweight as possible

SOLUTIONS :

- diodes
- electromechanical systems
- shape memory alloys
- MOSFET based circuits
- paraffine actuated systems
- low melting temperature metallic alloys

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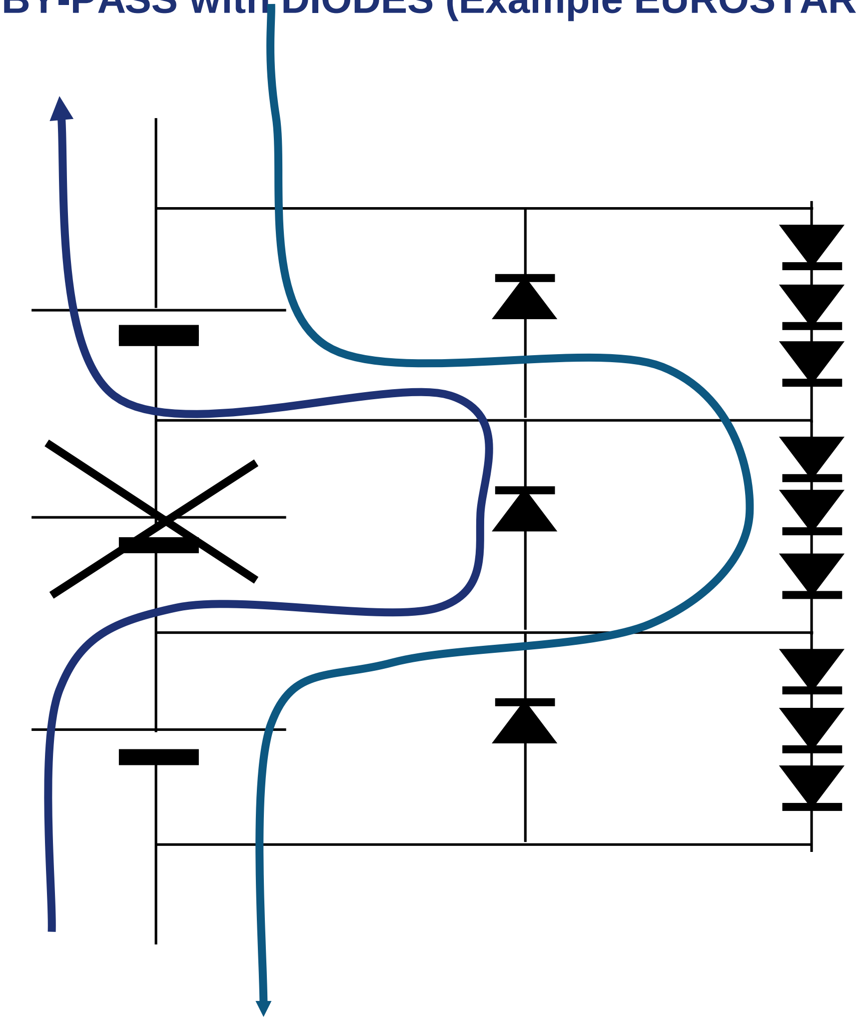
ENERGY STORAGE

Bypass system

BY-PASS with DIODES (Example EUROSTAR 2000, 3000)



ADVANTAGES :
- Autonomous
- Light : 66gr for 2 by-pass

DRAWBACKS :
- High dissipation
I discharge max = 160A
I charge max = 20A

APPLICATIONS :
- EUROSTAR 2000
- EUROSTAR 3000

MANUFACTURERS:
SSDI (USA)
Microsemi (USA)

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ENERGY STORAGE

Bypass system

BUT

- excessive dissipation on LEO, where the charging current is of the same order of magnitude as the discharge one
- not adapted to Li-ion, due to the high charging voltage
  - 8 to 9 series diodes would be requested
  - result would be a large dissipation, well in excess of the cells themselves

This prompt the need for non dissipative devices

- operate as a one shot relay
- single or double throw

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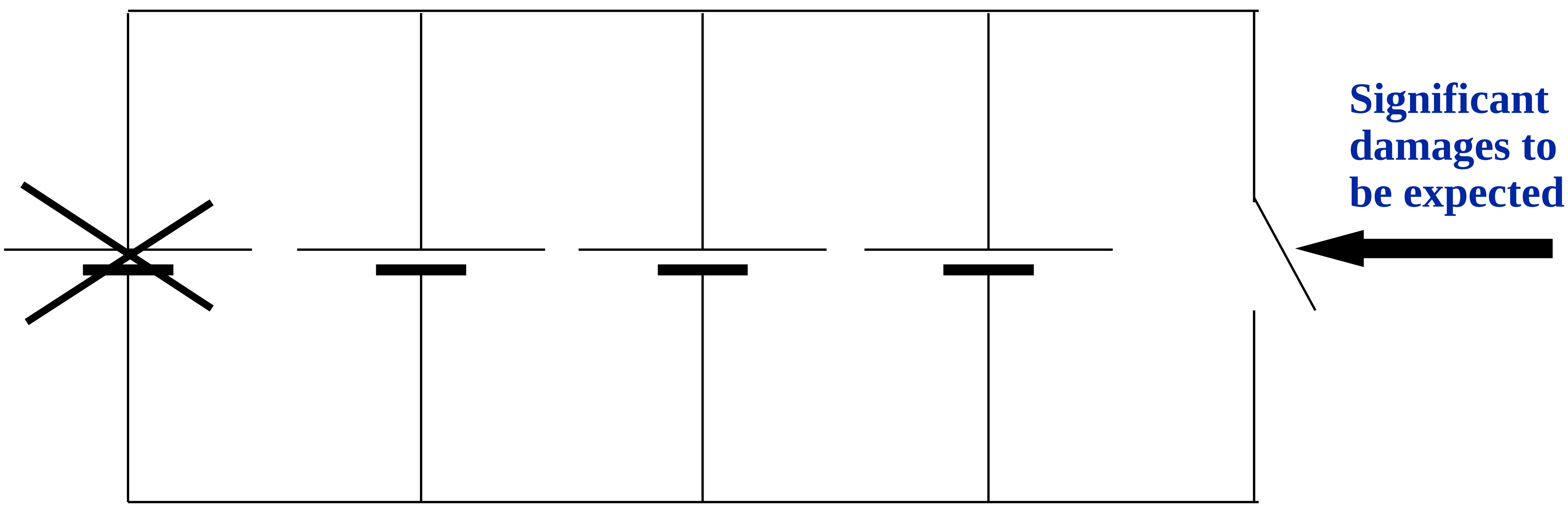
ENERGY STORAGE

Bypass system

SINGLE / DOUBLE THROW

- For a battery where several cells are connected in parallel, it is not possible to simply replace one failed cell by a short circuit :

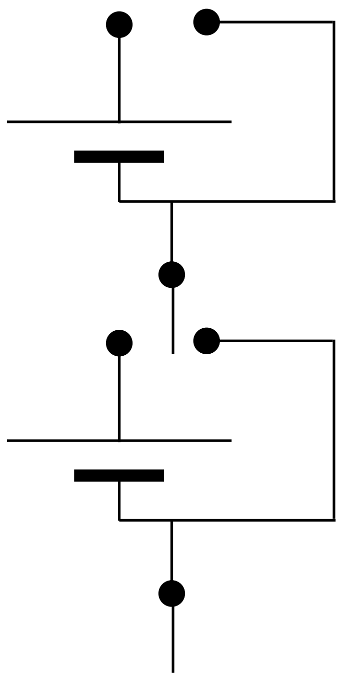


ENERGY STORAGE

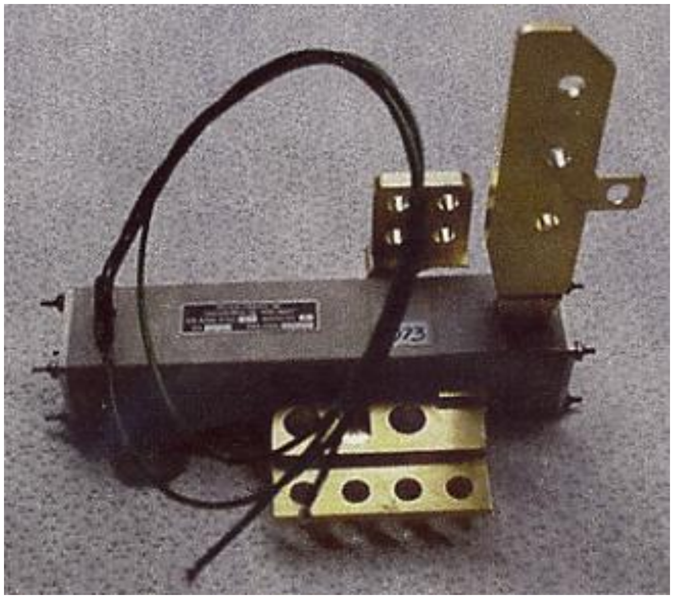
Bypass system

❑ SINGLE / DOUBLE THROW

- **a more complex double throw bypass is thus mandatory**



All the "normally ON" contacts are in series within the battery. To limit the ohmic losses, their series resistance must be very low. This means a rather large contact force that in turn does not help the transit toward the "normally off" position.



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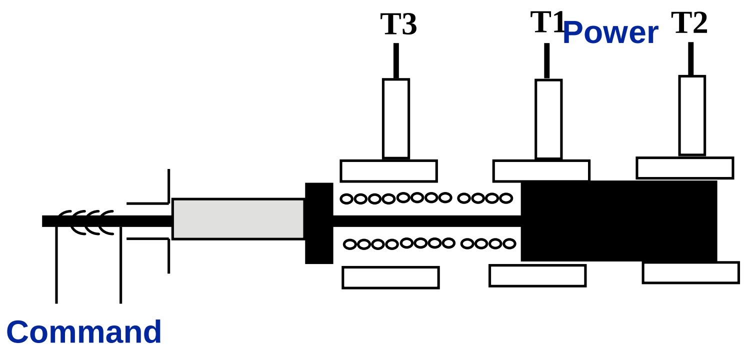
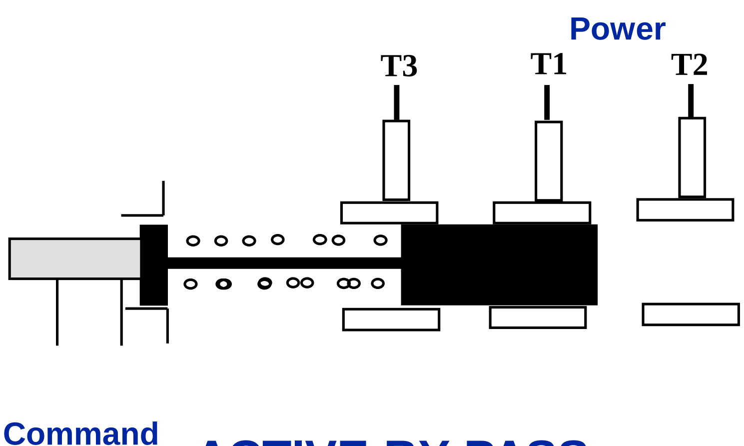
ENERGY STORAGE

Bypass system

ELECTROMECHANICAL BY-PASS



INACTIVE BY-PASS



ACTIVE BY-PASS

ADVANTAGES :
- very low dissipation

DRAWBACKS :
- not autonomous

APPLICATIONS :
- for large currents

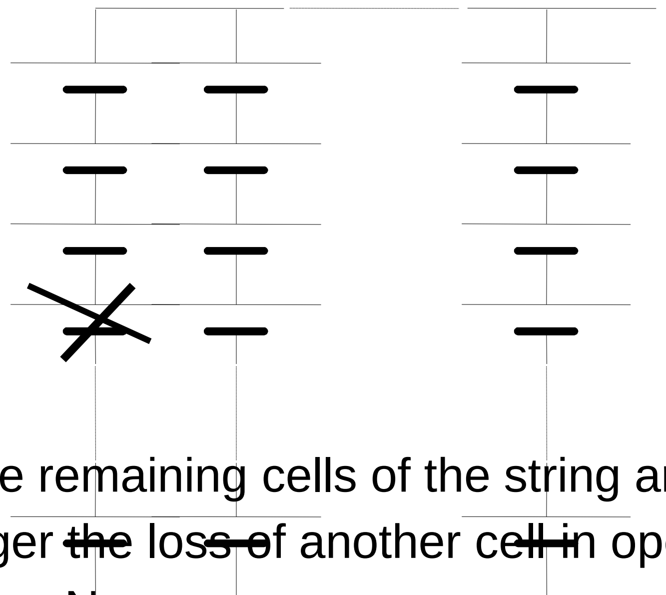
MANUFACTURER :
- NEA (USA)

ENERGY STORAGE

Bypass system

The approach based on small cells eliminates the need for bypass :

- open circuit failure : one string among N is lost (N ≈ one to several tens)



- short circuit failure : the remaining cells of the string are forced to a larger voltage that will ultimately trigger the loss of another cell in open circuit, also leading to the loss of one string among N

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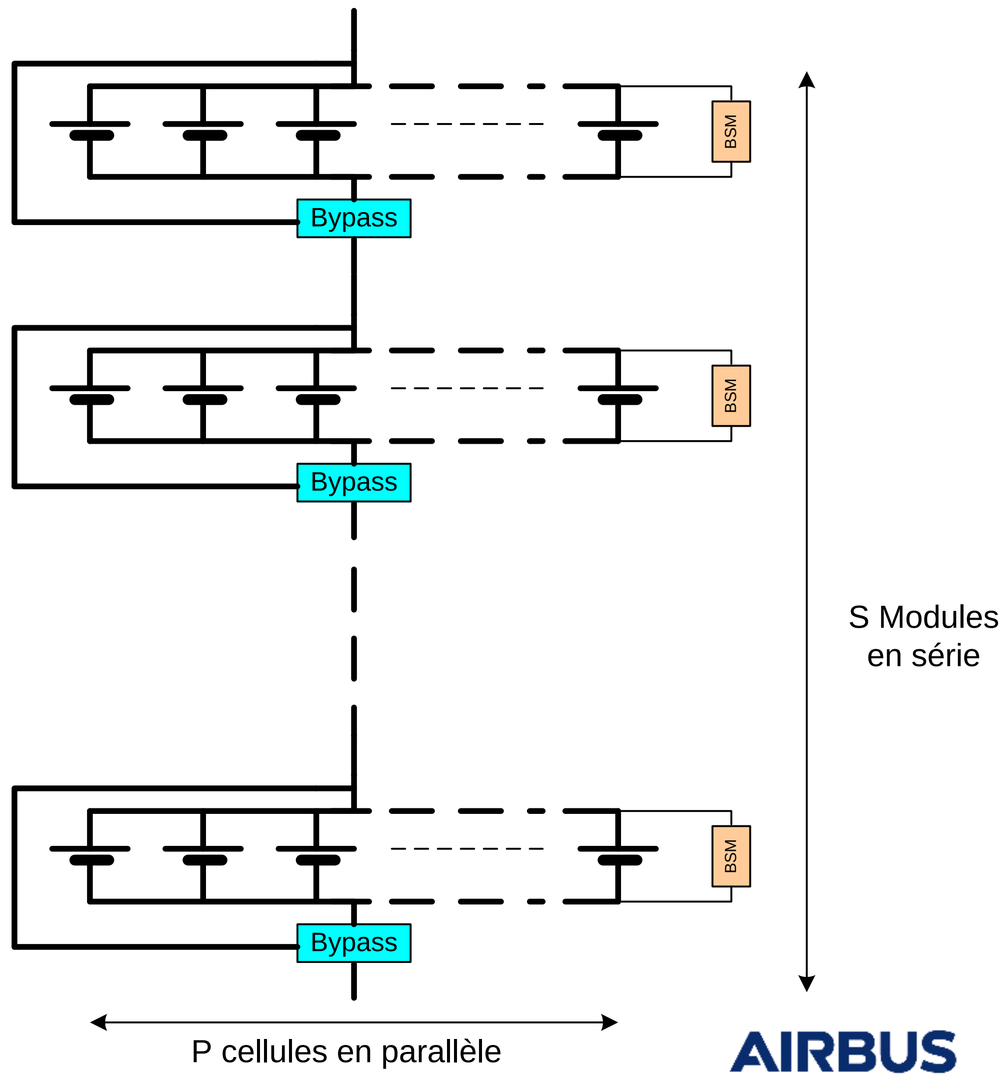
ENERGY STORAGE

Battery

ELECTRICAL DRAWING
OF A SAFT Li-ion BATTERY P cells in // (cell module)
S Cell Modules in serial

Each Cell Module included

- Bypass
- Balancing system



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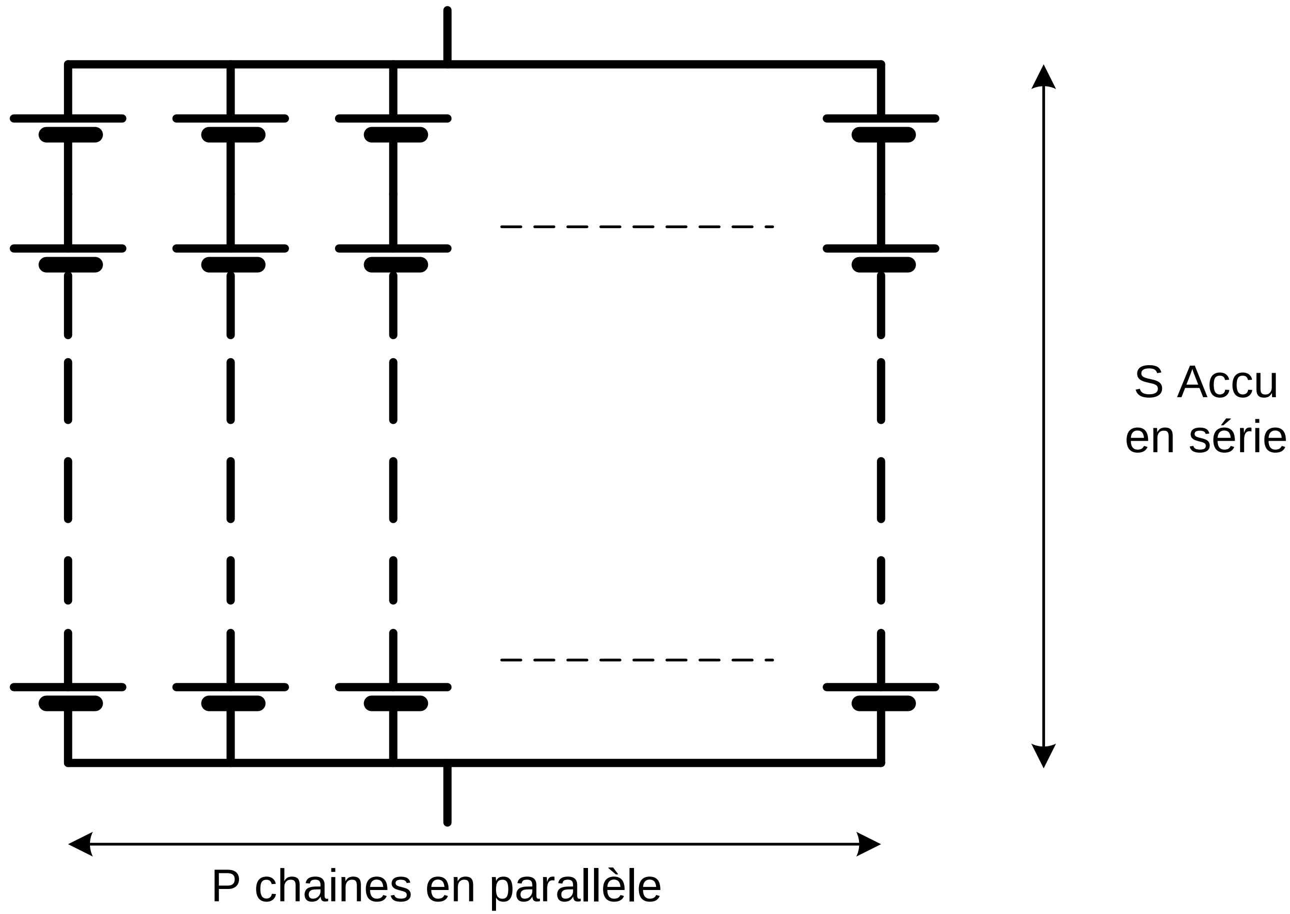
Battery(4)

ELECTRICAL DRAWING OF A ABSL Li-ion BATTERY (S-P)

- **S Cells in serial (String)**
- **P Stings in parallel**



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Battery(8)

Stentor

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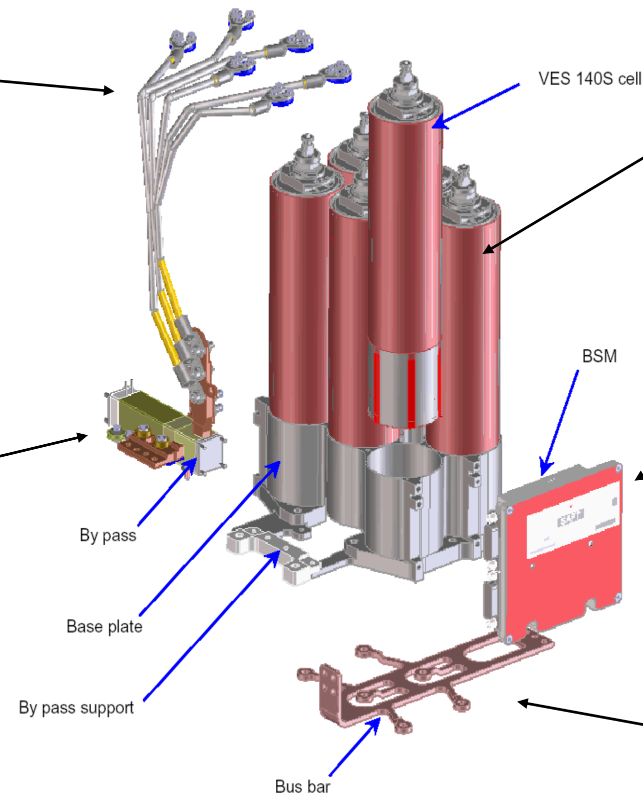
Battery(9)

E3000 cell-module design

Negative wire

SAFT
industrial VES 140 cells



Electronic board provide by EREMS and called BSM

By-pass device from NEA

Positive bus bar

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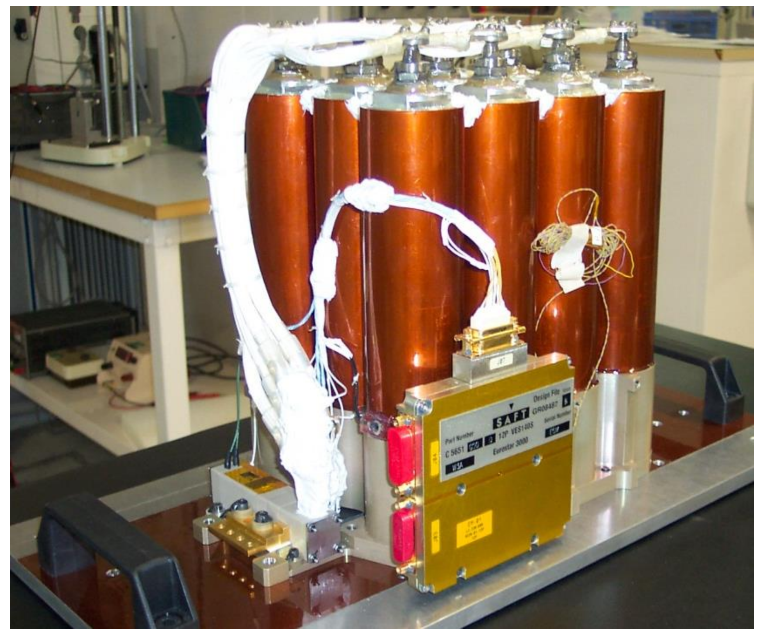
Battery(10)

E3000 cell-module design

6P Cell-module (230* Ah, 830* Wh)

12P cell-module (460*Ah, 1620* Wh)



* 20°C, EOCV = 4.1V and full discharge at C/1.5 rate

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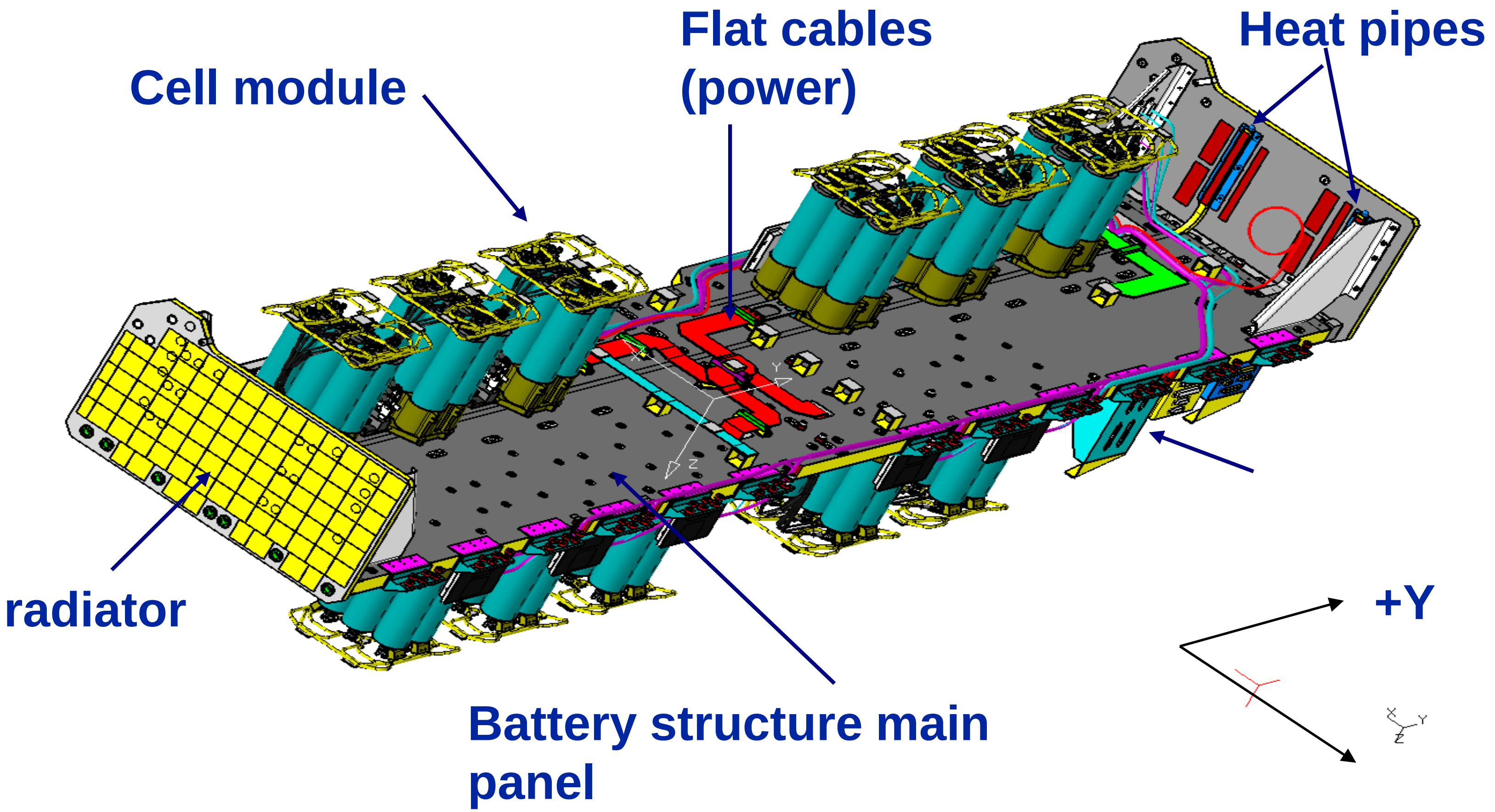
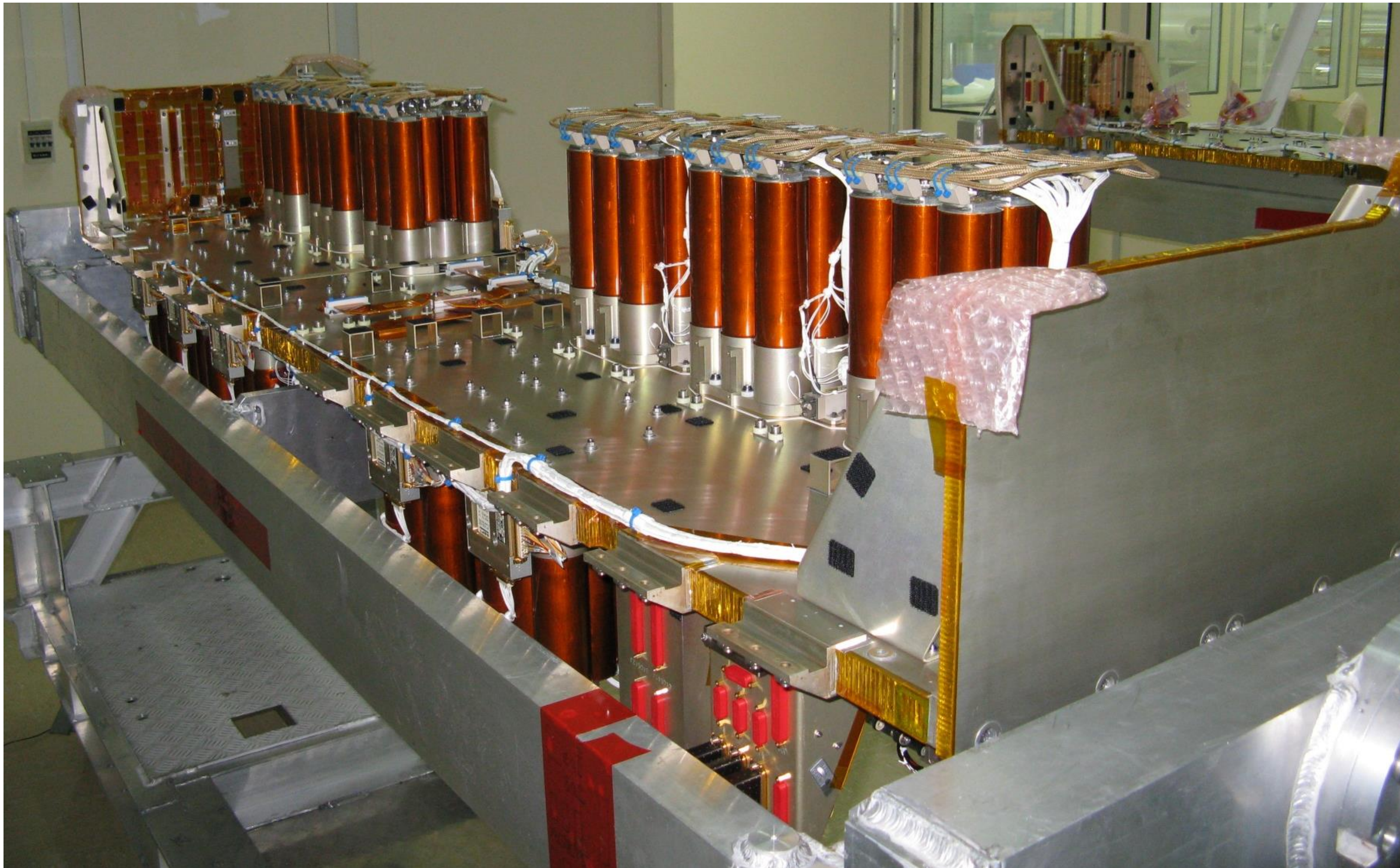
Battery(11)

E3000 batterie design



Battery(12)

E3000 batterie design



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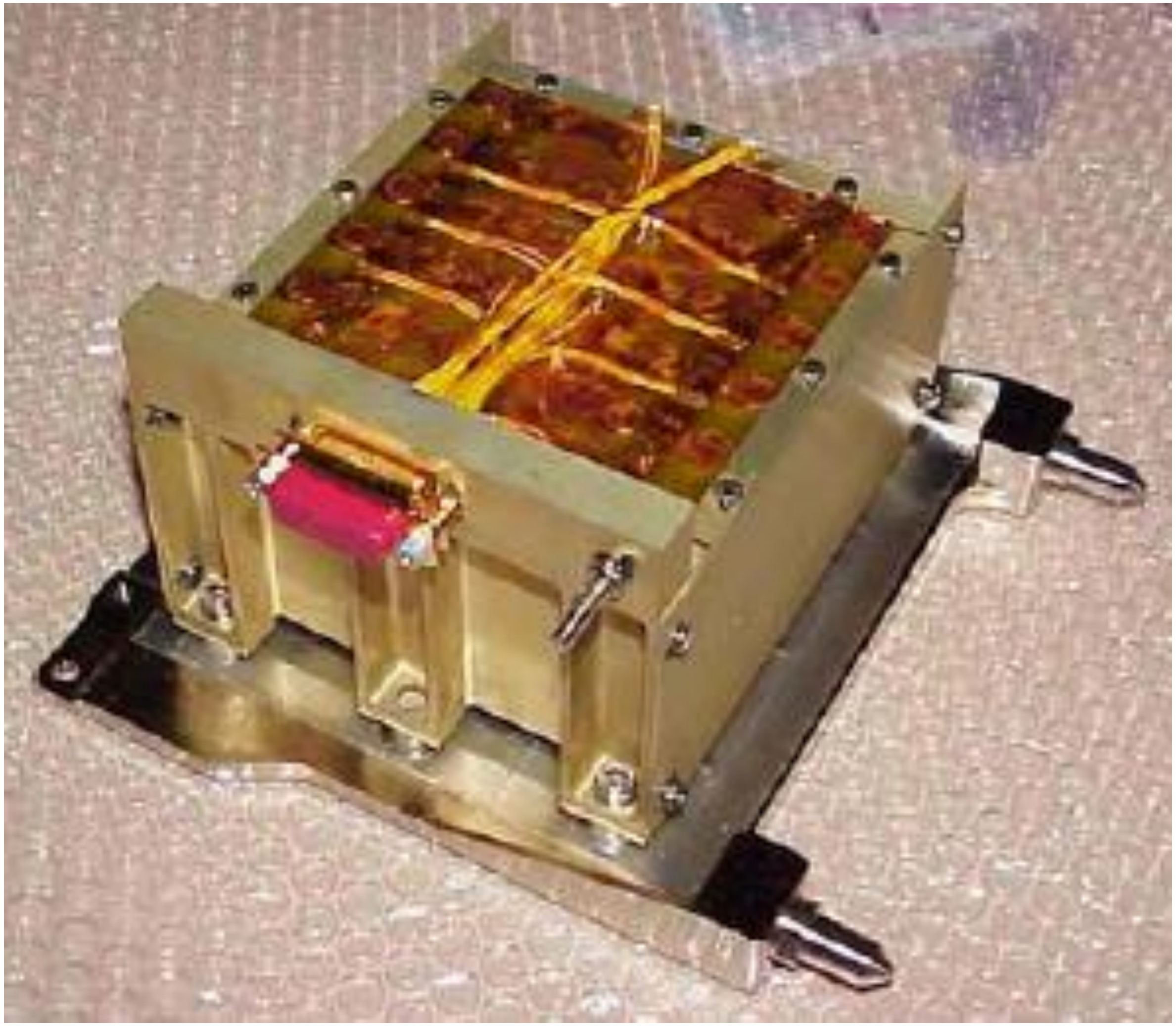
Battery(13)

PROBA



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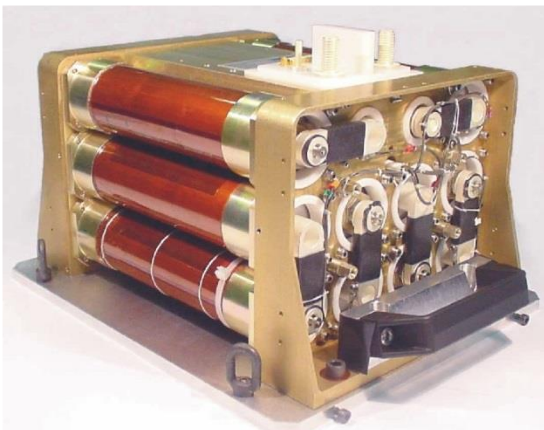
Battery(14)

Exemple of SAFT applications for launcher *(2008 ESPC)*



The KSR III rocket
High power battery for TVC
36V 35Ah pulses up to 600 A
First Li-Ion TVC launcher battery
Successfully launched in 2003

VEGA Battery module 15S VL8P
55 V 8 Ah
The modules have to cope
harsh environment
e.g. very high pyrotechnical shocks 24,000 g

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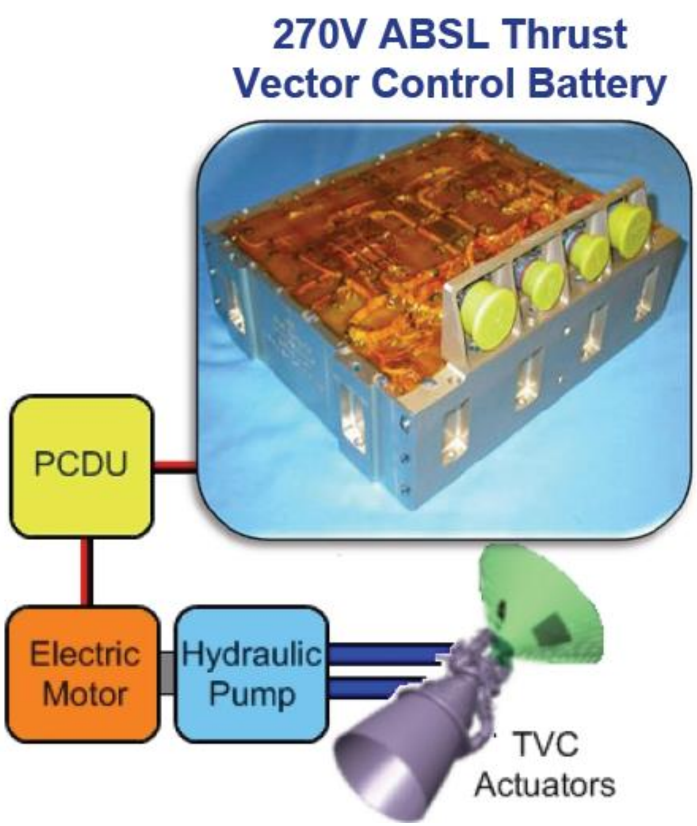
Battery(15)

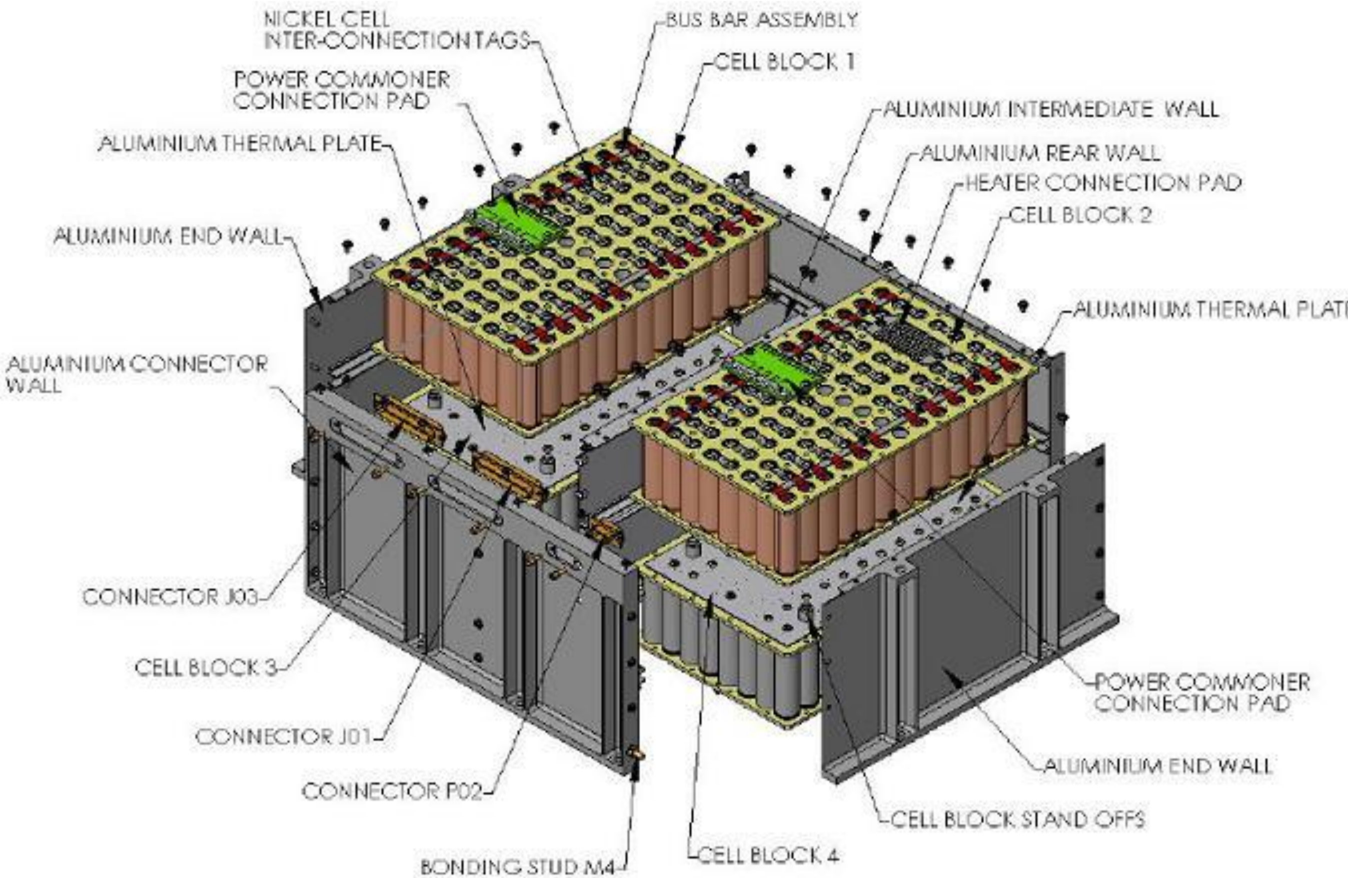
- **Examples of ABSL applications *(2007, NASA battery workshop)***
- **KSLV1 launcher batteries.**



Parameter	Performance
Cell	ABSL 18650HR
Configuration	84s2p
Capacity	2.2 Ah
Open Circuit Voltage	344.4 V
Mass	On request
Volume	On request

Battery(16)

ABSL 150 Ah



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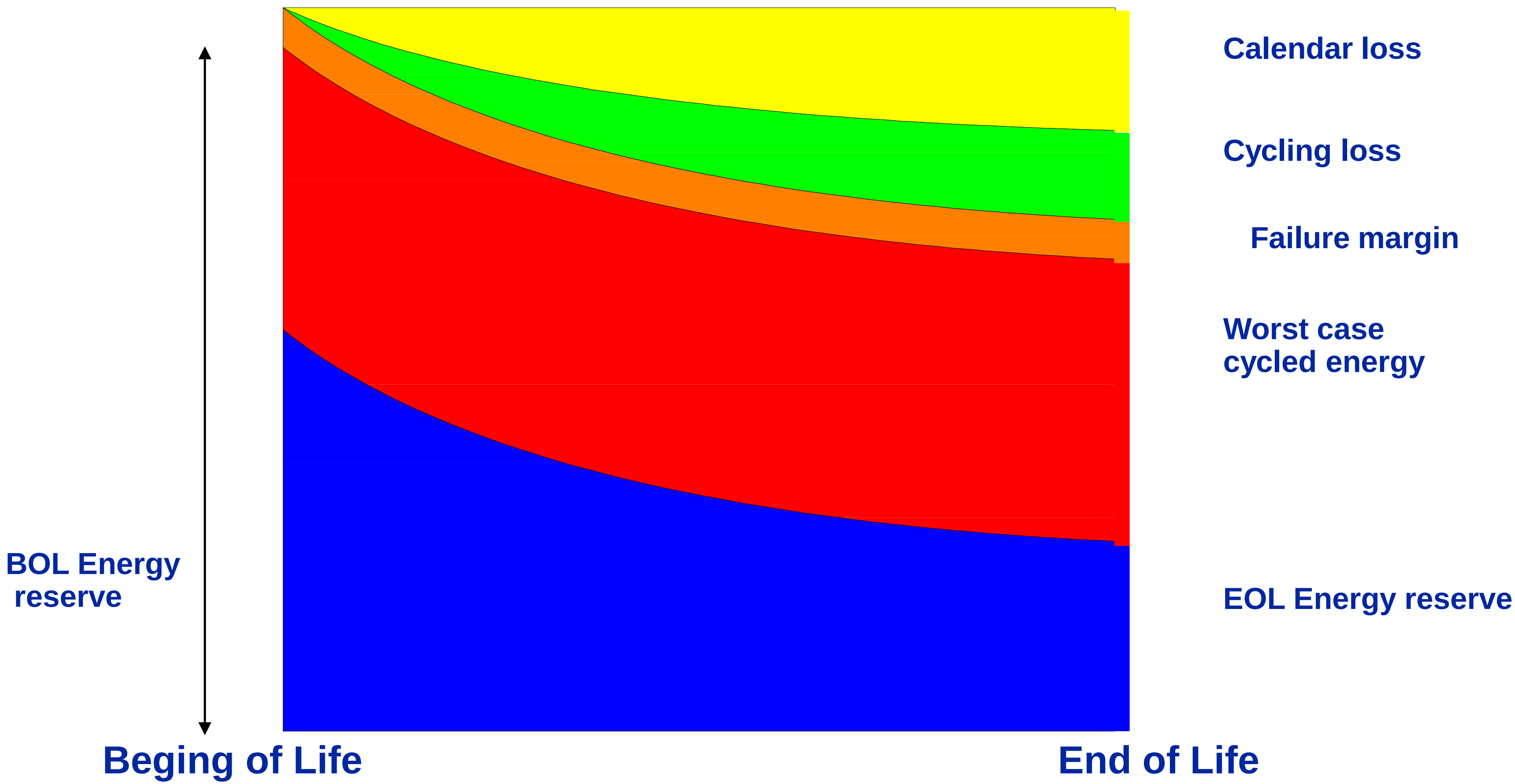
Battery(17)

Sizing Approach



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Battery(18)

AGEING PHENOMENA

- All electrochemical systems degrade with age, even if not put into use.
- Decay is more or less significant depending on the technology and the storage conditions
- Decrease in available capacity and increase in series resistance are the main effects. Evolution in self discharge current is also observed.
- This is called calendar ageing (in contrast to cycling ageing)
- It can be characterised by storing groups of cells under well defined voltage and temperature conditions and performing measurements of critical parameters at intervals.
- Currently only Li-ion presents significant calendar ageing (also called fading)

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Battery(19)

BATTERY CYCLING

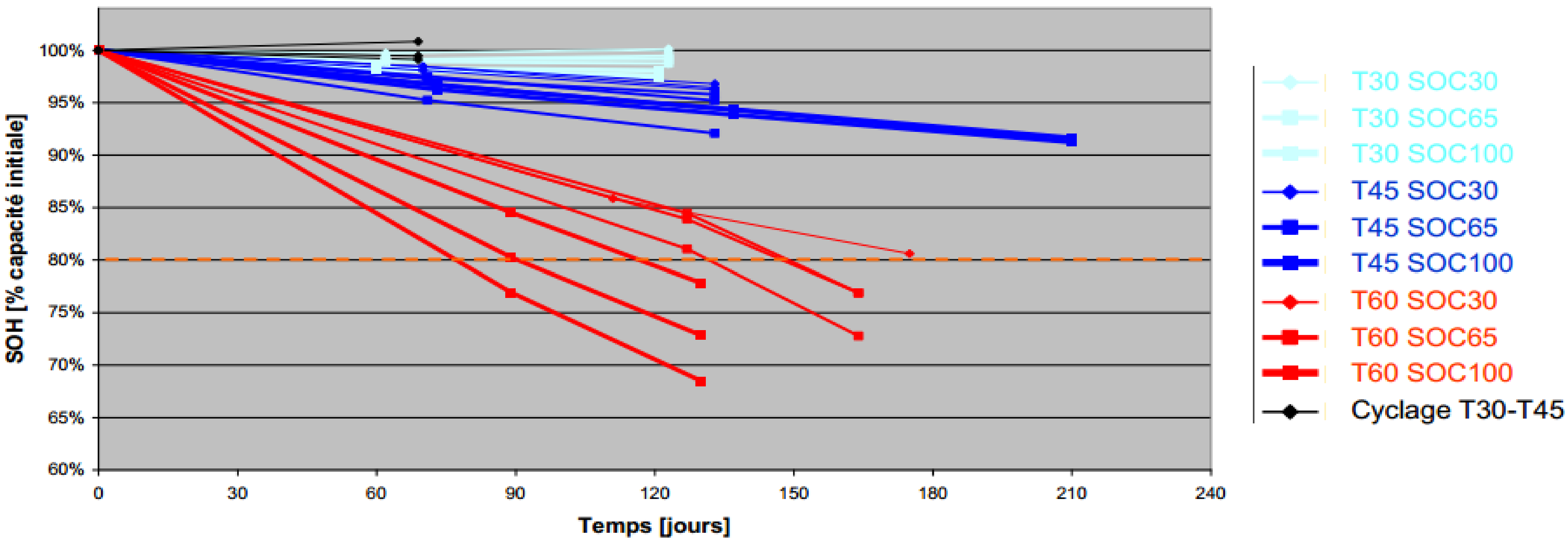
- Definition : for a battery, a cycle is made of a discharge followed by a recharge.

- Cycling is driven by the orbit :
  - GEO : 90 eclipses per year * 15 years = 1350 cycles
  - LEO : depends on the detailed orbit parameters. For a SPOT like Sun synchronous orbit, one revolution is accomplished each 100 minutes, leading to ca. 5300 cycles per year, i.e. 26500 cycles for a 5 years mission.
  - Example of SOHO : the S/C is always sun pointed on station, so no eclipse. The battery is used only for LEOP and to deliver peak power.

- The resistance of a battery to cycling depends on its electrochemistry and on a number of related parameters (Temperature, DOD, maximum voltage...).

Battery(19)

Calendar Ageing



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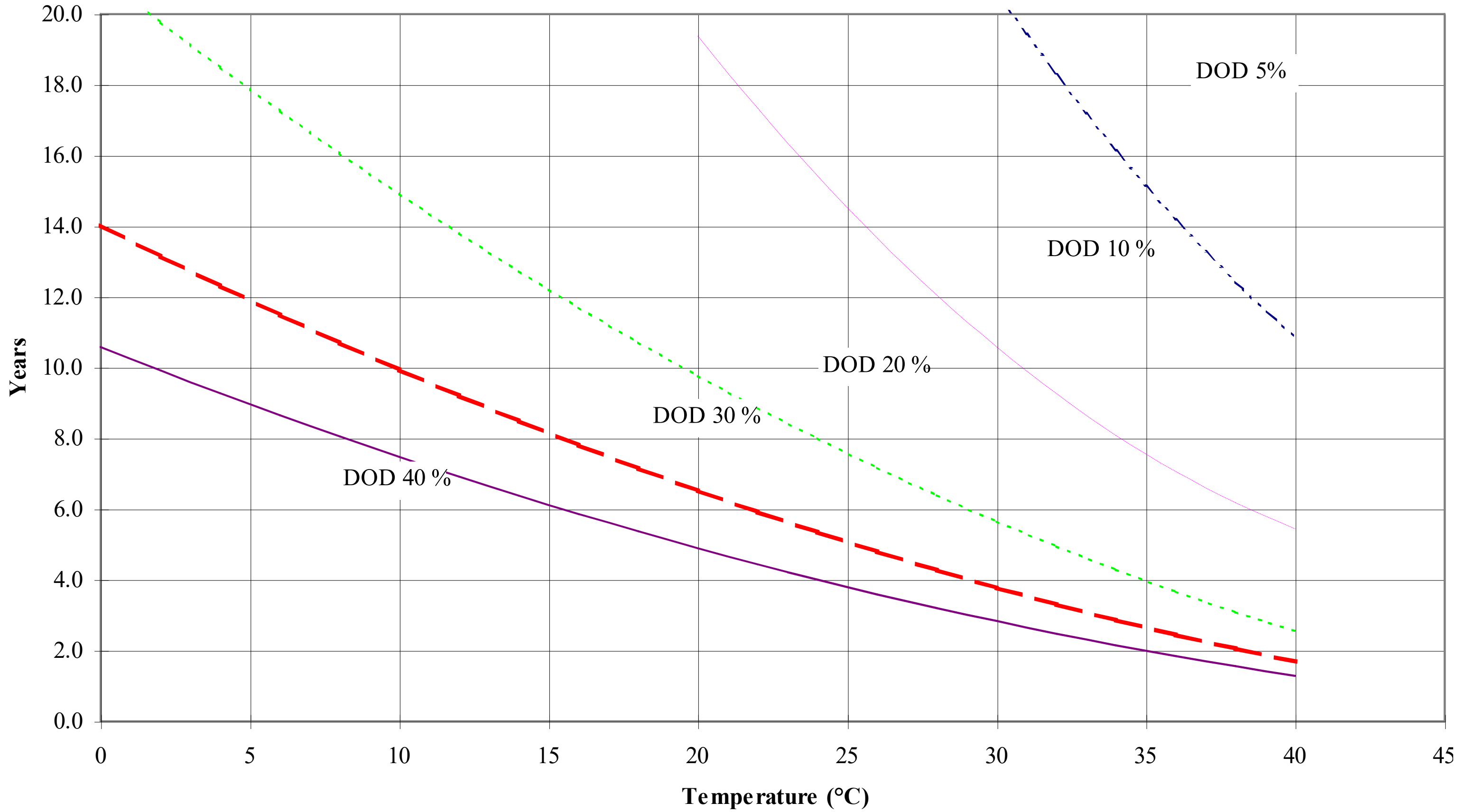
Battery(20)

BATTERY CYCLING – LIFE CYCLING TEST

- Estimated lifetime on LEO of a NiCd battery versus DOD and temperature (Results from ESA/CNES ELAN programme)



SUMMARY

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Summary

Main Space storage system :

- **cells in batteries**
- **Actual main use : Li-Ion cells**

Battery management

- **Very Important depending of the cell technologie**
- **Bad management catastrophic**

Battery sizing

- **Ageing to be take in account**
- **Cycling kind**
- **Storage condition are very important (before and during use)**

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Questions