"AGILE" BATTERY TECHNOLOGY TRANSFER - LESSONS LEARNED

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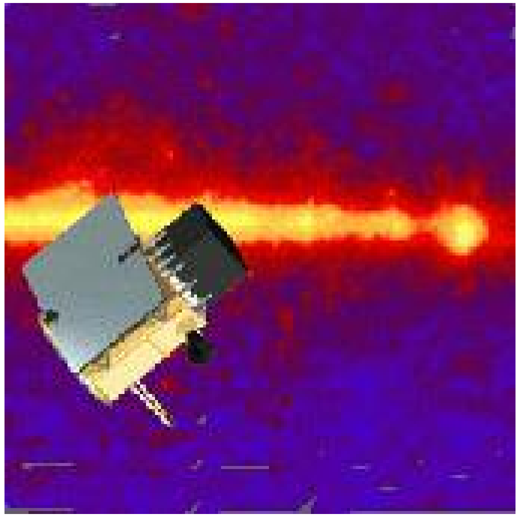
Photos D.R.

The Agile mission

- **Agile:**
  - Astrorivelatore Gamma a Immagini Leggero
  - 350 kg LEO satellite
  - Funded and managed by the Italian Space Agency (ASI)
  - Prime contractor Carlo Gavazzi Space S.p.A.
  - Simultaneous detection of hard X-ray and gamma-ray cosmic radiation (15-60 keV and 30 MeV - 50 GeV)
    - Active Galactic Nuclei and clusters of galaxies
    - Galactic Black Holes, Microquasars, etc.
    - The massive Black Hole at the Galactic Center
    - Gamma-Ray Bursts
    - Pulsars
    - Unidentified gamma-ray sources
    - Supernova Remnants
    - TeV sources
    - Gamma-ray diffuse emission
    - Fundamental Physics



The battery challenge

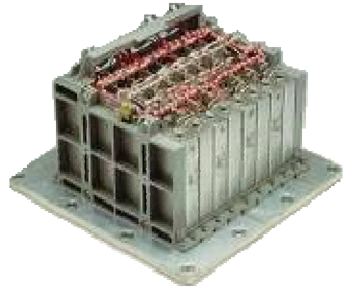
- **Early in 2006, AGILE was still pending the ITAR green light to use the already delivered Ni-H2 batteries**

- **Necessity to find a backup solution**
  - Flexible
  - Robust
  - Compliant
  - Quickly available

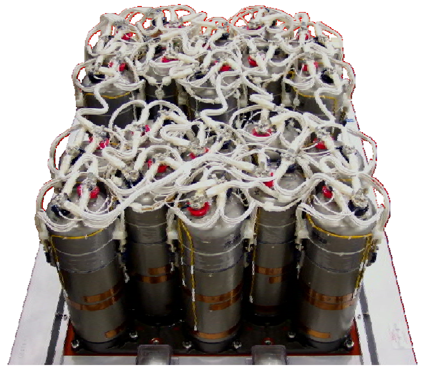
- **Saft was consulted to help**

Battery status at Saft at that time

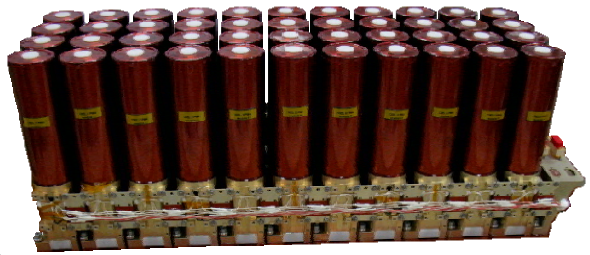
- **Conventional technologies**
  - Ni-Cd too heavy and bulky
  - Ni-H2 too ITAR and long to procure



- **Li-ion:**
  - Technically compatible and attractive:
    - Very compact and light solution
    - High performances (no memory effect)



  - Long history:
    - 1985: research on cell active material at Saft
    - 1992: selection of active materials
    - 1996: 1st Saft prototype cells and uses in industry



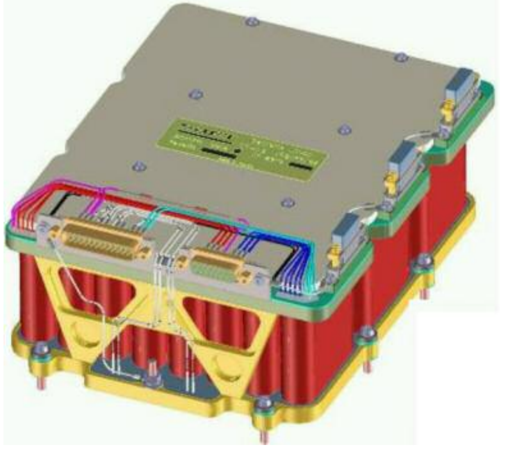
  - Heritage in progress:
    - 2002: Stentor launch, 1st GEO Li-ion (large VES cells)
    - 2004: W3A (E3000 Astrium), 1st GEO satellite in-orbit with Li-ion (VES cells),

The battery opportunity

- **Saft had already delivered the Proba-2 Li-ion battery to Verhaert Space**
  - ESA Program
  - Life test going-on (and still running today)
  - 7S3P MPS architecture
    - Mass 4.4 kg, capacity 16.5 Ah
    - Max voltage 28.7 V, avg 26.25 V, min 21 V

7S3P MPS (Proba-2)

- **Saft was also in the middle of the development of another µSAT-oriented module**
  - SAFT funding with CNES support
  - 8S3P MPS architecture
    - Voltage compatible with Agile
    - Procurement in progress
    - Possibility to adapt qualification tests for Agile



8S3P MPS “µSAT”

Cell selection

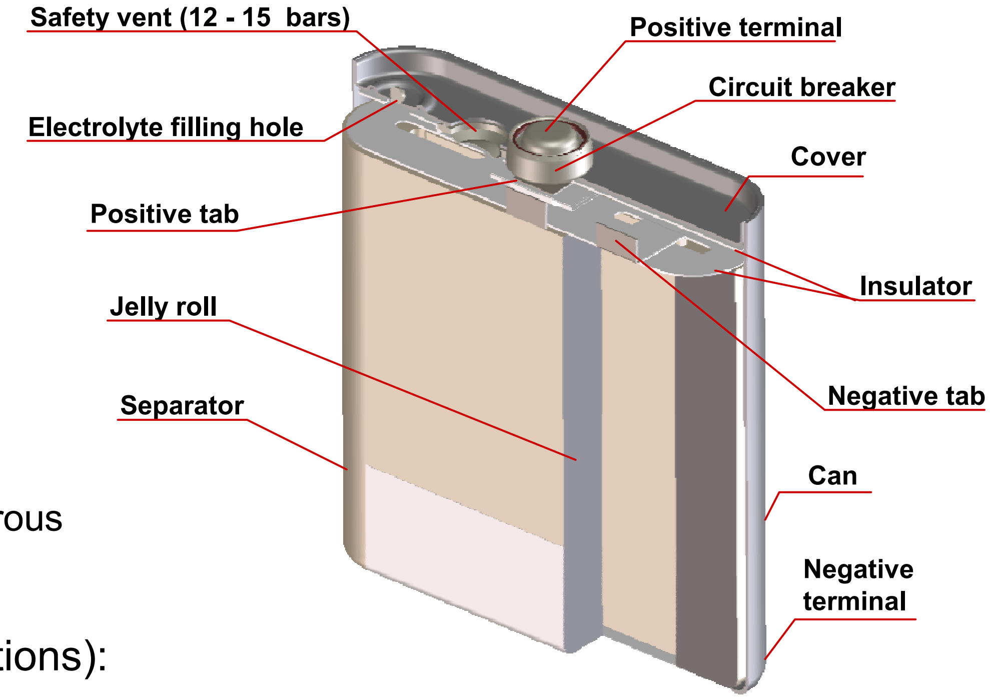
- **Saft MPS176065 Li-ion cell**
  - Main characteristics:
    - Energy: 20 Wh
    - Capacity: 5.8 Ah
    - Mass: 150 g
    - Dimensions : 17*60*65 mm
  - Industrial cell, space “lot” rules
    - Compliant with stringent regulations
    - Low discrepancy
    - Full control over production
  - Advantages:
    - Low fading
    - Small capacity format
    - Built-in protection devices
    - In-house product manufactured onto an industrial line (400 to 500.000 cells/per year)
  - Drawbacks:
    - Use of cobalt material for low capacity cells: higher fading than Ni-based chemistry used for GEO large Li-ion cells

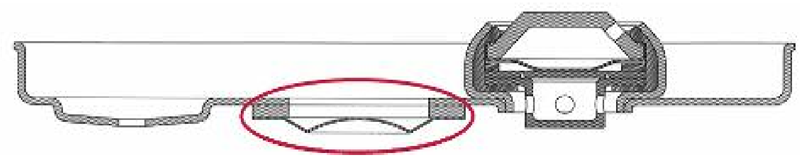
MPS176065 Li-ion cell

MPS cell main characteristics

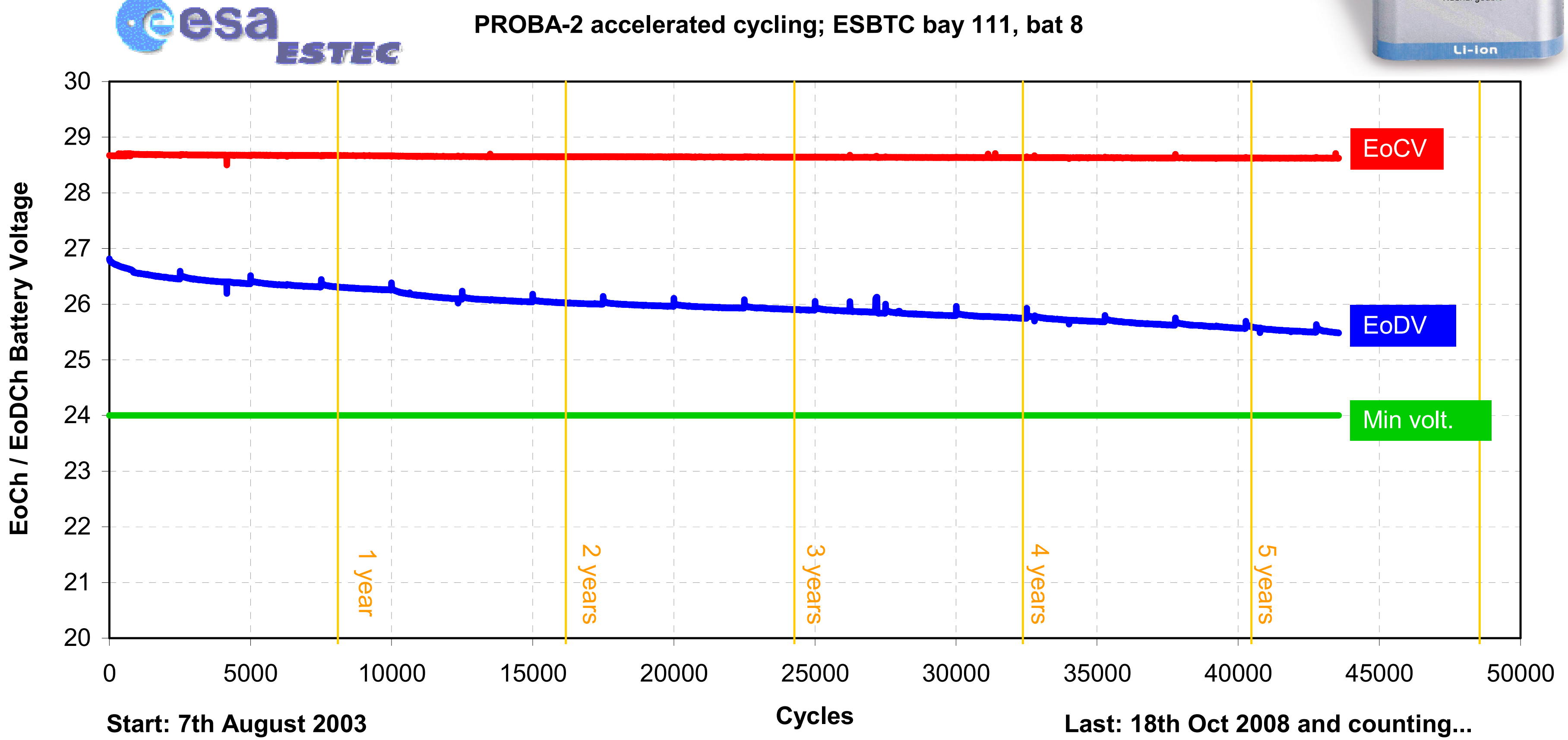
- **Chemistry:**
  - Cobalt oxide positive
  - Graphite negative
  - EA/DEC/EC/PC electrolyte 1M $LiPF_6$

- **Build-in protections**
  - Shut-down separator:
    - Polypropylene and polyethylene µ-porous separator
  - Mechanical current breaker (6 bars actions):
    - Protection against abuse overcharge
    - Activation by electrochemical reaction (irreversible) depending on voltage & temperature
  - Mechanical vent (12-15 bars):
    - To release high internal pressure (ie during exposure to fire)





MPS life-tests: Proba2



- **20 % DoD @ 20°C , 4.1V/cell, with individual resistive balancing**
- **Fading in line with prediction from electrochemical model**
- **More than 5 years, 43.500 cycles and counting**
- **Energy loss = 27 % only after 37.500 cycles (0.72 % every 1.000 cycles)**

A challenging : 3 Months to deliver

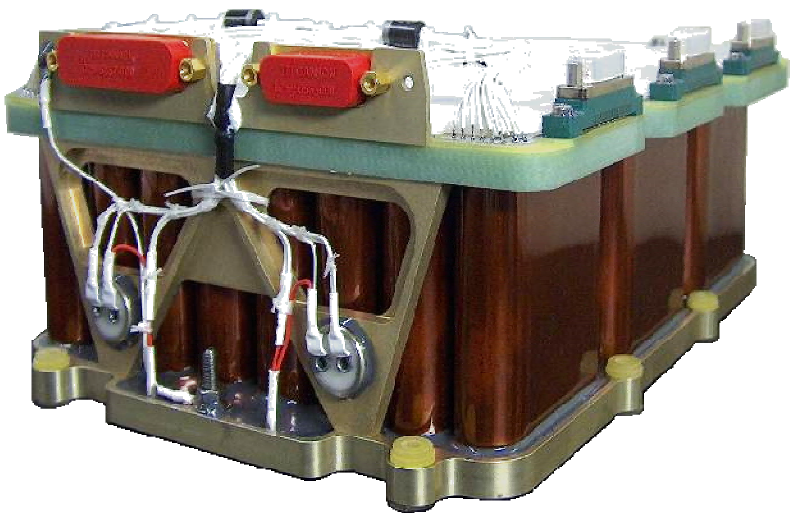
- **Kick-off: mid-April 2006**
- **Test readiness review: mid-June 2006**
- **FM delivery: mid-July 2006**
- **Battery integration and test: August-October 2006**
- **Satellite integration and test campaign: November-February 2007**
- **Satellite ready for launch: March 2007**
- **AGILE launch campaign: April 2007**
- **AGILE launch: 23rd April 2007**

The 8S3P module

Main features:

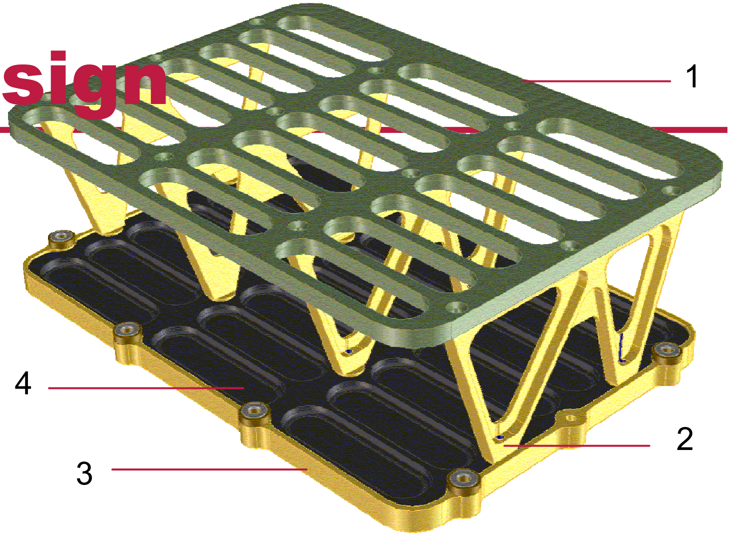
- Auto-balancing system
- Thermal regulation using thermostats
- Sensors for thermal monitoring
- Over-pressure & over-charge protection (included in cells)
- Compliant with EWR127
- ITAR-free
- Compliant with European Code Of Conduct For Space Debris Mitigation (ASI, BNSC, CNES, DLR, ESA)

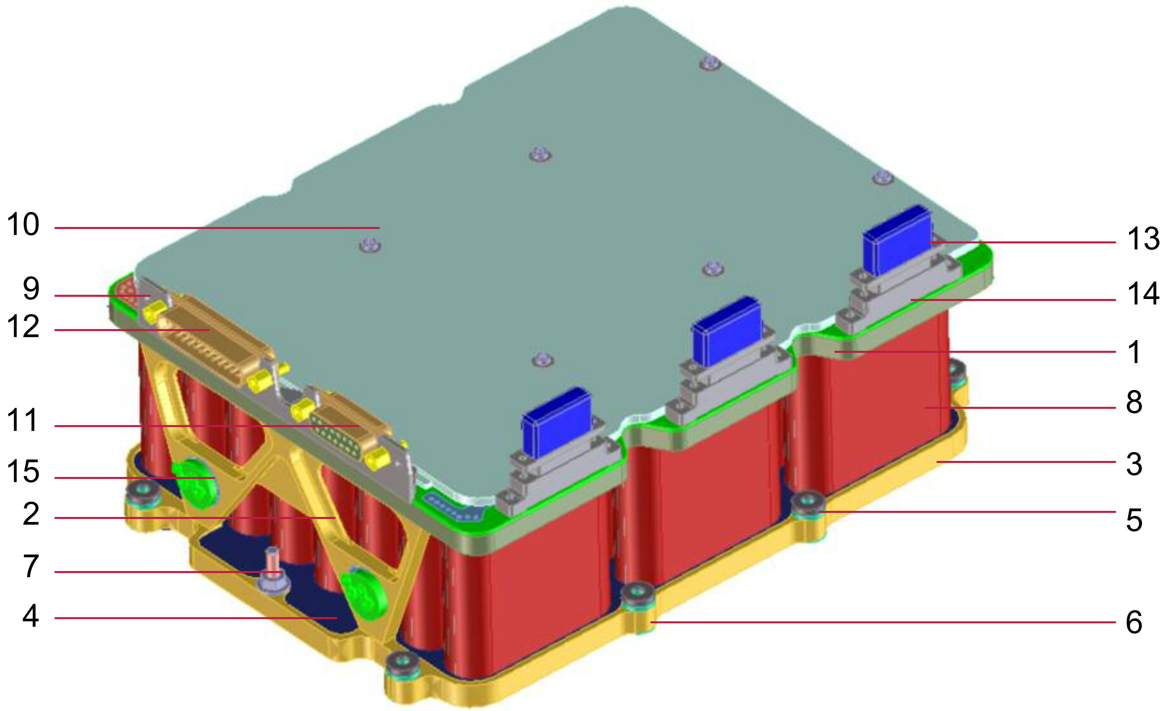
- **Module characteristics**
  - Battery configuration: 8s3p MPS
  - Mass: 4.5 kg
  - Dimensions: 225 x 175 x 100 mm3
  - Nominal capacity: 16.8 Ah
  - Energy BoL: 467 Wh
  - Typical use : 20% DoD, 20°C, for 7 years



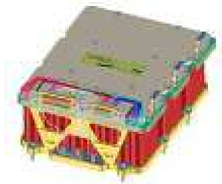
8S3P µLEO: module design

1. Top plate (laminate epoxy, SVA16)
2. stiffeners (aluminum 6061)
3. Base plate (aluminum 6061)
4. Resin (Scotchweld 2216)
5. Insulating barrel (SVA16)
6. Screw hole (x8 for M4))
7. Ground terminal (stainless steel, M4)
8. Cell MPS 176065
9. Equipped PCB
10. Cover (POM)
11. Power connector (SUB_D 15 S)
12. Thermal and EGSE connector
13. (SUB_D 25 P)
14. Balancing plug (Micro D 25 P)
15. Balancing connectors (Micro D 25 S)
16. Thermostat (COMEPA, model47)

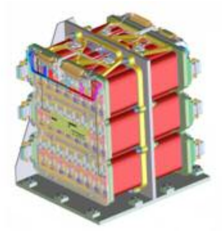




LEO: Extended Range Design 300W - 1200W

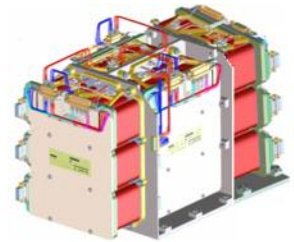


8S3P

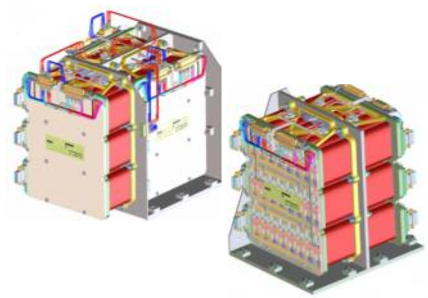


8S6P

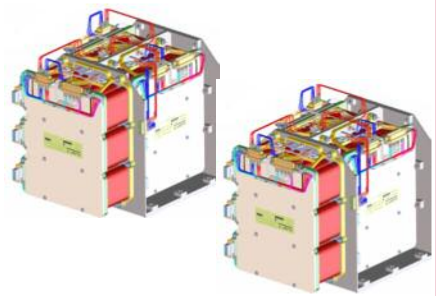
8S9P



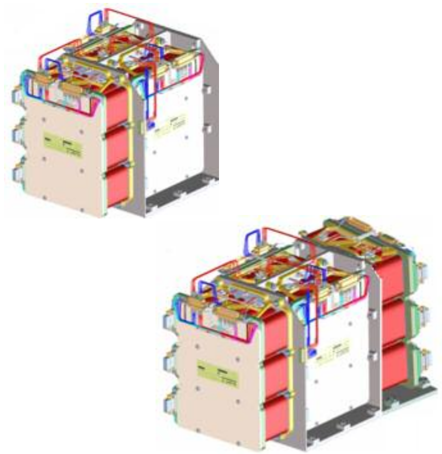
8S12P



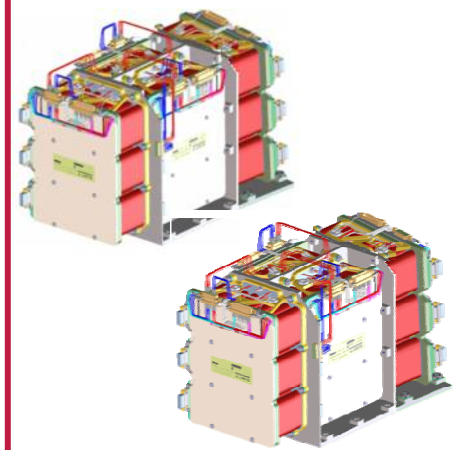
8S15P



8S18P



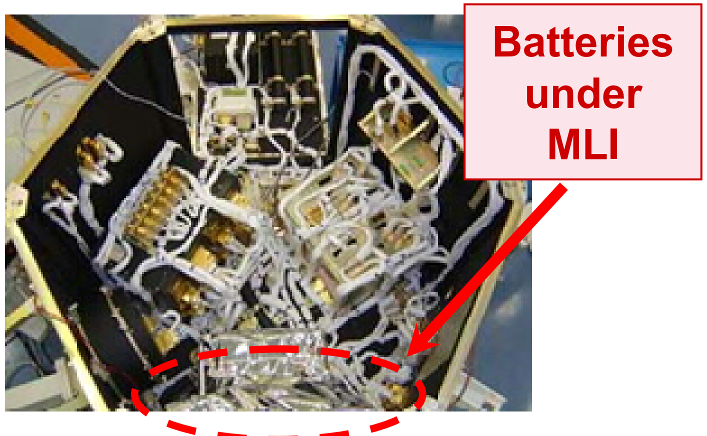
8S21P



8S24P

Assembly, Integration and tests

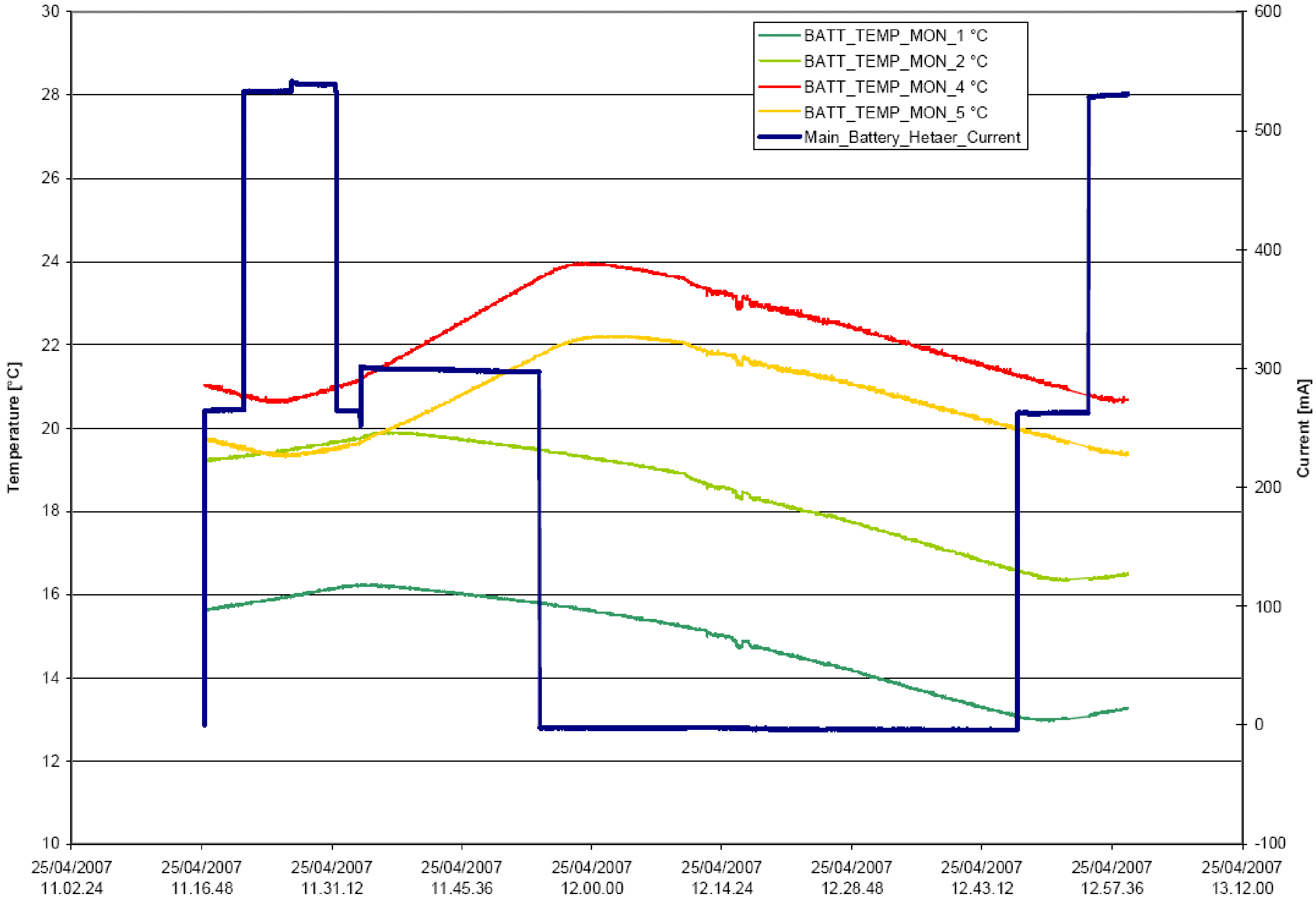
- **Impacts on satellite:**
  - Production of the new mechanical panel with new thermal interface
  - Extraction of power electronics unit for modification
  - Li-ion battery FM integration
  - Delta test campaign
- **Early delivery of EM:**
  - Test of the new software release
  - Tests of the modifications on power electronics
- **CGS and SAFT integrated teams:**
  - No interruption of the planned activities on the satellite



Launch

- **Successful launch on April 23, 2007**
  - PSLV-C8 launcher
  - Li-ion batteries started activities at separation of the 4th stage for acquisition of the sun pointing attitude
  - Nominal cycles of charges / discharges started just after
  - Excellent behavior of the battery so far

Battery thermal behavior in-orbit

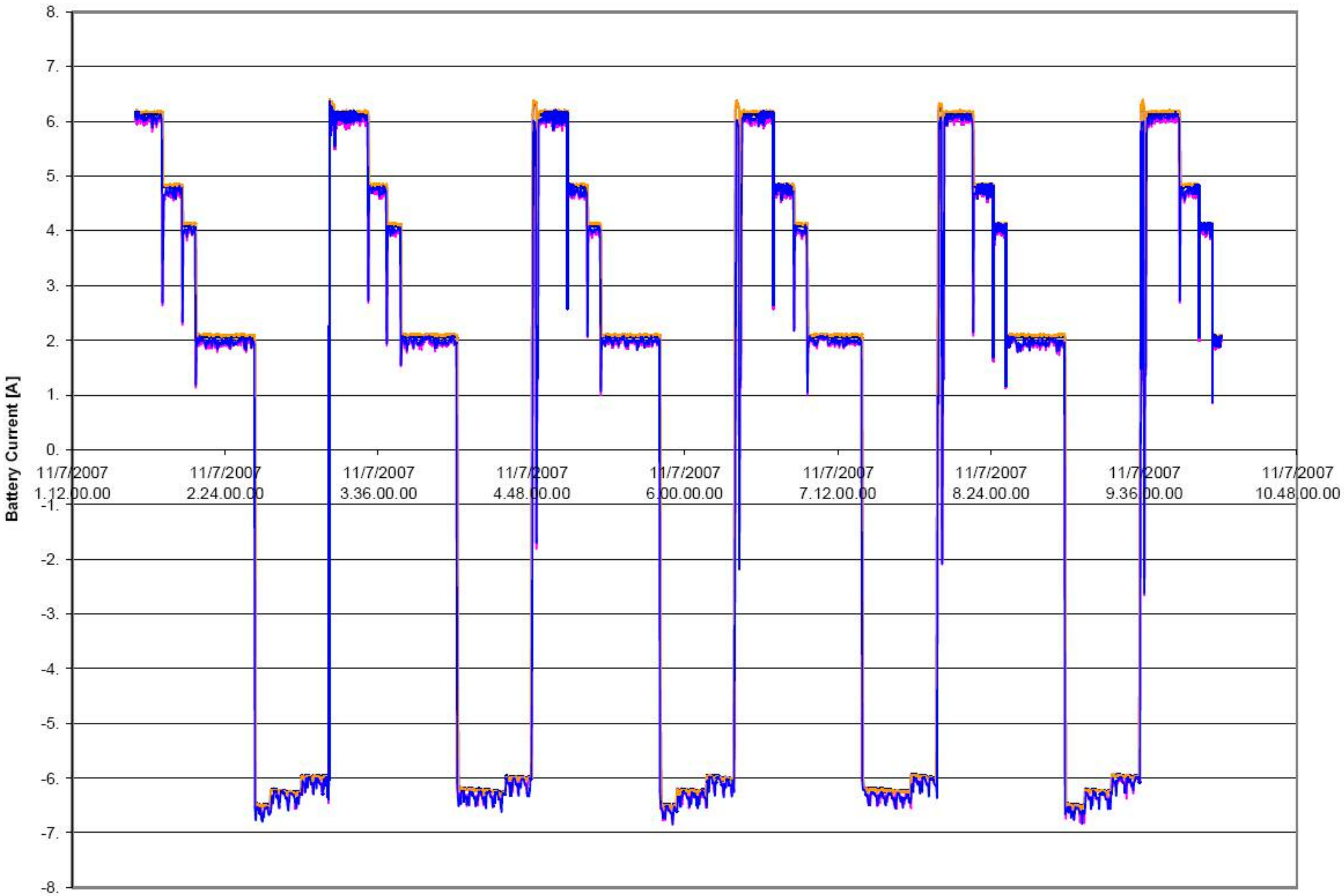


Battery thermal behavior in-orbit

- The battery thermal control works as expected keeping the battery in the optimal temperature range of +15°C/+25°C.

- The heaters activation has a duty cycle of about 30% for an average power dissipation of 4.5 W.

Battery electrical behavior in orbit

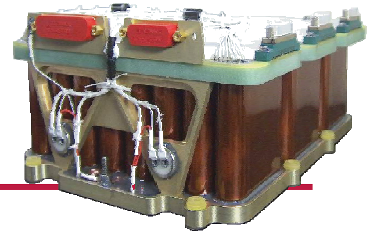


Battery electrical behavior in orbit

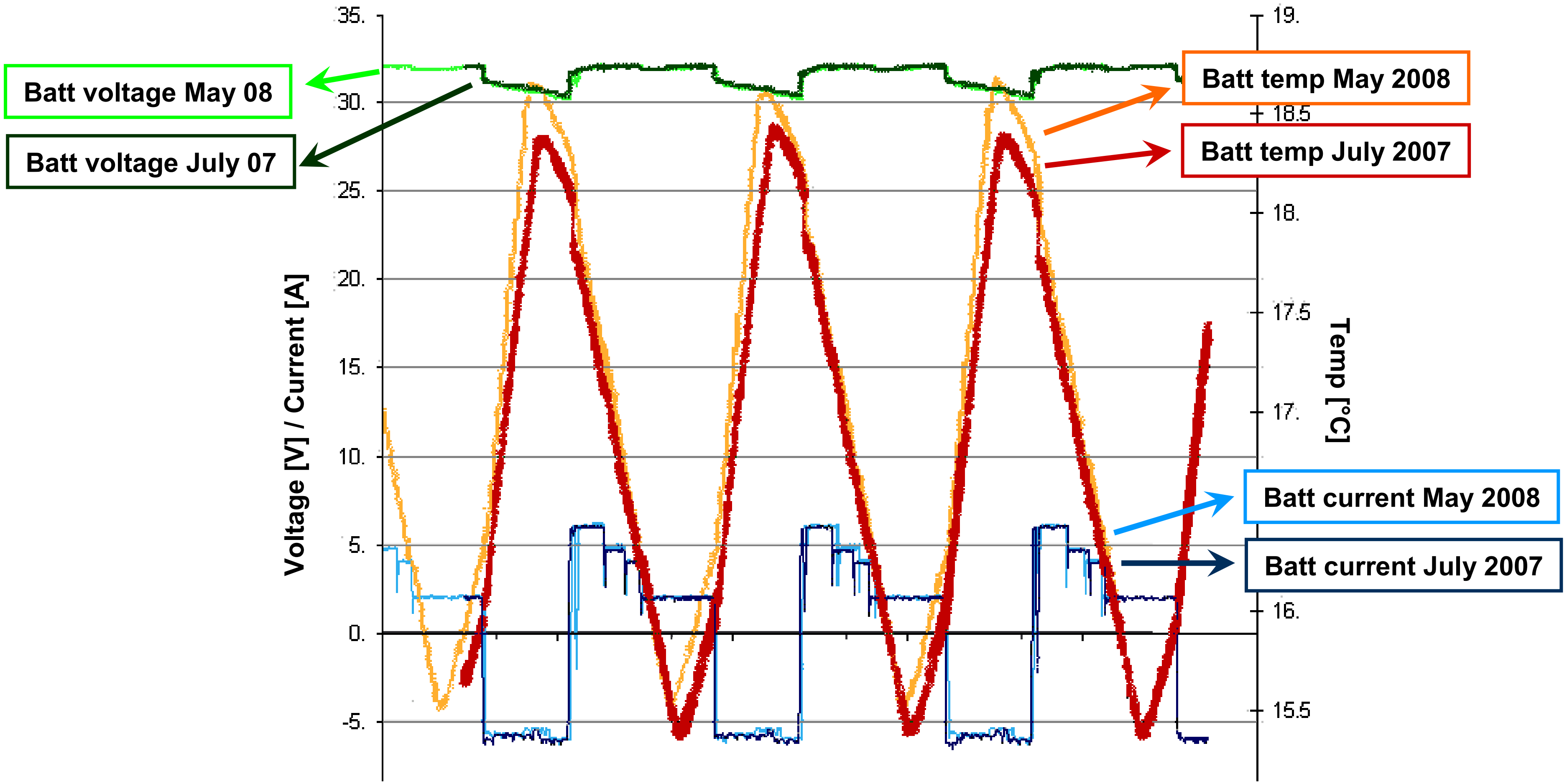
- The AGILE satellite is characterized by a power consumption profile quite constant (battery charge/discharge cycles are very similar for all the orbits)

- “Tapering process” implemented for charge management: step by step reduction of the charge current once the battery voltage reaches a predefined value.

Fading phenomenon

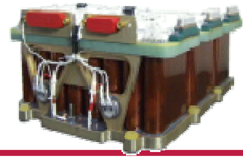


- Increase of max temp by around 0.25°C in almost 1 year due to increase of internal resistance (normal aging process)

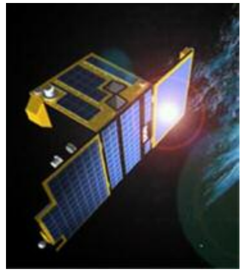


MPS heritage

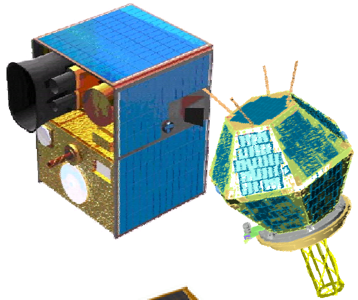




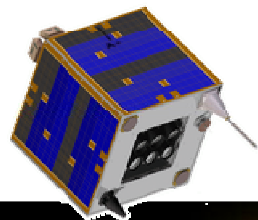
- **The Agile mission**
Carlo Gavazzi Space (*Italy*) selected Saft for its AGILE mission. Two 8S3P MPS modules are flying in the AGILE satellite since April 2007. According to in-orbit data, the battery behavior is in line with the prediction and the 20% DoD LEO mission is running with success.



- **The Proba-2 mission**
Verhaert Space (*Belgium*) selected Saft in the frame of the Proba-2 mission in the frame of an ESA program. One 7S3P MPS module is integrated in the Proba-2 platform, which is ready for launch.



- **The Nanosat-1B and INTAµSat-1 missions**
INTA (*Spain*) selected Saft for the INTAµSat-1 and NanoSat-1B missions. Two 6S1P MPS modules are delivered to INTA for integration in the NanoSat-1B satellite. One 7S3P MPS module is being manufactured for INTAµSat-1.



- **The Sapphire mission**
SSTL (*United Kingdom*) selected Saft for the Sapphire mission. One 8S3P MPS module will be delivered to SSTL.

- **The Orbcom-G2 mission**
MSI (*USA*) selected Saft for the Orbcom-G2 mission. A constellation of 18 satellites will be equipped with two 8S3P MPS modules each (for a total of thirty-six 8S3P MPS modules).

Li-ion global heritage

- **30 satellites already in-orbit with Li-ion (GEO, MEO & LEO), around 60 other contracted,**
- **21 GEO communication satellites flying today with VES technology:**
  - Typical mission: 5 years storage, 2 years AIT, 18 years in-orbit,
  - 5% expected energy loss at end of mission with typically 80% DoD,
  - 9th GEO season (4,5 years) finished on W3A (8.5 kW GEO satcom),
  - 5 military communication satellites.
- **1 MEO satellite flying with VES technology:**
  - Giove-B flying since April 08,
  - 4 other Galileo IOV contracted.
- **8 LEO satellites are today in-orbit with VES or MPS technologies:**
  - With VES technology: Calipso, Corot, Jason,
  - … and more to come with VES: Kompsat-3, Kompsat-5, METEOR-M3, etc.
  - With MPS technology: Agile, SSETI, CanX-2, NTS, Rubin,
  - … and more to come with MPS: Proba-2, NanoSat-1B, Sapphire, Orbcom-2, etc.
- **More than 30 million of cell*hours, and a total of 308 kWh in-orbit.**

Conclusion

- After 1.5 year in orbit, the AGILE batteries are performing very well and as predicted by the analysis.
- The successful commissioning of AGILE offers tangible recognition to the dedication of the CGS and Saft teams.
- Saft thanks CGS for its trust in our products and dedication
- Thanks to such results, CGS has decided to use the Saft Li-ion battery modules in the next generation of satellites (PRISMA, MIOSAT and others).
- CGS and Saft thank CNES for its contribution and support for the development of the AGILE 8s3p MPS battery.

Saft.
Energy Unlimited