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# Li-ion battery technology for compact high power sources (CHPS)

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**Abstract**

Li-ion is a relatively new battery technology that has been commercialized within the past 10 years for many consumer products, but especially for portable power. Li-ion operates by using a different principle to other battery technologies. This principle is called intercalation. Recently, work has been undertaken to explore the high power capability of this technology. The results indicate that present products can provide very high rate capability. Investigations are underway to improve this capability in anticipation of needs for defense and other advanced applications that will require compact high power sources (CHPS). 

*Keywords:* Li-ion batteries; High power; Defense applications

## 1. Introduction

SAFT has been developing and producing Li-ion technologies for more than 6 years. The cells and systems using this technology are now found in a wide variety of applications from undersea to space. Some examples are shown in Figs. 1–4, being the Mars Rover, electric and hybrid vehicles and most recently the DARPA CHPS (Combat Hybrid Power System) vehicle.

High power Li-ion/liquid electrolyte products were originally developed for use in hybrid vehicles. Early in the compact high power sources (CHPS) program the power performance of these cells was evaluated and was found to exceed expectations by significant levels.

## 2. The CHPS system integrated laboratory battery

The initial goal for SAFT in the CHPS program was to deliver a battery system that would support hybrid mobility testing in the CHPS SIL (System Integration Laboratory). During the early phases of the program it was decided to explore the characteristics of cells presently available. This investigation uncovered capabilities that were previously unknown. Some of these results are reported later in this paper. As a result of this investigation a new CHPS cell was designed to maximize both energy and power capabilities which will not only be required for mobility needs but would also support pulse power applications such as are being considered for the future, including new combat systems.

The characteristics of the CHPS Li-ion battery system are shown in Fig. 5. The packages were developed for hard use in the laboratory, including the need to be stacked. Therefore, the steel case weighs about as much as the internal battery components. It is expected that vehicle applications will allow for more effective packaging.

The design concept delivered a package that is totally sealed to provide both EMI (electromagnetic interference) and thermal isolation. Internal fans and a liquid/air heat exchanger provide a thermal management interface to the system integration laboratory. The heating/cooling liquid is provided via sealed fittings into a metal heat exchanger.

Included in the packs are telemetry and cell management systems that communicate with the SIL management system as shown in Fig. 6. Fiber optic interfaces are used to improve safety and to avoid ground loops and other EMI issues.

Fig. 7 shows the two Li-ion packs installed in the SIL. The packs are mounted on the floor within the notional outline of the vehicle. In the foreground is one of the traction motors. To the right of the packs is the SIL power distribution panel. At the rear, beyond the Li-ion batteries, is a 3.9 m × 1.6 m× 1.6 m rack of 764 commercial Ni/Cd cells. These were used to support SIL operations while the CHPS cells and packs were under development and production.

## 3. High power Li-ion cells

During an earlier phase of the CHPS program an investigation was started at SAFT using 500 A commercial test

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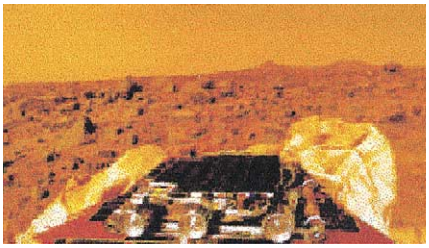

Fig. 1. Mars Rover.

Fig. 2. Hybrid electric vehicle.

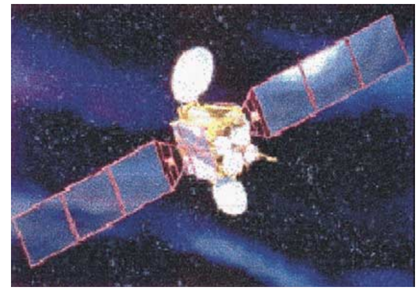

Fig. 3. Li-ion in space applications.

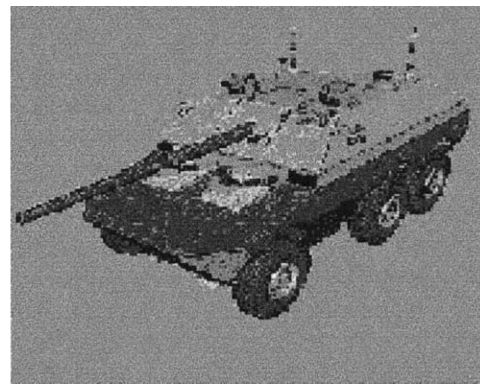

Fig. 4. Notional CHPS military vehicle.

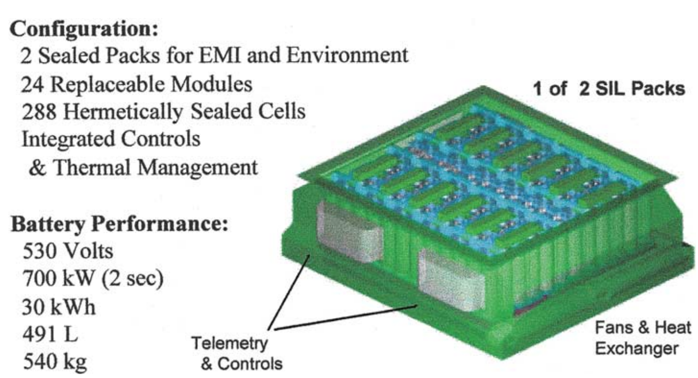


Fig. 5. The CHPS pack of Li-ion cells (two per battery).

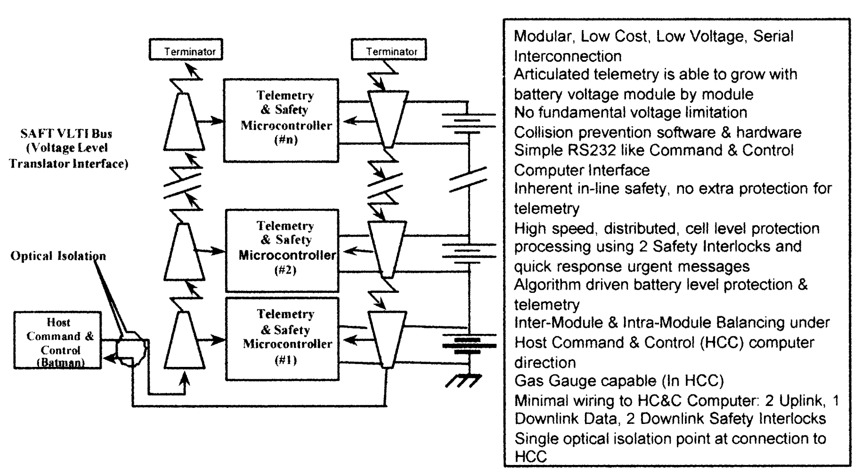


Fig. 6. Telemetry and management system for CHPS pack.

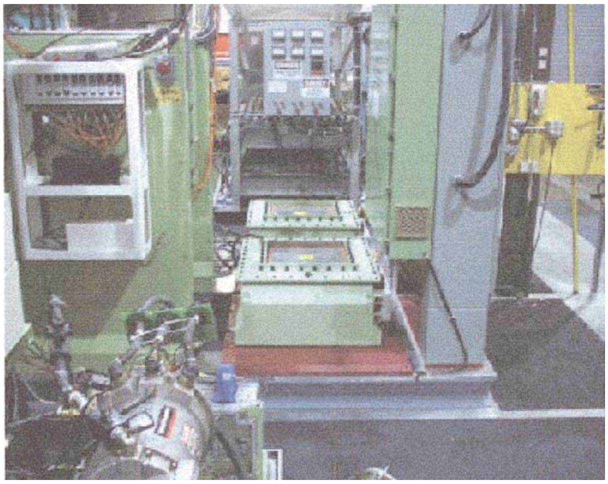

Fig. 7. Two CHPS packs located in the System Integration Laboratory.

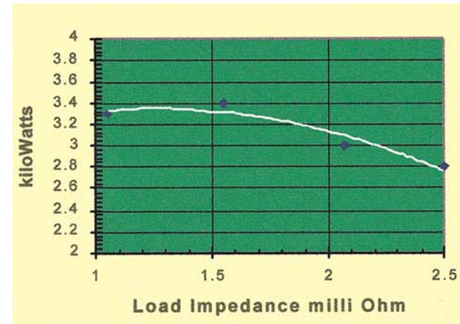


Fig. 9. A 30 Ah CHPS cell. Power output against discharge load.

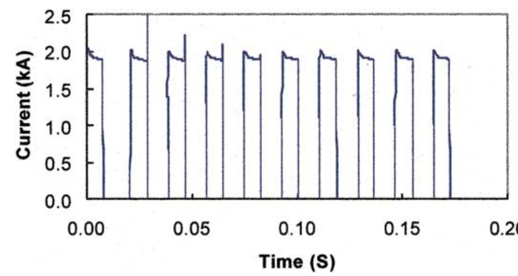


Fig. 10. A 30 Ah CHPS cell (2 kA, 7 ms, repetitive pulse discharges).

equipment to evaluate and characterize the pulse-power performance of the cells. Based on the results of this testing, a new cell was designed to provide both high power as well as high energy. This cell is rated at 30 Ah and has exceptional power delivery capabilities. Fig. 8 shows the discharge of a CHPS cell during a high current pulse test. This discharge pattern, of about 1500 W per 30 s pulse, demonstrates the efficient delivery of high power.

The waveforms show the constant current pulses and the voltages during each pulse.

Each of the 500 A, 30 s, pulses withdraws about 4.1 Ah or about 14% of the stored energy. A total of 29 Ah was withdrawn in seven pulses from this 30 Ah rated cell.

During the evaluation programs, which were conducted to verify tolerance to abuse, it was observed during short circuit tests that cells were able to support a very high current for a significant period without damage. DARPA commissioned the Army Research Laboratory (Aberdeen Proving Grounds) to explore behavior on this high current regime. The aim of these tests was to determine the peak power that could be drawn repetitively from the cell.

In order to gather the data above 500 A, ARL constructed a test fixture that was capable of operation in excess of 2000 A.

The initial results of these tests are shown in Fig. 9. This plot shows the power withdrawn from a cell while various loads are applied. This test was conducted on a 12 Ah cell. It should be noted that the peak current during this test was about 1200 A or more than the 100 C rate. This figure also shows that the peak power was about 3.4 kW for pulses of about 0.3 s in duration. With a cell mass of 0.68 kg, then the

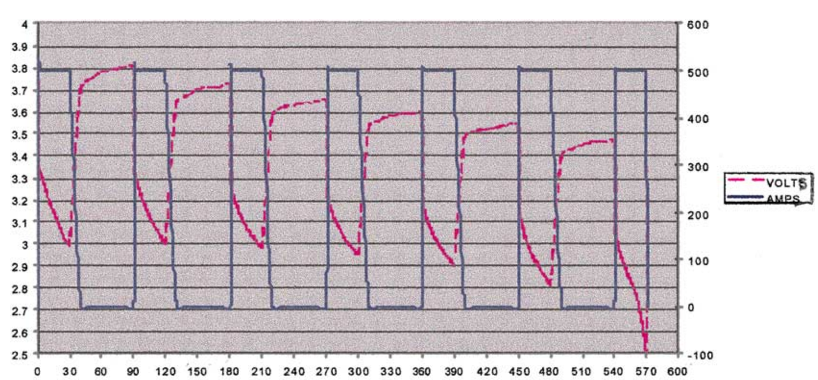


Fig. 8. Repetitive high-power pulse discharging of a 30 Ah CHPS cell at room temperature (500 A for 30 s, repeated seven times with 60 s between pulses; 26.16 Ah withdrawn; final temperature of cell case: 67.8°C).

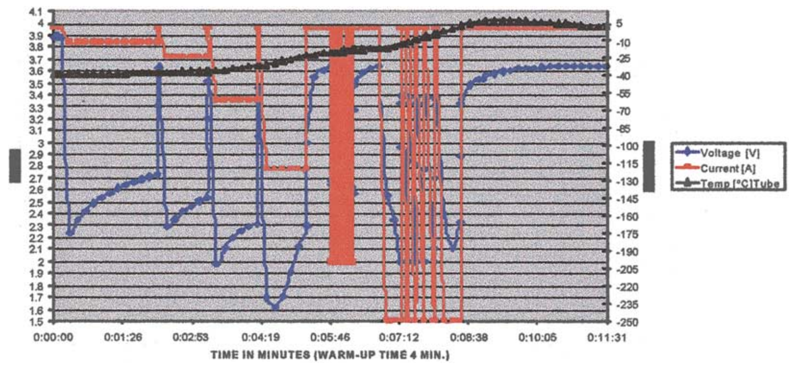

Fig. 11. Performance of a 30 Ah CHPS cell, initially at −40°C, under increasing loads 12 A, 120 s, then 24 A; 60 A; 120 A; all for 60 s, then 200 and 250 A, each for 30 s; final temperature of cell case: +6.9°C.

power density is about 5 kW $g^{-1}$ for an individual cell, whilst the equivalent specific power is more than 10 kW $dm^{-3}$.

Following these tests, additional work explored the capabilities of the larger 30 Ah CHPS cell that weighs about 1.1 kg and has a volume of 0.5 $dm^3$.

Fig. 10 shows a series of 2000 A pulses being withdrawn using a specific short-duration pulse pattern. These data were gathered using a new ARL test fixture that is capable of operation up to 3000 A and is electronically programmable.

During the evaluation of the CHPS cells, low temperature operation data was also collected. One of these tests is shown in Fig. 11.

This shows the temperature rise of the cell, initially at −40°C, whilst increasingly higher currents were applied. After about 4 minutes the cell was nearly capable of delivering full power.

These experiments and data have led to new thoughts regarding the capabilities of other types of solid state power sources (Table 1).

## 4. Future program

In order to identify possible new applications it was necessary to make some predictions regarding the future of the technology. Table 1 shows the SAFT estimates of the capabilities that are believed to be realistic. These estimates are based on the use of materials and processes that are being developed today for other products.

Table 1
Current and predicted performances for a battery, volume 1 $dm^3$ and weighing 2000 kg

| | At present | Near term | Far term |
|---|---|---|---|
| Energy (assuming 80% of usable energy)[a] | | | |
| kWh | 75 | 54 | 50 |
| MJ | 270 | 194 | 180 |
| Discharge power (MW) | | | |
| 0.2 s pulse | 6.8 | 13.4 | 40 |
| 2 s pulse | 4.2 | 10.4 | 30 |
| 18 s pulse 2.7 | 6.7 | 20 | |
| Applications | HEV power | HEV power | HEV power |
| | Lasers | Lasers | Lasers |
| | Targeting | Targeting | Targeting |
| | Defeating sensors | Defeating sensors | Defeating sensors |
| | Silent watch | Defeat light armor | Defeat heavy armor |
| | | Tactical aircraft | Tactical aircraft |
| | | Missile defense | Missile defense |
| | | | Long range missiles |
| | | | Theater defense |
| | | Electrothermal | ETC/electromagnetic guns |
| | | Cannon (ETC) | Counter kinetic/high power microwave |

[a] Energies available or predicted at indicated pulse-power levels.

## 5. Conclusions

High power Li-ion is a cornerstone technology for compact high power systems.

It combines the power performance of a flywheel combined with the energy density of a high capacity battery.

Many other applications have shown that it provides long life, low maintenance, and long-term affordability without environmental sensitivities.

This is a young technology, capable of significant increases in performance.