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Lithium-Ion Versus Nickel-Hydrogen Battery Chemistry in Space Applications
Energy storage advances are typically defined in terms of increasing energy or power density. However, the recent recalls of millions of lithium-ion batteries have placed the spotlight squarely on battery safety. While this is certainly not the first time that battery safety issues have risen to the surface, it clearly reminds us that the march towards more power or lower cost is not always the most important consideration when selecting a battery.

Several companies are tackling the safety issue head on. Valence Technology and A123 Systems have developed advanced lithium-ion chemistries that improve safety and lessen the chance of thermal runaway. Semiconductor companies have delivered power management ICs that improve battery safety by delivering ways to prevent the use of counterfeit battery packs and by improving the safety of the charging system.

While the majority of recent lithium-ion advances have been aimed at the portable consumer electronics market, lithium-ion batteries have found uses ranging from backup power to power tools to hybrid electric vehicles. In this issue, Saft discusses why using lithium-ion batteries in space applications may be superior to the incumbent nickel-hydrogen batteries.

Fuel cells, both stationary and micro fuel cells, continue to generate significant buzz throughout the industry. Maxwell Technologies and Hydrogenics have teamed up to show that fuel cells and ultracapacitors can be used in tandem to provide a reliable and cost-effective backup power solution. National Semiconductor discuss concerns related to the implementation of micro fuel cells, and also delivers solutions to improve the safety of micro fuel cells. Much like lithium-ion batteries, micro fuel cell makers will need to overcome perceived safety issues if they expect to be used in anything more than niche applications.

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<table>
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<th>Product ID</th>
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<td>600 mA</td>
<td>150 mA (low noise)</td>
<td>LLP-14</td>
<td>15 mm x 10 mm</td>
</tr>
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</table>
Micrel's MIC2285 is a high efficiency 8MHz pulse width modulated (PWM) synchronous buck regulator. It features a LOWO™ LDO standby mode that draws only 20µA of quiescent current. The MIC2285 is the industry's breakthrough ultra-low noise, small size, and high efficiency solution for portable power applications.

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Battery improvements are often measured in terms of increased density, but other concerns are taking on increasing importance. Safety improvements, rapid recharge rates and form factor flexibility reign as leading battery differentiators. However, according to the hype surrounding micro fuel cells, these battery concerns may become a thing of the past. Unfortunately, micro fuel cells still have several business model problems and technical challenges to overcome. So, developing better, safer batteries remains an important challenge.

Battery safety remerged as a leading concern following the recent Dell and Apple Computer recalls of Sony-made lithium-ion batteries. While both recalls involved Sony batteries, the problem is an industry problem and not simply a Sony manufacturing deficiency. For instance, Matsushita also launched a recall of non-Sony laptop batteries. While the threat of explosion of a lithium-ion battery is remarkably low, the perception of battery safety has changed. If battery makers want to secure growth in the lithium-ion and lithium polymer markets, which is currently projected to rise from $6.0 billion in 2006 to $7.3 billion in 2011, they need to ensure that the public believes the batteries are safe.

A number of companies have developed advanced chemistries aimed at greater safety. Valence Technology developed its Saphion technology to enable the creation of large-format lithium batteries. Valence’s Saphion batteries incorporate a phosphate-based cathode, whereas traditional lithium-ion technology utilizes cobalt-oxide cathode material. Since phosphates are more stable than traditional batteries, they have the ability to withstand high temperatures and abuse without decomposing and are not prone to thermal runaway.

A123 Systems has developed a safer lithium-ion battery, the M1 cell, which is predicated on the use of proprietary nanoscale electrode technology. Safety improvements are realized because the active materials are not combustible and do not release oxygen if exposed to high temperature or mechanical abuse. The materials are designed to ensure that all the lithium is fully extracted from the cathode when the battery is fully charged. As a result, safety issues relating to overcharge are reduced.

Many companies have taken other approaches while trying to increase density, while also offering greater safety. For instance, Zinc Matrix Power utilizes silver-zinc batteries that are based on a water-based chemistry. Unlike lithium-based batteries, these silver-zinc batteries are less likely to experience the problems of thermal runaway, fire, and danger of explosion.

An innovative nano-battery technology was recently developed at Tel Aviv University. This new battery uses a proprietary coating technology to allow for tens of thousands of miniature lithium batteries to be laid out in parallel within a half-millimeter thick non-conducting substrate. The substrate volume is used to increase charge capacity per footprint, up to 10mAh/cm², more than 80 times greater than similar area, similar cathode thickness planar thin-film batteries.

Figure 1: Worldwide Lithium-ion & Lithium Polymer Market (Billions of Dollars)
Even though most of the focus of recent battery developments has been aimed at lithium-ion batteries, there are several other developments occurring in the telecom and motive markets. While the portable market still swamps the telecom market in size, the telecom battery market remains significant. Between 2006 and 2011, battery revenue for this segment is projected to fluctuate between $1.2 billion to $1.3 billion. The vast majority of these sales are lead-acid batteries. However, even this stable giant is seeing advances and coming under threat from emerging energy storage technologies.

Firefly Energy developed a new lead-acid battery that uses an electrical current collector constructed of carbon or lightweight graphite foam. This foam exhibits a sizeable increase in surface area for chemical reactions to take place and eliminates the need for heavy lead plates. The graphite material resists corrosion and sulfation build-up, thus contributing to longer battery life and lower battery weight.

Despite lead-acid battery and other battery chemistry improvements, telecom service providers have remained conservative in selecting batteries. As such, any company that is trying to get a new technology adopted in this market will face significant hurdles. However, the allure of the market has brought many alternative technologies. Fuel cell makers Hydrogenics and Plug Power have developed fuel cell solutions designed to compete with traditional powering solutions for the telecom market. Similarly, IdaTech recently received Network Equipment Building Systems Level 3 certification, which is a requirement for sales to many North American telecommunications carriers, for its ElectraGen™ family of critical backup power proton exchange membrane fuel cell products.

Active Power and Pentadyne have brought flywheel technology as a challenge to the incumbent lead-acid market. While fuel cells and flywheels offer advantages ranging from reduced maintenance costs, higher reliability, and greater environmentally friendliness, these solutions must compete on acquisition price, while also dealing with a market that is highly reluctant to change. So, even

"Advanced Energy Solutions" continued on page 14)
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fuel cells and ultracapacitors

a proven value proposition versus incumbent technologies

By Bobby Maher, Director, Boostcaps Technical Sales, Maxwell Technologies
Jonathan Dogterom, Director, Business Development and Marketing, Power Systems, Hydrogenics Corporation
Toni Fisher, Systems Integration, Hydrogenics Corporation

THE SOLUTION
Hydrogenics Corporation has collaborated with Maxwell Technologies to demonstrate the viability of fuel cells and ultracapacitors for extended run backup power systems. Both companies have been working together to develop new products in combination that provide increased availability and backup power runtime to address the demanding standards and requirements of the telecommunication industry. Based on proton exchange membrane (PEM) technology, the fuel cell and ultracapacitor solution utilizes hydrogen for energy storage and has demonstrated the flexibility to meet real telecom load backup power needs. These rack-mountable and space efficient backup generators utilize hydrogen to offer high quality extended run backup power, zero emissions and are turnkey solutions capable of replacing incumbent technology.

ULTRACAPACITORS
Ultracapacitors range in capacitance from several farads to several thousands of farads. With this variety of capacitance, designers have the ability to customize energy storage to their exact needs, thus reducing size and overall cost of the system. A key advantage of ultracapacitors compared to batteries lies in the safety and ease of use. Batteries, especially Li-ion and Ni-MH, require extensive monitoring and charging circuitry, whereas ultracapacitors are easily maintained, and require no or minimal care when used. State of health is easily monitored during any cycle, and the life expectancy is not a surprise to the end user.

THE CHALLENGE
Recently there has been a major push in the backup power market for a reliable and cost effective solution. For years batteries have been the technology of choice for the UPS market and almost dominated the market. With the advancement of technology, especially in the wireless area, the need for a reliable and maintenance free solution has become a must, and batteries have not been able to stand up to this task. Thus, other technologies have surfaced to deal with this issue. Each of these technologies and solutions has their own challenges. Some are cost prohibitive, some rely on mechanical moving parts with low reliability, and others cannot meet the life goals.

In the midst of this change there has been a global push for a “greener” technology that does not damage our environment. Many areas of the world including Europe have adopted extensive environmental policies to deal with this issue. The short coming of lead-acid batteries when it comes to disposal is well known. Other battery technologies have their own challenges as well when it comes to environmental concerns.

Customer Profile
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FUEL CELLS
Fuel cells are similar to batteries in that they have an anode and a cathode. However, batteries are only capable of storing energy, whereas the fuel cell can create energy as long as hydrogen, the fuel, is supplied. With no harmful emissions created, concerns about the production of air pollutants or greenhouse gases (GHG) are eliminated. The PEM fuel cell, which operates from between 60°C to 100°C with very low audible noise, is extremely reliable and performs at >50% efficiency.

("Fuel Cells" continued on page 14)
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though these advanced energy solutions for back-up power offer several advantages, the short-term outlook for significant market penetration remains low.

Micro fuel cell makers face similar problems while trying to establish a foothold in the largest portable electronics markets, primarily mobile phones and cell phones. While the potential rewards are great, the likelihood of adoption is low. The recent recalls of certain lithium-ion batteries will make large computer and communications original equipment makers (OEMs) more cautious about shifting to another potentially volatile energy source. Fuel cell makers tout their ability to offer all-day-plus runtimes, but even though OEMs clearly want this, they have the capability to accomplish it with today’s battery technologies. They choose not to because they want to reach specific price points in these highly competitive markets.

There are other markets where micro fuel cells make sense, such as those that take advantage of fuel cells’ nearly instantaneous recharge and long shelf life, rather than longer runtimes. Jadoo Power has found success by targeting smaller niche applications ranging from first-responder communications equipment to professional video recorders and military products. So, while micro fuel cells are generating buzz, they are still several years from making a significant impact on the mobile phone or notebook PC market.

ULTRACAPACITORS AND FUEL CELLS – A WINNING COMBINATION

This is where the combination of ultracapacitors and fuel cells becomes very attractive. Fuel cells are an energy dense device that can provide power as long as a supply of hydrogen is available. Ultracapacitors, on the other hand, are powerful devices that can deliver and recapture energy at a rapid pace and are also a reliable solution for short term backup. Hence, when you combine these two technologies you get a reliable energy rich, maintenance free power solution that is also environmentally safe and friendly.

In a hybrid configuration, the ultracapacitors can “float” on the DC bus and provide continuity of approximately 350 farads to the supply of DC power when the utility supply fails. The ultracapacitors cover the need for power during the 10-15 seconds it takes for the fuel cell to reach full power. The response time of such combination is instantaneous. In the case of transient high power requirements, the ultracapacitors can cover power spikes in excess of the fuel cell rating, as well as minimal duration disruptions which are too short for the fuel cell to respond to.

One of the early adopters of this technology has been the telecom market, an industry that recognizes the shortcomings of batteries for extended run back-up power. Fuel cells can deliver power as long as hydrogen is available which allows the backup runtime to be extended and accurately predictable.

CONCLUSION

A compelling choice for a highly reliable backup power solution is a fuel cell/ultracapacitor hybrid combination. As with all new technologies there are early niche adopters that enable sufficient volume production that early high costs can be reduced, leading to increased demand and supply chain development for a growing number of applications.

Ultracapacitors have shown a clear price reduction in the last 10 years. They have become commercially viable seeing a significant jump in acceptance for various applications. Fuel cells are on the same path and are also seeing tremendous growth. Today the combination of these two technologies can provide the end user with an overall cost advantage. There is limited maintenance cost and the system lifetime is well beyond that of batteries which need to be replaced frequently.

Maxwell Technologies and Hydrogenics Corporation have had a strategic alliance for the past three years and see this ongoing partnership as a key attribute in developing and commercializing innovative solutions for critical backup power requirements.
Dell’s and Apple’s recent massive recalls of lithium-ion batteries used in the companies’ notebook computers put the spotlight on battery safety. This issue is not new, however. In 2000, Dell recalled 27,000 Sanyo Li-ion battery packs in some of their notebook computers. Dell said that, “the batteries can short circuit and catch fire, even when not in use.” Battery chemistries are inherently volatile, and lithium-ion is particularly subject to catching fire or “spontaneously deconstructing,” as it is sometimes called in the industry.

The recalls call attention to the problems that can occur with original equipment manufacturer (OEM) batteries, non-OEM batteries and “counterfeit” batteries. As far back as 1997, the Portable Rechargeable Battery Association said, “Replacement units of uncertain origin increasingly are available to consumers in the aftermarket. Regrettably, it is very difficult to be sure that all of these include the appropriate internal safety features, which are invisible to the product user.”

Brand-name battery manufacturers build safety protection circuits into their lithium (Li) battery packs to protect from over-current and over-temperature, along with over- and under-voltage. But even they admit that any rechargeable battery is vulnerable during the charging process. Stepping into the breach are semiconductor companies, who are “designing in” safer Li-based battery management systems for portable devices.

For example, according to Intersil Corp., “Most cell phone designs to date incorporate battery management architectures designed to protect against single event failures, with the rationale that the probability of two low-probability events occurring simultaneously is negligible.” Intersil identifies two basic approaches to designing safer Li-based battery systems. One is to find a way to prevent counterfeit battery packs being used; the other is to increase the safety of the charging system by using redundant protection systems.

Motorola has used both approaches, with some of their battery packs using encryption ICs to verify the authenticity of the pack and prevent the phone from powering up with a non-OEM pack inserted. Most portable devices do not discriminate, however, and a non-OEM pack can be used in place of the OEM battery. In this case, the non-OEM manufacturer might have attempted to cut costs by removing critical safety components, such as a fuse or safety IC.

Semiconductor companies have introduced various ways of dealing with battery safety. Intersil has a “dual-fault tolerant architecture” and a “battery pack authentication architecture.” In the dual-fault tolerant architecture, even if a counterfeit battery pack is inserted into the system, the system will remain safe when another element of the charging system fails. One approach to this system utilizes discrete components to guard against the three key hazards to a charging system: input over-voltage, battery over-voltage, and over-current to the battery pack. A second approach utilizes an integrated IC, such as Intersil’s ISL9204, to protect against the three hazards.

The battery pack authentication architecture prevents counterfeit packs from being used in the host system. Microchip Technology implements this approach with its KEELOQ® secure algorithm, which can be used for battery authentication in portable applications. This technology adds a low-cost safe-
ty layer in portable electronics, such as a cell phone, to identify if the battery pack in a charger or system is “friend” (factory authorized) or “foe” (counterfeit), a concept known as IFF. Microchip believes that, “Secure authentication should become a standard feature in rechargeable battery systems” in the future.

TI announced an intelligent battery management integrated circuit (IC) that easily identifies potentially unsafe batteries not approved by consumer electronics manufacturers for use in their devices. The bq26150 device authenticates battery packs used in cell phones, PDAs, digital still cameras, notebooks or other portable applications. The National Institute of Standards and Technology SHA-1 algorithm is the most popular security algorithm, and TI’s SHA-1/HMAC-based security and authentication IC provides an additional level of security. TI also has security ICs that combine battery validation with other functions, such as battery fuel gauging and primary safety control. Providing increased levels of integration, these battery management devices are designed to meet demands of future portable systems with regard to end-user safety, design features and cost.

National Semiconductor designs battery-charging products for portable electronics, including a single-cell USB/AC charger, and a charge control and protection circuit for embedded lithium-ion and lithium-polymer batteries. The LP3947 charge management system and LM3655 battery protection IC offer extensive battery over-voltage and over-current protection, battery pre-conditioning and one percent charger voltage accuracy. They are packaged in a small thermally enhanced LLP® (leadless leadframe) (LP3947) and a very small micro SMD (LM3655).

Linear Technology manufactures a line of so-called “high performance” battery chargers for rechargeable battery chemistries. These battery charger ICs are offered in linear or switching topologies and are completely autonomous in operation. The ICs offer many standard features for battery safety and management, including on-chip battery pre-conditioning, thermal regulation, NTC interface and dual Smart Battery systems management with SMBus or I²C interface.

The future of battery management could lie in digital control. Summit Microelectronics uses “programmable power control,” which allows parametric control and adjustments via software, and integrates multiple power delivery functions. The SMB135 is the first product in the company’s family of Programmable Li-Ion Charger ICs and is aimed at portable consumer applications. The SMB135’s programmability enables future battery upgrades while preserving safety. For example, as newer battery packs employ cell float voltages other than 4.1V or 4.2V, conventional, non-programmable charger ICs could disable charging, but the worst case could be a battery pack fire or explosion. With the SMB135, the charging algorithm is dynamically adapted (up to 4.62V) and it continues to safely charge the battery, according to the company. ■
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Additional Portable Power Solutions

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<th>IOUT (mA)</th>
<th>VIN (V)</th>
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Deployment issues with portable fuel cells

By Richard F. Zarr, Worldwide Program Manager for the Technology Marketing Partnership Group, National Semiconductor Corporation

The challenge

Direct Methanol Fuel Cells (DMFC) and other consumer size fuel cell devices are making headlines these days. With the struggle for efficiency and regulation of liquid fuel in power supplies, the allure of long operating life and a rapid simple “recharge” procedure outweigh the difficulties in bringing this technology to the mainstream. However, there are still issues with managing these tiny power plants. Some of these concerns include safety, power regulation, fuel capacity and system monitoring.

In looking at the basic design for Direct Methanol Fuel Cells (DMFC), the challenges become more obvious. Storage of flammable fuel is an immediate issue on aircraft as well as other transportation systems. However, similar issues have been addressed in the past. Lithium Ion batteries were considered extremely dangerous and now are common place on aircraft. Technology can solve most of the safety issues and this article will address both the safety issues and power conversion of fuel cells.

The solution: Regulation and technology

Safety of any system where catastrophic failure can injure or kill a user (or those around them) is always a primary concern. Energy storage device manufacturers have had to deal with this issue for years. In the case of fuel cells, these devices are energy generators, but still require a reservoir of fuel which has potential for fire or explosion.

There are several ways to address the issue. One way is to regulate the use of fuel cells and limit the amount of fuel in each device. Additionally, providing mechanical safety mechanisms can make tampering extremely difficult. Furthermore, monitoring of a fuel cell can add an additional layer of safety by shutting down the system during unsafe conditions. This is not unlike Lithium Ion batteries. These have mechanical safety systems inside the cells as well as monitoring systems that are engaged during charging or load. The added benefit of monitoring a battery or DMFC system’s performance is that the remaining energy can be calculated.

Figure 1 shows a sample block diagram along with several sensors used for monitoring a fuel cell system’s health. These include a pressure sensor on the methanol fuel source, temperature sensors on various sections of the system, a methanol sensor to ensure the proper concentration, and load sensors on the power supply. The pressure sensor is typically a strain gauge configured in a bridge topology. This requires a precision amplifier or instrumentation amplifier to provide the correct gain for the analog to digital converter. The amplifier requires low drift...
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over temperature changes due to the range of operation of the system. In the example system, a National Semiconductor LMP2011 was chosen due to the extremely low drift and wide operating temperature of the device.

To simplify monitoring thermal performance of the system, digital temperature sensors are recommended. These devices use a two wire system and can be optionally bussed together to reduce wiring. In the example, several LM92 digital temperature sensors were used which have a worst case accuracy of ± 0.33°C. Accurate temperature measurements of the cell, as well as the power regulators ensure safety and maximum performance.

A microcontroller is used to provide the brains for monitoring the operation and safety of the system. However, many modern microcontrollers have built in analog to digital converters (ADCs) that may have limitations in fuel cell applications. When the fuel cell system is in stand-by mode and the cell stack is not producing power, it may be best to use external ADCs and power them down to conserve energy. In this example, ADC121S101 external ADCs were used. These converters are serial 12 bit, single channel devices. Single channel devices provide the most flexibility in power management, but multi-channel devices are available as well from many manufacturers.

**OUTPUT POWER REGULATION**

Fuel cells exhibit a problem with cell voltage versus load current due to the electrochemical nature of the design. This variation under varying load (such as in a notebook computer) can cause the output voltage of a stack to vary significantly. This behavior is called Fuel Cell Polarization and is illustrated in Figure 2. There are three regions of cell polarization which are the “activation region”, the “resistive region” and the “diffusion region”. The activation loss is due to the basic energy required for cell operation. As the load increases it enters the resistive loss region. This is the normal operating area of the cell and the loss is due to ohm’s law of V=i*R as current increases. The diffusion loss is the point where the cell can no longer generate enough power and the cell voltage begins to sag. This behavior is unsuitable for directly powering most electronic systems, therefore voltage regulation is a necessity.

If the output voltage required is always lower than the minimum stack voltage, then a simple Buck converter can be used. Mainly, the issue with a buck converter topology is that the efficiency drops as the load is reduced. This is due to losses in the switching controller, resistive losses in diodes and FETs, as well as hysteretic losses in the inductor. To improve the efficiency dynamic range, National Semiconductor and other suppliers have created power converters that alter their operation frequency depending on the load. These devices are called Hysteretic converters (such as the LM27212 controller) and employ a constant on period followed by a variable off period. In this manner, as the load decreases, the off period increases and lowers the internal power consumption of the converter.

In cases where the output voltage may lie between the minimum and maximum voltages provided by the stack, a Buck-Boost, Septic, or Flyback topology can be used. These topologies share characteristics of both the buck and the boost topologies in that they can control the output voltage even when the input level drops below the output. For higher power applications (50-1000 watts), typically a forward, push-pull or current fed push-pull topology is used. These are much more complex power converters and require some expertise to design correctly. The semiconductor industry has simplified some of the design requirements by integrating much of the control loop functions into devices, such as the LM5041 buck fed, push-pull, current mode converter and others.

**CONCLUSIONS**

With the use of both regulations on mechanical safety along with the proper monitoring and control electronics, DMFC systems can be made extremely safe as was done in the past with the Lithium Ion batteries so common today. Simple electronics along with sensors can determine the safe operating condition of the cell and either allow operation or shut down the system to prevent failure or hazards.

Also, power converter technology has reached new levels of efficiency and power delivery at reasonable costs. Many different devices supporting various topologies are available for simplifying the design of these converters. By tightly coupling the control and safety functions with the power management functions, a user friendly, and extremely reliable and safe fuel cell system can be implemented.
Case Study

Lithium-ion vs. Nickel-hydrogen Battery Chemistry in Space Applications

By Anne L. Sennet-Cassity, Director of Space Sales, Space & Defense Division, Saft

The Challenge

As space technology develops, there is a demand for more powerful and lower weight battery systems. The role of satellite batteries is to provide power to the satellite when it is eclipsed from the sun, for several missions such as Low Earth Orbit (LEO) or Geosynchronous Orbit (GEO) applications. Moreover, batteries for high-tech space applications face a particularly tough life; for example, more than 15 years are requested as a nominal lifetime for such GEO systems. They must deliver additional guarantees of reliability, performance and durability.

How do you improve upon conventional energy storage capability such as nickel-hydrogen (Ni-H₂) batteries used for at least the past 20 years onboard satellites? Saft has the answer: based on the extensive work performed on the technology for applications such as electric vehicles, now lithium-ion (Li-ion) batteries are replacing Ni-H₂ onboard satellites.

The Solution

Until the recent past, geostationary communication satellites used the Ni-H₂ technology. The size of these satellites, and consequently the power demand during eclipses, has been continuously growing since the 1980s. By the early 1990s, the average satellite weight was two tons for a power demand in the range of 2 to 3 kW. Today, the average weight is at least five tons for a 10 kW power demand or more.

In 2006, and leading into 2007, satellite manufacturers have planned to build 15 to 30 kW satellites. For example, Alphabus is the next generation satellite under development in Europe (with power up to 25 kW).

Ni-H₂ battery technology for a 20 kW satellite weighs at least 700 kg. The complete battery will soon reach the critical weight. Considering the expensive launch price of each kilogram into GEO orbit, the battery is a strategic and key component. Moreover, the use of Ni-H₂ batteries is limited to the range of 14 to 16 kW due to the high thermal dissipation.

Significant research on Li-ion technology began in 1996 and was done under the Stentor technology project, including several major European agencies and customers. This demonstrated the ability to use Li-ion on GEO satellites using a Saft Li-ion battery. In fact, since Stentor was the first to even consider the use of Li-ion, it focused on the numerous advantages of Li-ion for evaluation, compared to Ni-H₂.

This work led to the insertion of Li-ion technology on true commercial telecommunication satellites. W3A and Amazonas launches in 2004 marked the beginning of the new battery technology era for GEO communication satellites.

Li-ion is considered the best-adapted battery technology due to its various advantages over the two other space technologies: nickel-cadmium (Ni-Cd) and Ni-H₂.

The main advantage of Li-ion is the weight reduction of the battery system due to higher specific energy. The specific energy of Li-ion is higher than 125 Wh/kg, whereas the maximum achieved with Ni-H₂ is 60 Wh/kg. At the battery level, the weight is reduced by at least 40 percent. More than 350 kg weight saving is expected on a 20 kW satellite.

The second advantage is also a weight saving linked to the lower thermal dissipation and higher Faradic efficiency of the Li-ion compared to the Ni-H₂. These characteristics impact the solar panel and radiator sizes. An additional five to ten percent of the weight can be saved.

Additionally, the self-discharge of Li-ion is very low compared to Ni-H₂; 0.03 percent of capacity loss...
per day compared to 10 percent. The management of the state of charge (SOC) on a satellite during integration, launch pad operations and solstice period is easier (battery charge on the launcher before launch is not mandatory as it is with Ni-H2 batteries). Ni-H2 battery self-discharge (30 times higher than Li-ion) imposes recharge of the battery up to the final countdown. This recharge operation performed under the fuse cap is a critical phase of the launch mainly because of the thermal management of the battery.

Furthermore, the memory effect observed in Ni-Cd and Ni-H2, which affects the cycling performance of such batteries, does not exist with Li-ion. So, in-orbit management can be simplified because using Li-ion can cut out the reconditioning operation necessary for Ni-H2.

Another major advantage of Li-ion is the direct relationship between the battery SOC and the OCV. This characteristic induces two functionalities of the battery. The voltage is used as a precise energy gauge, which allows the state of charge of the Li-ion battery to be known exactly at any time of the mission. In Ni-H2, strain gauges on the pressure vessel are used (as the cell H2 pressure increases with the charge) to indicate only a rough order of the state of charge.

Li-ion cells can be directly assembled in parallel giving high battery modularity in terms of capacity, using one cell size. The only attention needed for Li-ion systems is the need for a more sophisticated electronic system for battery management, instead of using a “brutal” overcharge management used by nickel systems.

The numerous advantages of Li-ion compared to the two current nickel technologies (Ni-H2 and Ni-Cd) have led to an increasing number of satellite projects adopting Li-ion batteries as the baseline power source. All satellite manufacturers have already adapted their platforms to the characteristics of this new electrochemical couple.

The Advantages and Drawbacks of the Li-ion Technology Versus the Two Current Ones

<table>
<thead>
<tr>
<th>NiCd</th>
<th>Ni-H2</th>
<th>Li-ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy Density (Wh/kg)</td>
<td>30</td>
<td>60</td>
</tr>
<tr>
<td>Energy Efficiency %</td>
<td>72</td>
<td>70</td>
</tr>
<tr>
<td>Thermal Power (Scale: 1-10)</td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>Self Discharge %/month</td>
<td>10</td>
<td>80</td>
</tr>
<tr>
<td>Temperature Range °C</td>
<td>0 to 40</td>
<td>-30 to 20</td>
</tr>
<tr>
<td>Memory Effect</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Energy Gauge Monitor Charge Management</td>
<td>No</td>
<td>Pressure, Voltage, OCV, Balancing</td>
</tr>
</tbody>
</table>

Performance Comparison of the Three Satellite Battery Technologies (for 8 kW satellite power)

To assess this last point, Saft has been in the last three years, selected by the main satellite primes to supply Li-ion batteries for their satellites in replacement of the previous Ni-H2 technology. Today, more than 45 satellites have base-lined power systems using Li-ion instead of Ni-H2. More than 35 are big GEO commercial satellites.

Saft is working mainly with the leading GEO commercial satellite manufacturers (in Europe, U.S., Asia and Russia) to install this technology onboard their platforms. It must be highlighted that the recent platforms have been designed to adapt this new battery technology from both the pure battery capability and system management points of view.

Currently, six GEO satellites and two LEO satellites have been launched with Li-ion batteries. The most recent are Hot Bird 8, manufactured by EADS Astrium; Koreasat 5 and Syracuse 3B, manufactured by Alcatel Alenia Space.

CONCLUSION

The benefits that flow from installing Li-ion bring significant advantages over traditional solutions such as Ni-H2. Major industries acknowledge these benefits and have turned to Saft’s expertise and extensive experience in space to adopt Li-ion batteries for their space programs. Saft is a world leading supplier and manufacturer of space batteries for a wide range of applications such as GEO, LEO, MEO, probes and launchers. In addition, Saft is the only space battery supplier who can offer all three battery technologies and demonstrates vast experience in the space battery business, dating back to the 1960s.
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<table>
<thead>
<tr>
<th>Component Type</th>
<th>Name Brands</th>
<th>House Brands</th>
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</thead>
<tbody>
<tr>
<td>LED, T-1 1/4, Red, 1200mcd</td>
<td>12.5–44.0% Savings</td>
<td>20.8–49.3% Savings</td>
</tr>
<tr>
<td>LEDTech LT1873-81-UR-P22</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Connector, RF, BNC, 50Ω</td>
<td>17.1–27.9% Savings</td>
<td>31.6–40.5% Savings</td>
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<tr>
<td>Amphenol 31-202</td>
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<td></td>
</tr>
<tr>
<td>Cable/Wire, CAT 5E</td>
<td>10–20.6% Savings</td>
<td>55–60.3% Savings</td>
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<tr>
<td>Belden 1000'</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Molex Mini-Fit Jr™ R/A Gold</td>
<td>14.7–37.3% Savings</td>
<td>22.1–70.7% Savings</td>
</tr>
<tr>
<td>Molex 39-30-1241, 24 pos.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Trimmer Pot, 1/4&quot;md, 1kΩ, 0.5W</td>
<td>15.6–28.9% Savings</td>
<td>24.6–36.5% Savings</td>
</tr>
<tr>
<td>Bourns 3329P-1-102</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

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