Extending the life of wireless sensor networks

Using smart NanoBatteries

Over the last few years, sensor systems are shifting from being mostly hard wired networks, which are cumbersome and expensive to manage, to wireless networks. Wireless networks inherently provide more flexibility by allowing placement of sensors in environments where installation of a wired infrastructure becomes impractical from a cost, physical layout, and maintenance perspective.

The popularity of integrated wireless networks is directly related to ongoing improvements of the following factors: Reduced hardware costs of sensor and communications components, miniaturization, antenna design, software protocols and standardization support that allows for interoperability and better communications among these devices, portable energy storage systems (e.g., batteries, supercapacitors, energy harvesters) to power these devices.

Independent of the transmission protocols used, no single sensor or actuator technology is appropriate for all situations. This is especially true in many defence related applications where single sensor solutions may be more vulnerable to countermeasures and it is likely that microsensor fusion, a combination of dissimilar sensor technologies, deployed in an integrated detection system, will likely result in fewer false positives or negatives, providing for more robust and secure devices.

SOFTWARE STRATEGIES. To add to this mix of technology improvements being made to the sensor hardware, and equally important, is the need to power these devices, with reliable power sources that match the form, fit and function appropriate for the application that the sensor or sensor network environment must work in. It is fair to say that for remotely based sensor applications, lowering the power consumption is essential for continued growth in the sensor markets.

For example, the increased popularity of adapting Zigbee based sensor designs for remote sensor applications, is grounded in the design philosophy that the hardware and micro code software running the hardware be based on low power electronics, optimized utilization of data sampling and good compromises in transmission distances for communicating with a base station or another sensor in a peer-to-peer network.

It should be noted that software in the context of this description includes both the micro code running the hardware and the end user application software running the sensors or sensor network, which also needs to be developed with power management in mind. Hardware that consumes lower power is only half the equation. The other component is that the application software needs to be judicially designed to activate the sensors receive/transmit capabilities and implement data sample rates in an intelligent manner to save power.

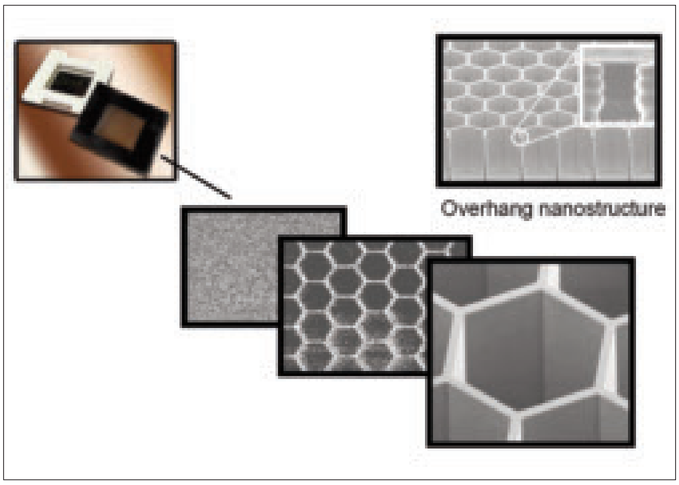

Fig. 1: Optical micrograph (top left) and scanning electron micrographs of silicon honeycomb membrane comprising the AlwaysReady Smart NanoBattery. The hexagonal pore opening is on the order of 20 micrometers across. (All figures, source: mPhase Technologies)

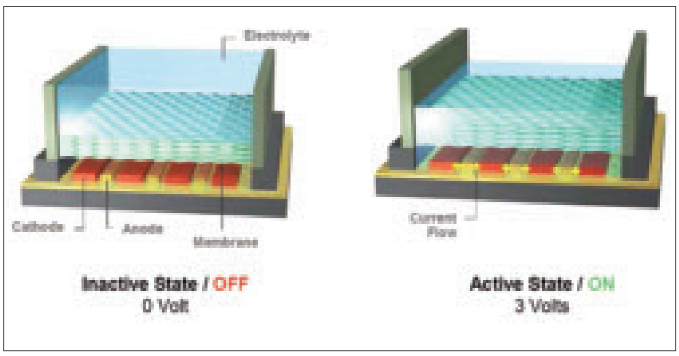

Fig. 2: Example of an individual cell of a Smart NanoBattery going from inactive to active state. Once activated, the chemical reaction inside the battery cell creates power to run the sensor device.

RUNTIME. The following chart shows relative transmission distances and battery life from the most popular wireless systems. Values are used to show relative comparisons of the designs and will vary based on parameters such as how many times the sensor's transmitter is activated (usually the most power hungry portion of the device) and how much data is sent.

Protocol	Transmission Distance (Estimate)	Power Consumption on Alkaline Battery
802.11	100 ft	2 hours
Zigbee	300 ft	6 months
Bluetooth	30 ft	3 days
Industrial Wireless	1000 ft	5 years

When designing wireless sensors or sensor networks, there are a number of approaches that can be used to improve the battery performance and runtime, which includes better utilization of the sensor transmission power, sensor hardware system power, intelligent algorithms for data sampling and acquisition based on the sensor type, hop distances to the next receiving station, choice of battery chemistry to meet the application requirements, battery power management techniques and potential incorporation of emerging energy harvesting technologies, such as converting light, thermal or vibration energy present in the surrounding environment to help supplement the power needs of the sensor system.

WHEN SMALLER IS BETTER. Even with these power management techniques, it is sometimes difficult to achieve an optimal design, especially when application requirements stress very small total sensor footprint package designs. Unfortunately, energy storage systems such as batteries, and energy harvesters, do not always follow the same shrinking footprint curve of the semiconductor industry, where smaller is always better. Power output from an energy storage device such as batteries, is proportional to the surface area of the active materials participating in the chemical reaction, while the overall energy capacity is determined by the amount of active material in the battery, which usually means degradation in performance and runtime from very small power sources. Designers of sensors and end user need to have reasonable expectations on what is realistically achievable from the real world designs.

BATTERY TECHNOLOGIES. For the remainder of this overview, we discuss how battery technologies can help play a key role in helping to increase the runtime of the sensor network. In designing good power management schemes into the sensor application, it is important to consider design options that start off with an optimized power source from which varying levels of power management optimization can be applied. Design considerations should focus on matching optimized hardware with low power consumption characteristics with a power source that maximizes the sensor application from a whole systems approach.

There are basically two types of batteries. Primary batteries are non-rechargeable energy storage units that are thrown away or recycled after discharge. Secondary batteries, which are also known as rechargeable batteries, many of which are based on sophisticated electrochemical systems.

In choosing an appropriate battery for sensor based applications, there has been a strong preference to use chemistries based on various lithium based designs. In general, lithium chemistries cost more than primary battery alkaline chemistry configurations, and for rechargeable application, are competitively priced with other rechargeable non-lithium based chemistries. Lithium chemistries provide a very good platform for developing lightweight battery designs having very good volumetric power and capacity ratios. In general, primary lithium chemistry designs provide for longer shelf life and lower leakage currents than primary alkaline based designs, resulting in an increase of a useful life of the sensor application. For batteries, shelf life and self discharge (leakage current) are important attributes to consider for remote sensor networks.

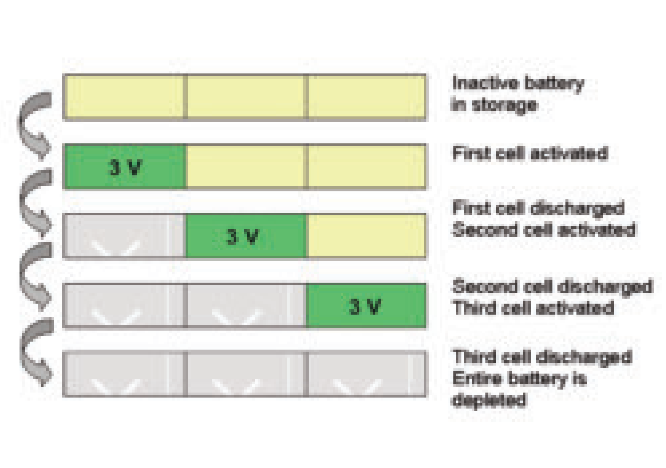

Fig. 3: Example approach for power management using sequential activation of individual cells in an arrayed configuration to extend the life of a reserve battery. Arrows indicate passage of time.

NANO BATTERY DESIGN. AlwaysReady, Inc., a wholly owned subsidiary of mPhase Technologies (Little Falls, NJ), is investigating a radically different type of reserve battery called the Smart NanoBattery. It is enabled by nanotechnology, microfluidics, and micro-electrical-mechanical system fabrication methods (MEMS).

At the core of the Smart NanoBattery is a proprietary honeycomb membrane made using standard silicon processing techniques used in the semiconductor industry (e.g., lithography and etching) that keeps the electrolyte physically separated from the electrodes until the battery is activated or «turned on» when needed. Prior to being activated, the battery remains in a quiescent state with no self-discharge, power drain, or leakage to worry about. Activation may occur via a remote control switch or triggering mechanism such as a mechanical jolt, electrical pulse, or wireless radio frequency signal, thus providing Power On Command – stored energy when and where it is needed. This enables significantly longer shelf-life compared to a typical battery (infinite in theory because there is no self-discharge prior to activation). This is valuable in situations where reliable power is critical, such as in emergency or medical equipment, remotely accessible sensors, or millions of RFID tags sitting in inventory waiting to be deployed.

In advanced versions of the AlwaysReady design, individual cells, or groups of cells, can be independently addressed and therefore turned on at different times or under different operating conditions based on the location of the sensor's placement in the network design. Using this inherent built-in power management design internal to the battery's architecture, a single battery powering a sensor can consist of several sub-cells that can be triggered individually, independent of each other, or sequentially by triggering the next unused cell as the previous one reaches its voltage or capacity limit. For instance, a smart battery based on chemistry that typically lasts ten years can have three groups of cells that turn on sequentially as one group exhausts its capacity, thus providing up to 30 years of uninterrupted service. It also makes practical for the first time the idea of integrating different chemistries (electrodes and electrolytes) into a single battery system. This potentially allows for a single battery to be built that runs continuously under temperature extremes from very hot to very cold.

REMOTE ACTIVATION ALWAYS READY. The AlwaysReady Smart NanoBattery under development has a unique architecture that enables a shelf-life of decades, remote activation, programmable control, scalable manufacturing, and adaptability to multiple configurations – zinc, lithium and other chemistries; primary, rechargeable, or reserve. In a wireless sensor network, the reserve battery design could be used as the primary source of power for running a sensor or used in combination to augment the primary battery only being activated when the sensor needed supplemental power.

In future advanced configurations, the shared hardware and software logic of the sensor could potentially manage and monitor the power requirements of the application, thus providing the triggering logic as to when to activate a new cell of the reserve battery. Ultimately a design approach could even consist of integration of the battery architecture directly onto the circuit board during the manufacturing process for providing reserved power for sensor. The value proposition to the end user is to have a source of energy or power that is literally always ready – reliable, convenient, low cost – a battery guaranteed to work at full capacity when you need it and where you need it. ↙ LO93127

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ABSTRACT

Mit dem Blick auf drahtlose Sensornetzwerke beschäftigen sich die Autoren mit Fragen der Energieversorgung. Die derzeit verfügbaren Batterietypen werden miteinander verglichen. Der Schwerpunkt liegt dabei auf dem Aspekt der Selbstentladung. Sie begrenzt den Langzeiteinsatz – auch wenn das Sensorsystem gar keine Energie entnimmt. Die AlwaysReady Inc. hat mittels Mikrosystemtechnik eine Batterie entwickelt mit einer praktisch beliebigen Lebensdauer – solange keine Energie entnommen wird. Die steuerbare NanoBattery flutet Batteriesegmente erst dann mit Elektrolyten, wenn sie gebraucht werden. Die Batterien können aus mehreren Segmenten bestehen, die nach Bedarf nacheinander in Betrieb gehen. [gaw]