WHITE PAPER

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TEXAS INSTRUMENTS

Approaching the horizon of energy harvesting

TI technology opens new frontiers for perpetual devices

Introduction

Ultra-low-power (ULP) technology is enabling a wide range of new applications that harvest ambient energy in very small amounts and need little or no maintenance—self-sustaining devices that are capable of perpetual or nearly perpetual operation. These new systems, which are now appearing in industrial and consumer electronics, also promise great changes in medicine and health. Texas Instruments, a leader in ULP technology and product offerings, plays a major role in enabling these new systems and bringing us into the newly opened frontier of energy harvesting.

Until recently, the idea of micro-scale energy harvesting, or collecting miniscule amounts of ambient energy to power electronic systems, was still visionary and limited to research proposals and laboratory experiments (Ref. 1, 2). Today an increasing number of systems are appearing that take advantage of light, vibrations and other forms of previously wasted environmental energy for applications where providing line power or maintaining batteries is inconvenient. In the industrial world, where sensors gather information from remote equipment and hazardous processes; in consumer electronics, where mobility and convenience are served; and in medical systems, with unique requirements for prosthetics and non-invasive monitoring, energy harvesting is rapidly expanding into new applications.

With the diffusion of low-maintenance systems that gather their own power, it is tempting to ask when all that intelligence will become completely self-sustaining. In other words, how close are we to achieving maintenance-free devices that can operate perpetually? The answer is that, in certain cases, perpetual devices are already in use. As long ago as the 1970s, TI, among other companies, introduced a handheld calculator powered by a small solar panel, and some of those first credit card-sized systems are still around, helping people figure tips and total their grocery bills. In the throw-away world of consumer electronics, thirty years of use easily qualifies as perpetual.

Self-powered calculators take advantage of the available light needed by the user to see the keypad and the display, illustrating that in many cases there is a symbiotic relationship between the energy in the environment and the application, and thus an opportunity for energy harvesting. But while a calculator needs only to display its results, other systems may be required to transmit data or information over a network. More typical of newly introduced energy harvesting applications are the numerous communicating sensors and monitors that are in use, powered by batteries that operate for several years without maintenance. These devices might be considered as near-perpetual, and while there are already a large number of them in the world, they are only an indication of things to come.

Within a very short time, a far greater number of energy-harvesting devices will be appearing in homes, offices, factories, roadways, hospitals, and even people's bodies. These environmentally-powered electronic devices, requiring minimal or no maintenance, will communicate with other systems and sometimes interface to the network "cloud." For designers creating these systems, the issues become not only the familiar ones of balancing performance and power requirements with cost, but also balancing utility with the available energy. There is also an issue of imagination: what can you do with all that intelligence when you're driving it with no more than the light falling on the table top, or the vibrations made by walking on the floor?

These are issues for TI as well, which is in the business of making the ultra-low-power (ULP) technology that enables energy-harvesting systems. TI products are already widely used in these applications, and the company's technology development is directed at future changes in this fast-growing area. As new applications develop that expect to operate from very low-energy sources, the definition of ULP will change. What is ULP today may be considered an energy hog in the future. Additionally, driving power requirements lower will push the deployment of these devices to greater numbers, which in turn may create higher-density networks. As industry and consumers continue distributing intelligence more extensively than ever, TI is investigating what it will take to move systems past traditional sources of power. Where are we going along the way toward perpetual devices?

Requirements for new areas of application

In the near future, it seems that energy-harvesting systems, whether perpetual or not, will serve most often as peripheral devices or remote nodes on networks. Applications where line power is readily available, or which need batteries for operating mechanical functions, will not change quickly; but new types of applications will spread the intelligence and communications farther from the central system. Some types of existing applications that use batteries or line power also may change over to energy harvesting in order to save cost and aggravation. Moreover, energy-harvesting applications often serve a communications role by registering something that happens remotely and reporting back to a central system, or by serving as transmitting switches. Such uses push the so-called Internet of things beyond appliances with traditional power sources into new areas where, to date, there may have been little communication taking place.

Early application spaces span industrial and consumer electronics, with medical systems offering interesting possibilities that are emerging rapidly. Industrial systems tend to be built for long-term installation, so the payback of initial cost can be long-term as well. The form factor is utilitarian and only important to the extent that it affects functionality. The importance of very micro-scale energy harvesting in industrial environments is that it allows small systems, sensors especially, to be placed in areas that are hard to reach and where maintenance is difficult and expensive.

One application that has received a great deal of attention recently is structural sensing for bridges and buildings, where sensors can register stress levels or material changes, then transmit data to a central system that uses it to determine the safety or health of the structure. Sensors in these environments use piezoelectric collectors to gather energy from the vibrational stresses themselves, which can create energy levels as high as hundreds of microjoules for short periods of time. In some of these sensors, the energy harvested drives ULP microcontrollers and transmitters from TI. Another type of application places sensors in industrial environments that are hazardous, where access to information required for maintenance is reduced. If sensors in such an area can harvest ambient energy, then they minimize the need for risk to personnel, or to shut down a process in order to service the equipment.

In consumer electronics, where cost and form factor are critical, there are opportunities for new types of conveniences that do not exist in the industrial world, or for extending existing conveniences to new uses. For instance, many consumer electronics come with remote controls using batteries that have to be changed periodically. These systems are good candidates for changing to energy-harvesting systems, though cost sensitivity means that designs that collect energy will have to be competitive in price with those that run on batteries. There is also a need for household and office gadgets that are completely wireless, such as light-powered computer keyboards and e-ink displays. In addition, as energy costs for the home and office become increasingly significant, thermostats and other sensors governing the indoor environment must be more efficient so that they can be placed in more locations and be moved to locations that are more appropriate. Even ordinary light switches are possibilities for perpetual devices: pressing a button can provide the energy needed to send a command to turn on or off a light bank. All of these systems are excellent candidates for energy harvesting in order to avoid having to run wiring or keep replacing batteries.

Medical systems offer a new frontier for electronics, and self-powering equipments have considerable advantages (Figure 1). Today, research is underway on pacemakers that can use the body's heat or motion as an energy source, avoiding the need for periodic battery charging and/or surgery for maintenance. Micro-scale energy harvesting that works for pacemakers will also work for other types of implants, which are rapidly being developed to augment hearing and sight, as well as aiding prosthetics. Wearable or implantable health

Spectrum of power dissipation in medical applications

Type	Application	Power	Rationale for power
Perpetual	Implanted in the body	<10 μW (>150,000*)	Micro-scale energy harvesting is primary source
	Bridge monitoring**		
Ultra-low power	Implanted in the body	100 μW (15,000*)	Size and battery life
	In the ear	1 mW (1,500*)	Ear size
	On the skin	10 mW (150*)	Ability to dissipate heat
Power-efficient	In the pocket	100 mW (15*)	Battery life of 10–14 hours on one AAA cell
	Rechargeable, portable	1–10 W	
High performance	AC powered	> 10 W	Plugged in

** Hours of battery life on one AAA (1500 mWH) in parentheses. Note, an AA cell has 3500mWH and a C cell has 10,000 mWH of battery life.*
*** Monitoring the stress levels on each structural member to determine weakening prior to failure.*

Figure 1. Medicine and health offer a wide range of possibilities for ULP technology at all levels of power consumption.

monitors are also likely, perhaps communicating wirelessly as a body network, then signaling individually or collectively to external systems that relay information to health specialists. In the future, such body monitors will extend more intensive care to the home or anywhere else a patient goes.

These examples demonstrate many of the serious possibilities for applications of energy harvesting, but it can be worthwhile to think of lighter ones, as well. For instance, imagine a coffee cup with a chip that operates off heat and tells your smart phone that your coffee is cool or your cup is low. Your phone can then tell the nearest coffee maker to get ready or alert you to make more coffee. Maybe such a cup would only be a gag gift, like the greeting cards that sing when you open them; but as the cards show, electronics find funny uses, too. Similarly, the heels of your shoes could be collecting energy as you walk, and so could the bricks in the walkway that you step on. Maybe your shoes would monitor the pressure points from your foot and help define the best socks or inserts for your path. The smart bricks can be used to monitor movement of pedestrians to control the traffic lights or even the street lighting. These may seem like frivolous examples, but the point is serious: that the circuits already exist for building self-powering perpetual devices, and the availability and affordability are ever-increasing.

Enabling technology from TI

The growing trend of energy harvesting is enabled by a number of changes in technology. The availability of the network cloud makes it useful to have widely distributed intelligence, effectively enabling computation and communication for any number of previously dumb devices. As for technology within the systems themselves, energy harvesters have to be able to collect ambient energy and buffer it, then use it in the most efficient possible way.

Improvements in light-converting panels, as well as piezoelectric and thermal transducers, are gradually making it possible to gather energy more efficiently on a small scale. For example, photovoltaic harvesters for indoors are expected to double in gathering efficiency, from 10 to 20 microwatts per squared centimeter at 200 lux. Advances in batteries make buffering more effective for a steady voltage supply, while supercapacitors store more energy efficiently for use in the high energy bursts needed for transmission. But the largest area of progress continues to be in the active electronics, where technology innovation makes it possible to do much more with less power at a lower cost.

TI plays a leading role in the industry in enabling the ULP technology that takes advantage of harvested energy. The company has a long tradition of supplying components for wireless phones and other mobile systems, giving the company extensive expertise in ULP design. For many years, TI has been a driving force toward greater ULP performance in digital signal processors, microcontrollers, power management, signal conversion, and other processing and analog circuitry. TI technology resources include the use of low-power transistors, rescaling and higher integration, plus power-efficient design of circuits, software and transmission techniques.

A world of perpetual electronic intelligence

For use in energy-harvesting systems, TI's ULP selections offer a complete range of signal chain products, including low-power data converters, TMS320 digital signal processors, and MSP430 microcontrollers, featuring the lowest power consumption among 16-bit devices (Figure 2). In addition, power management ICs, such as the nano-power bq25504 boost charger, provide exceptional charge control for batteries and supercapacitors in solar-, kinetic- and thermal-harvesting systems. Among the features built into the bq25504 is Maximum Power Point Tracking (MPPT) that optimizes energy collection from the harvester. These products and other ULP options reflect TI's long-standing commitment to low-power innovation for mobility and energy efficiency.

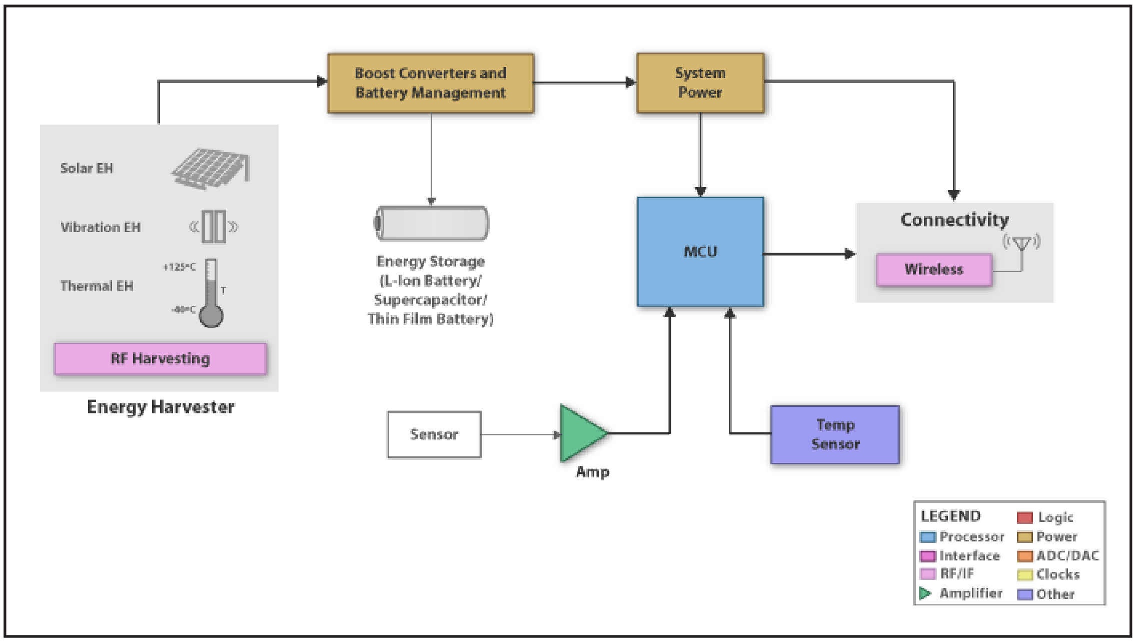

Figure 2. Energy harvesting requires ultra-low-power components for all stages of the signal chain and power management.

While the general public's attention is captured by developments in energy farming in large-scale solar, wind and tidal installations, small-scale systems that harvest energy from environmental sources on a micro scale are steadily growing in number all around us. These devices, which are rapidly becoming capable of perpetual or near-perpetual operation, are increasingly important in a variety of applications in the home, office, factory, roadway, hospital, and even the human body. The growth of these applications is driven by developments in collecting and buffering technology, but above all by rapid advances in ultra-low-power electronic circuitry. As an industry leader in ULP technology, TI plays a major role in advancing us to the widespread use of perpetual devices that appears on the horizon.

More on energy harvesting from TI

TI works closely with its customers toward the successful development of applications. In the case of new types of ULP systems such as energy harvesters, this effort goes beyond extensive design support to include help with the business aspects of introducing innovative technology.

For more information, see:

- TI bq25504 low power boost converter: www.ti.com/energy-wp2-bq25504
- ULP meets energy harvesting white paper: www.ti.com/energy-wp2-ulpwp
- Driving innovation in energy efficiency and low power white paper: www.ti.com/energy-wp2-energywp

References:

1) Smart Dust, Pister, Rabaey, Berkeley
2) ULP MSP430, Students of Anantha Chandrakasan at MIT

Other interesting publications:

http://ieeexplore.ieee.org/xpl/articleDetails.jsp?tp=&arnumber=6176896&contentType=Conference+Publications&sortType%3Dasc_p_Sequence%26filter%3DAND%28p_IS_Number%3A6176863%29%26rowsPerPage%3D75

http://www.ecnmag.com/articles/2011/12/energy-harvesting-enables-ultra-low-power-applications

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