Free energy? Well, almost. Super low-power circuitry makes it possible to scavenge enough power to run remote, hard-to-reach applications.

Harvest time near for energy ICs

by Vincent Biancomano
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"No batteries required," is still a far-off dream for most everyday applications that run on electrical power. But some kinds of systems are closing in on that ideal by harvesting energy from their environments.

Energy harvesting is more of a buzzword than a reality for most mainstream IC makers, and the playing field is still relatively small. Yet there is a growing collection of "energy scavenger" systems, ultra-low-power circuits and peripherals that store and make use of ambient energy collected by piezoelectric, solar, thermal, and various other "free energy" elements. All the component parts are coming into place — source/transducer, regulator/charger, thin-film battery and supercapacitor — supported by IC nanowatt technologies already in place.

IC makers in the traditional analog space are starting to provide products designed to work with what might be called harvesting-type sensors, usually photovoltaic and piezoelectric devices. The necessary building blocks to put together such a system typically include a detector, power supply and power management stage, energy storage, and an output switch. These blocks can be discrete chips or stand-alone, plug-and-play modules.

Such modules typically include the input and output stages (energy capturing element through wireless RF transmitter/transceiver for communications). They're available from well-known IC makers as well as from producers of thin-film batteries, and from numerous lesser-known energy harvesting names as well, many of them startup companies partnering with IC firms.

Towards perpetual motion

"While there are interesting transducer technologies (piezo, thermal, photovoltaic, motion, electromagnetic), the real difficulty or missing link is in the harvesting of power from them. You have to do it in such a way that the power management system can generate useful output power without consuming more power than the transducer can deliver," says Don Paulus, vice president and general manager of power products for Linear Technology Corp. (Milpitas, Calif.).

It's still early in the game. That leaves IC makers to focus on building general energy delivery systems, with specific applications left to the imagination of system designers. Today, the action focuses on getting the most from low-voltage, low-impedance sources such as solar cells; and from piezoelectric transducers, high-impedance, high-voltage sources. Each sensor provides its own system design challenge.

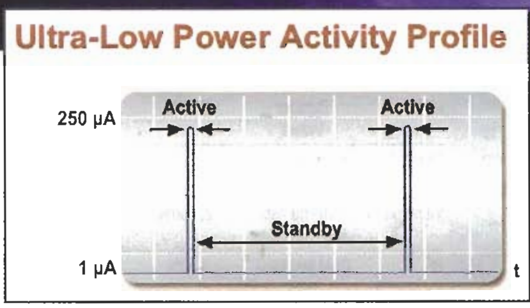
"The most-used sources commonly are solar panels, and the cost per unit output is highest," explains Adrian Valenzuela, Texas Instruments Inc. product marketing engineer for the MSP430 (microcontroller) business. "Complexity is low, and they're readily available. Beyond that, it tends to be an applications-specific scenario. We do have thermal-based elements, magnetic resonators that are in vibration-based systems, and lots of piezoelectric. There's a lot of potential in piezoelectric. We can get some extremely high output from these. But typically customers want the cost-per-unit comparable to that of a battery. In today's market, piezoelectric elements in some cases are hundreds of dollars per unit. Hopefully, as production volume ramps up, the cost of piezoelectric will come down. In a few years, piezo will be on the same level as solar panels."

As for the supporting ICs, a variety of chips across the industry tout low-power operation and, by many accounts, are suited to energy harvesting applications. Only a few, however, specifically target that arena. They include Linear Technology's first product for energy harvesting, the LTC3108 dc/dc synchronous-boost and data manager IC. It's suitable for use with thermoelectric or thermopile sources or small photovoltaic sources used in indoor lighting that generate as little as 20 mV.

In addition, the company just introduced its LTC3588 hysteretic

Battery not required

Here is an up-close look at a demonstration harvesting system that includes Powercast's P2100 Powerharvester chip. Also visible on the circuit substrate is a small form-factor capacitor and a low-power wireless board (TI eZ430-RF2500T).



The current-drain qualities of a typical system powered by scavenged energy often look something like this plot for the MSP430 processor from Texas Instruments. The unit spends most of its time in an ultra-low power standby mode and awakes only to service interrupts. Use of multiple oscillators makes possible both the ultra-low power standby mode and on-demand high-performance processing. A low frequency auxiliary clock is what enables the ultra-low-power standby mode.

synchronous buck converter, with similar power management capability. The device is for use with piezoelectric elements. Its quiescent current is less than 1 µA, and its hysteretic stage touts improved efficiency up to 20% more than traditional PWM devices.

But there's no shortage of new applications for the ultra-low-power ICs available today. Moreover, many others appear to be well along in development. Freescale Semiconductor, for instance, has announced several major breakthroughs in ultra-low-power conversion technology but has released no new products in this area.

Several microcontroller makers are in the low-power camp as well. Microchip Technology's (Chandler, Ariz.) new XLP (extreme low power) family of microcontrollers, for example, is touted as setting a new industry standard for low power. As embedded in the company's PIC16, 18, and 24 microcontrollers, the XLP technology features sleep currents down to 20 nA. "Our XLP devices have new modes and timers that are especially designed to be low power. Those are the things that can let you manage your profile," said Jason Tollefson, Advanced Microcontroller Architecture Div. product marketing manager. "Say you have a radio that is harvester powered, and you need to transmit the status of a sensor once every six seconds. The MCU with XLP consumes only 500 nA and still maintains an accurate timer to wake the thing up every six seconds."

The XLPs now have provision to connect to EnerChip CBC-EVAL-0x energy harvesting evaluation kits from Cymbet (Elk River, Minn.), a thin-film battery maker. Other major thin-film battery makers include Infinite Power Solutions, Littleton, Colo. Texas Instruments' MSP430, the company's flagship processor with over 250 variants, also sets claim to being the world's lowest-power microcontroller. This device serves as the brain for several energy-harvesting development kits/modules throughout the industry.

But the implementation of such systems isn't necessarily automatic, cautions Thomas Hoffman, strategic marketing manager for the low-power dc/dc converter business at TI. "Now one of the common challenges is that you have a strong load pulse at the output but the source doesn't support it. So you need a storage element in between, such as a big capacitor or a supercap, or a new battery technology. You need a charging device other than a voltage regulator. If you have a large capacitance you will have high inrush currents and will need to have under-voltage lock-out control, and the whole device must be hot-plug capable. At the same time, you want a device that increases your voltage at the input, as you can reduce capacitance size by increasing voltage. It's not only about a low-voltage supply."

On the air

Interest and potential are high, but systems that gather energy from RF sources have relatively low energy-gathering capability. They also lack the energy-versus-time profile required by most networks today. Practical deployments in the field are rare, aside from a few university-based experimental applications, so dedicated RF transmitters powered by dc sources are the rule rather than the exception. Indoor applications hold

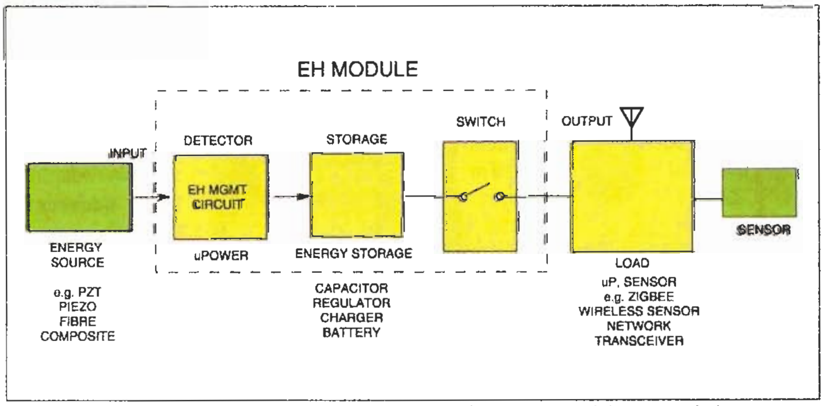
Basics of collecting 'free' energy

The basic blocks of a practical free-energy harvesting system include the energy harvesting transducer, power management components for generating an output voltage and current; a charging stage; a storage element (battery or capacitor); and a switching circuit to the load. Oftentimes, the load that energy harvesters power today is some kind of RF transmitter. That's because the technology is often applied in remote monitoring where the locale discourages the use of batteries that must be replaced periodically.

Typical energy sources today include piezoelectric transducers, photovoltaic sensors, thermal sensors, and RF sensors. These convert heat, strain, light, moisture, or motion to electrical current. Any excess energy collected beyond that needed to power harvesting circuits typically gets channeled into trickle-charging a battery or a storage capacitor. In most applications these storage elements help deliver pulses of power that normally arise when application circuits wake up from sleep mode and enter short periods of intense activity. The typical example is that of a sensor waking up every hour, delivering a reading to a wireless device for transmission, and then going back into sleep mode.

Designers look increasingly toward supercaps to deliver the required energy pulses in applications where batteries can be dangerous or otherwise impractical to install.

The transducer, storage, and output switching stages are typically packaged together in an energy-harvesting (EH) module, available from such makers as AdaptivEnergy, Hampton, Va. So-called "complete" modules, which include the RF transceiver, are available from such manufacturers as EnOcean (Boston) and Perpetuum (UK).



A block diagram of Advanced Linear Devices Inc.'s energy harvesting module as it might be configured for a wireless sensor application.

An enabling technology

Exemplifying one of the more notable low-voltage, low-current technologies is EPAD (electrically programmable analog device), from Advanced Linear Devices Inc., Sunnyvale, Calif. EPAD is an analog technology using a special CMOS MOSFET whose threshold voltage and on-resistance qualities can be electrically programmed to a precise level. Once programmed, the set parameters are indefinitely stored within the device even after power is removed. This technology employs a floating gate structure which can be precision-trimmed to produce tightly controlled transistor electrical qualities. ALD makes energy harvesting circuits that use EPAD MOSFET arrays for a major part of the detector, regulator, and switching stages.

EPAD has evolved over the years from micropower circuits to nanopower arrays that make up many of the stages within ALD's energy scavenging systems. The basic EPAD structure is a sub 1-µW, 0.1 nA device with precise turn-on voltages (within 10 or 20 mV of target for components like comparators and voltage detectors). The company now has zero-voltage gate-threshold MOSFETS with a tolerance of 0.01 V. The variation in offset voltage between two MOSFETS on the same die is within 2 mV.

ALD energy scavenging modules dubbed the EH-300 and EH-301 are optimized for piezoelectric sources. ALD plans to introduce energy harvesting modules later this year that will be optimized for thermoelectric and solar panels. The company says next-generation devices will include specific energy-harvesting circuit functions such as detectors.

Energy Harvesting Sources

Energy Sources	Characteristics	Efficiency	Harvested Power
Light	Outdoor Indoor	10-24%	100 mW/cm² 100 µW/cm²
Thermal	Human Industrial	~ 0.1% ~ 3%	60 µW/cm² ~1-10 mW/cm²
Vibration	~Hz- human ~kHz- machines	25~50%	~4 µW/cm² ~800 µW/cm²
RF	GSM 900 MHZ WiFi	~50%	0.1 µW/cm² 0.001 µW/cm²

How much can you get? One can get a feel for the amount of energy available for harvesting from typical sources by reviewing figures compiled by Texas Instruments Inc. Today solar is the winner in terms of energy available per unit of sensor area.

Self-Powered Solar Energy Harvester

One example of an energy harvesting module is this device constructed by Texas Instruments around its eZ430-RF25000T low-power processor/wireless circuit and a solar cell.

much promise; one example is that of a hotel room in which an energy harvester near a source of RF energy charges the remote-control unit for TVs.

Powercast Corp., Pittsburgh, fields one of the few practical products today. It targets energy harvesting and charging applications at milliwatt levels for products powered by batteries whose run times to discharge are measured in months to years. The basic system from PowerCast is a so-called "intentional source" application using transmitter modules (requires a 24-Vdc power source). It delivers up to 3 W EIRP (effective isotropic radiated power) at a nominal frequency of 915 MHz to a Powerharvester energy-harvesting receiver module. The receiver module – which includes the P1100/1200 energy harvester chip plus a microcontroller, supporting circuitry and storage capacitor – converts the corresponding input power (0 to 20 dBm) to a 2 to 4-V output at less than 100 mW average power with a conversion efficiency of about 50-to-70% (a function of the power input level). **EE&T**

For more information

AdaptivEnergy LLC, Hampton, Va., *www.adaptivenergy.com*

Advanced Linear Devices Inc., Sunnyvale, Calif., *www.aldinc.com*

Cymbet Corp., Elk River, Minn., *www.cymbet.com*

EnOcean Inc., Boston, *www.enocean.com*

Freescale Semiconductor, Austin, Tex., *www.freescale.com*

Infinite Power Solutions, Littleton, Colo., *www.infinitepowersolutions.com*

Linear Technology Corp., Milpitas, Calif., *www.linear.com*

Microchip Technology, Chandler, Ariz., *www.microchip.com*

Powercast Corp., Pittsburgh, Penn., *www.powercastco.com*

Perpetuum Ltd. UK, *www.perpetuum.com*

Texas Instruments Inc., Dallas, *www.ti.com*