New Energy Harvesting Technologies

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New technologies for harvesting energy are challenging the way designers can provide power to a system. Micro wind turbines for mobile phones and wideband thermal harvesting for pacemakers are creating new ways of generating power. This article looks at recent new energy-harvesting technologies in MEMS, and how designers can harness the generated power. The article will feature devices from Linear Technologies, STMicroelectronics, and EnOcean.

As the power requirements of sensors and wireless links fall, energy harvesting is becoming more significant as a way of easily powering devices in the home, on the factory floor and even in the body. This is stimulating researchers in companies and universities to look at different ways of generating power for the environment with some distinctly dramatic new approaches.

This includes thermoelectrics - generating power from heat - where organizations such as the Department of Energy in the US are working with BMW and GM to turn heat waste from engines and exhaust into power for the vehicle’s electrical systems. NASA uses thermoelectrics to power Mars rovers where they work without light, unlike solar cells. Piezoelectric energy harvesters are also of great interest due to their small form-factor and high efficiency. In 2022, these four energy harvester types will have near similar market share for industrial sensing applications, say market researchers IDtechEx. By 2024 the total market for energy-harvesting devices will rise to $2.6 billion.

![Figure 1: Market growth of energy-harvesting technology to 2024. Source: IDtechEx February 2014.](image)

One dramatically new approach is to use tiny windmills built with the same technology that provides the latest accelerometers in mobile phones. A research associate and electrical engineering professor at the University of Texas have designed a micro-windmill that generates wind energy that they say could be used to charge the battery of a cell phone.
Smitha Rao and Prof J.C. Chiao designed and built the device that is about 1.8 mm at its widest point. They see hundreds of the windmills embedded in a sleeve for a cell phone and the wind, created by waving the cell phone in air or holding it up to an open window on a windy day, would generate the electricity that could be collected by the cell phone's battery.

Rao's works in micro-robotic devices initially heightened a Taiwanese company's interest in having Rao and Chiao brainstorm over novel device designs and applications for the company's micromachining (MEMS) fabrication techniques that has been commercialized for accelerometers.

Rao's designs blend origami concepts into conventional wafer-scale semiconductor device layouts so complex 3-D moveable mechanical structures can be self-assembled from two-dimensional metal pieces using planar multilayer electroplating techniques that have been optimized by the foundry, WinMEMS Technologies. The micro-windmills work well because the metal alloy is flexible and Rao's design follows minimalism for functionality.

The micro windmills were tested successfully in September 2013 in Chiao's lab. The windmills operate under strong artificial winds without any fracture in the material because of the durable nickel alloy and smart aerodynamic design. The problem most MEMS designers have is that materials are too brittle, but using a nickel alloy avoids the problem and makes the devices durable.

This is just a first step, according to Rao, as the micro-windmills can be made in an array using the batch processes. The fabrication cost of making one device is the same as making hundreds or thousands on a single wafer, which enables mass production of very inexpensive systems.

The small size means flat panels with thousands of windmills could be made and mounted on the walls of houses or buildings to harvest energy for lighting, security, or environmental sensing and wireless communication.

However, whether it is charging a cell phone or mounted on a house, the arrays of windmills will generate small amounts of current, potentially creating significant variations that have to be handled by the power management system. While a cellphone battery can be used to smooth out some of this variation, the charging needs to be managed carefully. For a large array powering a house, this is even more dramatic.

Devices such as the \texttt{LTC3108} from Linear Technology provide a stable output from very-low-input currents. To be successful, the array of windmills will have to match the input range of the power management devices, and this is going to need careful optimization. It may require even lower input tolerances than are currently available, which will influence the next generation of power management device design.

STMicroelectronics is also opening up energy-harvesting applications with a new chip integrating all the functions needed to power electronic circuits and recharge batteries using either a solar cell or Thermo-Electric Generator (TEG). This builds on its \texttt{SPV1020} monolithic 4-phase interleaved DC-DC boost converter that is designed to maximize the power generated by photovoltaic panels, independent of temperature and amount of solar radiation.

Optimization of the power conversion is obtained with embedded logic, which performs the MPPT (max power point tracking) algorithm on the PV cells connected to the converter. One or more converters can be housed in the connection box of the PV panels, replacing the bypass diodes, and as the maximum power point is locally computed, the efficiency at system level is higher than that of conventional topologies, where the MPP is computed in the main centralized inverter.

Extending this capability to TEG systems as well, the SPV1050 supports applications with power requirements from a few microwatts to several milliwatts, and is equally suitable for both indoor and outdoor consumer and industrial applications using either solar or thermal energy.
Both 1.8 V and 3.3 V regulators are available to power a companion microcontroller or wireless transmitter directly without requiring additional components.

Inside the device, a buck-boost converter allows the device to connect to either TEG or indoor/outdoor solar-energy-harvesting modules by providing a wide input-voltage range from 180 mV to 8 V. Average operating efficiency of 90% allows fast battery charging even at low input power levels, while minimum MPPT accuracy of 90% maximizes energy extraction from solar or TEG sources. In addition, the integrated battery-charging controller uses highly accurate under-voltage and end-of-charge thresholds, and provides safe control logic to prevent excessive discharging for longer battery life.

**Piezoelectric heart power**

Different technology – a piezoelectric crystal – is being used to power the pacemaker that keeps the heart running.

From cochlear implants to implantable defibrillators, electronic devices have been developed to perform many functions inside the human body. At present, they almost all rely on some kind of battery that eventually runs down. For a pacemaker, this happens in 6-10 years. Changing the battery inevitably requires further surgery, which can be risky and expensive.

A flexible piezoelectric implant that harnesses energy from the body's natural motions has been developed by researchers in the US and China. The team hopes that one day such a device might supply the necessary electricity for various medical implants. Tests on cows and sheep suggest their device can already harvest enough energy from the beating of the heart to power a modern cardiac pacemaker.

![Figure 3: A piezoelectric power station for a pacemaker.](image)

A device able to generate power could, in principle, operate forever. The most obvious energy source in the body is some type of regular movement such as that of the heart, lungs or diaphragm. However, the requirements for a mechanical energy harvester are severe - it needs to generate enough electricity to power the implant without interfering with the natural motion of the body. This is a particular concern if an energy harvester is attached to the heart, as applying pressure to the outside of the heart can lead to an irregular heartbeat - the very condition cardiac pacemakers are usually implanted to treat.

The group at the University of Illinois led by John Rogers has developed a flexible, piezoelectric patch that harvests the mechanical energy of the beating heart. The implant contains a film made of 500 nm thick ribbons of lead zirconate titanate (PZT) surrounded by gold and platinum electrodes. PZT is piezoelectric, meaning a voltage develops across it when it is bent. The output is used to charge a tiny battery integrated into the device, and the whole thing is encased in a layer of polyimide to make it biocompatible.

The researchers tried out the patches by stitching them in different orientations onto the hearts of anaesthetized sheep and cows. The voltage they produced was almost exactly what they had predicted theoretically, and the implants did not obviously interfere with the natural beating of the heart.

They found that, when stitched at the optimal orientation onto the right ventricle, their device generated up to 0.18 μW/cm². State-of-the-art pacemakers can run on as little as 0.3 μW - a power output the team achieved by stacking multiple piezoelectric layers on top of one another. The team has now received ethics committee approval to leave the patches in place and wake the animals up, allowing them to monitor their behavior over months or even years to check that the devices continue to work properly and do not unduly...
Piezoelectric energy harvesting is already used in industrial applications with devices such as the Midé Volture V21BL. The crystal resonates with the vibrations of the equipment, generating enough current to power a sensor. Making such devices dramatically smaller, including the power management, and compatible with human tissue, is the challenge that the researchers are tackling.

**Clicks power wireless links**

At a slightly larger scale, German energy harvesting expert EnOcean has developed a low-cost energy-harvesting switch that could power a 2.4 GHz radio link such as its Dolphin system.

![Figure 4: EnOcean's Dolphin energy harvesting wireless development system.](image-url)

On one side, the 2.4 GHz demonstrator consists of a low-cost energy harvesting dual-switch, integrating a 2.4 GHz RF chip for communicating with sensor nodes and an NFC (Near Field Communication) radio chip to commission the switch. On the other end of the demonstrator is a board with an LED and control electronics, which receives the On/Off message when the switch is pressed.

Powered by EnOcean’s electro-mechanical energy converter, the press of a button is converted into enough power to generate the wireless signal, enabling data communication without cables and batteries. The prototype also pairs the transmitter functionalities with the receiver using a smartphone. This opens up many new ways for system developers and users to integrate battery-less components into their network.

The NFC chip allows installers or even consumers to configure the switch through any NFC-enabled smartphone. As the switches do not require any wiring and have a range up to 3 km, the devices could find use in many home automation or industrial applications. This is currently just a study to show that a simple off-the-shelf energy-harvesting switch can power a radio link in the free ISM band.

EnOcean has also developed a Linux-based middleware with a library to interpret all of its low-power radio Protocols and translate any sensor message from a logic level to an IP level so that other devices, servers and even cloud services can process it. This is part of its expansion into supporting a wide range of RF protocols with these energy-harvesting technologies. It has released a plug-in for the MiOS Marketplace to deliver control of Z-Wave® transceivers such as the ZM5202 using EnOcean self-powered switches and sensors.
Figure 5: The Z-Wave ZM5202 wireless transceiver can now be powered by energy-harvesting systems from EnOcean.

The new plug-in creates a bridge between EnOcean, an established standard in wireless building automation, and residential Z-Wave wireless products. This means Z-Wave developers can now use the energy-harvesting technologies from EnOcean, from physical to solar and thermal generation. This also allows the Z-Wave developers to tap into the members of the EnOcean Alliance, which now includes 350 companies around the world.

Conclusion

The reduction in power requirements demonstrated by companies such as EnOcean is driving the research into new energy-harvesting technologies. While the idea of an array of tiny windmills generating power from the wind for a cell phone may seem strange, it shows that mainstream MEMS technology can be used in new ways for generating power. This will impact the design and development of power management chips and subsystems that, like the new devices from STMicroelectronics, are combining support for several different energy-harvesting technologies via a wide input range. As EnOcean shows, these energy-harvesting technologies can now be linked to existing wireless technologies such as Sigma Designs’ Z-Wave, tapping into an existing, proven market. Designers developing ultra-low-power systems, whether for the home, industry or medical applications have a much wider range of options to power devices without the need for batteries.

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