What is Energy Harvesting and How Does it Work?

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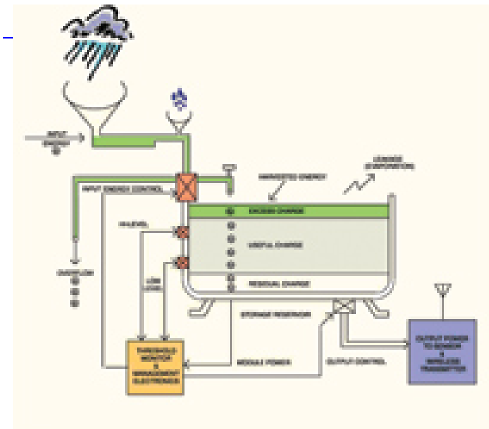

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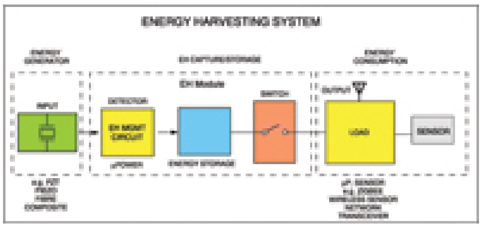
Energy harvesting is the process of capturing and accumulating byproduct energy as the energy becomes available, storing the energy for a period of time and conditioning it into a form that can be used later – such as operating a microprocessor with in its limits. Energy harvesting holds great promise for both low-voltage and low-power applications in a wide range of portable or mobile markets such as medical equipment, consumer devices, transportation, industrial controls and military. It is also a strong contender for applications that require a back-up battery, especially if the battery is in a remote or difficult location to reach. Perhaps the biggest promise is that energy harvesting will enable new market applications and products that are currently not possible or even thought of yet.

The energy can be captured from a variety of sources deemed wasted or otherwise unusable for any practical purpose. The process, also known as energy scavenging, captures residual energy as a byproduct of a natural environmental phenomenon or industrial process and is therefore considered "free energy." More often than not, this residual energy is released into the environment as waste. Examples include mechanical energy resulting from vibration, stress and strain, thermal energy from heat escaped from furnaces, combustion engines and other heating sources. Other sources are biological, solar energy from all forms of light sources; electromagnetic energy captured via inductors, coils and transformers; wind and fluid energy resulting from air and liquid flow; chemical energy from naturally recurring or biological processes; and huge amounts of RF energy in the environment because of ubiquitous radio transmitters and television broadcasting.



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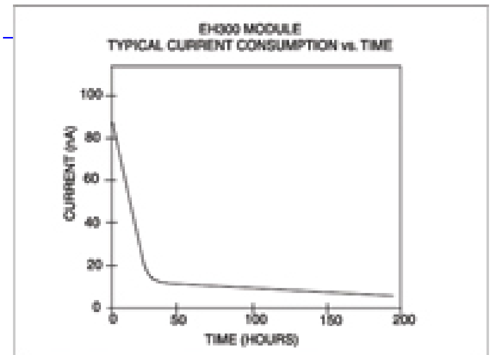
In most cases, these sources provide energy in very small packets that have been previously difficult if not nearly impossible to capture for use. Energy-harvesting opportunities are being enabled by new circuits that can capture and store these small energy packets and convert them into useful output. The energy management provided by these circuits needs to include high energy efficiency to capture and accumulate these small energy packets; high energy retention to store the energy for long periods of time; and the proper energy conditioning to perform the desired task.. The energy management must be well-defined — and tolerate a wide range of voltage, current and waveform inputs, including over-voltage, overcharge and other irregular input conditions.

A variety of well-know devices, materials or sensors are typically used to convert wasted energy into electrical voltages and currents, which can then be harvested, stored and conditioned for many low-voltage wearable electronics and wireless sensor applications that previously required AC power supplies or batteries. Examples of energy generators include materials such as piezoelectric (PZT) crystals or fiber composites, solar photo voltaic cells, thermoelectric generators (TEGs) and electromagnetic inductor coils. These materials generate a wide range of output voltage and currents. None, however, can be utilized directly as power sources for driving low-energy electronics without energy-harvesting devices designed to capture the available power, manage it and communicate handshake instructions to compatible wireless sensor systems.

In many cases, these sources provide energy as spurious, random and otherwise irregular spikes or in very low-level amounts. With recent developments in MOSFET "zero-threshold" transistor designs, energy-harvesting electronics have catapulted to new heights, enabling capture, storage (in a capacitor, super-capacitor or battery) and management with high retention efficiency.

Energy Efficiency



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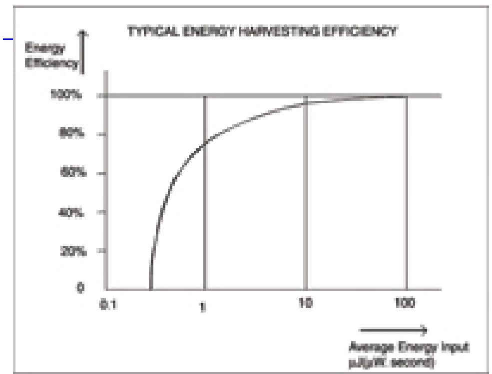
The capturing, accumulating and storing of small packets of electrical energy requires high efficiency. The circuit must stay in the active mode and be ready to perform the capture whenever harvestable energy becomes available. The device must be ready to provide an output as the application design requires it. For example, let's say the energy is vibration from someone walking on a surface embedded with a vibration-energy source with a circuit, temperature sensor and wireless transmitter. The small energy packets provided from the possibly infrequent pedestrian activity must power the circuit in the active mode for a long period of time until the circuit triggers the transmitter to send the temperature data. The efficiency must be high enough so that the energy consumed by the circuit is much smaller than the energy provided by the vibrations.

Classic Energy Harvesting Electronics

The classic (high-efficiency) energy-harvester system consists of an energy generator, capture/storage/management electronics and a load designed to be powered by the harvester, typically a wireless sensor network. In the block diagram below, a piezoelectric crystal membrane is shown as the energy generator. The piezoelectric generator transforms mechanical vibrations, strain or stress into electrical voltage/current. This mechanical strain can come from many different sources, including human motion, other low-frequency seismic vibrations, aircraft or vessel vibrations and acoustic noise.



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Except in rare instances, the piezoelectric effect operates in alternating current, requiring time-varying inputs at mechanical resonance to be considered most efficient at generating energy. Most piezoelectric sources produce very high voltages but extremely small currents, resulting in available power on the order of microwatts – too small for most system applications but an ideal generating source for energy-harvesting electronics.

AC energy from the PZT is input to the detector, which converts the voltage to DC and initiates the capture-and-storage operation. The detector can accept instantaneous input voltages ranging from 0.0V to +/-500V AC and input currents from 200nA to 400mA in either a steady stream of pulses or an intermittent and irregular manner with varying source impedances. Early harvester electronics required a minimum of 4V input to capture and store the energy from PZT and other generators. More recent designs feature a front-end voltage booster and claim to initiate capture and energy storage with voltage inputs at less than 100mV.

As the energy generating source injects energy into the detector electronics, these electrical impulses are collected, accumulated and stored onto an internal storage device, such as a capacitor. The capture mechanism is set to operate between two supply voltage thresholds – +V_low DC and +V_high DC – corresponding to the minimum (VL) and maximum (VH) supply voltage values for the intended "load" application. When (VH) is achieved, the output is switched "on demand" to power the load. As the output diminishes and falls to (VL), the output is turned off and the charging cycle begins again until it reaches (VH). In one example, typical charge/cycle times are within four minutes at an average input current of 10 uA and within 40 minutes at an average input current of just 1.0 uA. For optimum performance and long energy retention times, designing energy-harvesting electronics must incorporate micro-power devices so that the energy consumed by the harvesting electronics is much smaller than the energy input by the generating source. The net captured energy is a direct function of energy available for capture minus the energy the circuit must consume to stay in the active mode.

Energy Efficiency, Retention and Management

Let's say the charging energy for the harvester is derived from mechanical vibrations caused by one or more automobiles crossing a bridge whose surface has been outfitted with embedded piezoelectric crystal materials. The object of the application is to monitor roadbed displacement during certain traffic hours. The piezoelectric strips are connected to the energy-harvester electronics, which in turn are designed to power a wireless transmitter whose input is a series of displacement transducers also embedded in the roadway surface. If the harvester efficiency is typically low, the intermittent energy charges created by passing automobiles would have to charge the harvester almost continually while in the active mode in order to achieve the proper output power to drive the load. But with a well-designed harvester having greater than 90% efficiency, the energy consumed by the harvester electronics would be much smaller than the random energy generated by the mechanical vibrations and captured for storage, thus allowing for adequate powering of the transmitter even at times of lighter automotive traffic.

The graph depicts the typical percent of energy efficiency versus available active energy input in terms of μJ(μW seconds) that one can expect from a harvester designed with micro-power, zero-threshold MOSFET arrays.

Energy Retention

A second key component of energy management is storage and retention, with minimal leakage or loss. In the example of the bridge-monitoring application discussed above, when automobile traffic and vibration are minimized, there may be extended time intervals before sufficient energy has been captured and stored. Therefore, the harvester's electronic design must possess extremely high retention when the energy-generator function is randomly available or interrupted for long periods of time. Using alternative energy generators such as solar or thermoelectric generators may also be considered in order to heighten available harvested energy.

Management

Energy conditioning is a third key component of energy management and refers to critical monitoring of the harvester minimum (VL) and maximum (VH) output supply voltage, since the input energy is usually random and uncontrolled. To conserve power consumption, nanopower comparator circuits are typically employed to monitor and control the input capture and energy storage min/max limits. System-ready and other handshake commands are also generated in concert with requirements of the wireless sensor network.

The Energy Harvesting Forum, founded in 2007, is an information portal that aids in the advancement and adoption of practical commercial products for the energy harvesting market. For more information go to www.energyharvesting.net.

Michele Kinman is Administrator of the Energy Harvesting Forum.**Graph Provided Courtesy of Advanced Linear Devices, Inc.*

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