

The Evolution of Sensor Networks

Sensors networks are gaining widespread use in factories, industrial complexes, commercial and residential buildings, agricultural settings, and urban areas, serving to improve manufacturing efficiency, safety, reliability, automation, and security. These networks perform a variety of useful functions including factory automation, measurement, and control; control of lighting, heating, and cooling in residential and commercial buildings; structural health monitoring of bridges, commercial buildings, aircraft, and machinery; tire pressure monitoring systems (TPMS); tank level monitoring; and patient monitoring in hospitals and nursing homes.

To date almost all sensor networks use wired connections for data communications and power. The cost of installing a sensor network using copper wire, conduit, along with the support infrastructure has become extremely cost-prohibitive. There are new emerging solutions using various wireless protocols such as ZigBee Green Power, Bluetooth LE and 6LowPAN to network sensor devices and eliminate the data communications wiring. However, the wireless sensors still need to be powered. Using batteries such as AA cells has been used as a solution. But these batteries wear out and changing them out is often an expensive proposition. OnWorld Research has estimated that this battery change-out cost will approach \$1 Billion in 2013. What is needed is a solution that harvests the ambient energy around the wireless sensor device and we can cut the power cord forever.

Zero Power Wireless Sensors are the Solution

Wireless Sensor Networks (WSNs) is the term that is used for wireless sensor and control networks that use batteries or Energy Harvesting techniques to power the device. With the availability of low cost integrated circuits to perform the sensing, signal processing, communication, and data collection functions, coupled with the versatility that wireless networks afford, we can move away from fixed, hard-wired network installations in both new construction as well as retrofits of existing installations.

One drawback to moving toward a wireless network installation has been the poor reliability and limited useful life of batteries needed to supply the energy to the sensor, radio, processor, and other electronic elements of the system. This limitation has to some extent curtailed the proliferation of wireless networks. The legacy batteries can be eliminated through the use of Energy Harvesting techniques which use an energy conversion transducer tied to an integrated rechargeable power storage device. This mini "power plant" lasts the life of the wireless sensor.

White Paper:
**Zero Power Wireless Sensors
Using Energy Processing**

A Zero Power Wireless Sensor as shown in Figure 1 typically consists of five basic elements:

- 1) A **sensor** to detect and quantify any number of environmental parameters such as motion, proximity, temperature, pressure, pH, light, strain, vibration, and many others.
- 2) An **energy harvesting transducer** that converts some form of ambient energy to electricity.
- 3) An **Energy Processor** to collect, store and deliver electrical energy to the electronic or electro-mechanical devices resident at the sensor node.
- 4) A **microcontroller** or variant thereof, to receive the signal from the sensor, convert it into a useful form for analysis, and communicate with the radio link.
- 5) A **radio link** at the sensor node to transmit the information from the processor on a continuous, periodic, or event-driven basis to a host receiver and data collection point.

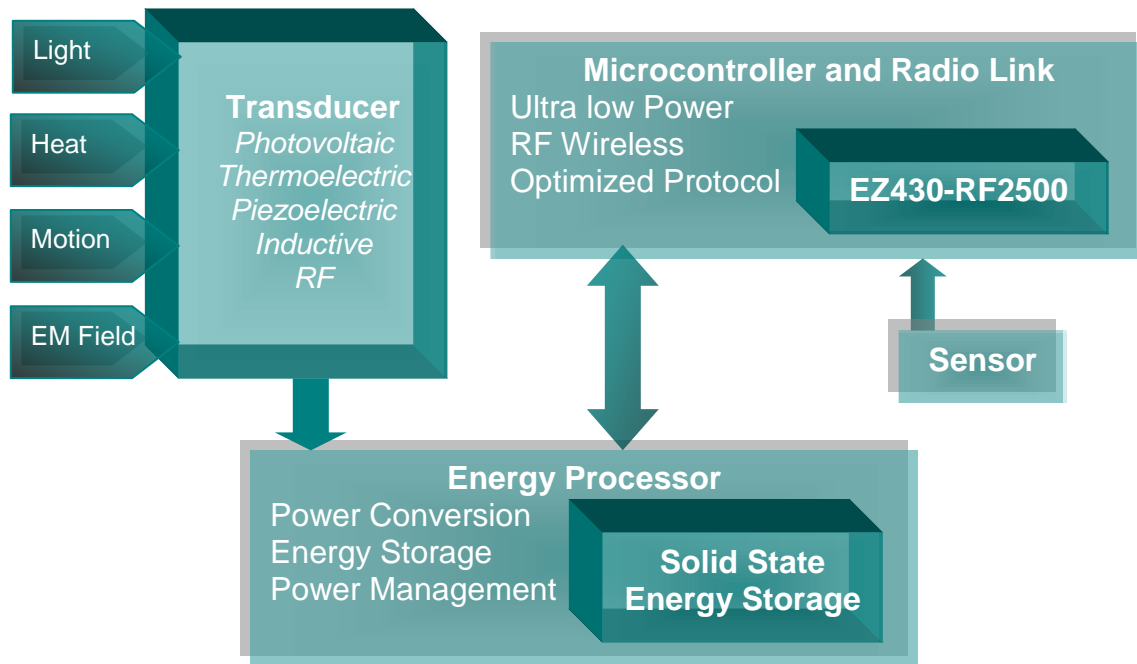


Figure 1: Zero Power Wireless Sensor Diagram

Energy Harvesting Transducers

White Paper:
**Zero Power Wireless Sensors
 Using Energy Processing**

Traditional power sources for wireless sensors have typically been a primary (i.e., non-rechargeable) battery such as AA or AAA alkaline cells, lithium thionyl chloride, lithium coin cells, or a host of other chemistries. But there is another way of providing the power source – harvesting the ambient energy surrounding the sensor device. Energy Harvesting delivers the necessary power and energy to operate the sensor node and, further, does not require battery maintenance during the operational life of the sensor node. In effect, Energy Harvesting enables perpetual sensors.

Energy Harvesting transducers are a source of power that is regularly or constantly available. This power source could come in the form of a temperature differential, a vibrational source such as an AC motor, a radiating or propagating electromagnetic wave, or a light source, as examples. Any of these power sources can be converted to useful electrical energy using transducers designed to convert one of those forms of power to electrical power.

The following transducers are the most common as shown in Figure 2:

- Photovoltaic: also known as solar - converts light to electrical power
- ElectroStatic or ElectroMagnetic – converts vibrations
- Thermoelectric: converts a temperature differential to electrical power
- Piezoelectric: converts a mechanical movement to electrical power
- RF and Inductive: converts magnetic power to electrical power

Energy Source	Challenge	Typical Electrical Impedance	Typical Voltage	Typical Power Output
Light	Conform to small surface area; wide input voltage range	<i>Varies with light input</i> Low kΩ to 10s of kΩ	DC: 0.5V to 5V [Depends on number of cells in array]	10μW-15mW (Outdoors: 0.15mW-15mW) (Indoors: <500μW)
Vibrational	Variability of vibrational frequency	<i>Constant impedance</i> 10s of kΩ to 100kΩ	AC: 10s of volts	1μW-20mW
Thermal	Small thermal gradients; efficient heat sinking	<i>Constant impedance</i> 1Ω to 100s of Ω	DC: 10s of mV to 10V	0.5mW-10mW (20°C gradient)
RF & Inductive	Coupling & rectification	<i>Constant impedance</i> Low kΩs	AC: <i>Varies with distance and power</i> 0.5V to 5V	Wide range

Figure 2: Energy Harvesting Transducer Comparisons

The efficiency and power output of each transducer varies according to transducer design, construction, material, operating temperature, as well as the input power available and the impedance matching at the transducer output.

New Energy Processors and Solid State Batteries Are Now Available

Zero Power Wireless Sensors require energy processing low power management circuitry to condition the transducer output power, store energy and deliver power to the rest of the wireless sensor. In most environments, any of transducers producing power cannot be relied on under all circumstances to continuously supply power to the load. While each transducer delivers power at some amplitude and with some regularity, they do not store energy. Consequently, when that source of power is not present, there would be no power to supply the load in the absence of an energy storage device. Moreover, the transducers typically do not deliver power at the proper voltage to operate the electronic system; therefore, conditioning of transducer power is essential to making the power useful in operating the sensor, processor, and transmitter. In particular, without an energy storage device, it would be difficult or impossible to deliver the pulse current necessary to drive the wireless transmitter. Traditional rechargeable energy storage devices such as supercaps and coin cell batteries have severe limitations with respect to charge/discharge cycle life, self-discharge, and charge current and voltage requirements.

An Energy Processor, such as Cymbet's EnerChip™ EP CBC915, provides all of the energy conversion, energy storage, and load power management for the Zero Power Wireless Sensor. In order to produce high efficiency transducer energy conversion the Energy Processor performs maximum peak power tracking by emulating the impedance of the transducer. The Energy Processor also coordinates all the power-up sequencing even from a dead start with no charge in the system. The Energy Processor also provides power and energy status information to the Microcontroller so the system can be made "Energy Aware". Figure 3 shows the EnerChip EP Energy Processor and EnerChip solid state batteries on the EVAL-09 Universal Energy Harvesting kit. This kit interfaces to any type of EH transducer, converts and stores the harvested energy and provides a regulated output voltage to a target system.

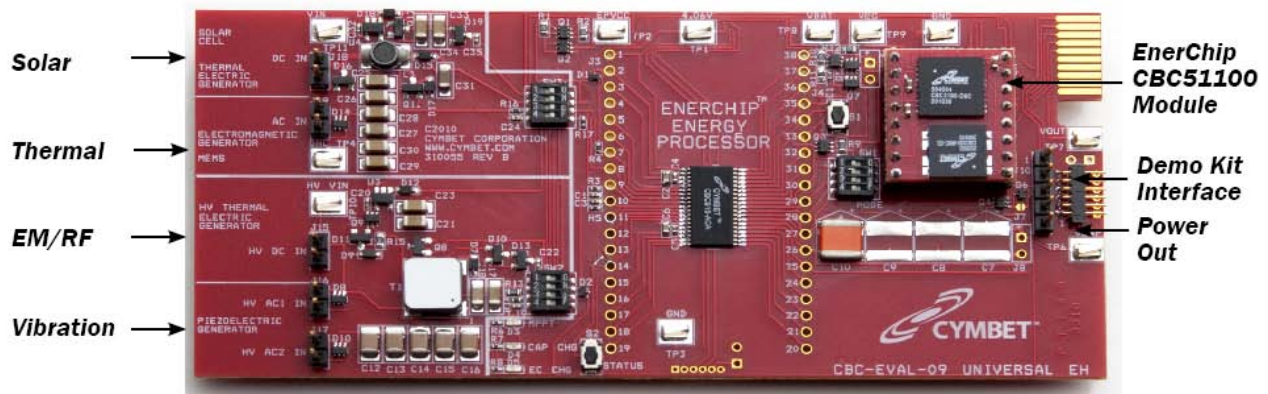


Figure 3: Cymbet EVAL-09 EnerChip EP Universal Energy Harvesting Kit

White Paper:

Zero Power Wireless Sensors Using Energy Processing

The Energy Processor performs several useful “Energy Aware” functions, including handshaking features for communication with the microcontroller. A detection circuit determines whether enough power is available from the transducer to operate the system. If so, the microcontroller receives a signal indicating that the power module is operating normally. If insufficient power is available, a signal alerts the microcontroller to go into a low power mode and, if so programmed, send a signal to the wireless radio to alert the access point accordingly. There is also a control line that allows the user to disconnect the EnerChip from the circuit in order to use all available input power to operate the system, rather than diverting some of the power to the EnerChip to charge the cell.

Microcontroller, Sensor and Wireless Radio

The output of the sensor is typically connected to a microcontroller that processes the signal created from measuring the parameter of interest (e.g., temperature, pressure, acceleration, etc.) and converts it to a form that is useful for data transmission, collection, and analysis. Additionally, the microcontroller usually feeds this information to the radio and controls its activation at some prescribed time interval or based on the occurrence of a particular event. It is important that the microcontroller and radio are operating in low power modes whenever possible in order to maximize the power source lifetime. Depending on the quiescent current of the radio and microcontroller, the transmitter power and duty cycle, and the complexity and duration of any signal processing required, the drain on the power source can be dominated by steady state or active power consumption. Power consumption can also be reduced through microcontroller firmware algorithms that efficiently manage power up and power down sequences, analog-to-digital conversions, and event-driven interrupts.

Zero Power Wireless Sensor Evaluation Kits

All of the elements described in the previous sections have been combined into autonomous perpetual wireless sensor evaluation kits. Figure 3 shows the EVAL-09 kit and Figure 4 shows the new Cymbet EnerChip CC Solar Energy Harvesting EVAL-10 kit combined with the Texas Instruments eZ430-RF2500 wireless evaluation kit to create a solar-based EH wireless temperature sensor. In this case, the on-board EnerChip CC CBC3150 provides the energy processing functions and the solid state battery energy storage.

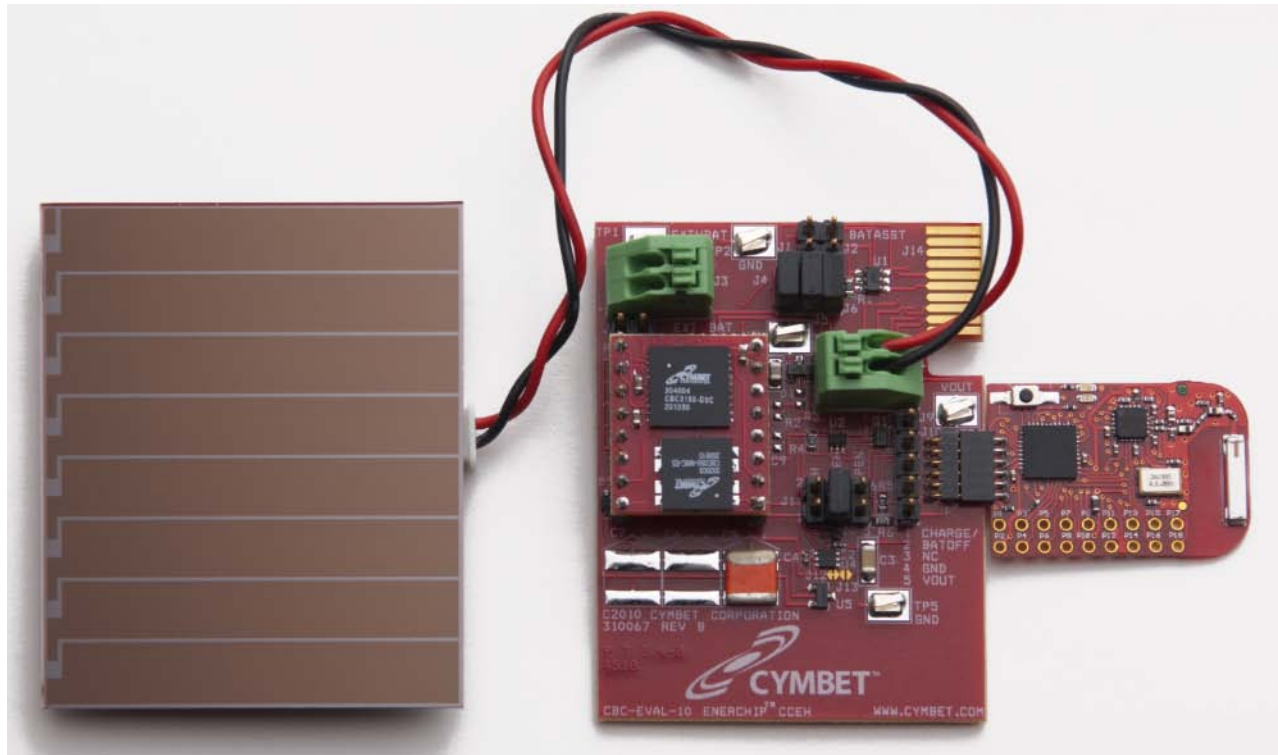


Figure 4: Cymbet EVAL-10 Solar EH Kit with TI eZ430-RF2500 Wireless Kit

Conclusion

Wireless sensor systems are becoming more prevalent due to the rising installation costs of hard-wired sensor systems, availability of low cost sensor nodes, and advances in sensor technology. Energy Harvesting-based autonomous wireless sensor nodes are a cost-effective and convenient solution. The use of Energy Harvesting removes one of the key factors limiting the proliferation of wireless nodes - the scarcity of power sources having the characteristics necessary to deliver the energy and power to the sensor node for years without battery replacement. Significant economic advantages are realized when Zero Power Wireless Sensors are deployed vs. hard-wired solutions. Additional savings are realized by removing the significant costs of battery replacement. Combining Energy Harvesting transducers, an Energy Processing Power Module, low power sensor, an energy aware Microcontroller, and an optimized RF Radio link delivers the reality of long life, maintenance-free Zero Power Wireless Sensor Networks.