


Alumni's Diary

Towards near Battery-free IoT Sensor Devices

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I. Introduction

Energy harvesting is now receiving particular attention in the world of sensor networks. With the advancements in semiconductor technology and improved communication infrastructures, it has become possible to connect many sensors via a network and collect/utilize a large amount of information (Big Data). This network of numerous wireless sensor nodes along with the gateways and remote servers make the so-called IoT aka Internet of Things. In recent years, full-scale utilization of IoT systems has begun, and the movement to install sensors with communication functions is becoming active. However, a power source is required for these electronic functions to operate at all times. For this reason, it cannot be placed everywhere. In other words, while it is said that all things are connected to the Internet, the places where IoT devices can be installed are limited to those within the reach of humans. When the power source is a battery, there is originally no power wiring, but battery replacement is required which increases maintenance cost. Incorporating energy harvesting technology into the sensor eliminates the cost of electricity, eliminates the need for wiring to supply power, reduces construction costs, and increases the degree of freedom in sensor installation. Employing energy harvesting will reduce the Bill of Materials (BoM) of maintaining the network as well as increasing the lifespan of the edge devices.

With energy harvesting, there is no need to pull power lines and worry about battery replacement and charging. This will reduce construction costs and electricity costs. An even bigger advantage is that this will enable hassle-free maintenance of remote sensors and allow the scope of always-on real-time sensing. Hence the use of energy harvesting is attracting attention.

It is a technology that converts natural energy such as light, sound, vibration, temperature difference, and electromagnetic waves into electric power and uses it as a power source for electronic devices. The main idea is to convert the small amount of energy around us into electric power and utilize it. This energy conversion technology with an output of about μW to W that can be a stand-alone power source for small electronic devices is gaining traction and attracting interest of various sectors such as consumer electronics, military and aviation, smart healthcare, smart agriculture, wearables, smart mobility etc.

In recent years, many high-performance, efficient harvesters have been commercialized, and the amount of power that can be obtained from these has increased significantly. For example, the power generation efficiency of solar cells continues to improve while the devices are becoming easier to use e.g., Dye-sensitized Solar Cells, which have high power generation efficiency within low light conditions such as indirect sunlight and indoor light. Thin and flexible organic solar cells are also an emerging technology trend.

However, properly designing an energy harvesting system is not so easy. Factors that previously did not have to be considered by electronics designers are so important that they determine the success or failure of the development. Until now, many electronic device designers have designed functions on the assumption that the power required to drive the device can be obtained abundantly.

However, energy harvesting equipment should be designed with the potential for power shortages and outages without warning. This is because the amount of power generated fluctuates greatly due to changes in the surrounding environment. The unstable power supply is a major premise for development. Wireless IoT nodes do not always match the timing of power generation and the timing of using electricity for transmission, and in the first place, it may not be possible to cover the amount of power that can be communicated unless a certain amount of power is accumulated. This calls for very stringent design conditions which can be addressed only by skilled electronics designers with niche expertise in developing energy harvesting solutions.

In recent years, power supply ICs designed for the use of energy harvesting has been commercialized, and this situation has improved considerably. These power supply ICs are designed to handle minute power, significantly reduce leakage current when not in operation, and increase conversion efficiency while driving low output currents. In the latest power supply ICs for IoT devices, analog IC manufacturers are now competing to reduce standby power consumption at the Nano-ampere level.

There is a paradigm shift in the energy market, which is the decentralization of power generation. In this trend, adopting energy harvesting technology, which can be said to be the ultimate distributed power source, will reduce power costs and the labor of battery replacement thus showing great promise for the spread of IoT technology.

II. Energy Harvesting Technology

Energy harvesting is a key technology to realize the self-sustaining power supply drive of wireless sensors. This will make it possible to realize work-saving (no wiring work required) and maintenance-saving (battery replacement not required) and be effective for environmental consideration, energy-saving, and sustainable society.

It can be said that the self-sustaining power source by energy harvesting is established when the following four elements (A) to (D) are balanced.

A. Power generation efficiency

In terms of performance metrics for designing an energy harvester, efficiency is of utmost importance. The magnitude of the rated power generation amount of the harvester depends heavily on the surrounding environment. When a sensor that measures temperature and humidity in an office is equipped with a power generation device that harvests from indoor light, depending on the location of the device the harvesting energy ranges from 10,000 lux to several hundred lux. Hence, energy harvester ICs must have a respectable and steady conversion efficiency under various operation conditions spanning across the entire spectrum of use cases.

B. Power durability

It is often difficult to know how much power a sensor or communication module consumes. Especially for wireless communication, it is necessary to measure the standby power when it is difficult to connect or when there is no communication. In these situations, it is quite difficult to manage the power supply scheme for different conditions.

C. Storage capacity

As the electric power system, a power storage device is indispensable for filling the gap between (A) and (B) by reserving the generated power for later use. Hence, the selection of an optimal power storage device is a challenge.

D. Cost

Incorporating energy harvesting in an existing application requires proper R&D and meticulous design which calls for an additional cost.

The challenge when applying energy harvesting to sensors is that the energy obtained from energy harvesting is still unstable at present.

The remote-control switch for lighting only needs to be driven when pressed, so there is no need to worry about running out of power when needed. However, the sensors used for monitoring need to transmit the sensed information on a regular basis, so there is a possibility that sufficient power cannot be obtained when needed. As a solution, it is necessary to develop a sensor with lower power consumption, and of course, a method for combining other technologies to achieve an optimal design.

III. IOT System

Figure 23 shows the block diagram of an IoT system with Energy Harvesting. The components of the system are Transducers corresponding to the specific form of energy, Energy Storage device(battery/Super-capacitor), Power Management Unit (PMU), Sensor devices, Micro Controller Unit (MCU), and Transceiver for communication.

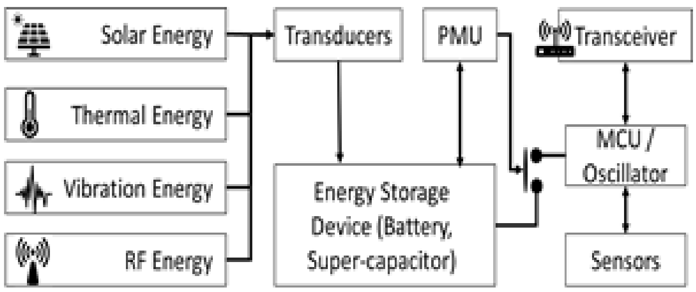

Fig. 24: Block Diagram of IoT system with Energy Harvesting

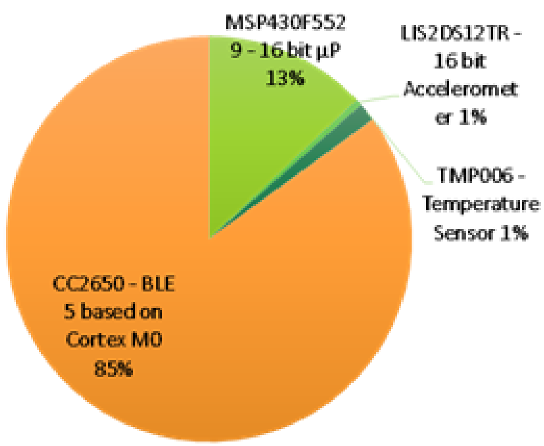

Fig. 25: Power Consumption in Active mode (µW)

Figure 24 shows the active mode power consumption of the components of the system with a temperature sensor, accelerometer, MSP430F552 microprocessor, and CC2650-BLE 5 based Cortex M0 modules.

The lifetime of the system running on a battery with a rating 40mAh is around 27 days. Through harvesting energy from multiple sources, considering the scaled power densities the battery life is extended by 12 days considering the energy harvested from Solar- 100µW, Thermal - 40 µW, Piezo - 10 µW, and RF – 0.1 µW. IoT system with energy harvesting would have a lifetime of 40 days as shown in Figure 25.

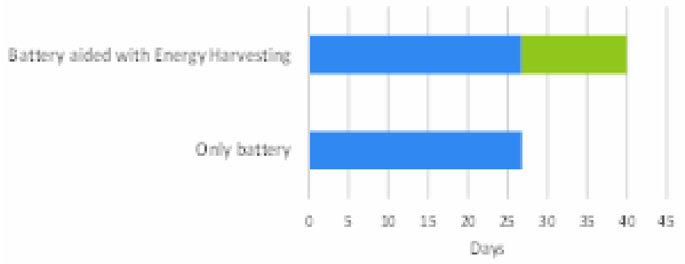

Fig. 26: Life-time extension with Energy Harvesting

It is possible to provide a stable power supply to sensors by properly combining other technologies with energy harvesting. This will make it possible to perform sensing closer to real-time even in cases where real-time sensing has not been possible so far. Building such a sensor network is only feasible through the efficient use of an energy harvesting scheme for optimum power management.

IV. IOT System with Energy Harvesting

IoT systems can obtain power by harvesting, storing, and utilizing a small amount of energy from external sources (for example, solar, light, heat, kinetic energy, etc.).

A. Solar Energy Harvesting

Energy harvesting that collects (harvesting) light energy (energy) from lighting such as sunlight, incandescent lamps, fluorescent lamps, and LEDs to obtain power is called photovoltaic power generation. The biggest feature of photovoltaic power generation is that the energy source is inexhaustible and clean. The power generation efficiency of photovoltaic power generation is almost constant regardless of the scale of the system to be installed. Since it does not generate noise or emissions during power generation, it can be installed anywhere if the amount of solar radiation can be secured.

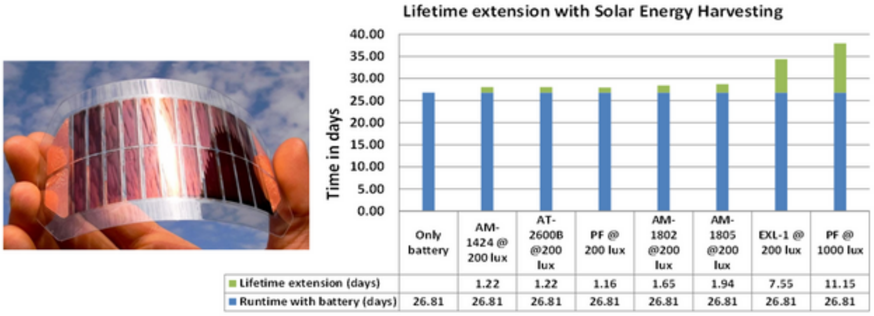

Fig. 27: Lifetime extension with different PV transducers on IoT System

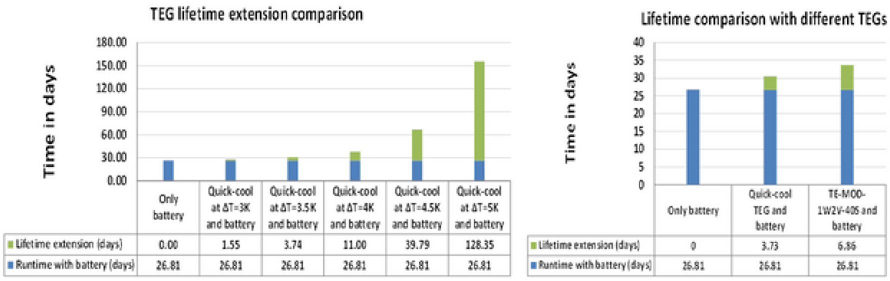

Fig. 28: Lifetime extension for different temperature difference and different TEGs on IoT System

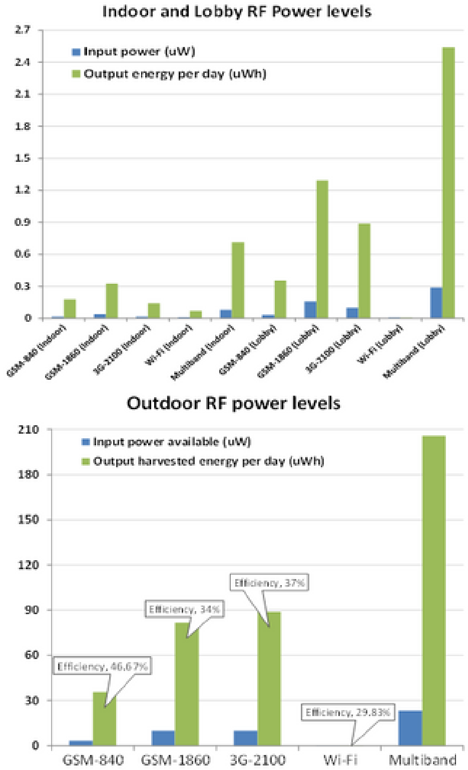

Fig. 29: RF power levels for indoor & outdoor environments

Due to the structural simplicity of the PV system, the life of the system is relatively long. Solar cell modules are readily available, easy to use, and inexpensive. The current and voltage generated is proportional to the cell configuration (series or parallel), module size, and changing ambient illumination. For different PV sources commercially available, the lifetime extension on the IoT System mentioned in Section III for illuminance of 200 LUX & 1000LUX is shown in Figure 26.

B. Thermal Energy Harvesting

Thermoelectric power generation is a technology that directly recovers electric power energy from waste heat and unused heat. Since there are no moving parts, there is an advantage that vibration does not occur, the life can be extended, and installation is space-saving. Focusing on the fact that there are few factors, and it is possible to supply stable power.

When a temperature difference is applied to a substance (conductor) that easily conducts electricity, such as a metal or a semiconductor, a voltage (thermal electromotive force) is generated across the substance.

The thermoelectric effect is the mutual influence of this thermal energy and electrical energy, and one of them is a phenomenon called the "Seebeck effect" in which the temperature difference between two junctions is directly converted into a voltage.

Recent progress in thermoelectric materials (materials that convert thermal energy into electrical energy and are the core of 3. thermoelectric power generation) makes it a suitable candidate is very promising and can be widely used for energy harvesting technology. For different temperature differences and different commercially available TEGs, the lifetime extension on the IoT system mentioned in Section III is shown in Figure 27. A TEG module can generate respectable amounts of voltage using the human skin as a heat source. The thermal resistance of the body can be significantly decreased by placing the TEGs in the locations on the skin, where the largest heat flows are available. So, putting the TEG near the artery with heated blood decreases the thermal resistance between the human body and the device.

C. Radio-Frequency RF Energy Harvesting

RF Energy Harvesting can collect small amounts of ambient energy to power wireless devices, and it can be used anywhere, anytime. For this reason, it is a very promising technology for applications where batteries are impractical.

Figure 28 shows the harvested energy power levels by harvesting different ambient frequency bands like GSM, 3G, and Wi-Fi under indoor and outdoor environments. Through multi-band harvesting the effective output power levels are high.

D. Multi-source Energy Harvesting

For an IoT system to run autonomously the harvested energy should be more than the energy consumed at any instant of time. It is evident that different energy sources have different harvested power densities, hence by considering multi-source harvesting the system can generate sufficient energy to become near battery-free or totally autonomous.

For the IoT system with a battery life of close to a month, through harvesting sufficient energy by selecting transducers accordingly the IoT system can be near battery-free/autonomous. In the multi-source harvesting, the PV panel area is considered as 8.8 cm2 with an illuminance of 1000LUX for 18hrs a day, the TEG considered has an area of 0.8cm2 with a temperature difference of 3.5 Kelvin, and a multi-band RF energy harvester as shown in Figure 29.

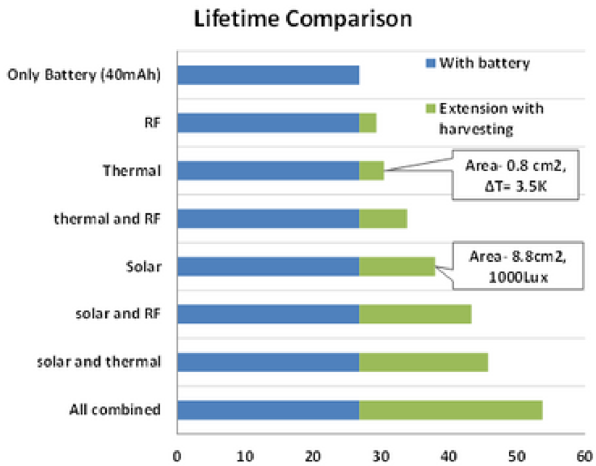

Fig. 30: Lifetime extension from multi-source energy harvesting

V. Summary

Energy harvesting technology, which has the potential of being ultra-compact, low-cost, lightweight, and flexible, will become an important basic technology to implement cyber-physical systems with various sensors and communication devices. Utilizing our team deep-tech expertise and passion for chip development, we at Green PMU Semi focus on the development of innovative Full-custom Energy-Scavenging and Power Management IC/IP Solutions for 'IoT Edge Devices'.

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