RF Energy Harvesting Perpetually Powers Wireless Sensors

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Wireless sensor network (WSN) deployments are rapidly increasing. ABI Research reported that in 2010, WSN chip shipments grew >300 percent and wireless-enabled building automation sensors grew 80 percent. The majority of these sensor nodes are battery-powered which deploy and install rapidly compared to wiring. Wiring is also expensive to install and relocate, but is otherwise a reliable long-term power solution. Battery-based devices are easy to deploy but the batteries, inexpensive themselves, eventually fail and the on-going maintenance cost to replace them is very expensive. In addition, premature battery failure or lack of discipline in replacing them can cause users to miss out on intended benefits such as optimized system performance and improved productivity. The industry needs low-cost, reliable, and long-term power sources to scale WSNs and extend deployment into hard-to-service areas where wiring or replacing batteries is impractical or prohibitively expensive.

As a result, there is tremendous interest in energy sources that can power sensors autonomously for the life of the application without wires or primary batteries. This is commonly referred to as micro-power energy harvesting where waste energy from ambient sources is converted into electrical energy. While solar has been popular for years, other types of energy-harvesting technologies have emerged for micro-power applications including vibration, thermal, mechanical, wind and radio frequency (RF). Each of these technologies could potentially be used in many applications and even co-deployed in the same network. To facilitate adoption, the ISA Power Sources Group is defining interface standards for interchangeability of energy-harvesting devices based on the available energy sources.

While the power from RF energy is typically very low, RF energy is unique among energy-harvesting options because it can either be harvested from ambient energy or intentionally broadcasted to provide more reliable power-over-distance using very little energy from the electric grid.

Ambient RF Energy Sources
Ambient RF energy is pervasive, especially from mobile and Wi-Fi networks. ABI Research and iSupply estimate that mobile-phone subscriptions have surpassed 5 billion, and the ITU estimates there are over 1 billion mobile broadband subscriptions. RF energy can be harvested from mobile phones in close proximity, potentially providing power-on-demand for short-range sensing applications. Other sources of RF energy such as Wi-Fi routers and wireless end devices (i.e. laptops) are also plentiful. At short range, such as within the same room, users can harvest a small amount of energy (microwatts) from a typical WiFi router transmitting at 50 to

100 mW. For longer-range operation, higher-gain antennas are needed to harvest RF energy from mobile base stations and broadcast radio towers. In 2005, Powercast demonstrated ambient RF energy harvesting at 1.5 miles (~2.4 km) from a small, 5 kW AM radio station. The company has also harvested RF energy from an iPhone (demonstration here) in the GSM band and from a nearby mobile base station.

Broadcasting RF for Predictable Energy
When more power or more predictable energy is needed than what ambient sources can provide, RF energy can be broadcasted in unlicensed frequency bands such as 868MHz, 915MHz, 2.4GHz, and 5.8GHz. For building automation applications, including HVAC and lighting control, broadcasted energy will typically be needed to create a reliable wireless power system.

North American regulations limit the output power of radios using certain unlicensed frequency bands to 4-watt effective isotropic radiated power (EIRP), as in the case of radio-frequency- identification (RFID) readers typically found in warehouses. For comparison, earlier analog-based mobile phones had maximum transmission power of 3.6W, and Powercast's TX91501 Powercaster® transmitter sends power and data at 3-watts EIRP using Direct Sequence Spread Spectrum (DSSS) modulation.

RF Harvesting Receivers
RF energy-harvesting receivers convert RF energy into DC. As an example, Powercast's Powerharvester® receivers store the energy directly into a battery for short-range applications, but for longer-range operation accumulate the energy in a capacitor before directly powering circuits or charging batteries. The P2110 Powerharvester receiver has a configurable, regulated output that is active on an intermittent basis. The time between the intermittent pulses is related to the amount of energy received.

These receivers are easily added to OEM circuit board designs and embedded into sealed end devices that are protected from environmental conditions. The receivers are designed with a 50-ohm input to work with standard or custom antennas which minimizes the RF expertise needed to implement a design. Rectenna-based designs require significant RF expertise and specialized test equipment to measure the complex impedance of the antenna.

Improving the RF sensitivity allows for RF-to-DC power conversion at greater distances from an RF energy source. However, as the range increases, the available power and rate of charge decreases. So, another important performance aspect of an RF energy harvester is its ability to maintain RF-to-DC conversion efficiency over many operating conditions, including input power and output load resistance variations. For example, Powercast's RF energy-harvesting components maximize efficiency in the RF domain and therefore do not require additional energy-consuming circuitry for maximum power point tracking (MPPT) like other energy-harvesting technologies require. Powercast's components maintain high RF-to-DC conversion efficiency over a wide operating range that enables scalability across applications and devices.

Typical Applications
Embedding wireless power technology in sealed devices that are protected from moisture and other environmental conditions improves reliability, extends lifecycles and frees systems from connectors, cables, and user access. At close range to a low-power transmitter, RF energy can trickle charge devices including GPS or RLTS tracking tags, wearable medical sensors, and consumer electronics such as e-book readers and headsets. Rechargeable batteries normally stored for long periods can also be trickle-charged and maintained at the preferred voltage for safety or battery cell performance. At longer range, RF energy can power battery-based or battery-free remote sensors for environmental monitoring and building automation. Depending on the power requirements and system operation, power can be broadcasted continuously, on a scheduled basis, or on-demand.

Available power from a 3-watt transmitter will be low milliwatts within a few feet and low microwatts beyond 50 feet. This amount of power is best used for devices with low power consumption and long or frequent charge cycles. Typically, devices that operate for weeks, months, or years on one set of batteries are good candidates for wireless recharging using RF energy. In some applications simply augmenting the battery life or offsetting the sleep current of a microcontroller is enough to justify adding RF-based wireless power technology. A network of transmitters can be positioned in a facility to provide wireless power on a room-by-room basis, or to create a many-to-many charging topology.

Real-World Example
Powercast has productized battery-less, wireless sensors that operate up to 90 feet line-of-sight from a 3-watt transmitter using a 4dBi receiving antenna inside a wall-mount enclosure suitable for office environments. (Note: These sensors are based on the same core RF energy-harvesting technology that is available for OEMs to embed in their own products.) The sensors do not have a real-time clock and are activated asynchronously when they reach a charge threshold. Figure 1 shows typical transmission intervals.
[Figure 1 – Typical Temperature Sensor Transmission Intervals Using a 3-Watt RF Transmitter Power Source]

In Powercast’s aforementioned Lifetime Power® Wireless Sensor System, each 3-watt transmitter covers about 2,500 square feet (SF) delivering facility-wide, wireless, micro-power coverage for around $0.12 per SF. Figure 2 shows a system block diagram to implement a battery-less sensor system similar to Powercast’s.
[Figure 2 - System Block Diagram]

In a 90,000 SF, 300’ x 300’data center, a network of 36 RF transmitters can power virtually unlimited wireless sensors, using less energy from the electric grid than a single 60-watt light bulb. The resulting “energy ROI” from using a few watts to control many kilowatts is significant.

Development Kits Shorten Design Time
Many development kits exist to assist WSN design. Powercast recently released several to help design RF-powered battery-less, or battery-based, wireless sensors.

Powercast developed its Lifetime Power Wireless Sensor System using the power source, communications protocol, processors, and antennas that are included in the company’s P2110-EVAL-01 kit.
[Figure 3 – Powercast P2110-EVAL-01 Development Kit for Wireless Sensors]

RF energy from ambient or intentional sources represents a viable and reliable energy source for many high-function wireless devices. Commercial products are available for deployment and components are available for OEMs. When ambient energy sources of any type are not available, broadcasted RF energy and corresponding RF harvesting receivers enable remote, maintenance-free power for low-power applications. RF energy-harvesting circuits that accommodate multi-band or wideband frequency ranges will further increase the received power, expand device mobility options, and simplify end-product design and installation.