Remote sensors powered by RF harvesting as a power source

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RF harvesting is a viable option for a wide range of applications, with proven technology providing a platform for prototyping new products. Battery-powered sensors can be replaced with a selection of components and power balancing.

Energy capture

Sources of energy, such as light, wind, temperature, vibration, radio waves and even pH have been converted to usable energy but the challenge is how to convert the tiny amount of energy generated to perform a useful function, such as reliably powering an environmental sensor. Table 1 shows a variety of these energy harvesting methods.

An examination of the power budget holds the key, together with the harvested source and the components. RF energy can be obtained from ambient energy or controlled by the use of a dedicated transmitter. Devices using RF harvesting can be untethered and work in almost any environment.

RF as a power source

RF energy can be harvested from sources such as broadcast TV and radio stations, mobile phones and base stations, and transmitters in unlicensed bands including 915 MHz, 868 MHz or 2.4 GHz, making it commercially viable worldwide. RF does not depend on the time of day or require exposure to heat or wind, and can be moved freely within the range of the transmission source. Energy can transmitted continuously, on a scheduled basis or on demand.

A rechargeable battery or super capacitor can store the converted RF energy for operation during the peak periods.

Selecting a low-power component

A convenient and reliable power source is just the start; a proper system design is needed to maximise performance with the tiny amount of energy provided. This can be addressed by either using extremely low power components or implementing power balancing.

The trend for lower-power electronic components is fueled by consumer demand for portable products, and has delivered new low power microcontrollers, analogie, radios and communication protocols that complement RF harvesting. Low power consumption levels are standard on microcontrollers. Microchip’s PIC24F with xXtreme Low Power (XLP) technology consumes only 20 nA while sleeping, and can execute code with currents as low as 8 µA.

Analogue components and a radio are required to complete an environmental sensor. The radio stretches the power-budget because of the protocol used and the transmit/receive (Tx/Rx) current. New radios have started to address the issue, and now feature receive currents as low as 3 mA, which helps to reduce power consumption, but the wireless communications protocol remains the driving factor.

Balancing power

Long execution times and bloated wireless protocols will consume the power budget when working with the tiny amounts of power generated by energy harvesting. The key reduction is to select a protocol that allows for scaling functionality. Microchip’s MIWi protocol allows for minimalist implementation, with radio transmission times driven as low as 5 ms. Power management through charge-based execution and state-of-charge monitoring will deliver further improvements.

Power is cut off completely from the sensor system in charge-based execution. When

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Energy harvesting (also known as power harvesting or energy scavenging) is the process by which energy is derived from external sources (e.g., solar power, thermal energy, wind energy, salinity gradients, and kinetic energy), captured and stored for small, wireless autonomous devices, like those used in wearable electronics and wireless sensor networks. Source: Wikipedia.

<table>
<thead>
<tr>
<th>Energy source</th>
<th>Power density &amp; performance</th>
<th>Source of information</th>
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<tbody>
<tr>
<td>Acoustic noise</td>
<td>0.003 µW/cm³ @ 75 dB</td>
<td>(Rabaey, Ammer, Da Silva Jr, Patel, &amp; Roundy, 2003)</td>
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<tr>
<td>Temperature variation</td>
<td>10 µW/cm³</td>
<td>(Roundy, Steingart, Frechette, Wight, Rabaey, 2004)</td>
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<tr>
<td>Ambient RF</td>
<td>1 µW/cm³</td>
<td>(Yeatman, 2004)</td>
</tr>
<tr>
<td>Ambient light</td>
<td>100 mW/cm² (direct sun)</td>
<td>Not cited</td>
</tr>
<tr>
<td>Thermoelectric</td>
<td>160 W/cm²</td>
<td>(Stevens, 1999)</td>
</tr>
<tr>
<td>Vibration (micro generator)</td>
<td>4 W/cm³ (human motion – Hz)</td>
<td>(Mitheson, Green, Yeatman, &amp; Hornes, 2004)</td>
</tr>
<tr>
<td>Vibration (piezoelectric)</td>
<td>200 mW/cm²</td>
<td>(Roundy, Wight, &amp; Pister, 2002)</td>
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<tr>
<td>Airflow</td>
<td>1 mW/cm²</td>
<td>(Holmes, 2004)</td>
</tr>
<tr>
<td>Push buttons</td>
<td>50 J/N</td>
<td>(Paradiso &amp; Feldmeier, 2001)</td>
</tr>
<tr>
<td>Shoe inserts</td>
<td>330 mW/cm²</td>
<td>(Shenck &amp; Paradiso, 2001)</td>
</tr>
<tr>
<td>Hand generation</td>
<td>30 W/kg</td>
<td>(Starner &amp; Paradiso, 2004)</td>
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Table 1: Power density of energy harvesting methods.
the RF harvester has collected enough energy the device consumes zero power while replenishing the energy reservoir. The frequency of the sensor’s execution is dependent upon the rate of charge to the reservoir. This is impacted by distance to the RF source, the receiving antenna, and obstructions such as walls, which works well when the sensor is located such that the frequency of sensor operation is fitted to the needs of the overall system. To avoid flooding the network with unnecessary packets the RF harvester can also use the received signal strength as a mechanism for controlling the rate of data transmissions.

If the RF harvester is charging a battery, a microcontroller can be used to monitor the length of the charging cycle and estimate the state of charge. It can then calculate the run-time based on what sensor operations are performed by recording the current consumed during the various parts of the sensor operation. For example, the sensor node might consume 100 µA when measuring the sensor’s output, and 20 mA during the radio transmission of that data. The microcontroller can use this information to estimate the charge that will be depleted each time one of these functions is completed. The state of charge is thus found in the comparison between charging and depleting.

This method can taper off the frequency of sensor transmissions, based upon state of charge and can even call for help, by transmitting a message to the RF power source to send more power.

Energy harvesting: the practical solution

RF harvesting is a viable option for a wide range of applications with proven technology providing a platform for prototyping new products. Battery powered sensors can be replaced with a selection of components and power balancing. RF harvesting is a practical option providing control of the source and the ability to operate in any environment, which may also drive RF harvesting to the mainstream.

<table>
<thead>
<tr>
<th>Advantages of RF harvested energy</th>
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<tbody>
<tr>
<td>Available “on demand”</td>
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<tr>
<td>Works in perpetually dark locations</td>
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<td>Works in hazardous locations</td>
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<tr>
<td>Provides mobility</td>
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<tr>
<td>Provides tracking capability</td>
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<tr>
<td>Can take advantage of electricity tariffs</td>
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<tr>
<td>Can charge a secondary battery</td>
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<tr>
<td>Scalable to many nodes without a change to source</td>
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<tr>
<td>Can be embedded between walls</td>
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<tr>
<td>Sealed within an enclosure</td>
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Table 2: Advantages of RF energy harvesting.

RF harvesting is the first proven and reliable option; it meets environmental regulations and corporate social responsibility requirements, makes economic sense and avoids being at the mercy of the sun, wind or unpredictable temperature conditions.

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