RECEIVING ELECTRICAL POWER WITHOUT THE USE OF WIRES HAS LONG BEEN AN IDEAL FOR ELECTRONIC DEVICES. HOW FEASIBLE IS IT, AND WHAT ARE SOME OF THE OTHER OPTIONS?

# POWER WITH NO STRINGS ATTACHED

BY MARGERY CONNER • TECHNICAL EDITOR

Any technology that offers to free applications from power cords and wall warts will confer a definite salable edge on electronic devices. Applications that would benefit from wireless power range from portable consumer electronics, such as cell phones and MP3 players, which could jettison their wall warts and power adapters, to low-power wireless-sensor networks, which could be free of frequent battery replacement, to medical implants in patients who could avoid surgery to replace batteries.

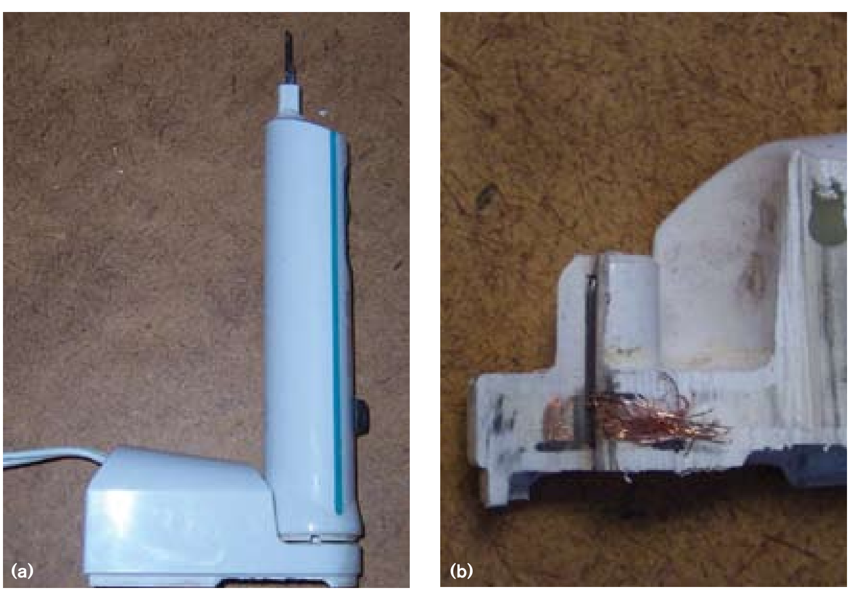


Figure 1 In this rechargeable electric toothbrush, no conductive contact occurs between the toothbrush holder and the charging unit. Energy transfer takes place through inductive coupling (a). This cutaway of the encapsulated base shows the primary winding of the transformer, with a ferrous rod pushing into the key that the toothbrush unit fits onto. Precise alignment is necessary to maximize the coupling between the two windings (b).

But how close are we to having a practical replacement for power cords, and what are the various options? What are the constraints these options imply in power levels, frequencies, and device placement? And, does power at a distance pose any health risks?

One wireless technology, inductive coupling, is familiar to anyone who has a rechargeable electric toothbrush, which has no conductive contact with its charging unit (**Figure 1a**). The charging unit, which is connected to ac wall power, has the primary side of a transformer in its base, with an iron center that keys into the secondary side of the transformer, which resides in the handheld toothbrush. After you brush your teeth, you typically remove the brush from the end of the brush unit and place the brush unit on the charging base. The brush unit, which an iron-cored key holds in place, fits perfectly over the primary. This key fits into the hole through the center of the secondary in the brush unit (**Figure 1b**). This keyed arrangement makes the physical alignment of the primary and the secondary coils fixed in the x, y, and z planes. This precise alignment is necessary; if the primary and secondary misalign by a fraction of an inch, the power transfer becomes inefficient. Cell-phone manufacturers could use a similar arrangement for recharging rather than rely on a charging unit. However, the transformer secondary is too bulky for consumer devices that must fit into a purse or a pocket, rather than spend their lives on a bathroom counter. And the primary reason the toothbrush holder uses the inductive power coupling is not for ease of connection, but because the holder's wet environment necessitates the sealed aspect of the power coupling.

To avoid the inductive coupling's constraints of close, precise alignment, eCoupled has introduced "adaptive-inductive coupling," in which the power circuit senses any change from the optimal positioning of the two coils and then looks for the best operating point for that configuration. The circuit's load shift causes the impedance and, thus, the resonant frequency of the circuit to change. In addition, eCoupled adds a digital-control loop to respond to changes in the load beyond the transformer coupling device. According to Dave Baarman, director of advanced technology for eCoupled, this combination of adaptive inductive coupling and a digital loop means that the power circuitry can maintain power to a device even when the device moves as much as several inches in the x and y planes and slightly less than an inch along the *z* axis.

## SKIN DEEP

But this less-than-an-inch constraint isn't as limiting as it first sounds. "The distance [in the *z* axis] you need is just the 'skin thickness' you have on your MP3 player or cell phone," Baarman explains. That's enough to be able to casually place a device in a charging region on a counter top. Magnets enable you to feel when a device is aligned in a charging spot, ensuring alignment in the x and y plane—the counter top. The company has announced adaptive-inductive-coupling licensing partnerships with companies such as Motorola, Visteon, and Herman Miller, although these companies haven't announced any adaptive-induction-coupling-based products. Herman Miller will be making such announcements by early 2008, however, according to Mark Sherman, the company's corporate communications manager. The technology does have a track record: eCoupled's sister division, Fulton Technologies, has since 2002 used adaptive-induction coupling to power the electronics in its water-purification system. Baarman claims that eCoupled has tested adaptive-inductive coupling at power as high as 1400W.

**AT A GLANCE**

- Recent work in wireless power has focused on inductive coupling and RF transmission.
- Inductive coupling offers more than 1 kW of power, but range is on the order of an inch or less.
- RF transmission has a range of 30 feet but at power levels of less than 100 mW.
- Battery technology has improved battery life and failure rates for industrial- or military-grade batteries, so batteries may also be options for wireless power.

The trade-off of inductive coupling is that it has a relatively high power level but a small range. For some applications, such as wireless-sensor networks, you may be willing to forgo high power for a greater power-transmission range. Transmitting RF energy may be a consideration for these applications. Powercast has developed the Powercaster transmitter and Powerharvester receiver chips operating at 900 MHz, through which you can broadcast and receive energy (**Figure 2**). Their range is several meters, and the power level is as much as 100 mW. This low power level may not be the restriction it seems: If your device, such as a node on a wireless-sensor network, has periods of higher power needs followed by long sleep states, consider adding batteries to the device and use the RF-power receiver to trickle-charge the unit. The devices sell for less than $5 each (production volumes).

An example of the devices' use in wireless-sensor networks is a temperature- and humidity-monitoring network in the penguin exhibit at the Pittsburgh Zoo and PPG Aquarium (www.pittsburghzoo.com). In this cold, wet environment, no power was available, and the exhibit's developers could not bring in cables. They originally set up the sensor network with alkaline batteries to power the nodes, but the batteries wore out within weeks. Powercast retrofitted the nodes with Powerharvester receivers and power circuits and placed a Powercaster transmitter with a patch antenna on the ceiling of the exhibit about 30 feet away from the receivers. Every two minutes, a pulse from the transmitter wakes up the sensor nodes, which reply with temperature, humidity, and state-of-charge information. They then return to a sleep state. They continuously charge from the transmitted RF power, however, keeping the rechargeable alkaline batteries at a constant 3V.

## SAFE POWER LEVELS

The Federal Communications Commission's Office of Engineering and Technology Bulletin 65 governs RF-safety issues, according to Keith Kressin, Powercast's vice president of sales and marketing. The bulletin tells you how much power is allowable for a device that sends out RF (**Reference 1**). A microwave oven has leakage levels of 50 $mW/cm^2$, about the same as a cell phone's radiated RF energy. TV/radio transmitters emits 10 $mW/cm^2$, and an RF-power transmitter emits about 20 $\mu W/cm^2$—far less than levels that are common in everyday life (**Reference 2**).

Energy harvesting of ambient RF power is another possible option for RF-power transmission, but, just as there's no such thing as a free lunch, you should be cautious when estimating the power available from RF energy. Zoya Popovic, PhD, a professor of electrical and computing engineering at the University of Colorado—Boulder (http://nemes.colorado.edu/microwave), suggests that you keep

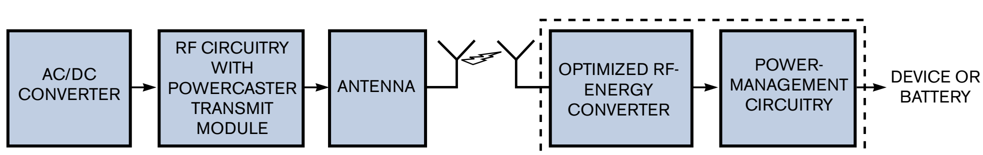


Figure 2 The Powercast RF-transmission platform comprises a Powercaster transmitter and a Powerharvester receiver. The power output is less than 100 mW, but that amount is sufficient to charge an internal battery in a wireless-sensor node or even a small, handheld consumer-electronics device.

# HIGH-EFFICIENCY RF-RECTENNA DESIGN

***By Hubregt J Visser, J Theeuwes, M van Beurden, and G Doodeman***

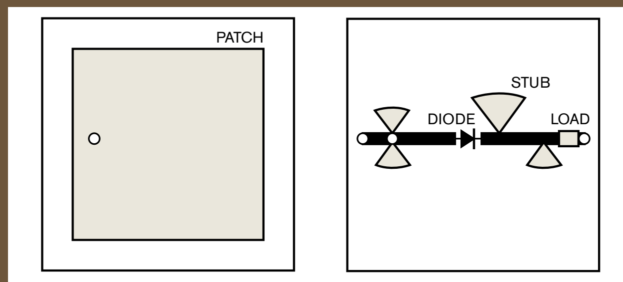


Figure A A PCB layout for a planar microstrip rectenna with a probe-fed antenna and an impedance-matching and filtering network shares a common ground plane with a microstrip network.

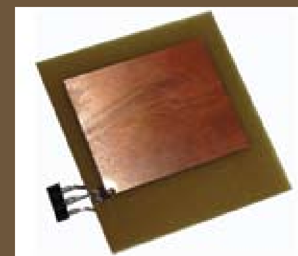

Figure B The newly developed, 28×31-mm rectenna is more compact, uses a single-layer PCB, and has an efficiency of 52%.

**A "rectenna" is a rectifying antenna. At its simplest, it comprises a Schottky diode and an antenna and converts the RF power it receives at the antenna into dc voltage. The challenge is how to maximize the power-conversion efficiency of rectennas for input-power levels of, for example, 0 dBm or less. We employed a method of directly conjugate-matching a rectifying circuit to a microstrip-patch antenna, so that the need for a matching network between the two no longer exists, and the rectenna's efficiency improved. This matching technique automatically suppresses the reradiation of harmonics by the microstrip-patch antenna, because the harmonics will be mismatched.**

**A PCB (printed-circuit-board) layout of a traditional planar-microstrip rectenna with a probe-fed antenna shares a common ground plane with a microstrip network (Figure A). With the aid of analytical models for the antenna and the rectifier, we designed single-layer, internally matched and filtered PCB rectennas with low input-power levels.**

**We analyzed the rectangular microstrip-patch antenna with a cavity model. A newly developed effective length and width take care of the fringe fields of the microstrip-patch antenna. A fourth-order Runge-Kutta routine solved for the packaged diode voltage and the generator current. An FFT then transformed these time-domain parameters to the frequency domain, in which, for each harmonic, a packaged diode impedance was determined for a fixed incident-power level.**

**After finding the complex diode impedance, we determined the microstrip-patch edge's feed point to obtain the conjugate impedance of the diode and thus a conjugate match between the antenna and the diode (Figure B).**

**With the developed analytical model, you can accurately determine the rectenna output voltage as a function of input power at the antenna (Figure C). This design realized an efficiency of 52% for 0-dBm input power at 2.45 GHz, showing an improvement of more than 10% over a traditional rectenna design (Reference A). A series connection of these rectennas power a standard household wall clock at a distance as long as 6m (Figure D). The eventual applications, however, will be in charging batteries at a distance.**

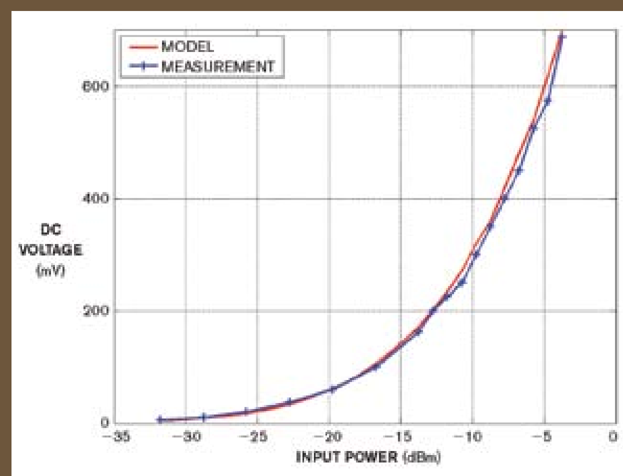


Figure C The rectenna's output voltage is a function of power incident upon the antenna.

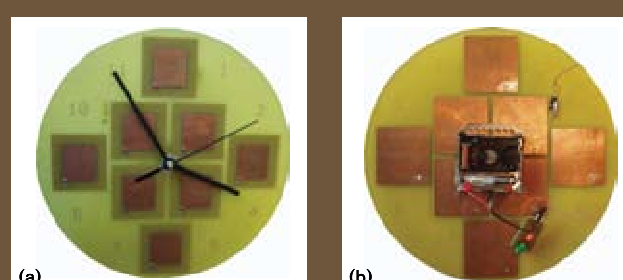


Figure D Eight 2.45-GHz rectennas in series power an electric wall clock (a). The back view shows a voltage-protection circuit (b).

### AUTHORS' BIOGRAPHIES

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these three points in mind: First, ambient power covers a broad range of frequencies. The best way to gather RF energy is to design an antenna and power circuit for that frequency; you need to have an antenna and power circuit that can work in that environment, which means it has to be broadband or at least multiband.

Second, when harvesting ambient RF, you have no idea how the electromagnetic wave is polarized. Popovic gives an example: "If you transmit from one corner of the room a vertically polarized wave with a wire antenna, by the time the energy bounces around the room and arrives at the other side, the power will be equally distributed in both the horizontal and the vertical polarization. If you want to capture that [power] efficiently, you must design for both polarizations."

Third, because of the multipath environment, the power at the RF receiver varies not only in frequency and polarization, but also in power level. Popovic's team designs RF-power-receiver circuits having "rectennas," antennas with rectifying circuits that produce dc voltages. As the power level varies, so does the dc voltage at the output of the rectenna. Because energy-storage devices, such as batteries and capacitors, cannot tolerate wide voltage swings, the team placed a power-management and -buffering stage between the rectenna and the energy-storage component (see **sidebar** "High-efficiency RF-rectenna design").

Another technology, although not contactless, is Wildcharge's wire-free development. A Wildcharge-enabled device contacts a charging pad through an ohmic contact—a sputtered metal pad produced through a photolithographic process—to charge a cell phone or a similar consumer device. Wildcharge plans this summer to introduce a 15W, $40 charging pad that can charge multiple low-power devices. Devices will require an adapter to use the pad, but they can also have built-in Wildcharge technology and charge from any Wildcharge pad.

New wireless-transmission technologies are still in the research phase. Massachusetts Institute of Technology (www.mit.edu) physicist Marin Soljacic has announced "nonradiative-resonant-energy transfer" for distances of less than a few meters. The technology relies on copper coils tuned to resonate in identical magnetic fields (**Reference 3**). In addition, researchers at the University of Tokyo (www.u-tokyo.ac.jp) have developed a four-layer plastic sheet with printed coils, organic transistors, and MEMS (micro-electromechanical-system) switches that use inductive coupling to power devices fitted with receiver coils (**Reference 4**). Both of these technologies are still un-

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dergoing research, and commercialization is at least a few years away.

But even the approaches from eCoupled and Powercast are still new and have potential drawbacks and unknowns. Keep in mind that battery technology has also advanced. All batteries are not created equal, and the alkaline rechargeable battery with a lifetime of less than a year is not your only option for charging a low-power device. For example, Tadiran claims that its industrial- and military-grade lithium-thionyl-chloride batteries have a lifetime of more than 20 years and a failure rate of fewer than one cell per million. These primary, nonrechargeable batteries have low leakage current and high energy capacity. Tadiran's AA-sized high-power lithium battery, for example, has a nominal voltage of 4V compared with the 1.5V of a consumer device's AA battery. The high-power unit also has an available net capacity per cell of more than 2 Ahr. The battery will last more than 20 years powering a system that consumes power at 81 mAhr/year with an end-of-life voltage of 3V. These batteries cost less than $10 each, or less than 50 cents per year. Consider whether an industrial-rated battery will serve your design before venturing into more expensive new technologies. EDN

## FOR MORE INFORMATION

**Colorado Power Electronics Center**
http://ece-www.colorado.edu/~pwrelect

**eCoupled**
www.ecoupled.com

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**Tadiran Batteries**
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**Wildcharge**
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