# TAKING THE LEAD

**If you tend to trip over the vacuum cleaner flex or lose your phone charger, your swearing days could soon be over. Simon Handby investigates wireless electricity**

We think nothing of being able to watch TV, talk on the phone and use the internet wirelessly, but the need for electrical power means we never get away from wires for long. Imagine how much easier life would be if we could power and recharge our gadgets without plugging them in. We could place lighting, speakers and even our PCs anywhere in a room with no messy cabling of any kind. Universal wireless power sources could charge all our portable gadgets without us even thinking about it. We could charge our notebooks, MP3 players and phones simply by placing them on a desk, or even by walking into a suitably equipped room. Wireless electricity could also make electrical devices more reliable, as power adaptors and sockets are common points of failure.

This may sound wildly futuristic, but wireless power transfer was first demonstrated by the Serbian-American scientist and inventor Nikola Tesla at the beginning of the 20th century. He was ahead of his time, but a century later his discoveries are helping to shape the race to make everyday wireless power a reality.

ILLUSTRATION: MAGICTORCH

## CATCHING WAVES

Electricity doesn't travel well through the air. It does happen – lightning bolts and spark plugs are two examples – but as Doc Brown from *Back to the Future* will confirm, it's a problematic way to transmit energy. However, energy travels through the air much more efficiently and safely in the form of electromagnetic waves. Electricity can be converted to visible light, microwaves or radio waves, which can then be directed at a receiver and converted back to electricity.

In the case of visible light, power can be transmitted by directing a laser at solar panels (more correctly known as photovoltaic or PV cells), but there are several drawbacks. The most powerful lasers produce many kilowatts of light, but even the best are typically less than 50 per cent efficient. PV cells are similarly inefficient, so at least 75 per cent of the power is lost between the source and destination. Laser light is absorbed by the atmosphere and high-powered lasers can be extremely dangerous, so they are rarely used to transmit power. However, in 2003, NASA demonstrated a model aeroplane powered by laser light.

Lower-frequency microwave energy is more efficient and straightforward. Microwave transmitters can achieve efficiencies of greater than 70 per cent, and the conversion back to electricity is up to 90 per cent efficient. In 1997, the University of La Réunion, a French overseas territory in the Indian Ocean, proposed an arrangement that could deliver 10 kilowatts of power to an unspoilt mountain village with a predicted overall efficiency of 57 per cent. Physicist and science fiction writer Geoffrey Landis has suggested that microwaves could be used to transmit energy to the earth from orbiting solar power stations, or from the earth to departing spacecraft.

## AERIAL VIEW

Microwaves have been used experimentally to transmit tens of kilowatts, but anyone with a wireless network already has a microwave transmitter with a power in the region of 100 milliwatts. Wireless networks use microwaves with a frequency of 2.4GHz or 5GHz as carrier waves, the frequency or phase of which is subtly modified to transmit information. Although these systems are designed for sending data, the receiving electronics obtain a tiny amount of power from the carrier wave when the antenna converts it to electricity. This is insignificant compared with the amount of energy a wireless device actually consumes, but one company is using the same phenomenon to broadcast milliwatts of electricity to low-power devices.

Powercast's Powercaster (see the box on the next page) is essentially a low-power, ultra-high frequency (UHF) radio transmitter. One or more Powerharvester units placed within range are able to convert the electromagnetic waves they receive into a small electric current. While this

## Case study 1 The Powercast system

An indication of the interest in wireless power is Powercast's award for the Best Emerging Technology at January 2007's Computer Electronics Show (CES).

Unlike the other technologies discussed here, Powercast's system transmits energy using an electromagnetic broadcast rather than induction. This potentially gives it a longer range than the inductive systems but, as with a wireless network, the system's practical range and coverage depends on the transmission power and frequency, the type of antennas in use and any obstacles between the source and destination.

Our calculations suggest that the system, which is likely to transmit with a maximum power of just a couple of watts, would need to use a directional antenna to make this feasible. Powercast told us that both the Powercaster source and Powerharvester receiver units could be equipped with either directional or omni-directional antennas, depending on the application.

Powercast has announced an initial partnership with Philips to develop a "simple lighting product" for 2007, and it expects other consumer products to appear in 2008. The company is understandably coy about what these might be, but CEO John Shearer mentioned the possibility of trickle-charging a mobile phone during a working day.

A case study available at *www.powercast co.com* shows the system's suitability for low-power applications in hazardous or hard-to-reach installations. From March to December 2006, Powercast's technology provided power to a network of wireless sensors used to monitor conditions in the penguin enclosure at Pittsburgh Zoo.

One possible drawback of using electromagnetic waves is their potential to create radio-frequency interference. Keith Kressin, Powercast's vice president of sales and marketing, told us that the system has been designed "to avoid interference with communication systems, and adheres to existing FCC rules". The system aims to minimise interference by transmitting at a very narrow band centred on 905.8MHz UHF radio waves. These have a wavelength of 33cm, making a 17cm antenna suitable.

We asked Kressin why they chose this frequency. "We think this antenna size is practical for a number of applications. In general, higher frequencies enable smaller antennas, though higher frequencies also do not propagate as well through objects or free space. It's important to select a frequency that provides acceptable propagation, but without requiring too big an antenna."

▲ Wireless power charges the batteries in a zoo's temperature sensors. An antenna (not shown) picks up an RF signal and feeds it to the Powerharvester chip (between the batteries)

power supply is only in the milliwatt range, it is enough to power or charge small devices such as flash-based MP3 players or even mobile phones.

Powercast's system is a novel way to power gadgets in the home but it's not the first practical example of a system powered by radio signals. Radio-frequency identification (RFID) tags are used, among other things, to track stock within distribution centres and shops, and have been incorporated into smart cards such as Transport for London's Oyster. Many RFID chips have no means of powering themselves. When subject to a radio broadcast at the correct frequency, such as when an Oyster card is placed on a reader in a station, they can extract enough power from the interrogating signal to transmit a response.

One problem that all forms of electromagnetic energy transmissions share is that there is little inherent feedback between the receiver and transmitter. If the power use drops to zero at the receiving end, the transmitter will continue sending power unless some kind of signal is sent back to tell it to stop.

## FOLLOWING INDUCTION

Of all the ways to transfer power wirelessly, electromagnetic induction is by far the most widespread and the longest established. In 1825, a British scientist, William Sturgeon, invented the first practical electromagnet by passing a current through an insulated coil of wire wrapped around an iron core. This created a magnetic field that disappeared when the current was stopped. Six years later, Michael Faraday discovered a process that appeared to be the reverse of Sturgeon's experiment. By subjecting a conductor to a changing magnetic field, he was able to create, or induce, a current within it. He built a device in which two insulated wire coils shared a single iron core, and found that passing an alternating current through one caused a current to flow in the other, unconnected coil – a process known as inductive coupling.

This discovery formed the basis of the electrical transformer. It was subsequently found that the ratio between the number of windings in the primary and secondary coils dictates the ratio of the input and output voltages. This is how the National Grid runs at up to 400,000V but is stepped down at local substations to feed homes at a relatively safe 240V. Transformers can be very efficient, with those in the national grid transferring as much as 95 per cent of their input power. Some energy is inevitably lost, though, due to resistance in the coils and because the core's magnetic field creates undesirable electricity inside it, producing eddy currents that generate heat.

Most electrical devices in the home rely on induction, too. Modern electronic chips and components typically require a power supply of five to 15 volts, so transformers are essential to the gadgets and computers that contain them. In the kitchen, induction hobs use a powerful magnetic field to deliberately induce eddy currents in the base of a compatible saucepan, which produce heat as they dissipate.

## SOMETHING IN THE AIR

More recently, scientists have found ways to exploit the fact that there is no physical contact between the coils in inductive-coupling circuits. The most widespread example is the electric toothbrush. Water and electricity are best kept apart, and induction enables the toothbrush and its charger to be sealed in plastic. The charger contains a primary coil powered by mains electricity, while the toothbrush contains a secondary coil. Placing the toothbrush on the base completes a step-down transformer, charging the battery with a suitable voltage.

American medical company Abiomed (*www.abiomed.com*) has used a similar technique to power artificial hearts. By using an external primary coil and a secondary coil implanted in the body just under the skin, the artificial heart's battery is recharged without wires penetrating the skin. As spokesperson Liza Heapes explained, "Eliminating the need for skin-piercing tubes has dramatically reduced complications caused by infection. Indeed, none of the 14 patients in [our] clinical trial died of device-related infections."

Inductive coupling is extremely efficient when the two coils are very close to one another or share an iron core, but typically it is ineffective over anything more than a few millimetres' distance. However, this doesn't mean induction has no useful applications for wirelessly powering consumer electronics. A handful of companies, including Splashpower (*www.splashpower.com*), Edison Electric (*www.aiye.com.cn*) and Fulton Innovation (*www.ecoupled.com*) are working on 'induction mats', which are essentially the primary coil of a transformer. Gadgets fitted with a suitable secondary coil can simply be placed on the mat to recharge.

These induction mats will power only devices that are placed directly on or very near them, but that's still a breakthrough compared with juggling lots of conventional chargers. However, the concept comes with its own set of problems – specifically, that different devices require different voltages and charge times, and also that the efficiency of an inductive coupling system depends not only on proximity but also on the precise positioning and orientation of the primary and secondary coils. Fulton Innovation explained how it overcame these issues – find out how in the 'Case study' box on page 140.

▲ Induction mats can transfer power to compatible devices wirelessly

## RESONANT COUPLING

Inductive coupling is clearly a very useful way of transferring electricity, but it would be even more useful if it were able to transmit power over a longer range – say, from a transmitter in the ceiling to a vacuum cleaner on the floor. In November 2006, a team at the Massachusetts Institute of Technology (MIT) announced a theoretical way in which such a power transfer might work.

In June this year, the team revealed details of an experiment (see the box below) in which they lit a light bulb by transmitting power wirelessly over a distance of up to two metres. The setup used induction, and even at the maximum distance the experiment's efficiency was as high as 40 per cent.

The key to the success of MIT's system, dubbed WiTricity, is resonance, a type of oscillation found in mechanical systems such as a drum or a building, and also electrical circuits. Almost any object has a natural frequency at which it will tend to oscillate when provided with energy. If the energy is actually provided at this frequency, a particularly energetic oscillation occurs. An example of this is during an earthquake, which typically shakes the ground a few times every second. Buildings that are around eight to 10 stories high tend to have a similar natural frequency, causing them to resonate powerfully and sometimes collapse.

◀ The MIT team with their WiTricity experiment in action (left to right: Peter Fisher, Andre Kurs, Marin Soljacic, Robert Moffatt, John Joannopoulos and Aristeidis Karalis)

Tesla discovered the importance of resonance in the efficient transmission of power without wires. In 1900 he filed a patent for a "means for increasing the intensity of electrical oscillations", in which he referred to the importance of resonance in "the attainment of the best result". The MIT team says that by using two coils resonating at the same frequency, the energy transfer at the full range of their experiment is almost a million times more efficient than it would be without resonance.

Given that the science behind WiTricity is not entirely new, we asked Aristeidis Karalis, one of the team working on it, why he thought nobody had attempted such a system before. He told us it was a case of motivation: "Ten years ago, a wireless power transfer technology would be completely useless. There were no portable electronic devices whatsoever." That may not be entirely true, but there has certainly been a massive increase in portable devices since then.

WiTricity is in early development, and the team doesn't yet have an industry partner for turning it into a commercial product. Karalis told us that among the issues to be addressed on the way from science to product are the full

### All shook up How resonant coupling works

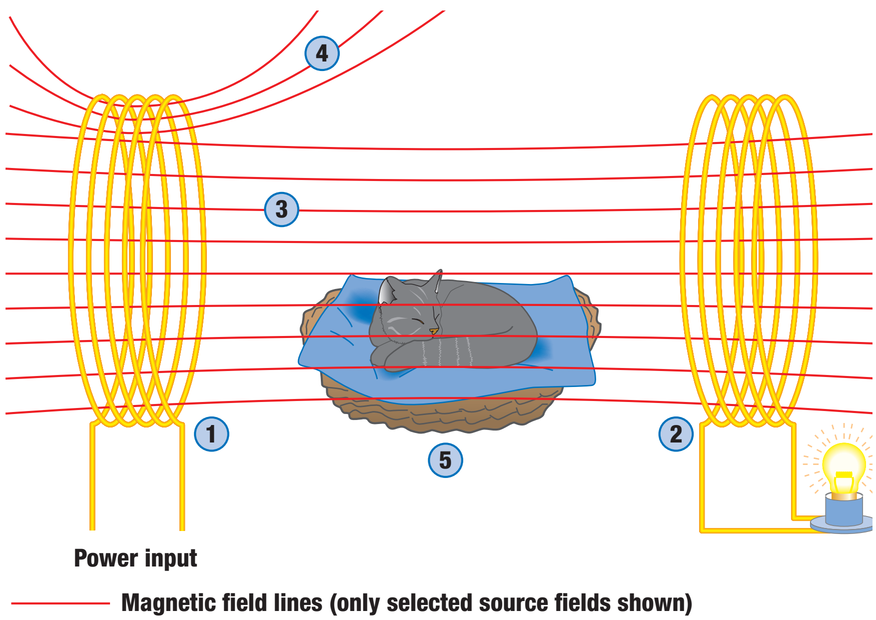
The MIT team's experimental setup (right) involves a source coil connected to an electricity supply (1) and a device coil connected to a light bulb (2). The source coil is essentially an electromagnet with an air rather than an iron core. This coil is driven by an oscillator with a 10MHz frequency and is designed to resonate.

This resonance relies on carefully tuned values for the coil circuit's capacitance (its ability to store electrical charge) and its inductance (the strength of the magnetic field that it creates when current flows within it). As the coil circuit discharges it generates a magnetic field, and as the magnetic field fades it recharges the circuit, so these two effects spontaneously alternate. Tuning the capacitance and the inductance of the coil gives the oscillation a natural frequency of 10MHz, which resonates with the input frequency.

This resonance helps the coil to produce a powerful, oscillating magnetic field (3). Importantly, as with other electromagnets, this field is non-radiative: in other words, energy doesn't escape the coil unless it is passed to another circuit.

Usually, introducing a secondary coil immediately next to the source would induce a current in the second coil, just as it does in a transformer. However, separating the coils by more than a centimetre or so would result in a crippling loss of efficiency. In the MIT setup, though, the secondary coil also resonates with exactly the same frequency as the source coil.

When placed in the same system, the two coils resonate together in such as way that the magnetic field created by the primary




▲ By tuning the primary and secondary coils to the same resonant frequency, inductive coupling can occur over distances of metres rather than millimetres

coil never has to work out of phase with the secondary coil's field. It's a bit like only ever pushing a pendulum in the direction it's already travelling – you're never wasting energy by trying to change its direction.

By resonating in this way, the two coils in effect work as a single system that exchanges energy with great efficiency, allowing the researchers to increase the distance between them far beyond what would usually be possible. The team calls this "strong coupling". Crucially, as the source magnetic field is non-radiative, only the portion of it that interacts with the device coil performs any work and removes energy from the source circuit. The remaining field (4) remains 'bound' to the source, so no energy is wasted.

Just as importantly, conductors that don't resonate at the same frequency (off-resonant objects, 5) interact very weakly with the magnetic field unless they're right next to one of the coils. Everyday objects can be placed around or even between the two coils with little reduction in the system's efficiency, and without dangerous eddy currents being induced within them.

DIAGRAM: MIKE HARDING

system design and packaging. "Hopefully, this should take three to five years. The device coil must be small enough to fit into the device of interest. The source does not have to be small, as it can be placed on the ceiling or under the floor. The goal is to address the average consumer and make this accessible to the home."

## POWERING FORWARDS

While Tesla developed many of the technologies involved in wireless power transmission, he struggled to secure funding for his ambitions and was never able to bring them to widespread commercial use. For a century, we've continued to rely on wires to transmit power, with only very limited use of niche wireless applications.

Now, though, the need to power an increasing number of gadgets and to cut down the rising number of power adaptors has made wireless power an attractive proposition. Technologies such as Powercast and eCoupled use well-established technologies in a new way, and seem poised to propel wireless power into the mainstream. Of all the technologies we've seen here, Powercast's radio system has the longest potential range, but safety dictates that it must also use the lowest power level. As such, it may prove to be a niche consumer product, but it's ideal for many industrial applications.

Induction mats, on the other hand, have the potential to free us from the array of AC adaptors that loiter behind a typical computer desk. Though they have the shortest range, they can transfer high amounts of power, making them a feasible way of charging everything from phones to electric cars, and also for directly powering toasters and kettles.

MIT's WiTricity technology is the furthest away from becoming a commercial product, but its reasonable range and moderate power capacity make it perhaps the most exciting of the three. If the team can develop it successfully, coils built into the buildings where we live and work could provide our electrical devices with continuous power.

For each of the technologies, however, there remain some significant hurdles. With the world's growing rate of energy consumption and our increasing concerns about conserving energy, future wireless technologies will hopefully be judged as much by their efficiency as by their convenience. Meanwhile, convenience isn't just about design. The consumer electronics industry is massive, and for any single company to make its product as commonplace as the mains socket is an enormous challenge. Let's hope it's not too long before the best design meets that challenge. CS

## Case study 2 The eCoupled system

Fulton Innovation's eCoupled is a system for transferring power wirelessly using inductive coupling. Coiled wire built into a base station creates a magnetic field, and simply placing a compatible gadget next to it induces a current in the gadget's own coils, providing it with power.

One of the hurdles the designers faced was that the efficiency of inductive coupling quickly drops – not just when the primary and secondary coils are moved apart – but also when they're not carefully aligned for maximum efficiency. For eCoupled to work with a wide range of portable devices, Fulton Innovation needed a system that was more tolerant to varying positions and orientations of the secondary coil.

The solution was to use wave-shaping circuits attached to the primary coil, which could vary its resonant frequency. Like the MIT WiTricity system described in the box on page 139, eCoupled's system improves efficiency by making the primary and secondary coils resonate together. Unlike WiTricity, however, the aim isn't to transfer power over any great distance. By tuning the primary coil's frequency, the system is able to adapt to different or even multiple secondary coils in different positions.

According to Fulton Innovation, the system "actively seeks" resonance. Dave Baarman, director of advanced technology, explained: "Our technology searches for the best operating [frequency] given the changes in devices, loads and spatial orientations. The varying loads and devices connected to the secondary reflect back to the primary, and the technology continuously reacts and adapts to those changes.

"The simpler systems... can detect and seek the best operating [frequency] based on

▲ eCoupled works over a very short range, but caddies and mats built into furniture or cars will charge any device placed on them

reflected load changes. Some of our more complex systems can send back digital data through existing coils and additional near-field communication technologies." This two-way data communication between the base station and the portable device not only helps to establish an efficient transfer of power, but can also ensure that the required amount of power is supplied and enables the base station to switch off when complete.

Fulton says it has achieved impressive levels of efficiency and high power transmission. Using two 19cm coils separated by a 13mm gap, the company has transmitted 1,400 watts of power with a total efficiency of 98 per cent. Fulton is working with various partners to create products that support the technology, including a Herman Miller desk that incorporates a charging surface.

According to Baarman, eCoupled "has potential applications virtually anywhere power is used, from milliwatts to kilowatts. [Fulton is] working with leading companies in a wide range of industries including consumer electronics, automotive, medical devices, electronic toys and lighting."

## Hard cell The health implications

The magnetic fields created by domestic appliances are generally accepted to have very little effect on plants and animals, and are widely considered safe. Fulton Innovation (see the 'Case study 2' box, below), says this includes its eCoupled technology, which, according to the company's director of advanced technology, Dave Baarman, "has been proven in the marketplace [to meet] all safety and certification requirements in the 55 countries where it is sold". The company also points out that, by eliminating exposed conductors, wireless power can reduce other hazards such as arcing, short circuits and electric shock.

Electromagnetic waves, on the other hand, can interact with living tissue, but they may not cause any damage. The risks depend on the frequency of the wave, the transmitter's power and the duration of exposure. Powercast's technology, described in the 'Case study 1' box on page 138) uses UHF waves that contain roughly a billion times less energy than an x-ray and, like other radio waves, are incapable of causing the damaging ionisation associated with radiation.

### WIFI WORRIES

There has, however, been concern over the safety of the microwave broadcasts used by wireless networks, which transmit at a broadly similar frequency and power to the Powercast system. The Health Protection Agency (HPA) says there is no consistent evidence that wireless networks adversely affect health. Professor Will Stewart of Southampton University's Optoelectronics Research Centre told us: "The majority of concerns over wireless power and safety are concerns over probably rather unlikely 'unknown unknowns'."

Despite having a greater range than eCoupled's technology, the magnetic field produced by MIT's WiTricity demonstration (see page 139) should also be safe. However, research published by the Childhood Cancer Research Group at Oxford University in 2005 described a correlation between children born in homes situated near pylons (which produce a magnetic field) and increased cases of leukaemia. The team didn't suggest that there was a direct link between the two but, as with most health issues, there are advocates for both sides of the argument.

A more plausible problem with WiTricity in its current experimental form is that a lot of power is lost to the production of unwanted electromagnetic waves. The team hopes that refinements will virtually eliminate this by the time the system is in production, but prolonged, close exposure to the experimental source coil's 5W transmission could conceivably pose a health risk.

"The concern over WiTricity's [broadcast] is as much over [radio] interference as over safety," commented Prof Stewart. "In any case, I would expect big reductions in this before deployment."