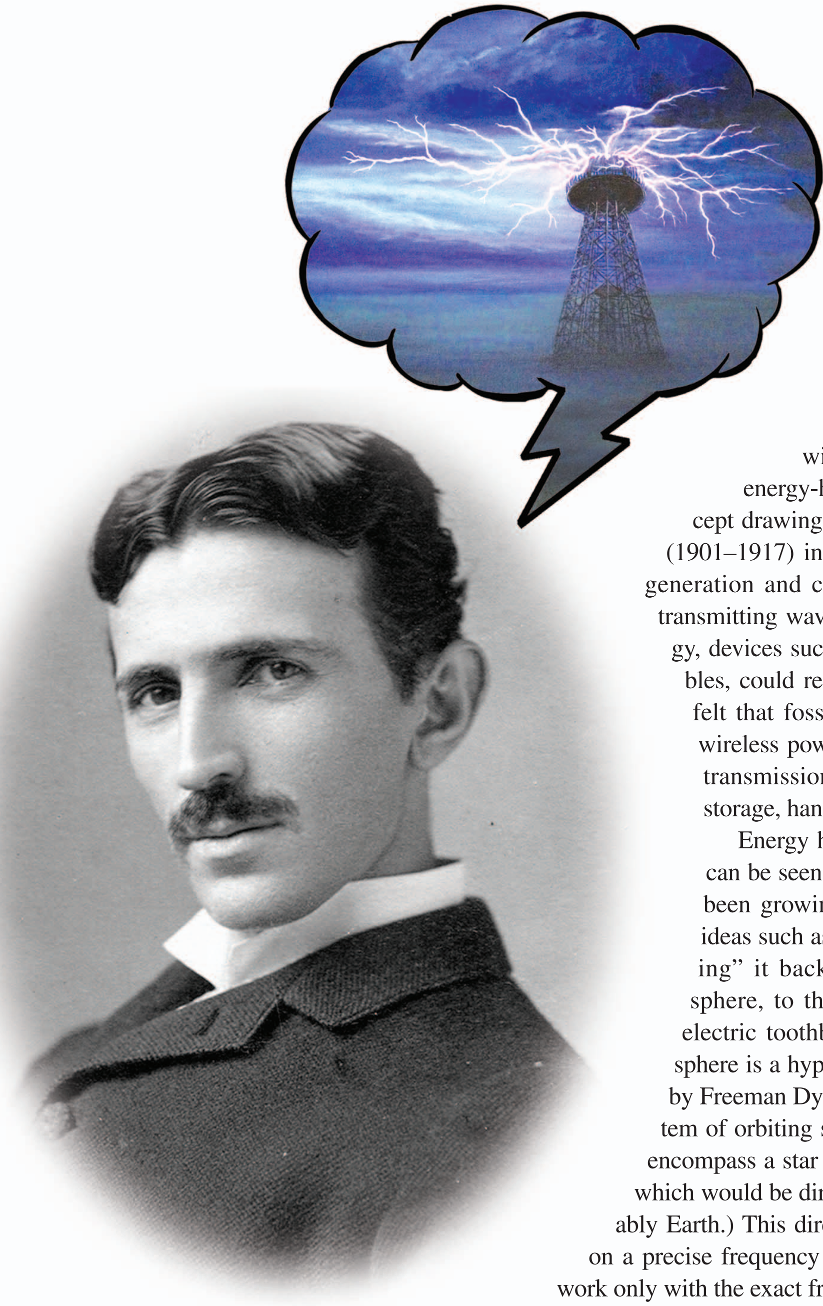
Nikola Tesla's Dream Realized

By William Lumpkins

Wireless power energy harvesting.



TESLA PHOTO COURTESY OF NAPOLEON SARANY, TOWER PHOTO COURTESY OF LISA CROW-BURKE

NIKOLA TESLA (FIGURE 1) dreamed of a day when all equipment requiring electrical energy would pull that energy from the air, either from directed wireless power or ambient energy harvesting.

Some called him a visionary, while others called him a charlatan, but many do attest that his early visions of alternating current (ac) transmissions systems and wireless power were the precursors of today's energy-harvesting technology. Figure 2 shows a concept drawing of the Warden Clyffe Tower that Tesla built (1901–1917) in Shoreham, New York, as a wireless power generation and communication tower. He believed that by transmitting waves of alternating radio-frequency (RF) energy, devices such as electric vehicles and even flying dirigibles, could reuse this energy for consistent operation. He felt that fossil fuels were not sustainable and that only wireless power held the key to near inexhaustible power transmission, unlike petroleum, which required costly storage, handling, and disbursement systems.

Energy harvesting comes in a multitude of forms, as can be seen in Figure 3. The field of wireless power has been growing over the past 60 years, from conceptual ideas such as collecting solar power in space and "beaming" it back to Earth-based collectors, like a Dyson sphere, to the reality of charging my Philips Sonicare electric toothbrush with an inductive charger. (A Dyson sphere is a hypothetical mega structure originally described by Freeman Dyson in 1959; such a "sphere" would be a system of orbiting solar-powered satellites meant to completely encompass a star and capture most or all of its energy output, which would be directed back to the destination planet, presumably Earth.) This directive, or inductive, wireless power is based on a precise frequency of RF power, with the receiver designed to work only with the exact frequency of the transmitted power source.

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The most common question for the use of this type of power transmission method is regarding whether the cost of power used to generate the power transmission is effective versus the amount of power that is transferred. In the case of solar power being beamed to Earth from space, the effective power source, the sun, is free; thus, the amount of loss is negligible for the equation of power conservation over power transmission. In the case of the Philips Sonicare electric toothbrush, although the base is plugged into a wall socket of ac power, any energy use is not perceived; the true goal is ease of use, and the fact that I do not need to change the battery of the device creates a false sense of cost savings. However, with the movement toward mobile devices or wireless sensor networks (WSNs), directed, or wireless, power starts to fail. Not to say that the fad of wireless charging stations will not be coming to a Starbucks near you (see "Starbucks to Offer Wireless Charging," which was published by *CBS News* on 30 July 2013).

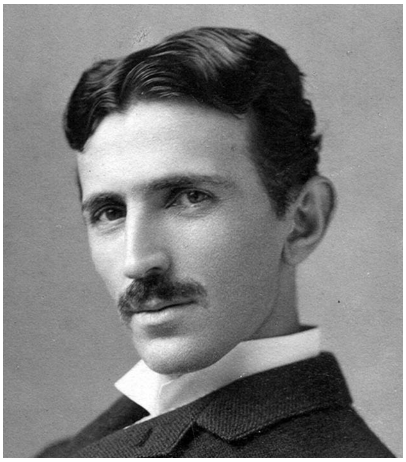

FIGURE 1. Nikola Tesla. (Photo courtesy of Napoleon Sarony.)

However, the Duracell Powermat, an inductive charging device, is limited to fixed "charging stations" and the availability of said stations. Thus, the age-old ecosystem question arises: should I, as a business owner, invest in the infrastructure of a Powermat or a Qi charging station? Will these types of phones even take off? Thus, there is a need for a system of energy charging that does not rely on a fixed infrastructure like inductive charging but instead uses the excess availability of RF energy already in the local environment. The implementation of energy harvesting is simple in concept, but more complex in implementation, as are most technical marvels (see Figure 4).

As shown in Figure 4, the load could be a standard mobile battery or microenergy cell (MEC), which exists today; one example is Infinite Power Solutions' THINERGY MEC201 solid-state, flexible, rechargeable thin-film micro-energy cell, with storage capacities up to 1 mAh (www.infinitepowersolutions.com). The next stage working backwards is the power conditioning block. This stage regulates the power to the MEC and cleans up any potential spikes of current that could damage the load. David Squires, vice president of business development for Infinite Power Solutions, stated in a phone interview "In energy-harvesting applications, a key enabler is the quiescent current drawn by the power-management IC." Squires added, "The MAX17710 has an unprecedented 1-nA battery current draw when a harvesting source is not present." The Max17710 is one of many solutions that could be chosen (www.maxim-ic.com).

The final two blocks depicted in Figure 4 are "where the magic happens," as some would say. The power conversion

FIGURE 2. Warden Clyffe Tower concept drawing. (Image courtesy of Lisa Crow-Burke.)

Starbucks to Offer Wireless Charging

Linda Mills, a spokeswoman for Starbucks, said that the company was looking at the next big thing to improve the coffee drinker's experience while in the store.

"Customers are using mobile devices more and more," she told *ABC News*. "Keeping your devices powered is a problem."

Starbucks uses the Duracell Powermat to charge both phones and tablets. Customers will lay their smart device flat on a designated Powermat surface. According to Daniel Schreiber, the president of Powermat Technologies, the closer the device, the more efficient the power transfer.

"Using wireless charges just as fast as a cable, with no degradation, at all," he told *ABC News*. He added that at each participating Starbucks, there are 10–12 wireless charging stations, meaning that even though the technology may not require a plug, you still might be vying for valuable coffee shop real estate with other customers.

The Powermat uses the PMA standard to charge wireless devices, in contrast with the Qi standard, which has been announced for the latest Google, Motorola, and Samsung products. Customers who own those devices can still use the Powermat to charge, though they will need to attach an additional case to their devices.

Customers may not need to buy the case if they are patient enough. Schrieber said that AT&T will be releasing phones in early 2014 that are able to wirelessly charge straight out of the box.

"AT&T has made it clear that by early in the new year, they are expected to have wireless charging capabilities," he said.

Starbucks has pilot-tested the wireless charging stations at several Boston locations.

–Jon M. Chang, *CBS News*

FIGURE 3. Energy-harvesting power sources. (Photo courtesy of http://techon.nikkeibp.co.jp/Tech-On Japan.)

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block may seem simple, but its function is quite complex: it must "sense" or "read" the receive signal strength indicator (RSSI) of a wide range of frequencies, pick the strongest signal, then have the antenna reconfigure itself for the optimum voltage standing wave ratio (VSWR; an ideal transmission line would have a VSWR of 1:1, with all the power reaching the destination and no reflected power). Then, after a period of time, it needs to rescan the band to find out if the antenna is configured correctly or if it needs to be reconfigured. I call this adaptive antenna frequency modification (AAFM); this is not a new or revolutionary idea, as it was used in World War II by the Allies' (the United States and Britain's) top secret communication stations. It was not used for energy harvesting but to extend their range of communication at sea during inclement weather and sun spot activity. This was done by manually changing out or switching out by mechanical means large capacitor, inductors, and/or resistive components to change the center frequency F_O (Figure 5). Today, this would need to be done by changing out varying gates of submicron material to achieve the same effect, in a much smaller form factor for mobile devices.

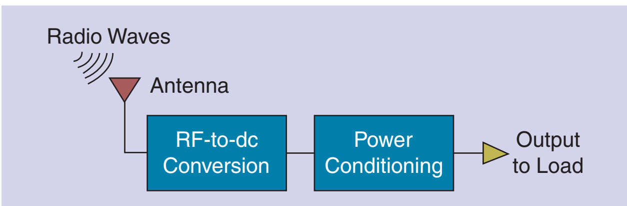

FIGURE 4. A block diagram of energy harvesting.

$$\lambda_{uppercutoff} = 2 \cdot a$$

$$f_{lowercutoff} = \frac{c}{2 \cdot a} \text{ (GHz)}$$

a = Dimension of Broad Wall (cm)

c = Speed of Light (29.979 cm/ns)

FIGURE 5. The cut-off frequency of antenna waveguide.

Finally, the antenna block: designing an antenna for a specific frequency, e.g., 2.4 GHz for Wi-Fi or Bluetooth, or for a global system for mobile communications (GSM) or long-term evolution (LTE), is not very difficult, and there are many companies that have these. However, designing a low-cost antenna that can "pull" or receive an adequate amount of energy (think low VSWR 1:1) from a frequency range of 2.4–80 GHz, is quite a challenge. Why would we need such a large range? This goes back to the concept of usable spectrum. Currently, 2.4 GHz is being broadcast everywhere, from microwave ovens, access points, cell phones, tablets, remote controls, portable headsets, earbuds, and so on. However, there will be a shift in the near future to move out of this band to 5 GHz and beyond. Already IEEE 802.11ac at 5 GHz is moving into the mainstream with IEEE 802.11ad close behind, operating at 60 GHz. Also, at 5.9 GHz is IEEE 802.11p wireless access in vehicular environments (WAVE) for intelligent transportation systems (ITSs) and dedicated short-range communications (DSRC), allowing vehicles to intelligently receive warnings from smart infrastructure on the national highway and interurban traffic systems. Another new technology that is quickly emerging is automotive radar (Figure 6).

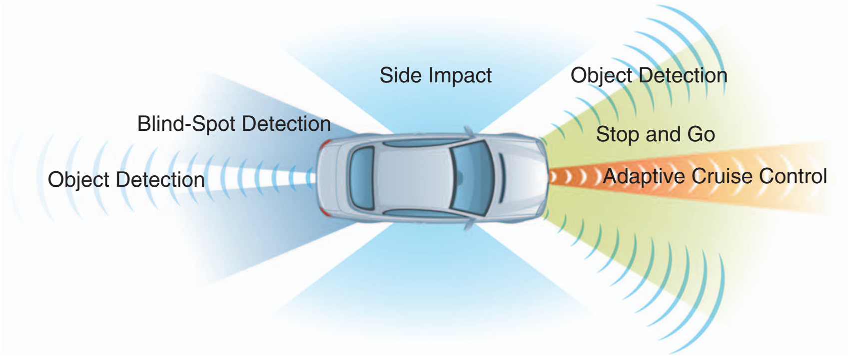

FIGURE 6. Automotive radar. (Photo courtesy of Freescale Inc.)

California recently passed SB 1298, which sets up procedures and requirements for determining when self-driving cars, or autonomous vehicles, are road ready. The idea of self-driving cars sounds a bit scary, but the law still requires a human to sit behind the wheel. So how does this relate to energy harvesting? With the advent of the new self-driving laws, 60–80 GHz will be prevalent radar frequencies used by these vehicles, which means an overabundance of "free" RF energy, ready to be consumed by energy-harvesting products.

A relevant example of an existing energy-harvesting IC is the Powerharvester receiver P2110 from PowerCast Corporation. PowerCast Corporation boasts that their tuning range is from 1 MHz to 6 GHz, but they do not have a circuit that swings the entire range; their circuit is currently only tuned for a center frequency of 915 MHz, which is perfect for third-generation (3G)/fourth-generation (4G) cellular phones. A designer that wants a frequency other than 915 MHz would need to license the frequency range IP from PowerCast to create a specific Mask ROM for that frequency, e.g., 2.4 GHz, with an appropriate antenna with the desired cutoff frequency. PowerCast estimates that the RF-to-dc conversion efficiency is as high as 70% in some scenarios (http://www.powercastco.com/frequently-asked-questions/). PowerCast estimates the range of their device from a suitable RF power source to be 40–45 ft (12–14 m). Figure 7 shows the Powerharvester evaluation kit with the Texas Instruments MSP430 evaluation board. A video of the Powerharvester in action can be found at http://www.youtube.com/watch?v=uox8Rmm9_c4.

In conclusion, while we may see induction chargers such as Powermat and Qi in the near future at Starbucks and other convenient cash-consuming locales, just over the horizon lies the true future of energy-harvesting technology, a day when a consumer does not need to charge his portable communication device and only changes out a battery when it quits recharging. Interestingly enough, we will not have to wait long; currently, the research and development divisions of Samsung, Intel, Qualcomm, and Texas Instruments, to name a few, are hard at work trying to make this a reality. They all know that the first to market with a viable solution will create huge amounts of good will (and loads of money). This will also create new marketplaces as power cables disappear (or just get very thin/light) and WSNs take off with no need for wired power, which will help to enhance our world and the environments of countries with poor infrastructure and/or failing power systems. The power grid may not be stable in your home or office, but everyone will be talking on their cell phones or driving their vehicles, which will be broadcasting RF and be recaptured by energy-harvesting devices to power themselves. Perhaps someday we will even have a true "perpetual motion machine," with energy harvesting of the Earth's magnetic fields. As you can see, I love science fiction, but we can always dream.

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Feel free to submit your comments and our questions on the latest technology to me at xillia@ieee.org.

FIGURE 7. The Powerharvester evaluation kit. (Photo courtesy of PowerCast Corporation.)

ABOUT THE AUTHOR

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