Review of "Wireless Power Transfer via Strongly Coupled Magnetic Resonances" [1]

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Introduction

The problem with many of today's electronic devices, such as cell phones, laptop computers, and personal digital organizers, is that despite their portability and ability to communicate wirelessly, these devices still require regular charging - usually by plugging into a wall outlet. The ability to provide power for these and other electric devices wirelessly would greatly increase their portability and accessibility for the public.

In a July 2007 article published by André Kurs et al. in *Science*, the group of researchers at the Massachusetts Institute of Technology claimed that they had produced a method of transmitting power wirelessly [1]. By using resonant coils coupled magnetically, the researchers were able to power a 60W light bulb wirelessly from over 2 metres away.

Context

Previous schemes for wireless power transmission included attempts by the late scientist Nikola Tesla, who demonstrated wireless power transfer using large copper elements in the early 1900s. His invention, however, required large scale construction of 200 ft tall masts. It also produced undesirably - and sometimes dangerously - high voltages that approached 100 000 000 V [2]. Later attempts at wireless power led to the development of microwave power transmission, but its line-of-sight requirements meant that any practical power source needed to be high in the sky. Previous proposed projects included large power platforms as well as microwave-beaming satellites. [2] Both Tesla's devices and the later microwave power were forms of radiative power transfer. Radiative transfer, which is used in wireless communication, is not particularly suitable for power transmission due to its low efficiency and radiative loss due to its omnidirectional nature.[1]

More recently, a company by the name of *Splashpower* developed magnetic charging pads on which to place electronic devices. The pad used magnetic induction to transfer energy to a specially designed receptor on the electronic device being charged [3]. This device required contact between the pad and electric device, as well as a specialized addition on the electronics needing to be charged. This made implementation impractical on a large scale.

Earlier attempts such as Tesla's inventions, microwave transmission, and the magnetic charging pads represented long range and close range wireless power transmission – however, implementation of those inventions has been slow or nonexistent, due to impracticalities in their design. The MIT researchers who authored this article claim to have developed feasible midrange wireless power transmission, without large scale construction or excessive electric fields due to high voltages.

Theory

Research done by some of the authors of the paper indicated that power transfer can be achieved efficiently using two or more resonant objects of the same resonance frequency [1]. Although the resonances can be of any physical nature, the choice by the researchers of this particular implementation was magnetic resonance. The authors noted that magnetic resonances were suitable for this application as most ordinary objects do not interact with magnetic fields. Compared to magnetically coupled nonresonant objects, the coupled resonant coils the researchers used were six orders of magnitude more efficient. The improvement is due to the researchers' use of the "strong coupling regime" of resonating objects, which maximizes energy transfer efficiency.

The equations governing magnetic resonance using coils were derived by the authors. Among these, of interest to the more casual observer are those describing theoretical and experimental efficiency of the wireless power transfer. The efficiency of power transfer depends only on Γ, the intrinsic decay rate of magnetic transfer (due to radiated losses and absorption by other objects), and κ, the coupling coefficient that describes the strength of resonance between the two resonating coils. Both κ and Γ are functions of distance between resonating objects and resonance frequency. The researchers noted that picking an appropriate frequency for their experimental set up played a major role in optimizing power transfer efficiency. The parameters κ for the transfer path and Γ for the two coils were experimentally adjusted to achieve strong coupling.

Implementation

Two identical helical copper coils, one for the source and one for the load, were constructed by the MIT team for magnetic coupling. By fine tuning the height of the coils, they were able to cause strong magnetic resonance coupling between the two coils at a midrange distance. The source coil was in turn inductively coupled to a single copper wire loop which is attached to a Colpitts oscillator. A Colpitts oscillator is a simple electronic oscillator that consists of two capacitors and one inductor to determine frequency [4]. The receiving magnetic coil was inductively coupled to a copper wire loop attached to a 60W light bulb.

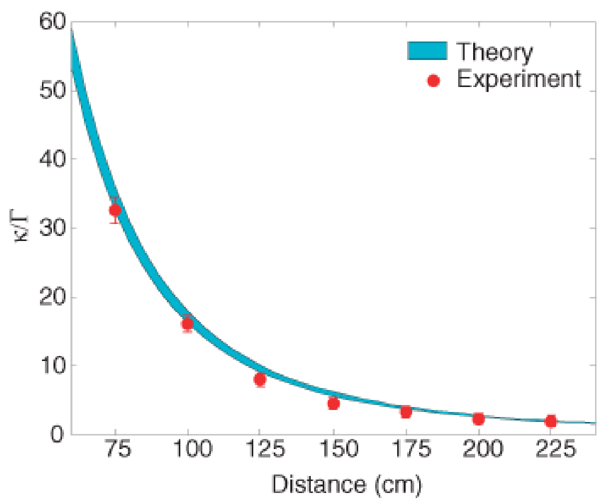

Fig. 1: κ/Γ as a function of distance [1]

To test the accuracy of their theoretical derivations, the authors compared the theoretical values to experimentally obtained values. In Fig. 1, experimental and theoretical values of κ/Γ as a function of coil separation were compared. As noted by the authors, the experimental values were very close to theoretical values, showing that their equations provided a valid model given their experimental parameters.

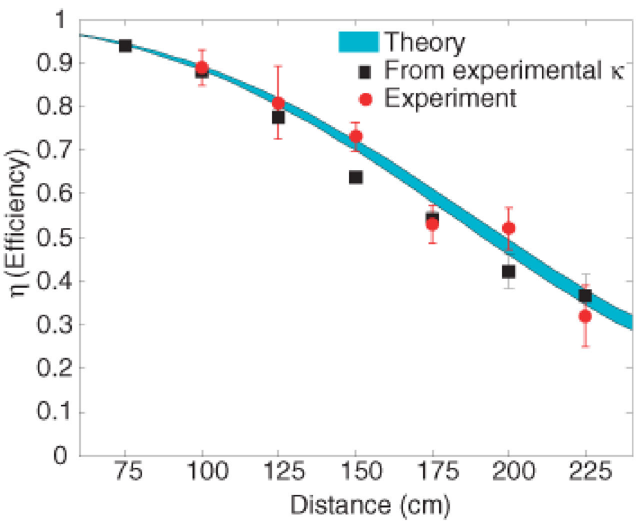

Fig. 2: Efficiency as a function of distance [1]

Power transfer efficiency was similarly compared by the researchers, resulting in the graph depicted in Fig. 2. As labeled on the figure, the experimental power transfer efficiency of the coupled coils decayed with distance, as expected from the theory derived by the MIT team. At the highest tested coil separation of 225 cm, the efficiency was just below 40%. The paper, however, noted that the practical "wall-to-load" (ratio of power supplied by the wall outlet to the power received at the load) efficiency of the overall circuit was only 15%, which puts a lower bound on the theoretical efficiency of the system. Coil efficiency was further affected by a supposed "layer of poorly conducting copper oxide" [1] on the wires forming the coil. While the measurements made between the coils agreed with the 40% theoretical value, the low overall efficiency was caused by the Colpitts oscillator [1]. The researchers stated that the precise efficiency of the Colpitts oscillator is not known. The discrepancy between wall-to-load efficiency and wireless power transfer efficiency leaves room for improvement, and more effort could have been made by the team to describe the effect of the Colpitts oscillator on overall efficiency.

Kurs et al. demonstrated that ordinary objects placed between the two resonating coils do not affect the magnetic field. Using foam, cardboard, and people as obstructions, the experimental efficiencies still remained relatively stable.

In addition, the measured power radiation at the midway point between the two copper coils was roughly 5 W, an order of magnitude higher than that of cell phones [1]. The authors noted that alternative resonance objects could be used in place of their specific coil design to reduce the power radiation to the levels specified by IEEE safety standards.

Conclusion

The research team at MIT succeeded in demonstrating the ability of magnetically coupled coils to transfer power wirelessly over a short distance. They successfully powered a 60W light bulb over 2.4 m wirelessly, with 40% efficiency between the magnetic coils. The experimental implementation yielded results that agreed very well with the theoretical predictions, confirming the validity of the magnetic resonance coupling model.

The authors' choice of using a Colpitts oscillator to adjust frequency, however, meant that they could not precisely calculate the efficiency of the overall system from wall outlet to load. More research in this area will help optimize the system further.

With the current performance of the system, however, it is already practical for implementation in real-world applications. For example, midrange wireless power transmission as discussed here can be used in particular situations where building wired infrastructure is impossible or highly unfeasible. It can also be used to increase the autonomy of both portable and non-portable devices. For example, normally non-portable electronic devices could be used in, say, a yard where a nearby wireless power source can be found. This development brings to life the idea of a fully wire-free electronic lifestyle.

References

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