Wireless Power Transfer to Moving Vehicles

Investigators
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Abstract

This project aims at the possibility of charging the electric vehicles wirelessly with a resonant inductive power transfer scheme. We are exploring a key enabling element that will overcome these challenges and which, if successful, will demonstrate the feasibility of wireless power transfer directly to vehicles cruising at highway speed, via magnetically-coupled resonating coils located in the roadbed and in the vehicles. We have numerically demonstrated that the energy can be transfer efficiently between two magnetically coupled resonating coils in a complex electromagnetic environment.

Introduction

Electric vehicles offer superior energy efficiency while offering an enormous potential for reducing CO_2 emissions if the electricity is supplied from a renewable or nuclear source. However, they are presently neither range- nor cost-competitive compared to conventional vehicles, due to limited options for recharging, and expensive energy storage (batteries). This project aims at extending the wireless power transfer to the charging of moving electric vehicles. The success of this program may prove to be a very significant step forward towards the possibility of unlimited range electric mobility. By extending the range of electric vehicles, this project will contribute to overcoming a critical limitation of existing electrical vehicles, by offering range at competitive costs.

Background

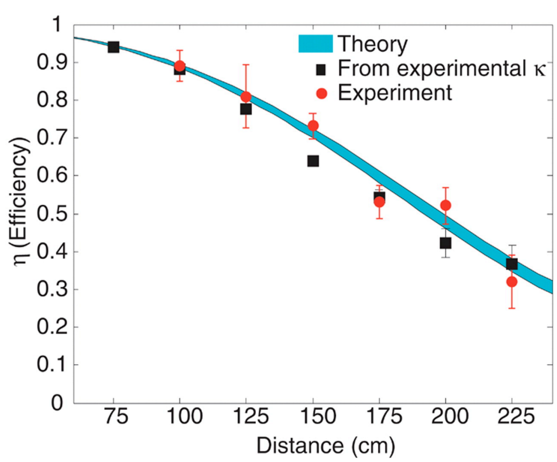

Figure1. Efficiency of wireless energy transfer as a function of distance between coils.

In recent years there has been renewed interest in wireless power transfer. In particular, a recent experiment, conducted at MIT, has demonstrated that two resonant circuits, with their magnetic fields strongly coupled in the near-field regime, allows highly efficient power transfer over a distance of approximately one meter. (See Figure 1). The MIT experiment, utilizes a magnetic field that oscillates at a few MHz for power transfer purposes. The use of such oscillating magnetic fields is crucial for safety reasons since they interact very weakly with biological organisms. Additionally power transfer occurs only when the two circuits are in resonance with each other. This ensures, on the one hand, a highly selective power transfer scheme between the two circuits, and on the other hand, the possibility of tuning power transfer on or off simply by tuning the resonant frequency of either circuit such that they are either on or off resonance.

Their experiments demonstrated power transfer of 60W between two objects that have no relative motion with respect to one another. In delivering power wirelessly to a moving vehicle, we envision a system in which a sequence of coils placed beneath the roadway will deliver the power wirelessly to cars moving above (See Figure 2).

We estimate that a power transfer of about 10-20kW will be quite sufficient for steady-state operation and the strength of the magnetic field generated will be less than 160A/m, which is only about five times stronger than the earth's magnetic field. Moreover, such a magnetic field largely exists between the road and the vehicle, and is located far from where people are sitting in the vehicle.

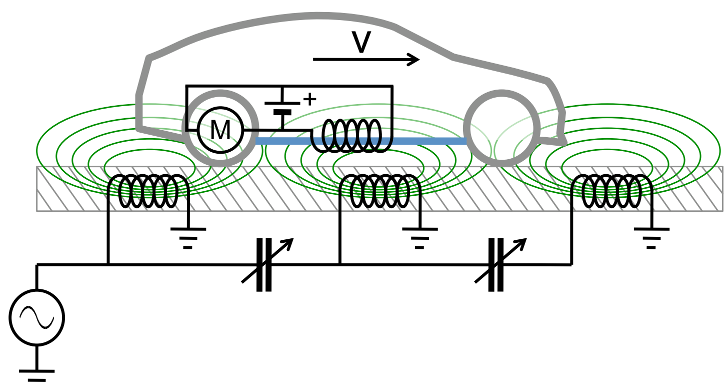

Figure 2. Magnetic Power Transmission to Vehicle on Highway.

Results

During the past few months, we have numerically demonstrated that mid-range non-radiative energy transfer can be achieved by using long-live oscillatory resonant electromagnetic modes. The proposed energy transfer scheme utilizes the result that energy can be efficiently coupled between objects in the extremely near field. It requires high quality factors $Q = \omega / 2\Gamma$ (ω is the frequency and Γ is the intrinsic loss rate); strong coupling rate κ and subwavelength size of the resonant object.

We simulate the energy transfer systems shown in Fig. 3 with the finite-different-time- domain (FDTD) method. All materials are assumed to be copper. In the simulation we excite a magnetic dipole source at the middle of the source coil. The source has a gaussian-like profile in time and its central frequency is the resonant frequency of the resonators. We record the magnetic field (with a direction perpendicular to the coil plane) at the monitor points which are placed near the source and receiver coil in a symmetrical way. From which we extract the instrinsic parameters (loss rate, coupling coefficient, resonant frequency) of the system and calculate the transfer efficiency.

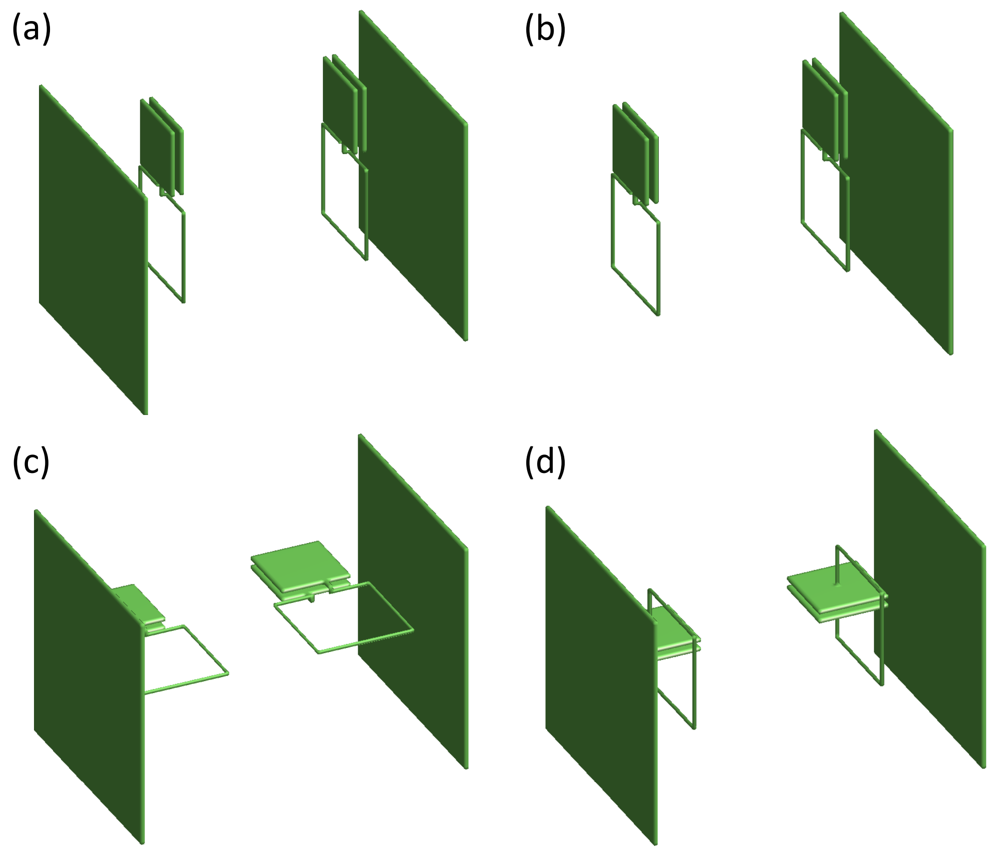

Figure 3: A variety of the resonator structures for the wireless energy transfer. (a) Our current optimal design with a "twisted" geometry. The distance between the coils $\sim \lambda/15$. Two metallic ground planes are placed near the system symmetrically. (b) Same system as (a) without the ground plane at the source coil side. (c) Same system as (a), but with the coil planes perpendicular to the ground planes. (d) Same system as (a) but with the capacitors at a different orientation.

Structure (a) in Fig. 3 turn out to be our optimal design. Fig. 4 shows the transfer efficiencies for the structures shown in Fig. 3 at different transfer distance. The efficiency of our optimal configuration (red curve in Fig. 4) decays slowly as a function of distance, and remains above 90% for a distance shorter than 2.8m (if it operates a 10MHz frequency).

Progress and future plans

We study the wireless energy transfer in a complex electromagnetic environment and propose an optimal system design for the case when a metallic ground plane needs to be in a close proximity of the receiver resonator. Transfer efficiency as high as 97% can be achieved when the transfer distance is about 2*m* (for an operating frequency of 10MHz). And the transfer time is shown to be much shorter than the time scale of a moving vehicle. We will continue our efforts to optimize the system design of the resonators for better transfer efficiency and investigate the influence of the extraneous objects to the power transfer system. We also plan to set up an analytical model and experiments for better understanding the physics within.

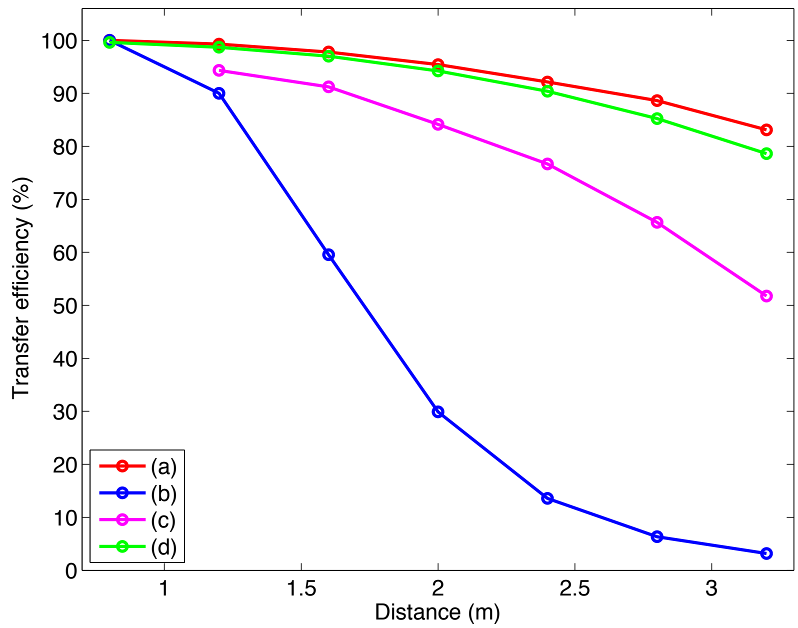

Figure 4: Transfer efficiencies as functions of the coil to coil distance for different structures shown in Fig. 3, assuming a working wavelength of 30*m*.

Publications:

X. Yu, S. Sandhu, S. Beiker, R. Sassoon, and S. Fan, "Wireless energy transfer with the presence of metallic planes", Applied Physics Letters 99, 214102 (2011).

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