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ENABLING IOT WIRELESS DISTANT CHARGING: 7.9-mW INTEGRATED POWER RECEIVER AT 30 CM

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ABSTRACT

In this paper, we report a near-field electrodynamic wireless power transfer (EWPT) system that includes a power receiver based on a rotating magnet. This topology allows power transfer at very low frequencies (<500 Hz) to a distant and compact receiver with a high robustness.

The 0.83 cm³ power receiver tested is actuated at distance by a 30-cm-diameter transmitter powered with 15 watts. Power transfers up to 7.9 mW at 30 cm from the center of the transmitter coil and 85 mW at a distance of 14 cm are experimentally demonstrated. These results are among the highest in the state of the art in terms of power density (176.8 mW/cm³/mT² at 30 cm) and distance range.

KEYWORDS

Electrodynamic Wireless power transfer, distant charging, continuously rotating mode.

INTRODUCTION

Nowadays, wireless power transfer (WPT) main challenges remain the safe transmission of power to multiple receivers that are compact enough for electronic integration over extended distances in cluttered environments. Inductive coupling WPT dominates the market for close range applications, but suffers from low couplings at long distances [1], and RF WPT could transmit meaningful levels of power at the cost of human exposure to high frequency fields, limiting its field of application.

Electrodynamic WPT (EWPT) is based on a receiver integrating a permanent magnet actuated by the time-varying magnetic field generated by a distant transmitter. The magnet mechanical energy is usually converted into electrical energy by a piezoelectric or an electrodynamic transducer. The use of a mechanical system results in a magnetic field operating at very low frequency and therefore allows transferring power through thin conductive media. The state of the art mainly presents solutions based on resonant systems using high quality factor to increase the receiver sensitivity to low magnetic fields at a distance [2-3]. In this paper, we prove that higher powers are achievable at a distance using a solution based on a continuously rotating magnet at high speed [4-5] (Figure 1).

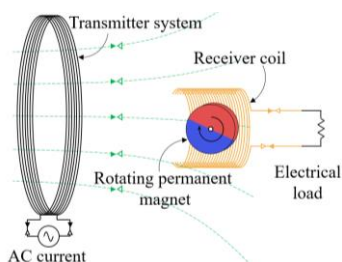


Figure 1: Principle of the EWPT system based on a continuously rotating magnet in a receiver.

OPTIMIZED RECEIVER AND SETUP

In this work, we repurposed a commercialized batteryless switch previously developed by our team [6]. The 0.83 cm³ integrated generator from the switch includes a flat diametrically-magnetized magnet and is based on a frequency-up conversion technique. In our case, the electronics and the magnetic launchers of the commercialized device are removed, resulting in a device operating henceforth in the continuously rotating mode (Figure 2).

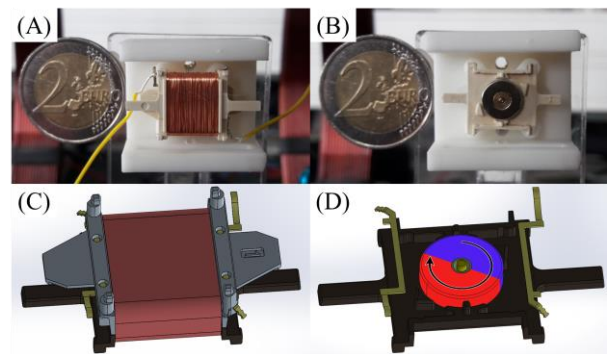


Figure 2: Pictures (A-B) and model (C-D) of the integrated electrodynamic receiver with and without the coil.

PERFORMANCES ON RESISTIVE LOAD

In order to characterize its performances, the receiver is placed at the center of a 30-cm-diameter Helmholtz coil: the magnetic field intensity at the receiver location is varied to simulate a variation of distance between a transmitter and the receiver. The output power is measured for various resistive loads while sweeping the transmitter frequency from 15 to 500 Hz for a given magnetic field amplitude. As the operating frequency increases, the magnet accelerates and generates an increasing power varying as the square of the frequency, up to a pull-out frequency. Indeed, when the frequency becomes too high, the torque from the mechanical losses and the receiver coil becomes too important and the magnet loses its synchronization with the magnetic field. Figure 3A shows an example of the output powers as a function of the frequency for various resistive loads for a peak excitation field of 0.99 mT.

The envelopes of the curves are extracted for various magnetic field amplitudes from 0.16 to 0.99 mT (Figure 3B). The rough appearance of the envelopes is due to the erratic variations occurring near the pull-out frequency. For each field amplitude, the electrical power reaches a maximum for a specific resistive load and frequency of operation.

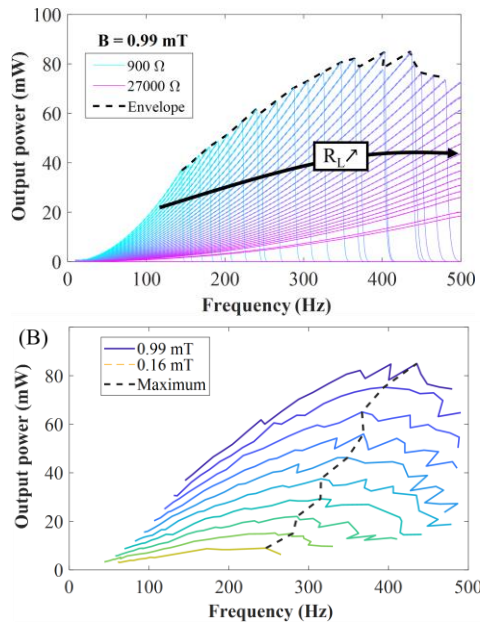


Figure 3: (A) Output power as a function of the frequency at 0.99 mT for various resistive loads. (B) Envelopes of maximum output power as a function of frequency for various amplitudes of exciting field.

Figure 4 shows the extracted maximum output power (blue line) as a function of the peak magnetic field amplitude and as a function of the corresponding distance from a 30-cm 15-W transmitter coil. Output powers from five experimental measurements at a distance from a single coil are also shown (red crosses) to validate the estimation method using Helmholtz coils. The proposed device generates a maximum power of 84.8 mW at 402 Hz for 0.99 mT (corresponding to a distance of 14 cm). At higher distance, the receiver generates 7.9 mW of power at 30 cm from the 15-W coil (0.23 mT), resulting in a normalized power density of 177 mW /cm³/mT², which is 8 times higher than previously reported receivers [3]. The good performances are explained by the low mechanical losses in the brass plain bearing guiding the magnet.

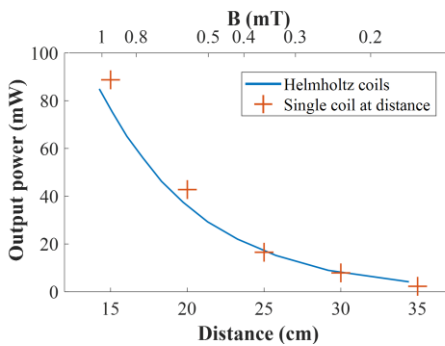


Figure 4: Output power as a function of the magnetic field amplitude and the corresponding distance from a transmitter coil: with Helmholtz coil method (blue line) and with the receiver distant of a single coil (red crosses).

The output peak voltages and the associate resistive load measured at the maximum power are shown in Figure 5. The voltages are high enough to pass a full-bridge rectifier.

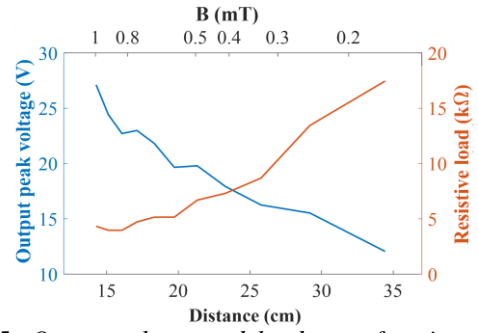


Figure 5: Output voltage and load as a function of the distance and the field amplitude.

PERFORMANCES WITH A RECTIFIER

The power levels previously presented are achieved on a simple resistive load, inducing a smoothly varying mechanical torque on the magnet. The use of a full-bridge rectifier (FBR) with a smoothing capacitor induces nonlinear current draw and torque that could lower the pull-out frequency. The receiver is connected to a FBR (threshold voltage of 2×0.3 V) and a smoothing capacitor (10 μF) in order to compare its performances with a resistive load (Figure 6). The power reduction is around 10%, showing that the performances are not dramatically affected by the FBR.

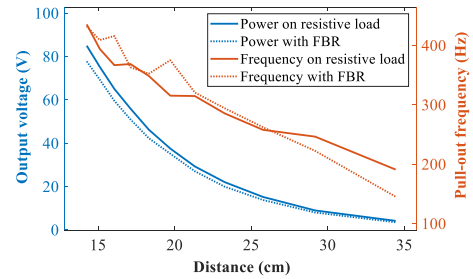


Figure 6: Output power and pull-out frequency as a function of the distance on resistive load and with a FBR.

In the near future, a model of this prototype will be developed in order to optimize the system and transmit power even further from the source.

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