ELECTROMAGNETIC TIME REVERSAL: FROM WIRELESS POWER TRANSFER TO RFID

A. Bréard[1], J. Huillery[1], Y. Duroc[2]

[1]Univ Lyon, Ecole Centrale de Lyon, INSA Lyon, Université Claude Bernard Lyon 1, CNRS, Ampère, UMR5005, 69130 Ecully, France
[2]Univ Lyon, Université Claude Bernard Lyon 1, INSA Lyon, Ecole Centrale de Lyon, CNRS, Ampère, UMR5005, 69622 Villeurbanne, France
arnaud.breard@ec-lyon.fr

Keywords: Time reversal, wireless power transfer, RFID, complex channel, waveform optimisation.

Abstract

This paper presents an overview of the researches done at the Ampere lab on the use of time reversal since 2012. The first project aimed at optimizing the energy transfer in a complex propagation medium dedicated to a remote system wake-up. The proposed solutions consisted in the design of an optimized broadband rectenna and the use of specific transmitted signal waveforms. In addition to the optimization of the rectenna, the optimization of the transmitted signal has been addressed in order to exploit the properties of the channel. Time reversal is the optimized signal in this case. The second project aims at optimizing power and information transfer in the context of passive UHF RFID technology. With the constraints of exploiting existing commercial tags and respecting as closely as possible the standards in force, the objective is to explore the potential of RFID in pulse mode while exploiting the time reversal technique

1 Introduction

In a context of wireless power transfer (WPT), the efficiency, the distance between transmitter and receiver, the emitted power are key elements which need to be optimised. To improve WPT, there is three main blocks which could be considered (as shown in figure 1): the RF source, the channel and the receiver circuit. With the RF source one could impact on the power delivered and the waveform. With the channel, one considers the association of the transmitter antenna, the propagation medium and the receiver antenna. In this part, one could work on antenna's efficiency, directivity, focalisation of electromagnetic wave, bandwidth. The receiver circuit, with its rectifier, adaptation and filters is crucial regarding the amount of energy transferred from the RF wave to the load.

Our researches on WPT have been focused on remote wake up of wireless systems (e.g. embedded sensors, sensors network or electrical systems in steady-state) across complex medium without direct line of sigh due the presence of obstacles between the transmitter and the receiver. In this context, channel-adaptive waveforms based on time-reversal (TR) and a new topology of rectenna have been designed.

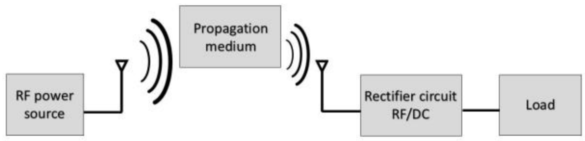

Figure 1: Global system for wireless power transfer

The follow-up to this work concerns the passive RFID technology where both power and information transfer are involved. The use of TR in this context will be introduce here and developed in the extended paper and the presentation.

2 Time Reversal: a channel-adaptive solution for WPT

In remote wake-up applications, the objective is to transfer enough power with a voltage higher than the threshold of a transistor to awake a system. It has long been shown that the classical continuous wave (CW) is not at all optimal for WPT as chaotic waveforms or waveforms with high peak-to-average power ratio (PAPR) could improve the efficiency of a rectifier circuit [1]. Here, a focus on time reversal and the different parameters of the transmitted signal as pulse length, bandwidth, carrier frequency are discussed

Time reversal [2] needs two different steps. The first step consists in transmitting a short pulse $x(t)$ and measuring a signal $y(t)$ on the receiver. The emitted pulse $x(t)$ can be defined as

$$x(t) = \omega_{\Delta T}(\mathrm{t}) \sin(2\pi \nu_0 t) \qquad (4)$$

where ν_0 is the carrier frequency and $w_{\Delta T}(t)$ is a Hamming window with a length ΔT. In the second step, the measured signal $y(t)$ is time reversed to give $y_{TR}(t) = y(t_0 - t)$, where t_0 is the focusing time, and transmitted again through the medium. A focused signal $z(t)$ could then be measured at the receiver as shown in figure 2.

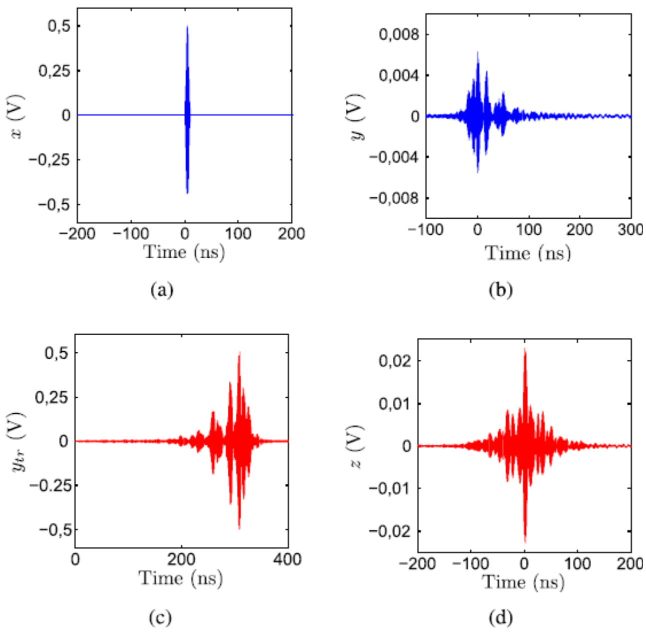

Figure 2: Waveforms involved in a TR experiment: (a) Pulse x(t) emitted during the first step. (b) Signal y(t) received during the first step. (c) Time-reversed signal $y_{TR}(t)$ emitted during the second step. (d) Focused signal z(t) received during the second step.

The efficiency of a signal $z(t)$ focused at the receiver for a given transmitted signal $x(t)$ of length T_a is computed as:

$$\eta_{TR} = \frac{E_z}{E_x} = \frac{\int_{t_0-\Delta T/2}^{t_0+\Delta T/2} z^2 dt}{\int_0^{T_a} x^2 dt} \qquad (1)$$

where ΔT is the focusing time duration. It is demonstrated in [3], that TR is the optimal solution for η_{TR}. For comparison with the CW mode which allows the optimisation of antennas and rectifier circuit around one frequency, one can evaluate the focusing gain defined as

$$G_{TR/CW} = \frac{\eta_{TR}}{\eta_{CW}} \qquad (2)$$

where the efficiency η_{CW} of CW defined as

$$\eta_{CW} = \frac{V_2^2}{V_1^2} \qquad (3)$$

is the ratio between the voltage retrieved from the rectenna over the generated signal feeding the transmitter.

In [3] a study of the impact on WPT efficiency of different parameters as the learning stage pulse bandwidth, the period Ta, the carrier frequency, was presented for an indoor experiment. The results highlighted that TR has a gain between 2.7 to 7.5 over the CW. The question of the impact of the increasing of frequency and the complexity of the medium over the increasing of the attenuation was treated in [4]. Even there is more reflexion at 5.8 GHz than at 2.4 GHz, the time reversal gain's over CW decreases.

Finally, a new topology design of rectenna adapted to pulsed wave and TR is proposed in [5]. The structure with inductance and diodes instead of capacitor and diodes allow an efficiency going from 50% at 0dBm in the entry of the rectifier to 70% at 15 dBm for pulse wave signal, and around 30% for TR signal at 10 dBm.

3 Time Reversal: a channel-adaptive solution for RFID ?

In passive RFID application, there is two different problematics: the first one is to feed a passive RFID Tag with enough power to allow it to backscatter an answer; the second is to have a maximum difference of Voltage between the "zero" and "one" states to be able to decode the information.

References

[1] A. Collado and A. Georgiadis, "Improving wireless power transmission efficiency using chaotic waveforms," in *IEEE MTT-S Int. Microw. Symp. Dig.*, Jun. 2012, pp. 1–3.

[2] M. Fink, "Time reversal of ultrasonic fields—Part I: Basic principles," *IEEE Trans. Ultrason., Ferroelectr., Freq. Control*, vol. 39, no. 5, pp. 555–566, Sep. 1992.

[3] R. Ibrahim, D. Voyer, A. Breard, J. Huillery, et al., "Experiments of Time-Reversed Pulse Waves for Wireless Power Transmission in an Indoor Environment," IEEE Trans. MTT, vol. 64, n° 7, july 2016, pp. 2159–2170.

[4] M. El Zoghbi, V. Abou Hamad, R. Ibrahim, et al. "A Wideband V-Shaped Coplanar Patch Antenna for 2-6 GHz Designed for Energy Harvesting and Wireless Communications". *International Journal on Communications Antenna and Propagation (IRECAP)*, 2018, 8 (5), pp.406.

[5] Rony Ibrahim, Damien Voyer, et al. Novel Design for a Rectenna to Collect Pulse Waves at 2.4 GHz. *IEEE Transactions on Microwave Theory and Techniques*, Institute of Electrical and Electronics Engineers, 2018, 66 (1), pp.357 - 365