Antenna impedance optimization for wireless power transfer applications

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***Abstract*—We consider wireless power transfer via RF/microwave energy, with rectification of the received RF power (i.e. a "rectenna" system). We address the issue of the impact of the internal impedance of the receiving antenna on the charging performance. This prototypical analysis considers the simplest configuration, with a half-wave rectifier, a storage capacitor, and a resonant antenna. The capacitor may be either a supercapacitor, or be seen as the input stage of a more complex charging system.**

I. Introduction

Wireless Power Transfer (WPT) from a source to a load is becoming more and more interesting and affordable, especially with the advent of several low-power sensors and boards for Internet-of-Things (IoT) applications [1], [2]. The technology is already available on some commercial devices, like mobile phones and Radio Frequency IDentification (RFID), but the need to provide energy independence, like wireless charging on-demand, to avoid overcharging problems and to minimize the costs, is increasingly stringent.

During the last decades, several studies have been performed to maximize the power transfer, i.e. the power conversion from RF to DC.

To do this, the key element is a *rectenna*, i.e. a circuit used to collect wireless transmitted power and to convert it to DC power. A typical rectenna is composed of an antenna, a rectifier, a matching circuit and a load (see Figure 1). Several

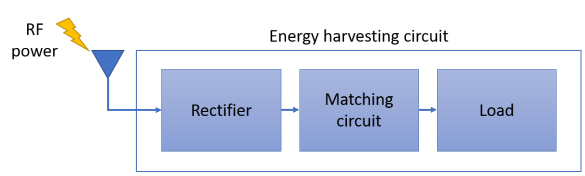

Fig. 1. Typical rectenna scheme.

high-efficiency rectennas for WPT have been studied in the past [3]–[7], and each of these studies usually tries to apply a dedicated RF solution to the specific application, even though the level of input power is significantly different.

Recently, an interesting and complete analysis on how to achieve the maximum power transfer has been proposed [8]. The authors show that the optimal rectenna structure should do without the matching circuit, especially in case of (ultra)low-power scenarios where the power involved is really low.

Starting from these considerations, in this paper the authors aims to concentrate on the input impedance of the antenna to analyze its impact on the power transfer.

II. Simplified circuit

The circuit used in this work to analyse the rectenna is an approximation of the real-one (see Figure 2) and it is formed by two distinct parts:

- the antenna, which is modeled as a single tone voltage generator $v_{in}(t) = \hat{V}_{in}\sin(2\pi ft)$, and its impedance Z_a;
- the rectifier, formed by a diode D in series to a load Z_o.

In this study, two assumptions are made: the first is to consider the antenna impedance as a pure resistance, while the second is to assume all components (e.g. diode, load, etc.) as ideal components, i.e. without losses.

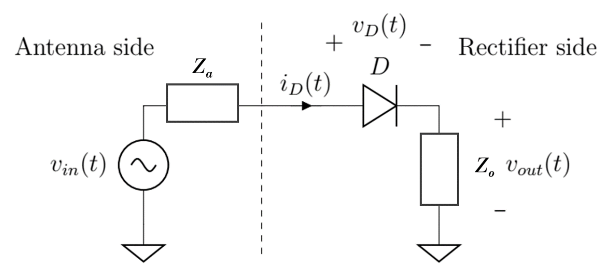

Fig. 2. Simplifed circuit of a rectenna.

A. Rectifier

The rectifier is composed of a detector, generally based on Schottky diodes due to lower voltage threshold, and a capacitor as storage element. The topology exploited for the rectifier is a half-wave rectifier, to reduce the losses due to the voltage drop present for each component added to the circuit and since it has been demonstrated that, although multiple-stage rectifiers are able to supply larger output voltage, the half-wave rectifier performs the maximum power transfer [8].

B. Antenna

The antenna selected for this analysis is a patch antenna, since it is quite easy to build and in can be integrated in the electronic circuits by exploiting the same fabrication techniques. Furthermore, it can be fed with a stripline (microstrip-fed) or with a coaxial cable (probe-fed), allowing to easy change the input impedance.

An important parameter for the antenna is the effective height $\bar{h}_e$, which relates the induced voltage to the incident electric field [9]:

$$V_{in} = \bar{h}_e \bar{E} = h_e \hat{h}_e \vec{E}_{inc}. \quad (1)$$

Assuming the antenna oriented in the direction of the maximum reception, the previous formula can be simplified as:

$$V_{in} = |h_e| \left| \vec{E}_{inc} \right|. \quad (2)$$

The effective height is related to the physical dimensions of the antenna and to the frequency:

$$|h_e| = \lambda \sqrt{G \frac{R_{rad}}{\pi Z_0}} \quad (3)$$

where G is the (maximum) gain of the antenna, R_{rad} is the radiation resistance and λ is the wavelength. From Eq. (3) it can noted that, the higher is the radiation resistance, the higher will be the effective height and then the input voltage.

III. Analysis

The system depicted in Fig. 2 is non-linear with memory and the mesh equation of the circuit is the following:

$$v_{in}(t) = R i_D(t) + v_D(t) + v_{out}(t) \quad (4)$$

Due to its characteristics, it is impossible to get a closed solution for the desired behavior. Then, to study the transient, a time-discrete analysis needs to be performed, by dividing each period T in several instant times ΔT. In this way it will be possible to get the behavior $v_{out}(t)$ as a function of the components R and C, the amplitude of the input signal $\hat{V}_{in}$ and the diode parameters D.

After several manipulations and exploiting some Taylor expansions, the behavior of the output voltage $v_{out}(t)$ (i.e. the voltage on the load), can be obtained. The solution obtained has been implemented in Matlab®, by imposing as initial conditions: $v_C(0) = v_D(0) = 0$.

Figure 3 shows the trend of the voltage as a function of the time, by exploiting a capacitor C as load and by varying the radiation resistance of the antenna. From the results it is possible to state that the antenna impedance affects the charging time of the capacitor, in the following way:

- an higer R_{rad} means higher $\hat{V}_{in}$, then the capacitor may reach higher steady voltage, by paying for a longer charging time;
- a lower R_{rad} conversely, it means lower $\hat{V}_{in}$, but small charging times.

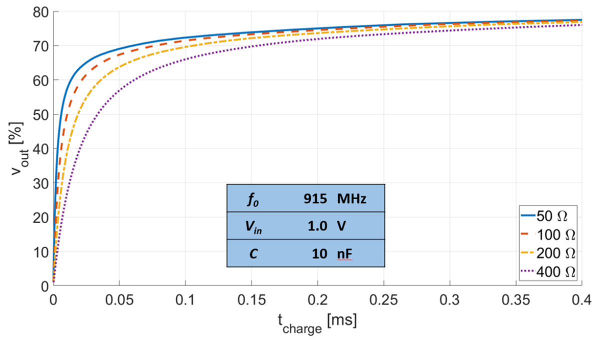

Fig. 3. Charging times by varying the radiation resistance.

IV. Conclusions

In this paper, an analysis to understand the impact of the input impedance of the antenna for wireless power transfer has been performed. From the preliminary results the radiation resistance is able to affects the charging time of the load. Future work will focus on a more complex scheme to take into account all parameters present in the circuit, like the real equivalent circuits of the patch antenna, the diode and the capacitor.

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