Eletrically-Small Rectenna with Huygens Radiation Pattern for Wireless Power Transfer Applications

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***Abstract*— An electrically-small Huygens rectenna is reported that operates at 915 MHz in the ISM band for wireless power transfer (WPT) applications. The rectenna consists of an electrically-small Huygens linearly-polarized (HLP) antenna and a rectifier circuit. The HLP antenna is developed by systematically combining two near-field parasitic resonant (NFPR) elements: an Egyptian axe dipole (EAD) and a capacitively loaded loop (CLL), together, with a small dipole antenna. The designed HLP antenna is electrically-small (ka < 0.89), low profile (~0.04λ_0), and produces cardioid-shaped directivity patterns with a very satisfactory peak realized gain value (4.4 dBi), wide half power beamwidth (~136°), and high front-to-back ratio (~26 dB). A rectifier circuit is designed and integrated with the HLP antenna to realize the rectenna. The rectifier consists of one HSMS286 Schottky diode and three lumped elements. The rectenna achieves a maximum RF to DC conversion efficiency: 86%, and a 2.4 V output DC voltage for a -5.0 dBm input power. Owing to its compact footprint and excellent radiation performance, this electrically-small rectenna is suitable for wirelessly powering sensors and unmanned aerial vehicles (UAVs).**

***Index Terms*—electrically-small antenna, Huygens source, near-field parasitic resonant (NFPR) elements, rectifier, wireless power transfer (WPT).**

I. Introduction

Electrically small antennas (ESAs) have drawn much attention during recent years as modern wireless systems have begun to require more compact, lighter weight, and more efficient platforms [1]. One promising application of ESAs is for wireless power transfer (WPT), i.e., to wirelessly power future 5G Internet-of-Things (IoT) devices. Electrically small rectennas (ESAs integrated with rectifier circuits) are capable receiving RF wireless power and converting it into DC power. Consequently, they could act as a remote power source for nodes in wireless sensor networks, thus eliminating the human intervention required to replace the batteries in them. These advanced battery-less sensor networks have many health and safety monitoring applications to the benefit of society.

Many reports have described a variety of antenna designs for rectennas, e.g., [2] – [5]. They include dipole [2], slot [3], planar inverted F (PIFA) [4], and patch [5] antennas. However, due to their electrically-large size, these designs cannot be fit into compact wireless devices. Thus, the electrically-small (ES) rectennas in [6] and [7] were developed. Although these ES rectennas achieve small footprints, their radiation directivity is low due to their dipole-like omni-directional radiation patterns. Therefore, ES rectennas with high directivity would have a high impact on far-field WPT applications.

In this paper, we introduce a 915 MHz (ISM band) ES Huygens rectenna. It integrates a Huygens LP (HLP) antenna with a highly efficient rectifying circuit. The reported rectenna not only achieves a high directivity (4.4 dBi), the desired cardioid-shaped directivity pattern with a wide beamwidth (~136°), and a high front-to-back ratio (~26 dB), but it also has a very good RF to DC conversion efficiency (86%). With its compact footprint (ka < 0.89) and low profile (~0.04λ_0), it is an ideal candidate for wirelessly powering a variety of 5G IoT devices.

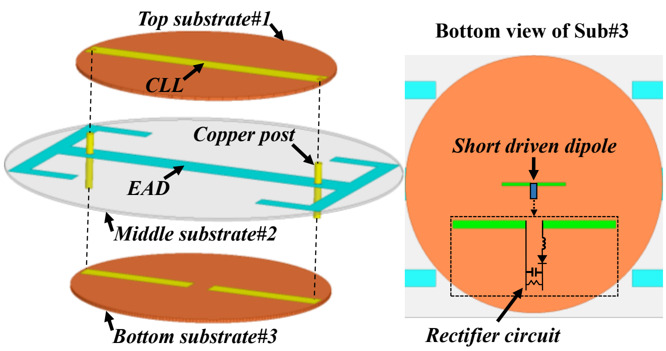
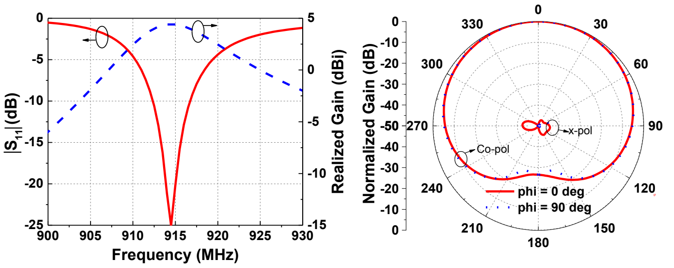


Fig. 1. Configuration of the electrically-small Huygens LP rectenna. (a) Perspective view. (b) Bottom view: driven dipole and rectifier circuit.

II. Rectenna Design and Performance

The ES HLP antenna is a modification of our previous designs [8] – [10]; it is shown in Fig. 1. It consists of two near-field resonant parasitic (NFRP) elements: an Egyptian axe dipole (EAD), which acts as the electric dipole element, and a capacitively loaded loop (CLL), which acts as the magnetic dipole element, integrated with a small electric dipole antenna. By properly adjusting the coupling between these elements, Huygens (complementary) dipole radiation patterns are obtained. Fig. 2 (a) shows the simulated $|S_{11}|$ and realized gain values as functions of the source frequency for the HLP antenna. It operates at 915 MHz with a -20.5 dB $|S_{11}|_{min}$ value and a 4.4 dBi maximum realized gain value. Fig. 2 (b) shows the simulated, normalized realized gain patterns in two orthogonal vertical planes. These cardioid-shaped Huygens patterns are almost identical in both the $\varphi = 0°$ and $\varphi = 90°$ planes, exhibiting wide beamwidths, ~136°; extremely low (below -50 dB) cross polarization levels, and large front-to-back ratios, ~26 dB.



(a) (b)

Fig. 2. Simulated HLP antenna results. (a) $|S_{11}|$ and realized gain values as functions of the source frequency. (b) Normalized realized gain patterns in the two orthogonal, vertical planes: $\varphi = 0°$ and $\varphi = 90°$, at 915 MHz.

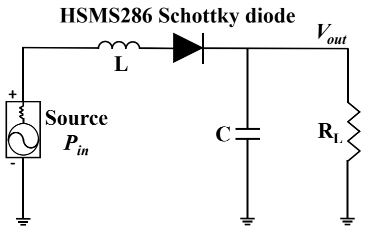
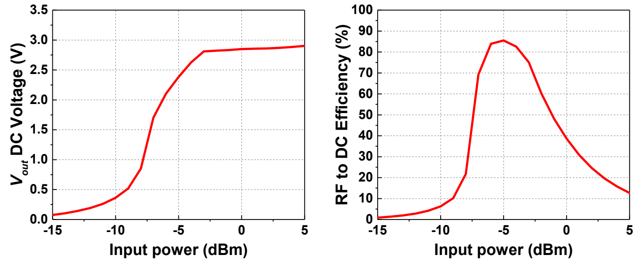


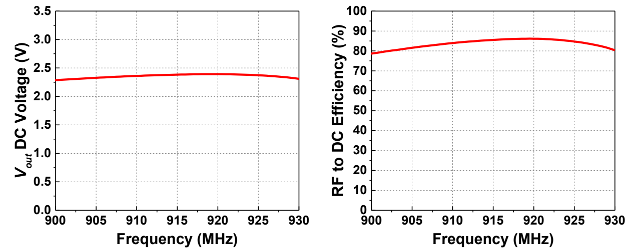
Fig. 3. The circuit simulation model of the rectifier is based on one HSMS286 Schottky diode and three lumped element components.

The rectifier circuit is based on a diode and an RLC combination as shown in Fig. 3. The HSMS286 Schottky diode was adopted due to its high detection sensitivity, i.e., up to 50 mV/μW at 915 MHz [11]. The capacitor C (47 pF) bypasses the RF signal from the output port to achieve a much smoother DC output voltage, V_{out}. The inductor L (170 nH) acts as a low pass filter that prevents higher order harmonic power from reaching the radiator, thus preventing unwanted re-radiation losses. R_L (21 kΩ) is the load resistor. Fig. 4 shows the simulated output DC voltage value and RF to DC conversion efficiency as functions of the input power (dBm). The peak efficiency, 86%, is at 915MHz when the input power is -5 dBm. Fig. 5 presents a similar set of data but as functions of the source frequency when the input power is -5 dBm. The maximum DC output voltage is 2.4 V at 915 MHz. Both the DC output voltage and conversion efficiency are smooth within the frequency range: 900 to 930 MHz.



(a) (b)

Fig. 4. Simulated results as functions of the input power (dBm) at 915 MHz. (a) Output DC voltage values. (b) RF to DC conversion efficiencies.



(a) (b)

Fig. 5. Simulated results as functions of the source frequency when the input power is -5 dBm. (a) Output DC voltage values. (b) RF to DC conversion efficiencies.

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