Far-field wireless power transfer (WPT) for IoT applications enabled by an ultra-compact and highly-efficient Huygens rectenna

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***Abstract*—Far-field wireless power transfer technology is very attractive for future Internet-of-Things (IoT) applications. It facilitates the realization of batteryless and sustainable wireless systems. An ultra-compact and highly efficient Huygens rectenna is introduced that is suitable for powering IoT devices whose footprints are small. The rectenna follows from the seamless integration of an ultra-compact Huygens antenna and a highly efficient, compact rectifier circuit. The Huygens antenna consists of two metamaterial-inspired near field resonant parasitic (NFRP) elements, an Egyptian axe dipole (EAD) and a capacitively loaded loop (CLL). As a radiator matched to a 50-Ω source, it exhibits a cardioid-shaped realized gain pattern whose peak, 4.58 dBi, occurs at its resonant frequency, 915 MHz. As a rectenna, it is modified to exhibit an inductive impedance that is conjugately matched to the capacitive value of the rectifier. The peak AC to DC conversion efficiency reaches 87.8%. The entire rectenna is electrically small with its *ka* value less than 1 and is realized on a single piece of PCB substrate.**

Keywords*—electrically small antennas; Huygens pattern; Internet-of-Things (IoT); planar; rectenna; wireless power transfer; ultra-compact

I. INTRODUCTION

Far-field wireless power transfer (WPT) is a revolutionary technology for current and future wireless Internet-of-Things (IoT) applications. It facilitates achieving batteryless, long-life, environment-friendly and sustainable IoT systems. Figure 1 illustrates a WPT-enabled IoT sensing system for smart agriculture and farming applications. A rectennas, i.e., an antenna integrated with a rectifier circuit, is an essential component in any far-field WPT system. Rectennas for many envisioned IOT applications must have compact sizes, large wireless power capture capacities, and high AC to DC conversion efficiencies. However, it has remained very challenging to achieve all of these desired features simultaneously in a simple design.

A significant number of far-field rectenna systems have been developed to date. Typical examples are reported in [1] – [8]. Nonetheless, all of these designs are not electrically small (compact in size); do not have large wireless power capture capacities (high antenna gain and large beamwidths), and do not achieve high AC to DC conversion efficiencies at the same time. Recently, several electrically small Huygens rectennas for far-field WPT systems have been reported by our group to overcome this challenge [9] – [12]. These Huygens rectennas require three pieces of manually-assembled PCB substrates and, hence, have complicated fabrication and assembly requirements. This paper introduces an ultra-compact and highly efficient Huygens rectenna. It exhibits excellent wireless power capture capacity and has a very high AC to DC conversion efficiency. Moreover, it only needs one piece of copper-cladded PCB substrate and, consequently, is suitable for mass production.

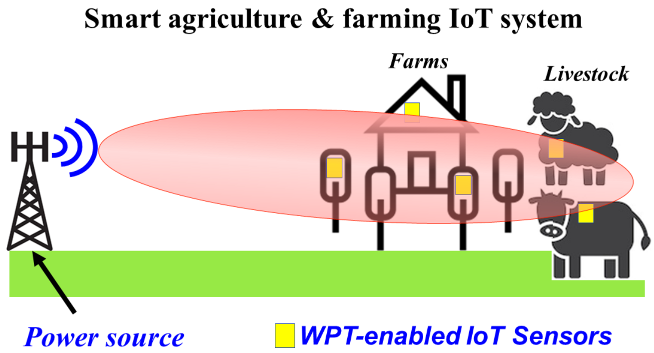

Figure 1. Illustrated far-field wireless power transfer system for IoT applications in the food and agriculture industries.

II. ULTRA-COMPACT HUYGENS ANTENNA DESIGN AND ITS MODIFICATION AS A HIGHLY-EFFICIENT WPT RECTENNA

A. Design configurations

The ultra-compact Huygens antenna and rectenna designs are shown in Fig. 2. Fig. 2(a) is the planar electrically small Huygens antenna. Two metamaterial-inspired near field resonant parasitic (NFRP) elements, an Egyptian axe dipole (EAD) and a capacitively loaded loop (CLL), are printed on the two surfaces of a single piece of Rogers^{TM}5880 substrate that is 0.508 mm thick and whose relative permittivity is 2.2 and lost tangent is 0.0009. A short driven dipole is printed on the same surface as the CLL element; the EAD element is printed on the opposite surface. The entire rectenna system is electrically small (*ka* < 1). Fig. 2(b) shows its modification as a rectenna. An ultra-compact rectifier circuit is seamlessly attached to the input port of the Huygens antenna. The entire rectenna remains electrically small. Since both systems are realized on a single 5880 sheet, they are very easy to fabricate.

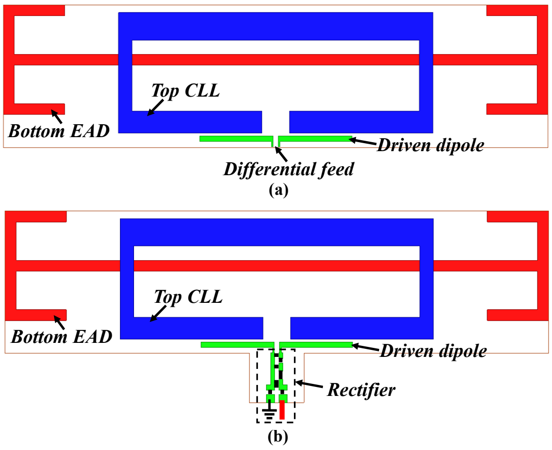

Figure 2. Configuration of the (a) ultra-compact and highly efficient Huygens antenna, and (b) its modification into a rectenna.

B. Performance of the Ultra-Compact Huygens Antenna

The simulated performance of the ultra-compact Huygens antenna is shown in Fig. 3. It resonates at f_{res} = 915 MHz in the ISM band with a minimum $|S_{11}|$ value less than -25 dB. It is linearly polarized and exhibits cardioid-shaped realized gain patterns at f_{res} in both vertical planes ($\varphi = 0^\circ$ and $\varphi = 90^\circ$). The peak realized gain value is 4.58 dBi. The 3 dB beamwidths are very wide, being greater than ±65˚ for both vertical planes.

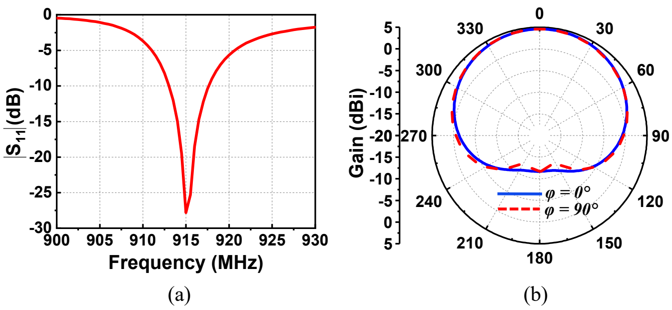

Figure 3. Simulated performance of the planar electrically small Huygens antenna. (a) $|S_{11}|$ values. (b) Realized gain patterns in its two vertical planes ($\varphi = 0^\circ$ and $\varphi = 90^\circ$) at f_{res} = 915 MHz.

C. Performance of the corresponding rectenna

Another advantage of this planar Huygens rectenna design is the inductive input impedance of its antenna which allows it to be conjugately matched to the capacitive impedance of the rectifier circuit. This feature is achieved simply by increasing the length of the short driven dipole by a small amount. It eliminates the rather lossy matching inductor necessitated in most rectifier circuits. The circuit design is shown in Fig. 4(a). Fig. 4(b) indicates that the input impedance of the antenna is 50 + j120 Ω at 915 MHz, a perfect conjugate match to the rectifier. The rectenna reaches a maximum achievable AC to DC efficiency of 90% as shown in Fig. 4(c). Comprehensive measurement results of this work are currently in progress and will be reported at the conference.

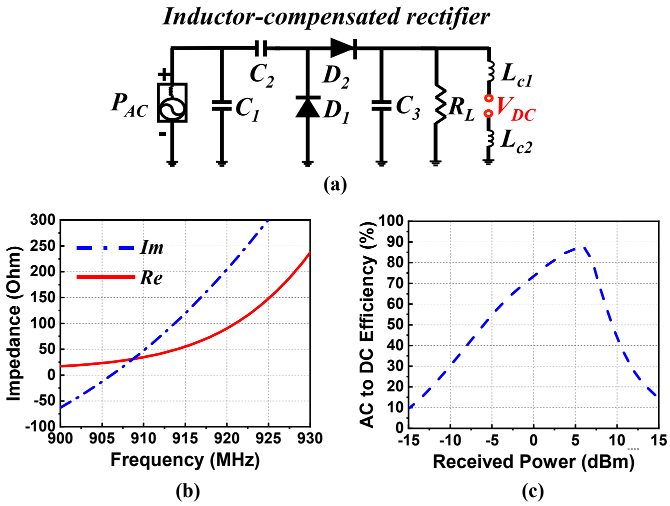

Figure 4. The rectenna system. (a) The inductor-compensated rectifier circuit. (b) Simulated input impedance of its antenna. (c) Simulated AC to DC conversion efficiency.

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