Wirelessly Powered IoT Sensor Facilitated by A Planar Electrically Small Huygens Rectenna

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***Abstract*— A wirelessly powered Internet-of-Things (IoT) sensor system is presented in this paper. It is facilitated by a highly compact, planar electrically small Huygens rectenna. The rectenna is based on two metamaterial-inspired electrically small structures, an Egyptian axe dipole (EAD) and a capacitively loaded loop (CLL). The near-field resonant parasitic EAD and CLL structures are carefully designed to be a compact entity that excites a short dipole. A highly efficient rectifier circuit is seamlessly connected to this driven dipole, forming a rectenna. The whole rectenna system is fabricated on a single piece of PCB substrate. It is electrically small, has an ultra-thin profile, and is low cost and lightweight. The developed rectenna is able to wirelessly power IoT devices to realize battery-free systems. A wirelessly powered light detection sensor system is successfully demonstrated by augmenting the rectifier with a photocell.**

***Index Terms*—Electrically small antennas, Huygens antennas, Internet-of-Things, rectennas, sensors, wireless power transfer.**

I. INTRODUCTION

Wirelessly powered Internet-of-Things (IoT) devices are an innovative approach to future IoT-based smart systems. Far-field wireless power transfer (WPT) technology eliminates the need for traditional short-life, bulky and heavy batteries. Moreover, it enables charging multiple WPT-enabled battery-free devices simultaneously, a crucial aspect given the anticipated growth in the number of IoT devices in the emerging 5G era. A rectenna is the vital, enabling component in any far-field WPT application. It converts received electromagnetic field energy into useful DC power. IoT applications require their rectenna(s) to be compact, lightweight, low cost and highly efficient. It is very challenging to achieve these features simultaneously.

A large variety of WPT rectennas have been reported to date. Typical examples are found in references [1] – [6]. The relevant literature indicates that a major challenge in designing a rectenna is reducing its size and complexity while maintaining significant wireless power capture and conversion capacity. Although several compact and highly efficient rectennas have been developed recently [7] – [10], they require multiple substrates and, hence, their fabrication and assembly is not easy. To address this challenge, a planar ultra-thin electrically small Huygens rectenna system has been developed which is simultaneously compact, lightweight, low cost, easy to fabricate and highly efficient. It is an ideal candidate for wirelessly powering IoT devices. By augmenting its rectifying circuit with a photocell, a wirelessly powered light detection IoT sensor system is successfully demonstrated. Measured results confirm excellent performance in agreement with their simulated values.

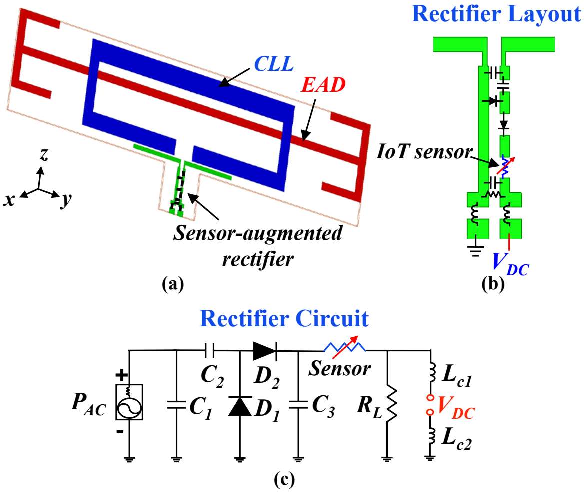
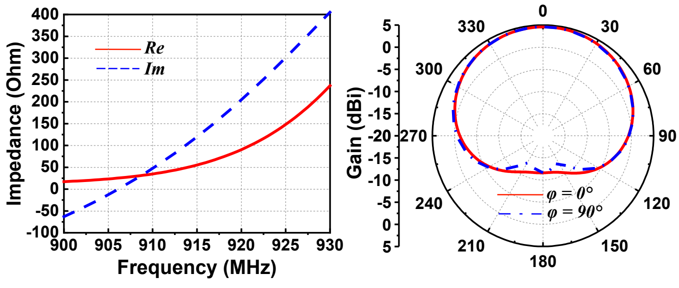


Fig. 1. Wirelessly powered IoT sensor facilitated by a planar electrically small Huygens rectenna. (a) System configuration. (b) Sensor-augmented rectifier layout. (c) Corresponding rectifier circuit model.

II. SYSTEM DESIGN

The wirelessly powered IoT system is illustrated in Fig. 1. It consists of a planar electrically small Huygens dipole antenna and a sensor-augmented rectifier circuit. The planar Huygens dipole antenna is realized by integrating two metamaterial-inspired near field parasitic resonant (NFPR) structures, an Egyptian axe dipole (EAD) and a capacitively loaded loop (CLL). Their resonant combination excites a short dipole. The impedance of the receiving Huygens dipole antenna is designed to exhibit an inductive value, 50 + j120 Ω, which conjugately matches it to the capacitive impedance of the rectifier in the ISM (Industrial, Scientific, and Medical) band at 915 MHz. Its input impedance is shown in Fig. 2 (a). Its Huygens realized gain patterns given in Fig. 2 (b) demonstrate that it has a wide beamwidth and high peak gain (4.6 dBi), indicating a strong wireless power capture capacity. The sensor-augmented rectifier is modified from a highly efficient full-wave version. Impedance varying elements such as photocells and thermistors can be integrated seamlessly with the rectifier circuit to realize wirelessly powered sensors.



(a) (b)

Fig. 2. Simulated results. (a) Input impedance of the electrically small Huygens antenna. (b) Principal plane realized gain patterns at 915 MHz.

III. Measured Performance

A wirelessly powered light detection sensor facilitated by the developed planar electrically small rectenna was fabricated and tested. It is shown in Fig. 3. The entire system is built on a single piece of Rogers^{TM} 5880 substrate, which has a thickness of 0.7874 mm, relative permittivity of 2.2 and loss tangent of 0.0009. A photocell augments the rectifier to realize the wirelessly power light sensor. The output DC voltage depends on the ambient illumination level. The system is compact, lightweight, low cost and electrically small (ka = 0.98 < 1). It operates at 915 MHz in the ISM band.

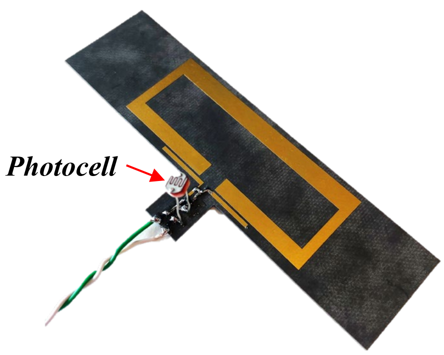
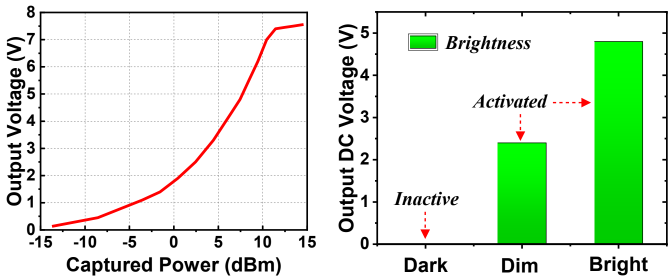


Fig. 3. Fabricated prototype of the wirelessly powered light sensor facilitated by the developed electrically small Huygens rectenna.

The measured results of the wirelessly powered light sensor are shown in Fig. 4. The measured operating frequency of the rectenna is 909 MHz, which is only shifted by 6 MHz (0.7%) from the designed 915 MHz. Fig. 4 (a) shows the output DC voltage of the rectenna (without sensor and R_L = 5.1K Ω) as functions of the captured power at 909 MHz. The output DC voltage increases rapidly from -10 to 10 dBm and saturates thereafter. Fig. 4 (b) shows the output DC voltage of the light sensor, i.e., the output of the photocell-augmented rectifier (in series with a load resistor R_L = 3.6 KΩ) under different illumination conditions. An audio alarm is connected to the load resistor. It sounds if the voltage exceeds 0.8 V. It is found that the alarm is inactive in a totally dark environment. It is activated in both dim and bright scenarios, thus successfully demonstrating a fully wirelessly powered light detection sensor system.



(a) (b)

Fig. 4. Measured results. (a) Output DC voltage of the rectenna as a function of the captured power at 909 MHz. (b) Output DC voltage of the light sensor-augmented rectenna under different illumination conditions.

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