Electrically Small Huygens Dipole Antenna Based Rectenna and Array for Wireless Power Transfer Enabled Internet-of-Things Applications

(*Invited*)

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***Abstract*— This paper introduces the electrically small Huygens dipole antenna (HDA) based rectenna and antenna array for wireless power transfer (WPT) enabled Internet-of-Things (IoT) applications. WPT-enabled IoT applications require two major sub-systems: the receiving rectenna and the antenna array that transmits the wireless energy. The developed electrically small Huygens dipole antenna (HDA) is the ideal candidate for enabling both sub-systems for WPT-enabled battery-free IoT ecosystems thanks to its ultracompact size and unidirectional Huygens radiation pattern with its wide half-power beamwidth. An ultracompact and highly efficient wireless power capturing rectenna was designed by seamlessly integrating the HDA with a compact rectifier circuit. Moreover, a linear-array also based on the HDA element was developed with a beam-steering performance that simultaneously realizes both long distance WPT and large area coverage.**

Index Terms— ***Electrically small, Beam-steering antenna array, Huygens dipole antenna, Internet-of-Things, rectenna, wireless power transfer (WPT).***

I. INTRODUCTION

Wireless power transfer (WPT) is a major enabling technology for future battery-free Internet-of-Things (IoT) ecosystem. It negates the bulky and short-life chemical batteries used in current systems, especially since the number of IoT devices will be rapidly increasing in the near future [1] – [3]. This paper will introduce innovations of its two major sub-systems: the rectenna that captures the wireless power and the transmitting beam-steering antenna array which radiates that wireless power. The designs of both sub-systems are based on the electrically small Huygens dipole antenna (HDA).

The electrically small HDA design is shown in Fig. 1. The entire structure is simple. It consists of an Egyptian axe dipole (EAD), a capacitively-loaded loop (CLL), and a short driven-dipole that excites these near-field resonant parasitic elements. All of these components are realized on a single piece of PCB substrate. The short driven-dipole excites the CLL, which forms a magnetic dipole. The strong electric fields from the upper strip of the CLL couple to and induces currents on the EAD to forms an electric dipole. Their phase difference is properly designed by adjusting this coupling. A pair of orthogonally-oriented and in-phase electric and magnetic dipoles is realized with this configuration and results in a Huygens radiation pattern being radiated. Due to its exceptional performance characteristics, i.e., its high directivity, large front-to-back-ratio (FTBR), wide half-power beamwidth, and ultracompact size, the HDA is an ideal choice for the development of the aforementioned WPT-enabled battery-free IoT ecosystems. A comprehensive discussion of its design and performance characteristics is found in the research works [4] – [6].

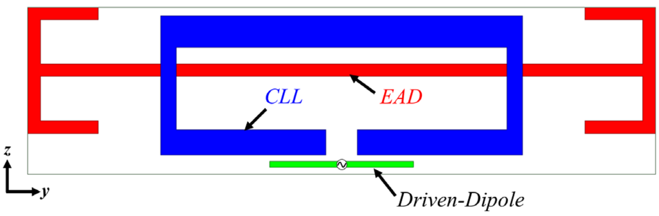

Fig. 1. The electrically small Huygens dipole antenna (HDA) configuration.

II. ELECTRICALLY SMALL HUYGENS DIPOLE RECTENNA

The trend in IoT applications, which emphasizes tiny devices, is to have the smallest possible rectenna. Moreover, the rectenna must ensure a large wireless power capture capability. The developed electrically small HDA facilitated the realization of an ultracompact rectenna. As seen in Fig. 2, its design was realized by seamlessly integrating a highly efficient rectifier circuit with the developed HDA on a single PCB substrate. The rectifier circuit consists mainly of two Schottky diodes, several lumped capacitors and one resistor. Note that the circuit does not require the matching inductor found in most rectennas and, hence, avoids around a 10% loss to the entire system. The HDA is designed to have an inductive impedance that is directly matched to the capacitive impedance of the rectifier circuit. This is achieved by properly designing the length of the short driven-dipole. Several prototypes have been successfully built and measured. Up to 90% AC to DC conversion efficiency was realized. The comprehensive design and measurement results are found in the reported works [7] – [9]. In a similar manner, two highly efficient WPT-enabled temperature and light sensor systems have been developed [10].

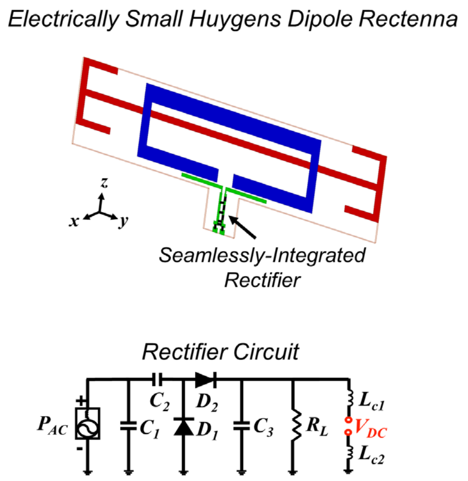

Fig. 2. Configuration of the electrically small Huygens dipole rectenna and the equivalent circuit model of its rectifier circuit.

III. Electrically Small HDA-Based Beam-Steering Antenna Array

The WPT transmitting antenna array sub-system must exhibit high directivity and large radiation coverage. Moreover, the array is required to be lightweight and compact for the ease of deployment. A uniform linear array formed with the electrically small HDA elements, as illustrated in Fig. 3, was developed to realize these objectives. It radiates a Huygens pattern with a large beamwidth in the principal plane orthogonal to the array axis. Large radiation coverage and high directivity are achieved simultaneously by steering the beam in the orthogonal principal plane. Full-wave simulations confirmed the theoretical calculations. e.g., a small gain variation was verified when the beam was steered. A three-element array prototype fed with a 3 × 3 Butler matrix was built and tested. The entire array was realized on a single piece of PCB substrate that is low-cost, lightweight, and ultrathin. The measured results verified the design concept, theoretical calculations and full-wave simulations. Its performance characteristics confirm that it is an ideal candidate for radiating wireless power to be captured by the battery-free IoT devices enabled by HDA-based rectennas. The detailed design processes, theoretical calculations, numerical simulations and measurement results are found in [11]. They will be reviewed in our presentation.

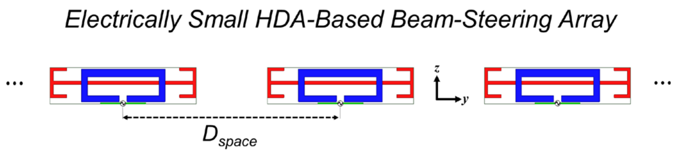

Fig. 3. The linear beam-steering antenna array based on the electrically small Huygens dipole antenna.

IV. Conclusion

This paper introduced electrically small Huygens dipole antenna (HDA) innovations to the two essential sub-systems of a WPT-enabled battery-free IoT ecosystem, i.e., an ultracompact, highly efficient rectenna and a transmitting antenna array with high directivity and large radiation coverage. These subsystems are enabling components for future WPT-enabled, battery-free IoT applications.

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