A Flexible Compact Rectenna for 2.4GHz ISM Energy Harvesting Applications

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***Abstract*—This paper presents a new compact ultra-lightweight radio frequency (RF) energy harvester fabricated on a flexible substrate. The proposed rectenna is designed to operate over the 2.4GHz ISM band. The rectifier includes a dual transmission lines tapered matching network that provides a combination of compactness, flexibility and an efficiency of up to 40%. The rectifier is then integrated with a miniaturized monopole antenna to form an ultra-compact, efficient and flexible rectenna. The system is characterized in multiple bent configurations featuring high and stable performance. It is demonstrated that for different bent states, the proposed flexible harvester displays a variation in harvested power that is less than 57 %.**

Keywords—Flexible Electronics, PCE, RF Energy Harvesting, Rectenna, ISM Band.

I. INTRODUCTION

A lot of effort has recently been invested into devising new ways of providing sufficient energy to power-autonomous and compact devices. Ambient RF energy harvesting is inherently attractive as an additional source of energy that is different from other sources such as solar, mechanical, or thermal. This technique enables a new form of green technology that "recycles" ambient RF energy. RF energy harvesting also allows wireless devices to become self-sustaining. Such energy drawn from propagating electromagnetic waves that originate from mobile cell phone towers or abundantly available Wi-Fi routers and access points.

Generally speaking, RF energy harvesting systems rely on efficient and well-designed "rectennas" that are the combination of an antenna and a rectifier. In earlier works, several efficient "rectenna" designs have been proposed, featuring characteristics such as flexibility, compactness or wideband operation. In [1], a multiband RF energy harvester is fabricated on a paper substrate. The proposed rectifier presented an efficiency in the range of 5%–16% for an available input power of −20 dBm over LTE bands. The paper presented in [2] reviewed the integration of additive manufacturing techniques (AMTs) in near field and far field RF energy harvesting applications. Some of the key advantages of AMTs are the realization of multi-material low cost RF structures by depositing any type of conducting or dielectric material on virtually any flexible or non-planar surface or component.

In this paper, we introduce the dual concept of flexibility and compactness for the realization of a curvature-rugged efficient rectenna system. In addition, the tapered matched rectifier circuit approach adopted here has been demonstrated to provide high rectification performance over wider ranges of loads and frequencies in [3], where an almost flat efficiency response over a certain range of load values was achieved. Section II of this paper presents the compact and flexible rectifier design with the dual line matching network and its characteristics. Section III presents the implementation of the associated high-performance flexible and compact rectenna system and its tested behavior over different curvatures, thereby demonstrating its ruggedness. The paper is then concluded in section IV.

II. RECTIFIER DESIGN AND CHARACTERISTICS

One of the main challenges in designing an efficient rectifier is the incorporation of an appropriate matching network that achieves adequate matching between the Schottky diode and the source. In this section, the proposed matching network aims to match the load composed of the SMS7630 zero-bias diode [4] to the 50 Ω source. The Schottky diode's impedance varies with both frequency and input power. In this work, the reference design point was chosen at 2.4 GHz, for an input power level of -10dBm. The layout of the proposed rectifier is shown in Fig. 1.

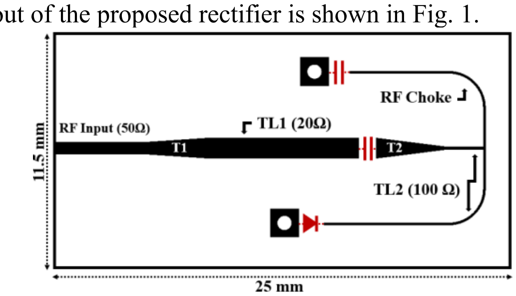

Fig. 1: Layout of the proposed 2.4 GHz rectifier circuit

In Fig. 1, the matching network consists of two lines "TL1" and "TL2". By tuning the lengths and characteristic impedances of both transmission line sections, the input impedance (Z_{in}) of the entire network was optimized to be 50 Ω. The abrupt change in characteristic impedances between the feeding line (50Ω), the first matching line "TL1" (20Ω) and the second matching line "TL2" (100Ω) was accommodated by the use of two tapered sections "T1" and "T2". The tapering smooths the transition between these lines and offers a wider bandwidth of operation. A capacitor placed between the two matching lines prevents the DC voltage generated by the diode from reaching the generator. The rectifier discussed above was fabricated on a 0.18 mm-thick liquid crystal polymer (LCP) substrate (dielectric constant of 3) using an inkjet-printed masking technique followed by etching. The "RF Choke" and the shorting of the λ/4 stub in the fabricated prototype were achieved using a shorted quarter-wavelength (λ/4) stub and a DC block capacitor, respectively. The measured and simulated power conversion efficiency (PCE) results are shown in Fig. 2. This rectifier achieved a high maximum efficiency of above 40% around the 0 dBm input power and R_L = 1 kΩ load operation point.

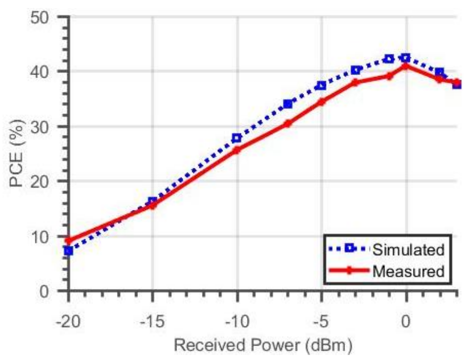

Fig. 2: Measured and simulated efficiency results for the proposed rectifier

III. Flexible Compact Rectenna Design

The previously-described rectifier was integrated in a rectenna configuration by the addition of a compact monopole antenna. A schematic illustration of the monopole antenna design is shown in Fig. 3. This design involves a meandered shape in order to miniaturize the size and allow operation at 2.4 GHz. The design was fabricated on LCP substrate with a thickness of 0.18mm and a size of 15.1mm x 8.15mm. The monopole displayed a measured gain of 0 dBi.

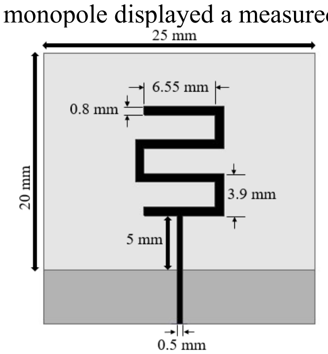

Fig. 3: Schematic of the 2.4 GHz meander monopole

The antenna and rectifier were then integrated into one circuit to form a rectenna design with an overall size of 50mm x 11.5mm as shown in Fig. 4. The resulting rectenna offers compactness as well as flexibility and ease of integration. For validation purposes, its performance was tested over curvatures of different bending radii. The output DC power was measured for four scenarios over a range of incident power densities. The rectenna featured a very good performance as seen in Fig. 5, while placed over a planar surface as well as curvatures such as cylinders of 0.75", 1.5" and 2" radii. The low maximum observed DC power variations upon bending (less than 57%) demonstrated its remarkable adequacy for bent implementations.

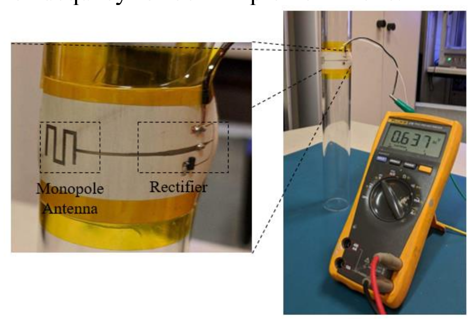

Fig. 4: Picture of the 2.4 GHz rectenna measurement on the 0.75" radius cylinder

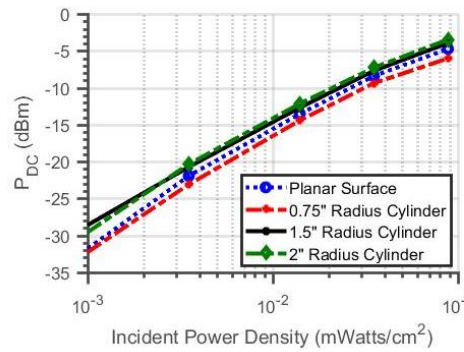

Fig. 5: Measured output DC power for different cylinders radii

IV. Conclusion

In this paper, a flexible 2.4 GHz compact rectenna system is presented and tested. It displays an unprecedented combination of properties with compactness, high efficiency, flexibility and stability relative to bending. Such an approach enables the introduction of integrated flexible durable and reliable energy-harvesting modules for wearable and Internet of Things applications.

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