An Efficient Mulitfeed Rectenna For RF Energy Harvesting

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***Abstract*—We propose to develop a multifeed rectenna for high-efficiency RF energy harvesting. By using a multifeed slot loop antenna and co-designing the antenna and the rectifier circuit, the conventional lossy impedance matching network between the antenna and the rectifier can be eliminated to boost the RF-to-DC conversion efficiency. Additionally, using multiple antenna feeds extends the high-efficiency working region of the rectifier to realize high DC output power and high efficiency simultaneously. As our preliminary data, a proof-of-concept two-feed rectenna is designed at 960 MHz. It achieves a peak efficiency of 64.5% and a combined DC output voltage of 1.72 V at an input power density of 2.3 μW/cm^2 in simulations, demonstrating state-of-the-art RF energy harvesting performance.**

***Index Terms*—Energy harvesting, Internet of Things (IoT), multifeed, rectenna, rectifier, slot antenna, wireless sensor network.**

I. INTRODUCTION

RF Energy harvesting is a promising solution to alleviate the need for battery replacement or recharging, where battery-powered devices can sometimes be hard to access or repair if their batteries die. The technological foundation of RF energy harvesting is a rectenna – an antenna connected to a rectifier circuit that converts the incoming RF power to DC [1]. However, existing rectennas usually suffer from two main challenges (Fig. 1). First, they often encounter limited RF-to-DC conversion efficiency due to the loss from the high-Q impedance matching network between the antenna and the rectifier circuit. Second, although the efficiency of rectifier circuits typically peaks at a certain power level, it begins to fall off rapidly when the input power further increases, making it challenging to support high DC output power while maintaining a high efficiency at the same time.

To address these two challenges, we propose a new multifeed rectenna topology based on a multifeed slot loop antenna. This strategy has two main advantages (Fig. 1). First, its impedance is up-scaled compared with a conventional single-feed antenna. By further co-designing the antenna and the rectifier, we are able to directly match the antenna source impedance to the high input impedance of the rectifier, thus eliminating the lossy matching network entirely. Second, by using multiple antenna feeds each connecting to a rectifier, we can extend the high-efficiency operation of the rectenna to the high-power region, thereby achieving high output DC power and high efficiency simultaneously.

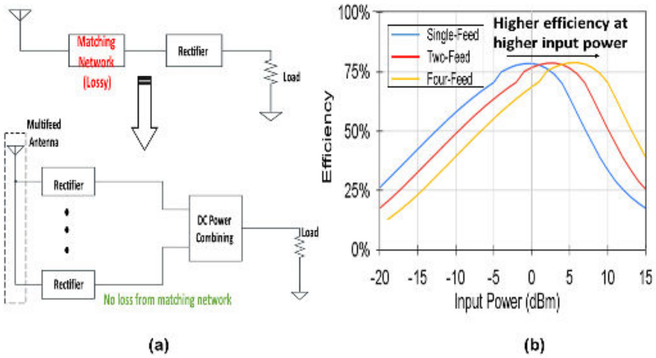

Fig. 1. (a) Difference between conventional and proposed rectennas. (b) Simulated rectification efficiencies for various multifeed antennas.

To demonstrate this idea, we have performed preliminary designs and simulations at 960 MHz, which will be elaborated in Section II and III.

II. METHODOLOGY BEHIND USING A MULTIFEED SLOT LOOP ANTENNA FOR RETENNA

One unique advantage of multifeed antennas is the capability to up- or down-scale the impedance while maintaining the same on-antenna current (or voltage) distribution and the resulting far-field radiation pattern as a single-feed one [2]. To show this, a two-feed slot loop antenna is designed on an FR4 substrate with a thickness of 1.6 mm. The EM simulation shows the voltage maxima are located at the two antenna feeds and the voltage nulls are located at the center of two sides, presenting an identical voltage distribution to that of a single-feed slot loop antenna. The radiation pattern of the two-feed antenna is also verified through EM simulations (see ref. [3]), also presenting an identical pattern as the single-feed antenna. Thus, the two-feed and single-feed antennas radiate out the same power, and the following impedance relationship can be derived [2]:

$$Z_{2feed} = 2Z_{1feed} \tag{1}$$

where Z_{1feed} are Z_{2feed} are the driving impedances of the the single-feed and two-feed antennas, respectively. Note that up-scaling the antenna impedance is particularly beneficial for rectenna designs because it allows the matching network between the antenna and rectifier, which is lossy and narrowband, to be eliminated.

In addition to eliminating the matching network, the second benefit of using a multifeed antenna is to address the issue of the rectifier efficiency drop at high power. The rectifier

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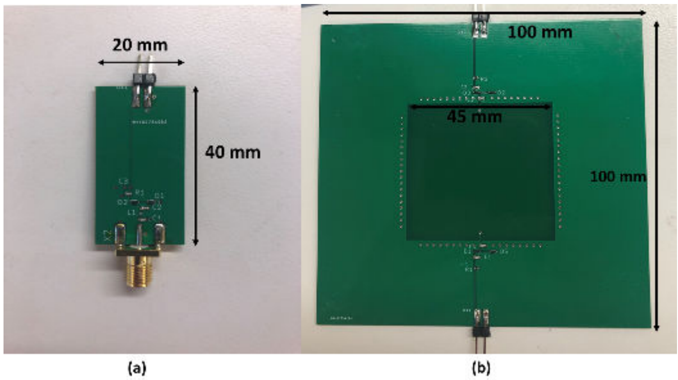

Fig. 2. (a) Rectifier testing board with the input matching network to 50 Ω. (b) Multifeed rectenna prototype.

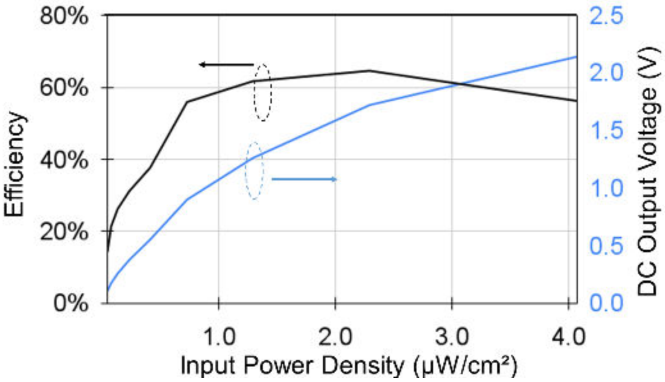

Fig. 3. Measured efficiency and combined DC output voltage of the multifeed rectenna prototype vs. the input power density.

efficiency used in this design, as is common with many RF rectifiers [4], peaks at a certain power level (e.g., around 0 dBm in this design) and then decreases rapidly. Since each feed of the two-feed antenna receives half of the input power, or -3 dB, than the single-feed antenna does, the two-feed rectenna becomes more efficient when the overall input power gets larger (e.g., >1 dBm in this design), thus allowing for high output power and high efficiency to be achieved simultaneously. Note that further increasing the number of feeds can extend the high-efficiency operation of the rectenna to even higher power levels. In practice, the optimal number of antenna feeds can be decided once the input power to the rectenna is known.

III. MEASUREMENT RESULTS OF THE MULTIFEED RECTENNA

For testing, two separate measurement boards are made - one for testing the rectifier itself(to ensure optimal efficiency) and another for testing the mutlifeed rectenna as a whole (Fig. 2).

To test the multifeed rectenna, an experimental set up is made in which the two rectenna DC outputs are connected to two multimeters, one for each feed, and set up a distance of 50 cm away from a dipole antenna (Pulse Larsen SPDA17RP918). The 50 cm distance guarantees that both the dipole antenna and our rectenna work in the far-field region.

$$R = \frac{2D^2}{\lambda_0} \tag{2}$$

In this scenario, D = 22.86cm and the largest λ_0 tested was 30cm, yielding a radius of 34.8cm. The signal ranged from 890 MHz to 1 GHz, and at each tested frequency the power was varied from 0dBm to 20dBm. At 960 MHz center frequency, the measured efficiency and combined DC output voltage are shown in Fig. 3. To calculate the power density received by the rectenna, we first determine the received power using the Friis transmission equation, as

$$P_r = P_t G_t G_r (\frac{\lambda}{4\pi d})^2 \tag{3}$$

where P_t is the output power of the signal generator, G_t is the measured gain of the dipole antenna, G_r is the simulated gain of the rectenna (1 dBi), λ is the wavelength, and d is the distance (50 cm). Next, the RF power density is calculated by dividing the received power P_r by the area of the rectenna board. The prototype multifeed rectenna has a peak measured efficiency of 64.5% at an input power density of 2.3 μW/cm^2. The efficiency remains >60% when the power density is from 1.0 to 3.0 μW/cm^2. In addition, the rectenna prototype is able to output a high DC output voltage of 1.72 V at the peak efficiency.

These results show that a multifeed rectenna eliminates the lossy impedance matching network between the antenna and rectifier circuit by boosting the antenna impedance and better utilizes the rectifier efficiency curve to achieve high output DC and high efficiency simultaneously.

IV. FUTURE PLANS

My primary career goal is to work on electromagnetics related technologies to create products that can save lives. I find this work to be both intellectually stimulating and purposeful. In the future, I plan on continuing to do cutting edge research in this field and mentor others on how to do the same. Here, I would like to immensely express my gratitude to the MTT-S society for supporting me with this prestigious scholarship to work on this project. Since I was awarded the IEEE MTT-S Undergraduate Scholarship, I was able to publish a paper on my work at the IEEE Texas Microwave Symposium [3]. Furthermore, I have been accepted to the Ph.D. program in the Electrical Engineering and Computer Science Department at the Massachusetts Institute of Technology with a focus on computational imaging for biomedical appliactions.

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