Abstract

A novel compact rectenna with high sensitivity for low power has been designed, fabricated and tested. The proposed rectenna includes a 3D antenna design operating at the European Industrial Scientific Medical (ISM) 868 MHz frequency band. It includes a modified T-match antenna vertically connected to two metallic arms. An optimized differential rectifier was added to the antenna in order to form the rectenna with an overall size of 40 x 30 x 10 mm$^3$. The fabricated rectenna exhibits a harvested dc voltage of 155 mV and 740 mV (a RF to dc conversion efficiency 21 % and 44 %) across the load (10 kΩ) respectively with an illuminated power density of 0.1 µW/cm² and 1 µW/cm².

1 Introduction

The development of new wireless devices for Internet of Things (IoT) applications involves new challenges, including but not limited to self-powering capabilities [1]. Most IoT wireless devices use a battery as an energy source. The use of battery implies maintenance and environmental issues: the battery needs to be periodic replaced and recycled. In addition, batteries have important size and weight that are not compatible with IoT applications. One solution to dc-supply low-power wireless devices for IoT applications is to capture and convert the electromagnetic (EM) energy available into dc energy via Wireless Power Transmission (WPT) and Energy Harvesting (EH) approach. As well, a rectenna (rectifying antenna) was utilized in order to achieve this feature. In this work, a rectenna featuring characteristics such as sensitivity and compactness was developed as compact as possible. The prototyped design was fabricated on FR4 substrate (thickness of 0.8 mm, $\varepsilon_r = 4.3$).

2 Proposed 3D rectenna

As shown in Fig. 1, the WPT is based on rectifying EM Field emitted by a Radiofrequency (RF) source to a dc power. The rectenna optimized for low power RF signals was designed as compact as possible. The prototyped design was fabricated on FR4 substrate (thickness of 0.8 mm, $\varepsilon_r = 4.3$).

2.1. Full wave Rectifier design

![Figure 1. WPT diagram, electrical schematic and photo of the fabricated rectifier.](image)
Figure 2. Comparison between the measured (dashed line) and simulated (solid line) reflection coefficient for two RF power (-15 dBm and -20 dBm) at the input of the rectifier.

Figure 3. Measured and Simulated dc voltage as function of the RF power at the input of the rectifier at 868 MHz. A capacitor of 100 pF was chosen for C2 and C3. For accurate simulation results, the Spice model of the diode [6] and the parasitic model of the SOT-23 plastic diode package [7] were included in the ADS simulation model. The non-linearity of the Schottky diode trend to modify the input impedance of the rectifier as a function of the input power. The prototyped rectifier (photo in Fig. 1) exhibits a good impedance matching for various low levels of the RF input power (-20 and -15 dBm) as illustrated in Fig. 2. There is a frequency shift between simulation and measurement due to an inaccurate model of the inductor and the manufacturing/soldering effect on the prototype. Concerning the harvested voltage, the presented design can exhibit a dc voltage of 200 mV for a RF input power of -18 dBm. As depicted in Fig. 3, the measured dc voltage fit well with the simulated results (offset of only 24 mV) and a measured efficiency of 51 % for an input power of -5 dBm.

2.2. 3D Dipole Antenna

In terms of compactness, a dipole antenna (at 868MHz) in 3D configuration was preferred in this design. Two different antennas (A1 and A2) were designed. The first design consists of a folded dipole antenna (FDA) commonly known as a modified T-match antenna [8]. A1 has a spline shape with a T-section in the driven port and the width of the line was optimized in order to obtain a good impedance matching (S11 under -10 dBm). A1 antenna was designed to operate at 1.15GHz as seen in Fig.4 (a).

Figure 4: (a) Designed antennas on HFSS (A1: Flat FDA and A2: 3D FDA); (b) 3D polar plot of the radiation pattern of A2 antenna at the resonant frequency (HFSS results).

Figure 5. Measured (dashed line) and simulated (continuous line) reflection coefficient of the A1 (blue line) and A2 (red line) antennas.

Figure 6. Simulated (red dashed line) and measured (continuous blue line) radiation pattern (gain plot in the E-plane) for the A2 antenna at the resonant frequency (868 MHz).

Therefore, two vertical metallic arms connected to the antenna with a short transmission line to the edge of the PCB, was added (A2). The size of A2 (represented in Fig.4 (a)) is only 40 x 30 x 10 mm and a maximum gain of 1.1 dBi was obtained as presented in Fig. 4 (b). Due to the vertical capacitive arms, A2 antenna resonates at 878 MHz as shown in Fig. 5. The measured and simulated gain in the E-plane are shown in Fig.6.

3 Experimental results

The integration between the rectifier and the antenna was done on the same Printed Circuit Board (PCB) as seen in the inset of Fig.8, which allows having great RF to dc conversion efficiency without any soldering effect.
Table I. Comparison with the state of the art

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Frequency (GHz)</th>
<th>Diode</th>
<th>Input Power (dBm)</th>
<th>Incident power density S (µW/cm²)</th>
<th>Efficiency (%)</th>
<th>Antenna gain (dBi)</th>
<th>Rectenna size (mm x mm x mm)</th>
<th>dc Voltage (mV) / Load</th>
</tr>
</thead>
<tbody>
<tr>
<td>[10]</td>
<td>5.9</td>
<td>HSMS 286B</td>
<td>-10</td>
<td>22.5</td>
<td>NR</td>
<td>500 / 10 kΩ</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[11]</td>
<td>2.45</td>
<td>SMS7630</td>
<td>--</td>
<td>1</td>
<td>NR</td>
<td>NR</td>
<td>100 x 100</td>
<td>140 / 10 MΩ</td>
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<tr>
<td>[12]</td>
<td>2.4</td>
<td>SMS7630</td>
<td>--</td>
<td>1</td>
<td>NR</td>
<td>NR</td>
<td>72.9 x 72.9</td>
<td>150 / 5.1 kΩ</td>
</tr>
<tr>
<td>[13]</td>
<td>0.868</td>
<td>HSMS285B</td>
<td>-12</td>
<td>33</td>
<td>1.43</td>
<td>24.4 x 24.4 x 29.85</td>
<td>(0.000433 m²)</td>
<td>310 / 2.193 kΩ</td>
</tr>
<tr>
<td>This work</td>
<td>0.868</td>
<td>SMS7630-005LF</td>
<td>--</td>
<td>44</td>
<td>Efficiency</td>
<td>40 x 30 x 10</td>
<td>(0.00029 m³)</td>
<td>740 / 10 kΩ</td>
</tr>
</tbody>
</table>

NR: Non reported

The measurement setup placed in an anechoic chamber contains a Patch antenna (gain $G_t$ of 9.44 dBi) connected to the RF signal generator (with RF output power $P_t$). It radiates an EM Field to the rectenna under test (distanced of 1.5 m, in the far-field region of the transmitting patch antenna).

4 Conclusion

A compact and sensitive rectenna is proposed in this paper with a size of 40 x 30 x 10 mm³. The proposed design combines a modified T-match antenna in 3D configuration and an optimized rectifier for low RF power levels (under -5 dBm). The experimental results confirm that the proposed 3D antenna (of the rectenna) exhibits a gain of 1.1 dBi in the operating frequency band (between 863 MHz and 889 MHz). The fabricated rectenna harvest a maximum dc voltage of 468 mV and an efficiency of 36% with a power density of 0.44 µW/cm² across a load of 10kΩ at 868 MHz.

5 References


