Yagi Rectenna Application to Increase the Battery Lifetime of Sensor Nodes

R. Fernández-García and I. Gil
Departmentof Electronic Engineering, Universitat Politècnica de Catalunya
08222 Colom 1, Terrassa, Spain

Abstract— In this paper a Yagi rectenna application to increase the battery lifetime of sensor nodes is presented. The proposed rectenna consists of a three pole Yagi antenna plus double voltage RF to DC converter based on a HSMS-268C Schottky diode. The rectenna has been designed by means of the commercial *SEMCAD software*. The measurement results demonstrate a maximum RF-DC efficiency of about 31% for 160 μW/cm^2.

1. INTRODUCTION

In the last years a massive increase of the use of wireless communications has been produced in industrial and domestic applications. Specifically, one of the latest applications of the wireless communication is the Wireless Sensor Networks (WSNs) [1]. The WSNs consist of small communication nodes. These nodes contain a sensing part, a microcontroller, communication components and power supply (typically a battery). Moreover, these nodes should fulfil restrictions of low-cost and low-power consumption to guarantee its usefulness. In this sense, the RF energy-harvesting technology can help to increase the battery lifetime of the sensor nodes and, in some cases, even to avoid using the battery [2]. The main RF energy harvesting element is the rectenna, which consists of an antenna plus a rectifier to convert the RF signal to DC voltage. Several rectennas have been proposed in literature. In [3] a narrowband rectenna to harvest the UHF RFID energy is presented. The achieved conversion efficiency is 54% when the incident power density is 80 μW/cm^2. In [4] a X-band rectenna is reported showing a conversion efficiency of 21% for a 245 μW/cm^2 power density. In [5] a dual band planar inverter F rectenna is proposed, and a conversion efficiency of 47.3% and 49.1% is obtained for 2.45 GHz and 5.8 GHz under 11 and 9 dBm, respectively. In [6] a 4×4 rectenna array for 35 GHz is developed. In this case a RF to DC conversion efficiency of 67% is achieved for 7 mW RF input power.

In this work, an alternative Yagi rectenna application to increase the battery lifetime of sensor nodes is proposed. The rectenna is designed at 1.8 GHz band, which is one of the main radiation bands due to GSM communications. This paper is organized as follows. In Section 2, the proposed rectenna and simulation results are detailed. The experimental results are reported and discussed in Section 3. Finally, in Section 4, the main conclusions are summarized.

2. PROPOSED RECTENNA AND SIMULATION RESULTS

2.1. Antenna

Figure 1 shows the proposed Yagi antenna implemented in a commercial FR4 substrate (dielectric constant $\varepsilon_r = 4.6$, thickness $h = 1.53$ mm). The antenna consists of a dipole radiating element. One arm of the dipole is located in the bottom PCB layer, meanwhile the other one is located in the top layer. This layer also includes three pole directors in the front of the dipole. The reflector in located in the bottom layer. The antenna has been designed and optimized by means of the commercial *SEMCAD X 14.8 software* [7]. The optimized antenna dimensions are shown in Figure 1.

Figure 2 plots the simulated antenna performance. It can be noticed a return losses lower that -10 dB in the frequency range [1.71 GHz to 1.93 GHz], corresponding to bandwidth of 220 MHz. In this frequency range, the antenna gain increases from 8.74 dBi to 10.7 dBi.

The simulated radiation pattern of the proposed Yagi antenna is plotted in Figure 3 in 3D and polar view at the maximum gain frequency (1.93 GHz). The figure indicates a half-power beamwidth (HPBW) of 48 degrees and 60 degrees for XY and ZY plane respectively.

2.2. RF-DC Converter

The RF to DC converter consists of a voltage double converter based on HSMS-268C Schottky diodes. The lumped-element and prototype photograph is given in Figure 4. In order to consider all the printed circuit board (PCB) parasitic effects, a cosimulation using the commercial *Keysight*

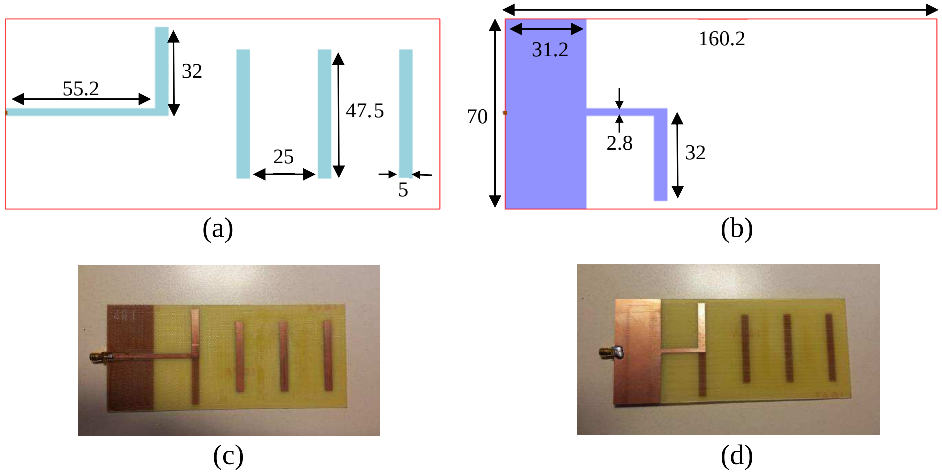

Figure 1: Geometry (in mm) and photograph of the proposed Yagi antenna. (a) Geometry top layer. (b) Geometry bottom layer. (c) Photograph top layer. (d) Photograph bottom layer.

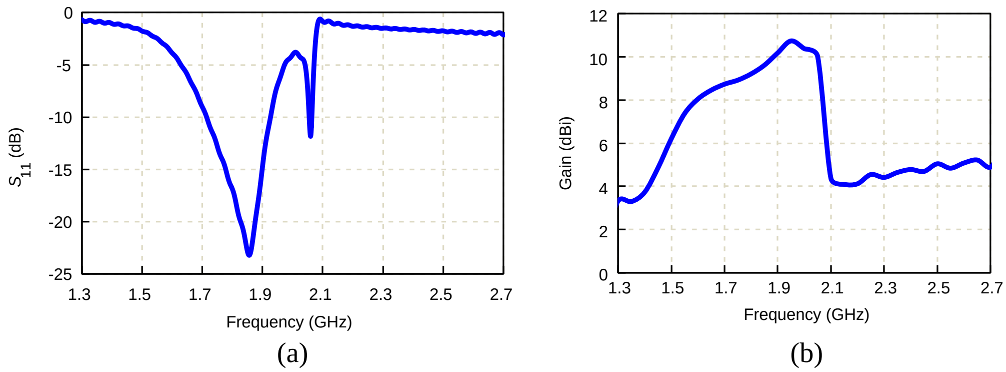

Figure 2: Simulated Yagi antenna performance. (a) Return losses. (b) Gain.

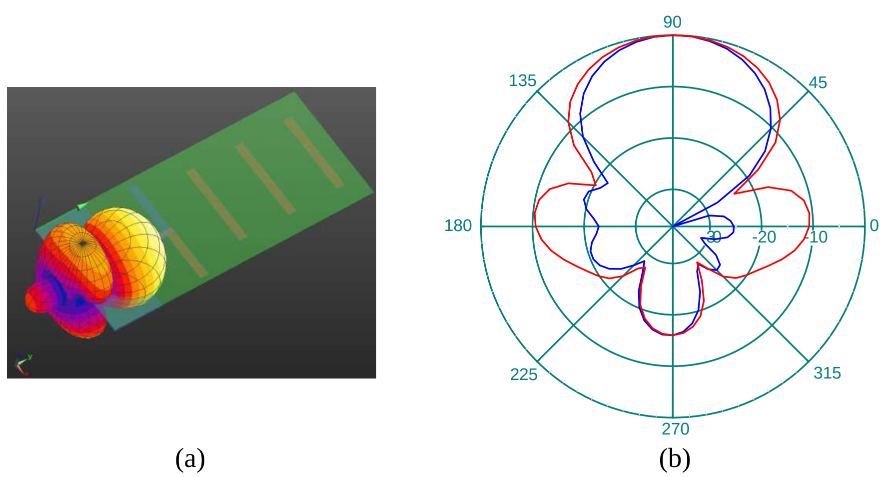

Figure 3: Simulated antenna radiation diagram. (a) 3D view. (b) Normalized polar view in dB.

ADS software has been done. Moreover, the parasitic impedances of the Schottky diodes HSMS-268C packed SOT-323 have been also included. Taking into account all these effects, a LC matching network with 2.2 nH and 8.2 pF is used to match the antenna and the RF-DC converter at the operation frequency. The load impedance has been fitted in order to obtain the maximum conversion efficiency. The simulation results denote that the optimum value is 2.2 kΩ.

3. EXPERIMETAL RESULTS

The S-parameters of the prototype shown in Figure 1 have been measured by means of a *Keysight FieldFox N9916A Microwave Analyzer* by selecting the vector network analyser mode. The return

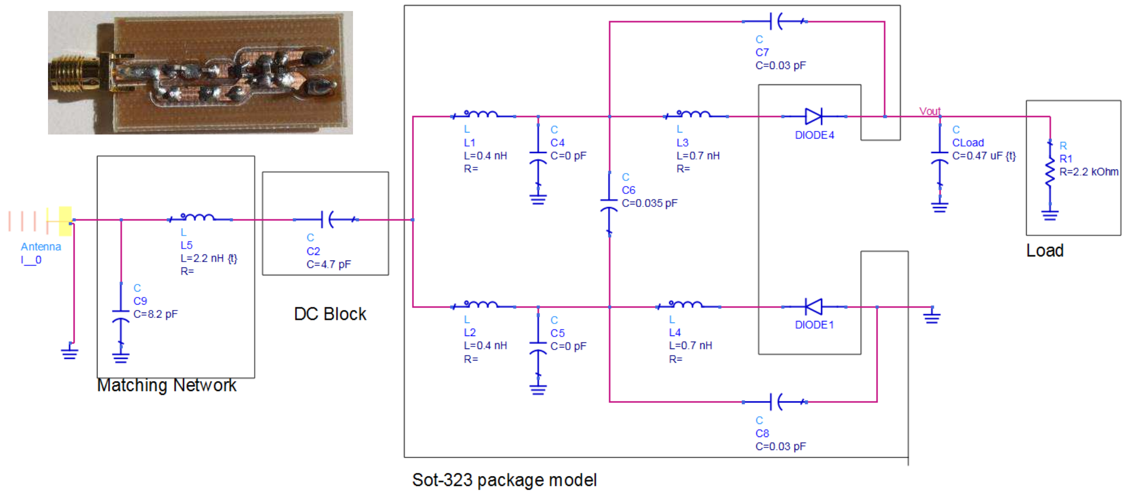

Figure 4: Schematic and photograph of DC-RF converter.

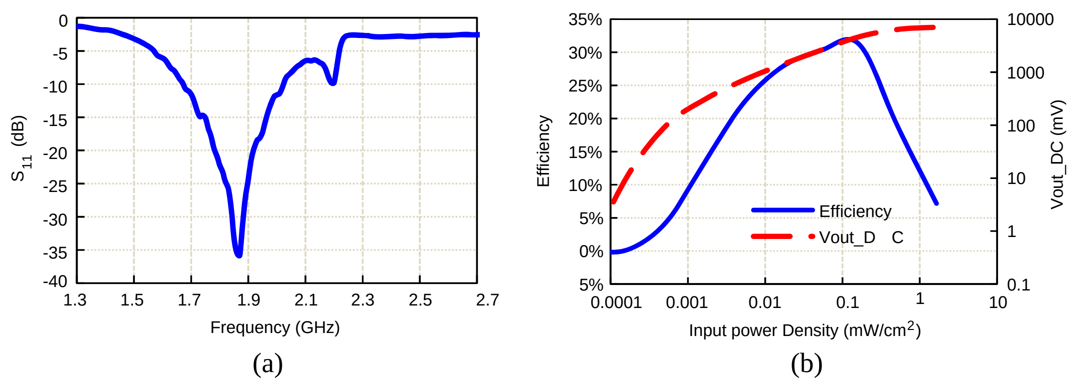

Figure 5: Measured rectenna properties. (a) Return loss. (b) Efficiency and DC output voltage.

losses of the designed Yagi antenna are depicted in Figure 5(a). It can be observed a return loss coefficient lower than -10dB in the frequency range [1.68 GHz, 2.02 GHz]. It confirms a good correlation between simulation and measurement results.

In order to obtain the RF- DC conversion efficiency, the Expression (1) has been used.

$$\eta = \frac{P_{DC}}{P_{RF}} = \frac{V_{out}^2/R_L}{\wp_{in} A_{eff}} \tag{1}$$

where $\wp_{in}$ is the incident power density, R_L is the resistive load (2.2 kΩ), V_{out}, is the DC output voltage and A_{eff} the effective area of antenna, determined by means of Expression (2).

$$A_{eff} = \left(\frac{\lambda_o^2}{4\pi}\right) G_{ant} \tag{2}$$

where λ_0 is the free space wavelength and G_{ant} is the antenna gain depicted in Figure 2(b). In Figure 5(b), the RF-DC efficiency and output voltage at 1.85 GHz are shown. It can be noticed a maximum efficiency of about 31% when the input power density is 160 μW/cm^2. In this case, the measured DC output voltage is 4.6 V for a load impedance of 2.2 kΩ.

4. CONCLUSIONS

In this paper, a Yagi rectenna has been presented. The rectenna consists of three element Yagi antenna plus a voltage double RF-DC converter base on HSMSC-286C. The measurement results show a maximum efficiency of 31% and output DC voltage of 4.6 V for 160 μW/cm^2 power density. These results show the feasibility of RF energy harvesting as an alternative method to increase the battery life time of the wireless sensor nodes.

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