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900 MHz Miniaturized Rectenna

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***Abstract*—This paper addresses the design and the characterization of a new topology of compact rectenna used for electromagnetic energy harvesting of low incident electromagnetic power densities. The rectenna uses a broadband miniaturized flat dipole antenna with a single diode rectifier. The experimental results demonstrate that the efficiency of the proposed compact rectenna is up to 38% at 900MHz for electromagnetic power density of 0.26µW/cm².**

***Index Terms*—energy harvesting, rectenna, wireless power transmission, flat dipole antenna.**

I. INTRODUCTION

Recently, Wireless Power Transfer (WPT) and electromagnetic Energy Harvesting (EH) have become an attractive solution for many industrial applications. The 3D indoor localization is one of these key applications. Nowadays, the 3D localization systems use batteryless tags and beacons in order to derive the position of tagged objects in a warehouse. Batteryless tags collect the power from the surrounding electromagnetic field generated by radiofrequency (RF) dedicated sources. Once enough power is harvested, tags wirelessly transmit their positions to beacons. The beacons communicate with each other through RF signals allowing the system to locate the objects. The RF sources generate the ambient electric field in the 868MHz - 915MHz ISM frequency band. A compact rectenna composed of a Flat Dipole Antenna surrounded by a rectangular metallic ring and a rectifier with a single diode is used here to harvest the ambient electromagnetic energy in order to supply the batteryless tags.

In this paper, the broadband Flat Dipole Antenna is presented in section II while the rectifier is studied in section III. The compact rectenna is detailed in the section IV and obtained experimental results are finally discussed.

II. ANTENNA DESIGN AND RESULTS

A. Flat Dipole (FD) Antenna

Recently, broadband dipole antenna topologies have been reported for electromagnetic energy harvesting [1]–[2]. The Flat Dipole shape is carried out by changing the geometry of a standard printed half-wavelength dipole. It is obtained by giving a round shape to the two constitutive quarter-wavelength monopoles, as illustrated in Fig. 1. Contrary to the standard dipole where the current density flows along the dipole axis, the current in the shaped dipole flows by following different paths. As sketched in Fig. 1, the current density Js2 goes through a longer path than Js1. As a result, for the same physical length, the lower operating frequency of the antenna is smaller than one of the standard dipole and the antenna bandwidth is increased. In this work, the designed antenna covers the 868MHz-915MHz ISM frequency band. It was rigorously simulated by using the commercial software HFSS [3].

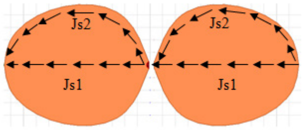

Fig. 1. Sketch of two paths of the current density on the radiating surface of the Flat Dipole Antenna

B. Miniaturization of the Flat Dipole Antrenna

The miniaturization of antennas can be performed from the use of dielectrics [4], magnetic materials [4], or metamaterials [5]. The modification of the antenna geometry may also be applied (see, e.g., by loading the radiating surface by slit [6], by designing highly irregular antenna profiles [7] or by using coupled ring resonators [8]). The miniaturization of the Flat Dipole Antenna (FDA) is performed here by adding a metallic rectangular ring around the antenna, as shown in Fig. 2. This allows reducing the physical length of the antenna of 25% while keeping the gain unchanged. Indeed, from appropriate design, the ring may favorably participate to the radiating field by increasing the antenna gain.

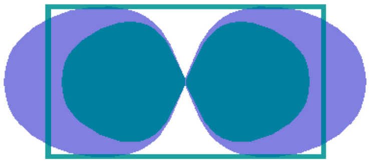

Fig. 2. Layout of the FDAs without rectangular metallic ring (purple) and with the rectangular ring (turquoise blue). The two antennas share the same lower frequency and gain.

The antenna is fabricated by using the lossy FR4 substrate (substrate thickness: 0.8mm, relative permittivity: 4.4 and loss tangent: 0.02). The size is of 10.5 x 6 cm². Fig. 3 displays the return loss with and without the rectangular ring. As expected, the ring allows increasing the antenna bandwidth and reducing the physical length of the antenna. The impedance matching is achieved between 840 MHz and 1.2 GHz. The radiation pattern is similar to one of the standard half-wavelength dipole with a maximum simulated gain of 2.8 dBi at 900 MHz (see Fig. 4).

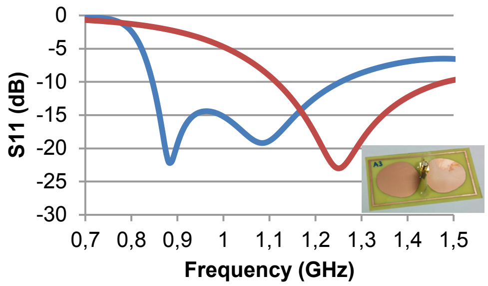

Fig. 3. Simulated return loss as a function of the frequency for the FDA without rectangular ring (red plot) and with rectangular ring (blue plot)

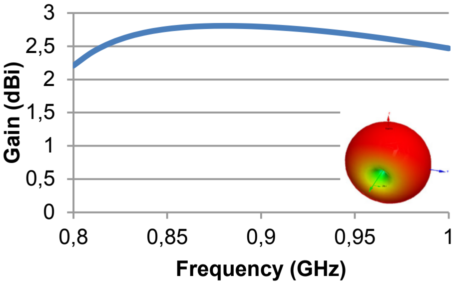

Fig. 4. Simulated maximum gain of the FDA with the rectangular ring as a function of the frequency for θ=0° and φ=0°.

III. RECTIFIER DESIGN AND RESULTS

The rectifier was simulated using the commercial software ADS. It is composed by the HSMS2850 Schottky diode mounted in series configuration, a low-pass filter (100pF capacitor) used for the filtering of the fundamental and the harmonics and, an adjustable resistive load (0 - 10kΩ potentiometer). The impedance matching circuit is composed of a short-circuited stub bent, and a 30 nH inductance for matching the input impedance of the rectifier at 900 MHz. Fig. 5 displays the simulated return loss of the rectifier. A good input matching is obtained between 860 MHz and 910 MHz.

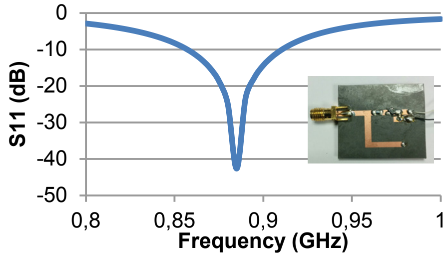

Fig. 5. Simulated return loss of the rectifier as a function of the frequency

The measured DC power is reported in Fig. 6 as a function of the frequency. The DC power of 12 µW is measured at 880 MHz with the 5 kΩ load (optimal load) and the input RF power of -15 dBm. An acceptable agreement is observed between simulation and measurement results.

The RF-to-DC conversion efficiency can be derived from the following expression:

$$\eta(\%) = 100 \cdot \frac{P_{DC}}{P_{RF}} \quad (1)$$

where P_{DC} is the measured DC power and P_{RF} denotes the RF power injected at the rectifier input port. The measured and simulated efficiencies are reported in Fig. 7. The obtained maximum efficiency is of 38.6 % at 880 MHz.

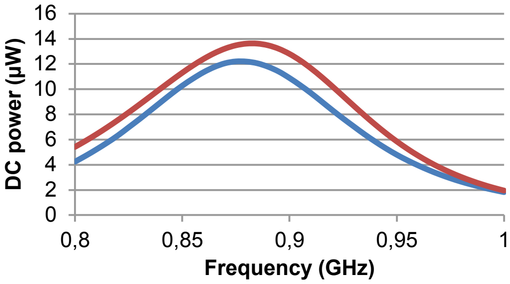

Fig. 6. Measured (blue plot) and simulated (red plot) harvested DC powers as a function of the frequency.

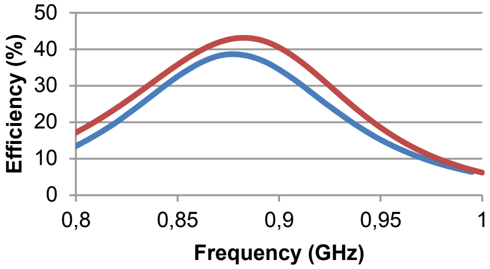

Fig. 7. Measured (blue plot) and simulated (red plot) efficiencies of the rectifier as a function of the frequency

IV. RECTENNA: FABRICATION AND MEASUREMENT RESULTS

As a first step, the rectifier and the tapered transition for feeding the antenna are assembled and fabricated on the same substrate (Duroïd 5870). The resulting 3D antenna is shown in Fig. 8. Its size is about 10.5 x 6 x 7 cm^3.

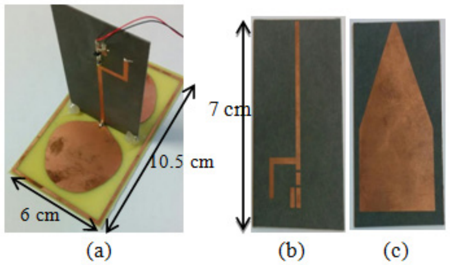

Fig. 8. The fabricated rectennas: (a) the 3D view of the rectenna (b) top view of the rectifier before mounting the lumped components and (c) bottom view of the rectifier

The experimental setup is shown in Fig. 9. The Anritsu MG3694B microwave generator is used for injecting the RF signal at the input of the transmitting (Tx) horn antenna (1–12 GHz) via a coaxial cable. The horn antenna illuminates the rectenna under test with a linearly-polarized E-field. An automatic acquisition routine is implemented in Labview software from National Instruments to speed-up the acquisition process. The harvested DC voltage is measured by using a standard DC multimeter. The DC power can be derived from the measured DC voltage as long as the load impedance is known. The measured insertion losses due to the coaxial cable are of 1dB in the entire frequency band of interest.

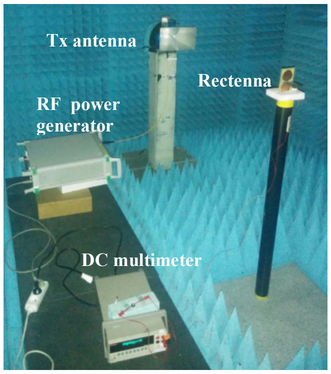

Fig. 9. Experimental setup used to characterize the rectenna

The efficiency of the rectenna can be derived from the following definition:

$$\eta = \frac{P_{DC}}{S.A_{eff}} \cdot 10 = \frac{4.\pi.P_{DC}}{S.G_R.\lambda^2} \cdot 100 \qquad (2)$$

where P_{DC} is the harvested DC power, S is the incident RF power density, A_{eff} is the antenna effective area, G_R is the gain of the rectenna's radiating element, and λ is the free-space wavelength at the operating frequency. The RF power density (μW/cm2) can be determined from the E-field root mean square (rms) value E(V/m) on the antenna surface. This field is computed from the RF power Pt injected to the input of the transmitting horn antenna of gain G_t located at the distance d from the rectenna. Consequently, the RF power density at the rectenna location is given by:

$$S = \frac{E^2}{120.\pi} \cdot 10 = \frac{30.P_t.G_t}{d^2.120.\pi} \cdot 100 \qquad (3)$$

Fig. 10 shows the measured harvested DC power at the input port of the resistive load (RL = 5 kΩ) between 800MHz and 1 GHz for an incident power density ranging from 0.25 μW/cm² to 0.6 μW/cm². The DC power of 32.6 μW is measured at 900 MHz for the incident RF power density of 0.52 μW/cm².

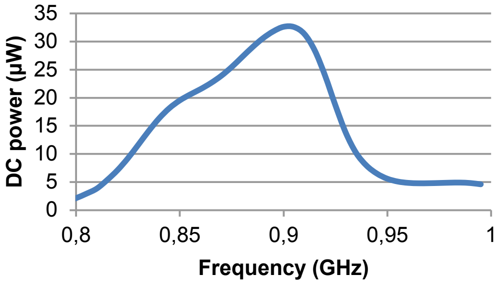

Fig. 10. Measured DC power at the input port of the resistive load (RL=300Ω) as a function of the frequency

The optimal load impedance was also experimentally determined. Fig. 11 shows the DC harvested power as a function of the resistive load value at 900 MHz. It can be observed that the maximum DC power is obtained for R=5 kΩ.

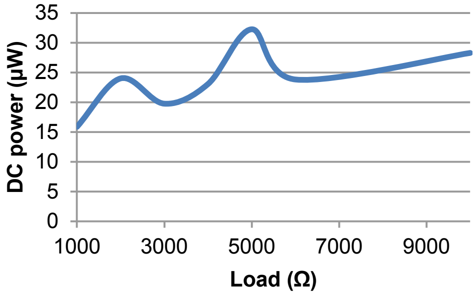

Fig. 11. Measured DC power harvested by the rectenna as a function of the resistive load value at 900 MHz

The conversion efficiency of the rectenna is derived from (2). Fig. 12 depicts the RF-to-DC conversion efficiency as a function of the RF power density illuminating the rectenna under test. The efficiency exceeds 30% for low input RF power densities and reaches 47% for a power density of 2.1 μW /cm².

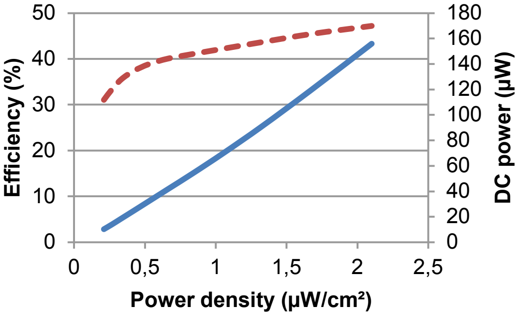

Fig. 12. Rectenna efficiency (red dashed line) at 900 MHz and the harvested DC power (blue continuous line) as a function of illuminating RF power density

Using the load impedance of 10 kΩ, the harvested DC voltage exceeds 330mV (see Fig. 13) when the RF power density is at least of 0.25μW/cm² or equivalently, if the RF input power is higher than -14dBm at the rectifier input. Consequently, the proposed rectenna may power-up the BQ25504 DC-DC boost converter [9].

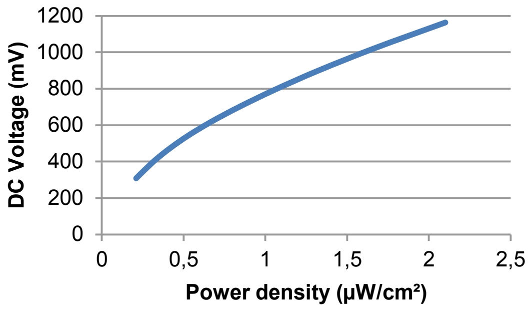

Fig. 13. Harvested DC voltage as a function of the incident RF power density with the load of 10kΩ

The Table I summarize key performances of the proposed FDA rectenna and of state-of-the-art rectennas operating at the same frequency. It can be observed that the FDA rectenna is the most compact while having a good efficiency for low incident RF power densities. Hence, it is a good candidate for achieving the best trade-off between compactness and efficiency.

TABLE I

KEY PERFORMANCES OF THE PROPOSED FD RECTENNA AND OF STATE-OF-THE-ART RECTENNAS OPERATING IN THE SAME FREQUENCY BAND

Ref	Freq (GHz)	PRF(dBm) S(µW/cm²)	η(%)	Antenna surface
[10]	0.915 2.45	1µW/cm²	37%	6 x 6 cm² $0.33\lambda_0^2$
[11]	0.9	10dBm	33%	NR
[12]	0.868	-20dBm	20%	NR
[13]	0.9	0.1µW/cm² 1µW/cm²	16% 40%	11 x 11 cm² $0.11\lambda_0^2$
In this work	**0.9**	**0.21µW/cm²** **1µW/cm²**	**31%** **42%**	**11 x 6 cm²** $\mathbf{0.05\lambda_0^2}$

NR : Non Reported

V. CONCLUSION

In this paper, a new rectenna based on a miniaturized Flat Dipole Antenna ($0.05\lambda 0^2$) is proposed. The miniaturization was performed by using a properly designed rectangular metallic ring. The measured efficiency of the fabricated rectenna exceeds 30% for a RF power density of 0.21 µW/cm² and reaches 47% for 2.1 µW /cm². Moreover, the rectenna may be used for powering-up a DC-DC boost converter for industrial applications.

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