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Cross dipole rectennas for satellite health monitoring

A. Okba*[*]*, S. Charlot*[*]*, P-F Calmon*[*]*, A. Takacs*[*]*, H. Aubert*[*]

**LAAS-CNRS, Université de Toulouse, CNRS, INSA, UPS, Toulouse, France*

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Abstract

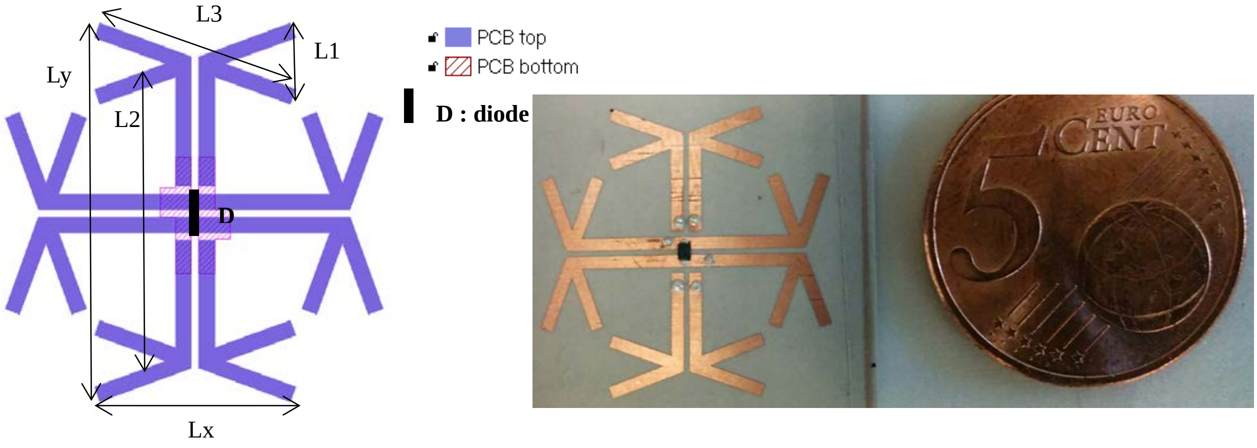
This paper addresses recent results obtained by using cross dipole rectennas designed for Ku band. The targeted application is the harvesting of the spill-over losses of microwave antennas in order to power autonomous wireless sensors used for satellite health monitoring.

Introduction

Recently, the harvesting of the spill-over losses of the microwave antennas was identified as a realistic solution to power autonomous wireless sensors for health monitoring of the antenna panels of the broadcasting satellites [1]. The electromagnetic power radiated by microwave antennas is almost constant and consequently the DC power regulatory circuits should be minimal for the harvesting systems/rectennas. Nevertheless the rectenna should be compact, energetically efficient and robust. Moreover it should be as simple as possible and compatible with space design requirements in terms of thermal, mechanical and radiation safety/immunity behavior. This paper presents recent results obtained in Ku band by using an innovative rectenna topology based on a compact printed cross dipole antenna array and low cost Schottky diode.

1. Topology

The proposed topology is composed by: four cross dipoles array (4CDAA) and a silicon Schottky diode – Skyworks SMS7630 [2]. The PCB layout and a photo of the manufactured rectenna is shown in Fig. 1. The antenna array and the diode are mounted on the top of the PCB while the RF shunt capacitor is mounted on the bottom side of PCB. A reflector metallic plate is added on the bottom side in order to improve the antenna gain. This compact topology (its size is fixed by the size of the antenna array) is an extension of a rectenna using two cross dipole antenna array 2CDAA presented in [3] and a non-resonant matching technique is used. This non-resonant matching is obtained by properly controlling (i) the input impedance of the antenna array and (ii) the input impedance of the rectifier itself (composed by the diode and the low pass RC filter implemented by using the shunt capacitor and the load).

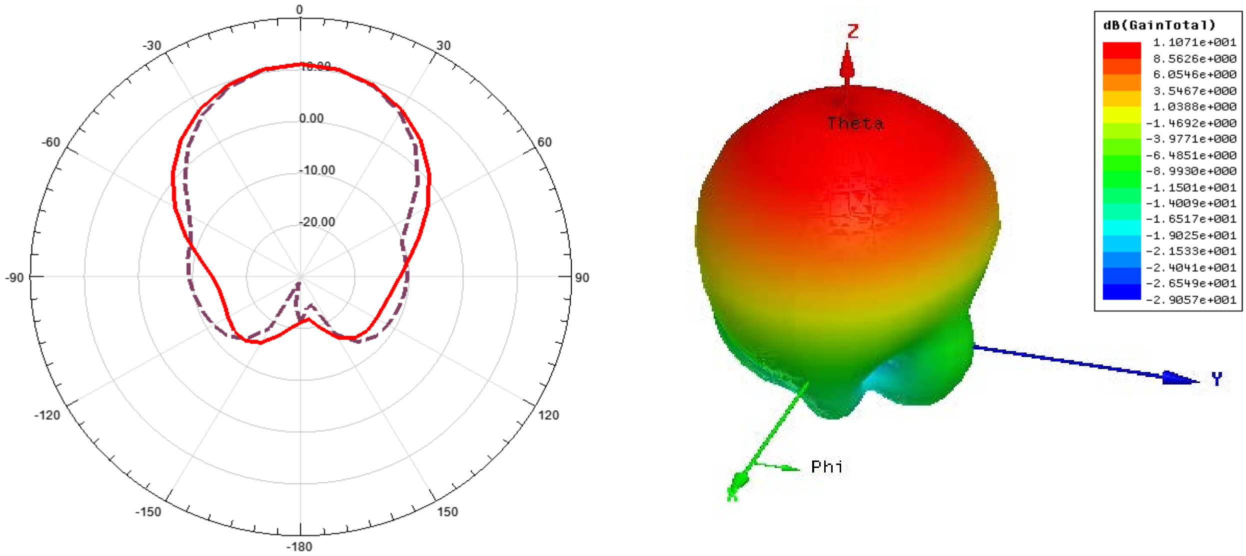


(a) (b)

Fig. 1. (a) Top view (not to scale) of the layout of the 4CDAA rectenna its main geometrical dimensions and (b) a photo of the manufactured rectenna

2. Design and Results

First, the cross dipole antenna was designed and optimized under HFSS software. Six via holes were used (as shown in Fig. 1) in order to connect the top and the bottom part of the PCB. The bottom side of the PCB (used to interconnect the cross dipole antennas and for the mounting of the RF shunt capacitor) was taken into account in the HFSS simulation model. The designed antenna was not measured separately. As shown in Fig. 1, the appropriate feed technique for such an array is based on the use of coplanar striplines. Consequently a complex transition between the coplanar stripline and a coaxial connector has to be designed and implemented before measuring such an antenna in a standard anechoic chamber. The simulated gain (maximum gain: 11dBi) obtained for the 4CDAA at the targeted operating frequency (12 GHz) as well as the 3D radiation pattern are shown in Fig. 2.



a) **b)**

Fig. 2. Simulated gain (HFSS) in the xOz plane (phi=0°, red continous line) and in the xOy plane (phi=90°, black dashed-line of the 4CDAA) at the frequency of 12 GHz.

Second, a generic electrical diode model existing in the ADS software was customized with the following parameters: ohmic resistance R_s = 20Ω, junction capacitance C_{j0} = 0.14 pF, saturation current I_s = 5 µA, forward voltage V_f= 0.34V, reverse breakdown voltage B_v = 2V and the current at reverse breakdown voltage I_{bv}= 0.1mA. This model allows performing an initial design of the PCB bottom side.

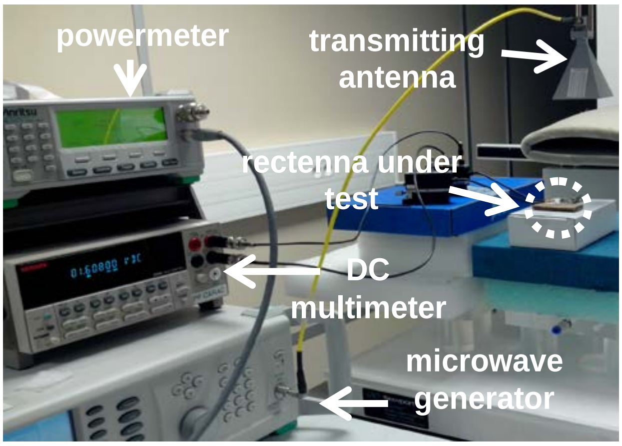
The experimental setup shown in the Fig. 3 was used to characterize the rectenna. A microwave signal generated from an Anritsu MG3694B generator was injected at the input of a horn antenna which illuminated the rectenna under test with a linear polarized E-field. An automatic acquisition routine was implemented in Labview software from National Instruments to speed-up the acquisition process. The harvested DC voltage was measured by using a DC multimeter. The DC power can be computed from the measured DC voltage as long as the load is known. The measured losses due to the coaxial cable and connectors between antenna and the signal generator were in the range of 3 dB in the operating frequency band. The main dimensions of the fabricated rectenna are: L1= 4 mm, L2= 15.3 mm, L3= 10.6 mm, Lx= 10 mm, Ly= 19.5 mm.
The efficiency η (in %) of the rectenna can be computed by using the following definition [4]:

$$\eta = \frac{P_{DC}}{S \cdot A_{eff}} \cdot 100 = \frac{4 \cdot \pi \cdot P_{DC}}{S \cdot G_R \cdot \lambda^2} \cdot 100 \qquad (1)$$

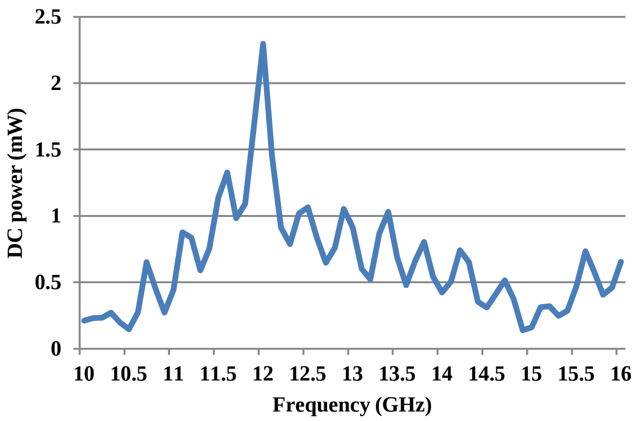
where P_{DC} is the harvested DC power, S is the incident electromagnetic power density, A_{eff} is the antenna effective area, G_R is the gain of the (rectenna's) antenna and λ is the wavelength of the illuminating electromagnetic wave. The power density (µW/cm^2) can be computed as a function of E-field effective value E (V/m) on the antenna surface or as a function of the RF power P_t injected to the input of the transmitting horn antenna of gain G_t and positioned at the distance *d* from the rectenna, as follows:

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

The experimenal results obtained as function of frequency are reported in Fig. 2 for an optimal load RL=300Ω (this is the optimal load for 2CDAA rectenna). The following configuration was used : d=21 cm, G_t=19 dBi, power delivered by the microwave generator: 22 dBm and the injected power at the input of the transmitting horn antenna: 19 dBm. The simulated (by using HFSS software) gain of the receiving antenna (4CDAA) was G_R=11 dBi. The maximum DC power (2.3 mW) was obtained at 12 GHz for RL=300Ω. By using equation (1) and (2) we obtain : E~65.5 V/m, S~1138 µW/cm^2 and the efficiency of the rectenna is 32% at 12GHz.



(a)



(b)

Fig. 3. (a) Experimental setup used to characterize the rectenna and, (b) Measured DC power on a load of 300 Ω as function of frequency.

3. Conclusion

A rectenna based on the use of four cross dipoles antenna array was designed, manufactured and measured. The experimental results demonstrate that a DC power of 2.3 mW can be obtained if the rectenna is illuminated by an electromagnetic field of E=65.5 V/m. This DC power is sufficient to power a wireless sensor (including the sensing device, the power management unit and the wireless tranceiver) for satellite health monitoring application.

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