Optimized Design of Multiband and Solar Rectennas

K. Niotaki[1], S. Kim[2], F. Giuppi[1], A. Collado[1], A. Georgiadis[1], M.M. Tentzeris[2]

[1]Centre Tecnologic de Telecomunicacions de Catalunya (CTTC), Castelldefels, 08860, Spain

[2]Georgia Institute of Technology, Atlanta, GA, 30332-250, USA

***Abstract* — This paper presents several designs of multiband and solar rectennas. The procedure in order to perform multiband optimization of rectenna elements is presented and two design examples of 850 MHz/1850MHz and 915MHz/2.45GHz dual band rectennas are discussed. Additionally, two designs of compact solar rectennas where the solar cells share the area of the radiating element in the rectenna structure are shown one of them operating in the 850 MHz/1850MHz bands and the other at 2.45 GHz.**

***Index Terms* — rectenna, solar, energy harvesting.**

I. Introduction

Due to the increasing demand of devices with autonomy in order to make viable the Internet of Things concept, where a large amount of sensors and devices are deployed, energy harvesting solutions appear as a potential solution to the issue of self-sustainability of these devices [1,2].

As the amount of available energy from electromagnetic sources is limited, the possibility of being able to harvest from several frequency bands simultaneously or to harvest from several energy sources is a desirable feature.

Several works have previously considered multiband rectenna designs [3,4] where energy can be harvested from more than one frequency band. Also solar rectennas were proposed [3-6] in order to harvest both from electromagnetic and solar energy. These works manage to obtain a compact hybrid harvester by placing the solar cells on the surface of the antenna element of the rectenna.

Here, in Section II, a methodology to perform optimized design of multiband rectennas is introduced where harmonic balance optimization is used in combination with optimization goals to maximize the RF to DC conversion efficiency. Additioanlly, two design examples of dual band rectennas are discussed. In Section III, two solar rectennas designs are presented.

II. Multiband Rectennas

The design of a multiband rectenna, requires to take into account several factors, such as that the rectifying device has to operate with a certain RF to DC conversion efficiency in two frequency bands, that the radiating element has to be able to capture signals in more than one frequency band and also that the power transfer from the antenna to the rectifier has to be maximum at two frequencies.

In order to achieve maximum power transfer at two frequencies a dual band matching network has to be used between the antenna and the rectifier circuit. The dual band operation of the antenna can be achieved be selecting dual band or even broadband antenna designs. Maximizing the RF to DC conversion efficiency at two frequency bands is achieved by using an optimization algorithm with goals at the two frequencies of interest.

A. Multiband Rectenna Optimization

The multiband optimization of the rectenna can be performed using harmonic balance in combination with optimization goals on the RF to DC conversion efficiency of the rectifier circuit (η). The matching network parameters (λ_i) as well as the rectifier load R_L are optimized to full fill these goals (1).

$$\begin{aligned} \boldsymbol{\eta}_{RF-DC@f_1}(\lambda i) &> \boldsymbol{\eta}_1 \\ \boldsymbol{\eta}_{RF-DC@f_2}(\lambda i) &> \boldsymbol{\eta}_2 \end{aligned} \tag{1}$$

In order to perform this optimization the Thevenin equivalent of the antenna in the receiving mode is used, where the antenna is represented by its impedance in the transmitting mode and a voltage source whose value is obtained by using reciprocity theory [7].

B. 850 MHz / 1850 MHz Dual Band Rectenna

A dual band rectenna covering the GSM-850 and GSM-1850 frequency bands was designed in an Akaflex PCL3-35/75 μm substrate with ε_r = 3.3 and tanδ = 0.08. The selected antenna topology was a broadband monopole antenna that covers the 0.7GHz - 6 GHz frequency band so it can be used for the dual band rectenna design.

The selected rectifying element was a silicon Schottky diode (Skyworks SMS7630). The matching network was a coplanar waveguide structure optimized to maximize the RF to DC conversion efficiency of the rectifier at 850 MHz and 1850 MHz. The optimization was performed for low input power levels in the order of -20dBm. The resulting design is shown in Fig.1a. The optimum load value obtained after the optimization was R_L=2.2 kOhm. The results in terms of RF to DC conversion efficiency are shown in Fig.2 where it can be seen that the efficiency has two maximums around the desired frequencies of operation.

Fig. 1 Photo of the implemented rectennas (a) dual band rectenna 850 MHz / 1850 MHz. (b) dual band solar rectenna 850 MHz / 1850 MHz.

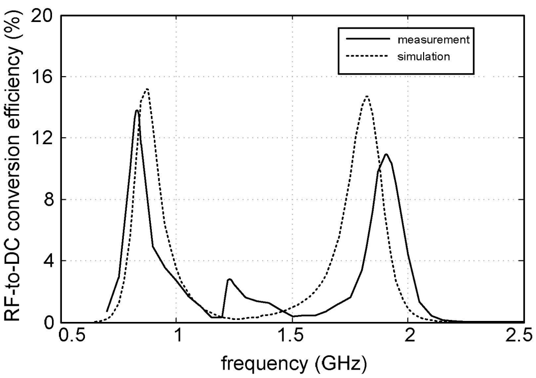

Fig.2 RF to DC conversion efficiency of the dual band rectenna 850 MHz / 1850 MHz.

C. 915 MHz / 2.45 GHz Dual Band Rectenna

The selected antenna topology was a slot-loaded dual band folded dipole antenna. A half-wavelength ($\lambda_0/2$) dipole antenna at 915 MHz was folded to miniaturize the antenna and a slot was placed in the middle of the antenna to introduce a second resonance at 2.45 GHz. It was fabricated on 0.76 mm thickness Arlon 25N with $\varepsilon_r = 3.38$ and $\tan\delta = 0.0027$ (Fig.3). The selected rectifying device for the rectenna element was the low threshold voltage Schottky diode SMS7630 and the rectifier topology was an envelope detector.

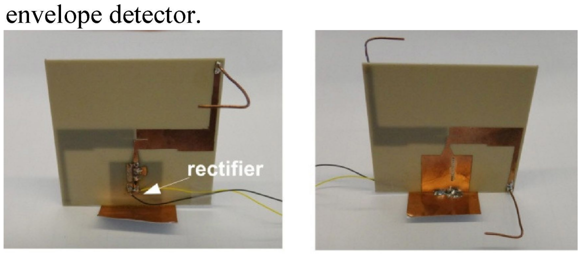

Fig. 3 Photo of the implemented dual band rectenna 915 MHz / 2.45 GHz

In this case, an LC matching network was used to maximize the power transfer from the antenna to the rectifier circuit. An optimization procedure was used to maximize efficiency at 915 MHz and 2.45 GHz for input power levels around -9 dBm. The performance of the dual band rectenna for this input power level is shown in Fig.4.

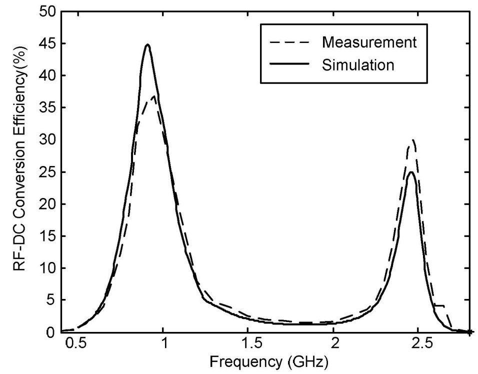

Fig. 4 RF to DC conversion efficiency of the dual band rectenna at 915 MHz/2.45 GHz.

III. SOLAR RECTENNAS

Solar rectennas can be used as hybrid harvesters that can harvest both solar and electromagnetic energy. By properly combining the outputs of the solar cells used and of the rectenna element, it is possible to combined the obtained DC power from both types of energy sources. One of the main challenges in solar rectenna design is to minimize the size of the structure. In the proposed designs the solar cells are integrated on the surface of the antenna element sharing the same area, thus creating a compact structure.

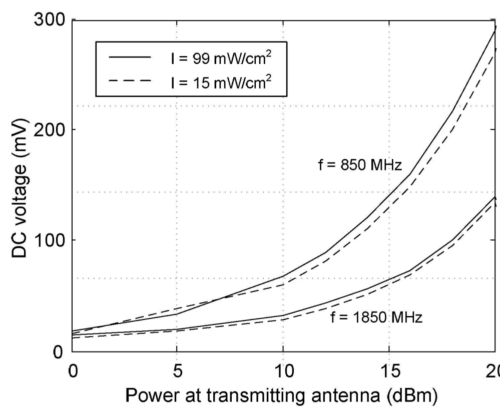

Fig. 5 DC voltage of the solar rectenna for different light intensities.

A. 850 MHz / 1850 MHz Dual Band Solar Rectenna

The dual band rectenna presented in the previous section was used to create a solar rectenna, by placing a solar cell on top of the antenna element (Fig.1b). The location of the solar cell was selected in order to minimize the effect it has over the performance of the original antenna. The sensitive areas of the antenna where the field distribution was higher were avoided. It was verified that the change in the antenna performance in terms of input matching and gain was minimum when placing the solar cells on top of the antenna.

The performance of the solar rectenna was evaluated and the obtained DC voltages at the output of the rectifier circuit for different illumination intensities of the solar cells was evaluated (Fig. 5).

B. 2.45 GHz Solar Rectenna

A single band solar rectenna was designed to operate at 2.45GHz. The antennas structure is a substrate integrated waveguide (SIW) cavity backed slot antenna. The design is made in FR4 of 1.6 mm height, $\varepsilon_r = 4.4$ and $\tan\delta = 0.02$. On one side of the substrate there is a 50 Ohm input line. On the other side of the substrate there is a slot, dimensioned to resonate around 2.45 GHz. The solar cells are placed around the radiating slot avoiding covering the area where the field distribution is stronger that corresponds to the conductive are surrounding the slot. The selected output load is 5.6 kOhm.

This solar rectenna is aimed to be integrated with a transparent polycarbonate box; for this reason, the testing of the structure was made by covering the solar rectenna with an additional layer of this polycarbonate (Fig. 6). The polycarbonate material was characterized and its electrical properties were $\varepsilon_r = 2.1$ and $\tan\delta = 0.005$.

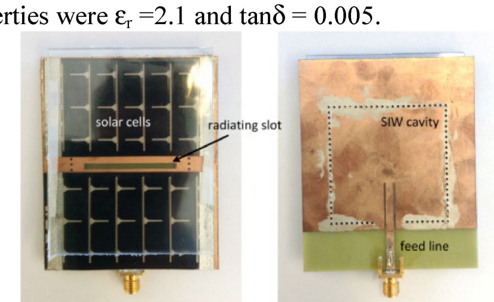

Fig. 6 Photo of the solar SIW slot antenna.

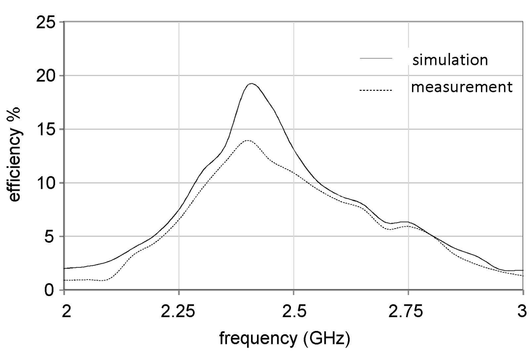

Fig. 7 Simulated and measured RF to DC conversion efficiency of the 2.45 GHz solar rectenna.

The rectifier circuit is formed by two parallel rectifiers with envelope detector topology. One of them is matched for no illumination of the solar cells conditions. The other rectifier is matched for illumination conditions. As the solar cells DC outputs are connected to the circuit, the impedance seen by the rectifier changes depending on the existence or not of light illuminating the solar cells.

Fig. 7 shows the RF to DC conversion efficiency of the rectifier circuit when there is no light illuminating the solar cells and for an input power of -14 dBm.

VII. Conclusion

This paper has presented some design guidelines towards the synthesis of single/multiband rectenna elements. Several design examples have been discussed showing good performance results in terms of RF to DC conversion efficiency for low input power levels in the range of -20dBm to -9 dBm. The paper also shows how sharing the antenna area it is possible to create solar rectennas that are capable to harvest both from solar and electromagnetic energy.

Acknowledgement

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