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An Efficient Rectenna for RF Energy Harvesting Applications at 2.45GHz

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Abstract— An efficient rectenna in the 2.45GHz ISM band dedicated to RF energy harvesting circuits is presented in this paper. A new methodology to improve rectanna performances is detailed. We demonstrate that the use of the optimization integrated in ADS for the overall circuit is the best method to improve the matching impedance between the antenna and the rectifying circuit and to increase the output voltage and the RF to DC conversion efficiency. Results compared to the state of the art show the effectiveness of the designed circuit. At an input RF power of 9.8dBm, it reaches an output voltage of 6 Volt and a conversion efficiency of 89%.

Index Terms—Rectenna, RF to DC conversion efficiency, antenna, rectifying circuit, Schottky diode, optimization, ADS, RF power.

I. INTRODUCTION

Nowadays, a widespread use of wireless communicating devices like wireless sensor nodes and mobile phones has led to a growing interest in energy harvesting applications from different sources such as solar energy source [1] and RF energy source[2] [3] [4]. The ambient RF energy has an advantage of availability during all the day and night unlike a solar energy, which is available only when sunlight is present. The use of the unutilized RF energy can reduce the costs of periodical battery replacement and extend the sensor's life. Moreover, it can present a promising solution when battery replacement is inconvenient, infeasible or may present a danger to human life.

The RF energy harvesting process consist of capturing ambient RF power and converts it into DC power for either using it directly to supply a low power device or storing it for later use. The key component of a RF energy harvesting system is the rectenna (rectifying-antenna). It is composed of receiving antenna and a RF to DC rectifier [5] [6].

Generally, the RF to DC rectifying circuit is made of an input HF-filter that ensure the matching impedance between the antenna and the rectifier, a combination of schottky diode, an output DC-filter and a resistive load that models the device to supply [7] [8]. The big challenge of designing a rectanna circuit is to combine its various comprising blocks efficiently and optimally.

The evaluation of rectenna performance is based on the level of its output voltage and its RF-DC conversion efficiency [9] [10] [11].The RF-DC conversion efficiency iscalculated by the equation (1):

$$\eta = \frac{V^2{}_{DC}}{R_L \times P_{RF}} \times 100[\%] \quad (1)$$

Where: V_{DC} is the output DC voltage of the rectenna (V), R_L is the resistive load (Ω) and P_{RF} is the input RF power, captured by the receiving antenna (W)

This paper proposes a new method to improve and optimize the performance of the rectenna. Habitually,we have just to find a reflection coefficient lower than -10 dB to evaluate the matching impedance as acceptable. In this work, the aim is to capture a very low RF power (of 5 dBm to 15 dBm) and convert it into useful DC power to supply low power devices. For this reason, we seek to find the most optimized rectenna circuit. After designing a matching impedance circuit, we optimize all components of the rectenna by setting several goals at the same time:

- Maximizingthe RF to DC conversion efficiency and the output voltage
- Minimizing return losses
- Ensuring thatthe input impedance antenna is equal to the complex conjugate value of the input impedance of the rectifier circuit (Zin), Za=Zin*, with Za=50Ω

This paper is structured as follows: in section2, we discuss the choice of the schottky diode and the topology of the rectifying circuit. In section3, we design a matching impedance circuit and demonstrate that the global optimization is the best method to improve the performance of a rectenna. Finally, wedraw the conclusions.

II. DESIGN OF RECTENNA CIRCUIT

For high frequency, schottky diodes are widely used because of its short reverserecovery time and low voltage drop, which is between 0.15V and 0.4V in their forward bias condition [12]. For low RF input power, HSMS2820, HSMS2850 and

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HSMS2860 are generally used [13] [14] [15]. A comparison of the RF to DC conversion efficiency for different diodes is presented in Fig.1. It is clear, that the choice of diode isdependent on the level of RF input power. In fact, for low power, it is preferable to use HSMS2850 characterized by a low junction capacitance and a low threshold voltage. For medium power, it is preferable to use HSMS2860 characterized by a low junction capacitance and low series resistance. Finally, for high power, it is preferable to use HSMS2820 with a high breakdown voltage. In our application, as the input power is around 10 dBm, the HSMS2860 offers best conversion efficiency.

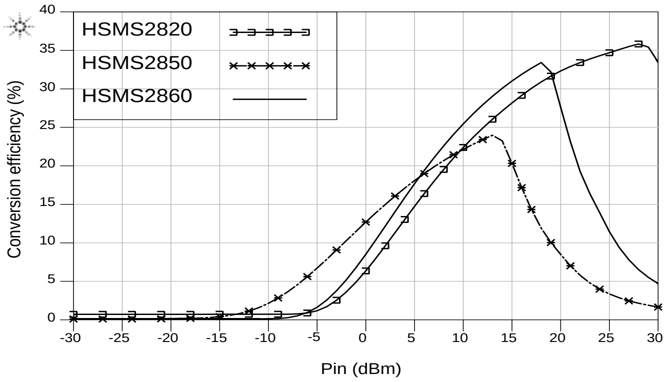


Fig.1. The conversion efficiency versus input power for different Schottky diodes

Several topologies can be used to convert RF power into DC power such as single serial or shunt diode, voltage doubler circuit and bridge circuit [16] [17]. The voltage doubler circuit has the advantage of achieving higher output voltage than the single diode configuration for the same RF input power. Hence, the suggested rectenna circuit (ciruict1) presented in Fig.2 is the voltage doubler configuration using schottky diode HSMS2860. A RF generator in series with 50Ω output impedance simulates the antenna.

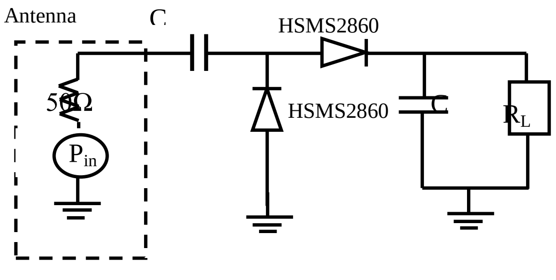


Fig.2. Architecture of the suggested rectenna

III. RECTENNA PERFORMANCES IMPROVEMENT

A. Design of Matching Circuit

The first step to improve the performance of a rectenna is to reduce reflection loss presented in Fig.3. To simulate the reflection coefficient S11 and the input impedance, we use the LSSP (Large-Signal-S-Parameter) type of simulator because it takes into account non-linearity of the diode.

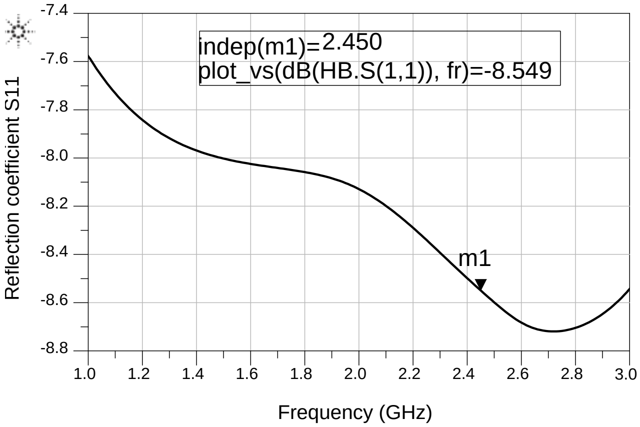


Fig.3. Reflection coefficient S11 versus frequency

The transfer of power from the antenna(Za) to the rectifier is maximum when the input impedance of the antenna is equal to the complex conjugate value of the input rectifier impedance (Zin): Za=Zin*, with Za=50Ω and Zin=91.2−j 35.5

The imaginary part of the input impedance is -35.5 j. In order to compensate this imaginary part, we have to insert a series inductance between the antenna and the diode in circuit1. The obtained circuit is referred as circuit2.

Thus, imag (Zin*) =35.5*j = L w j with f = 2.45GHz,therefore L = 2.3 nH.

The choice was just covers the insertion of an inductor and not to use smith chart to design a more complex filter in order to minimize the number of components and minimize the insertion losses.

Figure4 shows that the insertionof 2.3 nH inductance minimized reflection lossesS11 at 2.45 GHz.

S11 = -14 dB< - 8.5 dB, that means an acceptable matching impedance but not the maximum power transfer between the antenna and the rectifier because Za is slightly different from Zin* as presented in Fig.5.

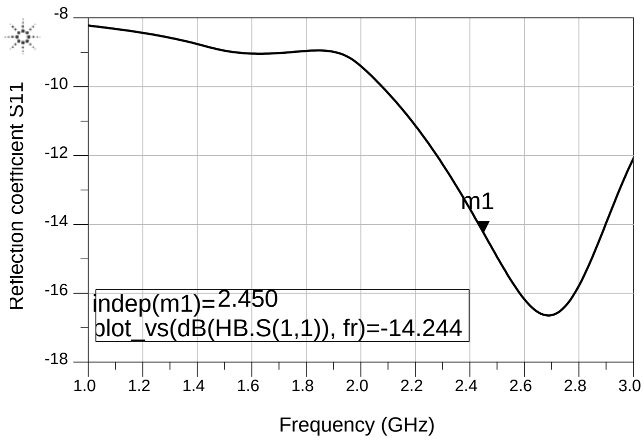


Fig.4. Reflection coefficient versus Frequency for circuit2

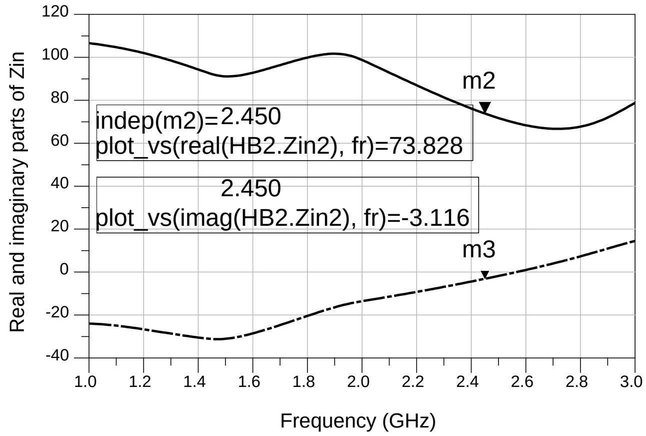


Fig.5. Real and imaginary parts of Zin vias frequency for circuit2

The value that compensates the imaginary part of Zin as shown in Fig.6, was found by tuning tool isL=2.5 nH. This difference is due to the nonlinear behavior of the rectifying circuit. The inductance value is, calculated for a value of Zin, measured before inductanceinsertion while, the inductance insertion in the circuit change the impedance of the diode, and consequently, change the frequency behavior of the diode. Therefore, the calculated value is slightly different from the actual optimum value.

Fig.6 shows that the insertion of 2.5nH inductance did offset the imaginary part of Zin but the real part is not equal to 50ohm which means we have not yet found the best matching impedance.

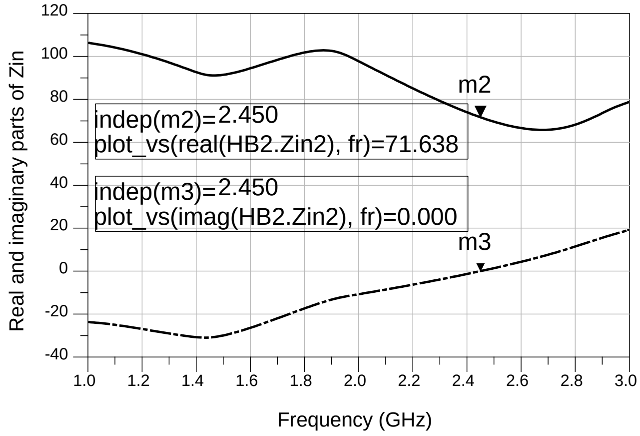


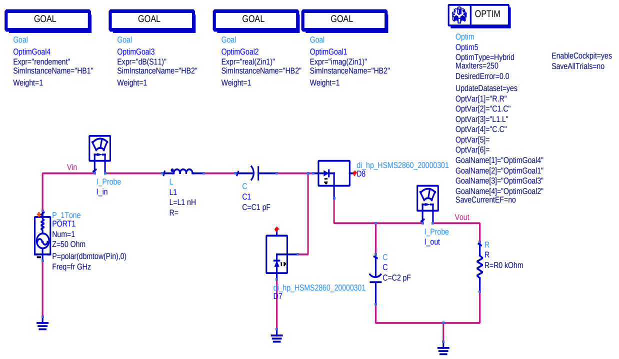
Fig.6. Real and imaginary parts of Zin vias frequency after 2.5 nH inductance insertion

B. *Optimizing Rectenna Circuit*

In this section, we demonstrate that to find the best matching impedance and performance in term of both conversion efficiency and output voltage, we have to use the optimization included in ADS. It consists of trial and error simulation that tries to achieve performances goals: best behaviour in matching impedance, output voltage and conversion efficiency.

The hybrid method which is a combination of Random and Quasi-Newton was choose as a search method because it offers the ability to find rapidly a minimum with a fewest possible circuit analyses (the strength of Quasi-Newton method), and to find the global cost minimum even in the presence of many local minima (the strength of Random method).

As goals, we look to find a set of values component L, c and R of the designed circuit, minimizing the value of S11 at 2.45 GHz, ensuring real (Zin) =50, imag(Zin)=0 and maximizing the conversion efficiency as shown in Fig.7. The optimized circuit is reffered as circuit3.



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Goal
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OptVar[3]="L1.L"
OptVar[4]="C.C"
OptVar[5]=
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GoalName[3]="OptimGoal3"
GoalName[4]="OptimGoal2"
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EnableCockpit=yes
SaveAllTrials=no

I_Probe
I_in

L
L1
L=L1 nH
R=

C
C1
C=C1 pF

di_hp_HSMS2860_20000301
D8

P_1Tone
PORT1
Num=1
Z=50 Ohm
P=polar(dbmtow(Pin),0)
Freq=fr GHz

di_hp_HSMS2860_20000301
D7

C
C
C=C2 pF

I_Probe
I_out

R
R
R=R0 kOhm

Fig.7. Optimization of all rectifier components by hybrid method

Figure 8 shows the results of circuit 3.The value of S11 reaches a minimum of -41 dB at 2.45 GHz and Zin= Za*as shown in Fig.9, which means a maximum transfer of power from the antenna to the rectifying circuit.

Conclude that the global optimization is the best method to match the impedance between the antenna and the rectifier.

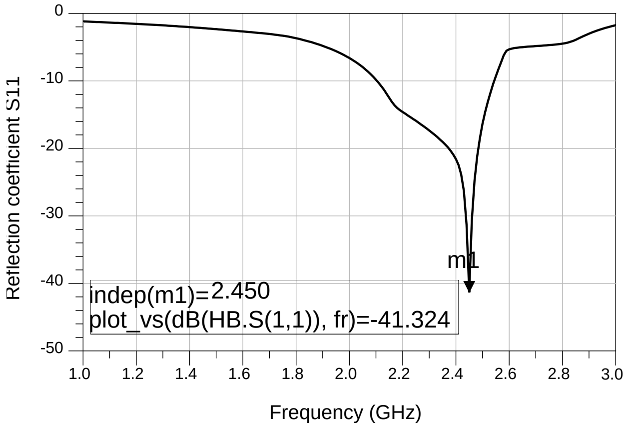

Fig.8. The reflection coefficient S11 versus frequency of circuit3

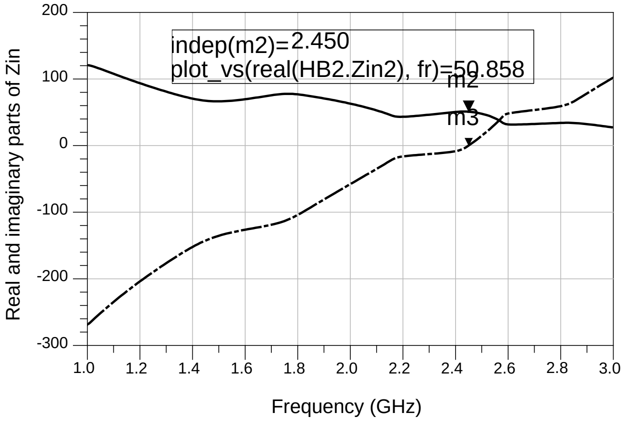

Fig.9. Real and imaginary part of Zin of circuit3

Figure10 and Figure11 show that the performances of the circuit 3 (optimized circuit) is better than those of the circuit1 presented in Fig.2 (before introducing the inductance) and the ciruit 2 described in section 3.1 (with 2.3nH inductance).

It is clear in Fig.10 and Fig.11 the optimization impovement in term of RF to DC conversion efficiency, from a max of 79.5 % to 89 % and in term of output voltage, from 1.5 v to 6.1 v.

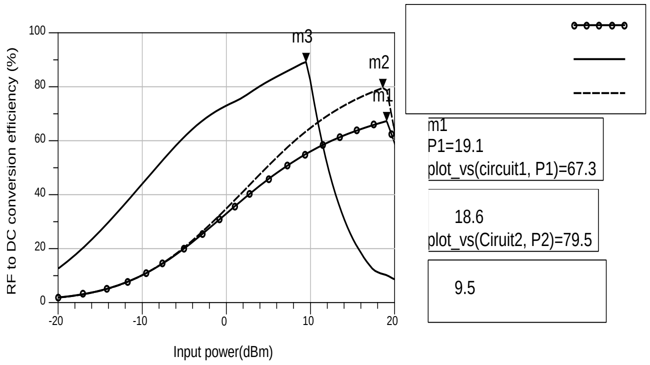

Fig.10. The conversion efficiency versus the input RF power for different developed circuits

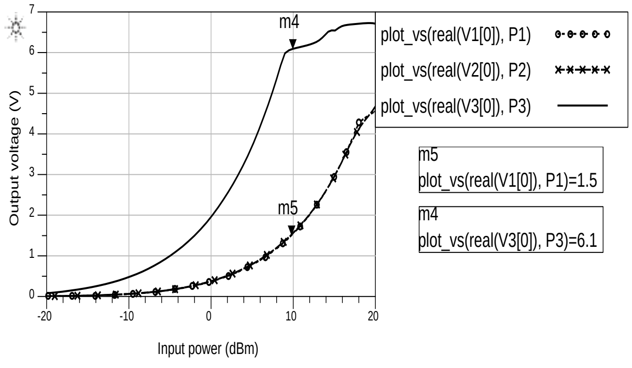

Fig. 11. The output voltage versus input RF power for different developed circuits

IV. CONCLUSION

In this work, an efficient rectenna dedicated to RF energy harvesting applications has been proposed. A new methodology to improve the rectanna performances has been presented. After designing a matching impedance circuit, we optimize all components of the rectenna by setting several goals at the same time: ensuring the maximum transfer of power from the antenna to the rectifying circuit, increasing the output DC voltage and the RF to DC conversion efficiency. The results of proposed rectenna showed an improvement of 10% in terms of RF to DC conversion efficiency and 4.5 volt in term of DC output voltage. The performances of the devopped rectenna are very satisfied performances (89% and 6 volt at 10 dBm) compared to the state of the art.

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