Optimum Design of a Scavenging Antenna System

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***Abstract*— This paper presents some guidelines for the design procedure of an optimum scavenging antenna system. Based on these guidelines, a scavenging antenna has been fabricated and characterized, achieving very good results in comparison to the traditional designs.**

I. Introduction

New applications demand autonomy, low cost and low consumption devices. Despite many applications, such as Wireless Sensor Networks, require little power, one of the backbones of the wireless devices is still energy efficiency. Energy scavenging is considered an advantageous solution for the powering subsystems, conforming then self-powered autonomous devices. Among all the ambient energy sources (vibration, thermal changes, wind), the RF energy is considered as a worthwhile option for indoor scenarios and inaccessible places [1].

The scavenging system (Fig. 1) is composed of an antenna that captures the RF ambient power, a rectifier, converting the available RF input power, P_{in}, into DC power, P_{out}, and a storage energy device. The amount of DC power obtained depends on the total efficiency of the scavenging system, η_{tot}, composed by the antenna efficiency, η_{ant}, the conversion efficiency, η_{rect}, of the rectifier and the losses due to the mismatching, η_{mis}.

It would be desirable to design an antenna with an impedance, Z_{ant}, matched to the rectifier input impedance, Z_{rect}, in order to avoid the use of an extra matching network, which will introduce extra power losses. In case of linear circuits, the design does not present major difficulties. It turns however into a very complicated task when dealing with non-linear circuits, as it happens with the low input power rectifier.

The aim of this work is to give some guidelines for a high efficiency scavenging antenna system design.

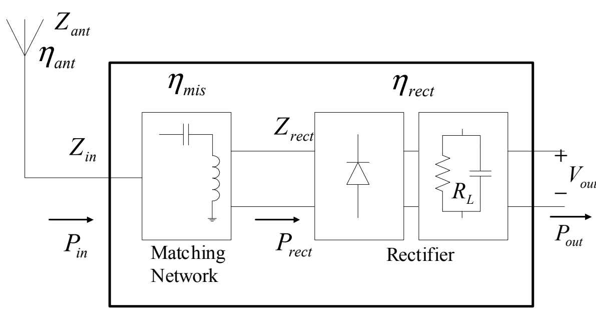

Fig 1. Scavenging system

II. Rectifying Circuit

For low-power applications as is the case of collected RF energy, the two main characteristics that determine the configuration and the elements constituting the rectifier are the conversion efficiency η_{rect} and the output DC voltage, V_{out}.

The rectifying elements in our design will be diodes. As a general rule, we could say that V_{out} increases with the number of diodes. However, the power dissipated by the diodes also increases with the number of diodes, taking a higher percentage of the available power at the input, and therefore reducing η_{rect}. Then, when looking at the optimum configuration to be used, we generally confront a trade-off in the rectifier design. In the particular case of low input power applications, diodes are working in the non-linear region of the V/I curve. In these cases, the increment of V_{out} with the number of diodes is not relevant, contrarily to the efficiency behaviour, where the decrease is noticeable. For this reason, we will concentrate our discussion on a rectifying circuit that includes only one diode, so this will be the configuration used for our design.

When looking at the elements constituting the circuit, they are desired to have low losses. The rectifying devices chosen in this design are schottky diodes, due to their low forward voltage, allowing higher voltage and efficiency for P_{in}.

In order to present a good matching with any antenna, it is important to know the exact Z_{rect}. Due to the non-linear behaviour of the diodes, Z_{rect}, depends on the delivered power to the rectifier, P_{rect} (Fig. 1) the load (R_L) and the diode physical characteristics (ohmic losses and junction capacitance and resistance). When placing a matching network, transforming the input impedance in the commonly used 50Ω impedance, the delivered power towards the rectifier (P_{rect}) gets higher and its Z_{rect} consequently changes, producing a mismatching between the network and the rectifier. Therefore, the matching network has to be redesigned, so the matching process ends up in an iterative process until the rectifier achieves an optimum Z_{rect} which gives the highest output power (and the highest η_{rect}).

The problem of the need of a matching network is the ohmic losses associated to its lumped components (LC). Nevertheless, it can be solved with an appropriate antenna design, whose input impedance fulfils the maximum power transference condition (Z_{ant}=Z_{rect}*) allowing direct connection between antenna and rectifier.

III. RADIATING ELEMENT

The antenna should be designed in order to work not only as a radiating element but also as matching network. The antenna input impedance should correspond to the complex conjugate of the optimum Z_{rect}. The tricky issue in the design is to know the optimum Z_{rect}: it can not be easily measured, since any additional measurement system can change the I/V conditions at the diode input, varying Z_{rect}. (Fig 2)

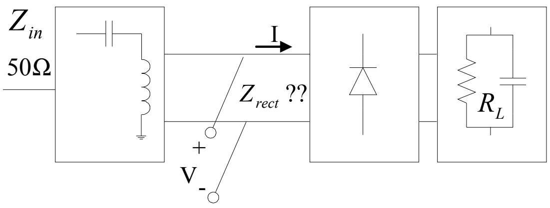

Fig 2. Z_{rect} evaluation

The solution proposed here entails starting with the iterative matching procedure previously explained in section II, using the lumped components LC, in order to arrive at the optimum matching network that gives the optimum Z_{rect}, Z_{rect}^{opt} Once the rectifier is matched to 50Ω (Z_{in}=50Ω), the matching network, LC, is extracted and characterized apart, measuring its input impedance, which is equal to Z_{rect}^{opt*}.

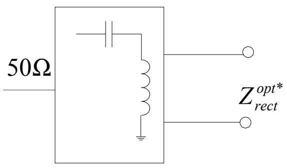

Fig 3. Antenna input impedance characterization procedure

In order to test our design method, we will work with a 868MHz design. In our specific application, the load impedance R_L is 4.3kΩ and the foreseeable input power is around -15dBm.

The efficiency of the total scavenging system will depend also on the size of the antenna, being less efficient when reducing the size ([2]).

In our particular case, the measurement result for the matching network connected to with 50Ω load presented an impedance of $Z_{rect}^{opt*} = 34 + j358$. According to this result, we require an antenna with inductive behaviour.

Due to its high efficiency and omnidirectionality, we have chosen a very common antenna design for RFID applications: a dipole of length, l_d, 126mm, and width, *a,* of 5mm, with a T-match connection, in order to introduce an inductive behaviour, as in [3] (Fig 4), being the small dipole length l_l, of 46mm, its width, *b*, of 1mm and the separation *s* equal to 4mm

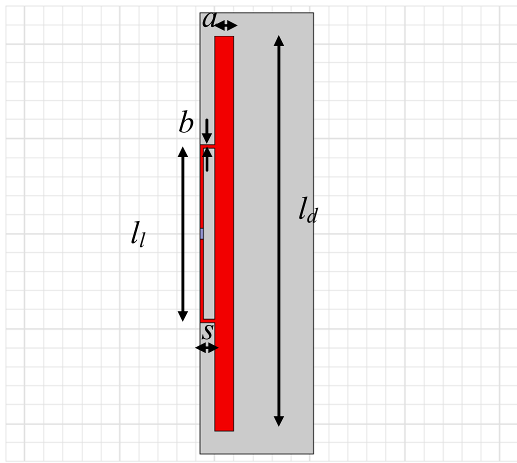

Fig 4. Dipole with T-match connection. Scavenging radiating element

After being simulated using the software tool Ansoft HFSS, the dipole has been fabricated on a low losses substrate material (Rogers 4003C) and has been characterized using a Network Analyzer N5242A. Simulated and measured results for Z_{ant} are shown in Fig 5 and Fig. 6.

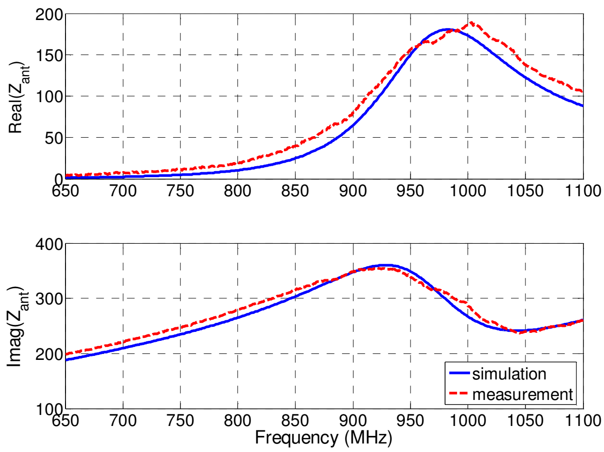

Fig 5. Z_{ant}. Simulated and measurement results

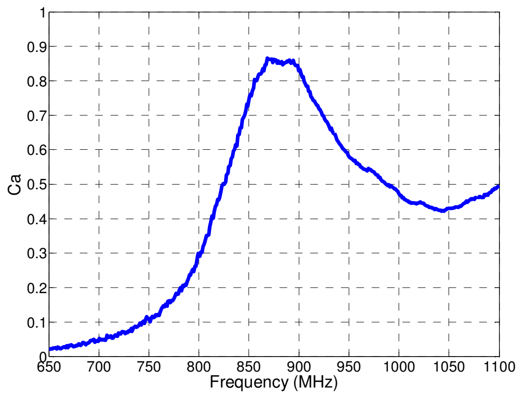

Fig 6. Antenna matching coefficient

IV. SCAVENGING ANTENNA

Once designed and fabricated the radiating element as a stand alone element and being characterized its input impedance, the scavenging antenna system was fabricated using also Rogers 4003C as substrate material. In Fig 7 the scavenging antenna system is shown.

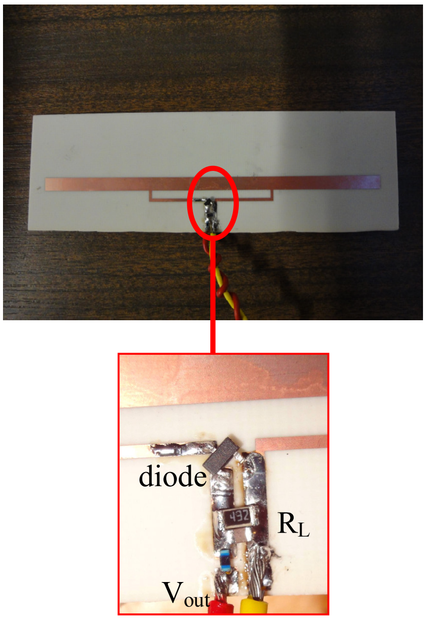

Fig 7. Scavenging antenna system

V. MEASUREMENT RESULTS

The optimum scavenging antenna system has been evaluated by measuring V_{out} when it is illuminated with different P_{in} values in a certain frequency range.

The measurement setup, which is shown in Fig. 8, consists on a Ridge antenna connected to a synthesizer sweeping the frequency between 650MHz and 1.5GHz. Our scavenging antenna system was located at a distance of 50cm, where, according to simulations, P_{in} should be 15dB less than the incident power at the ridge antenna port. V_{out} was captured by an oscilloscope. Measurement results are plotted in Fig. 9.

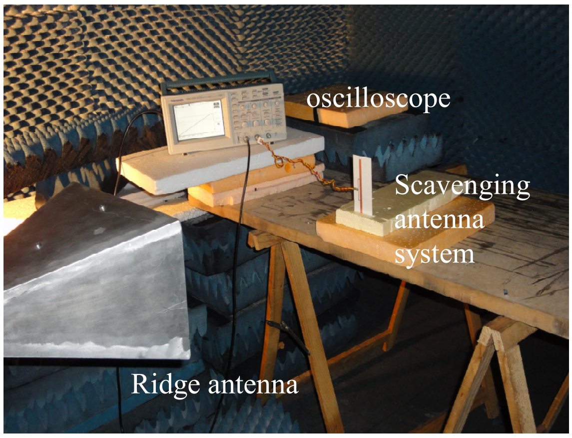

Fig 8. Measurement setup.

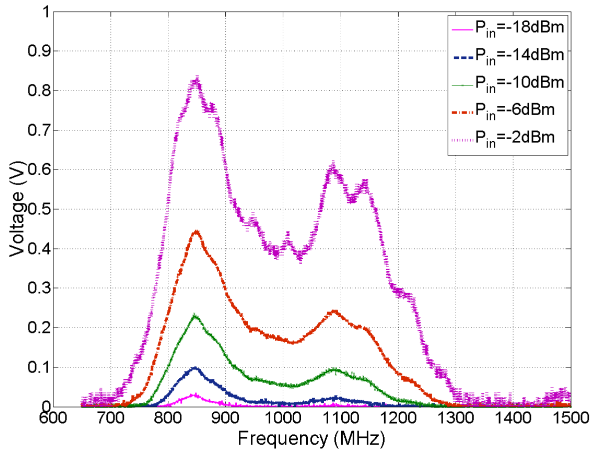

Fig 9. V_{out} of the optimum scavenging antenna system

In order to probe the proper behaviour of our scavenging antenna, the previous results have been compared with the V_{out} results of a system comprising a 50Ω dipole antenna, plus the optimum matching network and the rectifying circuit, shown in Fig. 10.

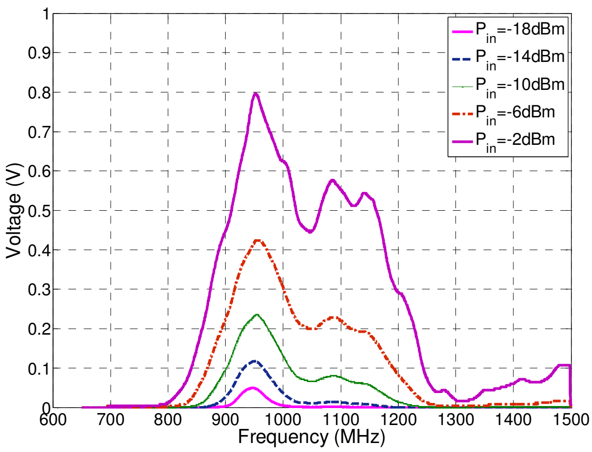

Fig 10. Vout of 50Ω scavenging antenna system, with matching network.

The voltage V_{out} obtained with both designs, with and without matching network, are quite similar. In order to improve the voltage obtained with the optimum scavenging antenna system, it would be necessary to increase the matching coefficient (Ca) up to 1 instead of 0.9, as it actually is (observed in Fig 6). Taking into account that there is a perfect matching in the 50ohm scavenging antenna (so there is not power lost due to reflections), the ohmic losses of the matching network avoid achieving the maximum V_{out}. Due to the fact that the matching network has been suppressed in our optimum scavenging antenna, it would be more efficient compared to the 50Ω design, when having also Ca=1.

VI. Conclusions

Due to nonlinear behaviour of the diode, the scavenging antenna system design is not a straightforward procedure. In order to achieve the optimum design of a high efficiency scavenging antenna system, a design procedure has been proposed in this paper. Basically, it requires a previous analysis of the rectifier as a stand alone element: For a certain rectifier configuration, R_L and P_{in}, after an iterative matching process of the rectifier, we can arrive to know the optimum antenna impedance for maximum power transference. Based on this antenna impedance, the antenna type and its dimensions will be defined.

Following these guidelines, an optimum scavenging antenna has been designed, fabricated and characterized. Measurement results show the improvement on the V_{out} attained in comparison to the non-optimum scavenging antenna, which includes matching network to 50Ω.

Acknowledgment

This work was supported in part by the Spanish Interministerial Commission on Science and Technology (CICYT) under projects TEC2007-66698-C04-01/TCM and CONSOLIDER CSD2008-00068 and by the "Generalitat de Catalunya" through the FIR fellowship program.

The antenna design is based on a remarkable previous work of the PhD student Beatriz Monsalve. The data acquisition was done with the help of the PhD student Santiago Capdevila. They deserve our acknowledgements.

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