A 927 MHz Solar Powered Active Antenna Oscillator Beacon Signal Generator

Francesco Giuppi[1], Apostolos Georgiadis[2], Selva Via[2], Ana Collado[2], Rushi Vyas[3], Manos M. Tentzeris[3] and Maurizio Bozzi[1]

[1]University of Pavia, Pavia, 27100, ITALY

[2]Centre Tecnológic de Telecomunicacions de Catalunya, Castelldefels, Barcelona, 08860, SPAIN

[3]Georgia Institute of Technology, Atlanta, GA 30332-0250, USA

***Abstract* — This work presents the design and implementation of a 927 MHz radio frequency beacon in coplanar waveguide technology, which scavenges through solar energy the power necessary for operation. Starting from a folded-slot antenna topology, a reflection-type oscillator is designed by combining full-wave and nonlinear analyses. Properly placed solar cells and a regulator are used to bias the device by scavenging solar energy from the environment. Prototypes have been implemented and measured. This low cost implementation could be useful in low-power wireless applications.**

***Index Terms* — Beacon, Energy Harvesting, Wireless Sensor Networks, Folded-Slot Antenna, Active Antenna, Oscillator.**

I. INTRODUCTION

In the recent years, the interest in low-power wireless sensor networks has been constantly growing. Small wireless computing, in fact, can integrate into everyday life, offering the possibility to increase the efficiency, comfort and security of many kinds of commonly used infrastructures.

The development of low-power sensor networks relies on their nodes, which should be cost-effective, energetically low-consuming and maintenance free. The energy needed to enable a RF link must be therefore harvested from sources that are directly available in the environment [1].

For this reason, the choice of the energy scavenging technique is crucial; with this respect, photovoltaic technology is quite mature, and has been widely studied in the literature for both outdoors and indoors applications [2]. Moreover, a solar cell based power source can be quite easily implemented using commercial off-the-shelf technology [3].

Folded-slot antennas appear as very attractive for this kind of application, as they provide relatively large bandwidth compared to other planar topologies; in addition to this, they are quite easy to fabricate through a single mask step, and can be easily integrated with other devices via a coplanar waveguide feed [4].

This paper describes the design and implementation of a 927 MHz antenna oscillator for wireless energy harvesting applications. The proposed folded-slot antenna oscillator was designed and optimized by carefully combining full-wave and nonlinear analyses. A passive antenna and an active prototype have been implemented and measured in order to verify the radiation performances. After that, solar cells were properly inserted for energy scavenging purposes, demonstrating the possibility to power the antenna oscillator by using scavenged solar energy only.

II. DESIGN OF A 927 MHZ FOLDED-SLOT ANTENNA OSCILLATOR

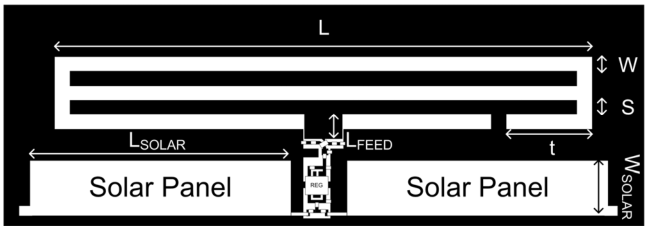
The antenna oscillator structure adopted for this work is shown in Fig. 1. Its design has been carried out by combining full-wave and nonlinear analyses. In fact, the passive antenna topology has been studied and dimensioned with a Finite Element Method (FEM) –based software (Ansys HFSS), while the optimization of the oscillating circuitry was completed by means of Harmonic Balance (HB) analysis.

A. Design of the passive antenna

The antenna developed in this work has a folded-slot topology. The resonance frequency, which is strongly dependent from the total slot length around the periphery, was chosen to be around 900 MHz. In [4], some useful piece of information for the design of folded-slot antennas is provided.

The slot is made up of three parallel branches, whose width strongly affects the bandwidth of the device. In particular, the triple-slot structure was chosen in order to produce an input impedance of around 50 Ohm for an antenna built on a 3.38 permittivity substrate. Also, a shorting strip was added in order to allow for size reduction of the antenna, and to be used as a DC ground for the Gate terminal of the device to be later inserted [5]. The geometrical dimensions used for the radiating element are listed in Table I.

A passive prototype was then built, on Arlon 25N substrate with a 20 mil thickness. In Fig. 2 the measured and simulated return loss for the passive folded-slot antenna is shown. The measurements were carried out using an Agilent E8361A network analyzer; as it can be seen, the structure shows a better that 10 dB matching from 800 MHz up to 1.1 GHz. Moreover, Fig. 3 shows the E- and H-plane radiation patterns of the passive antenna as measured in the anechoic chamber.



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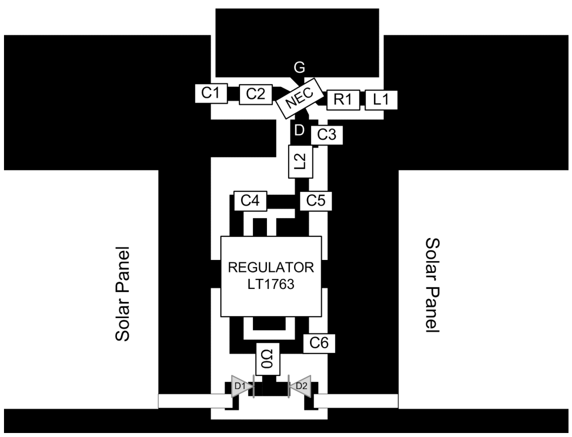

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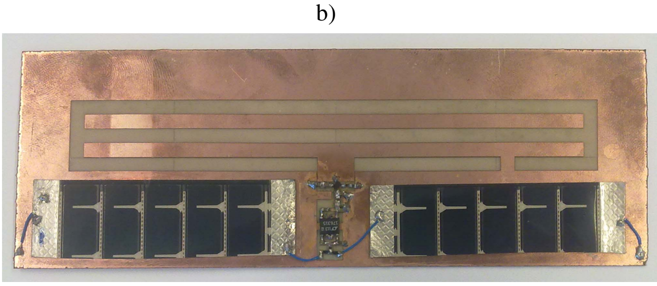

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Fig. 1. Layout a), circuit diagram b), and photo c) of the folded-slot antenna oscillator.

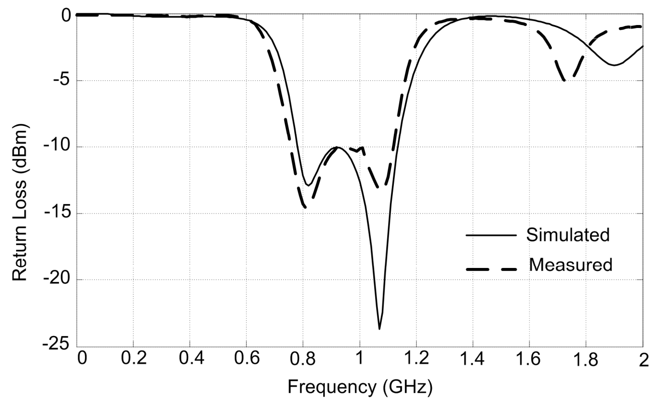


Fig. 2. Measured and simulated return loss for the passive antenna.

B. Optimization of the oscillating circuit

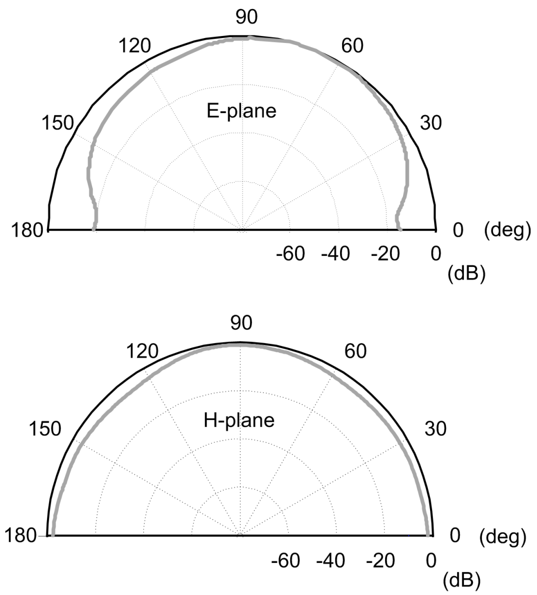
After simulating the passive antenna structure with full-wave analysis, the S-parameters resulting from simulation were imported in a circuit simulator (Agilent ADS). Then, with Harmonic Balance analysis the active circuitry was optimized in order to obtain oscillation in the desired bandwidth between 900 and 930 MHz.

The Gate of a N-channel HJFET (NEC NE3509M04) was connected to the antenna feed line, thus forming a reflection-type oscillator; the circuital parameters used for the correct biasing of the device and for the selection of the desired oscillating solution are listed in Table I, and a circuit diagram is shown in Fig. 1b.

Harmonic Balanced analysis was carried out by using an auxiliary probe, in order to prevent convergence to the DC trivial solution, as shown in [6] and references therein. Finally, a 918 MHz steady-state oscillating solution was found, whose stability was studied with Transient analysis.

A prototype was then manufactured and measured, exhibiting a 927 MHz oscillation and drawing 6 mA current out of 1.5 V supply.

The phase noise performance of the oscillator was also evaluated, showing a -86 dBc/Hz and a -114 dBc/Hz phase noise at 100 kHz and 1 MHz from the carrier, respectively. The results of these measurements are presented in Fig. 4, showing the 30 dB/dec slope of the 1/f noise, typical for the device. In Fig. 5, the measured normalized EIRP patterns of the active antenna oscillator are shown.



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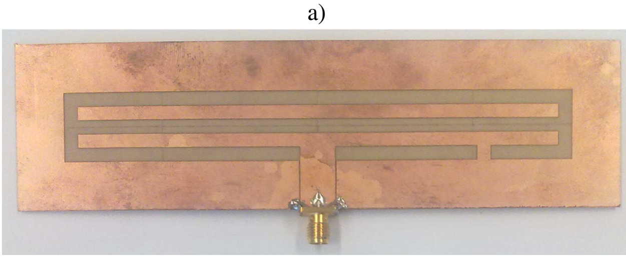


b)

Fig. 3. E- and H- plane co-pol radiation patterns for the passive folded-slot antenna a), and photo of the device b).

TABLE I
SUMMARY OF GEOMETRICAL AND CIRCUITAL PARAMETERS

Parameter	Value	Parameter	Value
L	13.1 cm	R1	10 Ohm
W	3.6 mm	L1	10 nH
S	3.6 mm	C1	1.8 pF
t	2.1 cm	L2	18 nH
L_{FEED}	6.1 mm	C2	3.3 pF
L_{SOLAR}	6.5 cm	C3	0.5 pF
W_{SOLAR}	1.8 cm	C4	0.01 uF
C5	10 uF	C6	1 uF

III. SOLAR ENERGY HARVESTING

After designing the antenna oscillator, solar energy was scavenged in order to power the device. A flexible thin-film amorphous silicon solar cell was used, due to its low cost, flexibility and easiness of interconnection. The amorphous silicon thin-film is deposited on a plastic backing, thus allowing flexibility and high robustness to the conditions of the surrounding environment.

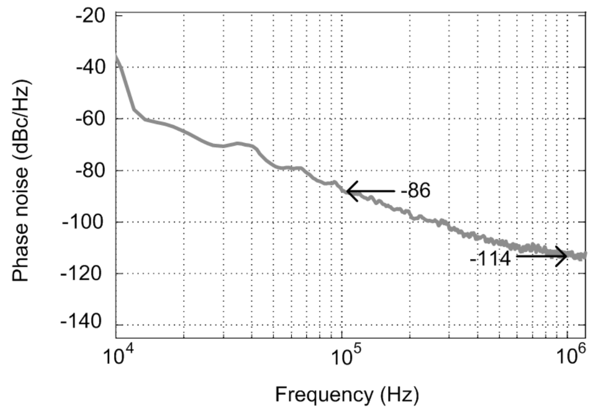


Fig. 4. Measured phase noise performance for the active antenna oscillator.

The commercial solar panel (FlexSolarCells SP3-37) features an open circuit voltage of 4.1V, and a short-circuit current of 30 mA under 1 sun (100 mW/cm^2) irradiance. The panel was divided into two halves, in order to fit into the layout. The two solar panels obtained exhibited 4.15 V and 3.8 V open circuit voltages, and 12.2 mA and 14.2 mA short circuit currents, respectively.

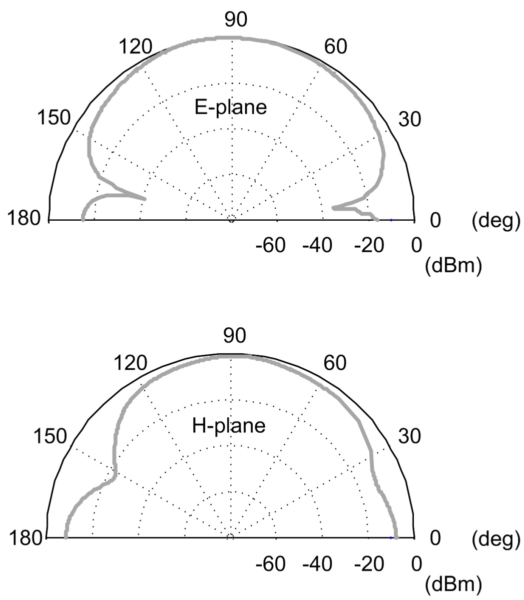
The two solar panels have then been placed over the ground plane, avoiding the antenna boundaries. As it was demonstrated in [7], the solar panel has a minimum effect on the antenna radiation performances, as long as it's kept at a convenient distance from the slot structure.

Furthermore, a Linear LT1763-1.5 regulator was added in order to provide a stable supply voltage to the oscillating circuitry. The device accepts at its input a minimum voltage of 1.8 V, offering at its output a fixed 1.5 V voltage. It can provide up to 500 mA current with 300 mV dropout voltage. The device has a very simple configuration where only three external capacitances need to be connected to the regulator in order to allow for its proper operation.

In this case, two different setups were considered; in the first one, only one half of the solar panel was embedded in the structure, whose positive terminal was directly connected to the input of the regulator (see Fig 6). In the second one, the two solar panels were embedded, and connected to the regulator input through two Shottky diodes (Skyworks SMS7630-079LF) in order to isolate them from one another. This final setup allows taking advantage of the whole available area for energy harvesting, as shown in Fig. 1.

Please note that since the oscillator requires a 1.5 V supply and a 6 mA current, each one of the panels is able to provide the correct biasing for the circuit.

Measurements taken under full sunlight have shown in both cases a 932 MHz oscillation for the device, thus demonstrating the possibility to power a 900 MHz antenna oscillator by using solar harvested energy. The slight change in the frequency of operation is eventually due to the loading of the solar cells.



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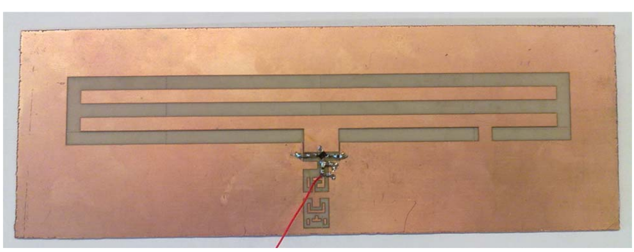

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Fig. 5. E- and H- plane co-pol radiation patterns for the active folded-slot antenna oscillator a) and photo of the device b).

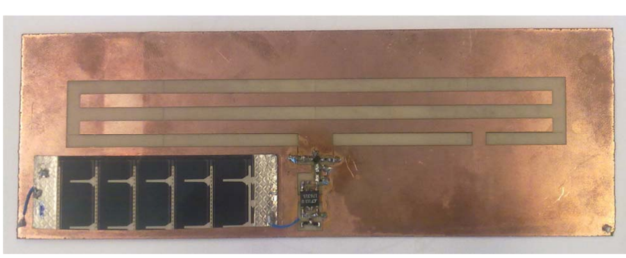

Fig. 6. Active antenna oscillator harvesting solar energy from one solar panel placed on its ground plane.

VII. CONCLUSION

This work presented an active folded-slot antenna oscillator with solar energy harvesting capabilities. A compact folded-slot radiating structure was designed and implemented in order to verify its radiation performances. The possibility to power the device by using solar panels in two different configurations was demonstrated. Further development of this work may consist in studying the realization of such structures on more cost-effective substrates, like PET and paper.

ACKNOWLEDGEMENT

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