UHF Solar Powered Active Oscillator Antenna on Low Cost Flexible Substrate for Wireless Identification Applications

†Apostolos Georgiadis[1], †Ana collado[2], ‡Sangkil Kim[3], ‡Hoseon Lee[4], and ‡Manos M. Tentzeris[5]

†Centre Technologic de Telecomunicacions de Catalunya (CTTC), Castelldefels 08860, Spain
‡Georgia Institute of Technology, Atlanta, GA 30309 USA
[1]ageorgiadis@cttc.es, [2]acollado@cttc.es,[3]ksangkil3@gatech.edu, [4]hoseon@gatech.edu,
[5]etentze@ece.gatech.edu

Abstract — **The design of a 920 MHz active oscillator antenna using low cost flexible substrate materials is presented. Flexible amorphous silicon a-Si solar cells are properly integrated in the available area of the circuit substrate preserving the conformal nature of the circuit and providing operational autonomy by harvesting solar power without affecting the radiation properties of the active antenna. Coplanar waveguide fed monopole and slot antennas are designed using EM simulation and harmonic balance simulation is subsequently used to design the oscillator circuit, including the equivalent circuit of the solar module. Two benchmarking prototypes were fabricated, one by method of laser prototyping on PET, and the other by inkjet-printing on photopaper, demonstrating that it is feasible to come up with a cost effective conformal circuit implementation of a beacon signal generator which can find application in wireless identification and monitoring applications.**

Index Terms — **Energy harvesting, flexible electronics, harmonic balance, beacon generator, active antenna, solar power harvesting.**

I. INTRODUCTION

The increasing use of RFIDs and wireless sensor networks in monitoring and identification applications has resulted in significant interest in flexible electronics combining low cost substrate materials and cost efficient fabrication technologies [1]-[2]. Furthermore, the need for numerous sensor circuits leads to the requirement for low power operation and increased circuit operational autonomy minimizing the use of batteries. In addition to low power circuit design, harvesting technologies provide alternative sources of energy to power the sensors and are receiving significant attention [3].

The objective of this work is to demonstrate the design of an autonomous active antenna oscillator operating at the 900 MHz ISM band, utilizing a low cost flexible substrate. The active antenna is powered by harvesting solar power through a solar module. Two circuit designs were performed (Fig. 1). The first one consists of a compact credit-card size monopole antenna fabricated by laser prototyping on a flexible PET substrate, additionally integrating a flexible amorphous silicon a-Si solar module, maintaining the conformal nature of the circuit. The second prototype consists of a folded slot antenna inkjet-printed on paper substrate. This second prototype was initially powered by an external solar module, but additionally allows for integration of flexible solar cells properly placed on top of the conductive area of the slot antenna as can be seen in Fig 1b. Fabricated prototypes were successfully tested and design and performance evaluation results are presented. Such circuits are compatible low cost and conformal RFID and wireless sensor technologies and pave the wave for the implementation of flexible electronics circuits finding application in monitoring and identification applications.

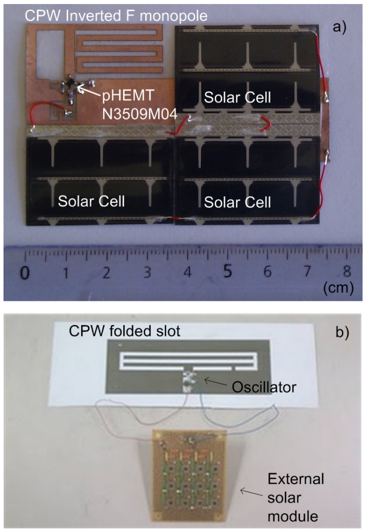

Fig. 1. Solar powered active antenna prototypes. (a) CPW inverted-F monopole on PET substrate. The prototype dimensions are 7.5 cm x 5.0 cm, which is slightly smaller than the standard credit card size. (b) CPW folded slot prototype inkjet-printed on photopaper, with dimensions 15 cm x 7 cm.

II. CIRCUIT DESIGN

The circuit design consisted of three stages. First the antenna was designed using a finite element electromagnetic simulator. Second, the antenna S-parameters were introduced in a nonlinear circuit simulator and the oscillator was designed assuming an ideal DC supply. Finally an equivalent circuit model was used for the solar module and the complete circuit was optimized.

A. Antenna

A coplanar waveguide (CPW) fed inverted-F monopole [4] was designed using a finite element electromagnetic simulator. The selected substrate material was 75 um thick

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PET with a dielectric permittivity of 3.3 and a loss tangent of 0.08. The monopole resonated around 900 MHz and a meander line was used to reduce its size while maintaining the resonance frequency at the desired value (Fig. 1a). A second CPW folded slot antenna was designed on a 254 um thick paper substrate based on the design presented in [5] (Fig. 1b). The paper substrate has similar electrical properties as the PET substrate. The thicker paper substrate and larger size of the slot antenna allowed for more area for the circuit electronics as well as more antenna bandwidth, and gain.

B. Oscillator

The S-parameters of the designed antenna were used in a commercial harmonic balance simulator in order to design a UHF oscillator. The oscillator circuit schematic used in the PET prototype is shown in Fig. 2. The circuit component values for the PET based circuit are shown in Table I. The paper based oscillator had a similar topology and components.

TABLE I

FIG 1A CIRCUIT COMPONENT VALUES

Part	**Simulation**	**Prototype**	**Variation**
C_d (pF)	1.4	1.5	-6.66%
L_d (nH)	15.5	16.0	-3.12%
C_s (pF)	3.1	3.3	-6.06%
R_1 (Ohm)	10.0	10.0	-
L_s (nH)	15.0	16.0	-6.25%
F_{osc} (MHz)	~920	~920	N/A

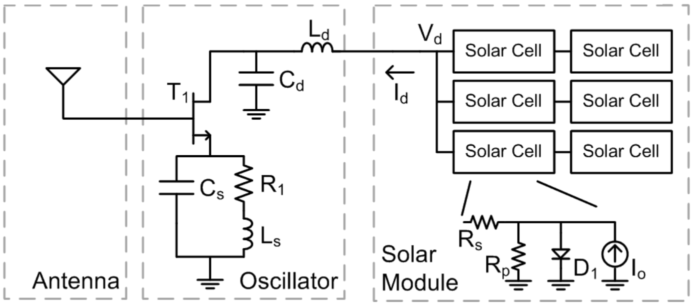

Fig. 2. Solar powered active oscillator antenna circuit schematic.

The active device that was used in the design is the NE3509M04 pHEMT. The pHEMT gate is DC grounded through the monopole and a source resistor R_1 is used to self-bias the device. The capacitors C_s and C_d and inductors L_s and L_d set the oscillation frequency around 920 MHz from a 1.5 V supply, drawing 8mA.

C. Solar Cell

An amorphous silicon a-Si solar cell (Power Film SP3-37) with open circuit voltage 4.1 V and short circuit current 28 mA under 100 mW/cm^2 (1 sun) solar irradiation was used to fabricate a solar module in order to power the PET based oscillator. The SP3-37 internally consists of 5 a-Si solar cells with approximately 0.85 V open circuit voltage and 28 mA short circuit current in a series connection. An equivalent model of the solar cell was created assuming an ideal current source I0 in parallel with an ideal diode D1 with I_s = 1e-9A, a parallel resistance R_p = 110 Ohm and a series resistance R_s = 7 Ohm, by matching the measured I-V characteristic of SP3-37 under 1 sun irradiation (Fig. 2). In order to ensure abundance of available current while providing a sufficient bias voltage, a solar cell module was created by connecting in parallel three pieces of properly cut SP3-37 containing only two its five internal series cells, shown in Fig. 1a. The module effectively has a 1.7 V open circuit voltage and 84 mA short circuit current under 1 sun solar irradiation. The paper based circuit was initially powered by an external solar module due to component availability, however flexible SP3-37 solar cell may also be integrated on top of the slot conductor as was done in [5] preserving the flexibility and size of the circuit.

D. Solar Powered Active Antenna

The complete circuit shown in Fig. 2 was simulated in harmonic balance ensuring an oscillation frequency near 920 MHz. The oscillation frequency depends on the current I0, which depends on the solar irradiation. The simulated variation of the oscillation frequency with the current I0 is shown in Fig. 3.

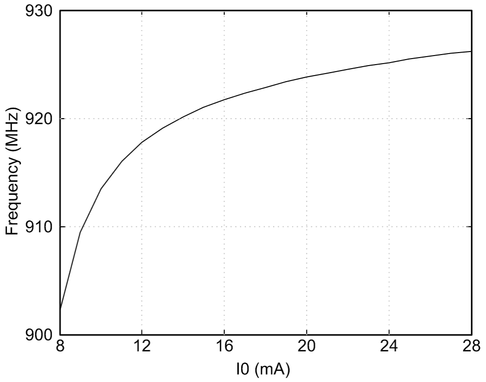

Fig. 3. Simulated oscillation frequency dependence on the short circuit current I0.

III. PERFORMANCE EVALUATION

Prototypes were fabricated and their operation was successfully verified using solar illumination as well as an indoor lamp. In the case of the PET circuit a Viva-Lite E27 25W full spectrum daylight lamp was used to activate the oscillator under indoor conditions. The final circuit components used in the prototype of Fig. 1a are listed in Table I, showing a reasonable agreement with the simulated values considering the various component yields and fabrication accuracy. Captured spectra shown in Fig. 4, indicate a noisy oscillator spectrum in the case of the lamp excitation. This could be potentially attributed to noise from the power supply of the lamp, although it was not verified. The capture corresponding to the solar irradiation also showed some noisy precursors at approximately 1.5 MHz offset from the carrier, which could potentially be attributed to intermodulation products from transmitted signals within the 900 MHz ISM band captured by the antenna. The use of a regulator circuit between the solar module and the oscillator is expected to eliminate frequency drifts associated with variations in the solar module output voltage and has been included in the paper based prototype of Fig. 1b.

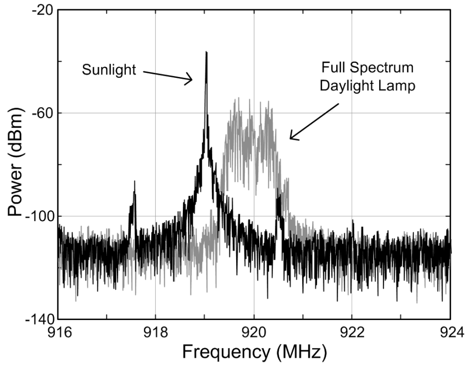

Fig. 4. Prototype oscillation frequency spectra.

The oscillator phase noise corresponding to the solar irradiation was measured using an Agilent PSA E4448A spectrum analyzer and is shown in Fig. 5. The measured phase noise at a 1MHz offset from the carrier was -108.7 dBc/Hz.

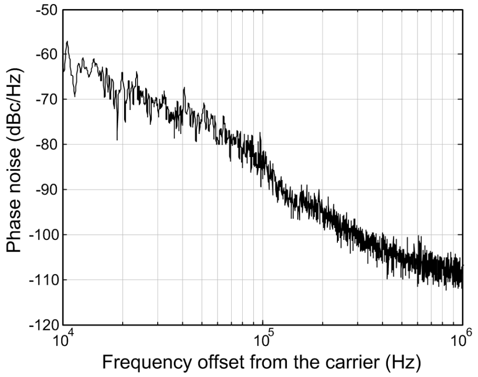

Fig. 5. Phase noise measurement. The measured oscillator phase noise was -108.7dBc/Hz at 1MHz offset.

Finally, the active antenna power gain product radiation pattern was measured in the anechoic chamber by exciting the solar module using the full spectrum daylight lamp. It should be noted that it was necessary to place the lamp at a distance of only a few cm from the active antenna in order to generate sufficient current to activate the oscillator. The measured radiation patterns are shown in Fig. 6. The power gain product (dBm) patterns at each plane XZ and YZ were taken with slightly different illumination conditions and are plotted in relative scale as it was not possible to measure the precise illumination conditions of the solar module and therefore the exact bias voltage and current of the circuit.

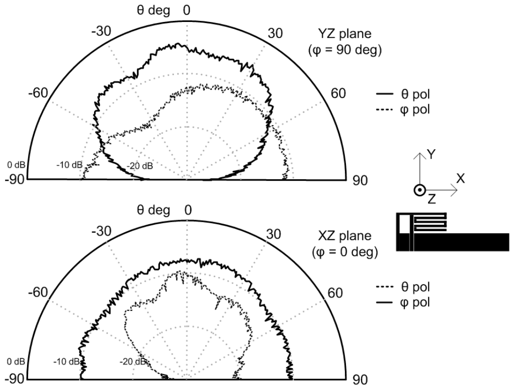

Fig. 6. Power gain product radiation patterns.

The same oscillator circuit shown in Fig. 2 was inkjet-printed and populated on a paper substrate (Fig. 1b) and its power spectrum was measured as well. The peak was observed at 863 MHz and it was drawing 22mA of current.

VII. CONCLUSION

The design of conformal, low profile active antenna oscillator beacon signal generator circuits on low cost flexible PET and paper substrates was demonstrated. Autonomous operation of the circuits was guaranteed by the use of a solar module. Such flexible and compact circuits find potential application in identification and monitoring applications.

ACKNOWLEDGEMENT

A. Georgiadis and A. Collado would like to acknowledge EU COST Action IC0803 (RFCSET) and EU Marie Curie project FP7-PEOPLE-2009-IAPP 251557. S. Kim, H. Lee, and M. Tentzeris would like to acknowledge SRC/IFC and NSF-ECS-0801798.

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