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Wireless Autonomous Communication and Energy Transfer

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***Abstract*—The feasibility study of a harmonic RFID chipless sensing tag is presented. The tag sensor is composed by an antenna at f0 = 1:2 GHz, a Schottky diode (HSMS2850), a balanced impedances bridge with a sensing variable element, and a second antenna working at 2f0 = 2:4 GHz. When interrogated with a signal at f0 the tag responds with a signal at 2f0 only when the bridge is unbalanced due to a variation of the sensible impedance value of at least 5. With this approach the system is energetically autonomous, being activated by the received signal and responds only when there is a change in the sensed quantity. No IC for carrier modulation is required to transfer the information.

Index Terms*—*chipless RFID; harmonic tags; RFID sensor;)

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I. Introduction

In view of the ever-increasing deployment of tagged objects wirelessly connected to networks, the ICT community seems to have taken up a revolutionary way towards the Internet of Things (IoT). The main challenge in this scenario is to find and foster technologies that can be very low cost, very low power, energetically autonomous, and as environmentally friendly as possible. The RFID approach seems to be one of the best candidates for these purposes; in particular, there is a category of passive RFID tags that greatly matches the new concept of "things" connected directly to the internet; this category is represented by the so-called "chipless passive tags". This type of tags has been developed pursuing the goal of transmitting the information, gathered from the environment, without integrated monolithic circuits on board in order to attain the maximum cost and energy saving. This has been proven feasible by some research groups worldwide, mainly implementing three different techniques: the more traditional Time Domain Reflectometry (TDR) and Spectral Signature based, proposed in [1]–[4], and the harmonic RFID [5]. This work is based on the latter approach and proposes a simple yet effective structure that can be exploited in much impedance based on the latter approach and proposes a simple yet effective structure that can be exploited in much impedance based sensing systems.

II. HARMONIC TAG CONCEPT

The harmonic tag is a chipless solution, deeply described in [5], that exploits the generation of the harmonics of the fundamental frequency in order to separate the input and output signals. When interrogated by the reader at a certain frequency f0, the tag responds at a harmonic frequency nf0 generated by a non-linearity embedded in the circuit (such as a Schottky diode), keeping the whole circuit passive [6]. In this way it is possible to transmit at least a bit of information without the need of any Integrated Circuit (IC) very simply. The approach proposed in [5] intends to transmit information (inherently more than one bit in the digitalized form) still passively and chip-lessly. The idea developed is to encode information in the phase difference between two signals transmitted by two orthogonal antennas, one acting as the reference for the other one [7]. In this way more information can be exchanged between the devices during the communication exploiting not only the presence or absence of Harmonics generation (one bit), but also the orthogonality of the antennas and the available phase difference between the radiated signals. As an example, the block diagram of such a tag is reported in Fig. 1.

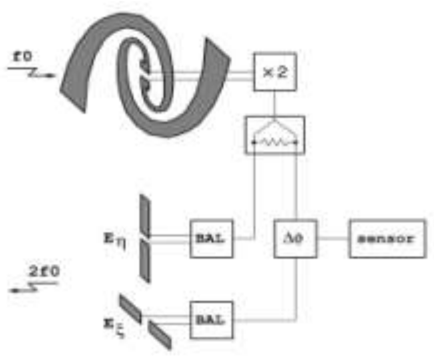

Fig. 1. Block diagram of the harmonic tag.

The harmonic tag is still activated only when there is a variation in the measured parameter and the transducer information is stored in the difference between the signals backscattered to the reader by the two orthogonal antennas.

III. PROPOSED APPLICATION AND CIRCUIT

The device proposed in this work aims at monitoring, passively and wirelessly, a certain parameter (without lack of generality: the temperature of an object) by means of an impedance-based sensible element just interrogated periodically by the reader. If, for example, the sensible device is a thermistor, the tag, once illuminated by the reader, will reply only when the variation of the temperature _T causes a variation of the resistance _R higher than a certain threshold _Rt, the latter depending on the circuitry sensitivity and on the thermistor temperature constant. The designed device is composed by: an input antenna working at f0, an output antenna working at 2f0, a Schottky diode able to double the frequency of the received signal and an impedance bridge in a differential configuration consisting of three fixed resistances R_{fix} and asensible element with variable resistance R_{var}. The bridge is connected to the second antenna and can be in two conditions: balanced, when no variation is sensed, and unbalanced, when the R_{var} generates a _R > _Rt; when balanced no output signal is produced, instead, when it is unbalanced the output voltage of the bridge differs from zero and an output 2f0 signal is generated and transmitted by the antenna back to the reader. Figure 2 shows the previously described block diagram.

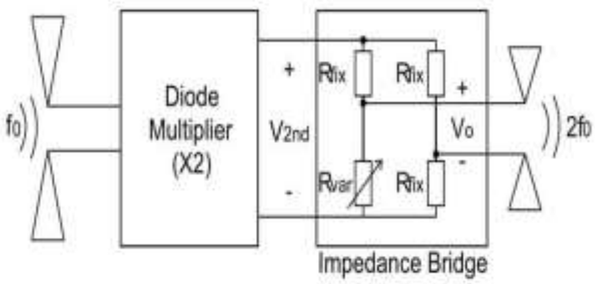

Fig. 2. Block diagram of the proposed tag.

IV. DESIGN

Before approaching the layout design of this circuit a preliminary step is needed: in particular, the R_{fix} value has to be determined by maximizing the 1st harmonic output power (Pout-harm) available at the load (output antenna) for a certain range of _R. This analysis has also to take into account the value of the input power at the fundamental frequency (Pin-fund), in order to optimize the reading distance and the power use. This design step has been realized by means of the Harmonic Balance tool, provided by ADS. The simulated schematic is reported in Fig. 3.

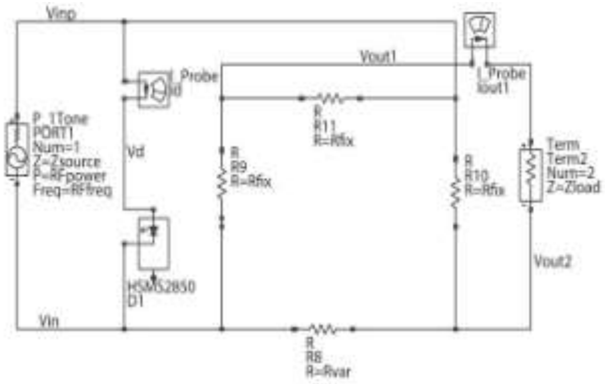

Fig. 3. Simulated schematic in ADS: the goal of this simulation is to optimize the input and output power values by choosing an opportune R_{fix}; the simulation is run by means of the Harmonic Balance tool.

The simulation results for the input power values of -5 dBm, 0 dBm, -10 dBm are reported in Table I. These values have been obtained by analyzing the same graph reported in Fig. 4 for each input power considered. In this paper only the one for Pin□fund = -5 dBm is shown because this is the value chosen for the input power in order to have a reasonable reading range and a fixed resistance close to 50. In order to have -5 dBm the transmitted power by the reader, at a distance of 50 cm, has to be about 16 dBm, considering the antenna gain of 5 dBi and assuming the free space loss model. It is possible to notice that, in the considered case, the output power is in the range of -57 dBm and -69 dBm, both of them detectable by a common reader with a sensitivity of at least -95 dBm.

TABLE I
MAXIMUM OUTPUT POWER VALUES OF THE HARMONIC OBTAINED BY VARYING THE INPUT POWER, THE ΔR AND THE R_{fix} .

	$\Delta R = 5$		$\Delta R = 20$	
$P_{in-fund}$	$P_{out-harm}$	R_{fix}	$P_{out-harm}$	R_{fix}
0 dBm	−57.3 dBm	40 Ω	−45.4 dBm	33 Ω
−5 dBm	−69 dBm	57 Ω	−57 dBm	51 Ω
−10 dBm	−84 dBm	73 Ω	−72 dBm	66 Ω

It is worth underlining that one of the advantages in the design of this kind of circuit is that, exploiting the harmonic generation, the input and output networks are relatively invisible to each other at the fundamental and harmonic frequencies; this allows to focus on the input and output sides separately. The input and output antennas have been designed as crossed dipoles in view of a System in Package on Paper (SiPoP) multilayer technology fabrication [8]. This fabrication method consists of the application of the lithographic steps to a copper adhesive laminate in order to obtain a certain layout

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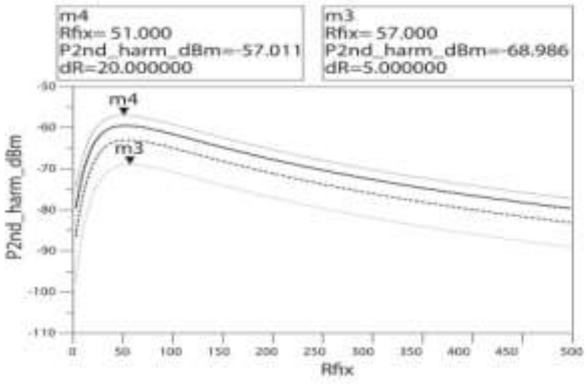

Fig. 4. Available output power of the first harmonic versus R_{fix}, for different values of ΔR. The input power in this case has been set at -5 dBm.

and transfer it to any kind of substrate, such as the simple photographic paper, by means of a sacrificial layer. A chipless sensor tag based on a variable resistor implemented in paper technology has been already proposed in [9], however the working principle there is to exploit the antenna mis-matching induced by the antenna load variation and the corresponding change of the backscattered signal without any harmonic generation; here we intend to improve the performance of that solution increasing the sensitivity (that is possible introducing the different working principle) and removing the environmental intrinsic sensitivity associated to the mono-frequency operation. In our design the chosen substrate is the Mitsubishi Electric photo-paper, while the conductive traces are made of the copper adhesive tape provided by ADVANCETM. In Table II the electrical and geometric characteristics of the substrate and the metal, are reported. It is important to underline that by adopting this technology, the proposed device is not only chipless and energetically autonomous, but also highly eco-compatible.

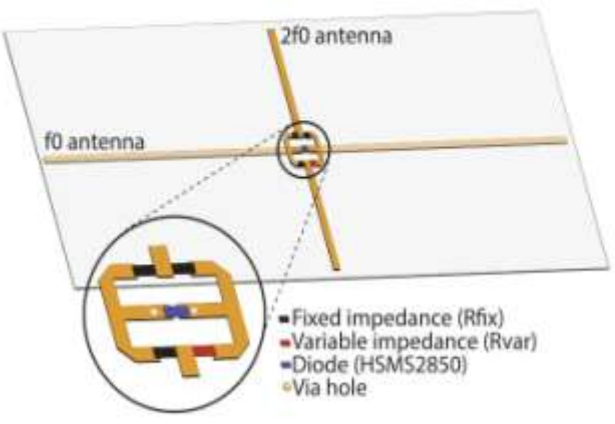

Fig. 5. Proposed layout: a multilayer crossed dipole structure connected with the impedances bridge and the Schottky diode, as shown in the schematic.

TABLE II
ELECTRICAL AND GEOMETRIC CHARACTERISTICS OF BOTH THE SUBSTRATE AND THE METAL ADOPTED IN THE EM SIMULATIONS.

Parameter	Symbol	Value
Paper relative permittivity	ε_r	2.9
Paper thickness	h	230 μm
Paper loss tangent	$\tan\delta$	0.08
Adhesive thickness	t_a	30 μm
Adhesive relative permittivity	$\varepsilon_{r,a}$	1.3
Metal thickness	t_m	35 μm
Metal conductivity	σ_m	5.8×10^7 S/m

The antenna layout is shown in Fig. 5. A multilayer structure is proposed: the antenna at f0 is in the bottom, instead, the antenna at 2f0, the bridge and the Schottky diode are on the top layer. The connection between the top and the bottom layer is possible thanks to via holes filled by a metallic wire soldered to the copper traces on both sides. The complete antenna structure have been simulated by the electromagnetic (S11 in dB) curves of the dipole at f0 (dashed line) and of the dipole at 2f0 (solid line): in both cases the resonance peak is widely under □10 dBm at the working frequency, proving a good matching.

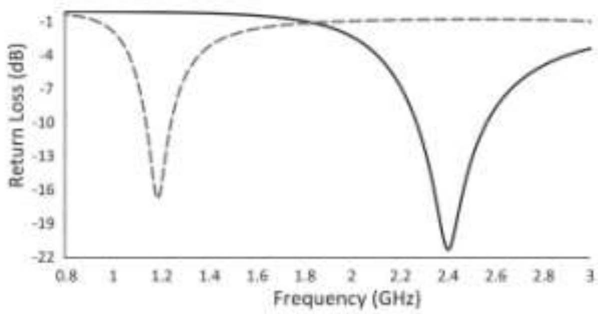

Fig. 6. Simulated return loss of the crossed dipoles: it is possible to notice the resonances at the fundamental frequency $f_0 = 1.2$ GHz (dashed line) and at the first harmonics $2f_0 = 2.4$ GHz (solid line).

Figures 7.a and 7.b report the 3D view of the radiation patterns of the 1:2 GHz dipole and of the 2:4 GHz dipole, respectively. As expected, given the crossed dipole structure, the two antennas irradiate orthogonally to each other. The antennas geometric characteristic and electromagnetic performance are summarized in Table III.

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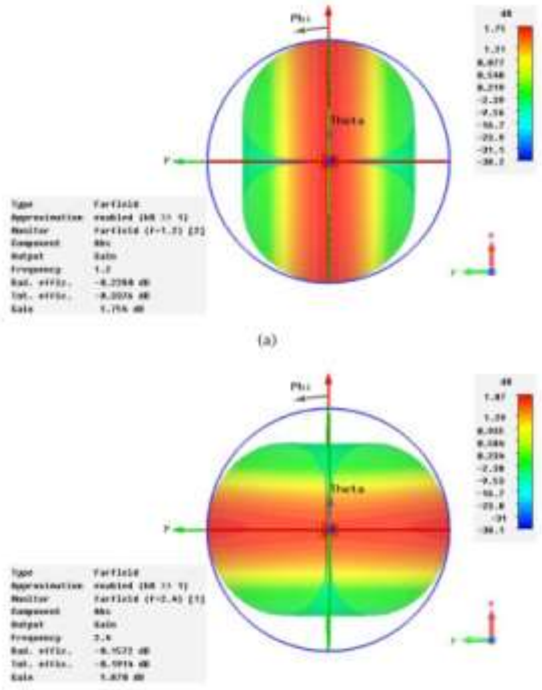

(b)

Fig. 7. Simulated radiation pattern of the antenna at 1.2 GHz (a) and 2.4 GHz (b); as expected they are orthogonal to each other. The gain is respectively of 1.75 dBi and 1.87 dBi.

TABLE III
ANTENNAS GEOMETRIC CHARACTERISTICS AND ELECTROMAGNETIC PERFORMANCE SUMMARY.

Parameter	1.2 GHz antenna	2.4 GHz antenna
Length (l)	54 mm	23 mm
Width (w)	1 mm	1.7 mm
Resonance peak	−16.7 dB	−22.2 dB
gain (G)	1.75 dBi	1.87 dBi

V. CONCLUSIONS

This work proposes and studies the feasibility of an harmonic chipless tag sensor able to monitor the change of a parameter by means of an impedance-based sensitive element (for example a thermistor to sense the temperature of an object). The proposed architecture, like other chipless ones (TDR - FDR) uses all the energy wirelessly transferred by the reader to the tag without empowering any electronic circuit for modulation; its efficiency, defined as the ratio between the power available at the input antenna at f0 and the power radiated at 2f0 by the output antenna, depends on RF losses and mainly on the conversion efficiency of the doubler. In this work it has been preliminary proven that a variation of 5, in a sensing thermistor with a quiescent resistant of 50, generates a second harmonic of □69 dBm that can be detected at the distance of about 50 cm considering a receiver sensitivity of at least □95 dBm and a reader antenna gain of 5 dBi in a way that, thanks to the harmonic RFID concept adoption, is totally immune from environmental scattering. Eventually, it is worth underlining that, thanks to the SiPoP implementation compliance and absence of ICs, the proposed tag is also eco-friendly, flexible, low-cost and energetically autonomous, thus well suitable for object monitoring in view of IoT applications.

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