Crossed Dipole Frequency Doubling RFID TAG based on paper substrate and ink-jet printing technology

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***Abstract*— A** #% %**TAG** % $ %% % % % ! %% % % % % % % % # % % % % #% % % %% %" #%" % % % % % % % % % % % % % % % " % % #% % % % % % % %

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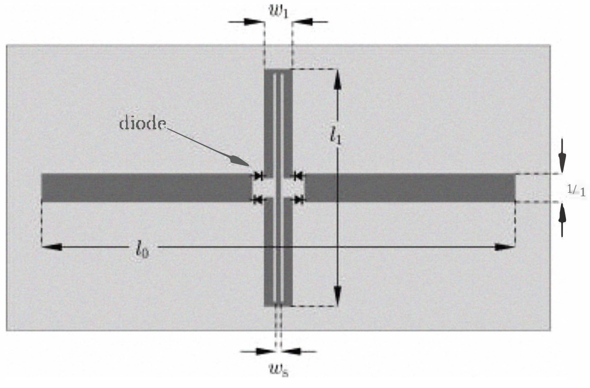
I. INTRODUCTION

Flexible electronics is facing a significant growth in terms of scientific attention and industrial investments. The consumer market continuous request for light weight, space saving and economical, as well as environmental friendly electronics, is leading the research towards the use of innovative technologies such as ink-jet printing on unusual substrates such as paper and Liquid Crystal Polymer (LCP). The exploitation of paper, in particular, is pushing the boundaries of conformal electronics where space saving, wearable shape and light weight are major requirements. Paper is recently showing to be more than a simple candidate for flexible RF electronics [1]: it's a low-cost substrate since it's organic and thus universally available; it is well suited for reel-to-reel manufacturing and mass production. Under the technological point of view there are several aspects that need to be set-up in a reliable process, such as conductive ink-jet printing, which will allow avoiding the commonly used etching process, the following ICs integration on paper and the interconnection methods in order to realize multi-layer electronic systems. Once these goals are achieved, paper will be the key solution for inexpensive electronics, due to its availability and low cost realization process and due to the fact that ink-jet printing is faster and cheaper technology with respect to the classical PCB manufacturing process.

In addition to technological aspects, new RF solutions are nowadays needed. The integration of nonlinear devices in a cost- and power-effective way that could be applicable in the very stringent space requirements of RFID's is the concept behind the present work. One-bit RFID systems are commonly used to check and monitor the possible presence of a transponder in the interrogation zone of a reader by means of simple physical effects [2]. Among various operating principles, the generation of harmonics is reliably adopted in the microwave frequency range, leading to the harmonic radar concept [3], [4] that has also recently been exploited in avalanche rescue systems to precisely localize victims buried under the snow.

In particular this paper will present the design, realization and measurement of a frequency doubling tag based on a crossed-dipole structure and UHF diodes realized on flexible substrate like plastic and most of all paper. Such a tag is useful for harmonic radar application and seems to be a good candidate for implementation exploiting fully green processes.



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In the tag with aerial antenna and diode a directional radar signal bounces back to the that of embedding the tags directly into the ski-pass cards. To this purpose both paper-based antennas [1] and organic diodes [5] can be used to provide a completely green solution at very low production costs.

II. THE CROSSED DIPOLE STRUCTURE

The structure has been previously proposed and simulated in [6], demonstrating to be particularly suited for the implementation of frequency doubling tag; such a structure exploits two dipoles in a crossed configuration and four diodes and has the advantage to separate fundamental and second harmonic antennas. Compared with structures based on a single radiating element such as single slots or dipoles, the crossed dipole approach offers an interesting advantage: the incoming and outgoing waves are orthogonally polarized and thus can be easily separated by polarization grids.

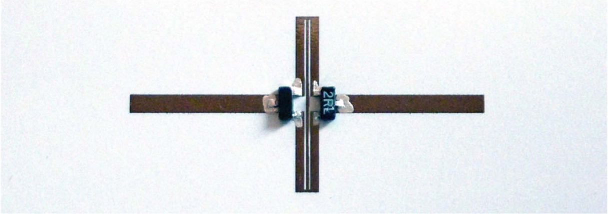
The layout of the proposed structure of the quasi-optical frequency doubler is shown in Figure 1. It consists of two $\lambda/2$ crossed-dipoles. The longest dipole receives the incoming power at the fundamental frequency f_0 = 3.5GHz, whereas the shortest dipole transmits the generated power at the doubled frequency $2f_0$ in an orthogonally polarized orientation. The multiplication is achieved by four diodes in a bridge configuration, thus forming a fully balanced multiplier bridge. Being the diodes self-biased without external DC-supply, a return for the self-generated DC-component must be provided for proper operation of the multiplier itself. This is done with a thin metal strip which is embedded in the short dipole connecting its outer ends. Thus a sufficient amount of inductance is provided together with DC path to avoid a major disturbance of RF performances.

III. MEASUREMENT RESULTS

The proposed tag was first realized on a plastic substrate with h = 0.813mm thickness and a dielectric constant ϵ_r of 3.38, a value very close to that of paper (ϵ_r = 3.2÷3.8). The dipole dimensions were $l_0=2l_1$=32mm, ω_0=1.6mm, ω_1=2.0mm and ω_S=0.2mm. Since the layout of the crossed dipole antennas, does not present any critical dimension and is completely uniplanar (no vias needed), it has been suitable for paper-based implementation.

Figure 2 shows the crossed-dipole printed on paper substrate. Silver conductive paint has been applied to fix the diodes on the substrate. The paint had to be cured to improve conductivity (2 hours in a controlled oven at $120^o C$ temperature). Figure 3 shows the test bench that has been set up for measurement purpose. The 3.5 GHz input frequency is generated by a frequency source and a 20dBm power signal is sent to the transmitting antenna. The helix antenna receives the doubled frequency and the signal power density is measured by the spectrum analyzer. The frequency doubling tag is aligned with the transmitting antenna and its distance is varied along this axis.

Figure 4 reports a comparison between the plastic and paper tag in terms of received power at the distance of 10cm. The paper tag shows a a lower conversion loss and this is confirmed by Figure 5, showing a comparison between the paper and plastic prototype measurements in terms of power level measured by the spectrum analyzer and the distance between the tag and the receiving antenna.



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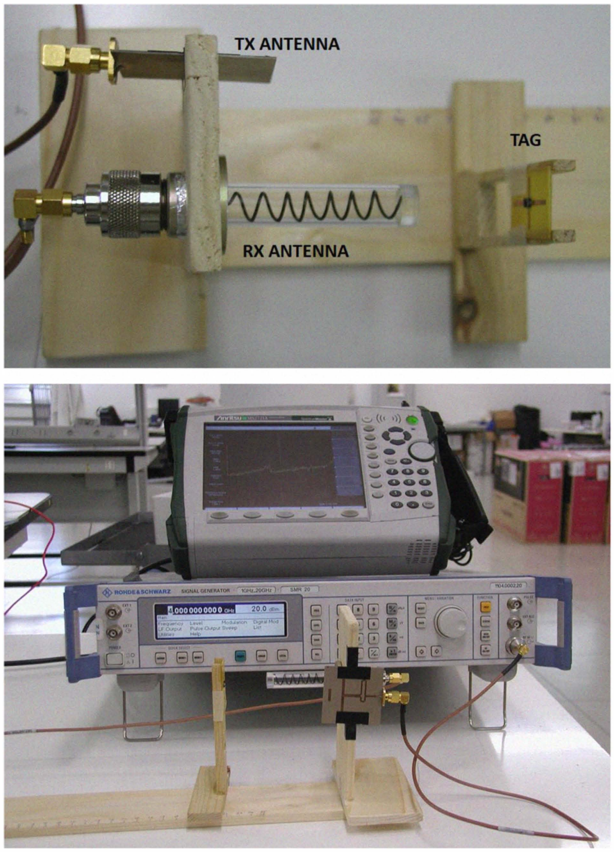

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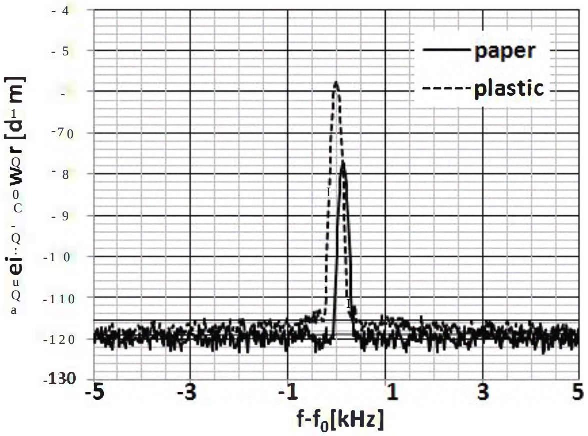
The lower conversion loss of the paper tag can be ascribed to the non negligible resistance of the conductive ink path. The longest dipole, in fact, shows around 2.5Ω resistance, the shortest dipole around 5.5Ω while the thin metal strip a 9.3Ω resistance. This is reasonable due to the fact that the material has not been passivated and protected by oxidation. Moreover the diodes threshold voltage measured in the plastic paper tag is 0.28V, while the paper tag shows 0.38V.

In order to properly investigate the reasons behind the losses, a further experiment has been carried out. The paper tag has been placed at the fixed distance of 10cm from the receiving helix antenna. The transmitting antenna operates at a



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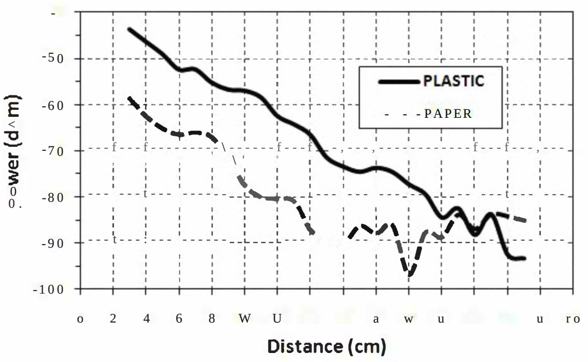

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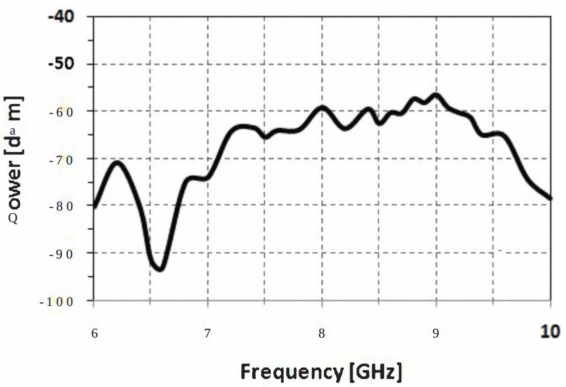
fixed transmitted power of 20dBm. The transmitting frequency has been varied between 3GHz and 5GHz an the doubled frequency has changed accordingly. The measurements result is shown in Figure 6. The crossed dipole seems to be shifted in frequency, showing a better performance at 9GHz (4.5GHZ of transmitted frequency), similar to that showed by the plastic tag at the same distance. The frequency shift is due to the uncertainty in both the intrinsic diodes capacitances and paper substrate dielectric constant.

Although a further optimization is needed, these results show that paper substrates and ink-jet technology are suitable for RFID applications. Some further efforts should also be devoted to improve the technological aspects such as passivation and components assembly.It is worth noticing that the achieved reader-tag distance is already sufficient for many applications such as ski-pass cards. In addition such a reading distance has been obtained with only 20dBm output transmitter power.

IV. CONCLUSION



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A fully balanced crossed dipole structure for frequency doubling RFID TAG for harmonic radar has been proposed. A comparison between a plastic and a paper prototype has been carried out and several results reported, showing that paper is a suitable, environmentally-friendly and cost effective candidate for the realization of green and flexible electronics in the area of UHF RFID's.

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