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A Simple Frequency Domain-Based Chipless Radio Frequency Identifier (RFID) System

Massimo Donelli[a,b,c], Viviana Mulloni[d], Giada Marchi[d], Irene Dal Chiele [a,b]

[a] Department of Civil, Environmental and Mechanical Engineering (DICAM), University of Trento, Trento 38123, Italy

[b] Center for Security and Crime Sciences, University of Trento and Verona, Italy

[c]Radiomic Laboratory, Department of Economy and Management (DEM) University of Trento, Italy

[d] Center for Sensors and Devices (SD), Fondazione Bruno Kessler (FBK), Trento 38123, Italy

Correspondence to: Massimo Donelli, massimo.donelli@unitn.it

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Abstract

This paper proposes a chip-less RFID tag based on microstrip resonators that works in the microwave frequency bands. The chip-less tag proposed is low-cost, easy to fabricate, and can be read wirelessly at long distances. Two tag prototypes, one with a single and the other with multiple resonators, have been designed, fabricated, and experimentally assessed. In particular, microstrip square resonators slotted in the center and loaded with capacitive structures have been considered. Moreover, to improve the sensibility and the operative range and to avoid alignment problems, the tags have been mounted on the focus of a linear 2D parabolic mirror. The obtained results are quite satisfactory in terms of operative range,

sensibility, and accuracy. The preliminary experimental assessment shows that the proposed chip-less configuration can be easily adapted to different application scenarios to improve the passive signal and wireless reading capability.

Introduction

Radiofrequency identification (RFID) is a well-known, non-invasive, and cheap technology [1], widely used in different practical applications with success [2, 3]. RFID systems are the most widespread method to protect, track, and prevent theft of luxury goods and foods in supermarkets and shops, acting ~~as~~ with unique identification codes [4, 5, 6]. RFIDs have been successfully used to reduce electoral fraud [7], identify people [8], control the production phase of drugs [9], and other practical applications [10, 11]. RFIDs have also been successfully used as monitoring systems to measure environmental parameters such as humidity, temperature, and for material ~~moisture~~ property estimation [3, 12, 13, 14]. Despite the success and widespread commercialization achieved, RFIDs present some drawbacks. In particular, the main limitation of ~~standard~~ near-field magnetic coupling (NFC) RFIDs is the required proximity between the reader and tags because they usually work thanks to an inductive coupling mechanism. Also far-field active and passive tags were proposed to improve the RFID system's operative range, obtaining good results [15, 16]. They work at higher frequencies, mainly in the UHF and microwave frequency bands. Unfortunately, in these attempts, the transmitted power required remains quite high in comparison to ~~a~~ standard NFC RFID system. Another interesting solution aimed at improving the distance between the reader and tags is the use of UWB technology [17, 18]. These attempts combine the capabilities of RFID tags and wireless devices, such as a radio modem, Zigbee, or WiFi modules [19]. This integration is effective in improving the range of standard basic RFID systems; the problem is that it requires the presence of an expensive RF front end. Another limitation of standard RFID tags is that they require specific integrated circuit chips to store and transmit the identification information. This prevents their use in large-scale industrial applications where the cost of the tags is comparable with the cost of goods, especially for large productions. Another issue for RFID tags is their dimensions since they usually operate at low-frequencies. To reduce the tag dimensions in order to hide it or to improve its coding capability the solution is to increase the working frequency. In such a scenario, a methodology that permits the impression of a passive tag directly on the product's surface to become a remotely readable, non-invasive, and cheap label is the so-called chip-less RFID [20, 21, 22, 23].

Chip-less technology is a chip-free tagging strategy able to encode the identification information directly in the tag's physical structure without dedicated chips. This led to a simple and low-cost fabrication process that permits the design of cheap mass-production tags thanks to suitable printing strategies [24]. Another benefit is that they can be made flexible, by making them on flexible substrates (e.g. paper, thin polymers) or directly on fabric. They can be easily integrated into industrial production processes characterized by high mechanical stress, temperature, or the presence of chemical and corrosive substances. In this work, we present a frequency domain chip-less RFID system based on tags composed of several microstrip resonators that try to combine the advantages of standard and chip-less RFIDs. The work is organized as follows: Section 2 introduces the RFID chip-less systems and details the reader and chip-less tag structures. Section 3 is devoted to the experimental assessment. Finally, Section 4 provides the concluding remarks.

System description

An accurate description of the chip-less RFID system will be described in this section. First, the bistatic reader structure is described. Then, a detailed description of the two chip-less tags used for the experimental assessment is reported.

Reader Description

Let us start considering the bistatic reader structure reported in Figure 1. It consists of a vectorial network analyzer (VNA) used simultaneously as a microwave generator and receiver and two high-gain antennas connected to the VNA output and input ports, respectively. This is a typical bistatic configuration that makes use of two antennas. The transmitting antenna is connected to the VNA output port and provides the interrogating electromagnetic wave. The receiving antenna is directly connected to the VNA input port (which acts as a receiver). Concerning the data encoding, it works as follows: the number of resonators represents the bits number of the code. Each resonator is designed to resonate at a specific frequency, its presence represents a bit of value 1, if a resonator is absent, the correspondent bit has a value of 0. The reader emits a wide band interrogating electromagnetic wave, which covers all the frequencies associated with the different tag's resonators. A fraction of the interrogating electromagnetic is reflected to the reader, received by the receiving antenna, and measured by the VNA. The resonance peaks on the VNA screen are shown due to the presence of resonators placed on the tag.

Chip-less Tags Description

The structure of a typical frequency domain chip-less tag is straightforward. It only consists of a set of resonators printed on a dielectric substrate with different techniques such as photolithography, control numeric machine (CNC) cutter, or additive conductive ink. An example of two chip-less tags fabricated with photolithography is reported in Figures 2 and 3, respectively. In particular, the tag reported in Figure 1 is a one-bit tag composed of a single microstrip square resonator [25], while the prototype reported in Figure 2 is a five-bit chip-less tag. Both tags are fabricated on a dielectric substrate RO4350 (ε_r=3.48, tan(δ)=0.00037 @ 10 GHz, substrate thickness t_s = 168μm, metallization thickness t_m = 17μm) by exploiting a photolithographic fabrication process within the clean room ISO 5 facility at Fondazione Bruno Kessler (FBK). The physical dimensions of the single-bit tag in Figure 2 are 30×30 mm^2 and its resonance frequency is at f_1= 2.2 GHz, while the dimensions of the five-bit tag are 50×60 mm^2, with the following set of resonance frequencies (f_1= 2.5 GHz, f_2= 2.7 GHz, f_3= 3.0 GHz, f_4= 3.4 GHz, f_5= 3.6 GHz).

Experimental Assessment

A selected set of measurements has been carried out to demonstrate the capabilities of the chip-less tag sensors and systems, considering the tags reported in Figures 2 and 3, respectively. The experimental setup, regarding Figure 1, consists of a vectorial network analyzer (VNA), two Vivaldi horn antennas (model PE9887-11 Pasternack company, range 1GHz -18GHz, Gain g= 11 dBi), a dielectric pedestal (for positioning the tags). A small bidimensional parabolic reflector mirror has been fabricated to simplify the alignment between the reader and the tags, while enhancing the passive tag signal without the need for active components in the system. The mirror has been obtained with additive technology employing a 3D printer and PLA material coated with a thin aluminum film. The tags are placed on a dielectric support located on the linear focus of the mirror, as can be noticed from Figure 4, which reports the experimental setup and the detail of the five resonators tag placed on the focus of the parabolic mirror. The experimental setup was not implemented in a shielded room as you can see in Figure 5, so it is subjected to external electromagnetic interferences. To limit their effects before measurements, the baseline (obtained with the automatic calibration of the VNA) has been collected to take into account the external background noise. In the first experiment, the single-bit tag was positioned on the focus of the parabolic mirror at an operative distance of d = 15 cm. The frequency span of the VNA is set in a range between 1GHz and 3GHz to cover the tag resonator frequency. The measures at the VNA are reported in Figure 5. As can be noticed, the single tag resonator is correctly identified, with an evident frequency peak of -20 dB located at f = 1.99 GHz. A frequency shift is observed, comparing the measured and theoretical resonator frequencies. In particular, the resonator should resonate at 2.2 GHz instead of 1.99 GHz. This frequency shift is probably due to the tolerances of the fabrication procedure and of the dielectric material. The second experiment concerns the measures of the five-bit tags. It has been placed on the reflector mirror focus support, as depicted in Figure 4. The distance between the reader and the tag was d = 25 cm. The frequency span of the VNA is set in a range between 1 GHz and 3 GHz to cover the tag resonance frequencies, and the measures at the VNA input are reported in Figure 6. The results are not so satisfactory only three of the five resonators have been correctly detected. However, the three frequency peaks of the detected resonators are visible. Also, in this case, a frequency shift has been observed for all three measured peaks in particular; the first resonator should resonate at f_1=2.5 GHz instead of 2.35 GHz, the second at f_2=2.7 GHz instead of 2.59 GHz, and the third at f_3=3.0 GHz instead of 2.77 GHz, as stated above resonators f_4=3.4 GHz and f_5=3.6 GHz were not detected. The strong frequency shifts in these cases are probably due to the material tolerances and the mutual interactions between the resonators.

Conclusions

A simple frequency domain chip-less tag based on five microstrip resonators has been presented and experimentally assessed. The tag has been mounted on a parabolic 2D reflector mirror's focus to enhance its operative range. The preliminary measurement campaign demonstrated the effectiveness of the proposed tag. An operative range of about 25 cm has been reached only considering the low signal produced by a vectorial network analyzer and focused by two Vivaldi horn antennas. The proposed experimental setup demonstrated their capabilities to operate at high-frequency bands, permitting further miniaturization of the tags and theoretically high operative ranges. The obtained preliminary experimental results are very promising and demonstrate the capabilities of these compact chip-less tags as a valid alternative to standard RFIDs, which are more expensive and can operate at a distance of centimeters.

Declarations

Conflict of Interest

The Authors declare that there is no conflict of interest.

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Author Contributions

MD, VM, GM, ID: Conceptualization, Investigation, Methodology, Data Collection, Data Analysis, Writing – Review & Editing.

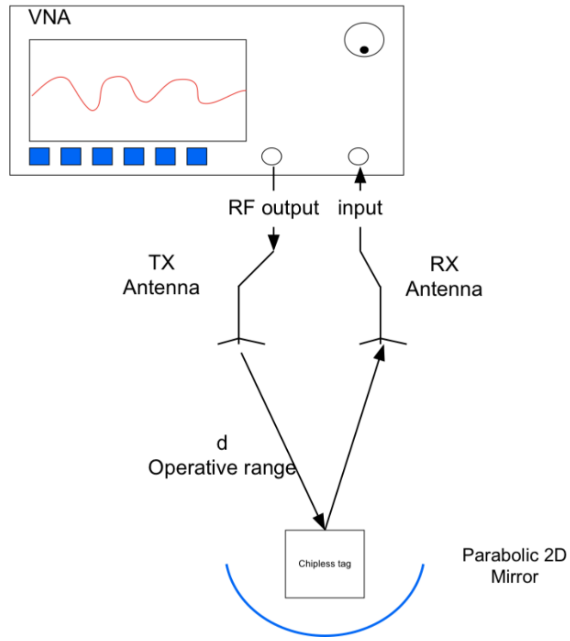

Figure 1. Schema of the chip-less RFID system.

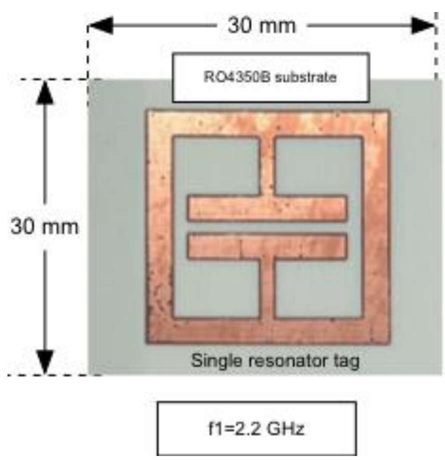

Figure 2. Photo of the single square microstrip resonators tag.

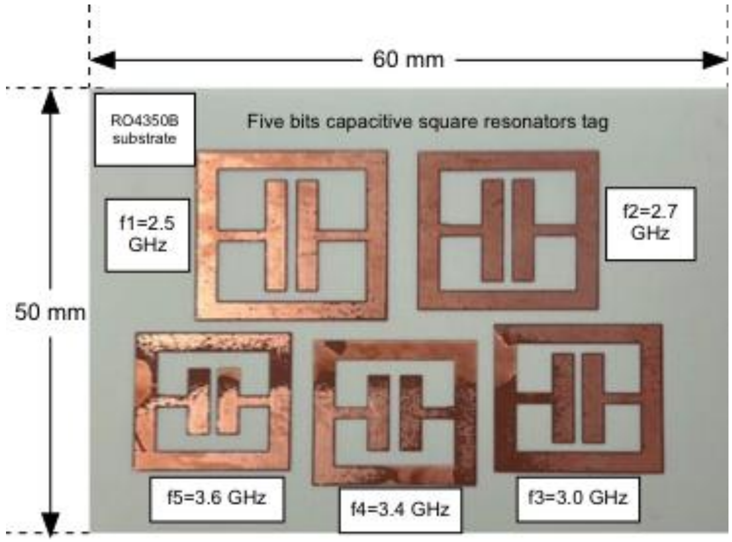

Figure 3. Photo of the five square microstrip resonators tag.

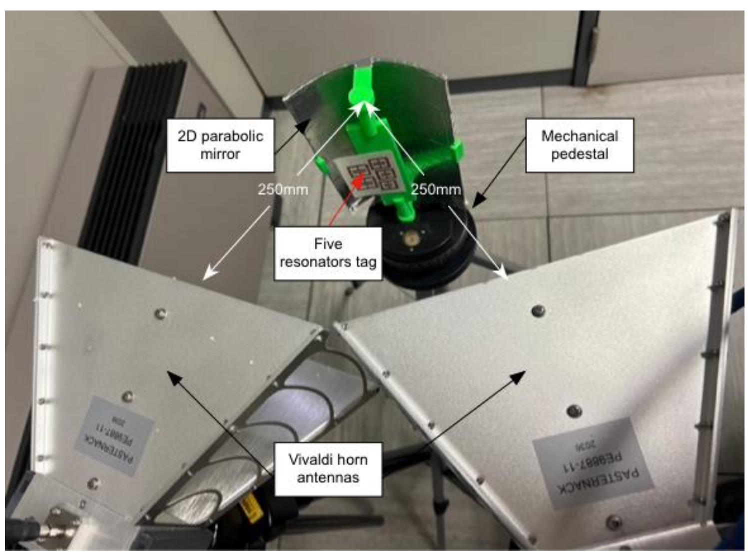

Figure 4. Photo of the experimental setup. In the photo, the five resonators chip-less tag prototype is placed on the focus of the parabolic mirror.

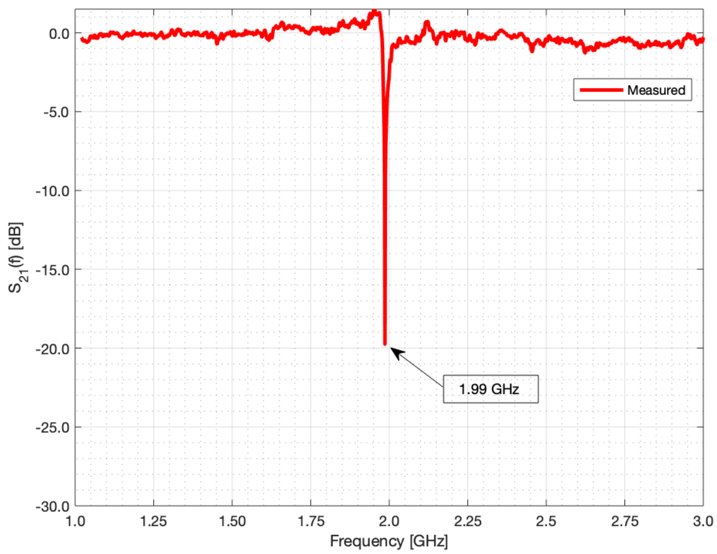

Figure 5. Single resonator tag response measured at the reader output, operative range 15 cm.

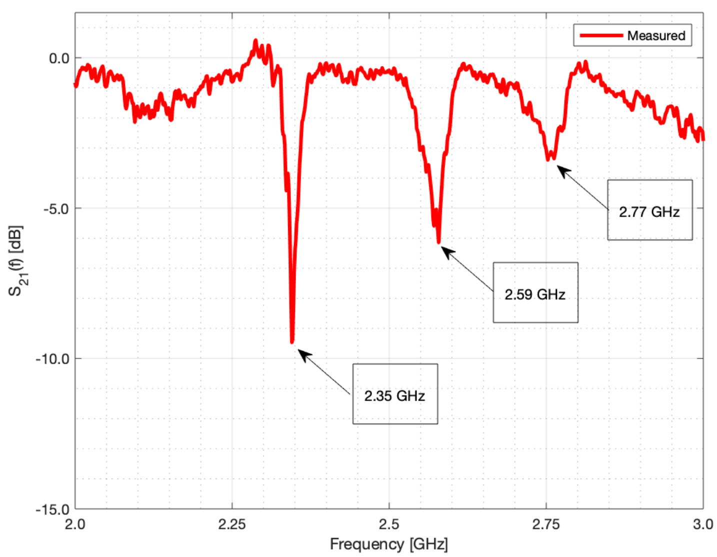

Figure 6. Five resonators tag response measured at the reader output. Operative range 25 cm.

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