A Novel "Green" Inkjet-Printed Z-Shaped Monopole Antenna for RFID Applications

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Abstract— **In this paper, a novel "green" inkjet-printed antenna for UHF Radio Frequency Identification (RFID) tags is presented. A slotted Z-shaped monopole configuration is selected and fabricated using inkjet-printing technology on a flexible, low-cost paper substrate utilizing a simple, fast, and environmentally friendly process. The design characteristics of the antenna are verified and the simulated results are compared with measurements showing good agreement.**

I. Introduction

The demand for flexible, low cost, efficient, broadband and compact size antennas for UHF RFID tags and wireless sensors (WSN) has witnessed a vast increase in the last couple of years due to the proliferation of wireless applications especially in fields such as: automotive/logistics tracking, biomedical sensing, item level tracking, retail management, and security [1]. Plus, their recent integration with power scavenging circuits (solar, piezoelectric, wireless) has enabled the realization of truly autonomous ubiquitous WSN nodes.

The most common antenna design for an RFID tag is a dipole [2]. In this paper, a CPW-fed monopole antenna [3] is proposed, because of its broadband characteristics and the use of a ground plane as an extra shield for other electronics, sensors, and power units in the system. Usually, the impedance of RFID IC's depends on frequency and the applied input power, and is sensitive to fabrication tolerances, thus decreasing the return loss and making the matching to the antenna more challenging. However, a wideband monopole antenna can achieve excellent matching without requiring a differentially fed input signal like a dipole, due to the existence of its ground plane. This ground plane also makes easier the 3D integration of the antenna with other electronic components (sensors, power sources, ICs) of the tag, alleviating the cross-coupling and interference.

The proposed antenna was designed and simulated using the 3D EM Simulator Ansoft HFSS and was fabricated on a paper substrate using inkjet-printing technology. First, the antenna design will be outlined and then the inkjet printing technique along with the measured results will be presented.

II. Antenna Design

The geometry of the proposed CPW-fed printed monopole antenna is shown in Fig. 1. The paper substrate has thickness of 0.254mm, relative permittivity of 3.4 and loss tangent of 0.08 with overall dimensions 75mm (width) x 100mm (length), including the feeding line. A CPW transmission line consisting of a single metallic layer is selected for feeding the antenna because of its easy integration on the paper substrate due to its planar structure. The antenna structure is composed of a planar Z-shaped rectangular monopole with width 50mm, length 56mm and a spacing of h=11mm from the ground plane. Two rectangular slots are embedded into the radiating element from both side edges, resulting in a meander-like antenna as shown in Fig. 1. Both slots have a width of 10mm and lengths of $l_1=l_2=40$mm, chosen to optimize the matching of the antenna to the load.

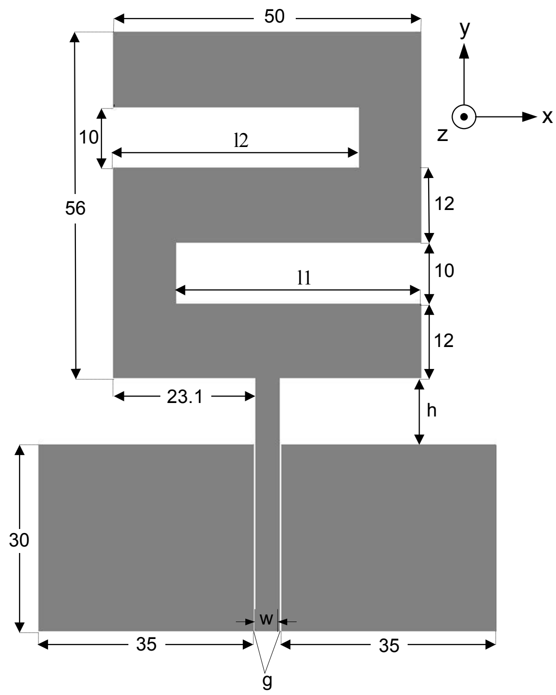

Fig. 1 Z-shaped CPW-fed printed monopole antenna configuration

RFID antenna design should fulfil several design requirements: "global-operability" UHF bandwidth [USA (902–928 MHz), Europe (865–868 MHz)] RFID band, omnidirectional radiation pattern, impedance matching with RFID circuitry, long read range, and compact size. Optimizing these parameters involves however inevitable tradeoffs between them [4]. Maximizing the size of the ground plane increases the directivity of the antenna, because the ground acts as a radiating element and also shields it from the rest electronic circuitry; however it increases the profile of the antenna. Impedance matching in RFID tags between the antenna and the load is very significant for the range maximization. In order to ensure maximum power transfer from the antenna to the load, the input impedance of the antenna must be conjugate to that of the tag's load chosen to be (37.3 + j65.96Ω) in our design, at the tag's operating frequency 904.5MHz [2]. The parameters h, g, and w were also optimized to fine tune the desired antenna impedance and increase the directivity. The height (h) of the radiating element from the ground has a major influence on the performance of the antenna, as it modifies the radiation pattern and the impedance of the antenna. Increasing it, guided waves of the antenna are transitioning more efficiently into free-space waves and the impedance becomes more capacitive. Maximizing it however results into thick and difficult to mount RFID tags. The value of the parameters after optimization where found h=11mm, g=0.3mm and w=3.8mm.

III. Prototype Fabrication

The proposed antenna was fabricated on a typical flexible photo paper substrate using inkjet printing technology, a direct-write technique for fabricating electronic circuits and RF structures. Here, the benefits of using paper as a substrate along with the inkjet printing process will be discussed.

A. Paper Substrate Advantages

There are many aspects of paper that make it an excellent candidate for an extremely low cost substrate for RFID and RF applications, such as antenna fabrication [5], [6]. Paper has excellent dielectric characteristics. Its dielectric constant is close to air meaning electromagnetic power can penetrate easily even if the RFID is embedded in the substrate. The high demand and the mass production of paper make it widely available and at the same time the lowest cost material ever made. From a manufacturing point of view paper can undergo large reel-to-reel processing, thus mass fabricating RFID inlays on paper becomes more feasible. Paper also has low surface profile and with appropriate coating it is suitable for direct write methodologies, such as conductive inkjet printing, instead of the traditional metal etching techniques. Moreover, paper is one of the most environmentally-friendly materials, because of its high biodegradability with respect to other ceramic substrates, such as FR-4, making it the ultimate solution for the first generation of truly "green" RF electronics and modules.

B. Conductive Inkjet Printing Technique

Inkjet printing is a fast, simple, environmentally-friendly process for efficiently printing electronics on paper [5]. Inkjet Printing; unlike etching which is a subtractive method by removing unwanted metal from the substrate surface, jets the single ink droplet from the printer's nozzle to the desired position, therefore, no waste is created, resulting in an economical fabrication solution. Silver nano-particle inks are usually selected in the inkjet-printing process to ensure a good metal conductivity. In addition, printing is a simple, fast and safe process that is completely controlled from the designer's computer and does not require a clean room environment. The savings in fabrication/prototyping time that inkjet printing brings to RF/wireless circuits are very critical to the ever changing electronics market of today's verifying its feasibility as an excellent prototyping and mass production technology for next generation electronics especially in RFID applications. The inkjet printer used to print the proposed monopole antenna is a "Dimatix Materials Printer DMP-2800 Series", which is depicted in Fig. 2.

Fig. 2 Dimatix Materials Inkjet Printer DMP-2800 Series

After the printing of the antenna, it is essential to cure the prototype in order to increase the conductivity of the silver ink [6]. The prototype is cured in a high precision industrial oven at a constant temperature of 100^o C for 10 hours. The conductivity of the silver ink varies from $0.4\sim2.5\text{x}10^7$ Siemens/m depending on the curing temperature and duration time. Before the cure, large gaps exist between the particles, resulting in a poor connection. After the cure, the high temperature has caused the particles to expand and the gaps between them to diminish, as shown in Fig. 3. That guarantees a virtually continuous metal conductor, providing a good percolation channel for the conduction electrons to flow and consequently high conductivity.

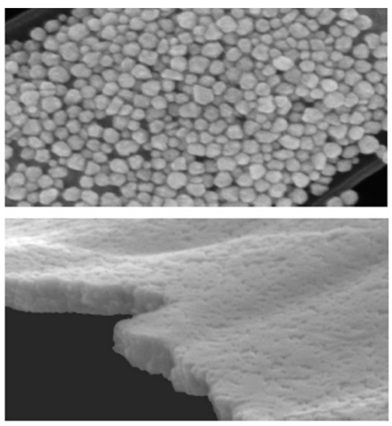

Fig. 3 SEM images of a layer of printed nanoparticle silver ink, before and after a 10 minute cure at 180^o C

Finally the prototype is assembled by attaching a typical SMA connector at the feeding line of the antenna, as shown in Fig. 4. An adhesive silver epoxy is utilized to mechanically connect the SMA connector to the paper substrate and ensure conductive electrical contact between the connector and the printed silver antenna trace. In terms of evaluating the inkjet printing technique, the antenna was also fabricated with formation of self adhesive thin copper tape glued on the paper.

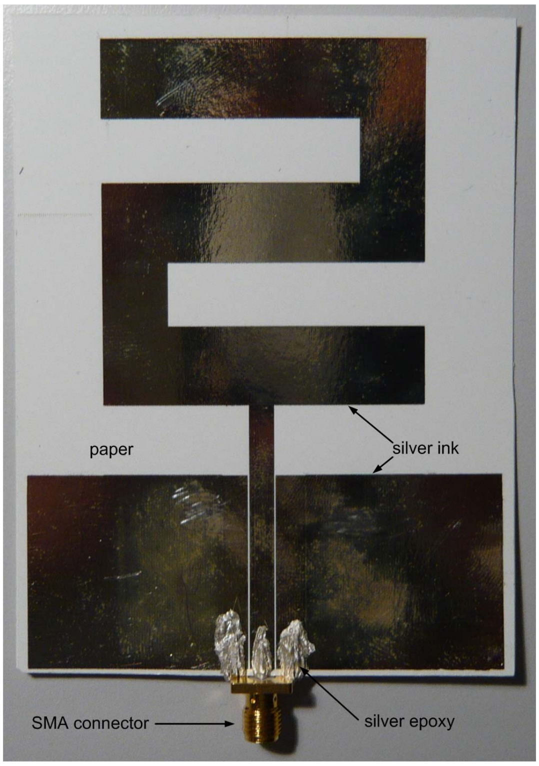

Fig. 4 Prototype of the fabricated inkjet printed antenna on paper substrate with attached SMA connector

IV. Simulation And Measurement Results

The performance of both prototypes (inkjet-printed and copper tape fabricated) was experimentally tested and the results are presented here.

Fig. 5 shows the simulated and measured frequency response of Return Loss of the fabricated antenna featuring a good agreement. It can be seen from the simulations that the inkjet-printed antenna has a resonance at 904 MHz and a –10dB impedance bandwidth of 132 MHz (822–954MHz) corresponding to 14.6% around the resonant frequency. The measured S_{11} plot of the inkjet-printed antenna is resonant at 898Mhz with bandwidth of 82Mhz (860–942MHz) corresponding to 9.1% around the resonant frequency, where the copper tape fabricated antenna displays a return loss plot with resonant frequency at 906Mhz and a bandwidth of 68Mhz (874 – 942MHz) corresponding to 7.5%.

The radiation characteristics of the proposed antenna have also been investigated and are depicted in Fig 6. The simulated radiation patterns for the x-z plane and the y-z plane at the resonant frequency 904.5 MHz demonstrate a radiation pattern similar to a conventional monopole antenna, displaying an omnidirectional radiation pattern on the x-z plane and a directional pattern with 2 nulls on the y-z plane. The directivity of the antenna was found 0.2dBi in simulation.

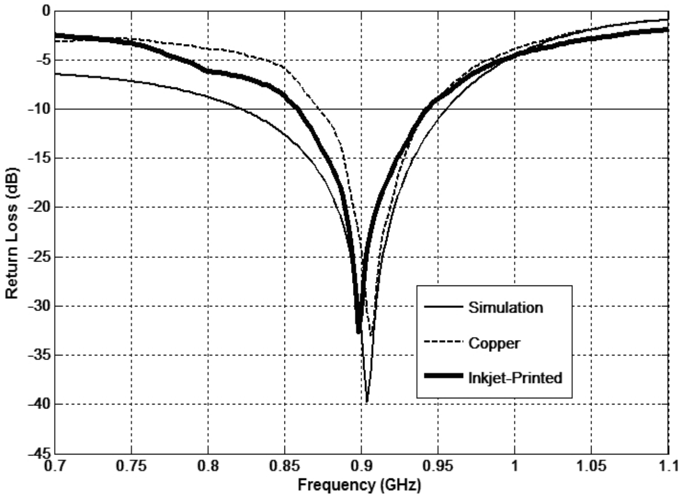

Fig. 5 Simulated and measured Return Loss of the inkjet printed and copper-tape fabricated monopole antenna

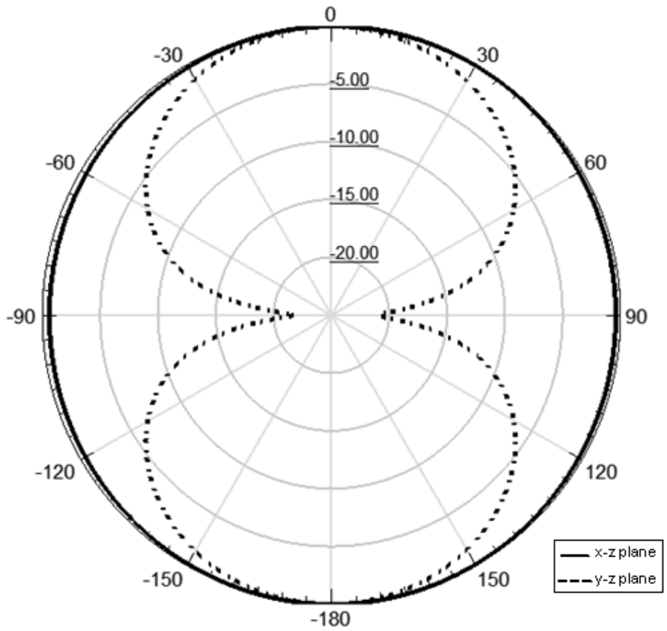

Fig. 6 Simulated radiation pattern of the Z-shaped monopole antenna for the x-z plane and the y-z plane at the resonant frequency 904.5 MHz

V. Future work/Internet of things

The proposed RFID antenna can be part of integrated modules on paper using inkjet printing technology. There is growing interest for wireless sensing/tracking/communication applications, married with RFID technologies [7]. This demand is further enhanced by the need for inexpensive, reliable and durable wireless RFID-enabled sensor nodes that is driven by several applications such as logistics, Aero_ID, anti-counterfeiting, supply chain monitoring, space, healthcare, pharmaceutical, and is regarded as one of the most disruptive technologies to realize truly ubiquitous ad-hoc networks.

Sensor nodes can compose "ad-hoc" Wireless Sensor Networks (WSNs) that beside processing and communication capabilities possess one or more sensing capabilities. Due to the big number of nodes that are usually deployed throughout the sensor field and the randomness of deployment and data generation and aggregation, various WSN routing and multihopping protocols have been developed. These protocols result in power lifetime efficiency and drastical range improvements [8].

The wireless and self configuring networks comprising of sensors and RFIDs on everyday objects will eventually set the foundation for the evolution of the first true implementation of "Internet of Things" that will enable novel forms of communication and cognition between people and things and between things themselves.

VI. Conclusions

A novel "green" CPW-fed Z-shaped printed monopole antenna for RFID applications has been proposed and fabricated on paper substrate, using inkjet-printing technology. This novel antenna was experimentally tested and the measured results showed good agreement with simulations featuring a "global-operability" UHF-RFID band and potentially enabling trully ubiquitous wireless sensing nodes.

Acknowledgment

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