Broadband UHF RFID/Sensor Modules for Pervasive Cognition Applications

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***Abstract*— In this paper, two inkjet-printed broadband antennas on flexible and organic substrates namely paper and Liquid Crystal Polymer (LCP) for the UHF Radio Frequency Identification (RFID) and sensing applications is presented. Paper is an excellent candidate for ultra low cost, flexible substrate while LCP, an organic and flex substrate shows superior electrical and mechanical characteristics while being at low cost as well. Two simple versions of CPW-fed Monopole configurations are selected: a planar configuration on LCP as well as one utilizing through vias on paper in order to prove the proof of concept of 3D functionality on paper. The antennas are fabricated using inkjet-printing technology utilizing a simple, fast, and environmentally friendly process. The design characteristics of the antennas are explained and the simulated results are compared with measurements showing good agreement.**

I. Introduction

The motivation of this work starts with the increasing demand for ubiquitous automatic cognition and wireless sensing. The two main factors targeted are cost and performance. While cost is a major key requirement for the mass deployment or Radio Frequency Identification (RFID) and sensor components, performance is equally important especially as technologies are emerging toward higher frequencies as they are bandwidth hungry. That being said, the two main parameters in the system cost analysis for good high frequency performance are the material and process used in fabrication. This paper will stress a low cost, fast, simple, yet efficient process of printing conductive silver nano-particles on one of the lowest cost substrates available in the market [1]. This paper will explore the printing on ultra low cost paper; as well as Liquid Crystal Polymer (LCP) for its superior mechanical and electrical characteristics [2]. LCP is favored in certain scenarios where paper might face some poor performance due to water absorption and humidity. The next sections of this paper will describe the two substrates paper and LCP stating their benefits, the inkjet printing process, while giving simple antenna examples showing the proof of concept of the merging of inkjet printing and the two substrate technologies.

II. Paper

Paper is considered one of the best candidates for organic substrates for RFID/sensing applications in terms of lowest cost substrate while having good electrical properties for UHF frequencies. It is not only environmentally friendly, but can also undergo large reel-to-reel processing and hence can be manufactures in mass quantities. Paper also has low surface profile with appropriate coating. This is very crucial since fast printing processes, such as conductive paste inkjet printing, can be used instead of metal etching techniques. In addition, paper is compatible with circuit printing by direct write methodologies. This is one of its biggest advantages since active tags require additional modules like sensors and batteries to be mounted on or embedded in. A fast process like inkjet printing can be used efficiently to print these modules on or in the paper substrate. Paper can also host nanoscale additives (i.e. fire-retardant textiles) and can be hydrophobic. Most importantly, its dielectric constant ε_r (~3) is close to air's which means electromagnetic power can penetrate easily even if the RFID is embedded in the substrate [1].

Dielectric constant, ε_r and loss tangent tanδ, the two most important dielectric properties for paper have been characterized in [1] using methods such as: microstrip ring resonator, cavity resonators and parallel plate resonators. Characterization results have showed that ε_r (~3.2) and tanδ (0.007) have been obtained for paper at UHF frequencies, both results of which are considered satisfactory for operation in UHF frequencies.

III. Ink-jet Printing

Inkjet-printing is a direct-write technology by which the design pattern is transferred directly to the substrate and does not require masks such as in the conventional etching techniques. Moreover, and unlike etching techniques which are considered subtractive methods since they function by removing unwanted metal from the substrate surface; inkjet-printing jets the single ink droplet from the nozzle to the desired position, therefore, no waste is created, resulting in a "green" and economical fabrication solution [1].

In order to ensure good conductivity for high performance circuits, silver nano-particle inks are usually selected. After the silver nano-particle droplet is driven through the nozzle, sintering process is found to be necessary to remove excess solvent and to remove material impurities from the depositions [1]. This is also essential to increasing the bond of the deposition with the substrate as well as a virtually continuous metal conductor, providing a good percolation channel for the conduction electrons to flow. The conductivity of the conductive ink varies from 0.4~2.5x107 Siemens/m depending on the curing temperature and duration time. Curing temperature of 100°C and a duration of few hours is used for the paper-based substrates and 200°C and duration time of two hours is used for the LCP-based antenna. It is to be noted that other curing methods may be utilized such as UV curing which will cut down the curing time to few seconds only. A photograph of the inkjet printer used for the fabrication is shown in Fig. 1.

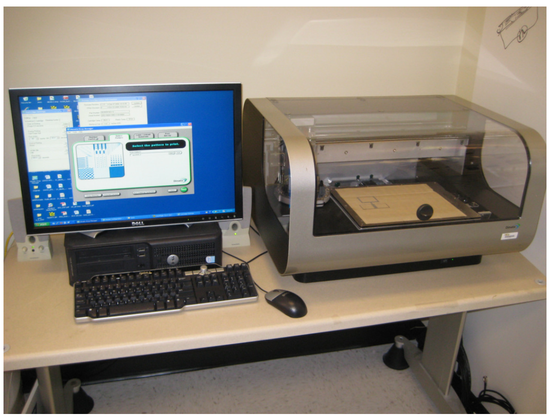

Fig. 1. Photograph of Inkjet Printer

IV. Double Layer Monopole Antenna on Paper

As a proof of concept for the inkjet printing on paper substrate, a monopole antenna is demonstrated. Fig. 2 shows this antenna as part of a wireless sensor node in detail. This antenna uses its ground planes as a radiating surface, which can also be used to shield any circuitry behind it. This would be an example of a paper-based sensor module using inkjet printing. However; the focus of this paper will be on the substrate, antenna, and fabrication technique while giving ballparks to the operation of the module as a wireless sensor node.

The top layer contains the printed antenna and most of the circuit components for the module [3]. While the bottom layer contained a Li-ion cell and the power supply traces, which were routed to the top layer through drilled vias as shown in the Fig. 2.

The monopole antenna had a planar coplanar waveguide (CPW-G)-fed wideband structure with a rectangular radiator to achieve a more compact and wideband design [4] that could be easily printed.

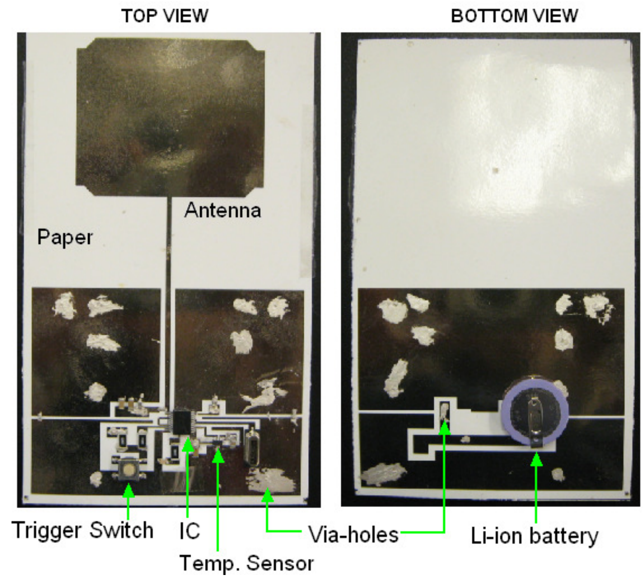

Fig. 2. Monopole Paper-based module topology.

This antenna was simulated using Ansoft's HFSS 3D EM tool and its Return Loss (RL) is shown in Fig. 3.The antenna was matched to an impedance of 60.1-j73.51 ohms which corresponds the Integrated Circuit (IC) impedance to which it is matched. The simulated return loss for the entire structure showed good wideband resonance of about 220 MHz around the design frequency of 904.4 MHz as shown in Fig. 3. The maximum directivity obtained was 2.6 dB as shown in the radiation pattern plot in fig 4 for both **E** and **H** planes. As a result of the operation of the sensor node, a reading of -26 dBm was obtained by the Real Time Spectrum Analyzer (RTSA) at a distance of 2 m which shows excellent transmission from this sensor node and the proof of concept of a 3D-paper based module.

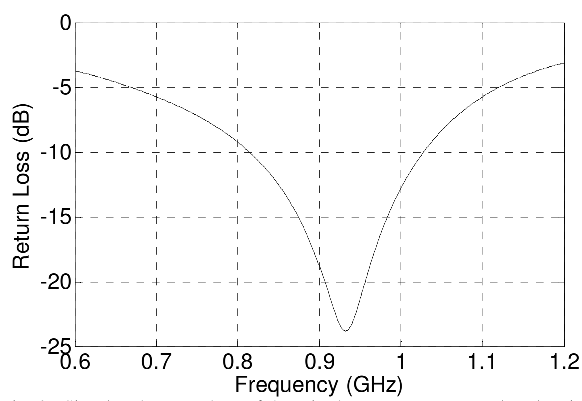

Fig. 3. Simulated Return loss of the Dipole antenna connected to the circuit.

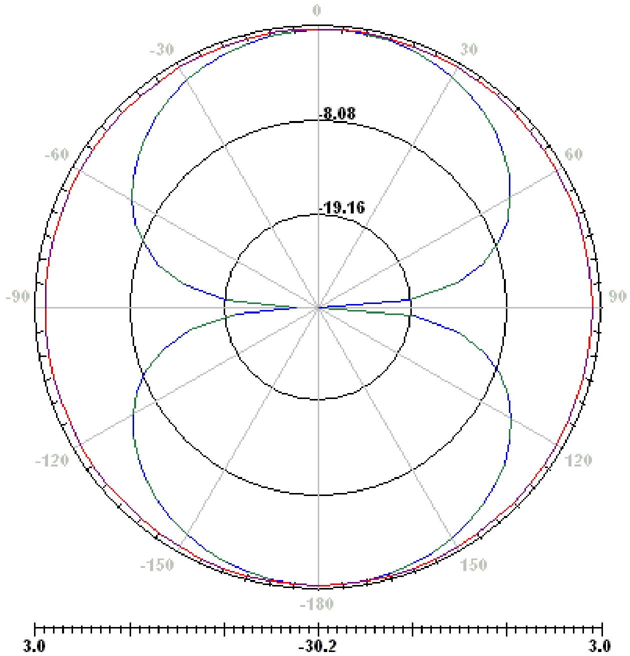

Fig. 4. Simulated 2-D Far field Radiation plots.

V. LCP SUBSTRATE FOR HIGH FREQUENCY APPLICATIONS

The low loss (tan δ= 0.002-0.005) up to mm-wave frequency range, near hermetic nature (water absorption < 0.04%), low-temperature and low-cost-large-format processing on an organic platform, make LCP appealing for high frequency designs where excellent performance is required for minimal cost [2]. LCP's low water absorption makes it stable across a wide range of environments by preventing changes in the relative dielectric constant (ε_r) and loss tangent (tan δ). Its Coefficient of Thermal Expansion (CTE) can also be engineered in the x-y plane to match integration with other materials such as Si or GaAs which gives LCP a broad range of applications. In addition, multilayer circuits are possible with LCP due to two types of LCP material (core layers and bond ply) with different melting temperatures.

VI. PLANAR MONOPOLE ANTENNA ON LCP

A CPW-fed rectangular monopole antenna was designed and is shown in Fig. 5, with dimensions: coplanar waveguide signal width w=3.8mm, gap spacing g=0.5mm and length Lg=30mm, hence ground length is also Lg=30mm. The width of the ground planes is chosen to be Wg=35mm and a typical value for the height of radiating element from the ground is chosen h=11mm, Lr=40mm and Wr=50 mm. This module was then inkjet printed using the procedure described in section III on 50 microns thick LCP substrate. Fig. 6 shows the fabricated antenna connected to a typical SMA connector for S-parameters measurements using silver epoxy. The Return Loss results are shown in Fig. 7 for measurements and simulations showing an overall good agreement, while the shift in frequency might have occurred due to the connectivity and the loss of the silver epoxy used in the measurement setup and/or surrounding objects in the lab where the Vector Network Analyser is placed. The radiation pattern is shown in Fig. 8 for both the **E** and **H** planes with an omnidirectional pattern and a simulated gain of 0.7dB at 1 GHz.

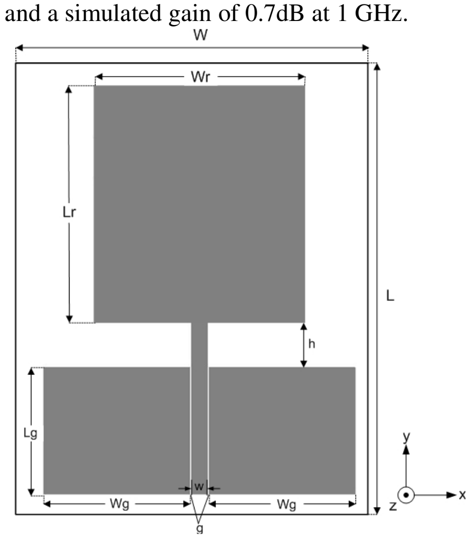

Fig. 5. Planar rectangular UHF monopole antenna configuration.

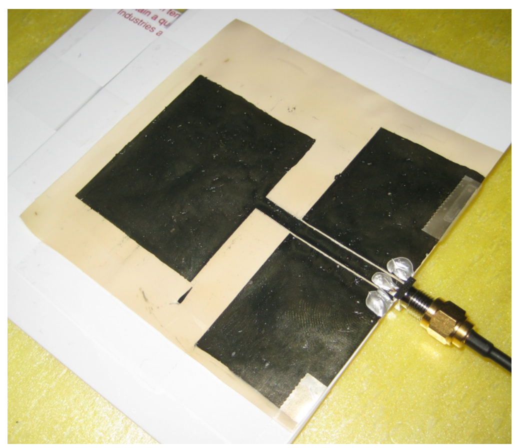

Fig. 6. Photograph of fabricated Antenna on LCP

VIII. CONCLUSION

Two simple CPW-fed monopole antennas have been designed, developed and characterized on paper and LCP material, low cost, flexible and environmental friendly microwave substrates. While the inkjet printing, an environmentally friendly fabrication technology, has been successful on paper substrate in a 3D configuration for a wireless sensor node, as well as on LCP for the first time. This shows the proof of concept for using ink-jet printing for various applications especially in RFID and sensing.

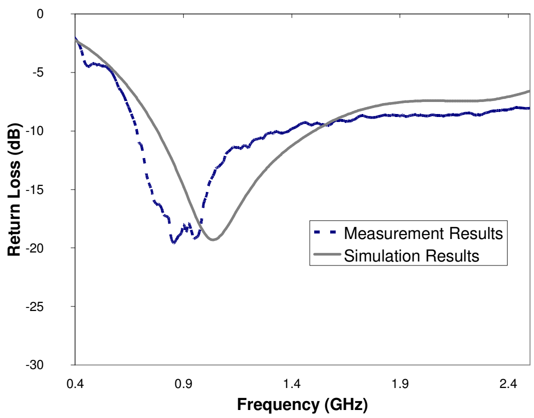

Fig. 7. Measurement and Simulation Results for the Return Loss of the CPW-Monopole Antenna

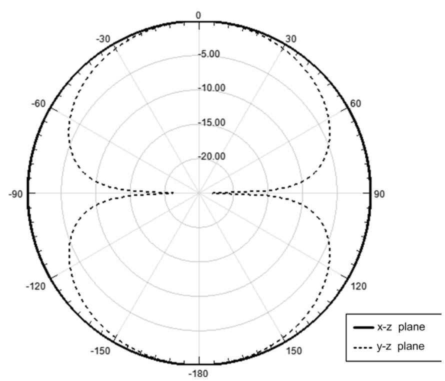

Fig. 8. Omnidirectional radiation pattern of RFID UHF Antenna.

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