A Novel Wireless Inkjet-Printed Chipless Sensor for Moisture Detection Utilizing Carbon Nanotube

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***Abstract*—A new chipless sensor for water droplet detection is proposed. This concept is demonstrated by inkjet-printing a dual rhombic loop scatterer on a flexible substrate having a size of 4x2cm^2 only. This sensor operates in the ISM band at 2.45 GHz. The scatterer is doped with a thin layer of carbon nanotube-based organic ink to enhance its sensitivity in the presence of water. Strong water molecule adsorption by the carbon nanotubes helps to detect and record when a water drop has been in contact with the sensor. The sensor's electromagnetic response is modified permanently so that a "water event" can be detected later. Simulation and wireless measurement results validate this new concept.**

I. INTRODUCTION

Wireless sensors are gaining great interest to monitor environment, food, and several biomedical conditions. Numerous sensors are required to monitor large outdoor areas, such as forests, and indoor "smart room/smart logistics" areas, effectively increasing the overall cost of the sensing system.. This brings us the need to have passive radio frequency identification (RFID) sensors [1], avoiding battery and maintenance costs. For the last 4-5 years, a new branch originating from RFID technology called chipless RFID [2] is under investigation. In contrast to conventional RFID, a chipless tag doesn't embed any IC or memory. It features a small coding capacity that can reach more than 40 bits [2]. A chipless tag can be seen has a static radar target reflecting always the same electromagnetic (EM) response for a given transmitting incident angle. The behavior of a chipless sensor (see Fig. 1) is not dependent on the variability of the chip connection, and its activation power threshold. This makes it possible to realize accurate and reproducible sensors. This paper studies the possible use of printed scatterers doped with an ink based on single walled carbon nano-tubes (SWCNT) for water droplet detection. The targeted application is humidity/leakage detection and frozen food chain monitoring.

II. CONCEPT OF THE APPLICATION

A chipless sensor is a static radar target, voluntary made sensitive to a physical quantity such as temperature, strain, light, movement, position, or a chemical element concentration. For this purpose, the basic principles involved with DC sensors can be applied to wireless sensors. This type of sensors involves a resonator around an RF frequency range that utilizes the change of a resistor or capacitor value as a function of the variation of the sensed parameter. To detect this variation remotely, the RCS of the resonator as a function of the frequency can be monitored. Small variations both in power level and resonant frequency of a peak or a dip can provide accurate information about a physical quantity change, as shown in Fig. 1 (a). The most promising and cost efficient solution consists of using a certain material featuring a complex permittivity value (including losses) that is highly sensitive, even when deposited in thin films [3]. We can cite two advantages for this technique. Firstly, printing techniques avoid additional costly operations. Secondly, for flexible sensors, this ensures the mechanical robustness of the assembly. Nano-particle-based sensors demonstrated high efficiency, and recently one can find inks embedding CNT or organic conducting nano-particles. CNT is sensitive to numerous physical quantities such as CO_2, NO_x and Ammonia [3]. They also present a strong adsorption behavior to water molecules or hydrogen molecules [4]. After having been exposed to a humid environment, the CNT deposit retains the water molecules. In terms of application, the information lasts and can be checked afterwards. Therefore, a water droplet sensor or a water leakage detector can be realized with even a small deposit of CNT on top of a microwave resonator. A potential application can include monitoring of cold storages

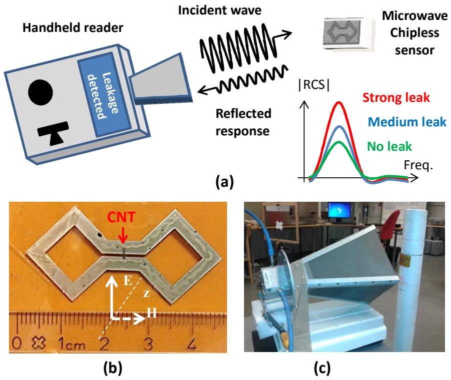

Figure 1. (a) Principle of detection (b) Inkjet-printed sensor for moisture detection. (c) View of the measurement set-up.

for food supply chain activities. In that situation, when "cold-chain" storage areas is warmed up, it creates condensation that can be detected by CNT based sensors and detected afterwards. Each sensor can be then controlled with a handheld short-range reader. Once the controlled areas have been warmed for a while, the sensor will change its state irreversibly even if the environment is re-frozen. The hypothetical “warm-up” event is then “recorded” by the sensor itself because its EM response is permanently changed.

III. RESULTS AND DISCUSSIONS

The sensor presented in Fig. 1 (b) is printed on Kapton, a flexible substrate, with silver ink using the Dimatix inkjet printer DMP-2800. It is based on a dual-rhombic loop [5] scatterer. The shape describes a closed loop. Thus, the first resonant mode appears when the wavelength is equal to half of the total length of the loop. The "diamond-shape" rings at the two edges of the scatterer allow for the increased RCS while the narrower strip spacing in the middle of the loop enhances the scatterer's selectivity. An organic ink based SWCNT embedded in PEDOT – PSS, from Polyink company [6], was inkjet printed in the middle of the tag to transform the scatterer as a water or liquid “dosimeter”. The observed phenomenon is the following: when a water drop comes in contact with the CNT deposit, the value of its electric resistance is increased. A variation of the resistance value from to two to three times the initial one, with “no-water”, can be observed. The first physical explanation is due to the adsorption of the water molecules by the CNT, creating holes in the conductive band [4]. The second explanation is due to the redistribution of the CNTs in the composite CNT / PEDOT - PSS in presence of water. Two layers of CNT ink have been deposited in the middle of the narrower strips. The gap is 0.75 mm long and the width of the deposit is 0.5 mm. This deposit can be roughly modeled by a resistance having an initial value of 500 Ω. Fig. 2 (a) shows the simulated RCS value of the scatterer shown around the ISM band at 2.45. These results have been obtained with the help of CST Microwave studio. A lumped resistance varying from 500 Ω to 10 kΩ has been used to model the CNT deposit. Strong resonant peak attenuation is observed for 500 Ω whereas for 10 kΩ, no significant effect is noticed. The measurement of the RCS response of the printed sensor has been carried out with a mono-static continuous-wave (CW) radar frequency sweep (see Fig. 1 (c)). It is composed of a vector network analyzer (VNA) Agilent PNA E8358A. The VNA is connected to a dual polarized wide-band antenna ETS Lindgren 3164-04 with a gain between 6 dBi and 12 dBi between 0.7 GHz and 6 GHz. The sensor is placed 20 cm away from the antenna aperture. The transmitted power at the output of the antenna is 0dBm. The record of the S11 parameter values allows the extraction of the RCS of the sensor provided that a free space calibration technique is made [2]. Fig. 2 (b) shows the RCS of the sensor with and without CNT deposit. Measurements after several exposures to a water droplet followed by a drying are also shown. This confirms that the RCS can gradually increase after few cycles of water exposure followed by drying..

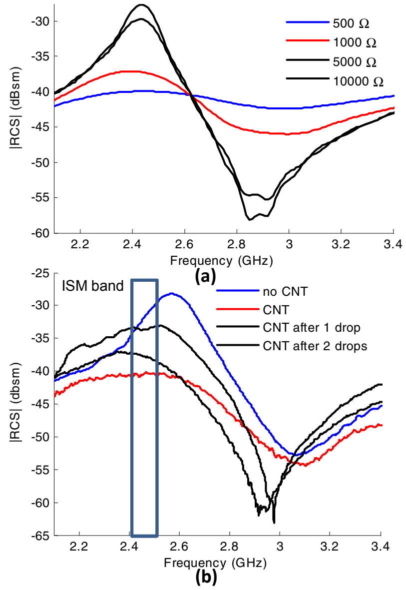

Figure 2. (a) RCS simulations results obtained as a function of the resistance of the CNT deposit. (b) RCS measurement results for several water exposures.

IV. CONCLUSION

A wireless inkjet-printed chipless sensor doped with an organic ink has been realized for moisture detection and validated by measurements. We showed that the effect of a water drop on the SWCNT/ PEDOT-PSS deposit provides a strong resistance increase which lasts even after drying. This effect has been detected by a wireless measurement of the RCS of the sensor. This behavior can be judiciously used for example in the frozen food chain failure detection due to formation of water droplets when temperature increases. A future work will propose a chipless sensor integrating some additional scatterers for identification.

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