A Thin Paper UHF Antenna on Nanocelloluse Based Substrate for Battery-free Geolocation Tags

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Abstract—**This paper presents the design and characterisation of an antenna on a paper-based substrate. The antenna is designed on a nanocellulose foil optimised with a highly conductive ink based on silver nanoparticles. The electrical and dielectric properties of the materials were characterised prior to the antenna simulation. The antenna is designed to operate at the ISM 868 MHz frequency band and has a maximum gain of +1.7 dBi. Its development is part of the first step in the implementation of a flexible battery-free geolocation tag, remotely powered by UHF Energy sources in the European RFID spectrum between 865.6 MHz and 867.6 MHz. An accurate characterisation procedure was carried out and the results show good agreement with the simulations.**

I. Introduction

The trend of new technologies leads to the development and production of several devices on a Printed Circuit Board (PCB), the manufacturing process of which can sometimes be complicated and expensive. There is therefore a drive to reduce costs in mass applications. In addition, with the need to recycle devices, make them smaller and thinner, electronics manufacturers are making many improvements to their processes and adapting them especially to the new generation of Internet of Things (IoT) devices in the Organic and Large Area Electronics (OLAE) branch. For these reasons, Uwinloc [1], a company that develops and commercialises an indoor location solution using a battery-free tag, decided to participate in the European project Madras [2] in order to meet the new challenges of the new markets requirements. Several research activities have been carried out previously on flexible antennas [3]. In [4], a Radiofrequency Identification (RFID) antenna on Polyethylene Naphthalate (PEN) substrate with a spray coating method is presented. Our proposal focuses on the design of an antenna with innovative materials. This antenna will cover the European Industrial, Scientific, and Medical (ISM) frequency band (865.6-867.6 MHz) to harvest the radiated electromagnetic (EM) waves by an RFID source. In section II, the materials developed for the antenna are presented and the simulation and characterisation procedure is presented in section III.

II. Antenna Materials

For energy harvesting, the antennas must have a high efficiency and an omnidirectional radiation pattern. The radiation efficiency of the antenna depends on the properties of the conductive ink, the dielectric, and the mismatch losses.

The materials were developed by considering the requirement (printed layer surface resistance lower than 100 mΩ/sq) for a competitive antenna design. Thus, it is necessary to have a high conductive ink.

A. Development of the conductive ink

The formulated ink called Smart Screen B (S-CS91349) is a sustainable conductive ink that has been developed for the printed electronics market and is particularly well suited for applications requiring high conductivity and high resolution on paper substrates. This ink, based on silver nanoparticles (Ag-NP), is perfectly adapted to design conductive tracks on flexible substrates and is suitable to produce antennas for IoT applications (RFID, NFC) using screen-printing technologies. It was developed by Genesink [5]. The sheet resistance was measured with a 4-point probe and gives a low resistivity around 20 mΩ/sq for a 2.4 μm thick layer. Therefore, this ink satisfies the specifications required for antenna development. The conductivity of this formulated ink is higher than the standard ink used on flexible or paper-based antennas as in [4], [6]. Its volume resistivity is between 4 and 5.5 μΩ.cm, which corresponds to a skin depth of 3.9 μm at 900 MHz.

B. Paper-based substrate

The advantage of using an innovative nano-cellulose based substrate is to give customers the opportunity to target new applications and develop smart systems for other use-cases. The paper substrate used is the antenna design was produced by Arjowiggins [7] with a certain amount (60%) of cellulose nanofibrils (CNF), which has a transparency of 79 %. This paper is made with pure cellulose, which is enzymatically treated, with endoglucanase, then mechanically treated by refiners. The resulting 60-μm thick Nano-cellulose Foil (NCF) substrate was characterised with cavity resonator method and has a dielectric constant of 4.2 (±0.2%) at 900 MHz and a dissipation factor of 0.135 (±0.015%) at 1 kHz.

III. Antenna Design and Characterisation

A. Simulation of the proposed antenna

In order to validate the developed materials dedicated for the final battery-free geolocation tag, a modified loop antenna is designed (Fig. 1 (a)). The 3D EM simulation and optimisation of the antenna were performed with Ansys HFSS software.

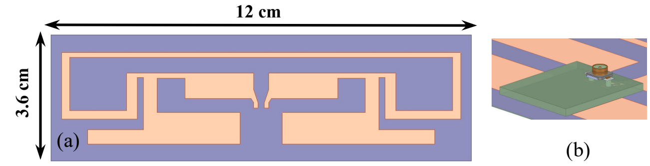

Figure 1. (a) Geometries of the designed antenna; (b) Representation of the excitation strategy with a hybridized PCB with U.FL connector.

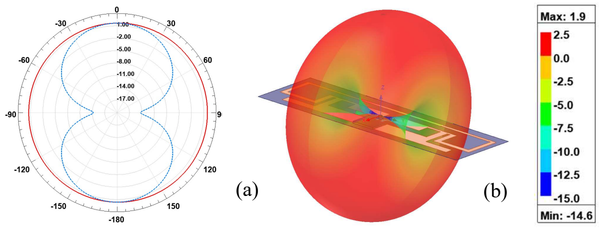

Figure 2. Simulation of the realized gain at 867 MHz: (a) Radiation pattern plot at φ = 0° (red line) and φ =90° (Blue dashed line); (b) 3D polar plot of the gain.

The loop antenna structure was optimised after several simulations steps to improve the return loss and the realized gain. It is simulated with the obtained parameters (dielectric and electrical) of the Ag NP ink and the NCF substrate. The PCB and the connector to be used for the characterisation were clearly modelled in the software to faithfully reproduce the fabricated samples. The simulated return loss of the antenna in Fig. 3 shows a resonant frequency at 855 MHz with a bandwidth of 67 MHz of under -10 dB. From the radiation pattern and the 3D polar plot in Fig. 2, the antenna exhibits an omnidirectional radiation pattern at 867 MHz with a maximum simulated gain of +1.9 dBi.

B. The antenna characterisation

The design was carried out at Eurecat Technology Centre [8] with screen-printed the Ag-NP ink on the NCF substrate. The nominal thickness of 1-layer ink coated on NCF is 2.7 µm, which is less than the skin depth. However, the power losses caused by the skin effect have been evaluated on the simulation before. They are only 2% of efficiency or 0.25 dBi gain less compared to a 9 µm thick ink. The characterisation procedure consists of using a small PCB with two pads on each side: on one side, a U.FL connector is welded while the other side is connected and fixed to the printed antenna with a conductive and a structural adhesive. Three samples were evaluated in an anechoic chamber at the LAAS-CNRS laboratory, where the antennas are placed under free space conditions to measure the performance in terms of the radiation efficiency as expected from the simulations. They were also placed on a Rohacell foam (εr ≃ 1; tanD ≃ 0.001) to emulate the software simulation condition.

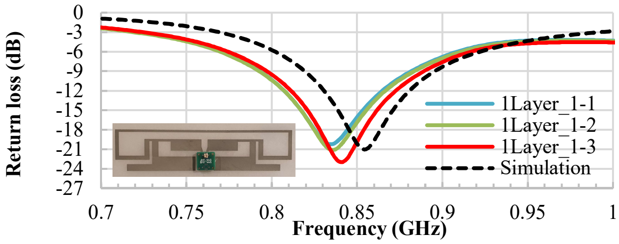

Figure 3. Simulated and measured return loss of the 3 samples of the fabricated antenna.

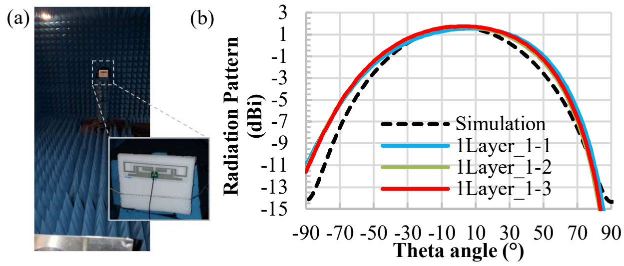

Figure 4. (a) Measurement setup on an anechoic chamber, (b) Comparison of the simulated and measured gain in the E-plane (φ=90°) at 867 MHz.

As shown in Fig. 3, the measured return loss of the 3 samples fits well, but there is a slight shift of 14 MHz (at the peak resonant frequency) from the simulation. This difference is probably due to the U.FL to SMA cable used. The measured gain of each sample also corresponds to the simulated value with a maximum of +1.6 dBi (±0.1) in E-plane at 867 MHz.

IV. Conclusion

In this paper, an antenna on NCF foil with a highly conductive Ag-NP operating in the narrow band of the European UHF Spectrum allocated to the RFID application is presented. The antenna achieves a maximum gain of +1.7 dBi in the E-plane at 867 MHz. It has the advantage of being on a thin, flexible, and low-cost substrate. It is also dedicated to being recyclable after the end of use. The manufacturing of the antenna does not require a complicated process (screen-printing) and an accurate characterisation can be performed with a low-cost U.FL connector. This preliminary design has validated the properties of materials developed by the partners. The authors are currently working on an optimised and more compact design that could be used with a small PCB module allowing RF-to-dc conversion, power management and transmission of an Ultra Wide Band (UWB) geolocation signal.

Acknowledgment

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References

[1] 'UWINLOC | New Indoor Location System for assets tracking', *UWINLOC | Indoor Location System*. https://uwinloc.com/ (accessed Feb. 09, 2022).

[2] 'MADRAS - Advanced materials and processing in organic electronics', *madras-project.eu*. https://madras-project.eu/ (accessed Feb. 07, 2022).

[3] S. G. Kirtania *et al.*, 'Flexible Antennas: A Review', *Micromachines*, vol. 11, no. 9, Art. no. 9, Sep. 2020, doi: 10.3390/mi11090847.

[4] A. Thielens, I. Deckman, R. Aminzadeh, A. C. Arias, and J. M. Rabaey, 'Fabrication and characterization of flexible spray-coated antennas', *IEEE Access*, vol. 6, pp. 62050–62061, 2018.

[5] 'Conductive ink for printed electronics : IOT, display and more', *GenesInk*. https://www.genesink.com/ (accessed Feb. 09, 2022).

[6] H. P. Phan, T. P. Vuong, P. Benech, P. Xavier, P. Borel, and A. Delattre, 'Novel ultra-wideband "robe" antenna on high-loss paper substrate', in *2017 IEEE International Symposium on Antennas and Propagation & USNC/URSI National Radio Science Meeting*, 2017, pp. 319–320.

[7] Arjowiggins. https://www.arjowiggins.com/ (accessed Feb. 09, 2022).

[8] 'Eurecat Centre Tecnològic - Innovant per a les empreses', *Eurecat*. https://eurecat.org/ (accessed Feb. 09, 2022).