Usage of printed graphene antennas in UHF RFID transponders

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Abstract

Radio-frequency identification (RFID) is based on exploiting electromagnetic fields to transfer data wirelessly, for the purposes of automatically identifying and tracking tags attached to objects. The basic elements of a passive RFID transponder are a microchip and an antenna. Typically, RFID antennas are fabricated using the copper or aluminium etching process after which the flip-chip type microchip is bonded to the antenna. The IC and tag antenna manufacturing processes are continuously developed in order to meet the demand of low cost for mass production of RFID tags. Printing metallic inks and pastes provides an alternative technology for antenna fabrication [1]. Antennas can be manufactured in roll-to-roll printing processes, which enable high-volume production under ambient conditions. However, metallic inks are expensive. Inks based on carbon nanomaterials, especially graphene, have reasonable conductivity along with advantages in cost, chemical stability and mechanical flexibility. Printed graphene antennas for low cost applications have been demonstrated recently [2]. In this work, we present full performance of a UHF RFID transponder with printed graphene antenna.

The conductivity of graphene inks is remarkably lower than that of copper, aluminium and even metallic inks that are the most commonly used conductor materials in the commercial UHF RFID transponders. Therefore any previously used antennas could not be utilized as such and thus, a new type of antenna should be designed for graphene inks.

Two requirements should be taken into consideration in designing a UHF RFID antenna: adequately high radiation efficiency of the antenna and matching impedances of the antenna and the microchip. The input impedance of the antenna should the complex conjugate of the RF impedance of the microchip at the intended operation frequency. In practice it means that the antenna impedance should be inductive with low real part.

Both of these requirements are a challenge in the case of graphene inks. Low conductivity of graphene inks has its impact on both the radiation efficiency of the antenna and the real part of the antenna impedance.

New geometry of the antenna was proposed to solve these challenges. The antenna is shown in Fig. 1 a. Geometry of the antenna is somewhat similar to the most common dipole type UHF RFID antenna. The size of the opening in the middle of the antenna determines the reactive part of its impedance as the length and the width of the antenna affect the real part of the impedance. Unlike the commercial transponders made of copper or aluminium, the proposed antenna has a wide and long conductor body that has a simple square shape with no meandering that would increase conductivity losses. Fig.1 a. also shows the microchip strap. In the prototypes the microchip was attached using a copper strap that is glued with silver epoxy to the antenna.

The antenna structure was optimized by electromagnetic simulations. The optimized parameters were the maximised radiation efficiency and the input impedance matched to the microchip. The microchip was NXP Ucode G2XM. The simulations were run using HFSS 15 by Ansys.

Due to fabrication tolerances, inaccuracy of the model and the possible variation of the graphene conductivity value, a series of prototypes were designed with a sweep of parameters. As the tuning of the transponder is most sensitive to the reactive part of the input impedance of the antenna, the dimensional parameter affecting the reactance, the size of the opening, was varied.

An additive printing process was applied for fabrication of the designed antennas. In order to optimize the conductivity for a specific graphene based printing ink, the printed layer should be as thick as possible, without losing the lateral definition of the layout. This can be achieved with a screen printing method. Commercially available graphene based printing paste was selected for the prototypes, namely

VorInk S301 from Vorbeck Materials [3]. The two main objectives of the printing process, maintaining structural dimensions and achieving maximum conductivity by increasing the thickness, were controlled by process parameters and printing screen characteristics. The wet thickness of the graphene paste was controlled by the mesh parameters of the screen. Several screen parameters were evaluated with mesh numbers from 120 – 325 lines / in, but finally a stainless steel mesh was selected with a line density of 120 lines / in and a 65 µm wire thickness. This is a durable and robust screen with a high transfer rate of printing paste and still the lateral structure could be reproduced reliably. As seen in Figure 1a, the lateral structure of the antenna consists of a large continuous area of printed graphene, thus the emulsion thickness of the printing screen has no effect on the wet thickness of the printed layer, but the thickness is determined by the wire thickness and open fraction of the mesh. The antenna structures were printed on PET (polyethylene terephthalate) substrates using an EKRA E2 a semi-automatic screen and stencil printer from ASYS Group GmbH. The printing speed and other parameters as well as the squeegee material and the edge profile were selected to achieve an optimal printing definition and a uniform layer thickness. The printed samples were dried in a ventilated oven at 100 °C for 5 minutes. Then the samples were further annealed at 130 °C for up to 30 minutes to further increase the conductivity of the printed graphene layer. One printed layer reaches approximately 5 µm in thickness and to further increase the conductivity of the sample, multilayer printing was applied. Double and triple layers were printed without affecting the lateral dimensions of the device. Example of a fabricated graphene antennas with a microchip strap is shown in Fig. 1 a.

All transponder prototypes were measured with Tagformance™ UHF RFID measurement system. The measured and simulated read ranges of the transponder prototypes at the frequency of 867 MHz are shown in Fig. 1 b. By the measurement, read range up to 3.8 m was achieved. Possible explanation for difference between simulated and measured read ranges is the contact resistance between graphene and copper of the microchip strap. The influence of bending fatigue on the performance of the antennas was also investigated. Each graphene antenna has been subjected to 1000 bending cycles with a span on 40 mm and a bending radius of ~ 42.5 mm per cycle. After these 1000 cycles the performance of graphene transponders was measured again. We did not find any influence of bending on the transponder reading distance.

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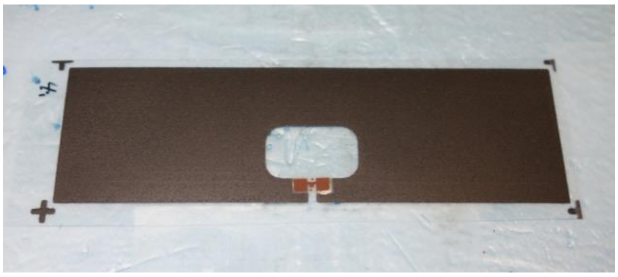

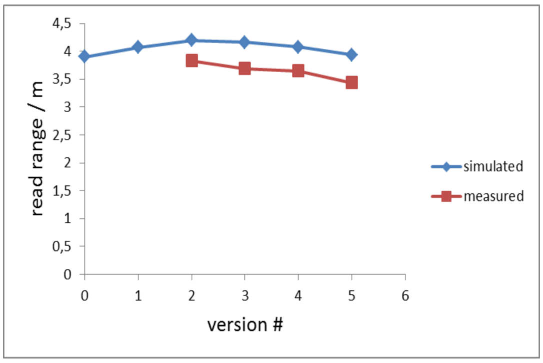

(a) (b)

Fig. 1 (a) fabricated transponder prototype with a microchip strap and (b) simulated and measured read ranges of the transponder prototypes with printed graphene antenna.