Design of RFID Antenna in Ink-Jet Printing Technology

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Abstract—In this paper design of 125 kHz RFID antenna is presented. The optimization and improvement of electrical characteristics, including inductance and Q-factor, is also discussed. Designed RFID antenna is part of the ID card, which has standard ISO ID1. It consists of two spiral coils in two layers. Comparison of antenna in flexible and PCB technology is presented. The aim of this work is to introduce novel cost-effective antenna in flexible technology instead of conventional RFID antenna in PCB technology.

I. INTRODUCTION

Printing techniques, such as ink-jet printing, are interesting alternatives to conventional photolithography for the production of electronic devices. The advantages of printing include the ease of mass production, low cost, and flexibility. Compared to other printing techniques (e.g., screen-printing), ink-jet printing does not offer the same production speed [1].

RFID devices are generally being deployed in four main communication bands, as allowed by the FCC and its global counterparts. These bands are: 1) the low-frequency range up to 135 kHz; 2) a band at 13.56 MHz; 3) a band at 900 MHz; and 4) a band at 2.4 GHz. Each band has its own advantages and disadvantages. For item-level RFID, typical read-range requirements are expected to be in the range of 1 m. Operating range of most low-cost RFID technologies is likely to be limited by power delivery from the reader to the passive tag. At the short distances required for item-level RFID, more power can be delivered to the tag at the lower frequencies that at the higher frequencies, since they lie within the near-field coupling region. Based on this consideration, it would be expected that the lower frequencies would be advantageous for power coupling. However, this is complicated by the fact that inductors at low frequencies are substantially larger and have significantly lower quality factor (Q) [2].

Starting from the traditional markets of ticketing and supplied chain management RFIDs will be used in coming years to allow identification of more and kinds of goods in retail shops. Nowadays very small silicon RFID chips costing few dollar cents a reality, but these components need to be assembled with antennas to build the full RFID transponder. Until now the cost of antennas and assembly does not seem to have come down as much as one would desire [3, 4].

An RFID tag achieved by a full inline inkjet printing process is proposed in [5]. Printing parameters are optimized and electronic performances of the tag are then discussed. The curing of metallic layers and dielectric is done inline using variable frequency microwave and UV lamp, respectively.

A sintering step is necessary to render the tracks conductive. The use of nano-particles reduces the sintering temperature due to their high surface to volume ratio. Thus, there is a clear need for a fast, simple, and cost-effective technique that would allow the sintering of the printed structures by the selective heating of only the printed components. Microwave heating fulfills these requirements [6, 7].

On the other hand, if the conductivity of the printed area is high enough, one must take care that the quality of the printing as well as the printed thickness is also high enough. One printing method widely used is inkjet printing which allows multiple thin (even less than 1 m) conductive layers with relatively low edge roughness. This is important since the radiation properties of the designed antenna depends on the thickness and surface roughness of the printed layer if its conductivity is high enough [8].

In this paper design and modeling of RFID antenna is presented. The optimization and improvement of electrical characteristics, including inductance and Q-factor, is also discussed. Comparison of antenna in flexible and PCB technology is presented. The aim of this work is to introduce novel cost-effective antenna in flexible technology instead of conventional RFID antenna in PCB technology.

II. DESIGN OF RFID ANTENNA

Designed RFID antenna is part of the ID card, which has standard ISO ID1 size (85.60 mm × 53.98 mm). It consists of two spiral coils in two layers, as it can be seen in Fig. 1. Layout of top layer of reader antenna is presented in Fig. 2.

Antenna is designed in flexible technology. The inductor is designed on polyimide substrate (which thickness is 75 μm). This plastic substrate is known for its flexibility and thermal stability. High flexibility is necessary for the targeted application (ID cards) which must comply to ISO, and endure more than one thousand bending and torsion cycles to pass the quality tests (ISO 7816-1, Annex A.1/ ISO 10373-1 §§ 3.2, 5.8 / ISO 14443-4 § 5.2). The thermal stability is necessary for sintering silver nano-scale particles, used in conductive ink.

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Silver conductive tracks are 600 µm and 700 µm wide and printed with 40 % Ag (specific resistance $\rho=8.27 \times 10^{-8}$ Ωcm). Distance between two neighboring conductors is $p = 150 \mu m$ or 200 µm.

A silver nanoparticle dispersion in an ethanol/ethylene glycol mixture was used (Suntronic U5603 and U5714, manufacturer Sun Chemicals, Slough UK). The silver ink contains 20 wt% and 40 wt% of silver nanoparticles, respectively, with the particle diameter ranging from 30 nm to 50 nm. The ink was inkjet printed onto transparent, characteristic orange/yellow color plastic/organic polyimide foil 300AV (manufacturer GTS Flexible Materials Ltd, 75 µm thickness, low glass transition temperature $T_g = 400^\circ$C) substrates using a piezoelectric Dimatix DMP 3000 system (manufacturer Dimatix-Fujifilm Inc., USA), equipped with a 10 pL cartridge (DMC-11610).

The print head contains 16 square nozzles in line with a diagonal of 30 µm. The dispersion was printed at voltage of 18 V and 23 V, using a frequency of 4 kHz for 20 wt% and 2 kHz for 40 wt% silver nanoparticle inks, and a customized waveform. Meniscus backup pressure was 2.65 kPa. The printing height was set to 1 mm, while using a dot spacing of 25 µm, which determines the thickness of printed layers.

The antenna architecture is chosen to maximize the stored energy, necessary the RFID transponder to operate (the antenna consists of two spiral coils in separate layers, with high number of turns, each spreading throughout the whole ID card area). The number of turns of each spiral in two-layer inductor $N$ is sufficient to provide 250 µH inductance of inductor in resonant LC circuit. Measured thickness of the printed layer with 20 wt% silver was around 160 nm, whereas this thickness for layer with 40 wt% silver was approximately 700 nm. From that fact, it can be estimated that the 2-layer printed conductive lines would be 1.5 µm thick. If the thickness of conductive layer is greater, even better Q-factor would be achieved [11], [12]. The geometrical parameters of two-layer spiral antenna are also presented in Table I.

### Table I. Geometrical Parameters of Two-Layer Spiral Antenna

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<table>
<thead>
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<tr>
<td>$N$</td>
<td>Number of turns</td>
<td>30, 35, 40, 45</td>
</tr>
<tr>
<td>$w$</td>
<td>width of conductive segments</td>
<td>600 µm, 700 µm</td>
</tr>
<tr>
<td>$p$</td>
<td>distance between two neighboring conductors</td>
<td>150 µm, 200 µm</td>
</tr>
<tr>
<td>$t$</td>
<td>thickness of conductive lines</td>
<td>1.5 µm</td>
</tr>
<tr>
<td>$t_K$</td>
<td>thickness of Kapton substrate</td>
<td>75 µm</td>
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</table>

III. Simulation of Antenna’s Electrical Parameters

To obtain the optimal design of antenna it is much more convenient to use some simulation tool, than make a specific test component. Because of that, the simulation tool AntInd (antenna’s inductance) for calculation of electrical parameters of RFID antenna is developed.

The calculation of antenna’s electrical parameters is obtained using a concept of partial inductances. The structure of antenna is divided into straight segments with rectangular cross sections. Furthermore, each conductive segment is presented with a set of filaments having small, rectangular cross section. The self- and mutual inductances were calculated using the concept of partial inductance [9].

The AntInd simulation tool uses the same principle as the DoubleInd, which is presented with more details in [10]. The AntInd provides fast and accurate way to calculate the electrical characteristics of antenna and to determine the optimal values of geometrical parameters (conductor’s width $w$ and thickness $t$, the distance $p$ between two neighboring conductive segments and number of turns $N$), which will provide the best performance of the RFID system.

IV. Simulation Results

Preliminary measurements of the electrical characteristics of the antenna in PCB technology intended for 125 kHz, which is a part of commercially available RFID system have shown that the inductance has to be at least 250 µH. Therefore, we have proposed two-layer spiral type structures, in order to achieve as great inductance as possible.

Geometrical parameters strongly determine the performance of RFID antenna. If the structure has more turns, the inductance will rise, as it can be seen in Fig. 3.
However, structures with greater number of turns have greater resistance (Fig. 4), which will deteriorate the Q-factor, as it can be seen in Fig. 5.

Wider structures provide slightly smaller inductance, but resistance is decreased more significantly, and Q-factor will be improved. Simulation results of the inductance $L$, resistance $R$, and Q-factor are presented in figures 3, 4 and 5, respectively. The thickness of conductive lines is $t=1.5 \, \mu m$.

The design simulation finds the optimal Q-factor is achieved for a relatively high number of turns ($N>30$), where the effect of increased resistance is mitigated by increasing the width of turns (Fig. 3). In addition, printing multiple layers of conductive material can provide the increase of the conductor thickness and thus further improve the Q-factor.

Great values of resistance make the RFID antenna less effective and lessen the distance at which the tag will be able to communicate with RFID system. In order to improve this efficiency, the Q-factor has to be increased. One solution is to print structures with at least 4 layers of silver, which will increase the thickness up to $3 \, \mu m$ (Fig. 6). The another solution presents the use of microwave techniques of sintering [6], which provides more than 5 times smaller resistivity compared to oven sintering.

This paper presents a 125 kHz antenna designed for ISO ID1 size cards and for implementation in ink-jet printing technique. The latter is a cost-efficient technique for printing smaller series of RFID antennas on plastic substrate or paper using conductive inks. In addition, the paper presents simulation results, based on a in-house simulation tool “AntInd”. The simulation model input parameters are based on the choice of antenna architecture and materials.

The optimization and improvement of electrical characteristics, including inductance and Q-factor, is also discussed. The aim of this work is to introduce novel cost-effective antenna in flexible technology instead of conventional RFID antenna in PCB technology.

The main disadvantage of flexible RFID antenna is its great resistance, more than 100 times greater than conventional antenna in PCB technology, which has the same geometrical parameters. The only difference is thickness of the conductive lines ($t=1.5 \, \mu m$ for multiple ink-jet printing, and $t=33 \, \mu m$ for PCB technology), which provides much better characteristics of PCB antenna. However, structures with greater number of turns have greater resistance (Fig. 4), which will deteriorate the Q-factor, as it can be seen in Fig. 5.

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can be achieved by improving the sintering procedure, as well as design optimization.

To obtain the optimal design of RFID antenna it is much more convenient to use some simulation tool, than make a specific test component. Because of that, the simulation tool AntInd for calculation of electrical parameters of antenna is developed. Obtained simulation results will be very useful for construction of the RFID antenna in cost-effective flexible technology.

REFERENCES


