RFID Tag Antenna Utilizing Ink-jet Printing Technology

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1. Introduction

The fabrication of conductive lines or connectors is vital in electronic industry. Various methods have been widely developed and employed. Typically, electroplating, photolithography and etching processes are adopted for manufacturing. However, this subtractive technique involves many complicated steps, those results in time consuming, generating waste chemicals and materials. The purposed additive approach with the adaptation of conventional ink-jet printer promises simplicity and reduction in manufacturing cost. Furthermore, the technique is suitable for foldable organic substrates, such as paper. This sets a foundation of 'green' electronics with the use of environmentally friendly process and materials [1].

An excellent demonstration of this affordable fabrication technology is through RFID antennas. The emerging UHF RFID technology is potentially applied to a variety of applications. Especially when the fabrication cost is comparable to that of bar codes, the paper-based RFID can be used in almost any low cost applications. In this article, ink-jet printed RFID antennas in different configurations are demonstrated, along with their measured performances compared to simulation results.

2. Printing Conductive Tracks

There are two essential components in developing a conductive ink-jet printed product: printer and conductive material. A commercially available ink-jet printer was employed in this study. In particular, EPSON C90, with 5760x1440 dpi resolution, was modified to be compatible with a conductive ink. A nano silver ink was chosen by mainly considering its uniform dispersion property in a solvent base. Although the given resistivity is wide-ranging (2.5-10 μΩ-cm), partially due to varied curing temperatures [2], its viscosity and surface tension specifications are essentially suitable for ink-jet printing [3].

Since a layer of printed track can be particularly thin, which can result in too high resistivity, multiple layer printing is necessary. However, the problem with printing misalignment can be expected, especially when the layout is placed further away from the left corner of the paper. The results from printing tracks with 1, 2 and 5 mm line widths for up to 21 prints show that the misalignment of all line widths was in the order of 0.5 mm.

The measured thicknesses of multiple-printed layers were shown in Fig. 1. From the figure, the thicknesses of more than 15 layers are not noticeably cumulative. This can be a consequence of ink spreading sideways, which also results in line width errors. The roughness results were also investigated, which suggested that more number of prints likely results in a smoother surface. However, cracks can be observed on tracks with too many prints, caused by different surface tension while solvent evaporating. Therefore, a layer of 10 prints is kept as a standard in this work. The uncured thickness and roughness are 5.10 μm and 0.31 μm, respectively. The printed layers are cured at 150^{o}C for 15 minutes in an oven. The sheet resistivities of 5 and 10 printing layers are measured, before and after curing, with the use of four-point-probe setup. The comparison of the results is listed in Table 1.

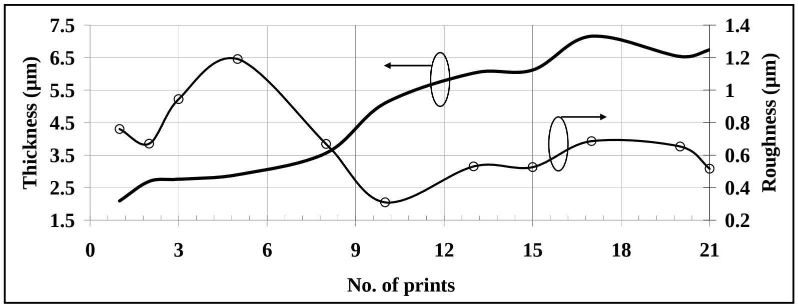


Figure 1 : The thickness and roughness of multiple-printed layers

Table 1 : Sheet resistivity obtained from four-point-probe measurement.

No. of prints	Sheet Resistivity (Ω/sq)	
	Uncured	Cured (150°C, 15 min)
5	0.47	0.16
10	0.62	0.15

3. Antenna Configurations

The performance of ink-jet printed antennas for RFID tag has been studied through three antenna configurations, namely a) dipole, b) dipole with tuning stub and c) meandered dipole [4]. All antennas are attempted to match with the conjugate of chip impedance, at operating frequency of 840-960 MHz. Until recently, the measured impedance of NXP's UCODE G2XL RFID chip was reported [5]. Specifically, the chip impedance is equivalent to a serial circuit of a 26 Ω resistor and a 1.15 pF capacitor. Photo-quality silky inkjet paper was used as a substrate, with dielectric constant of 2 [6]. The aforementioned measured sheet resistivity of the cured 10-print layer was employed. The dimensions of three antenna configurations are illustrated in Fig. 2. The simulated read range (r_s) of each antenna design was obtained from [7]

$$r_s = \frac{\lambda}{4\pi}\sqrt{\frac{EIRPG_r\tau}{P_{th}}} \quad (1)$$

where *EIR*P is the effective isotropic radiated power of both the RFID reader and reader antenna, G_r is the simulated gain of the receiving tag antenna, P_{th} is the minimum threshold power to provide sufficient power to the RFID chip, which is -12.6 dB [5]. The power transmission coefficient, τ, at each frequency is given by chip impedance $Z_c = R_c+jX_c$ and antenna impedance $Z_a = R_a+jX_a$, through the equation [7]

$$\tau = \frac{4R_cR_a}{\left|Z_c + Z_a\right|^2} \quad (2)$$

The antennas in design b) and c) are perfectly matched at 922.5 MHz, with τ is 1. It is, however, not feasible to match the dipole configuration, as the maximum obtained τ is 0.49 when $X_c=-X_a$, at 922.5 MHz.

4. Ink-jet Printed Antennas

The photographs of three ink-jet printed antennas with RFID chips attached are also illustrated in Fig. 2. The fixed distance method was utilized in order to measure the reading distance [7]. The RFID antenna was positioned at a distance '*d*' away from the transmitting antenna, which is connected to a RFID reader. The controlled transmitting power from RFID reader was attenuated by 1 dB step, until the signal is not readable. The measured reading distances (r_m) were subsequently calculated by

$$r_{\mathrm{m}} = d\sqrt{\frac{EIRP}{P_{\mathrm{min\_eff}} G_t}} \quad (3)$$

where $P_{\mathrm{min\_eff}}$ is the effective measured minimum transmitted power required to communicate with the tag and G_t is the gain of the transmitting antenna. Fig. 3 a), b) and c) present the measured reading distances, within 840 to 960 MHz, in comparison with the simulated ranges for the three antenna configurations.

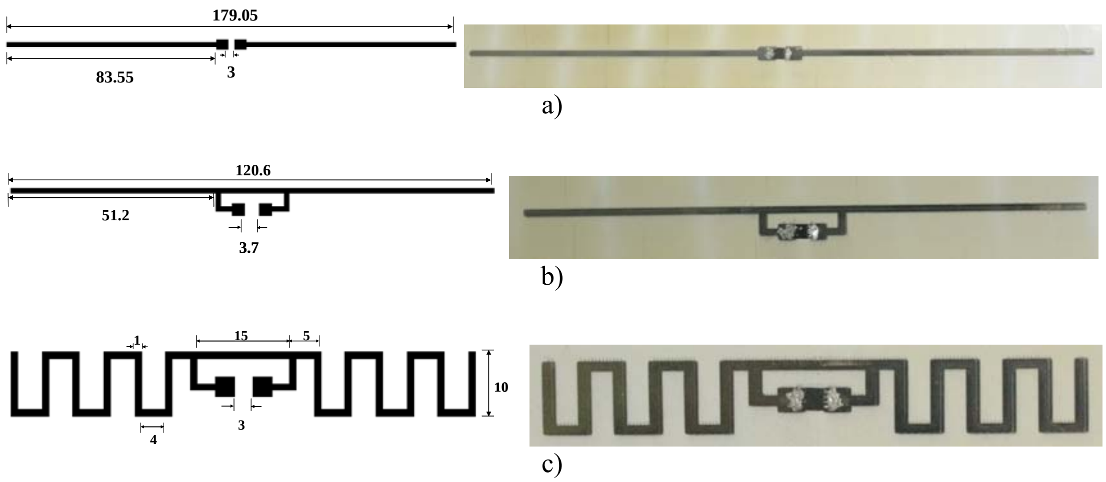


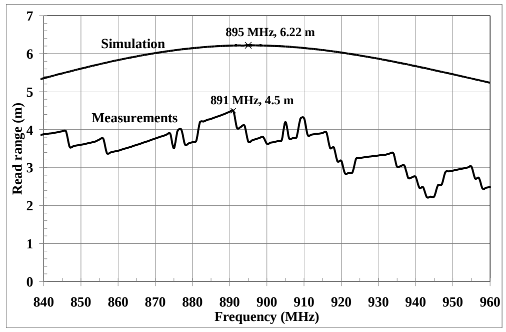
Figure 2 : Three designed and ink-jet printed antenna configurations: a) dipole, b) dipole with tuning stub and c) meandered dipole (unit in mm)

5. Discussions

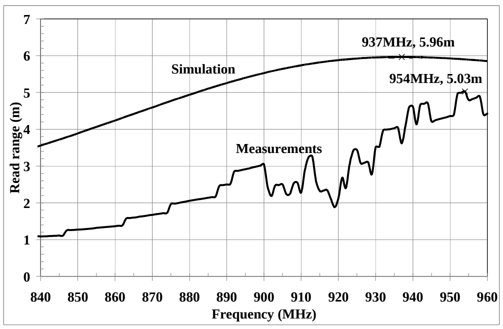
From Fig. 3, the maximum distances from all measurements are comparable and are generally lower than the simulated distances. In general, dipole antennas with tuning stub should give longer reading distance than simple dipoles, because of the higher degree of tuneable parameters for impedance matching. In our case, the loss is concentrated at the shorted circuit stub and results in low antenna gain. Therefore, the antenna performance can be improved with other less resistive tuning mechanisms. For the tuning-stub dipole and meander dipole antennas, the frequency points of printed antennas where the longest distance is obtained are slightly shifted from the simulations. However, both of the maximum reading distances are comparable. The differences can be mainly explained by the physical dimensions of the printed antenna. Specifically, the most important reason is arisen from the misalignment error. This error can be compensated by intending to print a smaller line width than the designed one. Roughness should also be accounted for. Additionally, uniform resistivity can possibly be obtained from adjusted curing temperature and time. Therefore, the performance of the printed antenna can be increased and better matched with simulation results by focusing on improving the print quality.

6. Conclusions

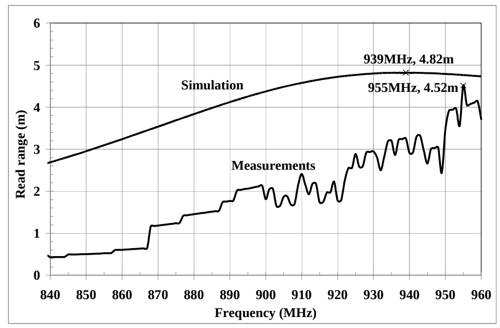
Paper-based ink-jet printed RFID antennas were successfully fabricated by employing conventional ink-jet printer. A study of printed antenna performances was carried out by employing three antenna structures. Even though the simulated and measured results are not well matched, the improvements can be made from the prints. One of many advantages of this technology is the capability to utilize low-cost substrate, such as paper and plastic sheet. To this end, this affordable printing technology can be promising for low cost and simple manufacturing process and suitable for prototype production.



a) dipole



b) dipole with tuning stub



c) meandered dipole

Figure 3 : Reading distances calculated from simulation results and measurements of the three antenna designs.

Acknowledgments

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