# Inkjet Printed Epidermal RFID Tags

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**Abstract—The issues of fabricating transfer RFID tags for epidermal application are discussed in terms of achievable ink conductivity, thickness and performance in the presence of minor printing defects.**

**Index Terms—epidermal antenna, Tattoo, RFID Tag.**

## I. INTRODUCTION

The Epidermal RFID tag presented in this work was fabricated using transfer tattoo paper [1]. An Inkjet printer was used to print the RFID antenna pattern on this tattoo paper while the pattern was transferred onto the skin with the aid of an adhesive film.

An RFID tag of this nature can be used where temporary tracking and identification of people is needed and offers an alternative to the use of implanted RFID chips. These tags can be used in places where there is a large gathering of people and also security is of concern for instance in stadia and musical concerts. They can also find application in healthcare services where they can replace the conventional wristbands used in hospitals as well as physiological sensors with the appropriate Application Sensitive Integrated Circuit (ASIC) mounted on it.

Because inject printing is an additive process with less fabrication stages when compared with the subtractive and multi-stage nature of conventional etching, inkjet printing has the potential to provide a cheaper means of tag fabrication because of little or no wastage of materials [2].

The possibility of skin mounted, low profile RFID tags have been studied in a previous work [3]. The same tag design was also used in this work.

This work studies the effects defects on the tag due to the printing process can have on the performance of the tag.

## II. INKJET PRINTING

Inkjet Printing fabrication of RFID tags and Antennas have been reported by various authors. These tags have different applications from the conventional item identification purpose to more complex uses [4]. There have also been works on inkjet printing of tags on porous materials (paper, cardboard, leather and wood) that have been reported by different researchers [2], [5]–[10]. The sintering technique and other parameters of these works have been summarized in Table I. From the table it can be seen that in some cases more ink layers were utilized more than the others, this is in order to compensate for soakage by the porous substrate used. Additionally, several hours of ink sintering can be needed to achieve maximum conductivity. This is because in addition to increasing the bond between the ink particles and also the bond between the deposited ink and the substrate, sintering eliminates excess solvent which the conductive particles were suspended in and also aids in the removal of impurities from the ink.

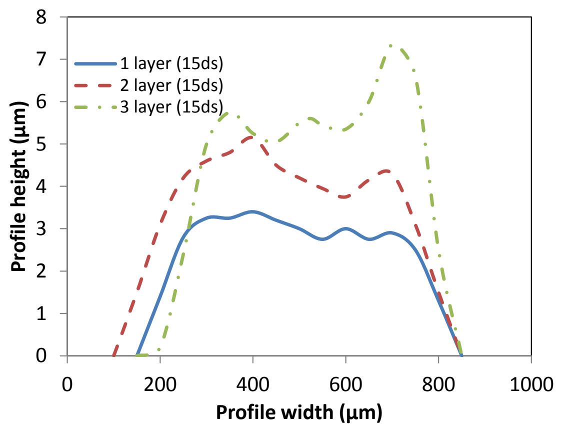


Fig. 1. Profile measurements of 1, 2 and 3 layer inkjet printed lines

Ink layer thickness varies according to formulation, substrate and surface preparation, however each layer is approximately 1µm thick for an ink dot spacing of 20µm.

TABLE I.

| **Reference** | **Substrate** | **Ink Layers** | **Sinter time (hour)** | **Temp (°C)** | **Cited σ (S/m)** |
|---|---|---|---|---|---|
| Shaker [a] | Paper | 3 (3µm) | 2 | 120 | $\sim 1\times10^7$ |
| Abutarboush [b] | Paper | 5 | 1 | 160 | $1.2\times10^7$ |
| Vyas [c] | Paper | 12 (12µm) | - | - | 0.4-$2.5\times10^7$ |
| Kim [d] | Paper | - | 4 | 130 | $\sim 1\times10^7$ |
| Lakafosis [e] | Paper | 7<br>12 (12µm) | 10<br>10 | 120<br>120 | $2.5\times10^7$ |
| Farooqui [f] | Leather | - | 6 | 160 | - |
| Bjorninen [g] | Wood<br>Cardboard<br>Paper | 20<br>20<br>15 | 2<br>2<br>1 | 150<br>150<br>150 | $>2\times10^7$ |

The objective of this work is to fabricate tags with the minimum number of expensive ink layers and the shortest sintering time while achieving an acceptable conductivity. 1-3 layers of Sun Chemicals Silver Nanoparticle ink were deposited at 15 μm dot spacing to form lines nominally of 400 μm width and the line profiles measured, Fig.1. A 25% increase in line width occurs, though this could be compensated for.

When printed on transfer tattoo paper, it was found that excess heat sintering caused a degradation in ink conductivity as well as the used tattoo paper. Because of this several trial sintering procedures were carried out and optimum settings of 135°C for 30 minutes were obtained which offered values of 20 to 40 times that of bulk silver resistivity. Although this resistivity is somewhat lower than the maximum datasheet value, the ink retains some plasticity which is important when transferred to the skin in order to avoid cracking hence ensuring durability. Tattoo tags of the type described in [3] were printed with 1, 2 and 3 layers along with one etched from copper cladding on a thin Mylar sheet. An NXP transponder chip (input impedance 15 – j128 Ω) [11] was attached to each tag and the read range was measured for skin mounting. The read range for the copper tag was 75cm which can be compared to the 12, 37 and 54cm obtained for the 1, 2 and 3 layer prints respectively. The lower conductivity of the ink and the corresponding skin depth loss contributed to the poor read range compared to the copper tag, though it was found that depositing an extra layers of ink around the feed line significantly enhanced the printed tag read range. For example, a 2 layer tag with 3 extra layers on the feed lines offered a read range of 68cm, 90% that of the copper. With some adjustment of the matching dimensions, read ranges of 2m on skin have been obtained. Care is to be taken however as depending on the nature of the ink used, additional layers do not always ensure an improvement in the quality of the tag and may actually lead to increase in fabrication cost [12]. It is therefore necessary to carefully study the electromagnetic behavior of the tag in order to determine where an additional layer of ink would be most beneficial.

## III. Effect of Printing Defects

As edge currents exist for conducting structures at microwave frequencies, an investigation was carried out to assess the significance of printing defects which can be assumed to occur as the printed conducting layers are thin by the standards of etched copper foils and also as a result of the possibility of a blocked nozzle in the print head. The feed lines around the transformer matching slot are deemed to be the most vulnerable part of the design owing to their narrowness and corresponding high current density. Fig.2(a) shows an unperturbed current distribution on the tattoo tag, while the effect of pin holes, an edge notch and a 10μm hairline break are illustrated in Fig.2(b)-(d). All simulated surface currents were calculated by CST Microwave Studio on a dielectric block representing human tissue.

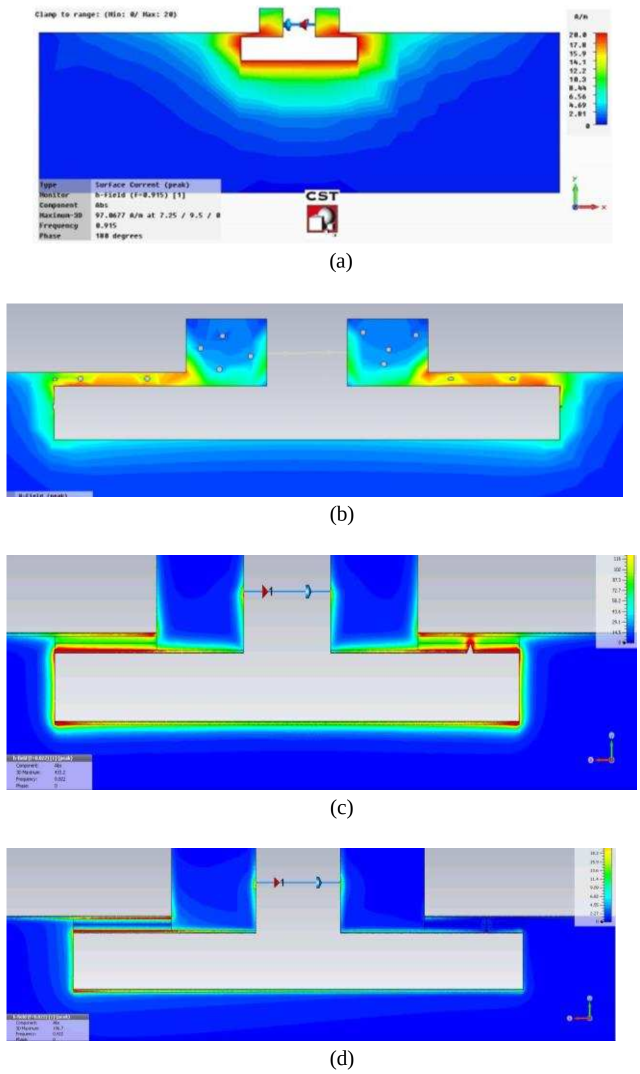


Fig. 2. Simulated current distributions for (a) fault-free tag, (b) pin holed feed, (c) notched feed line, (d) feed line with a hairline crack.

The efficiencies and corresponding read ranges for each of the situations illustrated in Fig.2 are given in Table II. It can be seen that while small faults in the feed line are detrimental to the overall efficiency and read range, providing there is not a total break in the current path, more than 60% of the maximum read range is available. This gives confidence that in an event of minor fabrication errors, or minor application and wear damage, a transfer tag may remain functional. Wear tests of prototype printed tags validate this assumption with the transfers remaining operational throughout a normal working day.

TABLE II.

| Fault | $S_{11}$ (dB) | Efficiency (dB) | Calculated Read range (%) |
|---|---|---|---|
| No fault | -17.9 | -11.5 | 100 |
| Pin holes | -12.5 | -12.7 | 80 |
| Edge notch | -8.2 | -14 | 65 |
| Hairline crack | -5.2 | -29 | 10 |

## IV. SUMMARY

When printing onto thin polymer layers such as the transfer surface of tattoo paper, the minimum resistivity to be expected from commercial silver nanoparticle inks is about 20 times that of the bulk metal. This value comes about partly due to the need to reduce sintering time and temperature; this though offers the benefit of plasticity in the final printed conductor. This expense may be reduced by overprinting additional layers only where the currents are high, in this case on the feed lines, and a read range just 10% lower than that of a bulk copper tag was achieved.

Inkjet layers are thin compared to etched metal foils (an order of 10 difference) and penetration loss may be significant. However, this is not a significant issue in the case of epidermal tagging as skin loss dominates conductor resistivity.

Tag efficiency is compromised by minor printing defects in areas of high current flow, though the ability to read is maintained unless a line is completely severed, when even a very thin crack is significant.

Studies of the flexing and stretching performance of epidermal tags for passive wireless control by muscle twitch are on-going.

## ACKNOWLEDGMENT

This project and Mr Oyeka's studentship are funded by the UK Engineering and Physical Science Research Council (EPSRC).

## REFERENCES

[1] "Laser Tattoo Paper | Crafty Computer Paper." [Online]. Available: http://www.craftycomputerpaper.co.uk/.-Laser-Tattoo-Paper_CPL214I.htm. [Accessed: 10-Oct-2013].

[2] R. Vyas, V. Lakafosis, and H. Lee, "Inkjet printed, self powered, wireless sensors for environmental, gas, and authentication-based sensing," *Sensors Journal, …*, vol. 11, no. 12, pp. 3139–3152, 2011.

[3] M. A. Ziai, J. C. Batchelor, and S. Member, "Temporary On-Skin Passive UHF RFID Transfer Tag," IEEE Trans. Antennas Propag., vol. 59, no. 10, pp. 3565–3571, 2011.

[4] L. Yang, G. Orecchini, and G. Shaker, "Battery-free RFID-enabled wireless sensors," *… Dig. (MTT), 2010 …*, pp. 1528–1531, 2010.

[5] S. Kim, A. Georgiadis, A. Collado, and M. Tentzeris, "An inkjet-printed solar-powered wireless beacon on paper for identification and wireless power transmission applications," IEEE Trans. Microw. Theory Tech., vol. 60, no. 12, pp. 4178–4186, 2012.

[6] B. V. Lakafosis, A. Rida, R. Vyas, L. Yang, S. Nikolaou, and M. M. Tentzeris, "Progress Towards the First Wireless Sensor Networks Consisting of Inkjet-Printed , Sensor Tags," Proc. IEEE, vol. 98, no. 9, pp. 1601–1609, 2010.

[7] G. Shaker and S. Safavi-Naeini, "Inkjet printing of ultrawideband (UWB) antennas on paper-based substrates," IEEE Antennas Wirel. Propag. Lett., vol. 10, pp. 111–114, 2011.

[8] H. AbuTarboush and A. Shamim, "Paper-based inkjet printed tri-band U-slot monopole antenna for wireless applications," IEEE Antennas Wirel. Propag. Lett., vol. 11, pp. 1234–1237, 2012.

[9] M. Farooqui and A. Shamim, "Dual band inkjet printed bow-tie slot antenna on leather," *Antennas Propag. (EuCAP), …*, pp. 3287–3290, 2013.

[10] T. Björninen, J. Virkki, J. Virtanen, L. Sydänheimo, L. Ukkonen, and M. M. Tentzeris, "RFID Tag Antennas on Renewable Materials with Porous Surfaces," in 7th European COnference on ANtennas and Propagation (Eucap 2013), 2013, no. Eucap, pp. 1721–1725.

[11] NXP, "SL3ICS1002/1202 Product Data Sheet," 2011. [Online]. Available: http://www.nxp.com/documents/data_sheet/SL3ICS1002_1202_139036.pdf. [Accessed: 10-Oct-2013].

[12] P. Pongpaibool, "A study of cost-effective conductive ink for inkjet-printed RFID application," Antennas Propag. (ISAP), 2012 …, pp. 1248–1251, 2012.