PRINTED RFID TAGS ON PAPER AND FLEXIBLE SUBSTRATES TOWARDS LOW-COST CONNECTED SENSOR SYSTEMS

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ABSTRACT

We present printed sensing radio frequency identification (RFID) tags on different paper and flexible substrates towards low-cost, automated connected sensor solutions. Combining the Internet of Things (IoT) with printed electronics and low-cost substrates, this work showcases prototyping of devices for automated sensor readout and wireless transmission using a screen printed antenna and RFID sensing chip. Functionality of the tags on three low-cost, flexible substrates was demonstrated through read range measurements and wireless built-in temperature read-out to illustrate the potential of low-cost, connected sensors to be utilized for a range of applications, from cold-chain monitoring to point-of-care diagnostics.

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1. INTRODUCTION

This work showcases the prototyping of printed ultra-high frequency (UHF) RFID sensing tags operating in the 868 MHz range. The tags were screen printed on three different low-cost, flexible substrates, with the long-term goal of providing solutions for point-of-care diagnostics in resource-limited clinic settings. The approach combines IoT with the field of printed electronics [1] to realize low-cost, automated devices with sensing and wireless communication capabilities which could be utilized for patient and sample tracking, ease of record keeping and automated read-out of a test result. The substrates used in this work are low cost, lightweight, flexible and accessible, and can be readily disposed of through incineration. Tag devices can be manufactured and instructions or information can be printed directly on to the devices. In addition, scale up of device manufacture is feasible using existing roll-to-roll printing technologies, which further supports the approach taken in this work.

UHF RFID is an advantageous technology as it affords longer read ranges than for example near field communication (NFC), with multiple instantaneous tag readings achievable. In addition, these tag devices can function in passive mode, eliminating the need for on-board power and reducing the cost of the tag devices. In this mode, the tags are powered from the electromagnetic field supplied by the RFID reader device, which could be a permanent fixture or a handheld solution.

Complementary to this is the development of printed electronics and printed antennas, where successful printing onto various flexible substrates has been achieved [2]. RFID antennas typically have simpler geometric designs, assisting with the printability of these devices. Sensing RFID solutions have also been explored, with this work focussing on the SL900A sensing RFID chip (AMS, Austria), which enables a number of different sensors to be directly connected and the readout from these sensors to be wirelessly communicated. The SL900A chip provides a versatile solution as resistance, capacitance, voltage and current measurements are possible. The IC complies with the Electronic Product Code (EPC Gen2 1.2), operating in the UHF band. Read distances in the cm to m range are achievable for a wireless solution to be realized using a straightforward dipole antenna design that can easily be printed.

This single chip solution allows for a simple, compact RFID tag design to be realized, with capabilities for identification and tracking of devices. Logging of data in real time is also possible using the SL900A chip with a built-in EEPROM, and an on-board temperature sensor provides useful monitoring of environmental conditions. Previous work using the SL900A for sensing applications has been carried out [3] and printing of tags using the SL900A integrated circuit (IC) on to various substrates has also been explored [4].

This work assesses the feasibility of using different low-cost paper and flexible substrates for implementing manually screen printed and assembled sensing RFID tags. Printed features were characterized, along with read range measurements in both passive (without a battery) and active (battery-assisted) modes to assess the performance of the low-cost tags for sensing and data logging applications. Practical functionality of the tags towards low-cost connected sensor solutions is illustrated through logging of temperature and battery voltage values, demonstrating the potential for these tags to be printed directly onto packaging or onto labels that could be applied to various objects or surfaces.

2. METHODS

RFID tag designs were based on the SL900A development kit (SL900A-DK-STQFN16, AMS, Austria), consisting of a printed dipole antenna and electronic tracks, a 39 nH surface mount inductor (WE-MK multilayer ceramic, Wurth Electronik, Germany), SL900A chip and a 3 V coin cell battery battery (CR1220, RS Pro, RS Components, South Africa) [4]. Tag designs were screen printed on to three different low-cost flexible substrates, namely standard printing paper, cardboard packaging and transparent adhesive vinyl (Table 1) using a silver screen printable ink (AG-800, Applied Ink Solutions, USA). Screen printing was carried out using a modified ZelPrint LT300 stencil printer (LPKF Laser and Electronics, Germany) with screens manufactured by Chemosol (Pty) Ltd. (Johannesburg, South Africa) using a synthetic mesh of 71 threads/cm (71/180-55 PW, SEFAR® PET 1500). Printed devices were cured in the oven at 90°C for 15 mins, after which components were assembled using a silver epoxy conductive adhesive (186-3616 RS Pro Silver, RS Components, South Africa). The battery was secured and connected using copper adhesive tape (3M Copper Foil Tape 1126, Digikey, USA).

Printed features were analysed using a brightfield microscope (Meiji Techno EMZ-8TR, Japan) and a laser scanning microscope (LSM 5 Pascal, Carl Zeiss, Germany). Brightfield microscopy was performed at 7× and 45× magnification to assess the consistency of the printing, the edge irregularities and resolution of fine detail, specifically for the IC pads. Laser scanning microscopy was carried out to measure the surface roughness for each substrate as well as the printed layer on each substrate. Roughness measurements were carried out at 200× magnification, with an average taken over three measurements taken at different positions along the printed layer. Surface roughness was calculated using the arithmetic mean roughness value (Ra).

Thickness measurements were also performed for the printed layers on each substrate using laser scanning microscopy. A theoretical wet print thickness of 28 µm is expected from the screen mesh used, and a corresponding reduction in thickness down to 30% can be expected for the dried ink thickness, resulting in expected print thicknesses of approximately 8.4 µm.

Read range measurements were carried out to assess the performance of the printed tags. The screen printed RFID tags were compared to printed circuit board (PCB) devices of the tag antenna as a benchmark, including the development kit and a milled PCB of the tag antenna manufactured and assembled in-house. The development kit reader recommended for use with the SL900A was used to perform read range measurements (AS3993-QF_DK_R Fermi reader, AMS, Austria). The set-up consists of a monopole antenna (gain = 2.2 dBi) connected to a reader module with a transmission power of 22 dBm. The reader setup was mounted on a sliding mechanism for ease of adjusting the distance between the tag and the reader. The reader IC sensitivity was set to the default of -68 dBm. RFID frequency settings were set to the 917 – 920 MHz range in the user interface as this aligns with the standard South African frequency range for RFID (915 – 919 MHz).

Measurements were carried out for three tags for each type of substrate, both in passive and active modes. For each tag, the maximum read range at which the tag could be detected was recorded, as well as the maximum read range at which a sensor value could be read out. The temperature read-out from the on-board temperature sensor of the SL900A was recorded as an example.

In active mode, logging of sensor data can be implemented through a built-in EEPROM in the SL900A, even when the tag is not in the range of the reader. This was demonstrated for temperature and battery voltage readout over a period of time using the printed tags.

3. RESULTS

Figure 1 shows examples of the printed and assembled tags on three different substrates. Brightfield microscopy results of the printed features are shown for each substrate. Laser scanning microscopy images are also shown for both the substrate and the printed layer in each case. Surface roughness measurements are summarized in Table 1. Thickness measurements were between 6 and 9.5 µm, aligning well with the expected print thicknesses of approximately 8.4 µm. Four probe resistance measurements using an LCR meter (LCR-8110G, GW Instek, Taiwan) yielded acceptable conductivity for all substrates, ranging from 0.047 to 0.073 Ω/sq.

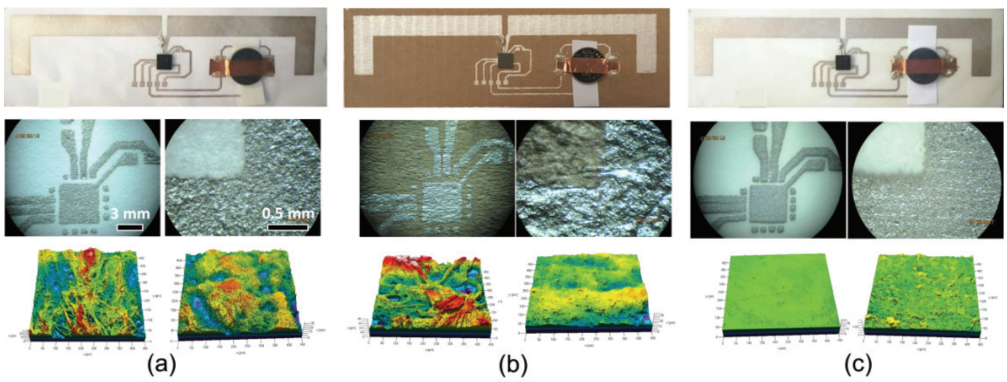

Figure 1: Assembled printed RFID sensing tags on low-cost substrates (110 mm x 30 mm) with corresponding microscope and LSM images (substrate = left, ink layer = right, scan area = 450 x 450 µm) for assessing printed features for a) standard printing paper, b) cardboard packaging and c) adhesive vinyl substrates.

Table 1: Surface roughness measurement results for three low-cost, flexible substrates and screen printed layers on each.

Substrate description	*Product and manufacturer*	*Roughness (µm)*			
		Blank substrate	*Standard deviation*	*Printed ink layer*	*Standard deviation*
Standard printing paper	Typek White Paper A4 80 GSM Premium, SAPPI, South Africa	4.96	0.74	4.33	0.55
Cardboard packaging	Typek White Paper packaging box, SAPPI, South Africa	5.05	1.11	4.58	1.63
Transparent adhesive vinyl	Grafitack Promo P100 Transparent Film, Grafityp Selfadhesive Products N.V., Belgium	0.24	0.09	0.89	0.13

Figure 2 shows the maximum read range results for each of the low-cost, flexible substrates compared to the development kit and the milled PCB tags. For each type of tag, read ranges for both passive and active modes were record. In each case the read ranges for tag detection as well as the read range for temperature sensor readout were recorded. Figure 3 shows the results of data logging of a printed tag on adhesive vinyl for temperature and battery voltage read-out over 140 samples, with readings taken each minute. The reader user interface displays the data recorded in the EEPROM directly, as shown in Figure 3b, but EEPROM data (Figure 3a) can also be accessed and processed separately when additional sensors are connected.

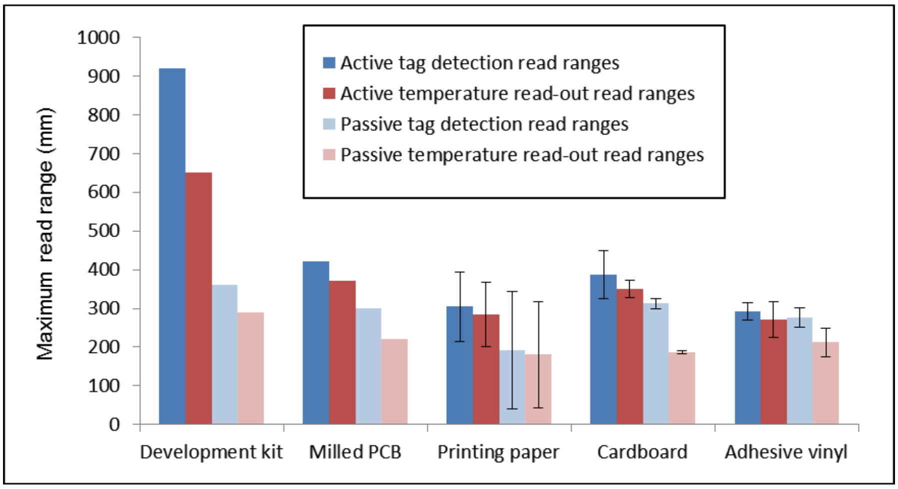

Figure 2: Maximum read ranges in both active and passive mode for tag detection and temperature read out for different tags compared to read ranges obtained using the commercially available printed circuit board (PCB) development kit for the SL900A as well as a milled PCB of the tag design manufactured and assembled in-house.

4. DISCUSSION

This work demonstrates printed UHF RFID tags on to different low-cost, paper and flexible substrates to implement sensing and wireless communication functionalities. Manual screen printing and assembly processes enabled prototyping of printed, low-cost and functional RFID sensing tag devices.

Surface roughness measurements for paper-based substrates (both standard printing paper and cardboard packaging) were high with large standard deviations as a result of the fibrous texture of the substrates. The printed layers on these substrates were less rough, with the ink coating the fibres and filling the porous spaces in between the fibres. The smoother adhesive vinyl substrate had a much lower surface roughness, but the printed ink layer had a higher roughness than the substrate. Variations in the thickness measurements are as a result of the manual screen printing process utilized.

Read range measurements showed successful operation of all the tags assembled and tested. Minimum read ranges of 100 mm were achieved for tags in passive mode, with read ranges of up to 500 mm in active mode. Read ranges when reading out a sensor value were slightly lower than the read range for tag detection alone. Maximum read ranges for the development kit in this work were around 900 mm in active mode and 360 mm in passive mode. The lower read ranges and variations in read ranges measured for the printed tags are a result of the manual printing and assembly procedures. In addition, the tags were tested in a standard laboratory, where reflections in the RF signal can occur, affecting the read range measurements. Impedance mismatch and poor antenna gain can be caused by printing, and could be improved by printing thicker, more uniform layers [5]. Although this affects the performance of the RFID tags, practical and reliable tag detection and sensor readout are still achievable, and is the ultimate goal of this work. If the working distances are chosen to be in the range of 50 – 100 mm, functional tags can be realized on any of the three low-cost, flexible substrates utilized in this work.

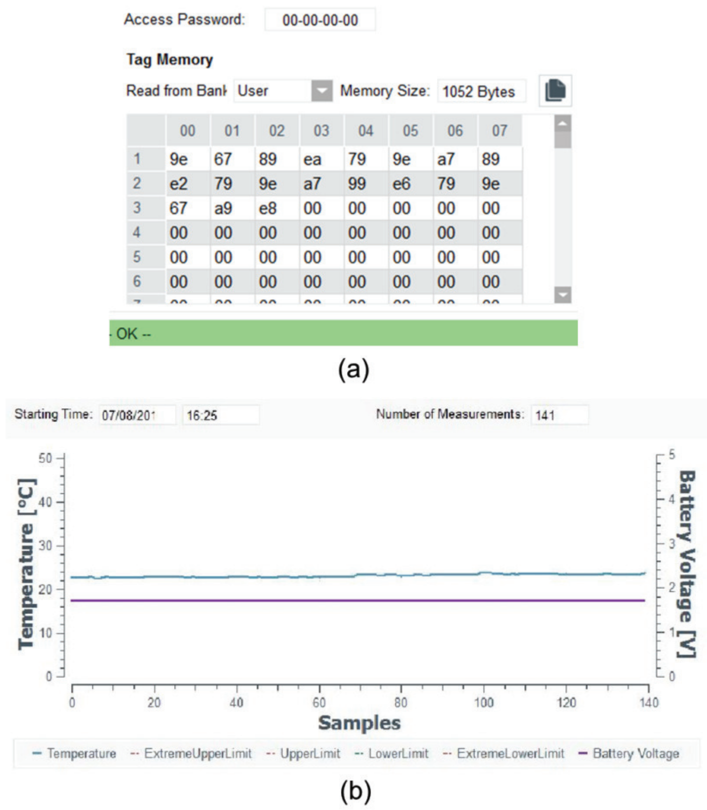

Figure 3: Example of temperature and battery voltage data logging, using screen shots from the AS3993 Reader Suite software (AMS) to show a) wireless read-out values stored in the EEPROM of the SL00A, and b) temperature and battery values plotted over time from a tag printed on adhesive vinyl substrate.

Logging of data was also successfully demonstrated, showing promise for the integration of various sensing capabilities with the printed RFID tags. Printed low-cost sensors for read-out from low-cost paper-based point-of-care diagnostic tests, tamper detection, environmental monitoring, and various other applications could be investigated and incorporated in to the printed tag devices.

Automated screen printing could be used in future development once successful prototypes have been realized, and can be scaled up for mass production using roll-to-roll techniques and further lowering the cost of the RFID sensing tag devices.

5. CONCLUSION

Prototyping of printed, low-cost, automated and wireless sensor devices on different flexible substrates has been successfully demonstrated. Low-cost, accessible substrates that can easily be integrated with other devices or diagnostics show repeatable wireless read-out of sensor values from the tags in both passive and active modes. Logging of sensor data over periods of time has also been successfully demonstrated. Future work will be built on the assumption that a reliable link to the outside world exists and will focus on the electrical readout of the diagnostic result on paper, with the potential to solve many of the challenges faced in diagnostic testing carried out at rural and resource-limited clinics.

REFERENCES

[1] Chang, J. S., Facchetti, A. F. and Reuss, R. 2017. A circuits and systems perspective of organic/printed electronics: review, challenges, and contemporary and emerging design approaches, *IEEE Journal on Emerging and Selected Topics in Circuits and Systems*, 7(1), 7-26.

[2] Kavčič, U., Pivar, M., Dokić, M., Svetec, D. G., Pavlovič, L. & Muck, T. 2014. UHF RFID tags with printed antennas on recycled papers and cardboards. *Materials and Technology*, 48(2), 261–267.

[3] Fernández-Salmerón, J., Rivadeneyra, A., Martínez-Martí, F., Capitán-Vallvey, L. F., Palma, A. J. and Carvajal, M. A. 2015. Passive UHF RFID tag with multiple sensing capabilities. *Sensors*, 15(10), 26769–26782.

[4] Smith, S., Oberholzer, A., Land, K., Korvink, J. G. & Mager, D. 2018. Functional screen printed radio frequency identification tags on flexible substrates, facilitating low-cost and integrated point-of-care diagnostics. *Flexible and Printed Electronics*, 3(2), 025002.

[5] Falco, A., Salmerón, J. F., Loghin, F. C., Lugli, P., and Rivadeneyra, A. 2017. Fully printed flexible single-chip RFID tag with light detection capabilities. *Sensors*, 17, 534,1-12.