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Comparison between the characteristics of screen and flexographic printing for RFID applications

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Abstract: In this paper, we investigated and compared the characteristics of novel smart card RFID antennas which were printed using two different fabrication technologies: industrial screen printing and industrial flexographic printing. After the printing process, the drying processes were optimized separately for each of the printing techniques in order to achieve optimal performances for the proposed antennas. The characteristics of the antenna were analysed by measuring several parameters such as resistance, backscattered power, antenna impedance and return loss. The effect of the lamination process on the readability and operability of the final cards were analysed in detail. The possibility of using the printing processes in the realization of RFID antennas was investigated in terms of fabrication speed, and repeatability of the printing. We have proved that industrial screen printing and flexographic printing techniques can be used equally well for producing RFID smart cards. Flexographic printing has proved to be a faster solution, but screen printing has shown higher repeatability.

Keywords: smart cards; printed antenna; RFID; screen printing; flexographic printing

Primerjanje lastnosti sito in fleksotiska za aplikacije RFID

Izvleček: V članku smo raziskovali in primerjali lastnosti novega dizajna anten RFID za pametne kartice. Antene so bile natisnjene z različnima tehnologijama: z industrijskim sitotiskom in fleksotiskom. Po tiskanju se je optimiziral postopek sušenja za vsako tehnologijo tiska posebej, da bi dosegli najboljše delovanje anten. Lastnosti antene smo analizirali z merjenjem velikega števila parametrov, kot so upornost, moč povratnega signala, impedanca antene in izguba povratnega signala. Podrobno smo analizirali tudi vpliv laminacije na končno berljivost in delovanje kartic. Možnost izdelave anten RFID z različnimi tehnologijami tiska smo proučili glede na hitrost izdelave in ponovljivost tiska. Dokazali smo, da se lahko industrijski sitotisk in fleksotisk uporabljata za izdelavo pametnih kartic RFID. Fleksotisk se je izkazal kot hitrejša rešitev, sitotisk pa omogoča boljšo ponovljivost.

Ključne besede: pametne kartice; tiskana antena; RFID, sitotisk; fleksotisk

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1 Introduction

The demand for RF and wireless systems that require low cost and high performance has been growing rapidly over the last decade. Radio frequency identification (RFID), one of the key technologies in the fast-growing printed electronics industry, uses an electromagnetic field to transfer data.

An RFID system consists of a tag that contains an integrated circuit (IC) chip and an antenna, and has the ability to respond to radio waves transmitted from an RFID reader. The main advantages of an RFID system are the non-contact and non-line-of-sight characteristics of the technology used. Because of those characteristics, RFID is suitable for operation in a variety of working conditions where there is, for example, dust, snow, ice, dirt, stress, humidity, etc. [1]. RFID is currently used in many applications such as medical products, pharmaceutical logistics, vehicle security, transportation, contactless payment, etc. [2].

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Printed electronics, such as RFID, may be printed using different technologies. Conventional printing processes are much faster and better suited to printing large areas than is the case with digital printing processes [3]. For example, inkjet printing [3-5], as a representative of the digital printing process, is very accurate but relatively slow. On the other hand, some conventional technologies, like flexographic-printing [6-8] or screen-printing [9-12], are suitable for large area printing and mass production. These technologies are characterized by high production speed, high resolution and the possibility of printing a number of different functional (conductive) inks [13]. Screen printing is a special type of stencil printing, which means that, in the printing process, the ink passes through the screen and onto the substrate. Flexographic printing, unlike screen printing, uses soft, flexible printing plates which were formerly made solely from rubber but are now usually made from photopolymers. Low pressure applied between the plate cylinder and substrate is sufficient to transfer the ink from the plate cylinder to the substrate [14].

Ink selection is one of the essential steps in the printing process. Besides conventional process printing inks, there are many types of functional printing ink available on the market today such as conductive, dielectric, electrochromic, thermochromic, etc. Conductive inks are far more expensive than conventional inks, and it is therefore necessary to find the best price and keep consumption to a minimum. [15] The factor of price is of great significance in mass production, since the final price of a single tag is a major barrier to greater popularization and application [16, 17].

In this paper, we studied and compared the characteristics of screen- and flexographic-printed UHF antennas. The proposed UHF folded dipole antenna was designed using the CST Microwave Studio, an EM simulator. After printing, the drying processes were optimized to achieve optimal performances for the proposed antennas and then chips were integrated with. At the end lamination process was used. The characteristic parameters of the antenna such as resistance, backscattered power, antenna impedance and return loss were measured as well as the operability of the laminated smart card. The possibility of using these printing processes for making of RFID antennas was investigated in terms of fabrication speed and the repeatability of the printing process.

2 Experiments

2.1 Antenna design

The UHF RFID antenna was designed and simulated using the CST Microwave Studio, an EM simulator. The laminated antenna is designed to operate according to the UHF standard with a central operating frequency of 868 MHz. The proposed antenna is folded to fit the size of a standard credit card, with a small or negligible reduction in antenna efficiency. It was designed on polycarbonate film (thickness: 120 µm; grammage: 120 g/m^2; surface roughness, ISO 4288: 2.3 µm) with a relative permittivity of $\varepsilon_r = 3.2$ and a dissipation factor of 0.0019. In simulations, 16 µm of silver were used for conductive material, and conductor losses were modelled using bulk conductivity for silver. The configuration of the proposed folded dipole antenna is shown in Figure 1.

Initially antenna dimensions were determined for the laminated case since the number and thickness of dielectric layers during lamination affects the characteristics of the antenna. Nine dielectric layers were used in the simulation, with the antenna placed between the fourth and fifth layers. Figure 2 shows the simulated return losses and the total efficiencies of the proposed non-laminated and laminated dipole antennas. It can be seen that the fundamental resonance occurs at 868 MHz with reflection better than −10 dB in the case of the laminated antenna. Lamination process significantly influences the resonant frequency of the antenna and its return loss, due to changes in the effective dielectric constant of the substrate and antenna impedance. Non-laminated antenna operates at 930 MHz with reflection better than −7.5 dB. Total efficiency of the proposed laminated antenna obtained using CST Microwave Studio is better than 90% at the resonance. Radiation efficiency of the proposed laminated antenna was also calculated, and it was found to be higher than 95% at the resonance. The efficiency of non-laminated antenna is significantly lower due to the impedance mismatch. Furthermore, it can be mention that the proposed laminated antennas has omnidirectional radiation pattern with the gain of 1.9 dBi.

2.2 Antenna fabrication

The proposed antenna is printed using screen and flexographic printing technologies. Two silver conductive printing inks were used in the printing processes: SunChemical CRSN2442 SunTronic 280 Thermal Drying Silver Conductive Ink for the screen printing and Acheson Electrodag PD-054 for the flexographic printing. SunChemical CRSN2442 is a thermal curing ink, whereas Electrodag PD-054 is a UV curing ink, but successive heat curing is recommended for better results. The

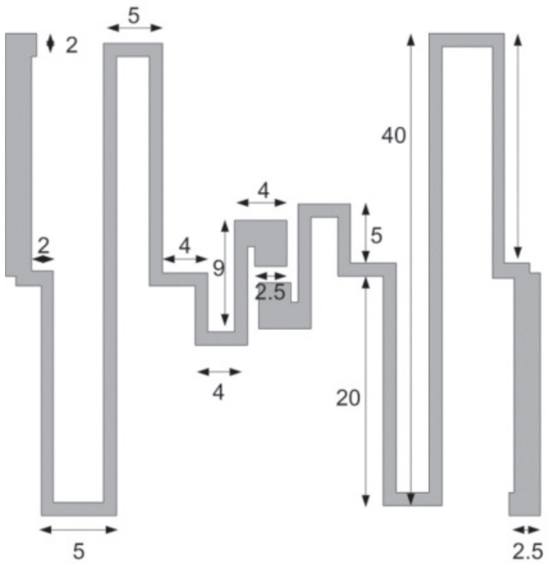


Figure 1: Design of a dipole antenna

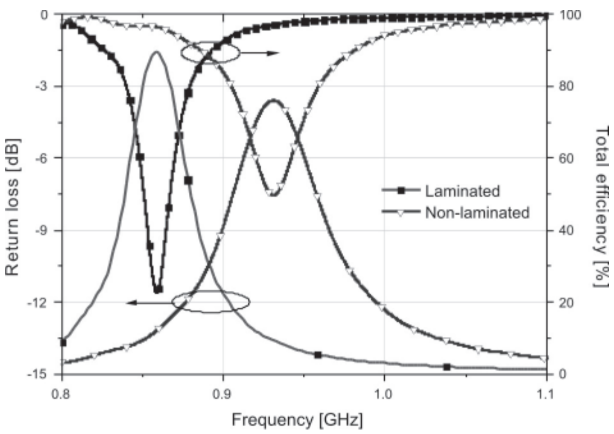


Figure 2: Simulated return loss and total efficiency of the proposed laminated and non-laminated antennas.

characteristics of both inks, with their recommended specifications, are presented in Table 1.

A block diagram of the fabrication process for the antenna is shown in Figure 3. In the screen printing process, antenna samples were printed using the Siasprint Novaprint-P screen printer with a monofilament polyester plain weave mesh of 120 l/cm and a theoretical ink volume of 16.3cm^3/m^2. After printing, the optimal drying process for the ink was determined. Optimal drying was determined to be the point where the sheet resistance of the printed samples became constant irrespective of longer drying time, higher temperature or higher or longer UV exposure. In accordance with the thermal ink specification, the drying was performed in a hot zone tunnel. The tunnel has the ability to heat up to 72 °C (maximal value). Therefore, in order to achieve optimal drying conditions, the maximal temperature was used with a different number of passages through the tunnel until the lowest sheet resistance was obtained. The best results, i.e. the lowest sheet resistances, were obtained when the samples passed through the tunnel seven times (at 72 °C for 30 s).

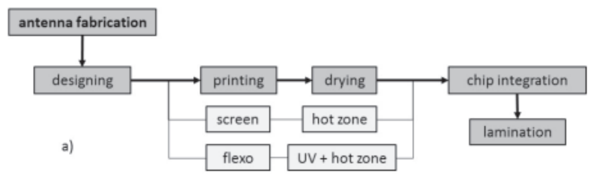


Figure 3: Schemes of smart card fabrication process

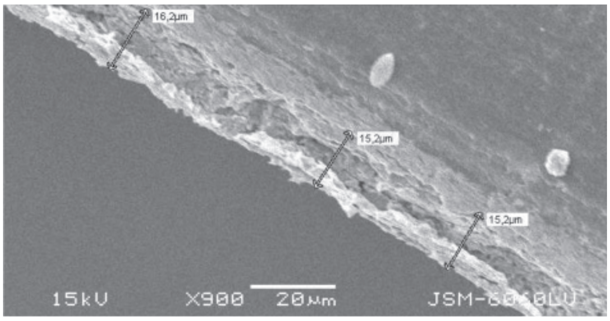
Flexographic antenna samples were printed using an in-line OMET XF 340 flexographic printing machine with eight printing units. All the printing units were equipped with a UV drying unit. The printing machine was also able to dry substrate using hot zone (heat curing/hot air drying), as was the case here. An anilox roller able to deposit large amounts of ink was used for this purpose (screen frequency of 60 cell/cm, cell volume: 30 cm^3/cm^2, cell geometry: hexagonal). The optimal results, with the lowest sheet resistance, were obtained when the substrate was dried seven times under the UV units, and at the maximum temperature in the hot zone at the end. The power of the UV lamps was 160 W/cm and the final printing speed was set to 25 m/min.

On the printed test elements, the thickness of the ink layer was measured using a JEOL JSM-6060LV scanning electron microscope. The measurements were performed on the 10-sample cross section. Figure 4 shows

Table 1: Characteristic properties of the printing inks used.

Printing ink	Solids	Drying condition	Sheet resistance (25 µm layer thickness)
SunChemical CRSN2442 SunTronic 280 (thermal ink)	69–71%	Heat curing / hot zone: 30–90 s at 100–130 °C	10–32 mΩ
Acheson Electrodag PD-054 (UV ink)	100%	UV curing: Fusion "D"; Light intensity 1.4 J/cm2, Power of UV lamp: 160 W/cm Heat curing / hot zone: 60 s at 100 °C	<75 mΩ

the variation in the ink thickness between the screen (Figure 4a) and flexographic (Figure 4b) printed samples.



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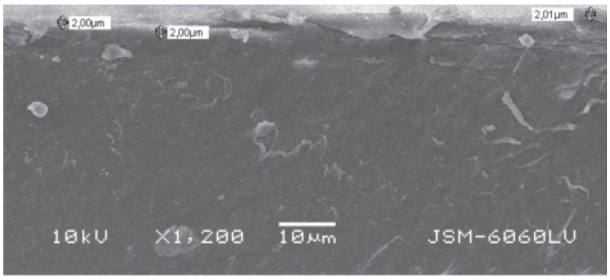


b

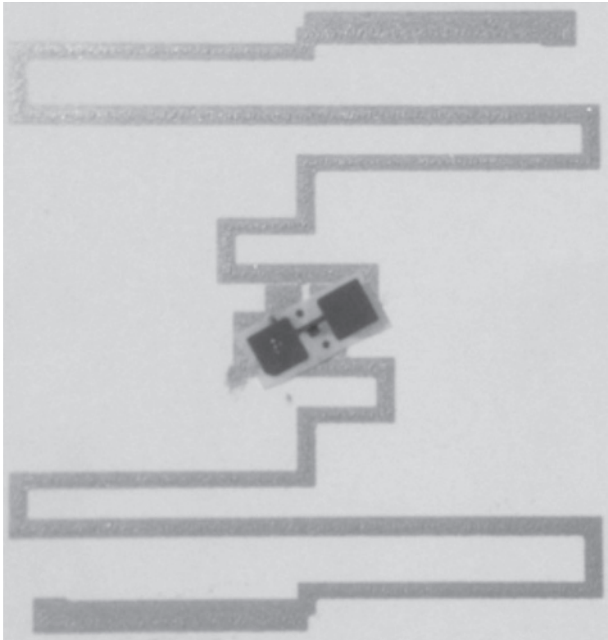
Figure 4: The cross-cuts for the screen- (a) and flexographic printed (b) samples.

The ink layer thickness for the screen prints ranges from 12.2 µm to 16.2 µm with a standard deviation of 2.13, and from 1.26 µm to 6.76 µm with a standard deviation of 1.91 for the flexographic prints. Non-uniformity is much higher in the flexographic prints.

2.3 Chip integration and card lamination

After drying NXP SL3ICS1002/1202 strap chips operating in a frequency range of 840–960 MHz with a characteristic impedance of Z = 22-j195 Ω and a Q-factor of 9 were integrated on the printed antennas. Figure 5a shows a photograph of the printed antenna with the mounted chip. The chips were assembled manually with isotropic conductive glue based on silver particles (Bison ELECTRO glue) and then dried in a thermal oven for 30 minutes at 120 °C.

After chip integration, a lamination process was performed to produce the final smart cards. To begin, in the heat phase, nine foil layers were assembled for 19 minutes at a high temperature of 199 °C and a pressure of 300 N/cm^2. The assembled foils were then exposed in the cold phase for 18 minutes at 25 °C and a pressure of 500 N/cm^2. Lastly, the standard cards were cut into the final standard format (ISO/IEC 7810), as shown in Figure 5b.



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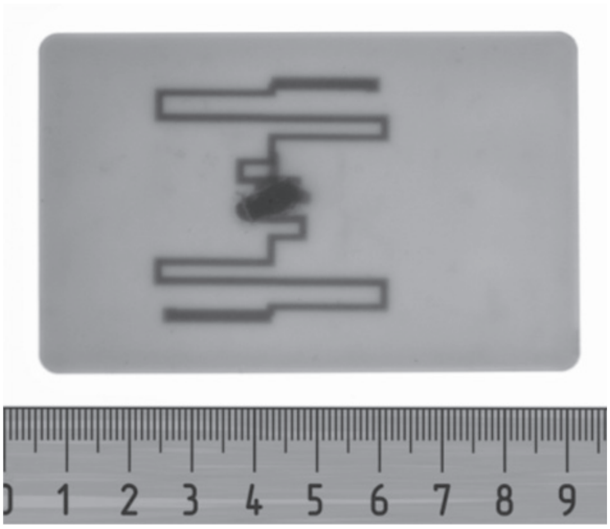


b

Figure 5: Printed antenna with integrated chip (a), final laminated smart card prototype (b).

3 Measurements and results

A card evaluation is presented in the part of the paper that follows. A block diagram of the evaluation process is shown in Figure 6. To begin, on the non-laminated cards, the sheet resistance and ink layer thickness of the conductive printed lines were measured. Then, using a network analyser, the antenna impedance and return loss of the proposed antenna were evaluated. To conclude, the backscattered power of the non-laminated and laminated smart cards was assessed in a real environment in order to determine the operability of the final card.

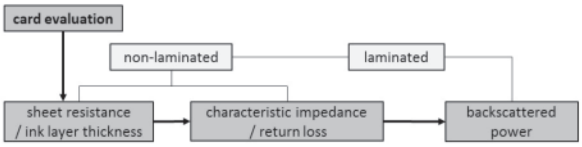


Figure 6: Testing and measurement process

3.1 Resistance measurements

The resistance was determined after drying the screen and flexographic printed samples. Figure 7 shows the printing form for flexographic printing. The printed antennas were positioned in the first three columns, and the test elements were positioned in the last column (vertically to print the length) on the polycarbonate foil in order to determine the resistance and uniformity of the printed conductive lines. The resistance was measured after 24 hours of conditioning with a 50% relative humidity at 23 °C using the Fluke 289 True-rms Industrial Logging Multimeter.

All the resistance measurements were performed on the test elements with a nominal length of 22 mm and a line width of 3 mm. The measurements were performed (along the print length) on each meter for the on-screen prints, while the measurements were performed on each three to five meters of the printed substrate for the flexographic-prints. Each measurement was performed three times on three successive elements.

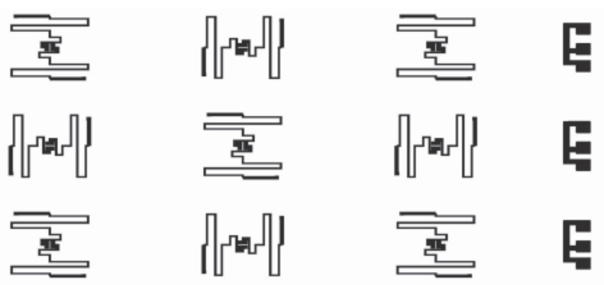


Figure 7: The printing form for flexographic printing: antennas (the three left-most columns), test elements for sheet resistance measurements (the last column on the right).

The results of the resistance measurements for the test elements printed using screen and flexographic printing machines are presented in Figure 8 and Figure 9, respectively.

Note that the average resistance of the screen-printed layer is much lower (1.20 ± 0.12 Ω) than that for the flexographic prints (31.90 ± 9.73 Ω).

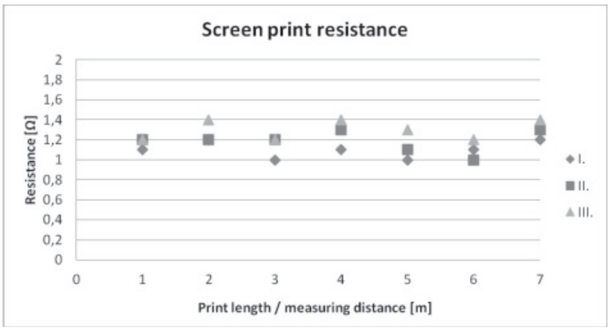


Figure 8: Screen print resistance measured three times on three successive elements (I., II., III.)

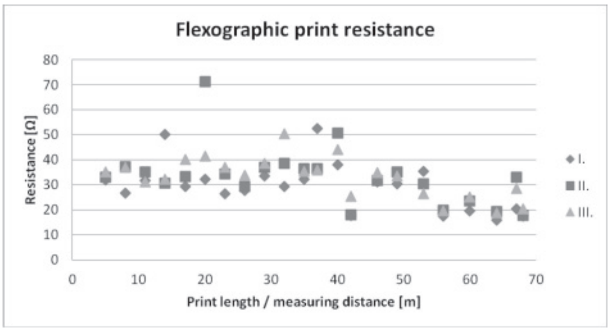


Figure 9: Flexographic print resistance measured three times on three successive elements (I., II., III.)

In terms of print length, the resistance is non-uniform. This is evident especially on flexographic prints, where the standard deviation reaches almost 10 Ω (9.73 Ω). The high ink layer thicknesses on screen printed samples consequently show lower resistance. On the other hand it is clearly evident that the low layer thicknesses for the flexographic printed samples yield resistance values which are almost 30 times higher. The reason for this lies in Ohm law, which states that resistance values are lower when the thickness of the printed conductive layer is higher. The thickness of the conductive layers printed using screen printing ranges from 12.2 µm to 16.2 µm, whereas the thickness for flexographic prints spans from 1.26 µm to 6.76 µm. Another reason is the mixture of conductive ink, where a specification given by the manufacturer shows different specific resistances for each ink. The results achieved demonstrate a high correlation with ink layer thickness.

3.2 Antenna impedance and return loss

The characteristics of the antenna were measured using an Agilent E5071C ENA Network Analyser. An ENA network analyser is used for measuring antenna impedance and return loss. The impedance of the proposed antenna was measured for the non-laminated cards in the anechoic chamber using a simple broadband network analyzer technique for measuring balanced antennas, without a balun described in [18]. The measured characteristics parameters were summarized in Table 2, where f_r denotes the resonant frequency, s_{11} denotes the return loss at the resonant frequency and *Real (Z)* are real parts of the impedance of the antennas. The real part of the impedance was shown at frequencies where the imaginary part was equal to zero.

The results of some of the characteristic parameters measured were summarized in Table 2 and Figure 10. Figure 10 shows the return loss measured and Smith charts for antennas printed on a flexographic machine (F2) and another for a screen-printed antenna (S4).

Table 2: Measured characteristic parameters of the proposed antennas.

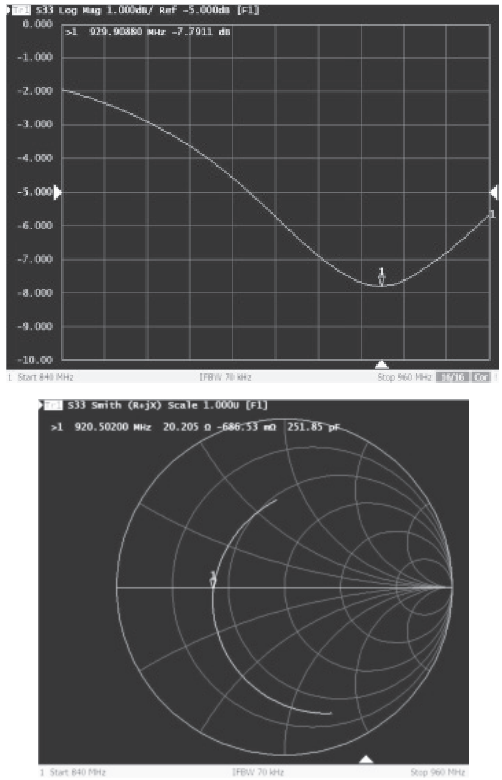
Technology	No. of antenna sample	fr [MHz]	S11 [dB]	Real (Z)/f [Ω/MHz]
Screen				
	S1	913,50	-8,450	22,04/908,44
	S2	929,42	-7,550	20,12/919,54
	S3	925,56	-7,290	19,02/917,36
	S4*	929,91	-7,791	20,21/920,50
Flexographic				
	F1	914,23	-12,018	86,08/924,60
	F2*	937,39	-16,755	67,51/943,40
	F3	923,39	-13,407	78,70/932,80
	F4	924,60	-32,710	52,50/924,60

**Smith charts for the denoted antennas samples are provided below.*

The resonant frequencies of the measured antennas are similar for all antennas printed using both technologies. However, the return losses and the characteristic impedances are much smaller for an antenna fabricated using screen printing technology.

Due to the fact that the thickness of the conductive ink in the case of screen printing was much higher, the inductance of the screen printed antennas was slightly smaller and resistance significantly decreased. It can be seen that the antennas implemented using screen printing show the value of the real part of the impedance to be around 20 Ω, while the imaginary part has an inductive character. On the other hand the antennas fabricated using flexographic printing show a higher value for the impedances – over 50 Ω, but their imaginary part was capacitive at the resonance (Figure 10). The output characteristic impedance of the SL3ICS1002/1202 chip was 22 – j195 Ω at 915 MHz. After mounting the chip on antennas, screen printed antennas show a better level of matching with the real part of the chip impedance. However, despite the higher resistance value for flexographic printing, it shows a better level of matching with its imaginary part.

a



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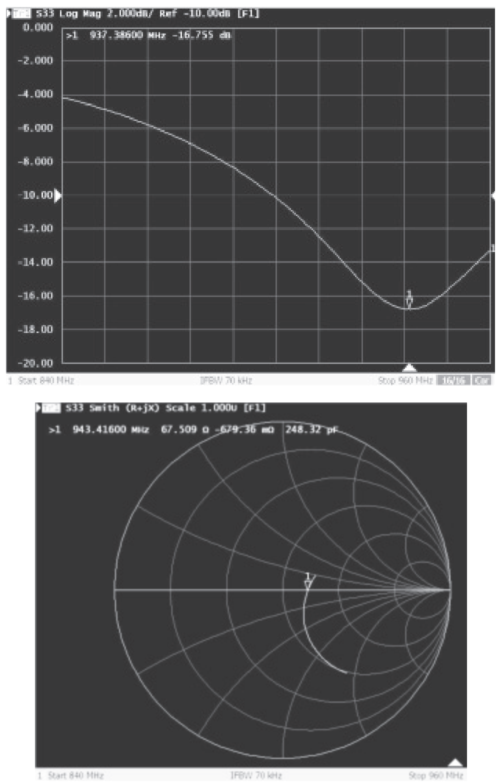

Figure 10: Measured return loss (left) and a Smith chart (right) for: (a) screen printed antenna (antenna, S4*), and (b) a flexographic printed antenna (antenna, F2*).

3.3 Backscattered power measurements

Non-laminated and laminated cards were evaluated by measuring the backscattered power. The backscattered power was measured using an IDS-R902 reader (Figure 11). It comprises the reader electronics and an A0025 circularly polarized patch antenna (Poynting GmbH, Dortmund, Germany) with gain of 6.5 dBi emitting UHF EM radiation at a frequency of f = 868 MHz. The reader electronics measures the intensity of the modulated backscattered signal. The backscattered power was measured on non-laminated and laminated cards by moving each card separately in a straight line perpendicular to the reader in 2 cm increments. The measurements were taken separately on 10 fabricated cards with screen-printed antennas and 10 fabricated cards with flexographic-printed antennas.

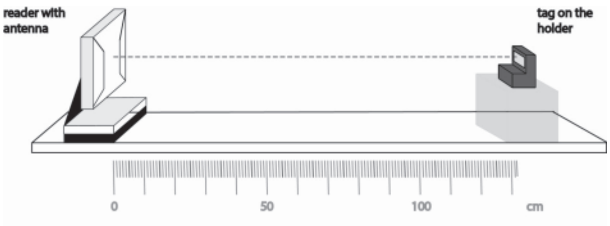

Figure 11: Schematic illustration of measuring the backscattered power

The results presented on Figure 12 show the median values of all the samples measured for the defined distances. The final median values of the reading distances and backscattered power achieved for screen- and flexographic antennas printed on non-laminated cards, with their related standard deviations, are shown in Table 3 below.

Table 3: Median values for reading distances and backscattered power achieved for non-laminated cards

	Screen printing		Flexography	
	Distance [cm]	Power [dBm]	Distance [cm]	Power [dBm]
Average	39,40	-57,67	34,73	-59,87
Standard deviation	±1,14	±1,11	±12,69	±2,03

It can be observed that card readability depends on the conductivity of the printing ink used to print the antenna. Antennas printed with screen-printing thermal ink with a resistance of 1.22 Ω (sheet resistance: 118.12 mΩ/sq), had 30-times higher conductivity than those printed with flexographic UV inks with a resistance of 35.94 Ω (sheet resistance: 3489 mΩ/sq). As a consequence, cards printed with thermal ink had slightly better readability and higher backscattered power (dBm) for the return signal than cards printed

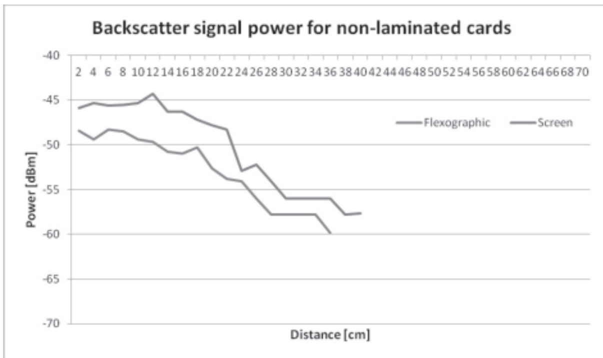

Figure 12: The effect of reading distance on the backscattered power achieved for non-laminated cards made using screen and flexographic-printing.

with UV inks. The maximum reading (working) distance showed differences between the inks applied. UV inks have a shorter reading range. The standard deviation values are very high for flexographic-printed antennas. The reason for such results can be found in the weak uniformity of ink layer thickness and the resultant high variability in sheet resistance.

Backscattered power measurements were also performed for the laminated cards (Figure 13). The median values for the reading distances and backscattered power achieved for screen- and flexographic antennas printed on laminated cards, with their related standard deviations, are presented in Table 4 below.

Table 4: Median values for the reading distances and backscattered power achieved for laminated cards

	Screen printing		Flexography	
	Distance [cm]	Power [dBm]	Distance [cm]	Power [dBm]
Average	62,84	-59,38	58,00	-65,27
Standard deviation	±5,79	±1,41	±3,46	±1,44

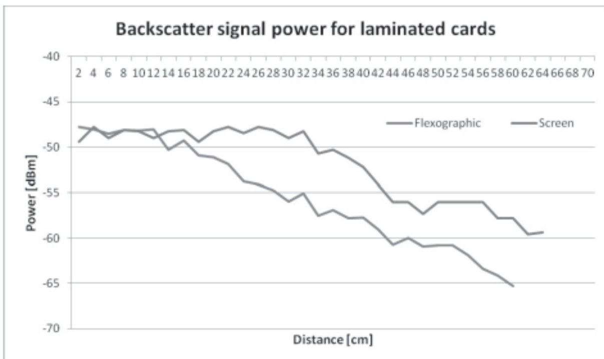

Figure 13: The effect of reading distance on the backscattered power of laminated cards made using screen and flexographic-printing.

The comparison of the maximum reading distances for non-laminated and laminated cards revealed some clear differences. Since the antenna is designed for laminated cards, the lamination process for screen-printing increases the reading distance from 39.4 cm to 62.84 cm.

As is the case with screen-printed antennas, the card lamination process also increases the reading distance also for laminated cards in which the antennas were printed using flexography (this time from 34.73 cm to 58.0 cm). This increase is similar to that for screen-printed antennas, but there are obvious differences in backscattered power, which is higher for laminated cards with screen-printed antennas. The main reason for this again lies in the higher resistance of flexographic - UV conductive ink.

4 Conclusions

In this paper, the possibility of utilising screen and flexographic printing processes in the fabrication of UHF RFID antennas has been investigated in terms of fabrication speed and the repeatability of the printing process. Through optimizing the antenna design and printing processes, it may be possible to streamline printing for low-cost mass production. In order to prove the aforementioned statement, industrial flat-bed screen printing and a roll to roll flexographic printing machine were used in to produce the proposed folded dipole antenna. The characteristics of the antennas were evaluated by measuring the resistance, antenna impedance and return loss. After the drying process and lamination had been completed, the operability of the smart card was ascertained by measuring the backscatter power.

It was demonstrated that the higher ink conductivity achieved using screen printing increases backscattered power. Furthermore, screen printing gives us a more stable response because of greater uniformity in the ink layer thickness and the lower resistivity (a median value of approx. 1.2 Ω), which is in contrast to flexographic printing which has a level of resistance that is approximately 26 times higher (approx. 31.9 Ω). The resistance of the antenna directly affects the reading distance and backscatter power. Screen printed card shows 8% better reading range with a stronger backscatter power. The main effect on the operability of the final tag is the quality of the conductive ink itself, and the repeatability and stability of the printing process. The research has proved that screen- and flexographic printing technology can be used equally well for printing of smart cards UHF antennas, but screen printing results in better card operability. Flexographic printing, on the other hand, has proved to be a faster and more cost-effective solution.

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