Seeking a Good Reception

How a UV-Curable Flexo Ink for RFID Antennas was Developed

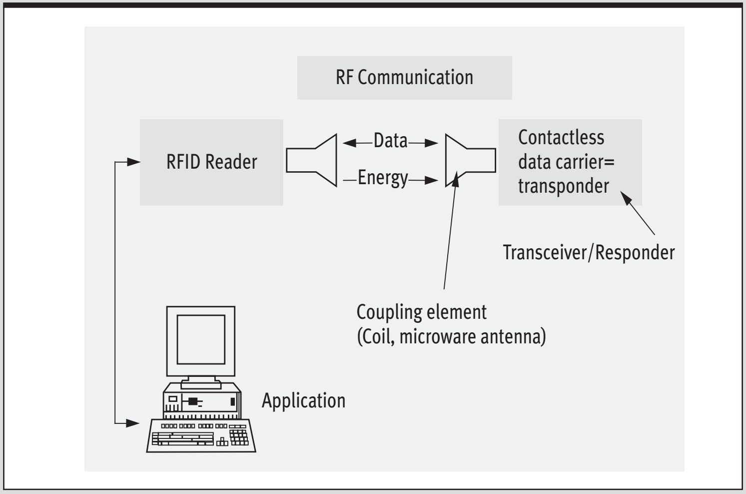
By Rudie Oldenzijl

Printing is a highly economical way to produce Radio Frequency Identification (RFID) devices and UV inks offer the advantages of high solids and rapid cure. UV-curable inks were optimized for conductivity and printability in the laboratory then tested on several flexographic presses. A performance close to target was obtained, though printing speed was limited by the need for a high UV energy density to cure the opaque ink.

Contactless smartcards and RFID labels are devices that are capable of uniquely identifying an individual or object when they are interrogated by an external radio frequency signal (Figure 1).

FIGURE 1

Basic schematic diagram of RF communication



A contactless smartcard or RFID label consists of a graphic overlay and an inlay (also termed a tag or transponder). The inlay is the functional or active part of the card or label, containing the die or chip (used to carry the coded information) and an antenna (used to both transmit and receive RF signals).

The design of the antenna depends partly on the frequency of the RF signal. Coil antennas operate at a low frequency (LF) of 125 kHz or a high frequency (HF) of 13.56 MHz, while dipole antennas are used at 800-1000 MHz (the UHF range), or at 2.45 GHz.

The read distance and speed of data transfer between reader and smartcard/label is determined by frequency and antenna size—the higher the frequency, the greater the read distance and the higher the speed of data transfer.

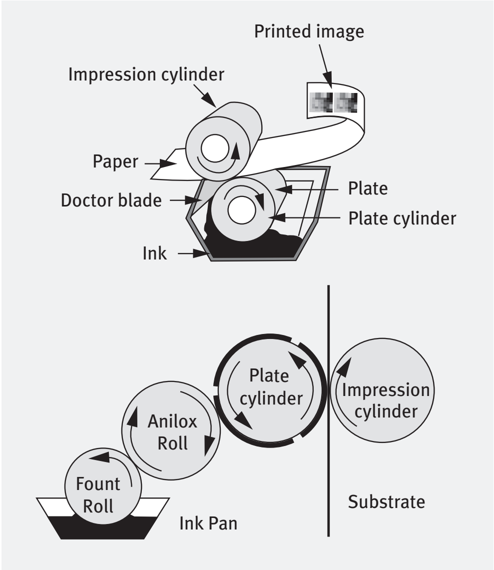
How RFID Antennas are Constructed

A range of materials and construction techniques is used to produce antennas. Those most commonly used are:

- **Wound copper wire**—coils for 125 kHz and 13.56 MHz;
- **Etched copper or aluminium**—coils for 13.56 MHz and dipoles for UHF + 2.45 GHz;
- **Die-cut stamped aluminium**—coils for 13.56 MHz and dipoles for UHF + 2.45 GHz;

FIGURE 2

Basic schematic diagrams for rotogravure printing (top) and flexography (bottom)



- **Plated copper**—coils for 13.56 MHz and dipoles for UHF + 2.45 GHz;
- **Printed conductive inks, mainly silver based**—coils for 13.56 MHz and dipoles for UHF + 2.45 GHz.

Solvent-based conductive inks are already produced for many electronic applications, and some inks are already used to print the antennas for 13.65 MHz coils. A UV-curable flexographic ink would be of interest for printing UHF dipole antennas. Many flexo printers use UV to cure their inks because it is a fast process and UV inks have no volatile organic compounds (VOCs). Other advantages are the low temperature curing and high coverage of a UV ink. There is no loss of solvent, so the applied thickness of the wet film will be about the same as the thickness of the cured film.

To obtain the required conductivity, a high silver loading is needed. This makes it hard to obtain UV curing of the ink and it will also influence the ink rheology. Inks suitable for flexography must have a specific rheology profile. The goal of this research was to develop a UV-curable conductive ink which could be applied by flexography at reasonable speeds.

After curing, the ink must have the right properties to function as an RFID antenna. The company already had a UV-curable conductive ink with a resistivity of 0.050 Ohm/square/25µm or 1.25E-04 Ohm.cm. The goal for this project was set at 0.010 Ohm/square/25µm or 2.5E-05 Ohm.cm, that is, a resistance five times lower than that of the current ink.

Formulation Variables and Print Quality Examined

An initial feasibility study was carried out on the main components of a UV-curable conductive ink—monomers, oligomers, silvers and photoinitiators (PI). Various common and more exotic monomers were combined with a silver flake which had been developed for UV-curable systems. At the same time, oligomers were tested using the same silver flake and different types of silver and photoinitiators were also evaluated.

The inks were applied with a 10-micrometer wire bar onto polyester and cured with a standard mercury or "H"-bulb at an energy density of 1700 mJ/cm^2. The sheet resistance of the cured films was measured in Ohm/square/25µm. (Resistance and conductivity have an inverse relationship—the lower the resistance, the better the conductivity).

A subsequent step in the feasibility study was to examine the printability of the inks. The flow properties of the inks were characterized with a rheometer. Several formulations were tested on a lab-scale gravure tester. Figure 2 gives a schematic overview of gravure and flexo printing.

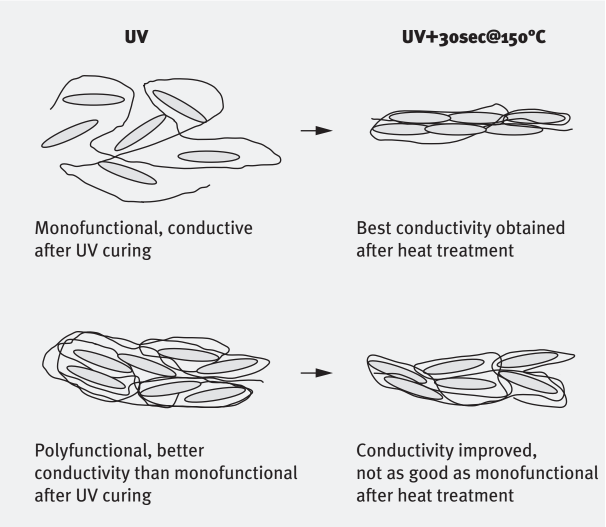
After these feasibility study steps, one of the formulations was optimized. The best formulations were printed on the gravure tester and modified until both print quality and conductivity were good. The printability of the best formulation was verified on a laboratory-scale flexo printer. After good results had been achieved, the product was evaluated on industrial printing machines at a customer site (beta site).

Reactivity and Silver Grade are Key Variables

In general, UV-curing of monofunctional systems gives conductive films. Conductivity increased enormously after additional thermal post-curing. After UV curing of a system containing a polyfunctional acrylate, a lower initial resistance or higher conductivity value is obtained, but the effect of heat treatment is not as significant.

FIGURE 3

Alignment of silver in coating is determined by functionality of the UV monomers and oligomers



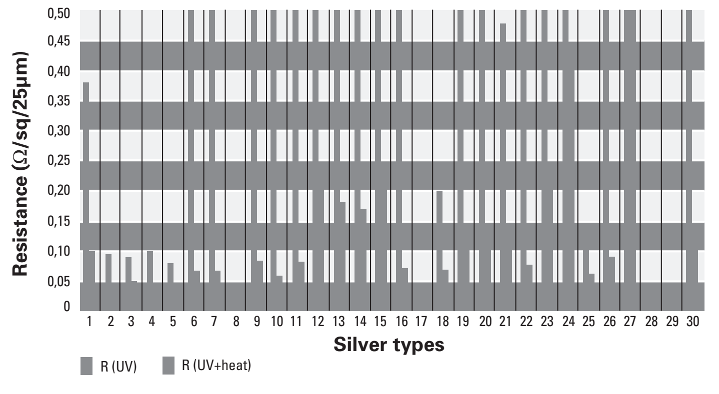
A hypothesis of what happens during UV curing is shown in Figure 3. In a solvent- or water-based ink, the solvent or water evaporates. Silver flakes are packed more and more tightly together during evaporation. At the end of this process, the silver flakes achieve good contact with each other. In a UV-curable ink, there is no solvent. The orientation of the flakes is determined by the reactivity of the system. Initially, a very reactive system will bring the silver flakes close together, but obtaining the best alignment will be difficult. This is hindered by the crosslinked network formation. A system which is not very reactive should give the best results.

The type of silver had an enormous influence on both the curability and the printability of the final ink. Figure 4 shows the conductivity values from the screening of several silvers. Initially, a silver which had been developed for UV-curable systems was used. Curing of this silver at higher loadings was difficult and printing was almost impossible.

Other silvers gave very good curing at high loadings, but the conductivity was dramatically reduced. Some silvers gave good curability and conductivity, but made printing the ink impossible.

FIGURE 4

Graph showing wide variations in conductivity of different silver flakes and improvement in conductivity after heat treatment of UV-cured inks



Silver flakes can be characterized by several properties such as particle size, surface area and amount of lubricant. The flakes which appeared most promising were the ones which showed little difference in conductivity between UV curing and heat treatment. Examples of these are flakes 2, 3, 4 and 5 in Figure 4.

Another very important part of a UV ink is the photoinitiator. Several types and blends were evaluated. It was assumed that a high PI concentration was needed to cure the ink. To reach the optimum conductivity, the opposite is true. PI levels of 1 weight percent (wt%) gave the best results.

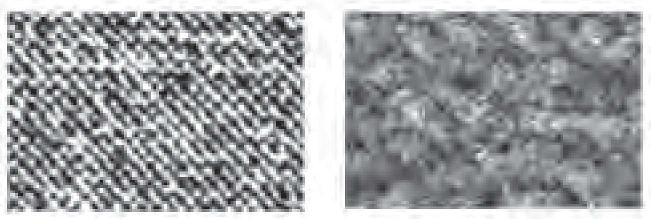
Printability and Conductivity Optimized in Laboratory

The initial screening of the inks was carried out with a wire bar coater, but this was not representative of the conditions when applying ink by flexography. Application with the rotogravure tester was more realistic, although again not the same.

The oligomer, monomer, silver and PI that gave the best results were combined. After a few tests, it appeared

FIGURE 5

Bad printability (left) and good (right) shown under the same magnification



that this ink was too viscous for a high-speed printing technique. Changing the silver, adding a levelling agent and changing the monomer to oligomer ratio gave a more suitable ink with improved printability (Figure 5 shows both inks at the same magnification).

Figures 6a and 6b show rheological characterisation of some samples. The upper curves are associated with “bad printability.” Figure 6a is a flow curve and shows that the material with best printability was initially lower in viscosity. The viscosity then dropped quickly at higher shear rates.

Figure 6b gives information about the elastic and viscous components of the ink viscosity. At higher stresses, the more printable ink has no elastic component. This implies that the viscous component dominates and this results in better printability. With an optimized ink, it was possible to reach a conductivity of 0.030 Ohm/square/25 µm, which decreased after post-curing to 0.015 Ohm/square/25µm. This was a gravure printed line and the ink was cured with an energy density of 1700 mJ/cm^2 in the laboratory.

UV Curing Level Restricts Practical Printing Speed

After these initial tests, the focus was now shifted to the application technique. An important part of a flexographic printing press is the anilox roll that contains tiny cells. Ink is transferred from a reservoir or fountain roller via these cells, which can have different shapes and sizes, to the image plate and subsequently to the substrate. These cells had a great influence on the final conductivity and resolution of the final film. Figure 7 shows a 100 µm line printed with three different anilox cell volumes.

During beta site tests, the UV-curable ink was printed with narrow and wide-web flexo printers on several substrates and at various speeds.

FIGURE 6

Rheological properties of two inks (a) viscosity (Pa.s) versus shear rate (s-1) and (b) amplitude or stress (Pa) versus G’ and G” (Pa); in both graphs, the upper curves show inks with bad printability

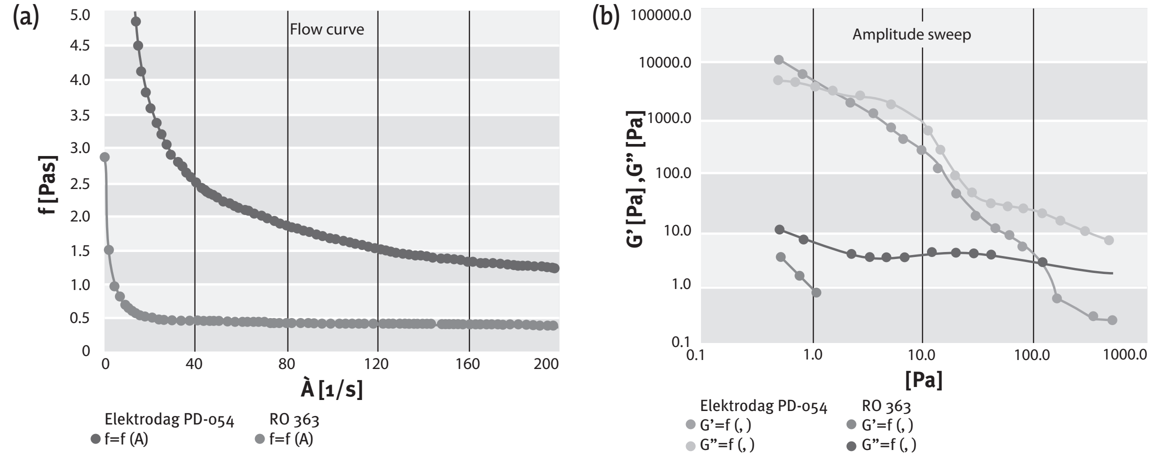
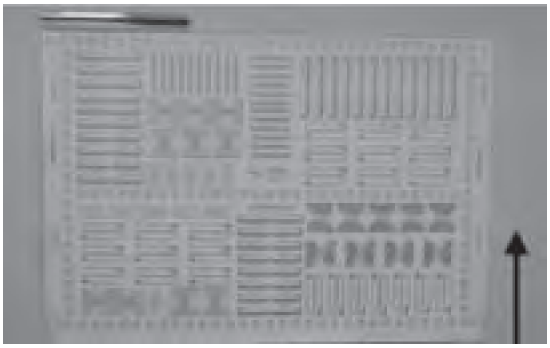


FIGURE 7

Appearance of a 100µm line printed with anilox rolls having different cell volumes: high (left), intermediate (center) and lowest (right)

FIGURE 8

Examples of printed RFID antennas



The most significant issue was found to be the UV energy density. It was impossible to apply a sufficiently high amount of UV energy during printing at high speeds. Usually three or four lamps were necessary to cure the UV ink.

The ink was printed at speeds of 100 m/min and the printed antennas still delivered acceptable reading performances. Figure 8 shows examples of these printed antennas. Performance measurements showed that it was possible to reach reading distances of around 2.5 meters and that the ink gave a good read rate. These read ranges were slightly worse than with a comparable etched copper antenna, although the conductivity of the copper antenna was about 100 times better than the conductivity of the UV-ink antenna.

A drawback of the ink is that it is not possible to cure the ink on all kinds of substrates. On very open substrates, the binder flows into the substrate and the silver remains on the surface. In this case, no curing is obtained. Another disadvantage at present is the high UV energy density that is necessary to obtain optimum conductivity. Further optimization of the system might overcome this problem in the future.

Optimized Ink Produces Usable Antennas

The goal of this research was to develop a UV-curable conductive ink which is applicable by flexography at reasonable speeds and which has the right properties after curing to function as an RFID antenna. The ink developed in this work had a resistance of < 0.020 Ohm/square/25 µm after UV curing and a heat treatment. This is close to the target value initially set. A few beta site tests have shown that it is possible to use this ink as antenna material for an RFID tag that gives good reading ranges and reading rates.

Results at a Glance

- Contactless smart cards and RFID devices require an antenna to receive and transmit signals. One of the most economical ways to produce such antennas for use at the highest frequencies is by flexographic printing.
- The possibility of developing a UV-curable ink with lower resistance than existing silver-based inks for this purpose was examined. Formulations were optimized for conductivity and printability in the laboratory, and were then tested on a number of UV flexo presses.
- Good printing quality was achieved, with conductivity close to the target value, and the resulting antennas delivered adequate performance.
- Printing speed was limited, however, by the need to apply a high UV-energy density to cure the opaque ink. In addition, inks of this type can only be printed on nonporous substrates, as binder absorption would prevent curing. ◗

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