

Low Cost Silver Ink RFID Tag Antennas

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In this paper, we discuss silver ink as a low cost option for manufacturing RFID tags at Ultra High Frequencies (UHF). An analysis of two different RFID tag antennas made from both silver ink and copper is presented at UHF. Influence of each material on tag performance is discussed along with the simulation results and measurement data which are in good agreement. It is observed from the results that RFID tag performance depends both on material and on the shape of the antenna. For some class of antennas, silver ink with higher conductivity performs as good as copper which makes it an attractive low cost alternative material to copper for RFID tag antennas.

Introduction

Radio frequency identification (RFID) is a rapidly developing technology which uses RF signals for automatic identification of objects. The first paper on modulated backscatter was published in 1948 [1]. There has been a lot of progress in RFID technology since then due to the advantage of read/write capability without the restriction of line of sight [2, 3]. A typical RFID transponder (tag) consists of a coil or an antenna and an integrated circuit (chip). Most of low frequency RFID tags utilize coils made from copper or aluminum. Recently, other materials became a viable option due to the requirement of low cost tags at large volumes. An evaluation of various polymeric films for low frequency inductive coil-based RFID tags appeared in the literature [4].

In this paper, we focused on RFID tags at UHF and analyzed the influence in their performance when an antenna is made either from silver ink or from copper. To the best of our knowledge, there is limited amount of literature available on this topic. The fact that passive RFID tags are powered solely by the incoming RF energy, combined with cost and fabrication requirements, imposes a unique set of criteria on RFID tag antenna design [5]. Tag cost and application scope impose restrictions both on antenna structure (single sided substrate, multiple layer structure, etc.) and on the choice of conducting and dielectric materials for antenna construction.

Typical dielectric substrate choices for RFID applications include polyester (PET), FR4 material, paper, high permittivity dielectrics, etc. For conducting materials, several choices are available, including copper, silver ink, and others. Copper has higher conductivity but is relatively more expensive. Silver ink is not as conductive but is inexpensive and can be printed in affordable way on thin substrates.

Evaluation of antennas made from different materials

To evaluate silver ink vs. copper in application to RFID tag antennas, we used two different antennas, both printed on single-sided dielectric substrate. One was straight dipole, another was meandered dipole, with geometry shown in Figure 1.

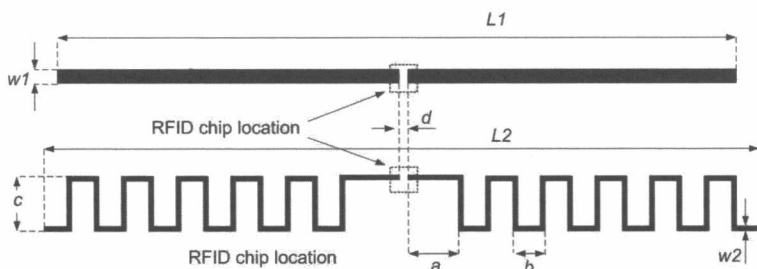


Figure 1: Geometry of the straight and meandered dipole antennas.

The following antenna parameters were chosen for analysis: $d = 2$ mm, $L_1 = 200$ mm, $w_1 = 5$ mm, $L_2 = 132$ mm, $w_2 = 1$ mm, $a = 9$ mm, $b = 6$ mm, $c = 10$ mm. Both antennas were printed on a thin flexible polyester (PET) substrate material with a thickness $h = 2$ mil ($51 \mu\text{m}$) and a dielectric permittivity of $\epsilon = 3.5$ using copper and silver ink traces with a thickness $t = 1$ mil ($25 \mu\text{m}$) and conductivities given in Table 1. The skin depth at 900 MHz is $2.2 \mu\text{m}$ for silver ink and $13.3 \mu\text{m}$ for copper.

Simulation results on impedance Z_a and maximum gain G_r using *Ansoft Designer* are given in Table 1. The impedance and the gain of the meandered antenna change much more significantly compared to the straight dipole. These results were also verified with Ansoft HFSS simulations of the same antennas. Similar results were observed for other straight and meandered dipoles with other geometrical parameters (width, etc.).

Material	Conductivity	Straight dipole	Meandered dipole
Copper	$5.8 \cdot 10^7$ S/m	$Z_a = 165 + j160$ Ohm $G_r = 2.41$ dBi	$Z_a = 90 + j313$ Ohm $G_r = 1.99$ dBi
Silver ink	$1.6 \cdot 10^6$ S/m	$Z_a = 166 + j160$ Ohm $G_r = 2.38$ dBi	$Z_a = 103 + j323$ Ohm $G_r = 1.46$ dBi

Table 1: Conductivity of copper and silver ink (DuPont 5029) and parameters of straight and meandered dipoles (impedance Z_a and maximum gain G_r) made from these materials and simulated at 900 MHz.

Results of RFID tag read range performance

An important performance criteria for RFID tag is its read range – the maximum distance at which tag can be detected. Theoretical read range can be calculated as:

$$r = \frac{\lambda}{4\pi} \sqrt{\frac{P_t G_t G_r \tau}{P_{th}}}, \quad (1)$$

where λ is the wavelength, P_t is the power transmitted by the reader, G_t is the gain of the transmitting reader antenna, $\tau = \text{Re}(Z_c)\text{Re}(Z_a)/|Z_c + Z_a|^2$ is the power transmission coefficient (Z_c is chip impedance), and P_{th} is the minimum threshold power necessary to power up the chip.

Two RFID tags were constructed using copper and silver ink antennas described above. Experimental read range was measured in the following way. Each tag was placed at a fixed distance from the reader antenna in an anechoic chamber and oriented in the direction of maximum gain. At each frequency, the minimum power required to communicate with the tag was recorded. Since the gain of the transmitting antenna (6.3 dBi) and the separation distance (3 ft) were known, the read range that tag would exhibit for a given EIRP (4 W) was directly calculated from power measurements using Equation 1.

The integrated circuit in both cases was Philips RFID ASIC chip in a flip-chip package mounted on a copper feedline fixture with solder bumps. The ASIC had a threshold power $P_{th} = -10$ dBm, and packaged impedance $Z_c \approx 12 - j300$ Ohm at 900 MHz.

Figure 2 presents a comparison between read ranges of RFID tags made from copper and from silver ink (both theoretical and experimental data are shown for both types of dipoles).

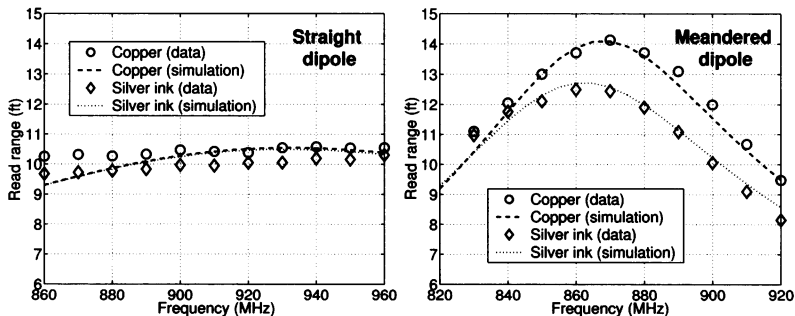


Figure 2: Theoretical and experimental read range for RFID tag with straight dipole (left) and meandered dipole (right) antennas made from copper and from silver ink.

It can be observed from the results shown in Figure 2 that theoretical and experimental curves for the tag range are in reasonable agreement. We can also see that the read ranges of the dipole tag made from copper and from silver ink are very similar, but read range of silver meander tag is smaller compared to its copper counterpart. In experiments with other meandered antennas we observed even further performance degradation. However, one can modify the design such that the impedance and gain of the antenna can be optimized for required performance with silver ink at UHF.

Conclusions

We analyzed RFID tag antennas made from silver ink and compared them with the same antennas made from copper. Modeling, simulation, and measurements show that antenna parameters and RFID tag performance change differently for different antenna types when copper is replaced with silver ink. For some antennas, such as straight dipoles, silver ink performs as good as copper. On the contrary, the parameters of antennas for meander structures change more drastically and can contribute for the degradation of performance.

It can also be concluded that the tag performance depends both on material and on the shape of the antenna. Overall, modern silver ink materials present an attractive low cost option for UHF RFID tags. Antennas can be designed specifically for silver ink in such a way that RFID tags made from silver ink have the performance comparable to RFID tags made from copper.

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