

# ON THE BEHAVIOR OF PRINTED RFID TAG ANTENNAS, USING CONDUCTIVE PAINT

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## SUMMARY

RFID stands for Radio Frequency IDentification and is a steadily growing family of technologies used for wireless transfer of information. In RFID systems data is stored on an electronic data-carrying device called a tag and the transfer of data and sometimes also the power required to operate the tags are achieved using magnetic or electromagnetic fields. A typical RFID tag consists of an antenna and a radio transceiver chip. RFID technology is, at present, in an emergent stage. Two examples of today's RFID systems are theft protection systems in shops and systems for remote road toll management. At present, a constraint for broader usage of RFID is the relatively high cost of the RFID tags. If the cost of the tags could equal the cost of printed bar codes, many new exiting applications of RFID could be conceived. In the future, electronic circuits hold in perspective to be manufactured out of conducting polymers utilizing ordinary printing techniques. When this technology matures it will give us the option of using RFID in almost any application. This is especially interesting for paper based products since they are often used in low cost applications. One step towards lowering the manufacturing cost for such applications is to print the tag antenna using conductive paint. In this paper, the performance of Bow-tie antennas printed with a conductive paint is compared to the corresponding antennas of solid copper. The Bow-tie antennas have been fabricated and their characteristics and performance have been measured. It is shown that due to limited conductivity of the conductive paint, special considerations to the paint thickness should be taken in order to achieve acceptable radiation efficiency. In the final evaluation, other aspects such as the production cost are also considered.

## INTRODUCTION

RFID is a steadily growing family of technologies, often claiming to have the potential of replacing barcodes [1]. RFID transponders, commonly called tags, consist of a radio transceiver chip with attached antenna structure. The tags are placed onto objects, allowing for remote identification by magnetic or electromagnetic fields. In many mass production wireless systems like RFID, cost-effective antennas are highly desired and every fraction of a cent per unit is accounted for [2]. One way to achieve this is to form the antenna structure using conducting paint and appropriate printing technology. By making the conducting layer as thin as possible, the cost for the conducting paint per tag will be kept at a minimum. The conductivity of conducting paint is however usually lower than other common antenna materials [3], for example copper, and a very thin layer of paint could lead to high ohmic losses in the antenna due to high resistance in its elements. This will lead to low radiation efficiency. In passive RFID systems the energy required to operate the tag's radio transceiver chip is obtained from the interrogating magnetic or electromagnetic fields and tag antennas with low radiation efficiency will therefore lead to short operating ranges.

Previous work has shown how limited conductivity of conductors affects low-frequency coil antennas [4]. In this paper we concentrate on how this affects high-frequency resonance antennas. The antennas studied are Bow-tie antennas with well-known characteristics for conductors with negligible losses [5]. It is shown how the layer thickness of a conducting paint affects the radiation efficiency of Bow-tie antennas and wire-approximations of the Bow-tie antenna. The antenna structures made out of conducting paint are also compared to corresponding structures made out of solid copper. The study is based upon the comparison of computer simulations and results of measurements on antennas manufactured using screen-printing technology. Since the conductivity of paint also depends on the curing process [3], it has been measured prior to using the corresponding value for computer modeling. Considerations are also made for how commercial Ink-jets, specially designed for printing with conducting ink could be beneficial for bulk manufacturing of antenna structures.

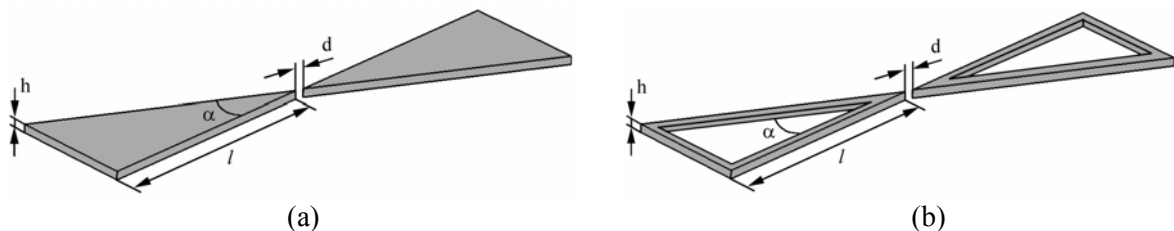
## PRINTED ANTENNA DESIGN

In investigating the behavior of antenna structures printed with conducting paint, a silver based conducting paint with a stated sheet resistance of less than  $0.015 \Omega/\text{square}$  at  $25 \mu\text{m}$  dry coating thickness was used [3]. Our DC measurements have shown a sheet resistance of about  $0.023 \Omega/\text{square}$  at  $25 \mu\text{m}$  dry coating thickness and at  $20^\circ\text{C}$ , which is probably due to a curing method differing from the one recommended for best performance. Both metal and paint versions of the investigated antennas are applied on FR4 substrates with dimensions  $134 \times 18 \times 0.85 \text{ mm}$ . The Bow-tie antennas are dimensioned to have input impedance  $50 \Omega$  with solid copper (conductivity  $5.8 \cdot 10^7 \text{ S/m}$ ) as the conductive material. The working frequency is  $869 \text{ MHz}$ , which is one of the frequencies available for RFID in Europe. The dimensions for the Bow-tie antenna are shown in Fig. 1(a) where flare angle  $\alpha=7.3^\circ$ , length  $l=62.0 \text{ mm}$  and feed-gap  $d=2.0 \text{ mm}$ .

To keep manufacturing costs down it is desirable to minimize the amount of paint used per item, but still maintaining good radiation efficiency, i.e. low ohmic losses. To see how the antenna performance degradation due to lower thickness and thereby higher loss resistance depends on the total antenna area we have also considered the wire-approximation of the Bow-tie antenna shown in Fig. 1(b). The parameters for this structure are  $\alpha=6.8^\circ$ ,  $l=62.1 \text{ mm}$ ,  $d=1.8 \text{ mm}$  and the line width is set to be  $1.5 \text{ mm}$ .

Computer modeling of the Bow-tie antennas with varying conductor thickness  $h$  was carried out for both solid copper-based and paint-based structures using a commercial Finite Integration Technique (FIT) software package [6]. The radiation efficiencies were studied at the frequency  $869 \text{ MHz}$ .

Verification of computer simulations has been done by measuring the radiation efficiency of corresponding antennas painted, using screen-printing, with diluted conducting paint. Measurements of the radiation efficiency were carried out by considering  $35 \mu\text{m}$  thick solid copper Bow-tie antenna as perfect radiator. With an *Olympus BX 51 Microscope* the thickness of applied paint was measured using a focal plane technique where the copper plating on FR4 was used as thickness reference.



**Fig. 1.** (a) Bow-tie antenna and (b) wire-approximation of Bow-tie antenna.

## RADIATION PERFORMANCE

Due to the skin effect the resistance experienced by the current varies with frequency and is influenced by both the thickness and the resistivity of the material [7]. In Fig. 2 radiation efficiency dependence upon the thickness of antenna conductor is shown. Simulations show that the loss resistance at the frequency 869 MHz increases significantly for a conductor thickness below about 10  $\mu\text{m}$ . Relative measurements with an *Agilent E8364 PNA Series Network Analyzer* on Bow-tie antennas manufactured with screen-printing technique show same tendencies for efficiency values as obtained through simulations.

By using Ink-jets designed to use conducting ink, very cheap and easily manufactured antennas could be achieved. These printers commonly provide a conductor thickness in the order of 1  $\mu\text{m}$  [8] and high printing definition, at least 600 dpi. As it can be seen in Fig. 2 this would yield antennas with very low radiation efficiency. Some Ink-jet technologies allow repetitive printing of the same pattern after each layer is cured, bringing the overall conductor thickness up to about 1 mm [9]. Poor edge profile with thick multiple-layer conductor structures would though probably limit its application for RFID tag antennas. Effect of the edge roughness is known to cause additional losses in flat conductors at high frequency [10] as current density at the conductor edges grows. Thus, its effect upon the performance of printed antenna structures should not be underestimated.

As also can be seen in Fig.2, the wire-approximation of the Bow-tie antenna is nearly as effective radiator as the ordinary Bow-tie antenna, even though much less surface area is covered by the conductor. Thus wire-approximated Bow-tie antennas made using conductive paint technology could be a good cost-effective option for RFID tags. Verifying measurements on this type of antennas has though not yet been done.

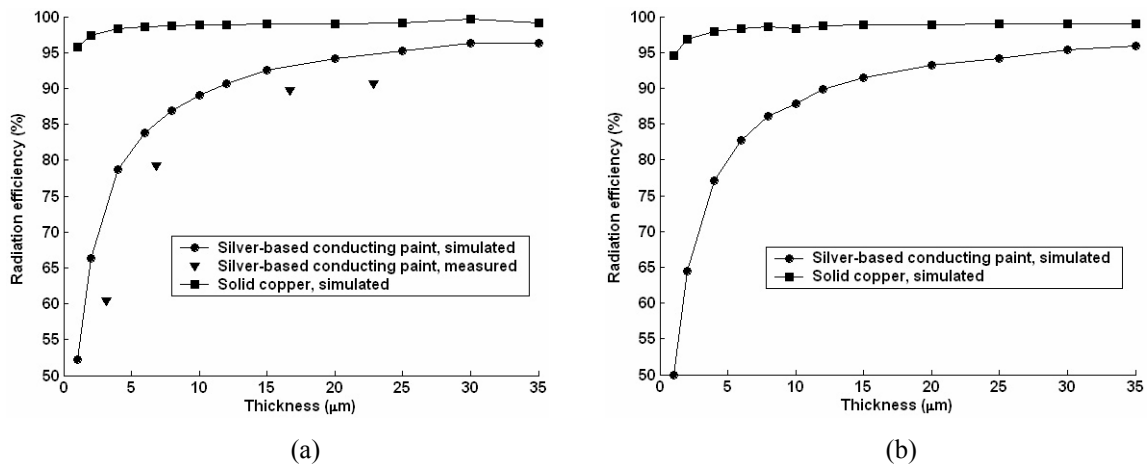


Fig. 2. Radiation efficiency versus conductor thickness for (a) Bow-tie antenna and (b) wire-approximation of Bow-tie antenna.

## DISCUSSION

It has been shown how silver-based conductive paint can be used for production of antennas. The investigation is based upon both computer simulations and measurements upon Bow-tie antennas manufactured using screen-printing technique. Investigation upon the antenna performance shows the existing trade off between the manufacturing cost reduction by using thin paint layers and degradation in radiation efficiency. It is also indicated that conductive layers of paint with limited conductivity have to be sufficiently thick in order to achieve high radiation efficiency. With conductive layers of thickness beneath 10  $\mu\text{m}$ , a commercially available silver-based paint with finite conductivity showed low radiation efficiency at high frequency. On the other hand, a thickness above 30  $\mu\text{m}$  closely resembled radiation characteristics for perfect conductor antennas, i.e. 100 % radiation efficiency.

Two different types of Bow-tie antennas were investigated, similar by characteristics but one with about one third of the area of the other. Results show that the degradation in radiation efficiency caused by thin layers is about the same for these two structures. Simulation results also imply that antennas printed using commercial Ink-jets with finite conductivity ink and with layer thickness about 1  $\mu\text{m}$  could lead to antennas with very low radiation efficiency. Only Ink-jet technologies allowing printing multiple thin conductive layers and with relatively low edge roughness would be able to compete with screen-printing technologies for RFID tag antenna manufacturing.

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