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PERFORMANCE OF PRINTABLE ANTENNAS WITH DIFFERENT CONDUCTOR THICKNESS

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Abstract—This paper shows that L-shaped monopole antenna on PPS manufactured by inkjet printing of nano silver ink is able to produce very competitive overall antenna performance against Rogers copper foil structures if the thickness of the printed conductor layer is about the skin depth at the operating frequency multiplied by four.

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1. INTRODUCTION

Printed electronics is a novel electronics manufacturing method widely researched recently. It is a promising low cost way to process allowing especially flexible component design of planar or even three-dimensional (3-D) structures using polymer substrate [1–5]. Printed antenna is amongst the most potential applications. In this case the performance of the antenna is mostly determined by the electrical properties of the conductive ink, thickness and accuracy of the printed conductive areas as well as the properties of the substrate. Suitable polymers for printed electronics substrate are nowadays widely available like polyphenylene sulphide (PPS) ($\tan\delta = 0.0001$ at 1 MHz), Kapton E ($\tan\delta = 0.002$ at 1 kHz) [8, 9]. However more critical is the conductive ink used and its printing process. The inks are commonly based on nano silver particles with low curing temperature. The conductivities and curing temperature reported e.g., to the inks produced by Harima 210°C [7] whereas the conductivity of bulk silver is 4.16×10^7 s/m [10]. On the other hand if the conductivity of the printed area is high enough, one must take care that the quality of the printing as well as the printed thickness is also high enough. One printing method widely used is inkjet printing which allows multiple thin (even less than 1 µm) conductive layers with relatively low edge roughness [1, 3, 4]. This is important since the radiation properties of the designed antenna depends on the thickness and surface roughness of the printed layer if its conductivity is high enough [2, 3, 5]. Especially the thickness of the metals should be several times greater than the skin depth [5]. On the other hand one must minimize the consumption of nano silver ink to enable low materials' costs.

In the present work the main target is to research the impact of the inkjet printed layer thickness to the performance of a L-type monopole antenna suitable for 2.4 GHz band using common antenna measurement methods with cross section studies.

2. DESIGN, MEASUREMENTS AND FABRICATION

The designed L-shaped monopole antenna shown in Figure 1 was modeled using Ansoft HFSS (High Frequency Structure Simulator). The dimensions of the ground plane made of Rogers 4003C were 80 mm × 40 mm × 0.83 mm, and the printed antenna structure utilized PPS (20 mm × 5 mm × 1 mm) fed by a strip line. The size of the antenna element itself was 18 mm × 4 mm. The inkjet printing was performed by Fujifilm Dimatix DMP-2831 printer [11] using nano silver ink produced by Harima.

Additionally, a reference antenna using Rogers with 20 μm thick copper foil was fabricated with the conventional etching method.

Optical microscopy in Figure 2 shows an example of the cross section of the conductive area after one inkjet printing. The results show that the first inkjet printing produced 1.5 μm thick conductive layer. The four following ones have 1 μm more each. Thus, the maximum thickness achieved was 5.5 μm studied by an optical microscopy. Figure 3 presents the fabricated antenna structure. The antenna is soldered with a cold silver soldering paste to the ground plane made of rogers 4003C copper laminate.

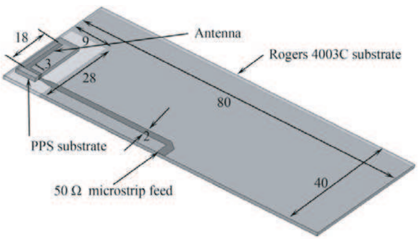

Figure 1. Schematic diagram of the designed L-shaped monopole antenna (dimensions in mm).

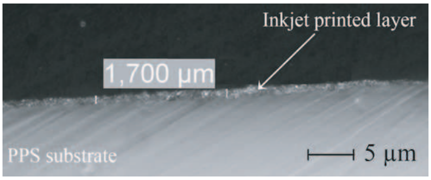

Figure 2. Cross section of the inkjet printed layer after one printing producing the thickness of 1.5 μm.

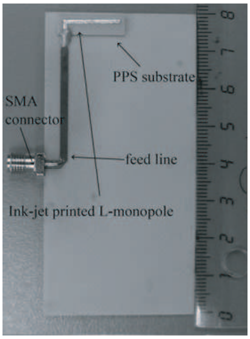

Figure 3. Fabricated inkjet printed L-shaped monopole antenna structure.

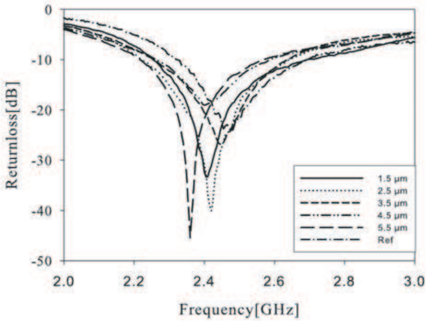

Figure 4. Measured return loss of the reference antenna and the inkjet printed antenna with different printed layer thicknesses.

3. RESULTS AND DISCUSSION

Figure 4 shows the measured return losses of the reference antenna and printed antenna after each printing.

The results show that with five printings even better return loss was achieved with the reference antenna. The reason is clear since the conductivity difference of the copper foil and printed nano silver ink is not very big. Additionally, the skin depth for silver in this frequency is about 1.3 μm. According to [5], the printed thickness of 5.5 μm should thus be enough to produce optimum return loss performance. Small variation in frequency can be explained by multiple printings changing the dimensions of the conductive area in some extent.

Figure 5 presents the measured percentage total efficiency of the inkjet printed and reference antennas in the frequency range of 2.2–2.6 GHz. The peak percentage total efficiency of the antenna as a function of measured thickness of the inkjet printed silver conductor thickness is shown in Figure 6. Figure 7 shows the measured total gain of the printed and reference antennas in dB. The total efficiency and gain measurement also support these conclusions. The peak total efficiency clearly increases with the thickness of the printed layer (Figure 6). After five printings producing silver conductor thickness of 5.5 μm the total efficiency is very close to the efficiency of the reference antenna. The gain value on the other hand with the printed silver layer of thickness of 1.5 μm showed minimum gain of 0.38 dB. Thickness equal to 5.5 μm showed the maximum gain of 1.96 dB where the maximum gain for the reference antenna was 2.2 dB. Additionally,

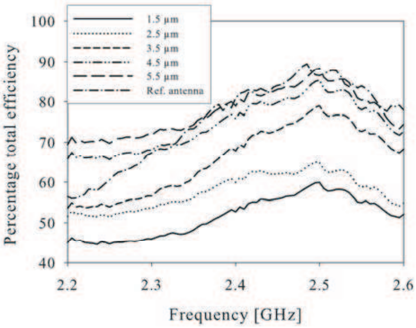

Figure 5. Measured total radiation efficiency of the reference antenna and the inkjet printed antenna with different printed layer thicknesses.

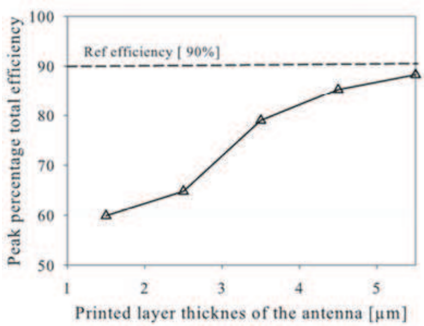

Figure 6. Measured peak total efficiency of the inkjet printed L-shaped monopole antenna as a function of different printed layer thicknesses.

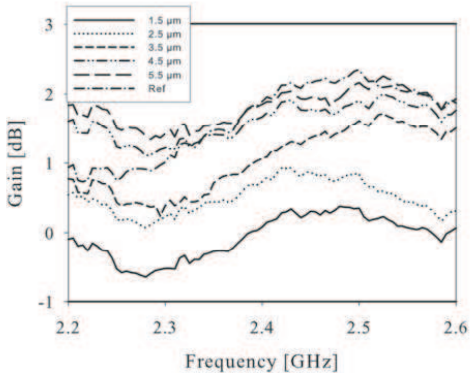

Figure 7. Measured gain of the reference antenna and the inkjet printed antenna with different printed layer thicknesses.

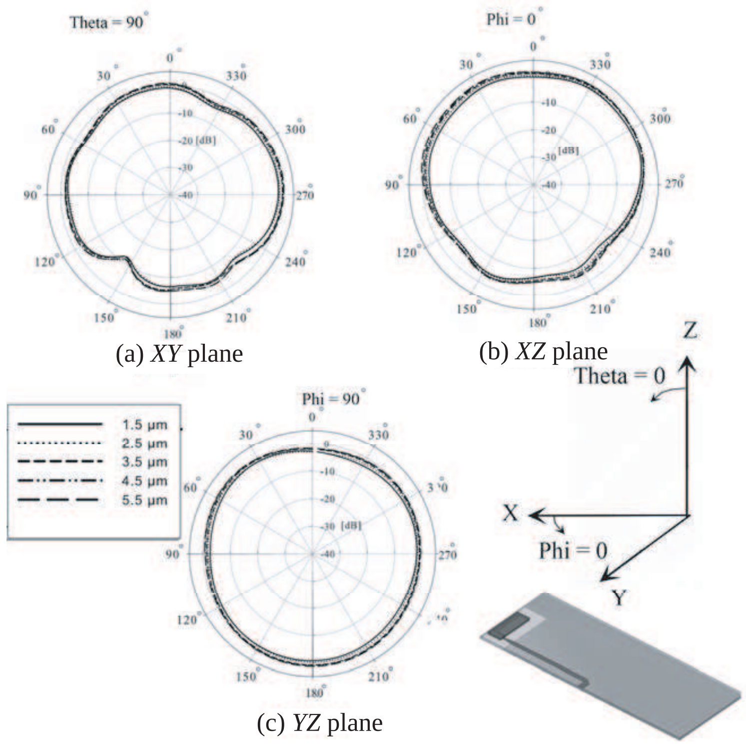

Figure 8. Measured farfield radiation pattern of the inkjet printed monopole antenna with different conductor thickness in (a) XY plane, (b) XZ plane, and (c) YZ plane.

when the radiation patterns (Figure 8) measured using Satimo showed actually no effect of the conductor thickness on the omni directional performance of the antenna, the final conclusion is that the L-shaped monopole antenna presented here can be fabricated by the printed electronics methods proposed without loosing its performance.

4. CONCLUSION

The inkjet printed L-shaped monopole antennas with different conductor thicknesses were designed, manufactured and measured. The results show that the printed electronics methods using nano silver inks with high enough conductivity can be used to produce antennas with very competitive performance. The main thing is to achieve printed thickness about 5.5 µm at 2.4 GHz, which is the skin depth multiplied by four at this frequency.

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