Technique for extraction of electric frequency parameters of conductive ink

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Abstract. In this paper, we consider a technique for extracting parameters that allows calculating nodes taking into account the properties of the material used in the technology of printer printing. As a result of the extraction of parameters, the real parameters of the material were revealed. At 1 GHz, the loss of a 20 µm microstrip line is 12 dB/m. With a threefold increase in thickness, the losses decreased to 7 dB/m.

1. Introduction
The manufacturing of printed electronics is at the research stage. The first works on the use of printed electronics in modern devices were discovered in 2008 [1]. In this paper, the University of California examines the application of inkjet printing to the fabrication of coplanar lines. The active use of printed methods of material deposition began in 2010 [2]. In this paper, we examined the effect of printed layer thickness on the performance of antennas for radio-frequency identification (RFID) tags. RFID tags are screen-printed. In articles [3-5] samples of the manufacture of dipole antennas by the method of inkjet printing. The use of printed methods for the manufacture of microwave devices allows:

– to ensure the introduction of combined integral technologies;
– to increase the speed of development of new serial products through rapid prototyping;
– to develop devices with new design and physical and technical qualities (flexibility, lightness, functionality.)

The use of printer technologies for applying material imposes a number of restrictions associated with the availability of materials on the Russian market. The solution to these limitations is the synthesis of their own inks that satisfy the throughput of the printer or the use of ink for screen printing, followed by dilution to lower the viscosity.

When the viscosity of the ink is reduced by dilution with a solvent, the electrical parameters deviate from the declared ones. This, in turn, creates certain difficulties in the design of units and components of the microwave range. The resolution method consists of the experimental determination of the parameters of the ink. The parameter extraction technique is to identify the parameters that affect the signal loss. The extraction is based on the method of computational and experimental design, the essence of which is the manufacture of a model based on the results of calculation and modeling.
2. Extraction
Polymeric conductive ink was chosen as an object for extraction. The advantage of using this ink is the low sintering temperature \( T = 125 \, ^\circ\text{C} \). First of all, a microstrip line (MSL) with a characteristic impedance of 50 ohms was calculated and modeled. The use of such lines makes it possible to expand the range of use of strip structures and to develop various microwave devices on their basis: antennas, phase shifters, filters, and resonators.

After calculations and modeling, and MSL with geometric dimensions of 60x0.85 mm was printed. Taking into account the technical requirements and the influence of spreading, the width of the digital model of the MSL was 0.55 mm. The thickness of the printed line is enclosed in 20 µm. The obtained S-parameter values were imported into AWR Design Environment 14, and a graph was built for comparing models and measuring the MSL (figure 1).

![Figure 1.](image1.png)  
**Figure 1.** Comparison of the frequency dependences of the model and the MSL layout.

The discrepancy between the calculated and measured values of S-parameters at frequencies is due to the fact that the calculation took into account the theoretical parameters of the materials and not the actual values obtained during the preparation of inks. Based on this, it is necessary to extract the parameters so that the model matches the measured characteristics.

For the extraction of frequency parameters, the MSL model was chosen, which takes into account: wave impedance, relative effective dielectric constant, losses. As a result of the extraction, it was possible to achieve the similarity of frequency characteristics at the values shown in figure 2.

![Figure 2.](image2.png)  
**Figure 2.** Frequency model of the MSL.

The resulting frequency dependencies are shown in figure 3.
Figure 3. Frequency dependence of the modulus of the transmission and reflection coefficients.

To bring the model closer to the measured values, capacities equivalent to the connectors soldered to the MSL were added to the circuit (figure 4).

Figure 4. Model of a microstrip line with parasitic capacitance.

Figure 5 shows the frequency dependencies after adding capacitance.

Figure 5. Frequency dependence of the modulus of the transmission and reflection coefficients of the signal.

As can be seen from figure 5, the parasitic capacitance had a positive effect on the refined model. However, for practical use of nodes with losses equal to 12.3 dB/m is not acceptable. As a result, it was decided to increase the thickness of the MSL by layering the material.
Based on the fact that increasing the line thickness also increases the width of the printed line, it was decided to layer not the entire microstrip line, but only the central part. In the printer settings, you can change the interval of the passage of the cartridge. When constructing a digital model with a width of 0.55 mm, the standard value of the cartridge passage interval is 0.18 mm (figure 6, a). Layering at this pass value will result in a significant increase in width. The minimum value of the passage interval is 0.1 mm (figure 6, b). Considering that lamination will take place without intermediate drying, it is preferable to use a passing interval of 0.1 mm.

![Figure 6. Adjustment of the passage interval 0.18 mm (a) and passage interval 0.1 mm (b).](image)

For printing, a nozzle with an inner diameter of 100 µm was used to reduce the spreading of the ink. After the first layer of MSL was printed, the central line was layered twice at cartridge heights of 0.20 mm and 0.22 mm. The result of the printed line is shown in figure 7.

![Figure 7. The width of the microstrip line.](image)

Figure 8 shows a microstrip line profilogram. As a result of layering the central part of the MSL, it was possible to increase the thickness to 65 µm.

![Figure 8. MSL profilogram.](image)

To investigate the thickness for frequency characteristics, the transmission and reflection coefficients were measured. The obtained S-parameter values were imported into AWR and a graph was plotted to compare samples of microstrip lines at different thicknesses (figure 9).
After comparing the frequency dependences of the modulus of the transmission and reflection coefficients of microstrip lines with different thicknesses, it was concluded that an increase in the thickness led to a decrease in losses. The figure shows the extraction of parameters for an MSL with a thickness of 65 μm (figure 10).

Figure 10. MSL model.

Figure 11 shows the S-parameters of the MSL model. Based on the graph of the frequency dependence of the modulus of the transfer coefficient, at a frequency of 1 GHz, there is a complete coincidence of the model and the MSL.

Figure 11. Frequency dependence of the modulus of the transmission and reflection coefficients of the signal.

End capacitors were added to introduce parasitic resonances. The added capacitance is equivalent to the soldered connectors (figure 12).
Figure 12. Refined MSL circuit.

Figure 13 shows the frequency dependences of the modulus of the transmission and reflection coefficients of the signal. The addition of containers had a positive effect on the graphics.

Figure 13. Frequency dependence of the modulus of the transmission and reflection coefficients of the signal.

As a result of the extraction of the parameters of a microstrip line with a thickness of 65 μm, it can be concluded that an increase in the thickness of the printed layer led to a decrease in losses to 7 dB/m at a frequency of 1 GHz.

3. Conclusion
As a result of the extraction of the parameters, real MSL models were obtained. An MSL with a thickness of 20 μm is characterized by losses of the order of 12 dB/m at a frequency of 1 GHz. For a 65 μm line, the loss is 7 dB/m at 1 GHz. The results obtained can be applied in the design of other microwave units.

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