

Environmental Effects on Electrical Properties of Textile Integrated Antennas

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Abstract— Wearable devices have a variety of applications in our daily lives. Antennas are an integral part of wireless connections between on-body devices. Recently, printed antennas have become increasingly popular due to their advantages of low-cost manufacturing and ability to be fabricated on flexible substrates. In this study, the environmental effects of screen-printed textile-integrated antennas are investigated. The antennas were fabricated onto a 100% Cotton Twill substrate using silver, copper and alloy silver-copper inks. The formation of the oxidation layer of the surface was analyzed in an environment chamber. Following the experiments, the performance parameters measured included sheet resistance and S-parameters of the printed antennas.

I. INTRODUCTION

On-body wireless devices are increasingly popular in healthcare and sport science applications, from chronic disease management and sport science for activity tracking [1]. The growth of body-centric wireless communication has created a need for fabric-integrated antennas that can be seamlessly incorporated into clothing. Such antennas provide unobtrusive monitoring while being designed to be thin, lightweight and conformal to the human body to prioritize the user's comfort [2]. Wearable antennas must withstand harsh environmental conditions, as temperature and humidity significantly affect their performance. Previous studies have investigated the effect of humidity on microwave characteristics of screen-printed paper-based electronics [3]. However, there is limited information of environmental conditions affecting metal-based ink for textile-integrated antennas. These antennas face unique challenges as temperature and humidity impact both the dielectric properties of the fabric and conductivity of the print.

Screen printing offers a low-cost fabrication for wearable antennas, where the composition of the conductive ink used influences conductivity and print quality. Silver (Ag) nanomaterials are widely used due to their high electrical conductivity, antioxidation properties and stability. However, their high cost and fluctuating market value. Copper (Cu) is a promising alternative, offering only a 6% loss of conductivity, 99% cost reduction and is significantly more abundant [4]. Yet, copper's susceptibility to oxidation and oxide layer formation remains a challenge.

This work investigates the environmental stability of screen-printed antennas designed for the Industrial, Scientific and Medical (ISM) band 2.4 GHz Bluetooth connection. Three conductive inks, silver, copper, and silver-copper alloy, were printed on textile substrates and subjected to oxidation studies.

The research evaluates long-term ink stability and its impact on antenna performance. The subsequent sections detail the design, fabrication and experimental assessment of these screen-printed antennas.

II. METHODS

A. Materials

Each antenna is integrated into a 100% Cotton Twill substrate. The thickness, determined using digital calipers, is 0.48 mm. Electric permittivity was measured to be $\epsilon_r = 1.67$ at 2.4 GHz using the Keysight N1501A Dielectric Probe Kit. During this study, copper, silver and silver-copper alloy ink were utilized to design each antenna. In [5], improved stabilization of alloy ink was demonstrated by printing a rectangular patch antenna. Ethyl Cellulose (EC) was used as the stabilizing agent, acting as both a dispersing and capping agent. It controls ink stability and increases viscosity at low concentrations. The polymer structure of EC allows it to stabilize particle size and form protective layers to the conductive filler [6].

B. Simulation

To reduce the antenna's susceptibility to oxidation, a patch antenna with rounded edges was designed and simulated on 100% Cotton Twill in Ansys HFSS, as shown in Figure 1. This design reduces the edge-to-area ratio to delay oxidation because edges and corners are more vulnerable to environmental effects due to higher surface energy. More edges create more points for oxidation to initiate and spread throughout the surface.

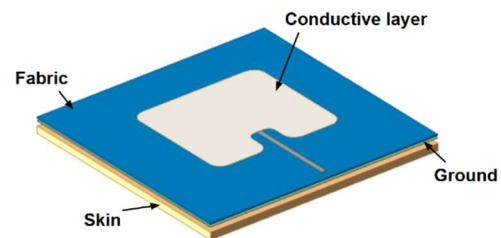


Figure 1. Layers of Antenna Design

Figure 2 shows the simulated results of the reflection coefficient of the silver and copper antennas integrated on fabrics. Each antenna resonates at 2.4 GHz with minor differences, which are attributed to the differences in material conductivity. In Figure 3, a simulated radiation pattern at 2.4 GHz shows a uniform pattern. Each antenna shows a similar maximum gain of 7.0 dB.

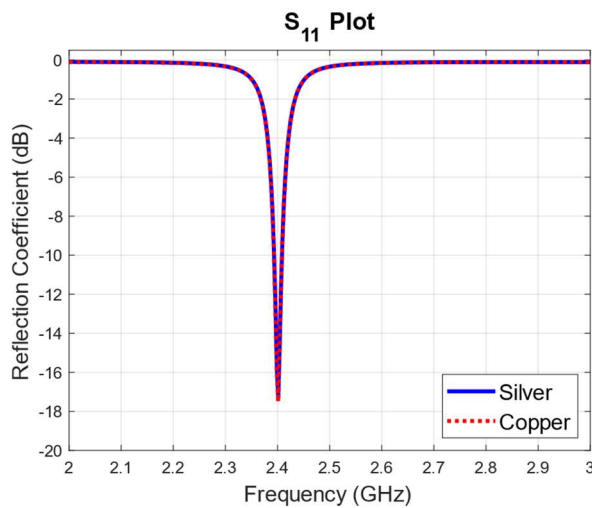


Figure 2. Simulated S_{11} Plot from 2-3GHz

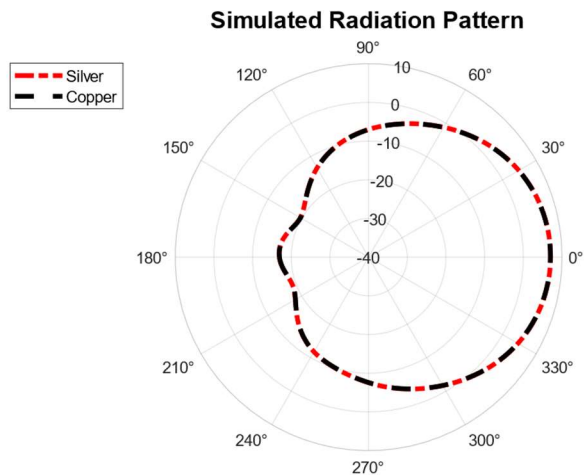


Figure 3. Simulated Radiation Pattern at 2.4GHz

C. Fabrication

Screen-printing is the preferred technique due to its ability to enhance print resolution, maintain control over ink deposition and ability to print on a variety of substrates. The copper and silver inks were mixed using a FlackTek Mixer, at 1500 rpm for 15 seconds, to minimize the air bubbles. A Cricut Maker was used to create vinyl stencils of the antenna design to achieve an accurate and precise cut of the print. The stencil is placed on the screen mesh and a squeegee is pressed to the mesh to transfer the conductive ink through to the textile. The printed patterns are cured by a hot gun for 60 seconds at 100°C and 30 seconds at 130°C to achieve optimal conductivity by evaporating the solvent and forming conductive pathways. SHIELDIT Super Conductive Fabric is used as the ground plane and is applied by an iron on adhesive.

D. Experimental Setup

To evaluate the environmental effects on antenna performance, the samples were tested using an AUTENS Dehumidifying Dry Box that consists of a TE Cooling system and a microprocessor for continuous monitoring. The relative humidity inside the controlled environment was adjusted between 25% and 60% in 10% intervals. A control sample was placed outside of the sealed environment with a DHT22 sensor connected to a Raspberry Pi to monitor ambient temperature fluctuations.

Daily measures included sheet resistance using a Four-Point Probe and S-parameters (S_{11}) using a Keysight PNA Network Analyzer N5227B. Sheet resistance was a key indication of the oxide layer forming, as a result of the current flow restricted, which causes an increase in the resistance across the surface. Real-time environmental conditions were recorded with each measurement. An initial measurement was taken after printing, with subsequent measurement conducted daily

III. CONCLUSION

The performance and oxidation stability of screen-printed antennas were investigated. Three antennas were fabricated on 100% Cotton Twill using copper, silver and silver-copper alloy inks. The alloyed ink was formulated to combine the high conductivity of Ag with the cost-effectiveness and abundance of Cu to provide a solution to the long-term limitations that Cu faces. This study addresses the limited information of how environmental conditions affect the oxidation stability of textile integrated antennas. The findings demonstrate a cost-effective approach through Cu-Ag alloying and improved oxidation stability, which can be achieved with post-print curing at temperatures suitable for wearable applications

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