



MORPHOLOGICAL AND PHYSICAL-CHEMICAL INVESTIGATION OF MICROWAVE TRANSMISSION LINES COATED ON TEXTILES

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Abstract: Textile structures for flexible microstrip transmission lines play a significant role in the development of wearable articles, as they connect the textile antenna with the wearable transceiver. Such articles are currently developed to monitor physiological parameters of humans with medical or sports applications. Our paper proposes two types of coated transmission lines on a textile substrate, one using silver coating and the other a carbon-based coating, with two geometrical dimensions. Their designed functionality is to act as band pass filters at the resonant frequency of 900 MHz, in order to deliver maximum power to a wearable antenna. The four coated transmission lines were prepared via screen printing on the dielectric substrate, while a conductive knitted fabric was sewn on the back side to act as ground plane. The transmission lines were characterized regarding their morphological and physical-chemical properties, in order to investigate the electrical conductivity and continuity of the coated transmission lines, as well as their adhesion onto the textile substrate. For this investigation scanning electron microscopy, X-ray energy-dispersive spectrometry and Fourier-transform infrared spectroscopy in the band of 4000-400 cm^{-1} were employed. The results of the morphological investigation proved good conductivity and continuity of the transmission lines, while the physical-chemical investigation showed the chemical elements of the coated microwave transmission lines. The reflection loss (also known as input reflection coefficient, return loss, S_{11}), of the transmission lines was measured via a vector network analyzer. Simulation results and measurement results show broad agreement, thus proving their functionality.

Key words: distributed elements, flexible microwave circuits, conductive coatings, band pass filters, microwave transmission lines

1. INTRODUCTION

Microwave transmission lines integrated into textile fabrics provide the connection between the transceiver and the textile antenna [1]. Several manufacturing technologies are available, such as embroidery of metallic yarns, or coating with conductive pastes [2-3]. The coating of transmission lines however, sets some challenges regarding adhesion onto the textile substrate, the quality of electrical conductivity and the continuity of the electrical signal transmission [4]. A resonant circuit

is needed in order for the textile transmission line to deliver maximum power to the textile antenna at a certain frequency [5, 7-8]. Our scientific contribution presents several variants of textile microstrip transmission lines coated on a textile substrate, acting as band pass filters with destination GSM communication (900 MHz). This paper describes an investigation of the morphological and physical-chemical analysis of the coated transmission lines with silver and carbon paste on a textile dielectric substrate.

2. MATERIALS AND METHODS

2.1 The dielectric substrate

The textile substrate was chosen for its suitable physical-mechanical and electrical properties and as well for its heat curing resistance: it is a woven fabric with 70% Kermel (polyamide-imide) and 30% viscose fibres [6].

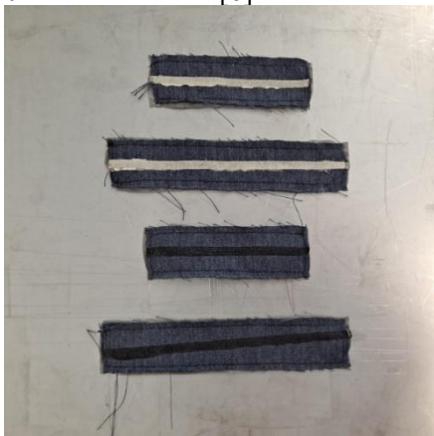


Fig. 1: The four samples acting as microwave filters

This woven fabric was screen printed with two types of conductive paste, namely silver paste from Sigma Aldrich (Ag 60% + AgCl 40%) and carbon paste from BareConductive. A knitted fabric with 10 Ω sq resistance was sewn on the back side of the dielectric woven fabric as ground plane, in order to achieve a micro strip textile structure. According to the simulation, two geometrical dimensions for the transmission lines were selected to be screen printed on the substrate with band pass filter functionality: 4 mm \times 100 mm transmission line and 4 mm \times 150 mm transmission line (Fig. 1).

The four resulting samples were cured in oven at 80°C for 30 minutes and the knitted fabric was attached afterwards by sewing on the back side as ground plane (electrical return path).

3. RESULTS

3.1. SEM analysis of the conductive coatings

Scanning electron microscopy (SEM) was used to analyze the morphology of the impregnated conductive inks as follows. A FEI Quanta 200 microscope was operated at 15 kV, 130 Pa pressure in low vacuum mode, large field detector and a working distance around 10 mm. The SEM images with 100 \times and 3000 \times magnifications were acquired for the textile substrate, for silver coating and carbon coating for 10 and 15 cm lengths (Figs. 2-11).

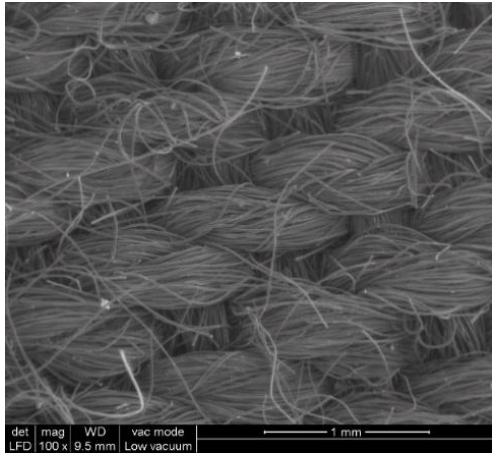


Fig. 2: SEM image of textile substrate (100×)

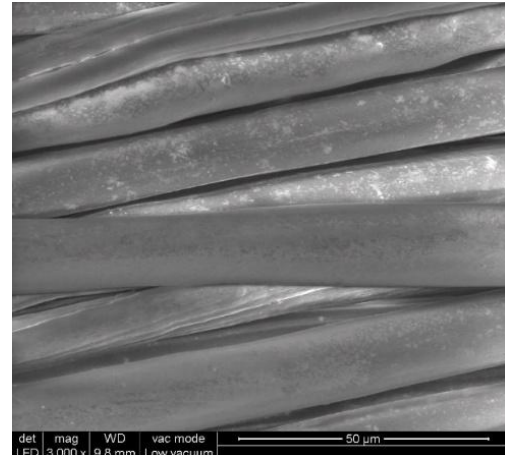


Fig. 3: SEM image of textile substrate (3000×)

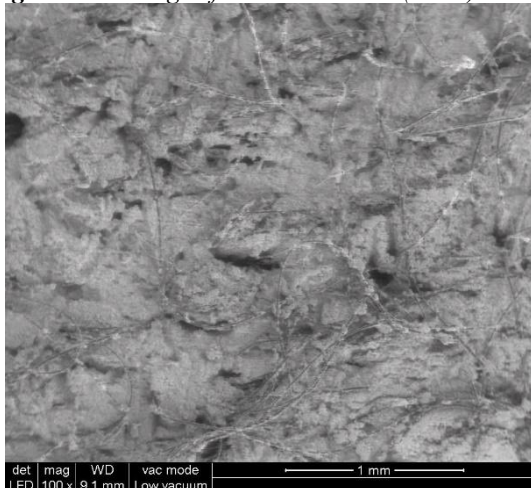


Fig. 4: SEM image of Ag 10 cm length (100×)

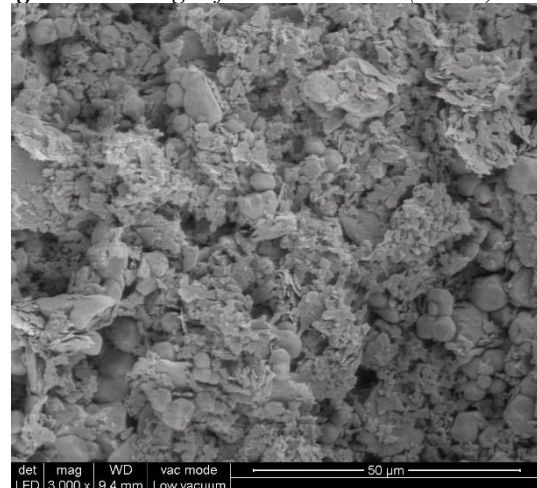


Fig. 5: SEM image of Ag 10 cm length (3000×)

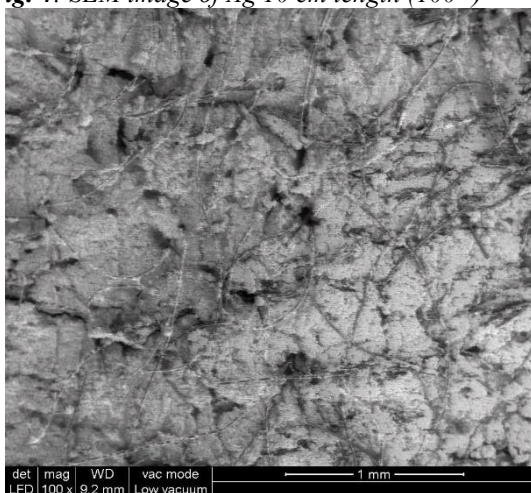


Fig. 6: SEM image of Ag 15 cm length (100×)

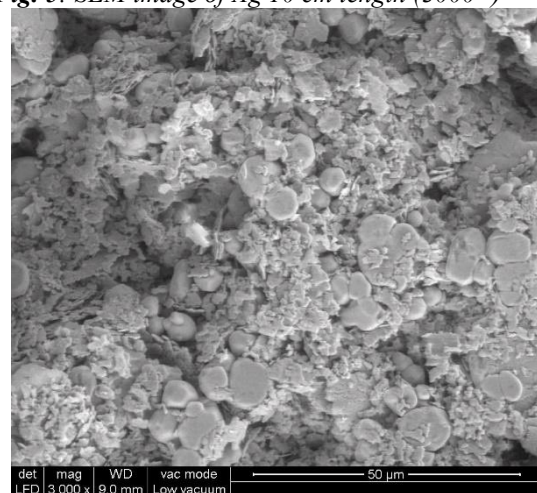


Fig. 7: SEM image of Ag 15 cm length (3000×)

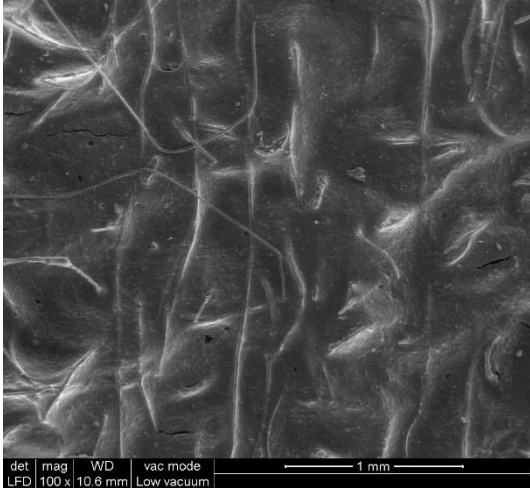


Fig. 8: SEM image of C 10 cm length (100×)

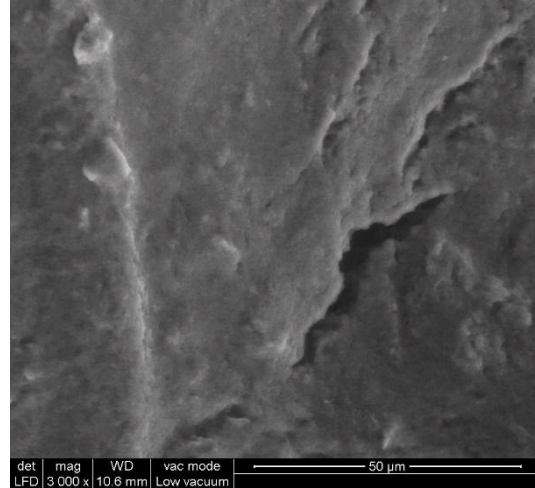


Fig. 9: SEM image of C 10 cm length (3000×)

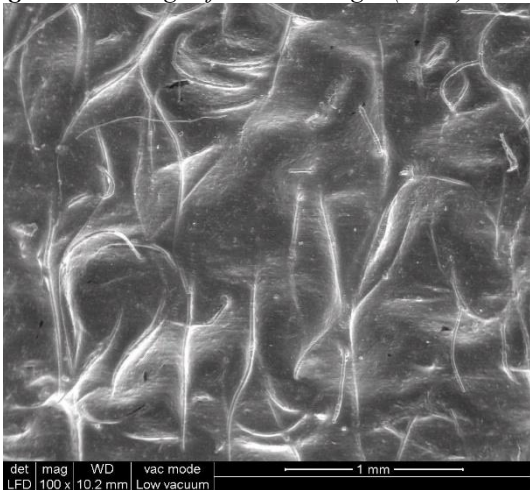


Fig. 10: SEM image of C 15 cm length (100×)



Fig. 11: SEM image of C 15 cm length (3000×)

The surface micro-structure of the silver coating presents some discontinuous features but having their regions in high electrical contact. This leads to adequate conductivity of the deposited layer, and sufficient mechanical strength, due to the high internal binding surface between these regions. The micro-structure of the carbon-based coating presents a better continues aspect, which provides a high conductivity and also a high mechanical resistance.

3.2. EDX analysis of the conductive coatings

X-ray energy-dispersive spectrometry (EDX) was performed to measure the chemical elements concentrations in the deposited conductive coatings, using an Ametek EDX Element instrument. The acquired spectra and percent concentration values are presented in Figs. 12 and 13.

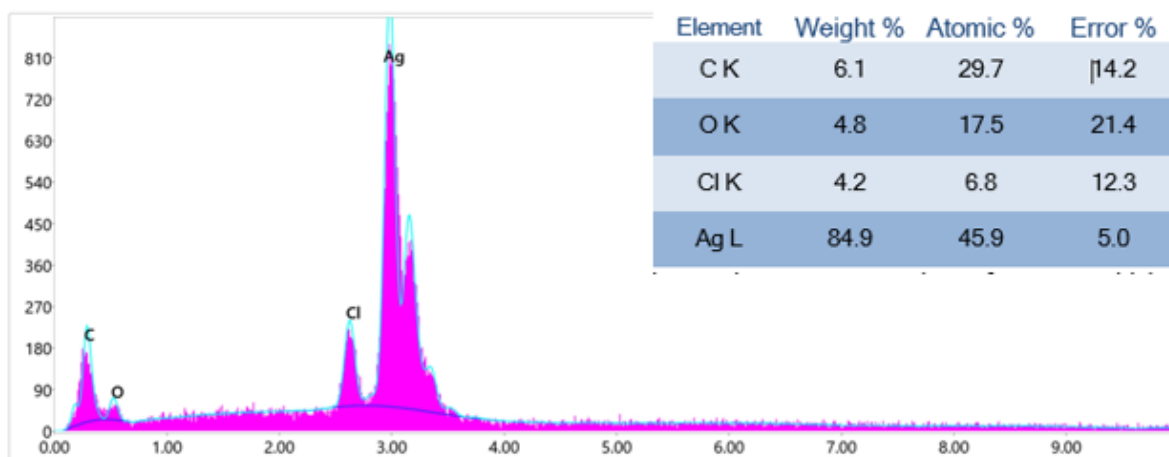


Fig. 12: EDX spectrum of Ag 10 cm length

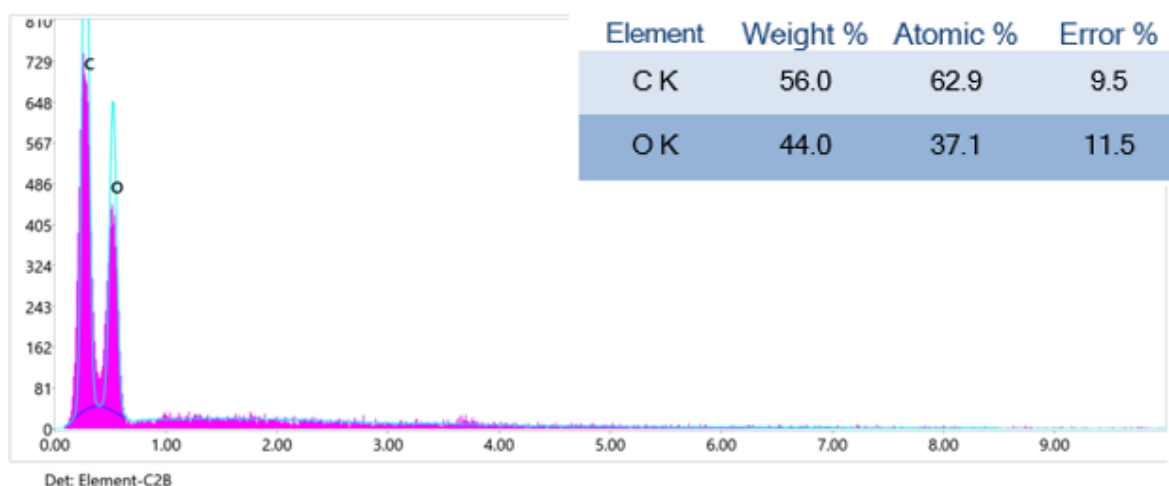


Fig. 13: EDX spectrum of C 10 cm length

The elemental composition of the silver paste indicates the presence of silver chloride in an organic matrix (composed of carbon and oxygen compounds) that disperses the silver salt, allowing the silver ions to interconnect and form a flexible, conductive network at the atomic level. In contrast, the elemental composition of the carbon paste reflects the presence of carbon, as well as the oxygen contained in its organic additives.

3.3. FT-IR analysis of the conductive coatings

The identification of chemical compounds in samples was made by Fourier-transform infrared spectroscopy (FT-IR) in the range of $4000-400\text{ cm}^{-1}$ in the attenuated total reflectance mode with a diamond crystal, using a Thermo Scientific Nicolet iS50 instrument. The spectra of 10 cm silver and carbon conductive films are shown in Figs. 14 and 15.

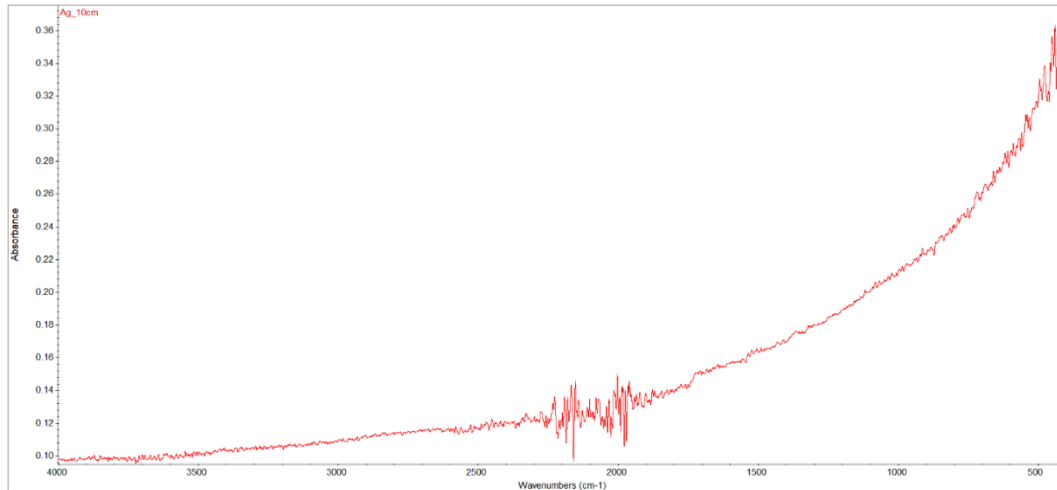


Fig. 14: FT-IR spectrum of Ag 10 cm length

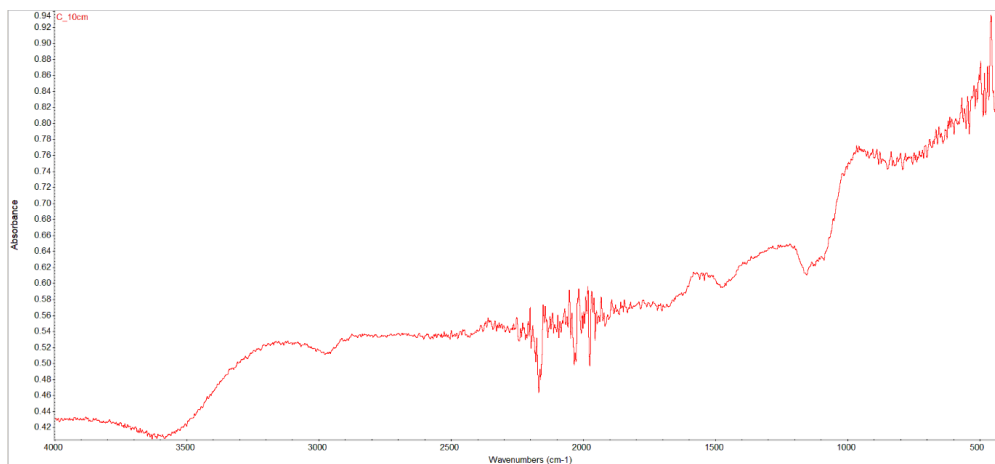


Fig. 15: FT-IR spectrum of C 10 cm length

FT-IR analyses of the carbon paste show that the carbon-carbon bond peaks of the carbon structures appearing in the mid-infrared band (1500–1000 cm⁻¹) from molecular vibrational transitions, a band that is absent in the case of silver paste due to the presence of silver-chloride ionic bonds instead of covalent carbon-carbon.

3.4. Electric microwave simulation and measurements

The manufactured transmission lines were simulated in microwave frequency range 100-2000 MHz, via the software SONNET LITE, in order to prove the band pass filter functionality. The 100 x 4 mm transmission line had a resonant frequency at 1100 MHz, while the 150 x 4 mm line had resonant frequencies at 700 MHz and 1400 MHz. The resonant frequency differed from the initial simulation target of 900 MHz, after introducing the substrate dielectric parameters. These simulation results were validated by vector network analyzer (VNA) measurements on the four coated samples. The PocketVNA 4G vector network analyzer attached to a laptop, with the related software was used in this regard (Fig. 16).

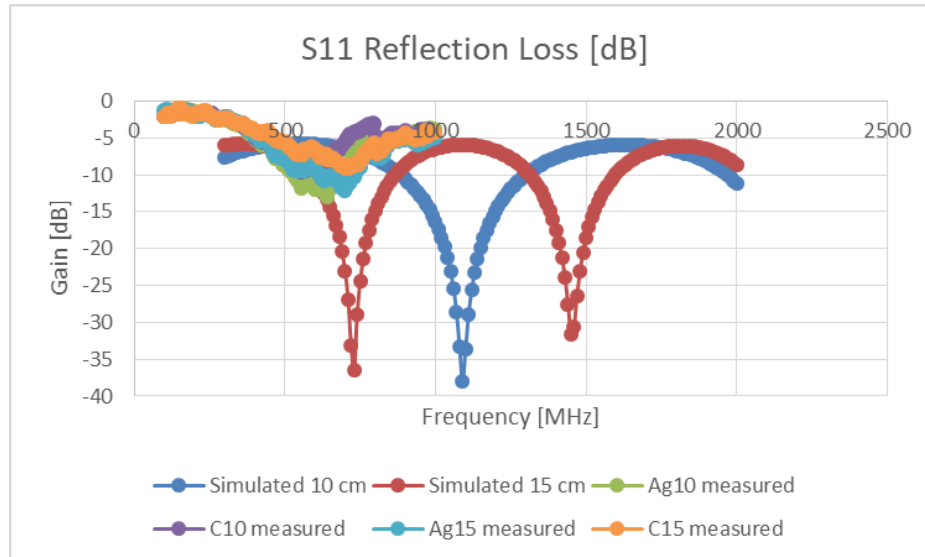


Fig. 16: Simulated and measured results for the four transmission lines

The measurements with the VNA were conducted in the frequency range 100-1000 MHz, as calibration results proved to be more stable in this frequency range.

4. DISCUSSION

The morphological investigations revealed that the surface of silver conductive coating is discontinued, containing very compacted granules which are enough in electrical contact to assure the electrical conductivity. The surface of C conductive coating is continuous, a fact which leads to a good electrical conductivity. The chemical investigations reveal the silver and the carbonic content of pastes, the oxides and other C-O organic compounds that are present in the paste matrixes and the C-C structures from carbonic paste (1500-1000 cm^{-1} band).

On the other hand, the measured reflection loss (S11) of the manufactured transmission lines broadly coincides with the simulation values (Fig. 16). This is mainly due to two reasons:

- the electric conductivity of the simulation was set to 10^7 S/m, while the manufactured transmission lines have 10^3 - 10^5 S/m, with a shift of the Gain in dB;
- the measured parameters of the dielectric textile substrate (relative electric permittivity and tangent delta) [6], may differ and hence the resonant frequency shifts.

However, in case of the 15 cm transmission lines, the measurement has same resonant frequency as the simulation.

5. CONCLUSIONS

The aim of this research was to provide flexible microwave transmission lines to deliver maximum power to wearable antennas. The resonant frequency was initially designed for 900 MHz (GSM communication), however after updating the simulation with the current physical parameters of the dielectric substrates, the resonant S11 frequency of the 100 mm line and 150 mm line shifted to 1100 MHz and 700 MHz. Specific aim of this paper was to analyze, from a morphological point of view (SEM), and from a physical-chemical perspective (EDX, FT-IR), the quality of the transmission



lines on the dielectric textile substrate prepared by coating with silver and carbon pastes. Envisaged analysis was directed to the electric conductivity and signal continuity, as well as adhesion of the conductive paste onto the textile substrate. The SEM analysis presents some discontinuous features of the transmission lines, and regions in high electrical contact. The EDX analysis showed the presence of silver chloride in the case of the silver paste, and carbon and oxygen, from the organic additives, in the carbon paste. The FT-IR analysis of the carbon paste shows the carbon-carbon bonds of carbonic structures manifested in the 1500-1000 cm^{-1} middle-infrared band of vibrational molecular transitions, which were absent from the silver paste due to silver-chloride ionic bonding rather than carbon-carbon bonding.

The proposed textile structure for the flexible microstrip transmission lines generally meets its designed functionality. The measured values of the reflection loss S11 shifted when compared to the simulated values in Gain and resonant frequency, due to differences in the electric conductivity of the traces and in the electric parameters of the dielectric textile substrate. Future work envisages a better correlation of the design and simulation of the band pass with respect to physical and electrical parameters.

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