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FLEXIBLE MICROSTRIP BANDPASS FILTER COATED ON TEXTILES FOR RESONANT SIGNAL TRANSMISSION

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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, with silver respectively with carbon paste, with two geometrical dimensions. Their designed functionality is to act as band pass filters at the resonant frequency of 900 MHz, (which is the GSM mobile phone frequency) in order to deliver maximum power at a wearable antenna. The four coated transmission lines were manufactured via screen printing on the dielectric substrate, while a conductive knitted fabric was sewn on the back side to act as ground plane. The manufactured transmission lines were characterized regarding their physical-mechanical, electrical and morphological properties. The reflection loss S11 of the transmission lines was measured via a Vector Network Analyser and the simulation data was subsequently updated with the parameters of the manufactured samples. Simulation results were validated with measurement results with a roughly agreement, mainly due to the differences between the electric conductivity of the microstrip ciruit in simulation and in manufacturing. These findings consolidate the continuation of the research work.*

Key words: *distributed elements, flexible microwave circuits, textile dielectric, transmission lines*

1. INTRODUCTION

Microwave transmission lines integrated into textile fabrics support smart garments wireless monitoring of physiological health parameters [1]. The advent of flexible textile antennas reaches back the early 2000, when a series of papers paved the first research results [2-7]. Their subsequent development was possible due to the progress of metallic yarns spinning and the miniaturization of electronic components [8-9]. A series of research contributions aim to reach a best possible integration of the electronic components into the garment's fabric structure, in order to ensure a reliable comfort, washability and electric functionality [9]. Applications focus on smart garments for monitoring of physiological parameters, especially for health and sport domains [10, 13-14].

Several scientific contributions dealt with the topic and brought both conceptual and technical developments. A scientific contribution related to five different textile materials for microstrip antennas and their electric and mechanic characterization was provided already 2004 in [1]. Another microstrip patch antenna with fewer risks for the humans than a wire antenna due to the groundplane close to the body was presented 2007 by [2]. Four types of patch antennas on different textile substrates, with simulation and measurement of reflection loss S11, Gain / Directivity and Far Field radiation pattern was achieved 2010 by [3].
Wearable antennas were developed for energy harvesting of EM radiation from the environment, in order to feed low-power devices attached to the smart garments [4]. Virtual prototyping (Lectra, Gerber, CLO3D) was used more recently to integrate wearable antennas into fashionable garments [5]. Slot antennas with circular shape were developed on two different textile substrates with simulation and measurement of reflection loss S11 in the ISM band of 5.8 GHz and 24 GHz (considered to be maximal frequency for wearable antennas) [6]. The bending properties and the simulation & measurement of a wearable microstrip patch antenna with and without high impedance surface structure was presented in [7].
Review papers [8,9] of the scientific domain related to wearable antennas tackle the various types adaptable to garments such as lens/array, reflector, horn, wire and patch antenna, the different manufacturing techniques as knitting, weaving, printing and embroidery and the main applications, such as cell phones, satellite communication, sports, military and telemedicine.
Microwave transmission lines enable communication at high frequencies (> 300 MHz) by connecting the textile antenna with the wearable transceiver [11], as an integrated system into the smart garment. A resonant circuit is needed in order for the textile transmission line to deliver maximum power to the textile antenna at a certain frequency. 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.

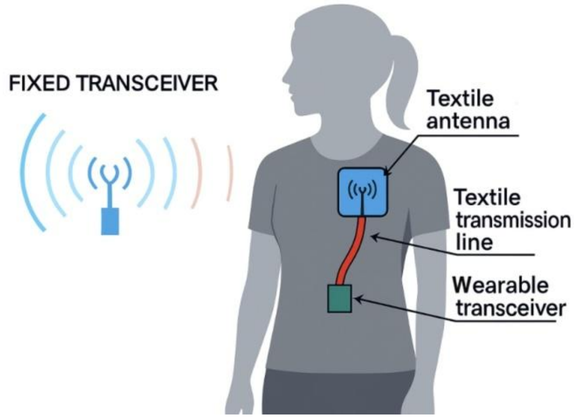


Fig. 1: *Graphical scheme for a wearable transmission line [11]*

The following research methodology was applied:

- a parametric study for modelling distributed microwave elements as bandpass filter at 900 MHz was developed;
- the bandpass filter circuit dimensional parameters were optimized (length, width), while considering given electrical (electric permittivity, electric losses) and dimensional parameters (thickness substrate, thickness coating) of the fabric and the coated circuit;
- the optimized microstrip circuit was coated by screen printing on the textile substrate, while a groundplane conductive fabric was sewed on the bottom side of the textile substrate;
- the Return Loss S11 of the resulting distributed circuit was measured via a VNA;
- modelled Return Loss S11 was updated according to physical textile parameters and validated with the VNA measurement.

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, having the following physical-mechanical and design parameters (table 1):

Table 1: *Physical-mechanical properties of the textile substrate*

No.	Physical mechanical property		UM	Values	Standard
1	Specific mass		g/m^2	268	SR EN 12127
2	Thickness		mm	0,59	SR EN ISO 5084:2001
3	Tensile strength	Warp	N	1389	SR EN ISO 13934-1
		Weft		905	
4	Elongation at break	Warp	%	24,6	
		Weft		14,0	
5	Tear resistance	Warp	N	66,0	SR EN ISO 13937-3
		Weft		70,2	
6	Dimensional change at washing	Warp	%	-1,72	SR EN ISO 6330
		Weft		-1,0	
7	Abrasion resistance		no. abrasion cycles	28.015	SR EN ISO 12947-2
8	Air permeability		l/m^2s (mm/s)	212	SR EN ISO 9237

2.2 Screen printing method

This woven fabric was screen printed with two types of conductive paste, namely silver paste from Sigma Aldrich (Ag60%+AgCl40%) and carbon paste from BareConductive. A knitted fabric with 10 Ωsq 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 x 100 mm transmission line and 4 mm x 150 mm transmission line (figure 2).

Fig. 2: *Screen printing of the textile substrate with the two types of paste*

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 (return path).

3. RESULTS

3.1. Electrical properties

A first task was to determine the electrical and geometrical parameters of the microstrip transmission line, in order to be able to complete the simulation. Several methods were applied in this regard (table 2).

***Table 2:** Electrical properties of the flexible microstrip textile*

No.	Electrical property	UM	Values	Standard
1	Groundplane electric surface resistivity	Ω_{sq}	914	SR EN ISO 1149-1
2	Groundplane electric volume resistivity	Ω m	236	SR EN ISO 1149-2
3	Groundplane electric conductivity	S/m	$4.2*10^{-3}$	SR EN ISO 1149-2
4	Relative electric permittivity textile substrate (ε_r)	[1]	2.11 [at 1 GHz]	Measured according to [12]
5	Dielectric losses textile substrate (tanδ)	[1]	0.015 [at 1 GHz]	Measured according to [12]
6	Electric resistivity silver layer 10 cm / 15 cm	Ω m	$3.56*10^{-5}$ $1.06*10^{-5}$	Measured via multimeter
7	Electric conductivity silver layer 10 cm / 15 cm	S/m	28106 94193	Measured via multimeter
8	Electric resistivity carbon layer 10 cm / 15 cm	Ω m	$2.52*10^{-4}$ $2.83*10^{-4}$	Measured via multimeter
9	Electric conductivity carbon layer 10 cm / 15 cm	S/m	3975 3534	Measured via multimeter

The surface and volume electric resistance of the knitted fabric used as ground plane were computed with a PRS-801B Teraohmmeter of Prostat with PRF-911 concentric rings, according to the standard ISO 1149-1/2. The electric conductivity of this knitted fabric was computed of the volume electric resistivity. The relative electric permittivity and the losses of the dielectric textile substrate were measured via a specialized experimental setup in a previous scientific contribution [12]. Due to the fact that the thickness of the coating on the textile is not uniform, an average value for the thickness was computed. The electric resistivity and conductivity of the transmission lines were computed by measuring the linear resistance of the conductor with a multimeter and considering its geometrical dimensions (length, width, thickness).

3.2. SEM analysis of the coated layer thickness

The thickness of the silver and carbon layer applied onto the textile substrate was determined by SEM analysis. Images with magnification of 800x prove a good adhesion onto the textile substrate, however a less uniform thickness.

***Fig. 3:** Measured thickness of the 100 mm Ag coating*

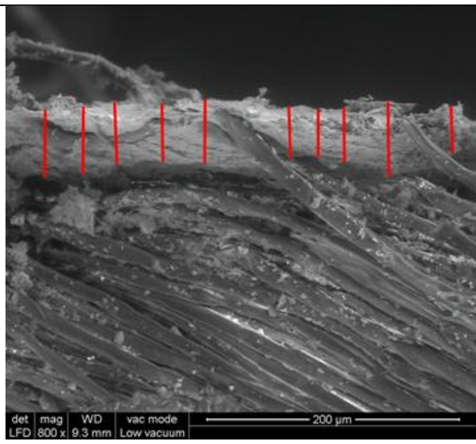


***Fig. 4:** Measured thickness of the 150 mm Ag coating*

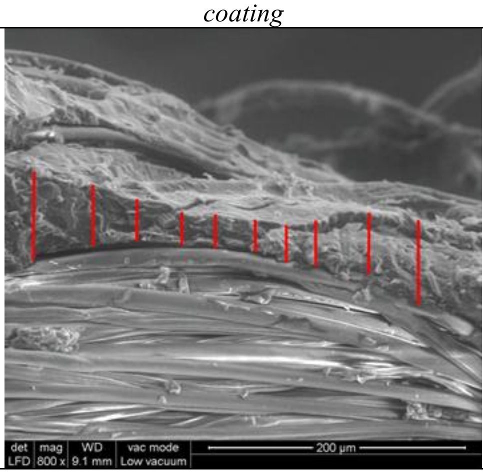


***Fig. 5:** Measured thickness of the 100 mm Carbon coating*

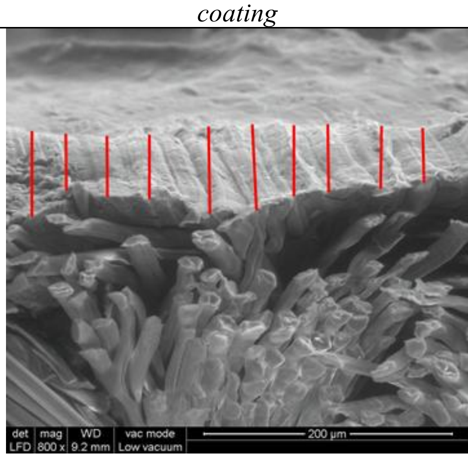
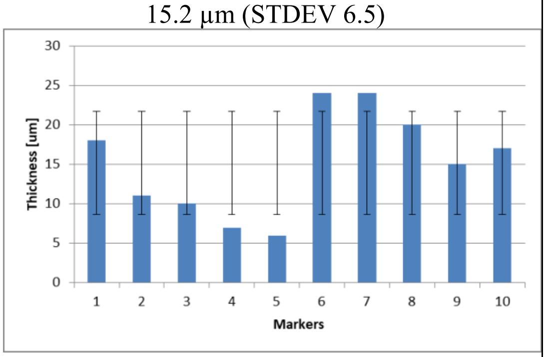
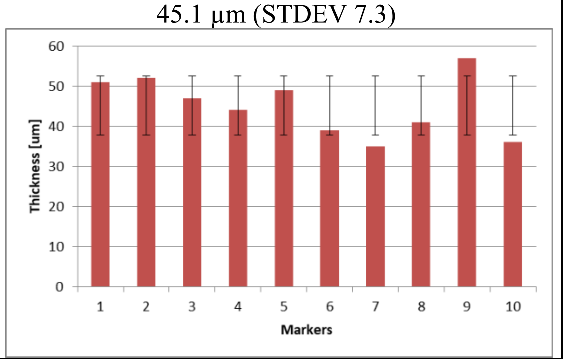
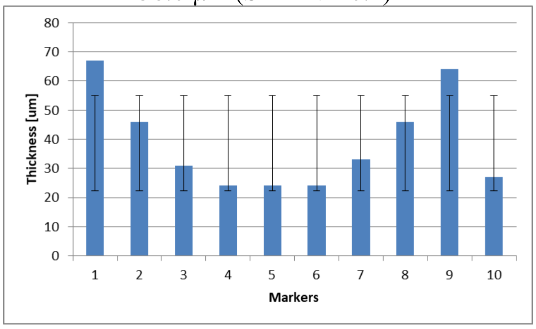
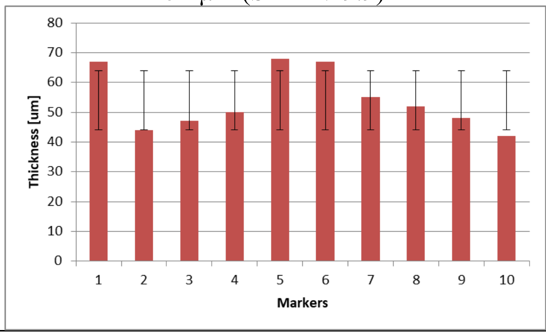


***Fig. 6:** Measured thickness of the 150 mm Carbon coating*

Table 3 presents the average thickness computed of the SEM images.

***Table 3.** Average thickness of the coated layers*

	100 mm transmission line	150 mm transmission line
Silver coating	15.2 µm (STDEV 6.5)	45.1 µm (STDEV 7.3)
		

Carbon coating	38.6 µm (STDEV 16.4) 	54 µm (STDEV 9.9) 

The values of the coated trace are quite scattered, but they ensure a continuous transmission of the electrical microwave signal.

3.3. Reflection loss simulation and measurement results

The S11 Reflection loss was simulated and measured for the four transmission lines. The simulation of the microstrip transmission lines was done in Sonnet Lite software, by introducing the electric parameters of the textile substrate and the geometric dimensions of the coated trace. The measurement was done via a Vector Network Analyzer, by connecting the electrodes to the 50 Ω input and output port, within the frequency range of 100-1000 MHz (Figure 7 and 8).

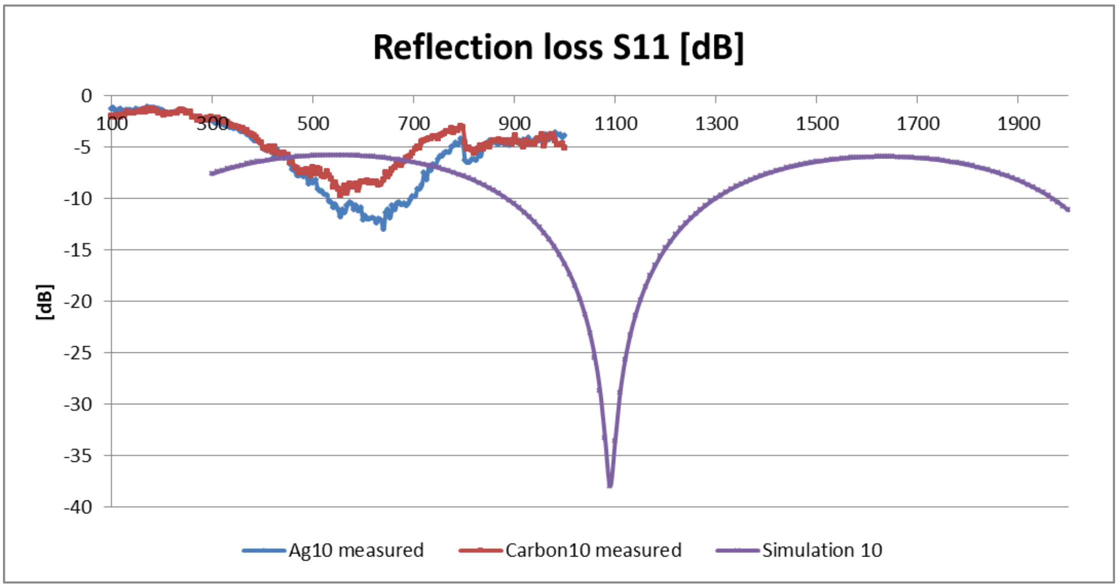


Fig. 7. *Simulated and measured results for the 100 mm transmission lines*

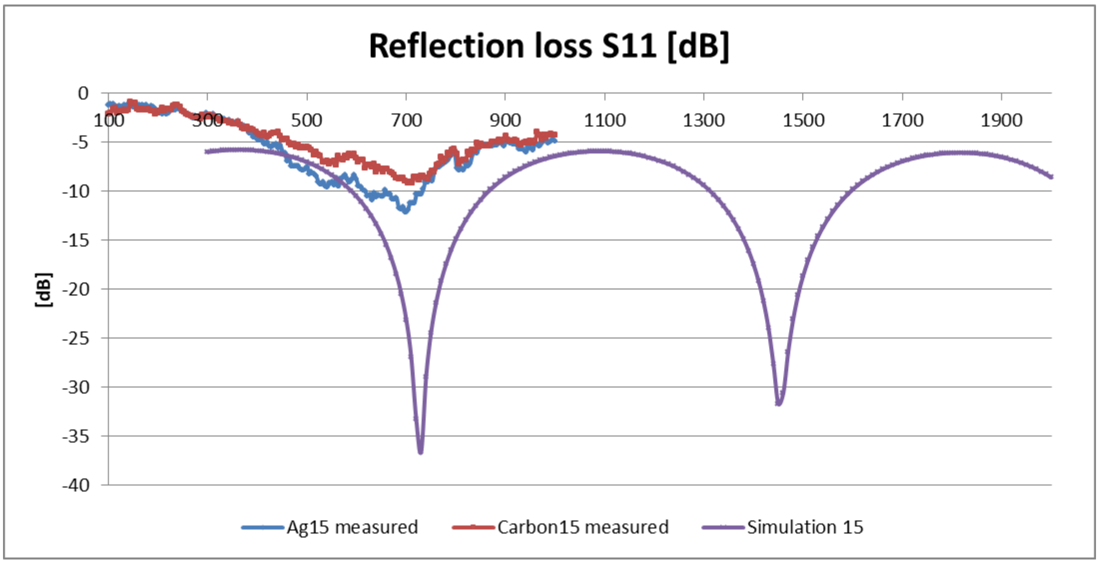


***Fig. 8.** Simulated and measured results for the 150 mm transmission lines*

4. DISCUSSION

The measured results differ from the simulated results, especially for the case of the 100 mm transmission lines, mainly due to the different values of the coated trace electric conductivity. The simulation was performed with a conductivity of the traces of 10^7 S/m. Instead, the silver traces have a conductivity of 2.8-9.4*10^5 S/m, while the carbon traces have a conductivity of 3.5-3.9*10^3 S/m. Another deviation between the simulated and measured results may come due to the deviations in measurement of the dielectric parameters of the textile substrate (relative electric permittivity and loss tangent). It is known that such deviations have as result the displacement of the resonant frequency. On the other hand, the results for the 150 mm transmission line show a good agreement regarding the resonant frequency (700 MHz). Single the gain differs, with about -35 dB for the simulation (trace conductivity 10^7 S/m) when compared to the -12 dB for the measured silver coating (trace conductivity 94193 S/m) and the -8 dB for the carbon coating (trace conductivity 3534 S/m).

5. CONCLUSIONS

Aim of the 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 coated transmission lines, the resonant S11 frequency of the 100 mm line shifted to 1100 MHz and the resonant S11 frequency of the 150 mm line shifted to 700 MHz. Moreover, due to significant differences of the electric conductivity of the traces (simulation = 10^7 S/m, measurement = 10^3-10^5 S/m), the gain in dB of the measured physical band pass filters is lower (simulation = -35 dB, measurement = - 8 dB and - 12 dB). Differences between the dielectric substrate parameters also play a role in the shift of the resonant frequency. Nevertheless, the proposed textile structure for the flexible microstrip transmission lines roughly meets its designed functionality. Future work envisages a better correlation of the design and simulation of the band pass filter in agreement with the physical and electrical parameters of the microstrip transmission lines.

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