Development of a Textile Antenna Using a Continuous Substrate Integrating the Ground Plane

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***Abstract*— The exponential growth in the wearable market is boosting the industrialization process of manufacturing textile antennas. The patch of the printed antennas can be easily cut, embroidered or screen printed by machines. The conception of an optimal industrial substrate that meets all the mechanical and electromagnetic requirements is still a challenge. This paper presents a printed textile antenna for ISM band using a continuous Substrate Integrating the Ground Plane (SIGP). The SIGP is a novel textile material, which is a double fabric that integrates the dielectric substrate and the conductive ground plane in a single textile.**

Keywords—continuous substrate; electromagnetic characterization; novel material; textile antenna; wearable technology.

I. Introduction

IDTexEx foresee that in this decade, 2017 – 2027, the market for wearable devices will reach over $150 billions per year [1]. For this reason, the industrialization of the manufacturing processes, aiming the mass production of textile antennas, emerge with great relevance. Although the patch of the printed textile antennas can be easily cut, screen-printed or embroidered by industrial machines, as presented in [2], the conception of a good industrial substrate that meets all the mechanical and electromagnetic requirements of textile antennas is still a challenge. Based on previous results reported in [3], which have proven that a continuous substrate does not influence the performance of the textile antenna, this paper presents the development of a printed textile antenna for ISM band (Industrial, Scientific and Medical), using a new textile material that integrates the dielectric substrate and the conductive ground plane in a single sheet. This novel material is from now designated SIGP "Substrate Integrating the Ground Plane" [4]. In this way, the manufacturing process of the textile microstrip patch antennas may become easier and faster.

II. Method and Materials

The concept of integrating the antenna in a multiple fabric, was already presented in [5]-[6]. In these works, the authors have presented a 3D Integrated Microstrip Antenna, which is woven into a 3D orthogonal fabric. This microstrip antenna, for aerospace application, was developed to work as radar L-band (1.5 GHz). It was made using copper yarns in the conductive parts and aramid (Kevlar 129) yarns in the dielectric layer.

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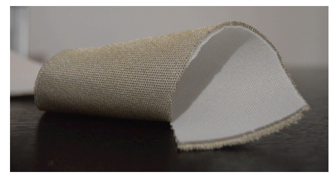


Fig. 1. Continuous Substrate Integrating the Ground Plane - 3D Weft knitted spacer fabric (white) with an integrated conductive layer (gold).

Despite the measured resonance frequency was 1.8 GHz, higher than the planned one, this antenna shown a great result proving that the antenna can be integrated in a unique material, composed of multiple layers. In this paper, a different approach is used: the SIGP is a weft knitted spacer fabric, produced in a double circular machine. The SIGP was developed and manufactured at Borgstena Textile Portugal Lda., following the manufacturing process of the Patent US 6779369 B2 [7]. Figure 1 presents an image of the SIGP.

The SIGP was developed, using a 100% PES yarn for the dielectric substrate, a 100% PES Monofilament yarn as the spacer yarn, and the Shieldex® yarn 117/17 dtex Z-turns HC+B for the conductive layer. The fully description of the materials and the manufaturing process can be found in [4]. Also, a control and reference material was produced using the 100% PES yarn on both sides of the spacer knit. This control material aims to serve as reference to compare with and to analyze the influence of the integration of the ground plane in the properties of the dielectric substrate. Both spacer knits present a total thickness (h) equal to 2 mm, measured using the KES-F-3 Compressional Tester of Kawabata's Evaluation System for Fabrics. The thickness of the conductive layer of SIGP was measured trough Scanning Electronic Microscope (SEM) image analysis, being $h = 0.043$ mm.

III. Electromagnetic characterization

A. Dielectric properties

The dielectric constant was measured through the Microstrip Resonator Patch Method [8]. It consists in designing a microstrip patch antenna using an estimated ε_r value, and calculating the real ε_r based on the shift of the measured resonant frequency of the tested antenna. Thus, one textile microstrip patch antenna to resonate at 2.45 GHz was designed, on the CST Microwave Studio 2017 full-wave simulator, using estimated values of ε_r = 1.10 and tanδ = 0.006 [2]. Also, a Pure Copper Polyester Taffeta Fabric (PCTF), with R_s = 0.05 Ω/□ and thickness equal to 0.080

mm, was used for the patch. As the conductivity of the integrated ground plane is unknown, the antenna was simulated considering the conductivity value of the PCTF for both conductive parts, patch and ground plane. Figure 2 presents the design of the textile microstrip patch antenna. The main parameters of the antenna topology are: W_{sgd} = 150 mm, L_{sgd} = 150 mm, F_p = 11.9 mm, W_p = 61.37 mm and L_p = 53.9 mm.

As control, a prototype using the reference spacer knit was also manufactured, using the PCTF for both patch and ground plane. Both antennas were assembled using the grid network adhesive sheet. Due to the knitted structure, it was impossible welding the SMA connector in the integrated ground plane. For this reason, the SMA connector was glued to the ground plane using a conductive glue Elecolit® and to ensure the mechanical stability an extra coating of Slow-Cure™ Epoxy was applied. In the patch side, the SMA connector was welded on the conductive fabric, as usual, as one can see on Figure 2. Figure 3 (a) presents the obtained S_{11} results.

As one can see on Figure 3 (a), the antenna using the reference spacer knit presents the best agreement with the simulated S_{11}. This was expected, as the simulation was made using the conductivity value of the PCTF. This result shows that the estimated values of the ε_r and tanδ well characterizes the dielectric behavior of the reference spacer knit. Comparing the S_{11} of both antennas, it is possible to see that the integration of the ground plane on the substrate increases the ε_r, as the resonant frequency of antenna made with SIGP has shifted for a lower frequency. This can be explained by the fact the integration of the ground plane reduces the thickness of the substrate, thus changing the Q-factor of the antenna. Based on these results, a new simulation was made changing the ε_r value until the new simulated S_{11} be in agreement with the already measured S_{11}, to then extract the real ε_r value, as show in Figure 3 (b). Through comparing these two S_{11} presented in Figure 3, the new value of ε_r = 1.28 was extracted.

B. Electrical properties

To characterize the electrical properties of the ground plane, the sheet resistance was measured following the ASTM Standard F 1896 – Test Method for Determine the Electrical Resistivity of a Printed Conductive Material [9]. The conductivity of the ground plane of SIGP was 54 kS/m.

IV. SIGP AS DIELECTRIC SUBSTRATE OF PRINTED TEXTILE ANTENNAS

To validate the results obtained in previous Section, a microstrip patch antenna for ISM band, between 2.4 and 2.5 GHz, was designed using the SIGP as substrate. For the patch, the PCTF was used. This printed textile antenna has the same design that the one presented in Figure 2, and also was manufatured using the same technique presented on Subsection A. The main parameters of the antenna topology are: W_{sgd} = 150 mm, L_{sgd} = 150 mm, F_p = 11.2 mm, W_p= 64.67 mm and L_p = 50.25 mm. The antenna stayed in rest 24hs before the S_{11} measurements and the Figure 4 shows the obtained results. As one can see on Figure 4, the antenna shows a good impedance, validating so the results of the electromagnetic characterization presented in previous Subsections. The small shift presented on S_{11}, as the simulated frequency is 2.42 GHz and the measured frequency is 2.40 GHz, is not significant and can be explained due to the inaccuracies on the manufacturing process, such as

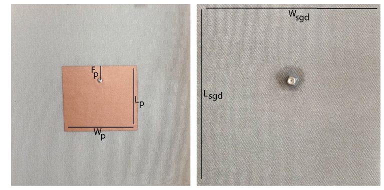
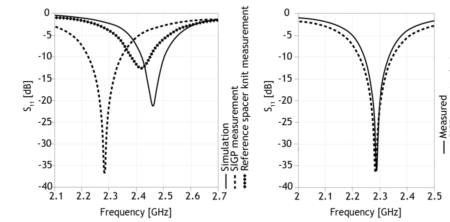


Fig. 2. Microstrip patch antenna designed for the dielectric characterization.



(a) (b)

Fig. 3. S_{11} of the textile microstrip patch antennas for the dielectric characterization (a) simulation and measurements using estimated ε_r value and (b) new simulation based on the measurements.

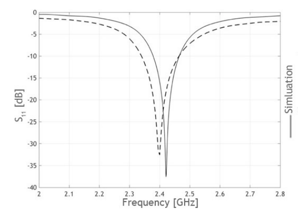


Fig. 4. Return loss of the printed textile antenna using SIGP as dielectric substrate.

the gluing of the SMA connector. Still, the antenna is capable to resonate in the proposed ISM band.

V. CONCLUSIONS

The greatest advantage of the SIGP is to reduce the steps and errors on the manufacturing process of printed textile antennas. This way, it is possible to decrease the losses and mismatches caused by the incurrences due to the hand-made manufacturing process. Despite the integration of the ground plane on the substrate cause a increase in the ε_r, the analyses of S_{11} of printed textile antenna has proven that the SIGP is suitable for the development of wearable antennas.

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