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Smart Coat with a Textile Antenna for Electromagnetic Energy Harvesting

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Abstract: In the framework of Wireless Body Sensor Networks (WBSN) for healthcare and pervasive applications, the textile antennas add wearability to the ubiquitous monitoring, communication, energy harvesting and storage systems. Wearable antennas are the bridge for a non-obtrusive integration of communication sensors and equipment, extending the interaction of the communication system. The integration of electronic devices on clothing brings the question about how to feed them. The batteries are an obvious choice, but they are bulk and require frequent replacement or recharging. Also, nowadays, their short longevity is an ecological problem. Currently, radio frequency energy is broadcasted from billions of wireless transmitters and therefore it can be harvested from the ambient. Responding to this context, this paper presents a smart coat with an embedded dual-band textile antenna for electromagnetic energy harvesting, operating at GSM 900 and DSC 1800 bands. The results obtained before and after the integration of the antenna into the garment are compared. For the highest and lowest frequency operating bands, the simulated gain is around 2.06 dBi and 1.8 dBi, respectively. Also, the textile antenna shows a radiation efficiency of 82% for GSM 900 and 77,6% for DSC 1800.

Keywords: Textile antenna; energy harvesting; smart clothing; wearable devices

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1. Introduction

Nowadays, the socio-economic development and lifestyle trends indicate an increasing consumption of technological products and processes, powered by emergent concepts, such as Internet of Things (IoT) and smart environments, where everything is connected in a single network. In this context, wearable technology has been addressed to make the person, mainly through his clothes, able to communicate with and be part of this technological network. Wireless communication systems are made up of several electronic components, which over the years have been miniaturized and made more flexible, such as batteries, sensors, actuators, data processing units, interconnectors and antennas. In these systems, the antennas have been challenging, because they are conventionally built on rigid substrates, hindering their efficient and comfortable integration into the garment.

Considering the flexibility and dielectric intrinsic properties of textile materials, embedding antennas into fabrics allow expanding the interaction of the cloth with some electronic devices, making them less invasive and more discrete. Thus, textile antennas that combine the traditional textile materials with new technologies, emerge as a potential interface of the human-technology-environment relationship, becoming an active part in the wireless communication systems [1], aiming applications such as tracking and navigation [2], mobile computing and other [3].

The civil society and the military domain have been potentiating these developments. Civil society is interested in communication devices for entertainment, information transfer and interaction in social networks, as well as in the development of medical sensors to enable a constant and ubiquitous communication between user and monitor [4]. In the military domain, the concern is the miniaturization of monitoring systems, mainly to reduce the burden on the military in adverse conditions [5] and increase their protection.

1.1. Textile Antennas

To be wearable, textile antennas should be thin, lightweight, of easy maintenance, robust, and moreover, must be low cost for manufacturing and commercializing. In this way, planar antennas, the microstrip patch type, have been proposed for garment applications, because this type of antenna presents all these characteristics, and also are adaptable to any surface [6]. These antennas are usually formed by overlapping conductive (patch and ground plane) and dielectric (substrate) layers, as shown in figure 1. For this reason, the knowledge of the properties of textile materials is crucial as well as the manufacturing techniques for connecting the layers such as glue, seam and adhesive sheets. Furthermore, the microstrip patch antenna radiates perpendicularly to a ground plane, which serves as a shield to the antenna radiation, assuring that the human body absorbs only a very small fraction of the radiation.

1.2 Energy Harvesting

The integration of electronic devices on clothing still puts another question about how to feed them. The batteries are an obvious choice, but they are bulk, require frequent replacement or recharging and their short longevity is an ecological concern of current times. Therefore, energy harvesting is a promising solution to consider in the next generation of Wireless Sensor Networks (WSN). Nowadays, radio frequency (RF) energy is currently broadcasted from billions of radio transmitters and thus can be collected from the ambient or from dedicated sources [7]. Currently, the advance of technology stimulates the growing number of wireless transmitters, especially in urban areas highly populated, increasing the power density of available RF in the environment [8].

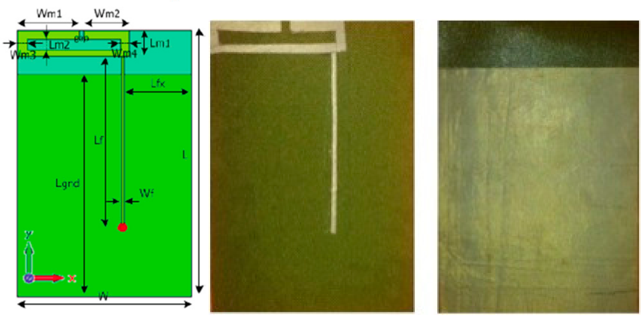
Coherently, in the past years, the integration of wearable antennas for RF energy harvesting in smart clothing applications has also increased. In [9] a scheme of jacket with harvester circuit is presented. A triple-band ring wearable antenna for RF energy harvesting, operating at GSM 900, GSM1800 and WiFi frequencies is proposed. For the conductive parts of the antenna, the Global EMC shielding fabric with surface resistivity of 0.02 Ω/sq was used. The Kapton® fabric with ε_r = 13.4 and tanδ = 0.002 was used as dielectric substrate. Another example is the coat presented in [10] where a multiple body-worn embroidered textile antenna is proposed to integrate a harvester system operating at 2.45 GHz.

2. Experimental Section

2.1 Dual-band Textile Antenna for Electromagnetic Energy Harvesting

A study to identify the spectrum opportunities for the RF energy harvesting, through power density measurements from 350 MHz to 3 GHz, was previously made and reported in [11]. Based on these results we proposed in [12] a dual-band wearable antenna for GSM900 and DCS1800 frequency bands.

Based on previous work [1], a 100% polyamide 6.6 fabric, named Cordura®, was used as dielectric substrate. This fabric presents a $\varepsilon_r \cong 1.9$, tanδ = 0.0098 and 0.5 mm of thickness. For the conductive parts, a commercial available electrotextile, named Zelt®, with electric conductivity of 1.75105 S/m was considered. The antenna design was presented in [12]; it is shown in the figure 1 and the table 1 presents the corresponding dimensions. This paper presents the inclusion of this antenna in a smart cloth, manufacturing the antenna directly on the clothing.



(a) (b) (c)

Figure 1. (**a**) Design of a dual-band textile antenna for energy harvesting (**b**) Front (**c**) Back.

Table 1. Dimensions of the textile antenna

Parameter	Dimension (mm)
L, Lgnd, Lf, Lfx	120, 100, 78, 30
Lm1, Lm2, gap, W	12, 5, 31, 80
Wf, Wm1, WM2, Wm3, Wm4	1.5, 31, 21, 8, 4

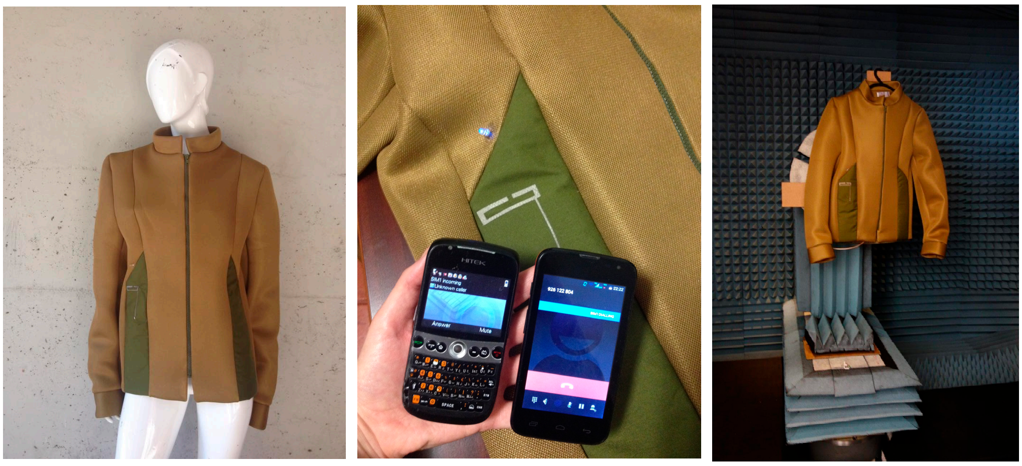
2.2 E-Caption: Smart & Sustainable Coat

The integration of textile antennas for energy harvesting into smart clothing emerges as a particularly interesting solution when the replacement of batteries is not easy to practice, such as in wearable devices. In the past years, some authors have already analyzed the influence of the human body on the performance of textile antennas [13]-[14], although no one has presented results about the influence of the integration of the patch antenna on clothing on the performance of the antenna.

Until now, the textile patch antennas have been built isolated and then posteriorly integrated in the lining of garment or pockets. Only in the Radio Frequency Identification (RFID) context, some authors have been investigated textile antennas for commercial advertisement proposes, such as brand names and logotypes [15]–[16].

This paper proposes an innovative solution as it includes the first patch antenna prototype manufactured directly on the clothing. Named "E-Caption: Smart & Sustainable Coat", it is a smart coat where the substrate of the antenna is continuous and was cut following the patterning of the coat, being thus part of it. A fully embedded antenna in clothing contributes for the advance of the integration of electronics devices in less obtrusive way, making the garment more confortable and pleasing to the eyes of the final consumer.

The smart coat "E-Caption" integrates the antenna presented in previous paragraph. It was built in a 3D fabric[1]. The textile antenna was manufactured using an adhesive sheet, glued by a simple ironing operation. The figure 2 shows the coat with the textile antenna for energy harvesting. The analysis of the antenna integration and the evaluation of their behavior are discussed in the section 3.



(a) (b) (c)

Figure 2. (**a**) E-Caption: Smart & Sustainable Coat (**b**) Textile antenna, in detail (**c**) Measurement of antenna's behavior at anechoic chamber.

3. Results and Discussion

The antenna's performance of the E-Caption: Smart & Sustainable Coat was tested in the anechoic chamber, as show the figure 2 (c). The textile antenna presents an operating frequency range capable of

[1] Reference 3003 - 3D fabric, from LMA - Leandro Manuel Araújo, Ltda. www.lma.pt

completely covering the GSM900 (880-960 MHz) and the DCS 1800 (1710-1880 MHz). The figure 3 presents the variation in the S_{11} parameter obtained through numerical simulation and measured values. It is possible to see the agreement between the simulated and measured values.

Even after integrating on clothing, the radiation pattern is clearly omnidirectional. The figure 4 shows the differences in the radiation pattern between the simulation and the measurement of the antenna fully integrated into the smart coat structure. Observing the XZ plane (blue line) we can see the line is not a perfect circle anymore. This deformation is due to the non-uniform garment's structure.

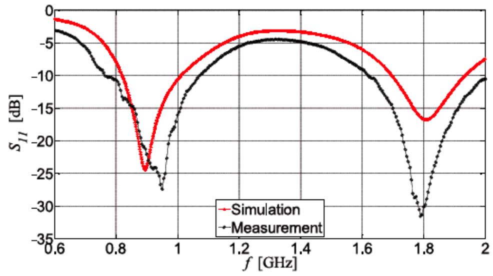


Figure 3. Simulated and measured return loss.

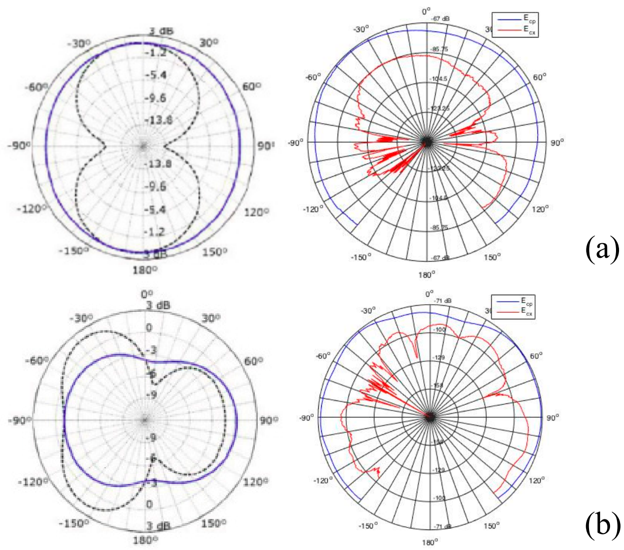


Figure 4. Simulated radiation pattern of the textile antenna in the YZ plane (dashed) and XZ plane (blue solid). Measured radiation pattern in the YZ plane (red line) and XZ plane (blue line) at (**a**) 900 MHz and (**b**) 1800 MHz.

For the highest and lowest frequency operating bands, the simulated gain is around 2.06 dBi and 1.8 dBi, respectively. Also, the textile antenna shows a radiation efficiency of 82% for GSM 900 and of 77,6% for DSC 1800.

4. Conclusions

In the future, the garments will not only communicate social condition or protect the human body against the extremes of nature, but also will provide information about the state of user’s health and environment. With the evolution of materials, clothes are becoming able to communicate via wireless without the necessity of big and expensive equipment. This is possible because textile technologies can produce new types of sensors and antennas that are so small, flexible and inexpensive that they can be applied in different types of clothing, shoes and accessories.

The integration of textile antennas for energy harvesting into smart clothing can be a solution for recharge wearable devices, such as low-power electronics and WBSN. Embedding antennas in clothing contributes for the advance of the integration of electronic devices in less obtrusive way making the smart clothes more confortable. Also, this work shows that a continuous substrate of the antenna does not influence its performance. Finally, this might open new horizons and concepts in the clothing development and in the sustainable communication.

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Author Contributions

CL designed the experimental plan. CL and CLO made the “E-Caption: Smart & Sustainable Coat” prototype. RG and PP designed and measured the textile antenna. CL and RS wrote the manuscript. CLO, RS, PP and RG revised the manuscript.

Conflicts of Interest

The authors declare no conflict of interest.

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