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## Developing Sustainable Communication Interfaces Through Fashion Design

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*The recent technological developments made electronic devices become imperative and indispensable, being present in our daily routines, all over the world. But, the continuous exposition of people to the electromagnetic radiation might cause illness. Electrosmog is the invisible electromagnetic radiation that results from the usage of electric equipment and wireless technologies. Some studies present electro sensibility as a contemporary illness affecting more and more people.*

*This paper analyses some of the challenges this reality puts to the fashion design and how textile materials may be used to protect the human body against the harmful radiation and to develop smart cloths incorporating textile antennas able to capture these radiations and feed low-frequency devices.*

*Thus, one considers the notion of “Transparent Sustainability” and the search for the smart energy explorations of/or in the human body. This way, the association of fashion design and technology can transform the garment in a sustainable communication interface.*

**Keywords:** *Electrosmog; textile antennas; wearable development; energy harvesting; smart clothing.*

## Introduction

The contemporary fashion designer must interpret the growing interaction between the individual and the technology, transforming the clothing in an interface of that relationship. The creations should respond to the consumer's desire, providing also protection, interactivity, sustainability and conceptual innovation.

The massive evolution of the telecommunication systems in the recent decades brought undeniable facilities to our everyday. But, the use of radio frequency (RF) devices triggered a new type of pollution, known as electromagnetic pollution or *electrosmog* (Diversos 2004). To understand the consumer needs in this reality is essential for the social-economic development of the fashion and textile industries (Li & Wong 2006).

The concept of *transparent sustainability*, according to (Saymour 2010) "*announces the entire life cycle of a product, reveals social interventions, exemplifies the environmental and health implications, finds solutions for the smart exploration of energy on and through the body*", inspire the development of the new multidisciplinary projects that help the individual to adapt to multiple changes in lifestyle.

In the future, the garments will not only protect the human body against the extremes of nature, but also provide information about the state of user's health and environment (Hertleer, Rogier, et al. 2009). For this, the person is likely to carry a range of devices and sensors, including medical sensors that constantly communicate with each other and the outside world (Bonfiglio & De Rossi 2011).

With the evolution of materials, clothes are becoming able to communicate via wireless without the necessity of big and expensive equipment. All of this is possible because textiles can produce new types of sensors, antennas so small, flexible and inexpensive that they can be applied in different types of clothing, shoes and accessories.

Linking all these concepts, this study proposes a development of a textile antenna for discreetly integration into the clothing, contributing to a non-intrusive integration of the electronic devices and harvesting electromagnetic energy from the environment – transforming this "polluting" radiation in a clean power source (Lopes et al. 2013). The design process to elaborate this project is illustrated in Figure 1.

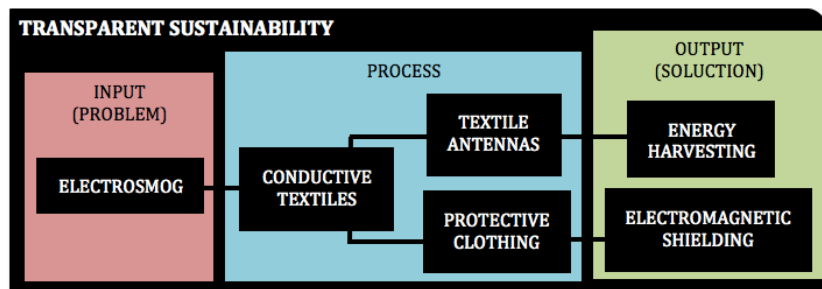


Figure 1. Schematic of project development in the transparent sustainability concept.

## Electromagnetic Shielding

Nowadays the modern consumer is more and more dependent of new technologies in everyday situation, like at home, transportation, embedded in clothing, alimentation and entertaining (Loss et al. 2014).

The human being is a complex biologic mechanism. The human body show ionic and electrical high conductive structures, such as neural networks and cerebrospinal fluid; moreover our brain and heart are regulated by feeble electric signals (Dode & Leão 2004). In this way, the constant exposition to the radiation of the electromagnetic fields affect the human biologic process, and may cause serious changes on it (Tejo 2004).

In this way, the World Health Organization (WHO) create a project named *International Electromagnetic Project*, which main objective is to establish and assess health and environmental effects of being exposed to static and time varying electric and magnetic fields in the frequency range 0-300 GHz.

Based in this problem some authors are developing new ways to protect people, equipment and buildings from electromagnetic radiation and interference. This protection is made through the method *shielding*. Historically, this method was achieved through metal boxes and have been used in two ways: to isolate equipment/people against EMF and to prevent electromagnetic emission from internal devices (Brzeziński et al. 2012). But this kind of "box shield" is heavy and difficult to use. Therefore, it is important to develop shielding methods through textiles, because textile materials are intrinsically flexible, porous, elastic, easy to carry and to apply.

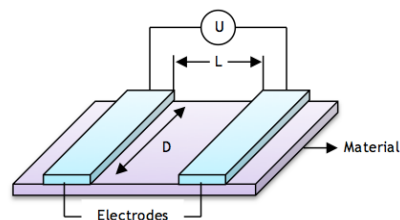


Figure 2. Basic setup for surface resistance and surface resistivity measurement

### *Conductive textiles materials*

Generally, textile fabrics are insulating materials. However, there are commercially available electrotexiles with high conductivity, well suited for shielding and antenna applications.

The conductive fabrics are planar materials; therefore, their electrical properties are characterized by an electrical surface resistivity. It is important to distinguish the surface resistance ( $R_s$ ) from the Surface resistivity ( $\rho_s$ ). The ASTM Standard D 257-99 is used, among other techniques, to measure them. The surface resistance ( $R_s$ ) is the ratio of a DC voltage ( $U$ ) to the current flowing between two electrodes of specified configuration that are in contact with the same side of a material under test, as seen in figure 2. The results are given in ohm ( $\Omega$ ). The surface resistivity ( $\rho_s$ ) is defined by the ratio of DC voltage drop per unit length ( $L$ ) to the surface current ( $I_s$ ) per unit width ( $D$ ). The results are given in ( $\Omega/\square$ ). The surface resistivity is a property of a material, not depending of the electrodes configuration (Maryniak et al. 2003). This parameter is usually given by the manufacturer of the conductive material.

### *Electromagnetic shielding process*

The electromagnetic shielding happens when the electromagnetic-rays react with the molecules of an object or material. As can be observed in figure 3, this phenomenon is divided in three steps (Bonaldi et al. 2010):

- Absorption attenuation;
- Attenuation due to reflection;
- Attenuation due to successive internal reflection

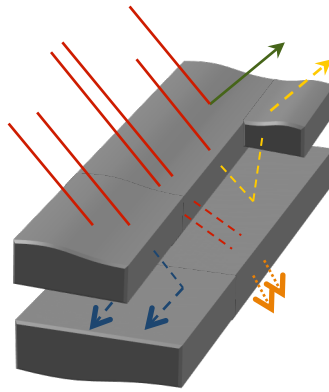


Figure 3. Electromagnetic shielding phenomena. **Red** - the electromagnetic waves, **green** – reflection, **blue** – absorption, **orange** – transmission, and **yellow** – secondary reflection (source: (Bonaldi et al. 2010))

## Textile antennas

The new generation of clothing will not only protect the human body against the extremes of nature, but also will be able to sense, communicate data and harvest energy in a non-intrusive way (Bonfiglio & De Rossi 2011).

The integration of electronics into textiles starts a new era for the apparel industry. In a near future, wearable antennas would be considered to be part of everyday clothing, transforming cloths in interfaces used for wireless communication purposes.

To achieve good results, the wearable antennas must be lightweight, inexpensive, low-maintenance, easily to integrate in radiofrequency circuits, have no setup requirements and robustness (Salvado et al. 2012; Brebels et al. 2004; Hertleer, Rogier, et al. 2009; Gupta et al. 2010). Thus, this study is focussed in the planar antennas, *microstrip patch* type, because these antennas show all previous requirements and can be easily integrated in clothing or accessories (Hertleer, Rogier, et al. 2009).

These antennas are formed overlapping layers of conductive and dielectric materials, as shown in figure 4. Therefore, they require conductive textile materials for the patch and the ground plane, and dielectric textile materials for the dielectric substrate (Locher et al. 2006).

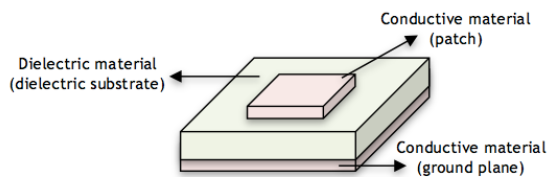


Figure 4. Schematic of overlap layers to planar antenna

Furthermore, the planar antenna radiates perpendicularly to the ground plane, which serves as a shield to radiations so only a very small fraction of the emitted radiation is absorbed by the human body.

### *Textile materials for wearable antenna*

The selection process of textile materials for the development of flexible antennas is critical. Many criteria should be considered, as several characteristics of textile materials directly affect the behaviour of the antenna, as for instance the thickness of the material influences the bandwidth and the size of the patch (Hertleer et al. 2008); the capacity of the material to absorb water reduces the resonance frequency (Salonen & Hurme 2003); the flexibility of the textiles interfere with the geometric precision of the antenna, which may result in the change of resonance frequency of the antenna (Locher et al. 2006).

Besides, the knowledge of the electrical and electromagnetic properties of textile materials is essential to a good design and antenna performance.

### **Conductive textile materials**

For a good textile antenna performance, is recommended the use of conductive textiles with surface resistivity less than  $\leq 1\Omega/\square$ , in order to minimize the losses of the superficial waves.

Flexibility and elasticity are required on the textile materials used in the development of wearable antennas to withstand the deformations caused by the bending angles of the human body.

However, it is important to note that a very large deformability, as typically occurs in knits, decreases the geometric precision of the antenna. The humidity is also one of the most important factors in determining the

electrical resistivity of textile materials, because the presence of moisture in the fibres significantly decreases the resistivity (Morton & Hearle 2008).

### Dielectric textile material

Materials that exhibit a resistivity exceeding  $10^8 \Omega/\text{cm}^2$  are classified as electrical insulating ones (Brandão 1983).

Some researchers have studied and analysed the dielectric characteristics of textile materials (Bal & Kothari 2009; Sankaralingam & Bhaskar 2010). These properties are influenced by the nature of the fibres and the polymeric material they are made, by the hygrometric state of the material, and by its purity, porosity and homogeneity. Thus, the accurate measurement of dielectric characteristics of textiles is a challenge and several experimental techniques have been used for this purpose (Baker-Jarvis et al. 2010; Declercq et al. 2008; Couckuyt et al. 2010). However, textile fibres incorporate some difficulties and none of the standard methods can be directly applied to measure the dielectric properties of the fibres.

Permittivity ( $\epsilon$ ) is the evaluation parameter for an optimal choice of textile material for the dielectric substrate.

The permittivity is usually expressed as a relative value:

$$\epsilon = \epsilon_0 \epsilon_r = \epsilon_0 (\epsilon'_r - j\epsilon''_r) \quad (1)$$

Where:  $\epsilon_r$  is the permittivity of vacuum, valued at  $8,854 \times 10^{-12} \text{ F/m}$  (Baker-Jarvis et al. 2010)

The real part of permittivity is called relative permittivity or dielectric constant. The ratio between the real part and the imaginary part is called the loss tangent being expressed by:

$$\tan\delta = \frac{\epsilon''_r}{\epsilon'_r} \quad (2)$$

Textile materials generally have a very low dielectric constant, which reduces the surface wave losses and improves the impedance bandwidth of the antenna (Grupta et al. 2010). Surface waves are connected to the guided wave propagation within the substrate, thus reducing the dielectric constant the spatial waves increase, and consequently the impedance bandwidth of the antenna increase, allowing the development of antennas with high gain and acceptable efficiency (Hertleer, Rogier, et al. 2009; Salonen & Hurme 2003).

A sufficiently wideband and efficient planar antenna is realized by selecting a substrate with a low dielectric constant (preferably  $\leq 4$ ) and a low-loss tangent ( $< 10^{-2}$ ) (Brebels et al. 2004).

#### **Some considerations about the influence of the textiles characteristics**

The textile materials are always establishing a dynamic equilibrium with the temperature and relative humidity of the ambient. However, the amount of water absorbed by a material to reach this equilibrium depends on the origin, on the type of molecular structure and on the type of chemical components of the fibres, resulting in very different moisture contents in the textile materials (Morton & Hearle 2008).

The moisture content changes the electromagnetic properties of the textile material. Being porous, textiles have many air cavities, and this presence of air approaches the textile permittivity to value 1. In fact, the relative permittivity of textile materials is usually between 1 and 2, while the permittivity of water is approximately 78 to 2.45 GHz and 25°C. This way, the higher dielectric constant of water dominates the moistened material causing an increase in their dielectric constant and loss tangent (Hertleer, Laere, et al. 2009).

Thus when water is absorbed by the textile material of the antenna, it dramatically alters antenna's parameters. The absorption of water by the dielectric substrate reduces the resonance frequency and the bandwidth of the antenna (Tronquo et al. 2006).

Besides, when the fibres absorb water, their dimensions and consequently their volume change. This effect, commonly known as swelling, directly influences the dimensional stability of some fabrics, since the increased diameter of the fibres results in the shrinkage of yarns and of the fabrics (Morton & Hearle 2008). This shrinkage of the fibres directly influences mechanical and geometrical stabilities of the antenna, which are essential requirements to preserve its performance.

The thickness of the substrate also is critical in the design of the antenna (Brebels et al. 2004). As almost all fabrics have the same permittivity, the thickness of the substrate is generally the parameter which will set the bandwidth of the antenna. Besides, the variation of the thickness also influences the resonance frequency.

In addition, the substrate thickness also affects the geometric dimensioning of the antenna, which means a thicker substrate with lower permittivity value (between 1 and 2) results in a larger patch, while a thinner substrate with high permittivity results in a lower patch ([Hertleer, Rogier, et al. 2009](#); [Brebels et al. 2004](#)).

After choosing the textile materials to design an antenna, the construction of the same is also crucial because the textile materials are highly deformable. Thus, the assemblage of the patch conductor with the dielectric substrate is critical ([Locher et al. 2006](#)). The majority of techniques that have been tested are low cost, requiring no specialised equipment and using commercially available materials ([Matthews & Pettitt 2009](#)).

## **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 finite lifetime has become a major concern over the past years.

Therefore, energy harvesting holds a promising future in the next generation of *Wireless Sensor Networks* (WSN). Since there are a variety of energy sources available for energy harvesting in the environment, the opportunities are vast ([Yildiz et al. 2010](#)). The vision presented in this paper is that energy harvested from Radio Frequency (RF) electromagnetic holds a promising future to power supply wirelessly electronics devices. Nowadays, RF energy is currently broadcasted from billions of radio transmitters that can be collected from the ambient or from dedicated sources ([Jabbar et al. 2010](#)).

One advantage of collecting RF energy is that it is essentially “for free”. Besides, RF energy is universally present over an increasing range of frequencies and power levels, especially in highly populated urban areas. These radio waves present a unique and widely available source of energy if effectively and efficiently harvested. Moreover, the growing number of wireless transmitters is naturally increasing RF power density and availability ([Tavares et al. 2013](#)).

### *Textile antenna for 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 (Barroca et al. 2013). Based on this identification, of the most promising opportunities, a dual-band wearable antenna operating at GSM900 and DCS1800 bands was proposed (Gonçalves et al. 2013). This antenna design is shown in the figure 5. The table 1 presents the corresponding dimensions.

Based on previous study (Salvado et al. 2012), a 100% polyamide 6.6 fabric, named Cordura®, was considered for the dielectric substrate. This fabric presents a  $\epsilon_r \approx 1.9$  and  $\tan\delta = 0.0098$ . For the conductive parts, an commercial available electrotexile, named Zelt®, with electric conductivity of 1.75105 S/m was considered.

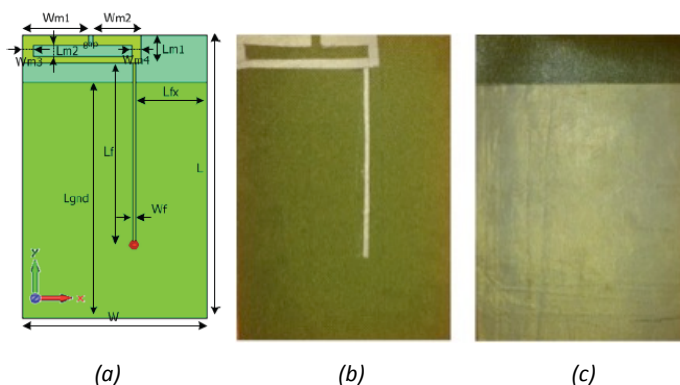


Figure 5. Textile antenna (a) antenna design (b) front (c) back

Table 1. Proposed antenna dimensions

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

The variation of the return loss obtained from numerical simulations and measurements is present the figure 6.

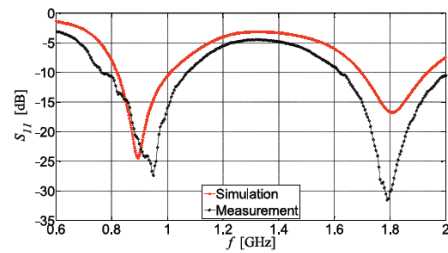


Figure 6. Simulated and measured return loss for the proposed dual-band antenna

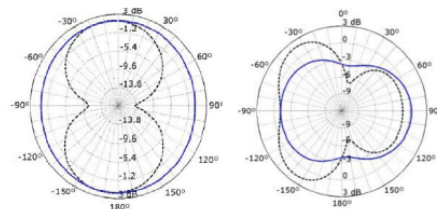


Figure 7. Simulated radiation pattern for the dual-band antenna in the YZ plane (dashed) and XZ plane (blue solid) at (a) 900 MHz and (b) 1800 MHz

From which is observed that this antenna present an operating frequency range capable of completely covering the GSM900 (880-960 MHz) and the DCS 1800 (1710-1880 MHz). Based on numerical simulations, we can see the radiation pattern of this antenna is clearly omnidirectional (see the figure 7). The gain obtained is about 1.8 dBi and 2.06 dBi, with radiation efficiency of 82% and 77,6% for the lowest and highest operating frequency bands, respectively.

## Conclusion

The synergy between design, science and technology, can transform clothing into a multidisciplinary interface, answering the needs of human beings.

In this case, a project based on the *transparent sustainability* concept, using conductive materials, was developed aiming two applications: shielding the electromagnetic radiation and harvesting the electromagnetic energy through textile materials and textile antennas respectively.

A major challenge for the future work is the development of flexible energy converters which can be fully integrated into the clothes with high efficiency and at low cost. Moreover, the influence of the human body on the performance of the antenna must be analysed.

Finally, this work might open new horizons and concepts in the clothing development and in the sustainable communications.

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