Electromagnetic Shielding Characterisation of Several Conductive Fabrics for Medical Applications

Renata Redondo Bonaldi*, Elias Siores, Tahir Shah

The University of Bolton, Deane Road, Bolton, Lancashire, BL3 5AB, UNITED KINGDOM

Abstract: This paper evaluates and compares the electromagnetic (EM) shielding characteristics of a diverse range of conductive fabrics in order to analyse their suitability for use in wearable medical applications. The Shielding Effectiveness (SE) was characterised in terms of fabric structures, conductive materials, mass, thickness and washing durability. Experiments were carried out on single and double layers of fabrics using broad frequency range and SE was measured using different methodologies. EM shielding is the process of limiting the flow of EM fields between two locations by a barrier. The shielding barrier needs to have high conductivity, dielectric constant or high magnetic permeability, and the shielding happens due to reflection, absorption or multiple reflections of the incident radiation by the barrier. Therefore, shielding is important to block electromagnetic radiation that could be harmful to electronic devices, environment and humans.

Keywords: Electromagnetic interference, shielding effectiveness, conductive fabrics, medical textiles.

1. Introduction

Textiles have been highly considered in applications of electromagnetic interference (EMI) shielding in the electrical & electronic industries as well as for the production of protective garments due to the increasing concern about health issues caused by human exposure to radiation. The emerging role of textiles in EMI shielding is mainly due to their desirable properties in terms of flexibility, versatility, low mass and low cost. Textiles are intrinsically non EMI shielding materials and are rather insulating materials; however, they can successfully turn to be EMI shielding materials after raw-material changes, new production process or process adaptations that can make them electrically conductive [1].

Some of the methods to obtain conductive fabrics are fibres and yarns made of copper, aluminium, stainless steel, intrinsically conductive polymers (ICP), and/or metallic fillers or coatings incorporated in the yarn production. These processes are based on mixing the fibre polymer with metal fillers during the chemical processes such as melt or wet spinning; or by twisting and wrapping a synthetic fibre with metallic yarns using mechanical spinning processes. These technologies are less often used due to their inherent complexities [2-20].

Other approaches include the application of conductive materials on the surface of the fabric itself using lamination, coating, spraying, ionic plating, electroless plating, vacuum metallisation, cathode sputtering, and chemical vapour deposition. Coating usually does not change the flexibility of the fabrics and is applied in very thin layer, low mass and closed fabrics. When coating is applied during the yarn production, it is possible to obtain small diameter conductive yarns, and therefore, very flexible and light weight fabrics. Most of the conductive fabrics in the market made by coating technologies have many homogeneous and closed structures thus exhibiting high EMI shielding capabilities and isotropic behaviour. [21-41].

Conductive fabrics can also be made of metallic yarns (i.e. stainless steel, copper); however, they are difficult to process. These types of yarns tend to have low flexibility due to their large diameter, which produces a heavier and uncomfortable fabric. To reduce this effect, metallic yarns are used to replace a few synthetic yarns in the structure, thereby reducing the overall stiffness of the fabric. There are several research works using this method, where the fabrics having diverse fabric constructions, different densities, patterns, yarn diameters, quantity of conductive yarns in the structure, layers and yarn direction are analysed [2-14,17-19,33,42-48].

1.1 Shielding Effectiveness (SE) measurement

The shielding effectiveness characterisation is usually evaluated by coaxial transmission line methods, waveguide methods and open space methods. However,

* Corresponding author's email: rr1cmr@bolton.ac.uk

there is a lack of generally accepted and official standard methods for measuring shielding effectiveness of fabrics. The following methods are normally used for research work and quality control purposes [49].

The "ASTM D 4935-99- coaxial transmission line method for planar materials" is the most common and easiest to use. The shielding effectiveness measurements are normally carried out from 30 MHz to 1.5 GHz. The measurement device consists of a network analyser, which is capable of measuring incident, transmitted and reflected powers, and a sample holder. The shielding effectiveness is determined by comparing the difference in attenuation of a reference sample to the test sample, taking into account the incident and transmitted power. This method can be applied assuming the following prerequisites: the measurements obtained pertain to the far-field (plane wave) and the thickness of the tested materials cannot exceed 1/100 of the wavelength of the EM wave in open space.

The "IEEE-STD 299-2006" (replaced the cancelled "MIL-Standard 285") is probably the most frequently referenced standard covering attenuation measurements for shielded enclosures within the frequency range of 100 kHz to 10 GHz. There are numerous adaptations of this method which have been devised to evaluate the properties of flat shielding materials. Measuring shielding effectiveness using this test setup is time-consuming and troublesome. It requires excellent proficiency and measurement experience. It consists of a transmitting and receiving antenna, a network analyser or similar equipments and an anechoic chamber with a probe window where the fabric is placed.

Some less used methods are: "ASTM ES7-83 coaxial transmission line method" and open space methods. These methods are not used commonly due to their complexity. The first one requires a network analyzer and a coaxial transmission-line cell, whereas the second one requires a network analyser, transmitting and receiving antennas.

2. Experimental work

In this study, the evaluation of the EM shielding capabilities of fabrics was made by measuring the Shielding Effectiveness (SE). SE is expressed in decibels (dB) and is a logarithmic representation of a ratio measurement. It is most commonly used for expressing power ratio at high frequencies (Eq. 1), where P1 is the transmitted EM power with the fabric and P2 is the transmitted EM power without the fabric, or P2 can also be assumed as the total incident EM power itself.

$$SE\ [dB] = 10 \log (P1/P2) \qquad (1)$$

2.1 Materials

The tested fabrics were knitted, woven, and nonwoven nylon and polyester fabrics, and were coated with metals, conductive polymers, or made by carbon fibres. Coated fabrics were chosen as they are isotropic, have high shielding effectiveness, high flexibility and low mass. The fabrics and their characteristics are summarised in Table 1.

Table 1 List of fabrics

Fabric	Material	Weight [g/m2]	Thickness [mm]
1 Nonwoven "Bonn"	Ag	na	0.235
2 Woven "Berlin"	Pu Ag	60	0.114
3 Woven "Nora Dell"	NiCuAg	95	0.130
4 Woven "Zell"	SnCuAg	72	0.073
5 Nonwoven	Carbon	34	0.640
6 Knit	Ag	40	0.250
7 Woven "Zelt"	SnCu	72	0.064
8 Woven "Flectron"	Cu	80	0.152
9 Stretch Knit	Ag	130	0.500
10 Nonwoven "SPB15"	Ag	62	0.240
11 Knit "STUL35"	Ag	35	0.250
12 Nonwoven	Carbon	12	0.150
13 Mesh "Eeontex"	Ppy	72	na
14 Woven "TCS72T"	SnCuAg	72	0.076
15 Woven "SBRM48"	Ag	48	0.114
16 Woven "CSR68"	CuAg	68	0.076
17 Woven "Eeontex"	Ppy	223	0.500
18 Nonwoven"Eeontex"	Ppy	na	0.600
19Woven"ShielditSuper'	NiCu	230	0.170

2.2 Shielding Effectiveness methods

The shielding effectiveness was determined using two methods, one for measurements up to 1 GHz and another from 1 GHz to 6 GHz.

2.2.1 Method for measurement under 1 GHz

The standard method ASTM D 4935 was used. The fabrics were tested in a flat configuration, with the same direction and side in relation to the sample holder. The shielding effectiveness was determined by comparing the difference in attenuation of a reference sample to the test sample, taking into account the incident and transmitted radiations.