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ELECTROMAGNETIC SHIELDING CHARACTERIZATION OF SEVERAL CONDUCTIVE TEXTILES

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Abstract: *The paper presents the influence of structure and conductive yarn of several knitted textiles about the electromagnetic shielding effectiveness. Method used for shielding effectiveness testing was IEEE STD-299 modified for textile applicability. The shielding effectiveness measurements were effected in anechoic chamber. The conductive textiles contain natural fibers (cotton and wool), synthetic fibers (polyester and nylon) with conductive yarns of metals (like copper and stainless steel) and carbon. Results are presented and discussed.*

Key words: *anechoic chamber, conductive textiles, electromagnetic shielding, horn antennas, shielding effectiveness.*

1. Introduction

The electronic devices such as digital computers, point-of-sale terminals, printers, modems, electronic typewriters, digital circuitry, and cellular phones are capable of emitting electromagnetic waves that will result in some electromagnetic interference (EMI) troubles [2], [4], [7]. Electromagnetic interference (EMI) shielding is critical to the proper functioning of devices; any electrical and electronic equipment that has changing voltages and currents can be viewed as a source of EMI. The victim equipment can be reached either by conduction or by electromagnetic radiation, or by both, that induce undesirable voltages and currents in it. The EMI phenomena can be viewed as a kind of environmental pollution of electromagnetic spectrum [15-16]. Also, the development of high-frequency telecommunication technology requires the need to protect users and electronic equipment from adverse effects of electromagnetic interferences. The device must not affect its environment, i.e. it cannot generate electromagnetic fields with intensities which would be disruptive to other devices or even threaten the operator of electrical equipment [17]. In this sense, the conductive textiles have been considered for electromagnetic shielding and anti-electrostatic purposes in various applications for the defense, electrical, and electronic industries. This is mainly due to their desirable properties in terms of flexibility, electrostatic discharge, EMI protection, radio frequency interference protection, thermal expansion matching, mechanical resistance (resistant to abrasion, tear) but flexible, light, with good hand and weight [1-3], [5], [9-11], [13],[18-19].

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2. Shielding Electromagnetic Theory

The term shield usually refers to a metallic enclosure that completely encloses an electronic product or a portion of that product. A shield can be used either to prevent the emissions of the electronics of the product from radiating outside the product or to prevent radiated emissions outside the product from coupling to the product's electronics, which may cause interference in the product [12]. Thus, a shield is a barrier to the transmission of electromagnetic fields [6], [21-22].

The effectiveness of a shield can be seen as being the ratio between the magnitude of the electric/magnetic field that is incident on the barrier and the magnitude of the electric/magnetic field that is transmitted through the barrier or as the ratio of the electric/magnetic field incident on the product's electronics without the shield removed to that with the shield in place.

In the latter sense, the shielding effectiveness can be seen as being equivalent to an insertion loss.

Electromagnetic shields are especially effective when are made of a material with high conductivity or which is characterized by structural parameters so that the field that propagates through it is highly attenuated. A plane wave which propagates in an material characterized by permeability μ, permittivity ε, and conductivity σ has a propagation constant given by $\gamma = \alpha + j\beta = \sqrt{j\omega\mu \cdot (\sigma + j\omega\varepsilon)}$, where α is the attenuation constant and β is the phase constant. Any combination of μ, ε, and σ that gives a high value of the attenuation constant, α, is suitable for shielding [8], [20], [23-25]. The shielding effectiveness of the barrier is defined for the electric field, in decibels, as:

$$SE_{dB} = 20\lg\left(\frac{E_i}{E_t}\right), \tag{1}$$

and for the magnetic field:

$$SE_{dB} = 20\lg\left(\frac{H_i}{H_t}\right), \tag{2}$$

where: E_i is the intensity of the electric field before installing the shield, E_t is the intensity of the electric field after installing the shield, H_i is the intensity of the magnetic field before installing the shield and H_t is the intensity of the magnetic field after installing the shield; their values are taken in the same point before and after installing the shield [2], [1], [25].

If the incident field is a uniform plane wave and the media on each side of the barrier are identical, then the two definitions are identical, since the electric and magnetic fields are related by the intrinsic impedance of the medium for a uniform plane wave [6].

When the power of the electromagnetic wave is considered, the shielding effectiveness of the barrier is:

$$SE_{dB} = 10\lg\left(\frac{P_i}{P_t}\right). \tag{3}$$

where: P_i is the power of the electromagnetic before installing the shield, P_t is the power of the electromagnetic after installing the shield, both measured in the same point.

3. Measurement of Effectiveness of Shielding

The MIL-STD-285-1956 method for evaluating shielding effectiveness was developed in the USA for military purposes, and was published in 1956. It is probably the most frequently referenced standard in attenuation measurements for shielded enclosures within the frequency range of 100 kHz to 10 GHz.

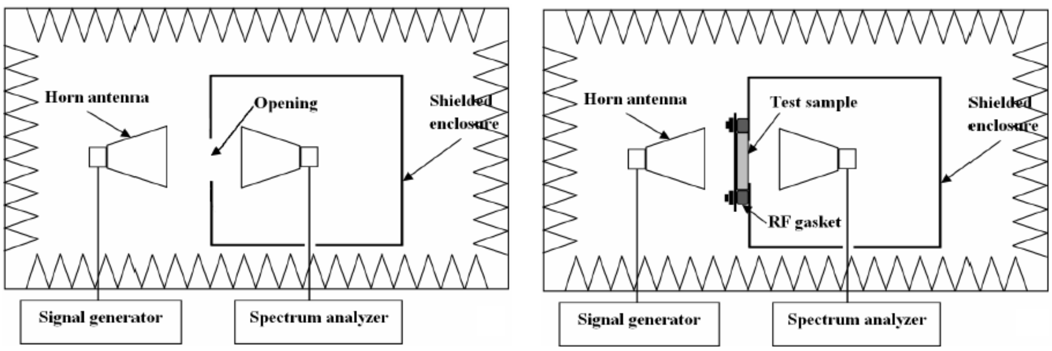
The standard defines the frequencies and electromagnetic field components which are subject to testing, and states the equipment required & the antenna configurations. The signal source is placed inside the tested enclosure, whilst the measurement device is located outside. The methods for measuring shielding effectiveness described in MIL-STD-285 were later replaced by those in IEEE STD-299-2006. This document describes methods for measuring shielding effectiveness for enclosures, although with the smallest linear dimension of such enclosure being at least 2 m [8].

The measurement range in this method is divided into 3 sub-ranges:

- low range - from 9 kHz (50 Hz) to 20 MHz - for the magnetic component (H),
- resonant range - from 20 MHz to 300 MHz - for the electrical component (E),
- high range - from 300 MHz to 18 GHz (100 GHz) - for the plane wave power (P) [14], [24-26].

The measurements of shielding effectiveness for the samples considered in this work were effected employing a modified version of the method described in IEEE STD 299-2006 standard [26], at frequencies in the range 1 GHz - 18 GHz. Thus, the transmitting antenna and the shielded enclosure with an open window and with the receiving antenna mounted inside it were placed in an anechoic chamber and the power level on electromagnetic radiation passing through the window was measured in two fashions-Figures 1a, 1b [13]:

- with antennas placed face to face without textile sample mounted on the window of the shielded enclosure;
- with antennas placed face to face and with textile sample placed on the window of the shielded enclosure;
- during measurements, between antennas the same distance of 0.6 m is kept.



a) b)

Fig. 1. *Experimental test: a*) *Reference measurement* (*without sample*) *and b*) *load measurement* (*with sample*)

Then, the shielding effectiveness was determined by using Equation (3).

Measurements apparatus:

- Signal generator HP 8614B: frequency range: 0.8 GHz - 2.4 GHz, output power: 15 mW controlled by attenuator;
- Amplifier Bonn Electronic BSA 0104-15/10D frequency range: 9 kHz - 4.2 GHz;
- Amplifier Research 20T4G18, frequency range: frequency range: 4.2 GHz - 18 GHz, maximum power 20W;
- Spectrum analyzer - Agilent 7405 frequency range: 100 kHz - 26.7 GHz;
- Antennas horn ETS Lindgren 3115 frequency range: 1 GHz - 18 GHz; gain: between 5.5 and 16 dB; VSWR: < 1.5:1;
- Zeiss Stemi 2000-C stereomicroscope with maximum magnification 50X.

Textile samples

The conductive textiles selected for tests can be divided into two groups:

- with copper and stainless steel conductive wire samples 1-5.
- with carbon conductive yarn - samples 6-14.

Table 1 presents the textiles samples structure and composition.

The structure and composition of textile samples Table 1

Sample	Structure	Face yarn*	Bottom yarn**	Percent carbon conductive yarn [%]
6	Glad vanished	1 yarn type 2 + 1 yarn BBC	1 yarn type 5 + 1 yarn BBC	4.5
7	Glad vanished	1 yarn type 2 + 1 yarn BBC	2 yarn type 5 + 1 yarn BBC	6
8	Glad vanished	1 yarn type 2 + 1 yarn BBC	3 yarn type 5 + 1 yarn BBC	7.5
9	Patent vanished	1 yarn type 2 + 1 yarn BBC	3 yarn type 5 + 1 yarn BBC	7.5
10	Patent vanished	1 yarn type 2 + 1 yarn BBC	2 yarns type 5 + 1 yarn BBC	6
11	Patent vanished	1 yarn type 2 + 1 yarn wool	2 yarns type 5 + 1 yarn wool	6
12	Patent vanished	1 yarn type 2 + 1 yarn wool	3 yarns type 5 + 1 yarn wool	7.5
13	Glad vanished	1 yarn type 2 + 1 yarn wool	3 yarns type 5 + 1 yarn wool	7.5
14	Glad vanished	1 yarn type 2 + 1 yarn wool	2 f yarns type 5 + 1 yarn wool	6

* Type 2: Cotton yarn (75%) + epitropic yarns (25% - polyester covered with carbon).

** Type 5: filament of nylon saturated at surface with carbon particles.

4. Results and Discussions

Figure 2 shows the variation of shielding effectiveness in function of frequency on the domain 1-18 GHz, for conductive textile samples knitted tubular with Cu yarn, knitted vanished with Cu yarn, knitted tubular with stainless steel yarn, knitted vanished with stainless steel yarn and 80% PED +20% stainless steel.

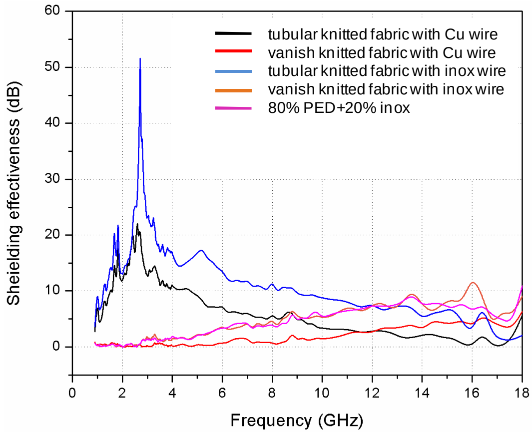


Fig. 2. *Shielding effectiveness versus frequency in domain 1-18 GHz for fibers with metal insertion*

The textile sample knitted tubular with stainless steel thread presents a very good shielding effectiveness of 54.7 dB at 2.7 GHz, the sample knitted tubular with copper thread presents a good shielding effectiveness of 20.18 dB at 2.4 GHz, the sample knitted vanished with stainless steel thread presents a weak shielding effectiveness of 10.24 dB for 13.6 GHz, the sample 80%PED+20%stainless steel thread presents a weak shielding effectiveness of 9.55 GHz at 13.6 GHz and 10.88 dB at 18 GHz and the sample knitted vanished with copper thread presents a weak shielding effectiveness of 5.69 dB at 16.4 GHz and 6.3 dB at 18 GHz.

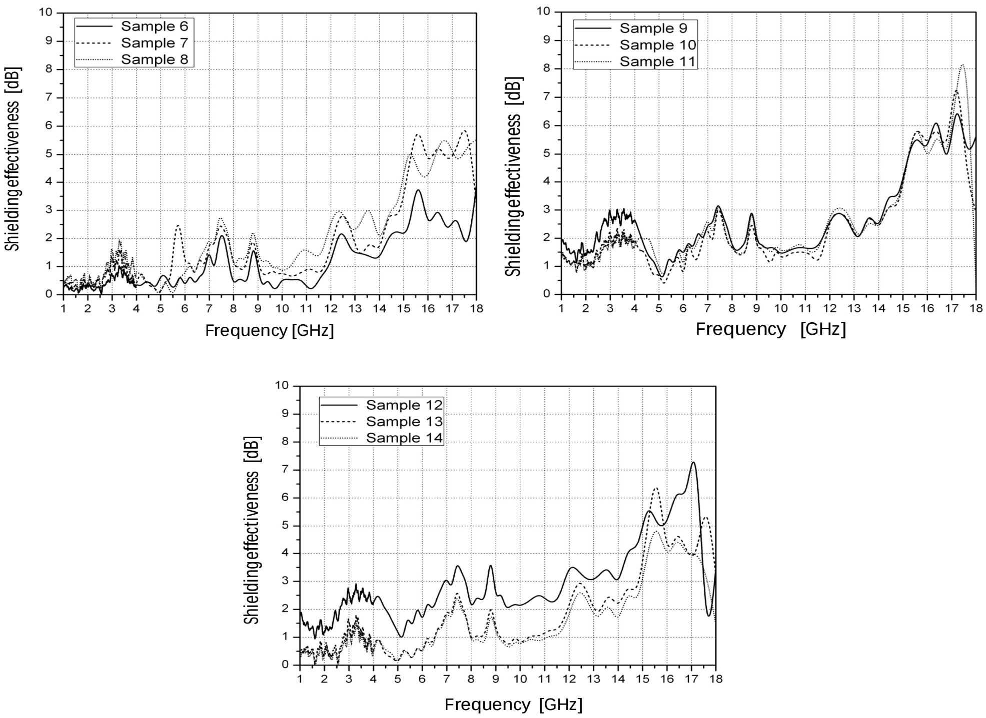


Fig. 3. *Shielding effectiveness versus frequency in domain 1-18 GHz for fibers with carbon insertion*

Figure 3 shows the shielding effectiveness in function of frequency in the domain 1-18 GHz for fibers which contain carbon. Sample 6 do not presents electromagnetic shielding effectiveness on the range frequency 0.9-4 GHz, for the range frequency 4-18 GHz presents the small values of shielding effectiveness of 2-4.59 dB.

Sample 7 do not presents electromagnetic shielding effectiveness on the range frequency 0.9-4 GHz. For the range frequency 4-18 GHz, the shielding effectiveness is 3.17-6.51 dB.

Sample 8 do not presents electromagnetic shielding effectiveness on the range frequency 0.9-4. On the range frequency 4-18 GHz the shielding effectiveness is 4.02-5.68 dB.

Sample 9 on the range frequency 0.9-4 GHz, the shielding effectiveness is 2-3 dB, a weak SE, on the range frequency 14.4-18 GHz, the shielding effectiveness is 3.77-7.46 dB.

Sample 10 on the range frequency 2.7-4 GHz, the shielding effectiveness is 1.8-2.0 dB, (weak SE), on the range frequency 15.2-17.2 GHz, the shielding effectiveness is 3.77-7.46 dB.

Sample 11 on the range frequency 2.7-4 GHz, the shielding effectiveness is 1.58-2.12 dB (weak SE). On the range frequency 15.2-17.6 GHz the shielding effectiveness is 4.48-9.35 dB.

Sample 12 on the range frequency 0.9-4 GHz the electromagnetic shielding effectiveness is 1.2-2.9 dB (weak SE). On range frequency 4.22-18 GHz, the shielding effectiveness is 0.8-8.9 dB.

Sample 13 on the range frequency 0.9-4 GHz do not presents shielding effectiveness. On the range frequency 4-18 GHz on register higher values of shielding effectiveness by 3.21-7.39 dB.

Sample 14 do not presents electromagnetic shielding effectiveness on range frequency of 0.9-4 GHz. On the range frequency 4-18 GHz, presents the small values of shielding effectiveness of 0-5.27 dB.

5. Conclusions

Technical textiles that contain fibers with copper and stainless steel will present shielding properties better than fibers which contain carbon. This behavior action of external electromagnetic field is due to the diamagnetic properties of copper and stainless steel which are better comparing to carbon which present weaker diamagnetic properties.

Therefore for technical textiles used in electromagnetic shielding if is using carbon in fiber textile is necessary to use them only to high frequency between 16-18 GHz or to add another material which present shielding properties in convenient percent to ensure the desired optimum shielding. Textile that contain only carbon, polymers and natural fibers have good dissipative properties and can be used in the manufacture of garments for protection against electrostatic discharges.

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