The Study of the Electromagnetic Shielding Properties of a Textile Material with Amorphous Microwire

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***Abstract*—The paper presents the results concerning the utilization of a new class of composite textile materials with electromagnetic properties and the possibility of their utilization in the production of electromagnetic field protective equipment. The experimental and theoretical results concerning the electromagnetic characterization of a new textile material with composite structure are presented also considering the following aspects:**

- evaluation of the possibilities to use amorphous magnetic microwires in electromagnetic shielding;

- study of the electromagnetic properties of the composite textile material, especially the electromagnetic field shielding, reflection and polarization;

- determination of the frequency range within which these properties can be used in the realization of materials for the protection against electromagnetic fields.

The experimental results of a material sample and a phantom for applications are connected with shielding in the frequency range used in mobile communications.

***Index Terms*—amorphous magnetic wires, electromagnetic compatibility, mobile communications, shielding.**

I. Introduction

The explosive increase of the number of electric power users and the applications in the field of information transmission on electromagnetic support – satelite transmission, mobile comunnications, utilization of microwave heating systems – led to the increase of the emission of electromagnetic radiations. Their influence on the living organisms resulted in the appearance of several noxious effects. The small and medium power electromagnetic and electronic installations enter the every day life, both in domestic and social-professional environment, especially affecting the population categories occupied in the fields of telephony, computer science, electric installations or systems.

At present, the development of IT communication techniques led to the outburst of the utilization of high and very high frequency spectra, in the microwave range. In order to diminish the effects of these radiations, various methods were developed, one of them consisting in the shielding, through different techniques, of both the used equipment, and the personnel working in electromagnetically polluted environment.

The materials recommended for shielding are those with high electric conductivity and magnetic permeability. To this end in mind, certain manufacturing companies have used composite structures shaped as absorbing or reflecting panels made of:

- Materials containing non-ferromagnetic metallic wires (Cu, Ag, Au) [1], [2], or Ni-based alloys [3] which present certain shortcomings: they are heavy, easy to break, get oxidized in atmosphere and can not be used in corrosive mediums;
- Carbon-based plastic composite materials;
- Ferrite and magnetic powder materials [4];
- Plasma metallization process [5];
- Nonwoven textile [6] and multimetal composite fabrics [7].

For walls, the chiral-honeycomb type structures are recommended [8]. For certain special applications, such as the protective clothing, light elastic, plastic structures are recommended, similar to the textiles, which permit the manufacturing of adequate protective equipment.

Research is focused on shielding properties of the material and mordant type and layers, pick density, yarn count [9]. Some textile composite has applications for increasing safety of aircraft [10]. The importance of using these materials in protective clothing is known for many years of patented news technical solutions [11]. Interest in these new materials has also led to the emergence of new manufacturing technologies [12]. Also, some properties of field electromagnetic shielding of this composite textile are used in physiotherapy [13]. In order to amplify the electromagnetic shielding factor, one can also use amorphous magnetic materials that have the following advantages: stability of electric and magnetic parameters against mechanical stresses, resistance to the action of oxidizing chemical agents, high magnetic permeability, GMI effect [14]. One can make of them textile or non-textile materials widely used in electromagnetic shielding: wall coating (total shielding), doors and windows coating, manufacturing of protective clothing or costumes for the personnel working in high intensity electromagnetic environment. This category of materials joins together the properties of the textile material in it and the properties conferred by the amorphous wire included in their structure.

Thus, a new class of materials appears, with specific peculiarities in the electromagnetic shielding and

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manufacturing of protective equipment; also these materials must submit good mechanical properties, low cost of production and a large diversity of structure and fabric geometry [15], for different applications [16]. Beside the shielding properties, these materials need to be biocompatible with the living structures.

II. Material Description

The studied material has a composite structure, being made of glass coated amorphous ferromagnetic wires, twisted together with cotton or synthetic (kapron) yarns.

The chemical composition of the amorphous wire is $Co_{68}Mn_7B_{15}Si_{10}$.

This type of microwires presents the following characteristics: high magnetic permeability within a wide frequency range, high corrosion resistance, quite large application field, well-established manufacturing technique.

The amorphous magnetic microwires were obtained through a well-known technology – fast quenching in water jet of the ferromagnetic alloy which is introduced in a glass tube. The material heating and melting is accomplished by high frequency induction currents. The microwire and the glass coating are drawn fast through a water jet, after which they are wound on metallic bobbin, the length of a wire sample being of about 1,500 m. For this study microwires produced by the Amotek company from the Republic of Moldova were used.

The diameter of the utilized microwires ranges between (10 – 13) μm, and the outer diameter of the glass insulation ranges between (15 – 20) μm. The values of the anisotropy field range between 60 A/m and 150 A/m, and those of the coercive force were between 18 A/m and 70 A/m; the B_r/B_s ratio is about 0.9.

The magnetoelastic anisotropy is one of the most important parameters that determine the magnetic behaviour of various amorphous materials, since this type of material has no magneto-crystalline anisotropy. This is very important for the composite structure in the case of glass coating of the microwires; the glass coating induces a higher internal stress during the manufacturing process (values of up to 1 GPa) due to the different coefficients of expansion of the amorphous wire and the glass coating respectively.

Thus, the magnetic properties of the glass-coated microwires are determined by the magnetoelastic energy, the dependence on the internal stresses induced by the fast quenching under water jet, as well as by the value and sign of the magnetostriction constant [14].

TABEL I. MECHANICAL AND MAGNETIC PROPERTIES OF THE UTILIZED MAGNETIC AMORPHOUS MICROWIRES

fiber type	Base	dt μm	dm μm	H_k A/m	H_c A/m	B_r/B_s	db_{max} dB	db_{min} dB	F_{max} MHz
1	0	17	12	60	18	0.3	-23	-15	1600
2	0	19	12	78	70	1	-24	-13	1550
3	1	20	13	73	63	1	-19	-12	1650
4	1	17	11	64	19	0.37	-32	-7	1600
5	0	19	12	71	62	1	-29	-7	1600
6	0	15	11	100	10	0.2	-27	-7	1500
7	0	15	10	148	8	0.11	-30	-7	1200
13	1	17	13	100	15	0.25			
17	1	17	13	95	15	0.22			
18	1	17	11	100	12	0.22			
19	1	17	12	110	10	0.2			
20	1	18	13	90	15	0.35			
21	1	17	12	75-150	15-20	0.2-0.5			

The value of the internal stress is determined to a great extent by the microwire geometry, namely the glass coating diameter and thickness.

In particular, the Co-containing composite structures present an un-hysteretic cycle with low coercivity, *Hc*, and a relatively large field of axial magnetic anisotropy, due to the transverse anisotropy [14].

The mechanical and magnetic properties of the utilized magnetic amorphous microwires are presented in Table 1,where: fiber # - wire type; base: 0 – glass coated wire, 1 – cotton coated wire; *dt* – total (outer) diameter of the microwire; *dm* – diameter of the microwire metallic core; H_k – anisotropy field; H_c – coercitive field; B_r/B_s – ratio between the remanent and saturation induction; db_{max} – maximum value of the best result; db_{min} – minimum value of the transmission; F_{max} – frequency value at which the transmission coefficient is maximum [17].

Textile materials with cotton wire warp were accomplished, and the weaving was accomplished in several versions with cotton yarns (C) and microwire made of magnetic amorphous wire (A). The wire alternance was as follows: ACACA.., CCACCA.., CCCACCCA. In order to execute the weaving, the glass coated magnetic amorphous wire is twisted with cotton fiber Fig. 1.

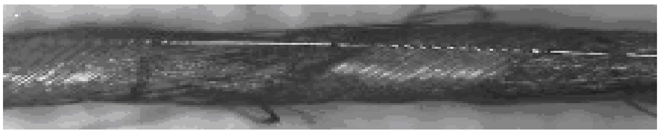


Figure 1. Amorphous microwire and textile fiber

Several technological solutions were tested on the classical weaving machines, adjusted such that the wires do not break and the textile material structure can be obtained.

The wire of ferromagnetic material presents certain difficulties during its independent utilization, since it broke very often during the the weaving machine operation. For this reason, the wire was „helped" to pass through the machine by twisting it with a cotton yarn that played the role of „carrier", which no longer resulted in its failure. Due to the microwire relatively high price, only two types of textile materials were executed (type T1-ACACAC... and type T2-CCAACC...), Fig. 2.

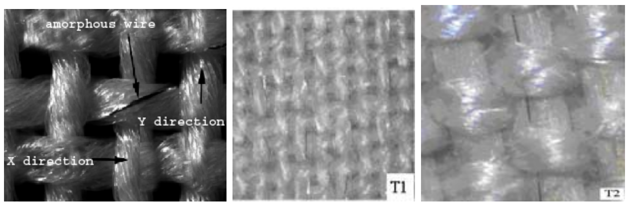


Figure 2. Composite textile materials – different weaving types

III. Experimental Results

A. Study of the shielding properties

The study of the shielding properties of the two samples of textile materials was carried out by using adequate systems for the measurement of the shielding factor within the radiofrequency and microwave ranges.

The electromagnetic shielding factor is defined as the ratio between the electromagnetic field intensity E_0 measured without the tested material and the electromagnetic field intensity E_t with the material interposed between the radiation source and the receiver:

$$S = E_0 / E_t \tag{1}$$

The basic test methods for the shielding factor measurement of a material sample are [18]: the coaxial holder, the dual-TEM cell, nested reverberation chamber [19], anechoic chamber with aperture and time domain method [20], [21]. Referring to the measurement sites, the shielding properties measurements for materials can be made in controlled test sites or in free space [22]. The emergence of new textile materials composite structure stimulate the development of some specific methods for measuring the shielding properties of the electromagnetic field in a wide range of frequencies [23], [24], [25].

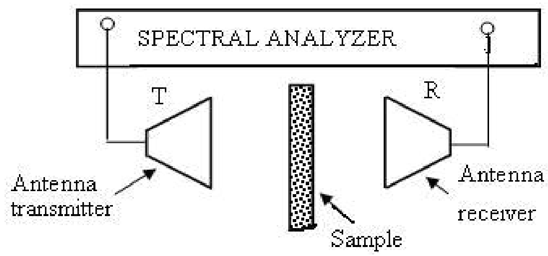
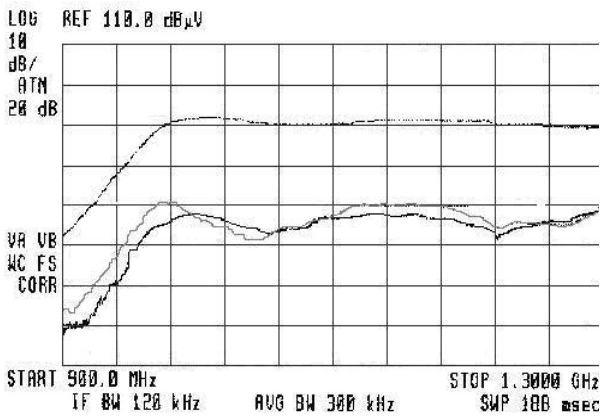
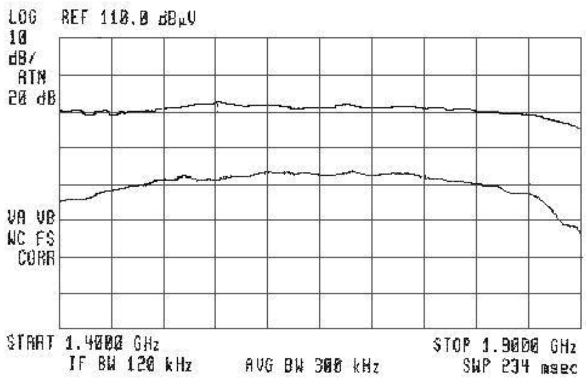


Figure 3. The block diagram of the installation for textile materials testing



(a)



(

b)

Figure 4. Shielding factors within the (900-1800) MHz range for various structures of composite textile material

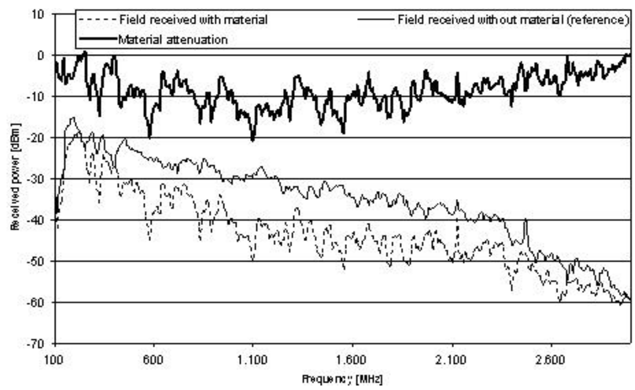
The free-space technique allows wide frequency range measurements with the upper frequency limit around of tens of GHz. Moreover, this method allows the shielding coefficient measurement for the large samples size. Thus, this electrical contact-free method is suitable for a large class of shielding and in-situ measurements become possible. The measurements were carried out with two different measuring equipment, covering the frequency range (0.8 – 1.9) GHz, and a wider range of (0.8 – 3) GHz respectively. The block diagram of the textile material testing installation is presented in Fig. 3.

The installation for shielding factor testing for the first frequency range consists of a receiver coupled with a wave guide who has a 150 mm diameter illuminator for the frequency of 1800 MHz, and 250 mm diameter one for 1200 MHz, as well as a microwave transmitter (Fig. 3).

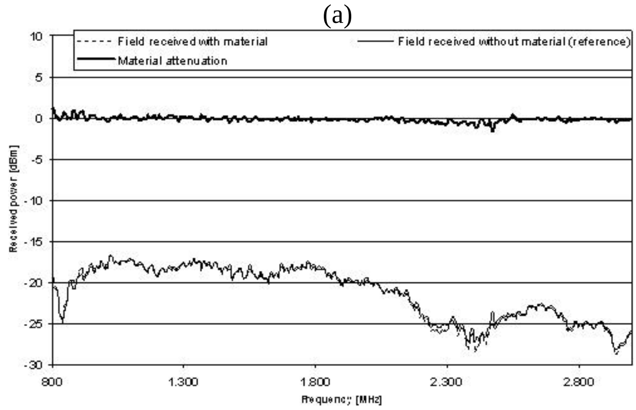
The shielding factors were determined for structures which contain 1-7 cotton yarns between the two magnetic wires. The attenuation coefficient ranged between 7 dB and 32 dB within the frequency range (900 - 1800) MHz. The measurements results are presented in Fig. 4a and 4b respectively.

The results obtained for the measurements with the two antennae types are as follows:

a) in the case of measurements with the horn antenna, the average attenuation of the T1 sample was of about 17 dB within the range (800 – 2000) MHz when the dry material was at middistance between the antennae and with the wires parallel with the *E* vector, Fig. 5a. The attenuation increases at 20 dB if the material covers the receiving antenna. This difference of 3 dB appears due to the finite dimensions of the material interposed between the two antennae. If the textile yarns are disposed perpendicularly to the *E* vector, the attenuation is very small (about 0 dB), Fig. 5 b.



(a)



(b)

Figure 5. The shielding coefficient, sample T1; (a) yarns parallel to the *E* vector; (b) yarns perpendicular to the *E* vector

The textile sample T2 has the attenuation of about 2.5 dB when the yarns are parallel to the *E* vector, Fig. 6.

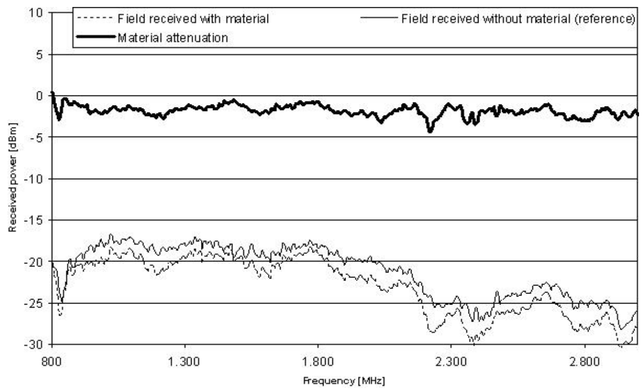


Figure 6. The shielding coefficient, sample T2; yarns parallel to the *E* vector

b) in the case of Log per antennae utilization, the mean attenuation of the material T1 within the (300 - 2000) MHz range is about 12 dB when the material is located at the middistance between the horizontally polarized antennae and with the yarns parallel to the *E* vector, Fig. 7.

If the material is wet, the attenuation has the same mean value, 12 dB.

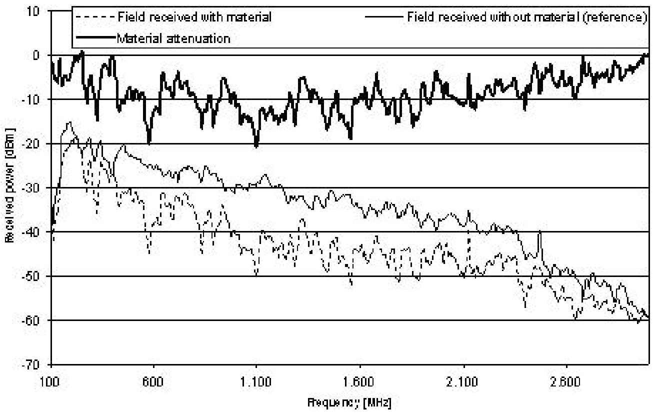


Figure 7. The shielding coefficient, sample T1; measurements carried out with the horizontally polarized Log antenna, the material yarns placed parallel with the *E* vector

It has been found experimentally that the material preserves its shielding factors after the hygienizing operation, Fig. 8.

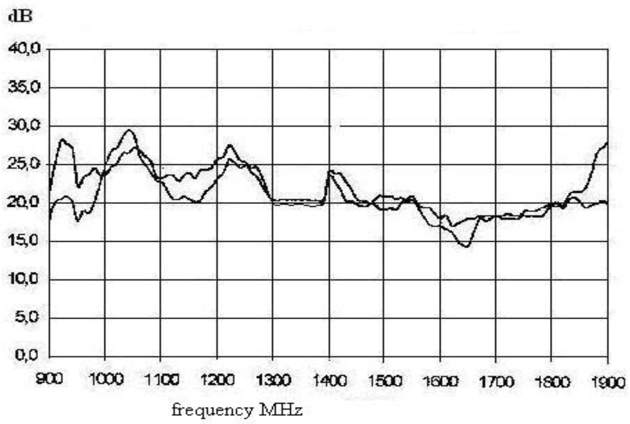


Figure 8. Shielding factors for the sample T1, after hygienizing operation

B. Study of the polarization properties

According to the Malus law, the electromagnetic field intensity E at the polarizer output varies with the angle θ between the polarizer axis and the electromagnetic field intensity E_0 at the polarizer input, according to the relation:

$$E = E_0 \cos^2 \theta \quad (2)$$

For the study of the electromagnetic field polarization properties, the installation from Fig. 9 was used.

The textile material sample T1 was fixed on a non-metallic support, between the two horn antennae, such that to form a plane surface perpendicular to the direction of electromagnetic field propagation.

The support is endowed with a goniometer in order to obtain variable angles between the polarization direction (the *E* vector of the electromagnetic field) and the direction of the amorphous wire.

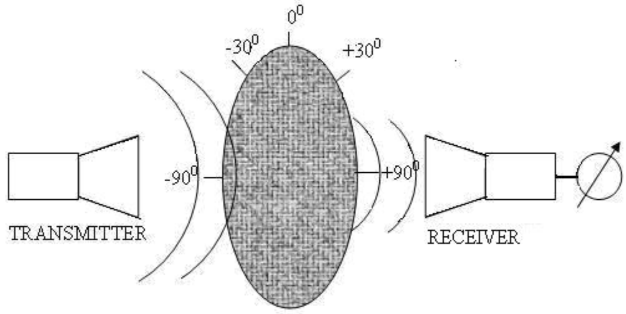


Figure 9. Installation for the study of the electromagnetic field polarization

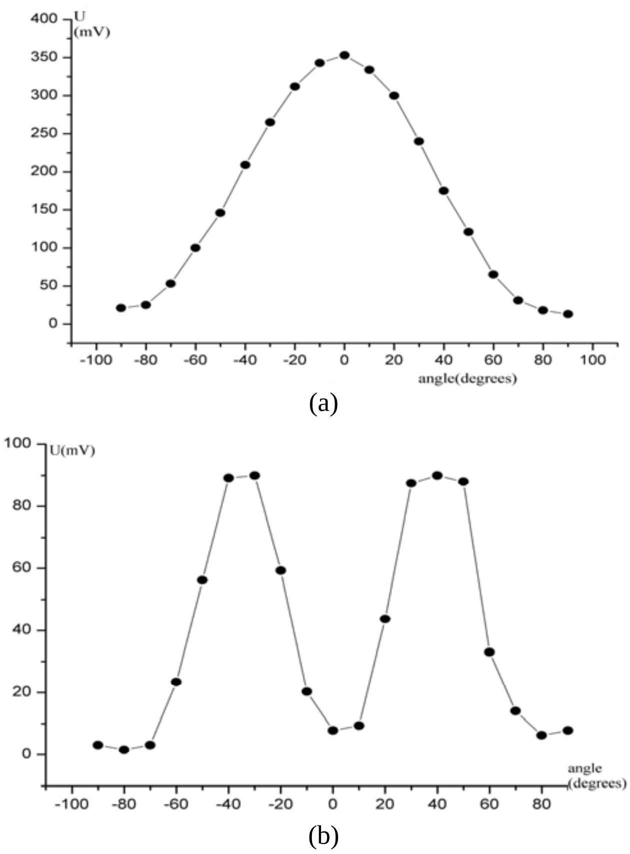


Figure 10. Verification of Malus law; (a) parallel polarization planes; (b) perpendicular polarization planes

The measurements were carried out at the frequency of 8.7 GHz.

The Malus law was verified by modifying the amorphous wires angle with polarizing plane between -90^0 and $+90^0$.

The results concerning the polarizations are presented in Fig. 10.a for a single layer sample (horn antennas of the transmitter and receiver are parallel with polarizing plane E). Fig.10.b shows the results for the situation in which the two horn antennas are perpendicular to each other.

C. Phantom study of the shielding properties

The experimental results concerning the shielding properties of the textile materials are confirmed by the measurements carried out on a phantom model of human head.

The complex installation from the Laboratory of Bioelectromagnetism of the Faculty of Medical Bioengineering, utilized for the measurements, consisted of a shielded room sized (2x2x3) m, with aluminum walls covered at the inside with pyramidal absorbing material. For the measurements, a microwave generator with the frequency of (500-1000) MHz was used, as well as the phantom of a human head and a spectrum analyzer whose omni-directional measuring probe was introduced in the middle of the phantom. The distance between generator and omnidirectional antennae was approximately 1.5 m. The human head model was made from polyethylene with 1mm thickness. The block diagram of the utilized installation is presented in Fig. 11.

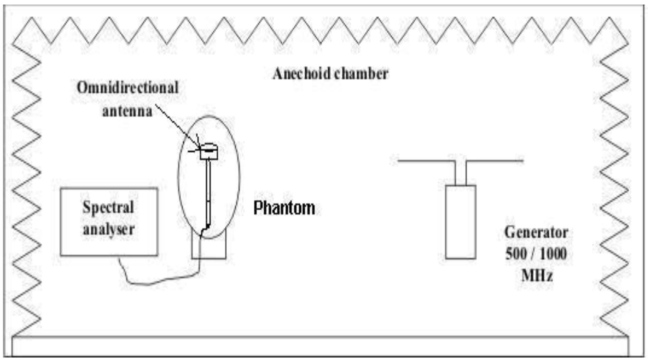


Figure 11. The block diagram of the installation for the shielding factors measurement

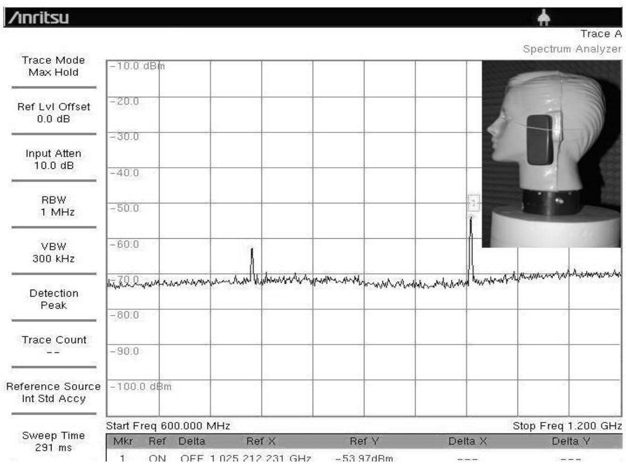


Figure 12. Recording of the frequency spectrum produced by microwave generator

At first, the frequency spectrum produced by the microwave generator was recorded, out of which the (550 – 1030) MHz range was selected, the human head model was uncovered and the mobile phone was situated in the ear region, Fig. 12. Then the phantom was covered with the textile material sample in variable proportion, approximately 70% and 90%, the mobile phone was situated in the same region and the shielding factors were recorded after that. The explored frequency range was (900 – 1100) MHz. The results are presented in Fig. 13, 14, 15.

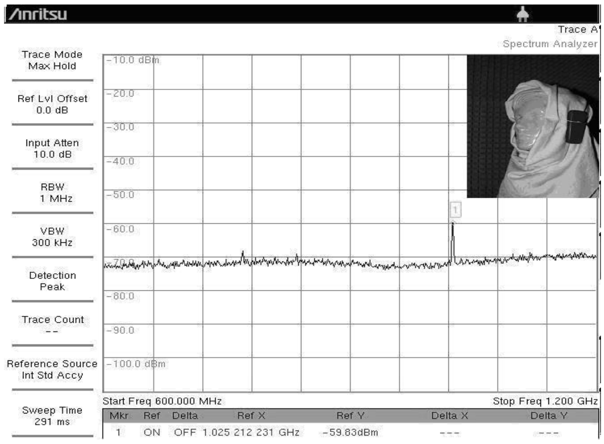


Figure 13. Recording of the frequency spectrum after the phantom was partially covered

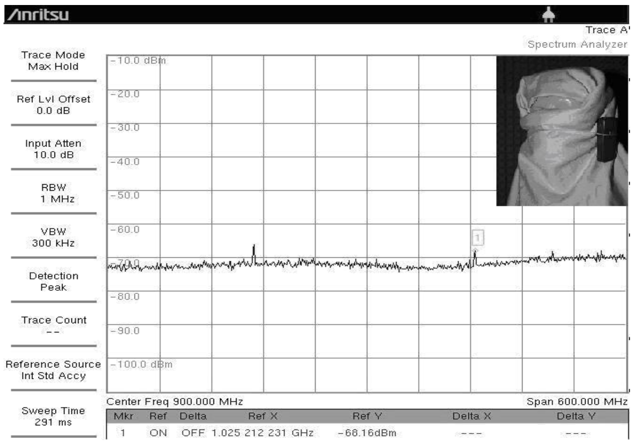


Figure 14. Recording of the frequency spectrum after the phantom was partially covered in different position and area

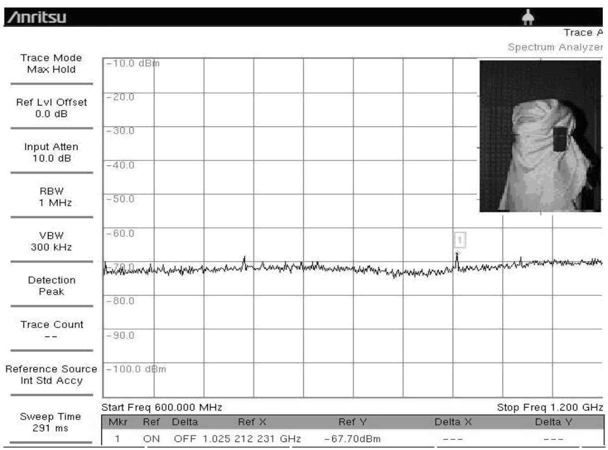


Figure 15. Recording of the frequency spectrum after the phantom was partially covered in different position

The phantom was partially covered with the textile material in order to simulate the utilization of a mean to completely or partly protect the head and to verify its efficiency in the simulation of the mobile phone. Note that the attenuation coefficient varies depending on the position in which they find the head model and the covered surface, the highest value obtained (20 - 25) dB when the head model was covered in approximately 90%, Fig. 14 and 15.

IV. CONCLUSION

The amorphous magnetic materials can be used to shield the electromagnetic field within the ultra-high frequency range.

The amorphous magnetic wires present advantages as against the magnetic tapes because they can be easily introduced in textile structures. The experimental results confirm that the amorphous magnetic microwires can be woven if they are twisted with a cotton yarn, and that the thus obtained material preserves the specific properties of a textile material, such as washing resistance, mechanical and elastic properties, the composite textile materials with amorphous wires being adequate to execute various clothing, protective equipment, curtains, drapes, protective tapestry, wrappers etc.

The composite textile structures present the advantage that they are elastic and take easily the shape of various surfaces.

The production costs diminish with the diminution of the microwire diameter, by reducing the specific material consumption per unit length.

The experimental method and modeling confirmed that the textile material with amorphous microwires show shielding properties with values ranging between (12 -25) dB. The shielding factors do not decrease after the material is subjected to the hygienizing operation, neither when it is wet, which recommend its utilization under the conditions of increased humidity.

The frequency range within which these materials have the highest efficiency is those of ultra-high frequencies, corresponding to the mobile communications and the microwave ones.

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