Lukas Vojtech, Marek Neruda

Department of Telecommunication Engineering, Czech Technical University in Prague,
Technicka 2, Prague, 16627, Czech Republic
E-mail: vojtecl@fel.cvut.cz
nerudmar@fel.cvut.cz,

Design of Radiofrequency Protective Clothing Containing Silver Nanoparticles

Abstract
Electromagnetic shielding materials find use not only in electrical device construction, but also in personnel protective aids constructions for fitters and maintenance workers of power devices under operation. Standards for the effects of electromagnetic fields are published and producers manufacture protective aids, suits, etc. especially for antenna systems in microwave frequency bands, whose power levels of electromagnetic fields exceed the hygiene limits required. However, the performance of protective clothing applications is still discussed in the radio frequency band. Research of textile material properties shows different ways of producing conductive material, most of which embody some disadvantage considering protective clothing construction, i.e. versatility, peeling, etc. However, using silver nanoparticles increases product manufacture qualities. Therefore the paper focuses on a proposal for a construction design of a protective clothing structure using silver nanoparticles, standardisation of the effects of electromagnetic fields, as well as measurement and simulations of such material. The results show satisfactory values of electromagnetic shielding efficiency, i.e. about 40 dB (30 MHz – 1.5 GHz). Considering the most unprotected parts, i.e. eyes, mouth and nose, measurement results of hoods reach about 15 dB. Our experiments show that protective clothing can be manufactured from textile material with silver nanoparticles and with breathable and transparent material which protects the eyes, mouth and nose.

Key words: *clothing design, electromagnetic fields influence, shielding efficiency, silver nanoparticles.*

Introduction

Human protection from the effects of power electromagnetic fields is one of the main hygienic requirements which are asked of producers and operators of power microwave electrical engineering. It is possible to meet the local maximal radiated power allowed, especially in the field of transmitting microwave systems. The influence of the radiated power on workers can be limited by mechanical barrier, because it includes only local maximums, which are given by radiation pattern of used antenna systems. In specific situations, such as services with whole day operation without possibility of technological dead plate, it is necessary to equip the service by suitable protective aids, which ensure not to exceed SAR (Specific Absorption Rate) in every part of the human body. It expresses a measure of energy, which is absorbed by the body exposed to a radio frequency (RF) electromagnetic field. It is also common to convert the SAR values into ESE (Electromagnetic Shielding Efficiency) values.

In 1996, the WHO (World Health Organisation) established the International Electromagnetic Fields Project with a view to investigating potential health risks associated with technologies producing an electromagnetic field.

A review of the health implications of extremely low frequency fields was concluded in 2007. Acute exposure at high levels (above 100 μT) can cause nerve and muscle stimulation and changes in nerve cell excitability in the central nervous system. The average value of an magnetic field is about 0.07 μT in residential areas in Europe. Long-term effects of the average exposure value were not clearly proven. These facts led to the establishing of two international exposure limit guidelines (ICNIRP (International Commission on Non-Ionizing Radiation Protection), 1998, IEEE, 2002). Undesirable health effects were scientifically established in 2003 (ICNIRP) for high-level short-term exposures to an electromagnetic field. Basic recommendations follow long-term effects [1]:

- Reduce the uncertainty of the scientific evidence
- Establish effective and open communication programs with all stakeholders to enable informed decision-making
- Explore low-cost ways of reducing exposures while designing and constructing a new product

An Environmental Health Criteria monograph was released by the WHO in June 2007. It considers low frequency fields, summarizes a health risk assessment and gives a recommendation for further research [2]:

- Studies published since 2001: when IARC (International Agency for Research on Cancer) published an evaluation of the carcinogenicity of an electromagnetic field, it did not provide evidence to change IARC's classification. The classification was based on limited scientific evidence of studies of magnetic field effects on carcinogenicity.
- The WHO recommends precautionary measures that are low cost and do not compromise the health, social and economic benefits of electricity.
- It also includes the implementation of very low cost measures in the design and engineering of new products.
- Future research, which can confirm or disprove any evidence of the effects of magnetic fields on childhood leukemia.

ICNIRP published Guidelines for limiting exposure to time varying electric, magnetic and electromagnetic fields (up to 300 GHz) in 1998 [3]. Since many studies had been published, ICNIRP included these studies in Exposure to High Frequency Electromagnetic Fields, Biological Effects and Health Consequences (100 kHz - 300 GHz) [4]. It describes biological evidence for interaction mechanisms (biophysical, biochemical, cellular studies, etc), animal studies (cancer, nervous system, skin, eye, etc.), human studies (nervous system, endocrine system, cardiovascular function, thermoregulation and summary on human studies), the dosimetry of high frequency electromagnetic fields (measurement, natural high frequency fields, etc.), the epidemiology of the health effects of radi-

Table 1. Basic restrictions for whole body average SAR and spatial peak SAR [5].

Exposure category	Frequency range	Whole-body average SAR, W/kg	Spatial peak SAR in the head & torso, W/kg	Spatial peak SAR in limbs, W/kg
Occupational	100 kHz – 6 GHz	0.4	10	20
General public	100 kHz – 6 GHz	0.08	2	4

ofrequency exposure and epidemiologic evidence for mobile phones and a review of tumour risk.

The standards are also prepared in specific countries. A standardisation institution DIN (Deutches Institut fur Normung), located in Germany, promotes the harmonisation of the standards for Europe. The commission in the USA is called FCC (Federal Communications Commission). The agency ARPNSA (Australian Radiation Protection and Nuclear Safety Agency) updated the ICNIRP guidelines from 1998 in a standard called Maximum Exposure Levels to Radiofrequency Fields - 3 kHz to 300 GHz in 2002. It was approved by the Radiation Health Committee on 20th March 2002 [5], ***Table 1***. Notes added to measurement results shown in ***Table 1*** [5]:

- For comparison with the limits in Tab. 1, the SAR exposure level measured or calculated should be averaged over any six minute period.
- The whole body average SAR is determined by dividing the total power absorbed in the body by the total mass thereof .
- The average mass of the spatial peak SAR is any 10 g of contiguous tissue in the shape of a cube.

Since the discussion about the effects of high frequency radiation electromagnetic fields started, protective clothing has been available on the market. In the past the performance of protective clothing could not be proven because standards and measurement methods were not available. Therefore this clothing was not used very much.

Standard DIN 32780-100 "RF Protective Clothing" was published in March 2002, describing protection against electromagnetic fields in the frequency range from 80 MHz to 1 GHz, requirements and test methods [6]. A measurement setup according to DIN 32780-100 is shown in ***Figure 1*** [7].

Papers published represent successful solutions in human protection against the effects of electromagnetic fields. Papers [8] and [9] describe RF protective clothing and its measurement results. For example in [8], the values of ESE are about 12 dB (ankle) and 17 dB (wrist). Paper [10] evaluates KW-Gard™ RF Protective Clothing, where the ESE values reach about 30 dB in 450 MHz, 835 MHz and 1900 MHz frequency for the head, chest and thigh. The main reason of such ESE values is that KW-Gard™ fabric contains 25% stainless steel. Papers [11] and [12] describe characteristics of EGIS® materials, where the weight is 2358 g and 1890 g, respectively, and the ESE value is about 20 dB and 14 dB, respectively. EGIS® materials also contain stainless steel. Paper [13] describes using vacuum deposition technology for the manufacturing of a conductive layer on the surface of a textile. It shows that the distribution of the resistance can be irregular. Other methods are also known, e.g. printing of different materials such as polypyrrole or using copper threads.
The limitations of clothing produced can be seen in three issues:

- Protective factor: the attenuation of the intensity of the electromagnetic field at current solutions of protective clothing is about 30 dB.
- Material: Stainless steel in the fibres can represent a stability risk of defined attenuation characteristics by using the clothing frequently. Vacuum deposition technology limits the versatility of textile materials. Printing method malfunctions because of material peeling, which results in damage to the protective layer and decrease in ESE values. Copper threads oxidise and transition resistance can decrease the efficiency of the textile material.
- Weight of protective clothing: Stainless steel used in the production of protective clothing increases the weight of the clothing and it also decreases wearing comfort.

Therefore the paper focuses on solutions of these issues. We propose using fibres which contain silver nanoparticles. Fabrics using these types of fibres are being developed in the scope of our projects called BE-TEX and KOMPOZITEX [14, 15]. The fabrics can easily replace current textiles based on stainless steel fibres. The main advantage of their applications is lower weight at higher mechanical ruggedness and textile stability, which is increased by the use of a composite structure with nanoparticles instead of metal macro structures. A very important characteristic is also increasing the protective factor. One of the outcomes of the project is a textile material whose ESE value is about 40 dB in the 30 MHz – 1.5 GHz frequency band. The fabric is composed of 60% SilveR.Stat®/40% PES in the warp and 40% SilveR.Stat®/60% cotton in the weft, 35.5 tex. SilveR.Stat® fibres are polyamide conductive fibres produced by coating pure silver onto the polymer [16]. The structure shows that silver nanoparticles are used in the yarn.

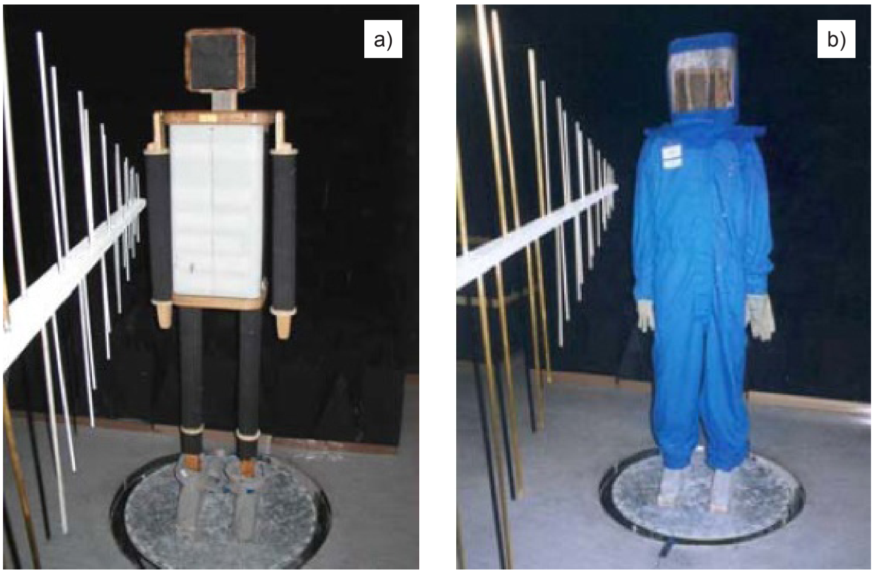

Figure 1. *DIN 32780-1400 measurement setup – human body phantom with vertical transmitter antenna [7].*

The samples are measured according to Standard ASTM D4935-99 [17].

The rest of the paper is organised as follows: Section A focuses on the proposal for protective clothing. Section B describes measurement methods and the modelling of the electromagnetic shielding efficiency of planar textiles, which can be easily used for the realisation of protective aids and work clothing. Section C represents modelling results of ESE, measurement of newly developed planar textile materials and ESE evaluation of the protective head hood developed. Future work is suggested in conclusions.

Proposal of protective clothing construction

Newly developed textile fabric with silver nanoparticles and their use in clothing construction are introduced in this section.

Planar textile material design

One example of the shielding textiles developed is the fabric composed of 60% SilveR.Stat®/40% PES in the warp and 40% SilveR.Stat®/60% cotton in the weft, 35.5 tex. The structure shows that the shielding textile is based on synthetic yarn with the addition of silver nanoparticles. The advantage of the structure is that silver nanoparticles are metal components of the structure instead of stainless steel, i.e. the metal macro structure is replaced by metal nanoparticles, which leads to increased textile stability and lower weight.

Critical parts of protective clothing

Many opportunities can be found in the design of planar textile materials for protective clothing production. One of the critical parts is the production of gloves and socks as well as protection of the head. It is necessary to reduce the number of seams in these critical places. The seams are the main source of ESE reduction because of inhomogeneity in textile material. An effective solution is offered by other types of weave and knitted fabric, which leads to the production of seamless shapes of gloves, socks and especially protective hoods. One of the outcomes of the projects is also a prototype of two human head protective hoods [14, 15], ***Figure 2***.

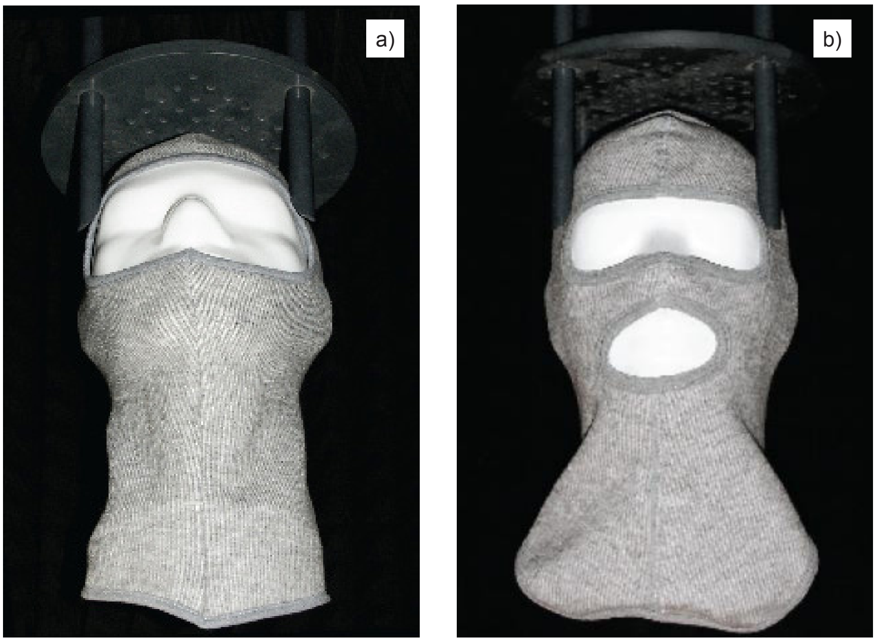

Figure 2. *Picture of head hood prototype: a) I and b) II – protection of head, mouth and neck.*

Protection of exposed facial parts can be realised by protective shields or masks which use transparent sheets with a shielding effect [18]. These materials are used for example on the transparent front doors of some data switch-boards.

Construction of protective clothing

It is possible to consider two basic groups of textile materials. The first one is woven surface textile from endless fibre, which enables to achieve the ESE required at a specific level of "transparency" of the material. A "transparent" material which achieves similar results to our textile material is, for example, Swiss Shield® material [19]. However, it does not allow long-term repetitive bending and therefore it can only be used for inflexible parts of the clothing, e.g. facial part of head. A transparent composite for the face shield can be produced from chilled plexiglass, which can carry shielding textile material and mechanically protect the face. The second group of textile materials is woven textile from yarn containing cotton and synthetic fibres as well as synthetic fibres with nanoparticles of silver on the surface of the fibre.

Recently developed synthetic yarn with silver nanoparticles enables to fabricate new surface textiles with the ability to shield high frequency electromagnetic fields. It also enables to guarantee high-comfort-of-wearing clothing for applications in the clothing industry (air permeability, durability of electrical parameters, technological capacity and price).

Protective clothing creates a protective barrier which prevents the absorption of high frequency radiation into the human body. The barrier has to be constructed as a homogenous layer to protect the body as well as face.

Our proposal for a construction of protective clothing from a composite layer is defined as:
- An outer mechanically resistant layer against attrition
- An inner functional and comfortable layer attenuating high frequency radiation
- An inner layer protecting the functional layer against damage and ensuring clothing comfort even on the skin
- Protective plexiglass with a layer of endless fibre textile for the construction of a face shield

The construction of clothing is a standard procedure of the clothing industry. An important part is the realisation of seams of the functional enclosure. This part of clothing technology requires using conductive threads with endless conductive fibre (monifilament). Suturing has to be accomplished carefully regarding the homogeneity of the functional shielding enclosure. Sufficient care is also necessary during the connection of the face part with the hood. The zip area and dividing plane hood-clothing can be made with the aid of sufficient overlaps of functional textile with an electrically conductive overlapping or by the quilting of monofilament metal fibre.

Evaluation of clothing proposed

In this section, *ESE* and *SAR* calculation, methods of *ESE* and *SAR* measurements and their conversion are described. Modeling of *ESE* is also discussed.

Electromagnetic shielding efficiency modelling

ESE is a parameter which describes the ability of a specific material to limit the penetration of a high frequency signal over a certain barrier. The incident electromagnetic wave, to a certain degree, can be reflected from the surface, *R*, rereflected inside the barrier, *B,* or transmitted through the barrier, *A*. This principle is described in a formula for *ESE*:

$$ESE = R + A + B \tag{1}$$

where, *R* is the single/reflection loss, *A* - absorption through the barrier, and *B* denotes the multiple/reflection coefficient.

It is also possible to express *ESE* by a logarithm of quotient intensities of the electric or magnetic component of the electromagnetic wave or also by power levels:

$$ESE = 20 \cdot \log \cdot \left|\frac{E_i}{E_t}\right| = 20 \cdot \log \cdot \left|\frac{H_i}{H_t}\right| = P_i - P_t \tag{2}$$

where, E_i is the intensity of the electric component of the incident electromagnetic wave and parameter E_t represents the intensity of the electric component of the transmitted electromagnetic wave. The intensities of magnetic components of the electromagnetic wave are denoted by parameter H_i for the incident wave and by parameter H_t for the transmitted wave. The power of the incident electromagnetic wave is expressed by parameter P_i. The power of the electromagnetic wave transmitted is represented by parameter P_t.

Basically there are two types of planar textiles: woven and unwoven. Unwoven textiles are not in common use in shielding applications because the structure is based on irregular shapes. Therefore the resultant textile has an inhomogeous structure from the viewpoint of the geometric arrangement of the textile coupling.

Woven textiles in a plain, sateen or twill weave meet the requirements of the regular geometric arrangement, and therefore it is possible to model these types of textiles.

The structure of textile in a plain weave is similar to a homogenous sheet with square slots. Similar structures can be found on the ventilation grille used in electrical devices. The *ESE** of these structures is given by a well-known parallel from the branch of circuit theory between gain and attenuation. Each of the square apertures is an antenna emitter under certain conditions (wavelength < the longest aperture dimension). This antenna emitter decreases the *ESE** of the virtual compact sheet by its antenna gain. The compact sheet is formed from material with characteristics which corresponds to the material structure of fibres used in the fabric. The apertures can generally be rectangles (twill wave), not only squares (plain wave). Therefore *ESE** derivation has to be based on a common rectangular shape, i.e. rectangle.

The *ESE** of a barrier with rectangular slots can be expressed by formula:

$$ESE^* = R + A + K \tag{3}$$

where *R* is the reflection loss, *A* - absorption through the barrier, and *K* describes the correction parameter.

The reflection loss can be calculated as:

$$R = 10 \cdot \log\left(\frac{1}{G}\right) \tag{4}$$

where parameter *G* describes the gain.

The gain of one aperture is expressed by:

$$G = \frac{4\pi}{\lambda^2} \cdot S \tag{5}$$

where, parameter *S* represents the surface of one aperture and *λ* the wavelength.

The gain of *n* apertures is described by formula:

$$G = \frac{4\pi}{\lambda^2} \cdot S \cdot n \tag{6}$$

The surface *S* of one aperture is calculated according to:

$$S = l \cdot s \tag{7}$$

l, s represent the sides of the rectangle in m.

The second term is the absorptive attenuation *A*, which not only takes into account the thickness *t* of the barrier, but also the length *l* and width *s* of aperture. The value *A* can be calculated after mathematical modifications by [21]:

$$A = 27.3 \cdot \frac{t}{l} \tag{8}$$

The last term is the correction parameter *K*, which takes into account geometric dimensions of the apertures. Value *K* is equal to zero if the aperture is a square, i.e. $l = s$. If $l > s$, $K > 0$. If $l < s$, $K < 0$. Correction parameter *K* is expressed by:

$$K = 20 \cdot \log\left(1 + \ln\left(\frac{l}{s}\right)\right) \tag{9}$$

The correction parameter can also describe the worst case of incident electromagnetic wave on the shielding barrier, i.e. the influence of the vector parallelism of the incident wave and the biggest dimension of the slot.

Measurement methods of ESE

Relationship between *SAR* and *ESE* parameters can be represented by the following formula:

$$ESE_{SAR} = 10 \cdot \log \frac{SAR_{without}}{SAR_{with}} \tag{10}$$

where, SAR_{with} describes the time-averaged specific absorption rate in a body model with shielding, and $SAR_{without}$ represents the time-averaged specific absorption rate in a body model without shielding.

The value of the *SAR* can be calculated according to:

$$SAR = \int_{sample} \frac{ó(r) \cdot |E(r)|^2}{ñ(r)} \tag{11}$$

where, *SAR* is the specific absorption rate, *σ(r)* - the electrical conductivity of the sample, *E(r)* the RMS (Root Mean Square) electric field and *ρ(r)* describes the sample density, the sample being, for example, a model of the head, body, etc.

The electric field is measured via e.g. a model of the head. This cored model is filledup with liquid which has similar electrical features to human tissue. This liquid also considers brain tissue, scalp tissue and the skull. The device measured, often a mobile phone, is put near the head model in a specific position (position during making a call) and in this position the device transmits the highest possible intensity. During the test, the automatic probe moves around the head model and measures the intensity of the electromagnetic field. *SAR* is calculated from these values. The next step is *SAR* calculation by the same procedure but with a shielding barrier placed between the model and radiation source. Then ESE_{SAR} can be calculated.

Standardised methods for *ESE* measurement of planar materials containing textiles use three basic procedures, i.e. Standard EN 50 147-1 [22], Standard ASTM D4935-99 [17] and the method which uses the Dual-TEM cell [23]. The ASTM D4935-99 standard was used for ESE measurement of planar textile material samples. Each method mentioned corresponds to different practical applications of the shielding material. Moreover an important part of *ESE* is not generally analysed, which is called the reflection loss.

The method from (2) was used for measurement of the head hood prototypes produced. It is based on comparison measurement, i.e. measurement with and without the hood. The prototypes were manufactured from the same textile material as planar textile material samples.

Results obtained from measurement

This section describes modelling results of *ESE* measurement of newly developed planar textile materials and *ESE* evaluation for the protective head hood developed.

Modelling of ESE of textiles with electrical conductive particles

Modelling results are obtained from the formulas of ESE modeling mentioned (3-9) and from programming software. It enables to simulate different structures of the material from the dimensions of the slots (rectangles and squares), the thickness of the barrier and the different numbers of slots. ***Figure 3*** shows an example of the influence of the longest dimension *l* of the slots on the *ESE** value. The results show *ESE** values of about 40 dB in the frequency band 100 kHz – 10 GHz for an aluminum sheet of thickness 0.1 mm, and for slots of dimensions 0.1 × 0.1 mm, 0.1 × 0.2 mm and 0.1 × 0.3 mm, with the distance between slots set at 0.1 mm. The model neglects material characteristics of the theoretical compact textile sheet, the surface conductance in particular. Considering the number of slots in the textile structure, the *ESE** of the surface conductance is insignificant. The number of slots *n* used in the modelling corresponds to the surface of the circular ring of the coaxial adapter, which is constructed according to Standard ASTM D4935-99 [17] for *ESE* measurement.

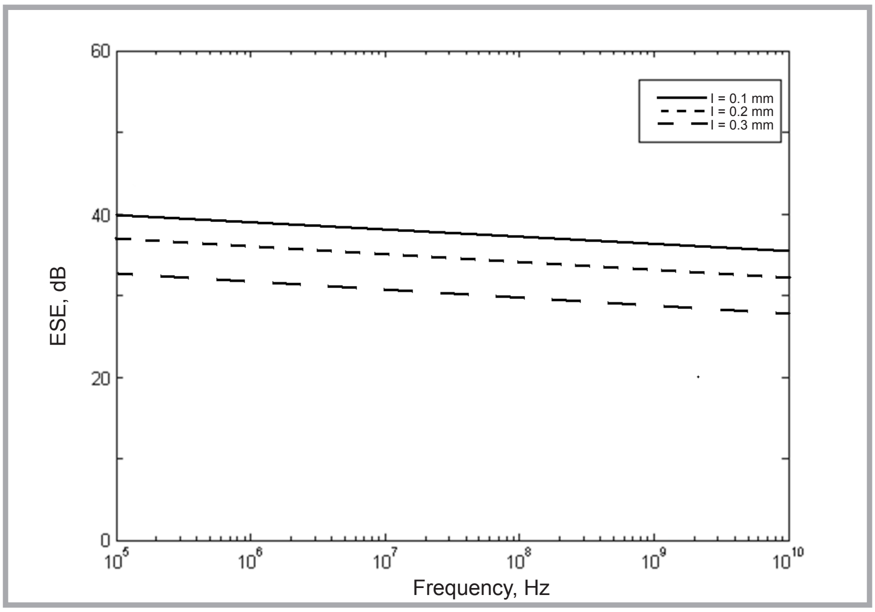

Figure 3. *Simulation of the dependence of ESE on frequency for different lengths of aperture slots l.*

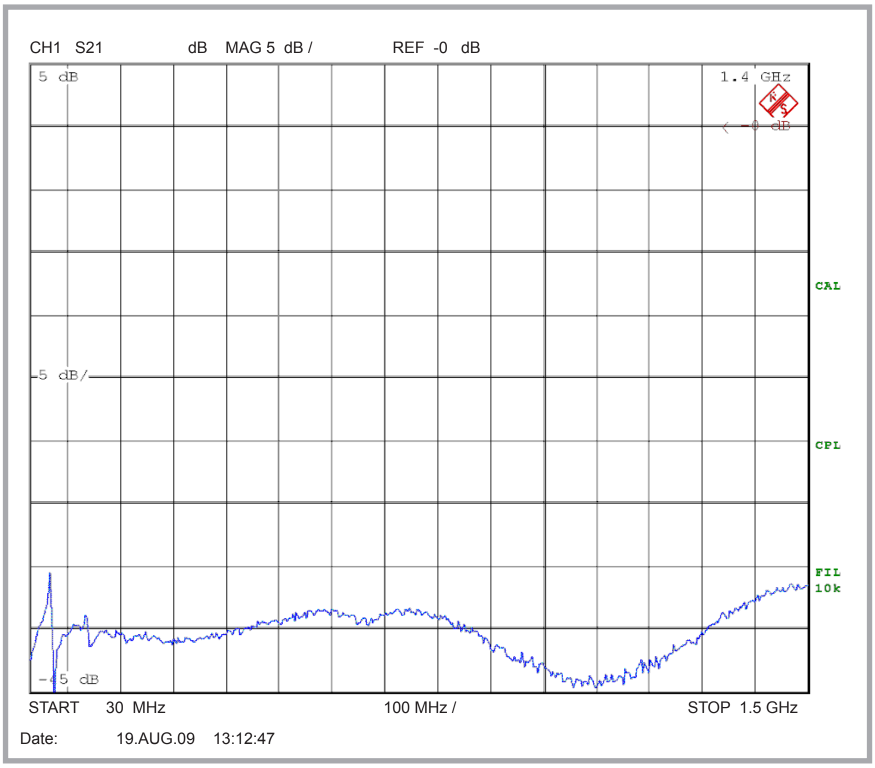

Figure 4. *Measurement of ESE of shielding textile in dependence on frequency.*

Planar textile material measurement

The textile fabric samples developed, i.e. 60% SilveR.Stat®/40% PES in the warp and 40% SilveR.Stat®/60% cotton in the weft, 35.5 tex, are measured according to Standard ASTM D4935-99 [17] by means of a ASTM coaxial adapter. The results are depicted ***Figure 4***. It shows *ESE* results of this textile in a frequency band from 30 MHz to 1.5 GHz. The *ESE* values reach 40 dB for a frequency

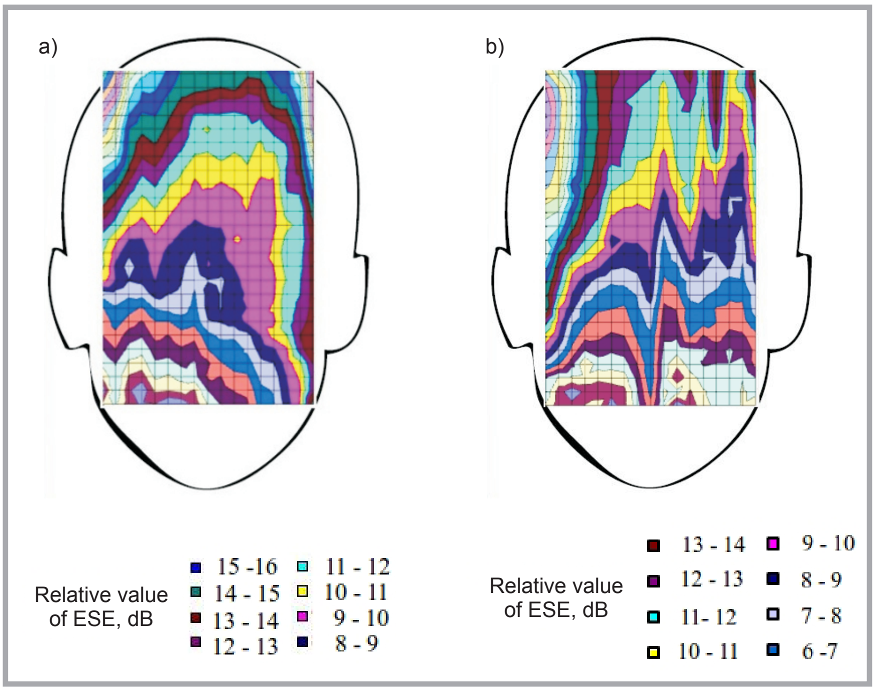

Figure 5. *Visualization of ESE measurement at 500 MHz frequency for head hood: a) prototype I and b) prototype II.*

of 500 MHz, which is about 10 dB more than materials marketed [10]. A specific *ESE* value is given by the structure of the yarn and textile fabric construction, therefore these parameters are variable – programmable [24].

Prototyped head hood measurement

The *ESE* value is calculated according to (2) with the aid of the measurement of electric components of the electromagnetic wave. This formula was used for the measurement of two prototypes of head hoods fabricated from the textile fabric samples developed, i.e. 60% SilveR.Stat®/40% PES in the warp and 40% SilveR.Stat®/60% cotton in the weft, 35.5 tex. The hoods were chosen with respect to the most sensitive part of the protective clothing (eyes and mouth/nose are not protected). Measurement components were located in the shielding chamber. At first, an electromagnetic wave was generated by a power high frequency generator at 500 MHz frequency and by a transmitting panel antenna 1 m distant from the shell of a man-made head. The measuring probe was located inside the head. The positioning system and controlling computer were set up to record values of the incident electromagnetic wave. In the next step, the measuring protective hood was set on the shell and measuring was repeated.

The first prototype of the hood protects the whole head, mouth and neck. It does not include the protection of eyes and nose, ***Figure 2.a***. Results of *ESE* measurement at a frequency of 500 MHz are shown in ***Figure 5.a***. The second prototype includes, in addition, nose protection but not mouth protection, ***Figure 2.b***. Results are depicted in ***Figure 5.b***. The ESE measurement results show the highest value is 16 dB for the first prototype and 14 dB for the second for a frequency of 500 MHz. The values are quite low in comparison with measurement results of planar textile material, i.e. 40 dB, which is caused by missing protection of the eyes and mouth/nose.

Conclusions

This paper focuses on human protection against high frequency electromagnetic fields and related protective clothing. Specific standards describing limits of electromagnetic fields, application of constructed protective clothing and measurement procedures are presented. Measurement methods and modelling of electromagnetic shielding efficiency enable to improve current textile materials with respect to characteristics such as attenuation, weight and textile stability. The textile fabric developed herein is based on synthetic yarn with the addition of silver nanoparticles. It decreases the weight in comparison with marketed fabrics, which contain stainless steel fibres. Textile stability is increased by use of composite structures with nanoparticles instead of metal macro structures. The textile fabric achieves *ESE* values of about 40 dB, which is about 10 dB better than the best existing solution known for a reference frequency of 500 MHz. The modelling results of ESE, measurement results of the textile fabric developed and measurement of the prototype head hood confirm the improvements of these characteristics as well as the feasibility of the proposal for protective clothing construction.

Future work will focus on the construction of protective clothing with the aid of the yarns and textile materials developed. The final protective clothing will also be put to the test for parameters such as constancy, the subjective level of comfort while wearing the clothing, air permeability and its influence on electric parameters. The fact that the functional layer contains nanoparticles of silver bring about an antibacterial effect.

Acknowledgements

*This work was supported by project FR-TI4/202 - KOMPOZITEX - Composite Textile Materials for Protection of Humans and Devices Against the Effects of Electromagnetic and Electrostatic Fields, supported by the Ministry of Industry and Trade of the Czech Republic as part of the TIP program and project FI-IM5/202 - *BE-TEX Human and equipment protection against high-frequency electromagnetic radiation - research and development of new textiles, supported by the Ministry of Industry and Trade of the Czech Republic as part of the IMPULSE program.*

References

1. IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. IARC Monographs on the Evaluation of Carcinogenic Risks to Humans, IARC Monograph, Volume 80, Non-ionizing radiation, Part 1: Static and extremely low-frequency (ELF) electric and magnetic fields, Lyon, IARC, 2003.
2. WHO - World Health Organization, Extremely low frequency fields. Environmental Health Criteria, Geneva, World Health Organization, vol. 238, 2007.
3. ICNIRP – International Commission on Non-Ionizing Radiation Protection, Guidelines for limiting exposure to time varying electric, magnetic and electromagnetic fields (up to 300 GHz). *Health Physics* 1998; 74: 4.
4. ICNIRP – International Commission on Non-Ionizing Radiation Protection, Exposure to High Frequency Electro-

magnetic Fields, Biological Effects and Health Consequences (100 kHz-300 GHz), Munich, 2009.
5. ARPNSA - Australian Radiation Protection and Nuclear Safety Agency, The Radiation Protection Standard for Maximum Exposure Levels to Radiofrequency Fields — 3 kHz to 300 GHz, 2002.
6. DIN - Deutsches Institut Fur Normung E.V. (German National Standard), DIN 32780-100, Protective clothing - Part 100: Protection against electromagnetic fields in the frequency range from 80 MHz to 1 GHz, Requirements and test methods. Germany, 2002, p. 29.
7. Arps V, Koch M. Personal safety in high frequency electromagnetic fields, Protective clothing, standards and measurements procedures.In: *EMC York 2004 International Conference and Exhibition*, York, 2004.
8. An Evaluation of Induced Body Current and Contact Current Reduction Effectiveness with the KW-GARD™ RF Protective Clothing at a High Power AM Radio Broadcast Transmitter Site. Las Vegas: Richard A. Tell Richard Tell Associates, Inc., 1998, p. 12.
9. An Evaluation of Induced Body Current and Contact Current Reduction Effectiveness with the KW-GARD ™ RF Protective Clothing at a High Power VHF-UHF Broadcast Transmitter Site. Las Vegas: Richard A. Tell Richard Tell Associates, Inc., 1998, p. 11.
10. An Evaluation of Test Measurement Data Obtained on the KW-Gard ™, RF Protective Clothing, Las Vegas: Richard A. Tell Richard Tell Associates, Inc., 1998, p. 7.
11. Radiofrequency Electromagnetic Field Protection, RadioFrequency Personal Protection Equipment, RF PPE, EGIS® RF PPE Ref. 503246. Rennes, France: EGIS®, 2008, p. 1.
12. Radiofrequency Electromagnetic Field Protection, RadioFrequency Personal Protection Equipment, RF PPE EGIS® RF PPE Ref. 403246, Rennes, France: EGIS®, 2008, p. 1.
13. Pawlak R, Korzeniewska E, Frydrysiak M, Zięba J, Tesiorowski L, Gniotek K, Stempień Z, Tokarska M. Using Vacuum Deposition Technology for the Manufacturing of Electro-Conductive Layers on the Surface of Textiles. *Fibres & Textiles in Eastern Europe* 2012; 20, 2: 68-72.
14. Research and Development and Innovation Information System of Czech Republic. FI-IM5/202 - *BE-TEX Human and equipment protection against high-frequency electromagnetic radiation - research and development of new textiles (2008-2010, MPO/FI). [online]. 2010 [cit. 2011-04-19]. http://www.isvav.cz/projectDetail.do?rowId=FI-IM5%2F202.
15. Research and Development and Innovation Information System of Czech Republic. FR-TI4/202 - *KOMPOZITEX - Composite Textile Materials for Protection of Humans and Devices Against the Effects of Electromagnetic and Electrostatic Fields (2012-2015, MPO/FR). [online]. 2013 [cit. 2013-05-2]. http://www.isvav.cz/projectDetail.do?rowId=FR-TI4%2F202
16. Products : silveR.STAT® fibres. R.STAT Technical fibres. http://www.r-stat.fr/uk/silveRstat-fibre.php
17. American Society for Testing and Materials, Standard Test Method for Measuring the Electromagnetic Shielding Effectiveness of Planar Materials, Standard D4935-99, 1999.
18. Vojtech L, Neruda, M, Hajek J,Korinek T. Full Face Hood for Electromagnetic Shielding. In: *International Workshop RTT 2009*, Praha, 2009.
19. Swiss Shield®, Special fabric for electromagnetic compatibility. http://www.swiss-shield.ch/en/spezialgewebe.htm.
20. Technical University in Liberec, Department of Textile Materials, Home page. [online]. 2005 [cit. 2011-04-19]. http://www.ft.vslib.cz/depart/ktm/?q=en/cotton_fiber.
21. Soucek J. Methods for electromagnetic shielding efficiency modeling", diploma thesis, Czech Technical University in Prague, 2011, p. 61.
22. Anechoic chambers – Part 1: Shield attenuation measurement. Standard EN 50147-1: 1996.
23. Avloni J, Florio L, Henn AR, Lau R, Ouyang M, Sparavigna A. Electromagnetic shielding with polypyrrole-coated fabrics. In: *EMC Europe Conference*, Barcelona, Sept. 2006.
24. Vojtech L, Neruda M, Hajek J. Measurement of electromagnetic shielding efficiency of planar textiles. In: *Digital Technologies,* 2009.

Received 09.07.2012 Reviewed 11.03.2013