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SHIELDING EFFICIENCY OF A FABRIC BASED ON AMORPHOUS GLASS-COVERED MAGNETIC MICROWIRES TO RADIATION EMITTED BY A MOBILE PHONE IN 2G AND 3G COMMUNICATION TECHNOLOGIES

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* ³1LFRODH %OFHVFX´ /DQG)RUFHV $FDGHP\ 6LELX 5RPDQLD
1DWLRQDO $XWKRULW\ IRU 0DQDJHPHQW-$1&2G 5HJXODWLRQ5RP&
*** 7HUUDIOX[&RQWURO ,DúL 5RPDQLD

ABSTRACT
$ GXDO EDQG PRELOH SKRQH PRGHO ZDV XVHG WR FKHFN WK
DPRUSKRXV IHUURPDJQHWLF WH[WLOH DJDLQVW WKH UDGLDW
7ZR IUHTXHQFLHV EDQGV LQ WKH QHDU ILHOG RI PRELOH HPLVVLRQ WHFK
ZHUH XVHG 0+] DQG 0+] 7KH VSHFLILF DEVRUSWLRQ U
GHSRVLWLRQ LQ KXPDQ KHDG SKDQWRP ZDV PHDVXUHG LQ VWDQG
7KH WH[WLOH FRQWDLQHG FRPSRVLWH PLFURZLUHV RI D IHUURPDJQHWLF PL[WX
LQ D WKLQ JODVV FRDW DQG ZHDYHG LQ D VSHFLILF ZD\ $ VH
FRQILJXUDWLRQV ZHUH SURYLGHG LQ WKH H[SHULPHQW LQ RUGH
VKLHOGLQJ WR WKH SKRQH¶V UDGLDWLRQ FRPSDUHG ZLWK
6$5 GHSRVLWHG LQ WKH KHDG SKDQWRP EHIRUH DQG DIWHU
WR RI LWV LQLWLDO YDOXH * WHFKQRORJ\ DQG XS WR
* WHFKQRORJ\ 7KLV W\SH RI PDWHULDO VKRZV RQH RI WKH KL
WKH HOHFWULF FRPSRQHQW LQ QHDU ILHOG H[SRVXUH FRQGLWLRQV UHSRUWHG
$ FXELF FXUYH RI 6$5 GHFUHDVH LQ GHSWK RI WKH KHDG ZDV U
FRYHUHG KDQGVHW WKH HIIHFW RI VKLHOGLQJ EHLQJ ODUJHU D

KEYWORDS: mobile phone, SAR, near-field, electromagnetic shielding, magnetic amorphous material

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1. Introduction

Solutions for an efficient protection of the user against the radiation emitted by a mobile phone were continuously investigated, so that literature on this subject was published starting with the first years after 2000. A brief review of the proposed shielding solutions and of the materials used for radiation reduction is presented in (Miclăuş et al., 2016). Materials such as conductive meshes, conductive fabrics, conductive foams, wire-mesh screens, multi-layers, ferrites, resistive sheets and metamaterials were all checked for their efficiency. Simulations were also conducted at microwave frequencies so as to emphasize for example the differences due to particular geometries of the metallic wires in a textile or their weaving density when a wire-meshed material was used as a shield (Rosu, Druta & Baltag, 2016). In general the results concening field reduction showed that shielding efficiency greatly depends on a series of variables: position of the material with respect to the handset's antenna, structure and composition of the material, orientation of the absorbing/reflecting fibers with which emitted radiation interacts, dimensions of the entire shield, etc. (Tomovski, Grabner, Hungsberg, Kallmeyer & Linsel, 2011; Wessapan, Srisawatdhisukul & Rattanadecho, 2011; Dutta, Jayasree & Srinivasa, 2016; Miclaus et al., 2016). Both a decrease of the specific absorption rate (SAR) of energy deposition in the head exposed to a "shielded" mobile phone can be achieved, but sometimes even an increase of local SAR could be observed. The highest reduction percentage of SAR ever reported when using a shielding solution for a mobile phone was of 60% (Miclaus et al., 2016) but few such results were generally reported, while the average percentage of SAR reduction was usually situated at around 15% from the value obtained when using the mobile handset as it is – with any shield.

The subject of mobile phone radiation reduction is of continuous interest, especially for the safety of sensitive persons, hard users and children. The use of fabrics based on amorphous magnetic microwires for SAR reduction was scarcely studied to date, as of our knowledge, but their shielding properties at microwave frequencies were carefully studied (Makhnovskiy & Panina, 2006; Yongjiang, et al., 2007; Liberal, 2013; Devkota et al., 2014; Baranov, Larin & Torcunov, 2017). Therefore we proposed here a preliminary empirical study in which single or multiple layers of such a material to be used as a cover of the mobile handset and then tracing SAR modifications in a phantom human head. By using a standardized SAR measurement procedure we determined the SAR reduction factor due to the presence of the fabric in a set of experimental configurations. The shielding effect was assessed for just one model of mobile phone which was used consecutively in two communication standards: 2nd generation (GSM) technology and 3rd generation (UMTS) technology respectively. The preliminary results indicate that this material type provides significant radiation attenuation in both frequency ranges, fact that entitles further future research on this subject.

2. Materials and Methods

SAR is a measure of tissue heating when radiofrequency (RF) radiation propagates thru it. SAR depends on both local internal E-field strength (E_{int}) and on the dielectric properties of the tissue. On the other hand, the connection between SAR and heating rate ($\Delta T/\Delta t$) is made thru the specific heat capacity of the tissue, c. Therefore, the ways to express SAR are:

Where σ is the electric conductivity of the tissue and ρ is its masic density.

The normative reference used for present SAR measurements in the phantom of the human head when it is exposed to RF field emitted by the mobile phone antenna was standard "Recommended Practice for Determining the Peak Spatial-Average Specific Absorption Rate (SAR)" (IEEE 1528, 2013). The handset was tested in the "cheek" position. The earpiece of the handy was always in contact to the ear or to the fabric covering the handset respectively. The COMOSAR-SATIMO measurement system was used and it functioned in a shielded room where all experiments took place. SAR distributions in the human head phantom could be observed by area and zoom scans, and values of average or peak SAR could be calculated by the OpenSAR software. European legislation indicates averaging of SAR on 10g of equivalent tissue that is why we will refer mainly to this parameter. SAR_10g value should not exceed 2W/kg in the human head when using a phone, for safety reasons (ICNIRP, 1998). The 6-axis robot measurement system of COMOSAR-SATIMO enabled fine movement of the miniature electric (E)-field probe to scan the volume of the head in 27 measurement points, very fast (steps of 8mm on each direction). This method was used in the present approach for just coarse assessment of SAR reduction capabilities of the amorphous magnetic fabric.

A mobile phone model Samsung GT-I9195I was used in all the experiments. The phone was used in two emission situations: a) a signal specific to 2G – GSM900 communication technology – a time division multiple access (TDMA) scheme was initiated (crest factor = 8) at the frequency f1 = 897.6 MHz; b) a signal specific to 3G – UMTS communication technology – a wideband code division multiple access (WCDMA) scheme was initiated (crest factor = 1) at the frequency f2 = 1950 MHz. In each case the call was established at the maximum output power with the base station simulator.

At frequency f1, the liquid simulating human brain filling the head phantom had the next dielectric parameters: real and imaginary part of the relative permittivity were $\varepsilon'_r=41.5$, $\varepsilon''_r=19.4$ and the electric conductivity was $\sigma=0.97$ S/m. At frequency f2, the dielectric parameters of the liquid were: $\varepsilon'_r=40$, $\varepsilon''_r=12.93$, $\sigma=1.4$ S/m.

SAR in the head was measured initially with no material covering the handset, and this measurement was called REF since it was used as a reference SAR value. Then the amorphous magnetic material was used as a cover on the surface of the handset and the contact was maintained with the phantom's head during measurements. All the time the phone was in touch with either phantom's shell directly or indirectly, by inserting the textile. The fabric cover was used in 1, 2 or 4 layers respectively while the direction of the weaving yarns was positioned in 2 ways: normal (A) or rotated by 90 degrees (B). Finally, shielding cases were called 1A, 1B (meaning one layer of material in normal and then in rotated position was used as a cover); 2A, 2B; 4A, 4B.

The fabric used in current measurements is based on glass-coated amorphous ferromagnetic wires twisted together with cotton or synthetic (kapron) yarns. The chemical composition of the amorphous wire is $Co_{68}Mn_7B_{15}Si_{10}$. The diameter of the microwires ranges between (10 – 13) µm, and the outer diameter of the glass insulation ranges between (15 – 20) µm. The main charecteristics of the fabric were presented in Baltag et al., (2000) and Rau, Iftemie, Baltag & Costandache (2011).

3. Results and Discussion

Figure no. 1 presents examples of SAR values distribution on a surface containing peak SAR value, when the phone was used in GSM standard, while Figure no. 2 refers to the same situations but when phone was used in UMTS communication standard. Each first image called "REF" in both figures refers to the unshielded phone, while the other three situations refer to single or double layered shielding fabric applied over the handset surface. We notice that in some cases, multilayers do not necessarily conduct to a drop in SAR values. Also, in some cases (GSM900 – situations 2B, 4A, 4B), the OpenSAR software detected, at the surface scanning, a secondary hot spot comparable to the main one (in these cases, 2 values of SAR have been computed and finally it has been reported just the higher value).

For a proper comparison of the situations we used the SAR value averaged over 10g of equivalent brain tissue. In Figure no.3 we represented SAR_10g values in the phantom head for all investigated cases (six cases in which amorphous magnetic shielding was used and one without shield, REF) when 2G communication signal was emitted by the phone. In all situations when the material covered the phone, a reduction of the average SAR was gained. The highest SAR reduction was obtained when just one layer of material was used and when the orientation of its fibers was "B" – in that case SAR_10g was reduced 3.3 times from its value when the phone was uncovered. Interesting to note is that using 2 or 4 layers of material didn't improve shielding, but contrary.

REF 1A

1B 2B

)LJXUH QR :6XUIDFH GLVWULEXWLRQ RI 6$5 LQ WKH SKDQ
*60 HPLVVLRQ WHFKQRORJ\ 5() LV IRU SKRQH ZLWKRXW
OD\HU RI DPRUSKRXV IHUURPDJQHWLF IDEULF VHW LQ WZ
GRXEOH OD\HUHG [illegible] WDWLRQV

In Figure no.4 SAR_10g reduction can be observed when the phone emitted 3G signal. In this case, significant SAR reductions were obtained with "B" orientation in all cases, and by using multiple layers of fabric we gained even better reduction capabilities in some cases. The highest SAR reduction factor was of 1/4 from the SAR value of unshielded handset. "A" orientation of the shielding fabric was in all cases less efficient than "B" orientation.

Table no. 1 synthesizes the reduction factors of SAR_10g when using the amorphous magnetic microwires textile as a cover. Maximum percentage of SAR_10g reduction in the material in case of GSM emission was of 70%, and in case of UMTS emission was of 76%. Such significant reductions of the radiation in a material have rarely or never been reported before.

REF

1A

1B

2B

)LJXUH QR : 6XUIDFH GLVWULEXWLRQ RI 6$5 LQ WKH SKD
LQ 8076 HPLVVLRQ WHFKQRORJ\ 5() LV IRU SKRQH ZLWK
RI RQH OD\HU RI DPRUSKRXV IHUURPDJQHWLF IDEULF VH
XVH RI GRXEOH OD\HUHG IDEULF LQ RQH RI WKH

Figure no. 5 and Figure no. 6 indicate the curves of SAR attenuation in depth of the head phantom for GSM and UMTS signals respectively. By comparison between uncovered phone (REF case) and shielded phone by a single layer fabric (cases 1A and 1B), one observes that decreasing rate may be different. At least in case of higher frequency of UMTS signal, local slopes of SAR decrease with distance are different in each case. However, all SAR attenuations follow a 3^{rd} degree polynomial regression curve which is printed on the graphs, while the coefficient of determination is $R^2 = 1$. This behavior indicates that the fabric introduces

)LJXUH QR : $YHUDJH 6$5 YDOXHV IRU *60 HPLWWHG VLJQDO
XQVKLHOGHG KDQGVHW 5() DQG LQ FDVH RI GLIIH

)LJXUH QR : $YHUDJH 6$5 YDOXHV IRU 8076 HPLWWHG VLJQDO 0+] L
XQVKLHOGHG KDQGVHW 5() DQG LQ FDVH RI GLIIH

Table no. 1

)DFWRUV RI 6$5 UHGXFWLRQ GXH WR DPRUSKRXV
SUHVHQFH UHSRUWHG WR WKH FDVH ZKHQ WKH K

Fabric Covering/ case no.	GSM emission/ Factor of SAR_10g reduction	UMTS emission/ Factor of SAR_10g reduction
1A	0.78	0.64
1B	0.30	0.47
2A	0.50	0.69
2B	0.53	0.24
4A	0.57	0.66
4B	0.65	0.26

different volumic shielding coefficients mainly at frequencies whose wavelength tend to approach the texture dimensions of the magnetic fibers. In this regard, simulations would indicate more precisely the "rule" of improved shielding capabilities.

Based on the SAR results and by applying relation (1), we can calculate the duration a call might be prolonged with, by using the magnetic amorphous shield, for the same temperature increment in the head: for the GSM phone the call length may be increased 3.33 times and for UMTS phone the call length may be increased 4.17 times. These values, of more practical significance for a user, indicate the shielding efficiency range of this material.

)LJXUH QR 6$5 DWWHQXDWLRQ ZLWK GHSWK LQ WKH SKDQ
VLJQDO IRU XQVKLHOGHG 5(ELHOGHG KDQGVH

)LJXUH QR : 6$5 DWWHQXDWLRQ ZLWK GHSWK LQ WKH
VLJQDO IRU XQVKLHOGHG 5(ELHOGHG KDQGVH

4. Conclusion

One phone model was investigated by a standardized procedure in order to report the specific absorption rate of energy deposition in a human head phantom while using the phone at its highest emission power –either in direct contact to the head or covered by a material with electromagnetic shielding properties. The study was a pure preliminary experimental approach of the shielding capabilities of an amorphous ferromagnetic textile fabric used to decrease human exposure to mobile phone radiation. While inserted in the near field zone of antenna, the material, containing micrometric dimensions magnetic wires covered by thin glass, was checked in two positions and with three thickness values (by layering) for its SAR reduction properties when it covered the handset. Since modern phones make use of both 2G and 3G communication technologies, two frequencies of these technologies were investigated.

It was revealed that this material has exceptional shielding properties on the electric-field component at investigated frequencies of 897 MHz and 1950 MHz and needs further study. The SAR reduction percentage due to the fabric presence on the handset surface was of maximum 70% if reported to SAR value of the unshielded phone functioning in GSM standard and of 76% in UMTS standard. Layering the fabric is not more efficient generally, but rather the position and orientation of the microwires relative to the handset antenna plays an important role in shielding.

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