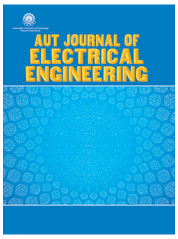

AUT Journal of Electrical Engineering

AUT J. Electr. Eng., 55(1) (2023) 81-90
DOI: 10.22060/eej.2022.20912.5445

The Effectiveness of Non-Ionizing Radiation Protective Clothing: A Computational Study

Zahra Hajizadeh Bakhtiary, Mehrdad Saviz*

Biomedical Engineering Department, Amirkabir University of Technology (Tehran Polytechnic), Tehran, Iran

ABSTRACT: Exposure protective clothing has been suggested as a protection against RF and microwave electromagnetic fields, especially for pregnant women. These clothings are usually made of metal-woven fabrics. In this article, we use computer simulation methods with a homogeneous human model and plane wave exposure at different polarizations and wave incidence angles over a wide range of frequencies to inspect if a typical anti-exposure clothing model might fail to reduce the fields inside the body under certain exposure conditions and/or at some frequencies. Indeed, as far as our model and computational study can represent actual conditions, it is found that for waves incident along the body axis (as arises e.g. in the sleeping status against a cell-phone tower) the clothing might not only fail to reduce the penetration of EM fields, but can rather increase the electric field intensity in certain body areas, including the abdominal parts which were intended to be protected during pregnancy. We conclude that more physics-aware designs should be employed for such clothing.

Review History:

Received: Jan. 16, 2022
Revised: Aug. 04, 2022
Accepted: Oct. 16, 2022
Available Online: Mar. 01, 2023

Keywords:

Homogeneous Human Model
Plane Wave Radiation
Anti-Radiation Fabric
Electromagnetic Shielding
Shielding Effectiveness

1- Introduction

Health risks associated with Radio frequency and microwave exposure have been under study for decades, including carcinogenicity, eye damage, DNA damage, Cell cycle alterations, etc [1]. Obviously these hazards are more serious for a developing embryo. Providers of protective clothing advertise their clothing as a complete shield for pregnant women against such radiation. However, they usually present data related to reflection/transmission through the fabric (textile) itself, which is measured in a planar geometry with the fabric stretched against a flat frame. In one example, the fabric, which is referred to as anti-exposure clothing, is a combination of the following materials: 45% cotton, 20% polyester, and 35% silver, which can reduce the induced electric field by 30-40 dB and reject up to 99.9 percent of the incoming exposure with a frequency of 10 MHz to 20 GHz (further measurement data in [2]). In other words, the specifications of attenuation are given for plane wave incidence on a flat sheet of fabric. Such reporting of textiles rejection measurements neglect the important fact that when the fabric is made into clothing, the clothing geometry plays an important role in wave amplification/attenuation within the body, especially because of the possible resonance effects due to the rims of the clothing when the wavelength is on the order of the periphery of the cloth rim. This paper intends to investigate the possibility of such possible amplification effects.

Regarding computational 3D body models, complex body models exist [3], but we have chosen a homogeneous human body model since our full-body full-wave problem is already computationally demanding, and the general clothing behavior is expected to remain qualitatively correct with a homogeneous body model. The human model employed in this work is based on actual body aspect ratio and limb sizes of a volunteer.

Regarding tissue properties, most previous studies rely on a limited frequency band [4-5]. In this paper, a computational model is constructed which includes realistic geometry, wide-band frequency dependent tissue properties (2/3 muscle properties by convention), and a comprehensive set of angles of incidence and different wave polarizations at each incidence. These are solved by running days-long simulations on a 32-GB RAM station for all possible plane-wave exposure conditions and over a wide range of frequencies.

Our results can be alarming for the society. It is found that amplification/energy concentration can occur at certain points within the body and is more so for certain incidence angles. These angles and the probability of their real-life occurrence is discussed in the discussion section. We further propose that the more complex nature of wave-behavior (which can cause local resonances with the rim of conductive clothing) calls for full-scale simulation and computational methods [6], and physics-aware design of radiation protective clothing.

*Corresponding author's email: msaviz@aut.ac.ir

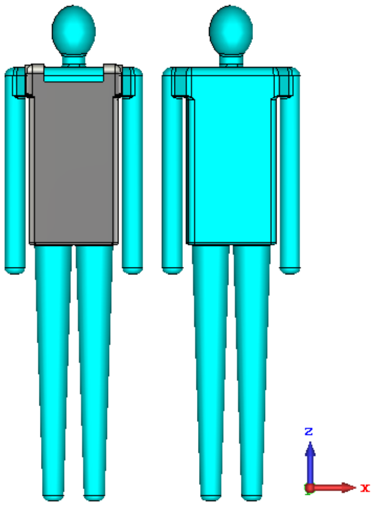

Fig. 1. The model without (right) and with anti-exposure clothing (left)-(Model specifications: Height 1.68 m, Shoulder width 0.39 m, Depth of abdomen 0.15m)

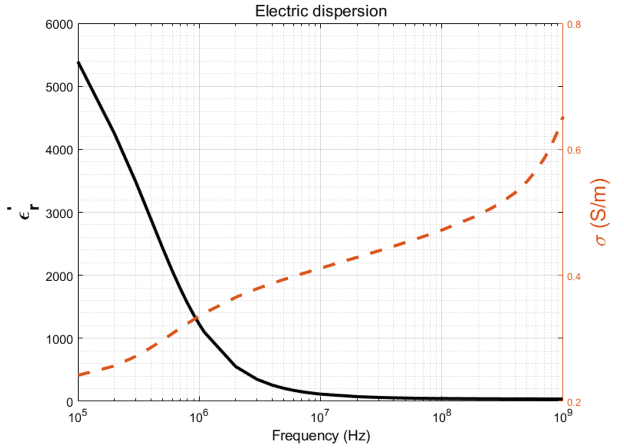

Fig. 2. Electrical properties of the tissue in the homogeneous model (two-thirds of the muscle properties)

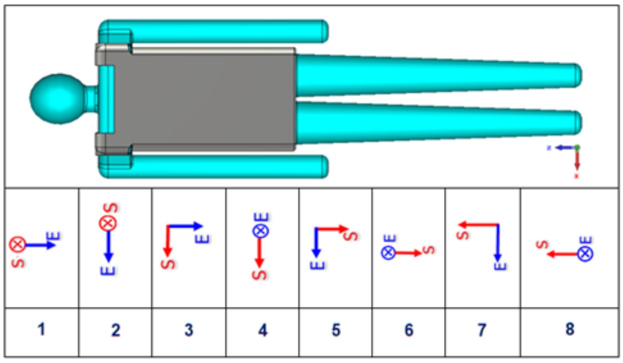

Fig. 3. Human model exposed to plane wave - propagation normal (S), Electric field vector (E)

physics-aware design of radiation protective clothing.

2- Model and Simulation

A homogeneous model of the human body is constructed, coated once with Perfect-Electrically-Conductive material (PEC), and once with no anti-exposure clothing. We assume that at frequencies of interest, a fine metallic lattice, such as the silver woven fabric, behaves similarly to a PEC surface, and PEC surfaces can be expected to model the clothing with good accuracy.

By comparing the induced electric fields in both cases, we investigate the effectiveness of this clothing model in reducing the induced electric field (i.e. its protective effects). The shielding factor can be expressed as Eq. (1).

$$S.E.=E^{dB}_{(with)}-E^{dB}_{(without)} \qquad (1)$$

The model under study is a model with the physical dimensions of a normal human (Figure 1- right) whose tissue is assumed to be homogeneous as a first approximation. Although more sophisticated computational models exist [10] we reasonably expect that qualitative results would be the similar regardless of tissue complexity, considering the fact that the relatively high number of scenarios for this study did not allow more complicated models to be used.

The electrical data of the muscle is taken from the conventional tissue database of [7,8] Two-thirds of this value is conventionally applied to a homogeneous body model to obtain the nominal properties of body tissues [9]. The final electrical properties used for simulation are given in Figure 2. Electric field simulations were performed in CST studio suite 2016 software with the time domain solver. All simulations were performed with an incident electrical field of 1 v/m in the frequency ranges of interest and with mesh numbers 5,586,240 and 5,672,832 for with and without PEC clothing, respectively. The Maxwell equations are linear, and attenuation coefficients can be found by the ratio of the internal to the incident field. This ratio would be the same for any incident amplitude.

The minimum mesh step size was 0.002m, and the maximum mesh step size was 0.0216m.

By defining probes in different parts of the model, the acquisition of an induced electric field was possible at several sensitive points (such as heart, brain, and abdomen). Induced fields were also computed at different points and graphically provided over different cut planes under different exposure conditions. Radiation conditions used in this study is summarized in Figure 3.

There are two parameters that define the exposure condition for plane wave exposure, namely the vectors **E** (wave polarization, or the electric field orientation), and the vector **S** (orientation of the propagation normal, i.e. direction of incidence). Considering the six different possible directions of incidence relative to human body (left, right, top, bottom, front, and behind) and two polarizations (vertical, horizontal), are twelve possible exposure conditions. However, the inherent symmetries of the body model reduce the number of possible exposure conditions to eight, as shown in Figure 3.

3- Results

First, field distributions in 2D images of the induced electric field of the body under different exposure conditions at various cut planes are given in Figure 4 to 6, and at a frequency of 70 MHz (the frequency of maximum field penetration inside the body model). The exposure conditions are indicated with the corresponding numbers in Figure 3 at the top left of each image. Second, field attenuation or

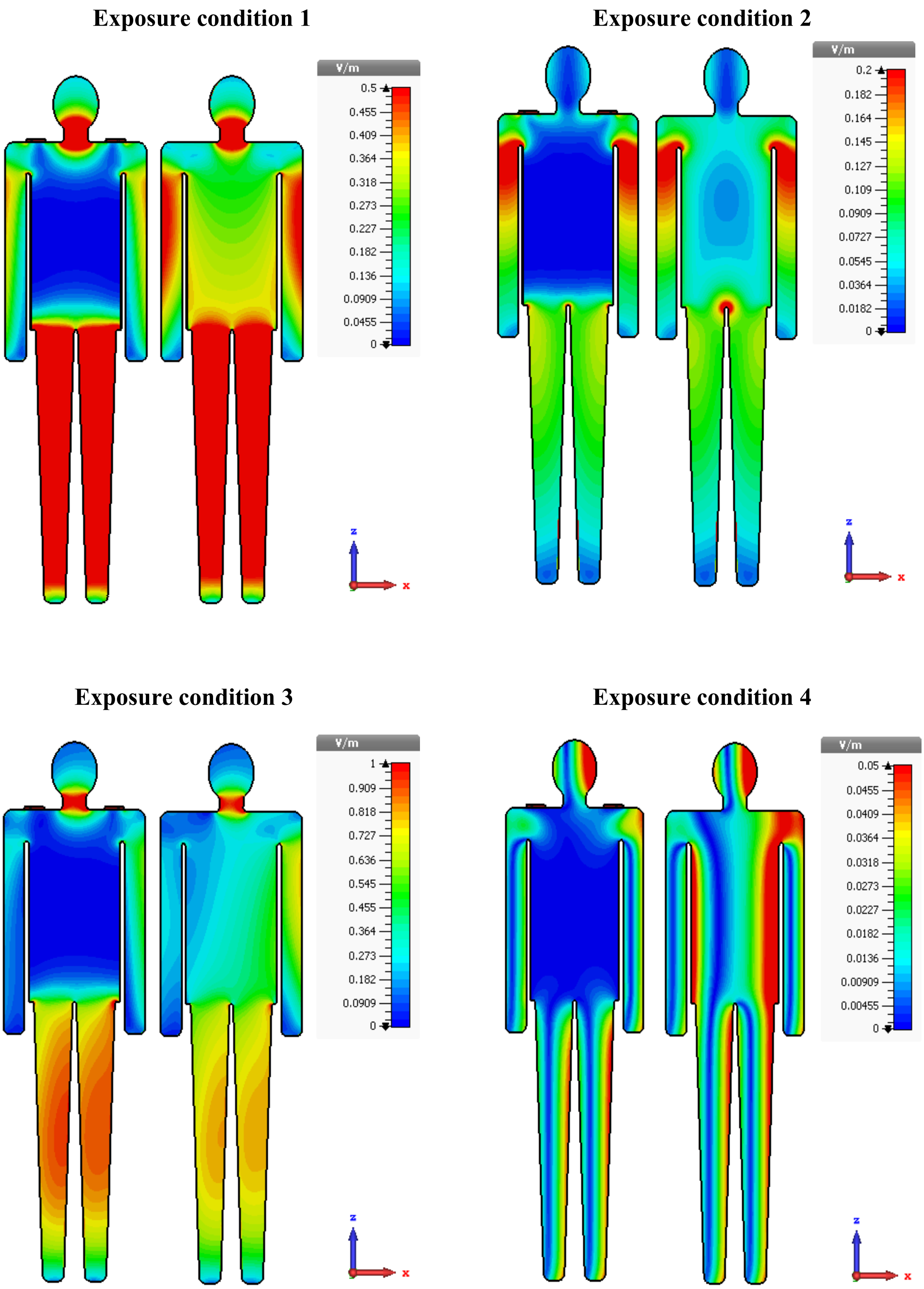

Fig. 4. 2D distribution of the induced electric field intensity at 70 MHz at the middle of the body (xz- plane). Without clothing (right) and with PEC clothing (left). (continued)

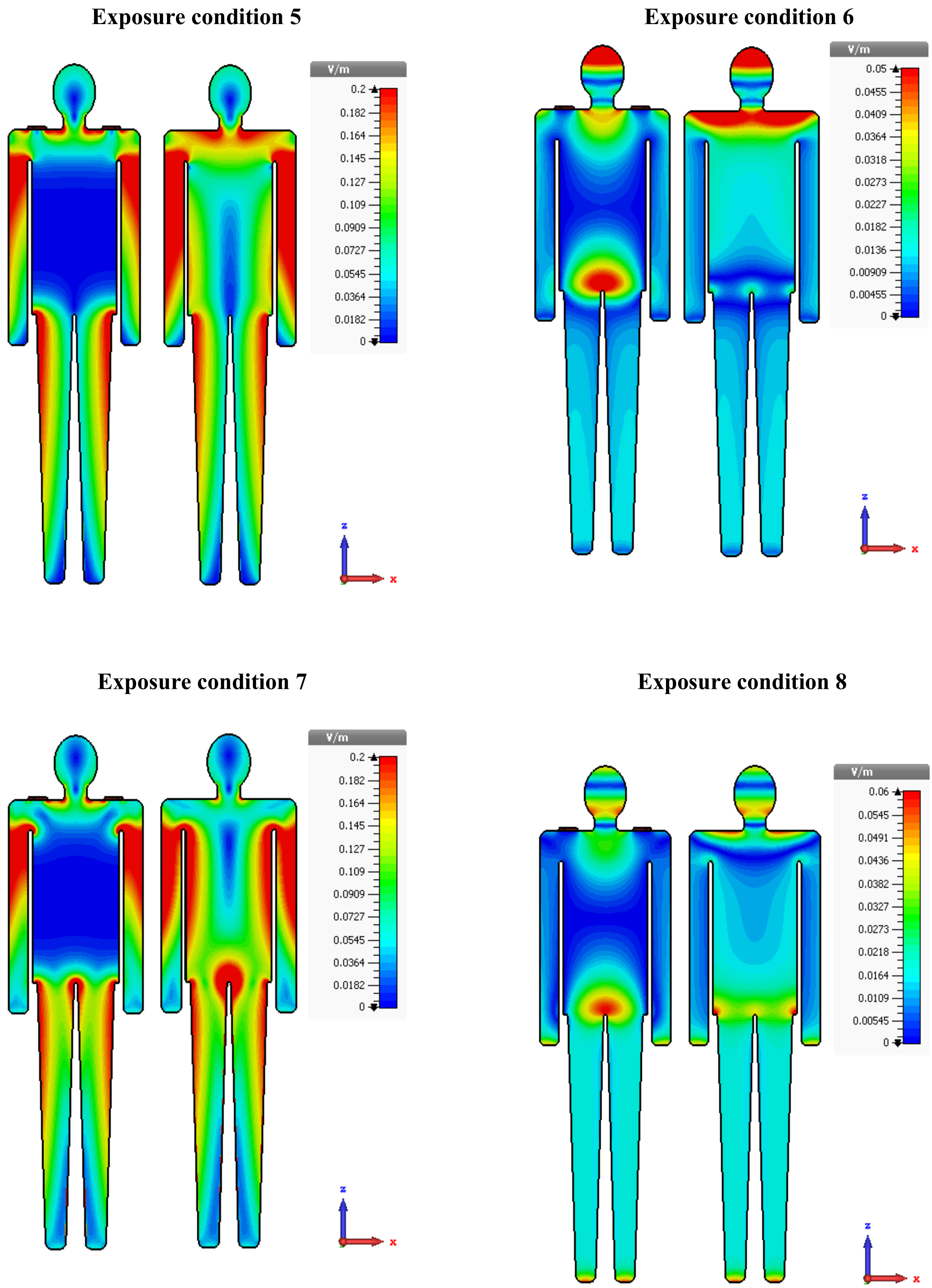

Fig. 4. 2D distribution of the induced electric field intensity at 70 MHz at the middle of the body (xz- plane). Without clothing (right) and with PEC clothing (left).

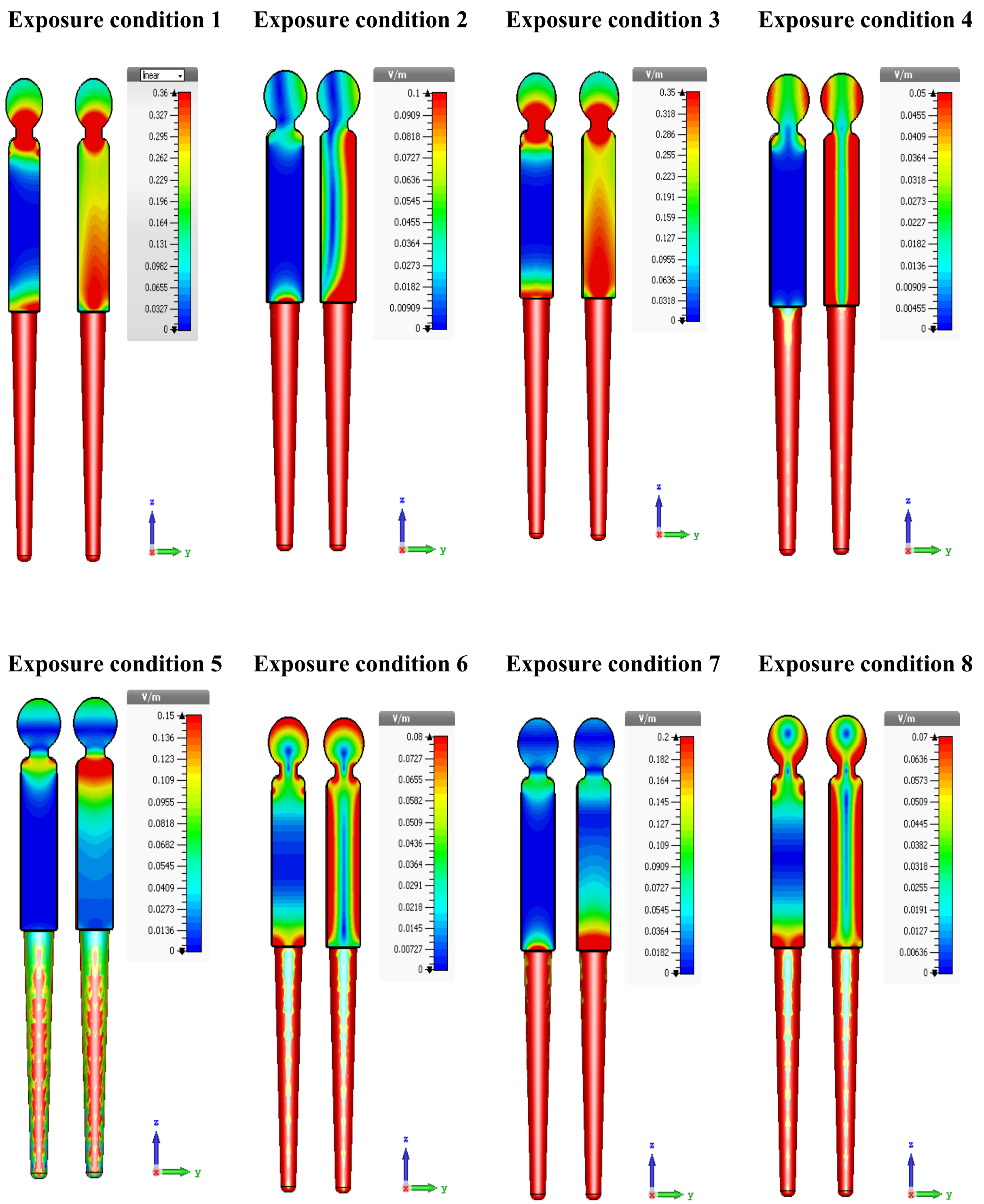

Fig. 5. 2D distribution of the induced electric field intensity at 70 MHz at the middle of the body (yz-plane). Without clothing (right) and with PEC clothing (left).

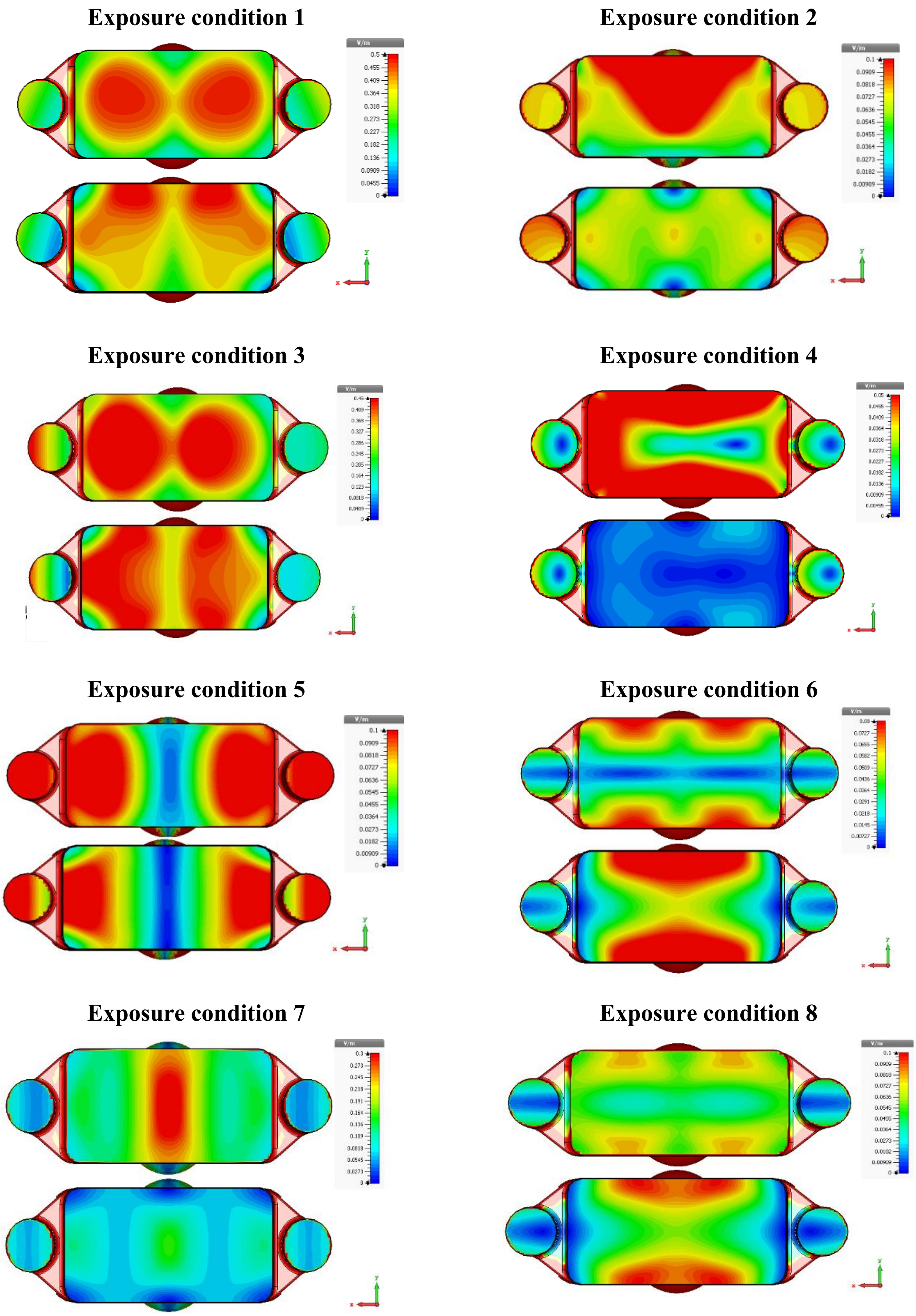

Fig. 6. 2D distribution of the induced electric field intensity at 70 MHz at the cut-plane in the abdominal region (approximate uterus position). Without clothing (top) and with PEC clothing (bottom).

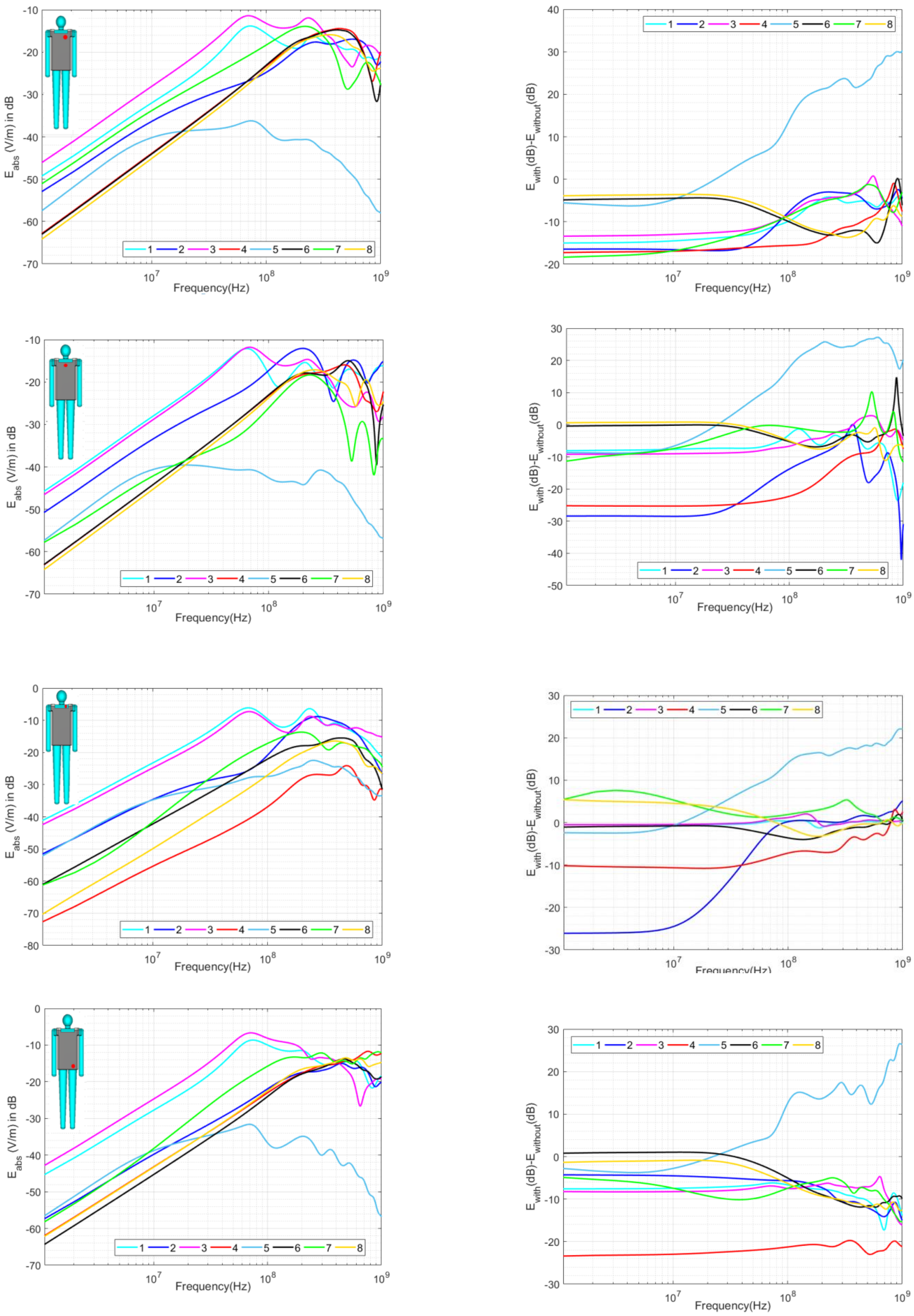

Fig. 7. Induced electric fields in the position of the heart (a), sternum (b), above the neckline (c), bottom corner of the cloth (d), top of the foot (e), below the armhole (f), uterus (g), knee (h); In each section, the left diagram is related to the induced electric field in the body without clothing. The right diagram shows the S.E. It should also be underlined that the PEC clothing in the body model inset is only included to indicate the relative location of the probe, and the plotted field intensity values are for the without-clothing model. (continued)

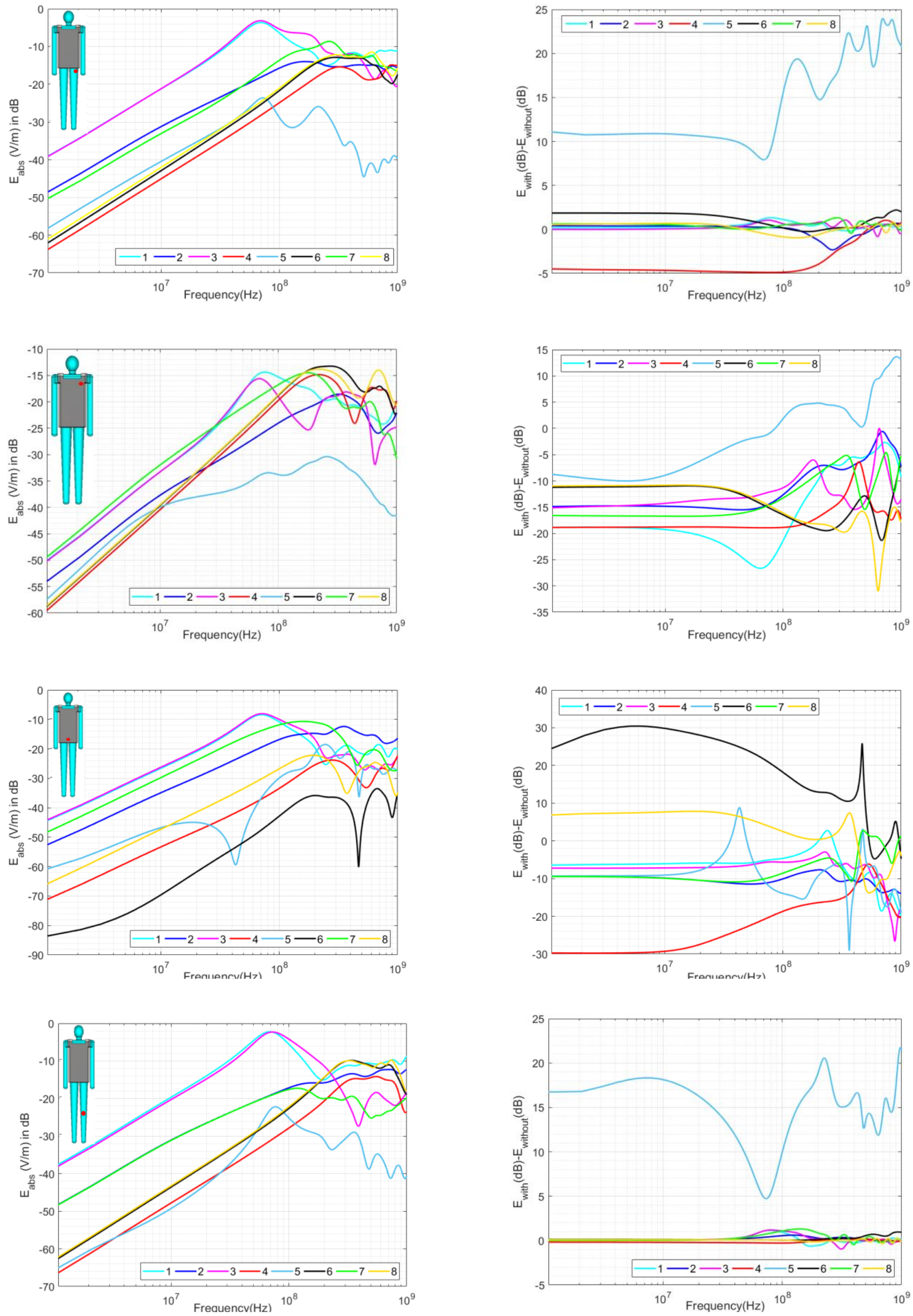

Fig. 7. Induced electric fields in the position of the heart (a), sternum (b), above the neckline (c), bottom corner of the cloth (d), top of the foot (e), below the armhole (f), uterus (g), knee (h); In each section, the left diagram is related to the induced electric field in the body without clothing. The right diagram shows the S.E. It should also be underlined that the PEC clothing in the body model inset is only included to indicate the relative location of the probe, and the plotted field intensity values are for the without-clothing model.

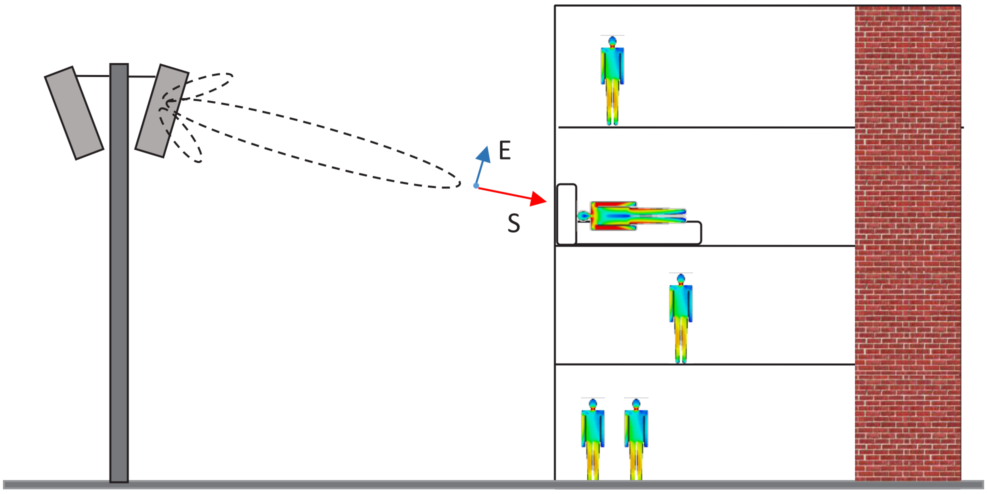

Fig. 8. The occurrence of body-axis exposure under real-life urban conditions is very probable. This simple drawing shows how radiation by a mobile Base Transceiver Station with it radiation pattern (shown with dotted line) can produce these radiation conditions for residents of a multi-story building

amplification due to anti-exposure clothing has been plotted as S.E. (Eq. (1)) versus frequency for selected locations inside the body.

At the end, the induced electric fields are given for the numerical probes embedded within the homogeneous tissue at different points and under different exposure conditions. The diagrams also show S.E., which is the dB-difference between fields in a "without clothing" state and "with the PEC clothing" state as in Eq (1). It shall be noted that protection corresponds to negative values of S.E., while positive values of S.E. represent undesired electric field amplification in the presence of PEC clothing (Figure 7). The dots on the body model (marked at the top of each diagram) refer to the location of the probe inside the body.

According to Figure 4, the protective clothing has a fairly good shielding effect. It should be noted under certain conditions of exposure. However, in conditions 5, 6, 7 and 8, amplification of the induced electric field is observed with the PEC clothing, In these cases, the field around the uterus has been mostly counter-protectively increased. Figure 5 illustrates the fact that the exposure conditions 1, 2, 4, 5, and 7 are among the cases where the protective effects of PEC clothing in the middle of the body is observed. However, the amplification of the induced field in the legs is observed under the third exposure condition, and the abdominal area experiences amplified field strengths under exposure conditions 6 and 8.

In Figure 6, adverse effect of PEC clothing in exposure conditions 1, 6 and 8 are well seen.

Counter-protective increase in field strength can be seen for the uterus position (g) under conditions 5,6,7,8. The results of point field values versus frequency in Figure 7 show that in the heart (a), except for exposure condition 5 where the amplitude of the field was up to 30 dB stronger with clothing, other cases were relatively protected, and the protective effect of PEC clothing was an attenuation up to 18 dBs. The same behavior applies to the sternum (b), with the difference that the shielding of the PEC clothing is close to 30 dB. The internal electric field above the neckline (c) shows conter-protection under exposure conditions 7 and 8 as well as 5. Exposure condition 5 also shows amplification for points (d), (e) and also below the armhole (f) and (h). It can be seen that angle/polarization condition 5 results in counter-protective increase of radiation at many locations within the body model. Generally, more pronounced amplifications are observed at higher frequencies (f>10MHz) and for conditions 5 to 8.

4- Discussion

The results clearly show that the clothing model is not capable of attenuating the incoming radiation at all frequencies or incidence angles. The fact that electric fields at certain polarizations are more penetrative in cases of protective clothing, has also been experimentally found in the literature. In a work comprising of several commercial samples of non-ionizing radiation protective suits, the attenuation by some suits have been shown to drop by about 18 dBs when polarization switches from parallel to perpendicular [11].

The fact that counter-protective amplification occurs more often above several tens of MHz and peaks at GHz frequencies, supports our intuitive understanding about the resonant nature of this effect. The half-wavelength between 100MHz and 1GHz ranges from 1.5 meters to 15 cm, quite comparable to the periphery of the clothing rim (e.g. around the waist).

A general understanding from our results is that the uterus position (g) does not receive good protection in the PEC clothing model under most exposure conditions, which is against the basic claim of the clothing advertisements. However, it can be seen that the amplification **is worse (higher) for waves penetrating the body from the ends, head or feet (i.e. along the body axis)** (conditions 5,6,7,8). This might be the most important outcome of these simulations.

The violation of the protective effects at the uterus are generally seen for conditions 5-8 (i.e. waves incident from top or bottom with the radiation direction along the body axis).

It is important to realize that waves incident from top or bottom can occur frequently in real-life situations, especially when electromagnetic fields from a mobile-phone base-transceiver station impinge on the body of a sleeping (horizontal) person along the body axis (Fig.8). To the best knowledge of the authors, this finding has not been reported elsewhere and constitutes the main qualitative outcome of this study.

5- Conclusion

In conclusion, the results indicate that clothing with a similar design to our model cannot protect the body at certain frequencies and under certain exposure conditions. Remarkably the EM fields are strongly intensified rather than attenuated under exposure conditions 5-8. These exposure conditions have the property in common that the waves are incident on the body in a direction parallel to the body axis (i.e. either from top or bottom).

The results of this study indicate that such clothings, if found necessary, have to be designed in a physics-aware manner, in order to keep with their intended performance. Obviously, this constitutes a whole new area of research for medical physics.

Acknowledgement

The authors would like to acknowledge the valuable comments and suggestions of F. Ehsan, which have improved the quality of this paper.

References

[1] R. Tinker et al A coherent framework for non-ionising radiation protection, J. Radiol. Prot. 42 (2022) 010501.

[2] N. Erdumlu, C. Saricam Electromagnetic shielding effectiveness of woven fabrics containing cotton/metal-wrapped hybrid yarns, J. Ind. Text. 46 (2016) 1084–1103. https://doi:10.1177/1528083715613628.

[3] S. N. Makarov et al., "Virtual Human Models for Electromagnetic Studies and Their Applications," in IEEE Reviews in Biomedical Engineering, vol. 10, pp. 95-121, 2017, doi: 10.1109/RBME.2017.2722420.

[4] R.P. Findlay, P.J. Dimbylow An investigation into the effectiveness of ELF protective clothing when exposed to RF fields between, Phys. Med. Biol. 57 (2012), https://doi:10.1088/0031-9155/57/9/2775.

[5] A.W. Guy, C. Chung-Kwang, J.A. McDougall, C. Sorensen, Measurement of Shielding Effectiveness of Microwave-Protective Suits, IEEE Trans. Microw. Theory Tech. 35 (1987) 984–994. https://doi:10.1109/TMTT.1987.1133796.

[6] C. Chung-Kwang, Guy A.W , J.A. McDougall, Shielding Effectiveness of Improved Microwave-Protective Suits, IEEE Trans. Microw. Theory Tech 35 (1987) 995–1001. https://doi:10.1109/TMTT.1987.1133797.

[7] S. Gabriel, R.W. Lau, C. Gabriel, The dielectric properties of biological tissues: II. Measurements in the frequency range 10 Hz to 20 GHz., Phys. Med. Biol. 41 (1996) 2251–69. https:// doi: 10.1088/0031-9155/41/11/002

[8] S. Gabriel, R.W. Lau, C. Gabriel, The dielectric properties of biological tissues: III. Parametric models for the dielectric spectrum of tissues., Phys. Med. Biol. 41 (1996) 2271–93. https://doi:10.1088/0031-9155/41/11/003

[9] C. Furse, D. Christensen, C. Durney, D.A. Christensen, C.H. Durney, Basic Introduction to Bioelectromagnetics, Second Edition, CRC Press, 2009. https://doi:10.1201/9781420055436.

[10] M. Saviz, L. Mogouon Toko, O. Spathmann, J. Streckert, V. Hansen, M. Clemens, R. Faraji-Dana, A New Open-Source Toolbox for Estimating the Electrical Properties of Biological Tissues in the Terahertz Frequency band, J. Infrared, Millimeter, Terahertz Waves. 34 (2013) 529–538. https://doi:10.1007/s10762-013-9997-z.

[11] A. W. Guy, Chung-Kwang Chou, J. A. McDougall and C. Sorensen, Measurement of Shielding Effectiveness of Microwave-Protective Suits, IEEE Transactions on Microwave Theory and Techniques, 35 (1987) 984-994. doi: 10.1109/TMTT.1987.1133796.

HOW TO CITE THIS ARTICLE

Z. Hajizadeh Bakhtiary, M. Saviz, The Effectiveness of Non-Ionizing Radiation Protective Clothing: A Computational Study, AUT J Electr Eng, 55(1) (2023) 81-90.

DOI: 10.22060/eej.2022.20912.5445