NUMERICAL DOSIMETRY SCHEMES FOR THE SIMULATION OF HUMAN EXPOSURE TO PULSED HIGH-POWER ELECTROMAGNETIC FIELD SOURCES

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Abstract — In this paper a numerical dosimetry scheme is proposed for pulsed electromagnetic high-power (HPEM) sources, which may induce biological effects such as "microwave hearing". This auditory effect is linked to the specific absorption (SA) of biological tissue which is subject to regulatory limits. The presented simulation scheme using high-resolution human body phantoms takes into account the wide spread spectral excitation range of pulse sources with the frequency dependency of dispersive biological tissue properties and of corresponding regulatory restrictions. Different examples of numerically computed and evaluated HPEM exposure scenarios are presented.

I. Introduction

Electromagnetic pulsed high-power sources are used e.g. for medical diagnosis in magnetic resonance imaging scanners or also for the disruption or destruction of electronic systems and equipment. Such systems are now of interest in terms of electromagnetically provoked biological effects in exposed human bodies. The resulting impact to the human body is quantified by physical basic parameters, such as specific absorption rates, electrical current densities, etc.. Varying with intensity, frequency and the direction of incidence of the electromagnetic immission, the admissible values of parameters (so-called "basic restrictions") for general public and for occupational exposure are recommended by various national and international guidelines (e.g. [1]).

In vivo measurements of the EM field distributions and thereby of the basic parameters within the human body are usually not possible. Alternatively, a numerical analysis based on FDTD simulations allows the usage of various highly resolved anatomically correct 3D computer models of humans and realistic configurations of EM sources including relevant environmental structures (e.g. [2]) In this paper we will show that such a computational analysis enables the prediction of power thresholds of different HPEM signals corresponding to the basic restrictions and the results can be assessed according to the requirements of the specific signal pulse form with respect to the tolerable EM exposure.

II. Pulsed HPEM Sources

Typical electromagnetic pulsed electromagnetics high-power field sources are distinguished in small-band (high-power microwave, HPM; damped sinusoidal, DS) or wide-band (ultra wide band, UWB) field sources. Fig. 1 depicts an example of an idealized 3ns UWB pulse and its corresponding widespread spectral density.

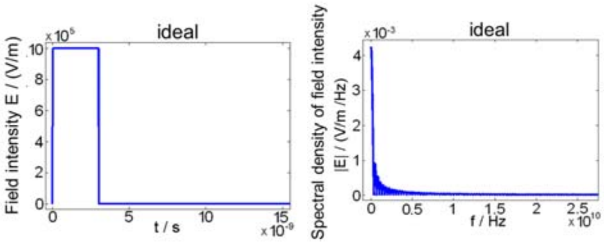

Fig. 1 Idealized representation of UWB electromagnetic pulse form in time and frequency domain

Measured pulse forms and corresponding spectra of typical pulse sources are given in [3].

III. Biological effects of Pulsed HPEM Sources

For continuous wave (CW) electromagnetic field exposure situations in the low-frequency the current densities induced in biological tissue are mainly considered because of their possible interaction with neural paths and muscle tissue contractions. For high-frequency CW exposure of biological tissue mainly the specific absorption rate in units Watt/kg averaged over 6 minutes of exposure time and different tissues portions for the assessment of thermal energy conversion effects.

For pulsed HPEM field sources, however, only the effect of "microwave hearing" is considered a crucial key effect in full body exposure situations due to the short duration of the pulses. It originates from very short time and small scale thermal heating due to field immission (in the range of 10^{-6} °C) induced in the head resulting in a thermoelastic expansion. This causes a mechanical shock wave inside the head tissue structure which couples into the inner ear and thus can be heard as clicking, humming or knocking noises. This auditory effect is mainly linked to the localized specific absorption (SA) in the head which is subject to ICNIRP basic restrictions in the head between 300 MHz and 10 GHz, i.e. the 10g specific absorption SA is restricted to 10 mJ/kg for occupational exposure and to 2 mJ/kg for general public exposure [1]. Results from experiments, however, show that auditory reception was also measured in a frequency range below 300 MHz and even below the 2 mJ/kg threshold [4] which is not covered in ICNIRP regulations.

IV. Numerical Dosimetry of Pulsed HPEM Sources

A. *Simulation Scheme for Small-band Sources*

For small band HPM and DS sources it is sufficient to perform a number of single frequency simulations. In simulations performed in this paper with human body phantoms, a plane wave excitation is performed at four different incident direction (front, back, right, left) in order to make sure that the maximum localized SA values are calculated in the head.

B. Simulation Scheme for Wide-band Sources

For UWB pulse source the problem arises that the wide band spectral excitation has to be considered along with the frequency dependent dielectric biological tissue properties. As a result, the computation of the resulting SA is performed in the frequency domain:

The normalized frequency-dependent $SA_{10g}^{head}(f)$ is weighted within the head with the normalized spectral power density function S_{UWB}^{f} of the UWB signal transmitted by the antenna and then integrated over the relevant frequency interval (here: 200 MHz to 3 GHz) and with this quantity the local SA maximum is searched:

$$\underset{\forall \vec{r}}{Max}\left\{\int_{200\,MHz}^{3\,GHz} \frac{1}{\Delta f}\frac{S_{UWB}^{f}(f)}{S_{UWB,\,norm}^{f}} \cdot \frac{SA_{10\,g}^{head}(f,\vec{r})}{SA_{10g,\,basic}^{head}(f)}\,df\right\} \le 1, \quad (1)$$

If the left hand side value in this eqn. (1) exceeds the value 1, then corresponding ICNIRP threshold value is exceeded. This approach allows to take into account frequency dependence of the dielectric properties of human tissue and the corresponding frequency dependent energy absorption while having to perform only FDTD simulation at single exposition frequencies, whereas a full transient signal frequency-dependent FDTD simulation requires a broad band energy deposition monitor [2].

V. NUMERICAL DOSIMETRIC FIELD SIMULATIONS

Numerical FDTD simulations are performed using the male and female high-resolution human anatomy voxel models “Duke” (72kg) and “Ella” (58 kg) of the IT’IS family of human body phantoms.

A. Localized SA Calculation for a HPM Source

For a HPM system FDTD single frequency simulations are performed ranging from 200 MHz ≤ f ≤ 3 GHz, assuming a pulse width of τ_p = 300 ns and a repetition rate f_R = 10 Hz. For each frequency, the maximum SA-value is taken from 4 different directions of incidence and the results are shown in Fig. 2. They show that for typical distances the SA_{10g} values in the head may be exceeded in such a HPM exposure situation.

B. Localized SA Calculation for an UWB Source

Fig. 3 shows how the normalized frequency-dependent $SA_{10g}^{head}(f)/\ SA_{10g,Basic\ restriction}^{head}(f)$ calculated in frequency intervals Δf is weighted with the normalized spectral power density function $S_{UWB}^{f}(f)/\ S_{UWB,Norm}^{f}(f)$ of an standard UWB signal. Scaling the results correspondingly achieved from multi-frequency superimposed SA calculation in eqn. (1) yields the following results: Only a peak electric field strength scaled up to large value of 207 kV/m will result in a $SA_{10\ g,\ max}$ of 2 mJ/kg in the head of the "Duke" model, i.e., due to the low energy content of the UWB pulse signal no microwave hearing is to be expected.

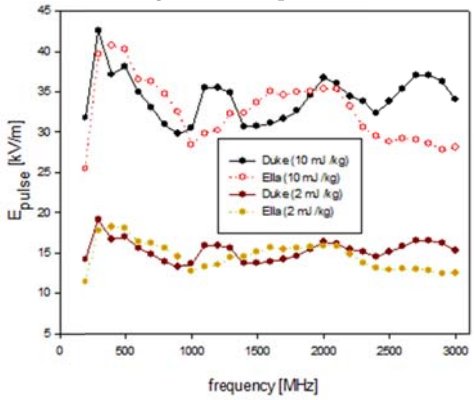

Fig. 2 Peak field values from an HPM source corresponding to the basic restrictions (occupational & general public) of the localized SA_{10g} values

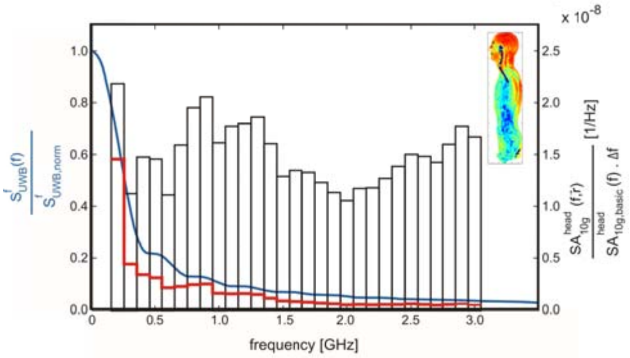

Fig. 3 Blue curve: normalized UWB signal spectral power density.

VI. CONCLUSION

Numerical dosimetry simulation techniques were presented for small-band and wide-band pulsed high-power electromagnetic field sources in order to assess the possibility of a microwave hearing effect. For this, FDTD simulations with high-resolution body phantoms were used for the calculation of basic restrictions values for the maximum specific absorption in the head (averaged over 10 g tissue). Numerical results were presented for a HPM and a UWB signal exposure. The full paper will also report on results for HPEM pulses within modern MRI systems.

VII. REFERENCES

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