Thermal Modeling for the Next Generation of Radiofrequency Exposure Limits

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Extended Abstract

We describe the use of simple models for heat transfer in tissue as they relate to the design of RF exposure limits in the frequency range from 6 GHz to 300 GHz, where the basic restriction limit is expressed in terms of the incident power density. This frequency range will be increasingly utilized by many consumer devices as new communications technologies (5G) are introduced.

The work considers thermal hazards only; "nonthermal" effects, which are occasionally reported in this frequency range, will need to be considered during revision of the guidelines but are outside the scope of this paper. We examine scaling principles that determine the thermal response of tissue to RF exposure over a broad frequency range (6-300 GHz); more detailed thermal models are examined in related work by Hirata and his group and presented elsewhere in this meeting.

We consider a simplified thermal model based on Pennes' bioheat equation (BHTE) using parameter values identical to those used in a commercial electromagnetic/thermal modeling program (IT IS) (as summarized in [1]). Tissue models include a seminfinite plane with dielectric properties characteristic of skin, and, in a second study, a multilayered skin-fat-muscle model. The thermal response was calculated numerically using a finite element program, or analytically for simple limiting cases. Results are described in detail in [2,3,4].

Summary of Results:

1. The simple BHTE model, with no adjustment in parameters, satisfactorily accounts for published data on human skin response to microwave exposure in the presently considered frequency range. However, the available data are very scattered, with limited ranges of exposure times, frequencies, and areas of skin exposed. In particular, virtually no data exist for steady state thermal responses of skin to RF exposure, a significant limitation.

2. The model suggests that present IEEE and ICNIRP exposure limits over the frequency range of 3-6 to 100 GHz (10 W/m^2) are very conservative as related to thermal hazards, with anticipated steady-state increases in skin temperature in the range of 0.1-0.2 ^{o}C. Anticipated thresholds for thermal hazards in this frequency range (thermal pain sensation, burns) correspond to skin temperatures of approximately 43-44 ^{o}C or about 9-10 ^{o}C above normal skin temperature of 34 ^{o}C.

3. Over the presently considered frequency range, times of the order of 10 min are required for skin temperature to approach the steady state for exposure areas greater than 1-2 cm^2. This suggests that the exposure guidelines should provide temporal averaging times of this order; by contrast the present guidelines specify temporal averaging times as low as 10 sec at 300 GHz. Additional limits, e.g. on fluence, are needed for extremely high amplitude but very short pulses.

4. Analytical solutions to the BHTE (the Green's function) and numerical experiments suggest that skin exposures should be averaged over areas of the order of 1-2 cm^2 (but somewhat smaller for very localized exposures). Both IEEE and ICNIRP guidelines specify considerably larger averaging areas. However the analytical solution to the BHTE does not provide a rigorous definition of "averaging area" as it appears in the exposure guidelines and the high level of conservatism in the current or foreseeable guidelines allows considerable flexibility in choice of these parameters in the guidelines.

The above considerations suggest that exposure limits and averaging area and time specified in current IEEE and ICNIRP guidelines should be reconsidered in future revisions of the guidelines. The present exposure limits to arbitrary areas of skin (10 W/m^2 between 10-300 GHz for ICNIRP and between 3-100 GHz for IEEE) are far more conservative with respect to potential thermal hazards than ICNIRP limits for far infrared radiation, which also has a very short penetration depth in skin. This work was supported in part by Microwave Manufacturers Forum (MMF).

References

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