Effect of tissue parameters on skin heating due to millimeter EM waves

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***Abstract*— This paper investigates the influence of electrical and thermal human tissue parameters on the heating of a body illuminated by a millimiter plane electromagnetic wave. A stochastic approach is considered with a three-layer model of the body: it is found that the parameters of skin play a major role.**

***Index Terms*—dosimetry, millimeter wave propagation.**

I. Introduction

The increasing application of millimeter electromagnetic (EM) waves makes important the investigation of their effects on human health, in particular the related heating of tissues. In the present work, we use a 1D model, previously developed under steady-state conditions [1], to evaluate the heating of tissues when exposed for a limited time to a 100 GHz linearly polarized plane wave, carrying a unitary power density and normally incident to the body surface. The human body is modeled as a stratified structure with 3 layers: skin, subcutaneous adipose tissue (SAT) and muscle. Due to the large variability in electrical and thermal characteristics found in the literature for each of these layers, the main purpose of the paper is to investigate the influence of tissue parameters in the thermal response of the body. Helmholtz's electromagnetic equations are solved analytically [1], to compute the volume power density P_{em} transferred by the field to the tissues. Then, P_{em} becomes the source term for the bioheat equation [2], which is solved by Finite Elements in the time domain through a Crank–Nicolson procedure. An exposure of 1 s followed by a "cooling period" of 100 s is simulated and the maximum temperature elevation θ_{max} is analyzed.

II. Results of Variability

The input parameters reported in Table I are taken into account in a stochastic approach [3]: the permittivity ε_r, the electrical conductivity σ, the thermal conductivity λ, the perfusion coefficient h_b and the specific heat capacity ρc_s are varied according to the variability found in literature. It is assumed that all the parameters are independent and follow a uniform distribution. The stochastic method is based on a polynomial chaos expansion of θ_{max} and requires simulations of the numerical model above described for judicious values of the input parameters. Using polynomials of order 3, the algorithm converges with 439 simulations. Figure 1 gives the probability density function computed from the polynomial chaos expansion. The stochastic method also gives the partial variance and the total effect [4] of the different input parameters (Table II – no significant effect is found for missing parameters). The skin seems to be the most influential tissue, as expected since the millimeter EM wave does not significantly penetrate the other tissues. Moreover, the electrical parameters (ε_r and σ) are uncoupled from the thermal ones (λ and ρc_s) since the total effect and the partial variance are the same for thermal parameters: this result is more surprising because P_{em}, the source term for the thermal equation, depends on electrical parameters.

TABLE I
Range of variation for the parameters of the model

	Skin	SAT	Muscle
ε_r	2.8 – 8.4	3.67	8.63
σ (Sm^{-1})	19.7 – 59.1	10.6	62.5
λ (Wm^{-1}°C^{-1})	0.32 – 0.50	0.16 – 0.50	0.32 – 0.56
h_b (kWm^{-3}°C^{-1})	3.34 – 12.3	1.15 – 4.75	1.31 – 6.49
ρc_s (MJm^{-3}°C^{-1})	3.46 – 4.12	1.47 – 3.08	2.73 – 4.48
Thickness (mm)	1 – 4	1.5 – 10	∞

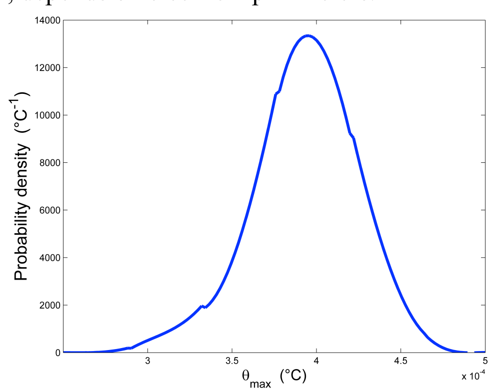

Fig 1: probability density function of θ_{max} (cf. Table I)

TABLE II
Sensitivity analysis

Parameter	Partial Variance (%)	Total effect (%)
ε_r skin	28.2	36.2
σ skin	20.8	29.1
λ skin	23.3	23.9
ρc_s skin	18.9	19.0
Thickness skin	0.3	0.4

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