The Role of Skin in mm-Wave Exposure of Human Body

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***Abstract*—The advent of 5G/B5G wireless communications networks has stimulated research efforts in assessing health effects of human tissues exposure to electromagnetic fields (EMF). In this paper, we investigate the role of skin thickness in the exposure of human body to EMF at mm-Waves. Different skin models and dielectric characterizations, including layered skin, are studied using the equivalent multi-layer model framework. Simulation analyses show that as frequency increases the impact of changes in the dielectric and geometric characterization of the skin is less and less relevant due to the decreasing penetration depth. Additionally, the presence of stratum corneum determines an increased power absorption.**

I. Introduction

Wireless technologies operating in the mm-Wave spectrum, such as 5G/B5G mobile networks, have been experiencing a wide spreading in the last decade. However, besides the much larger bandwidth and data rates enabled by mm-Waves with respect to lower frequencies, the development of such wireless systems is also raising concerns in general public about potential health effects [1]. To promptly face such concerns, the International Commission on Non-Ionizing Radiation Protection (ICNIRP), has recently released updated guidelines on safe radio-frequency (RF) exposure [2]. For unrestricted environment/general public local exposure in the frequency range >6 GHz to 300 GHz, which is of interest in mm-Wave applications, reference levels have been provided in terms of frequency-dependent incident power density S_i as follows

$$S_i = \frac{55}{{f_G}^{0.177}} \qquad (1)$$

where f_G is the operating frequency in GHz. The expression in (1) has been derived from basic restrictions, which are specified in terms of absorbed power density, assuming normal incidence, as it is recognized as the worst-case exposure scenario [3]. Actually, (1) should ensure an absorbed power density not larger than the basic restriction, i.e., 20 W/m^2 for general public, in most exposure scenarios.

In this paper, we focus on the role played by the skin in case of local exposure, as it is well recognized that mm-Wave exposure is limited to superficial tissues. More specifically, we analyze the effects of skin thickness and dielectric characterization on the local absorbed power density.

II. Human Skin Model

In this paper, two planar models of human skin commonly adopted for local exposure analysis are compared in terms of absorbed power density, see Fig. 1. The three-layer model includes homogeneous skin, subcutaneous adipose tissue (SAT) and muscle; a layered skin, comprising stratum corneum (SC) and viable epidermis and dermis (ED), is conversely assumed in the four-layer model. Radio-frequency (RF) power absorption is studied by means of the equivalent transmission line (ETL) model, whose secondary constants are shown in Fig. 1.

Assuming an incident plane wave, the power density locally absorbed by human body can be written as

$$S_{ab} = S_i cos\,\vartheta (1 - |\Gamma_{AA}(\vartheta)|^2) \qquad (2)$$

where ϑ is the incidence angle and Γ_{AA} is the (complex) reflection coefficient at the air-skin and air-SC interfaces in the three- and four-layer model, respectively.

The reflection coefficient depends on both the geometric, i.e., thickness d_i, and electromagnetic, i.e., complex dielectric constant, parameters of the layered model and can be evaluated in a straightforward way from the ETL model. In (2), the term $S_i \cos\vartheta$ can be easily recognized as the normal component of the Poynting vector associated to the incident plane wave, i.e. the component of the Poynting vector actually contributing to the power flux through the interface.

III. MM-Wave Exposure Analysis

For the exposure analysis, we assume an incident power density set according to (1), i.e., the maximum value allowed by ICNIRP at the considered frequency. Unless otherwise stated, all layers are characterized according to a multiple-term Cole-Cole model with Gabriel's fitting parameters [5]. Additionally, d_3 = 3 mm. RF power absorption is studied in the following configurations:

- Model #1 (3-layer model): skin thickness d'_1 varying in the range [0.47, 1.16] mm.
- Model #2 (4-layer model): SC thickness d_1 = 10 μm; ED thickness d_2 varying in the range [0.46-1.15] mm.
- Model #3 (4-layer model): SC thickness d_1 varying in the range [10, 700] μm; ED thickness d_2 = 0.46 mm.

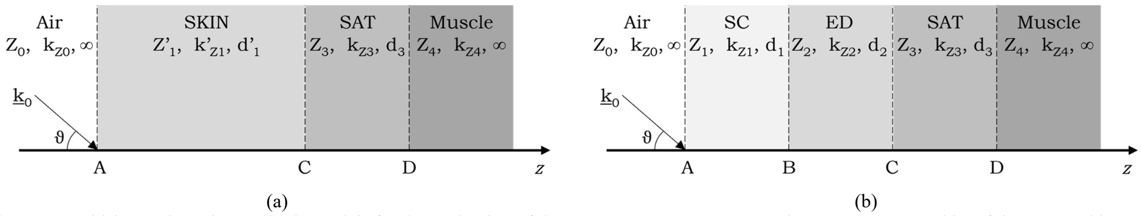

Figure 1. Multi-layer planar human body models for the evaluation of the mm-Wave exposure. Secondary constants Z_i and k_{zi} of the ETL and layers thickness d_i are shown. (a) three-layer model; (b) four-layer model.

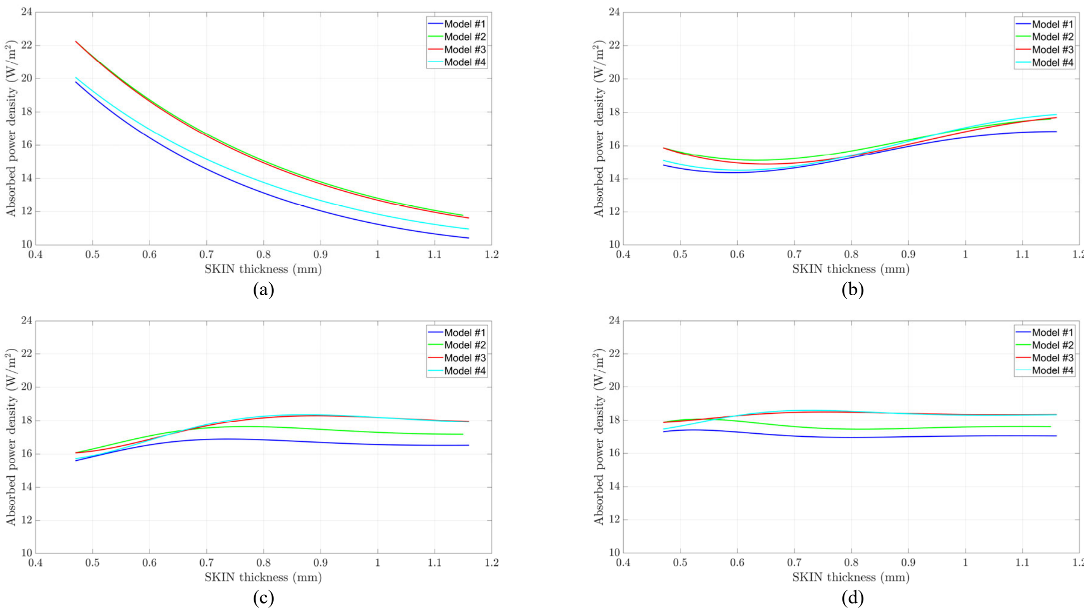

Figure 2. Absorbed power density as a function of skin thickness at (a) 10 GHz, (b) 30 GHz, (c) 60 GHz, (d) 100 GHz.

- Model #4 (4-layer model): same as Model #3, but the dielectric characterization of ED is the same as the homogeneous skin in Model #1.

Layers thickness is in accordance with [3].

Numerical results relevant to the four analyzed models are shown in Fig. 2, where skin thickness has to be intended as the sum of SC and ED thicknesses in the four-layer models.

IV. Discussion

Numerical results in Fig. 2 show that:

- The presence of the SC determines a larger absorbed power, irrespective of thickness and frequency (compare three-layer models with four-layer model).
- Dielectric characterization of ED becomes less and less influent on S_{ab} as frequency and skin thickness increase. This is in accordance with decreasing penetration depth with increasing frequency (compare Model #4 with Model #1 and Model #3).
- Sensitivity of absorbed power density to skin layering increases with increasing frequency (compare Model #2 and Model #3).
- Sensitivity of absorbed power density to skin thickness decreases with increasing frequency irrespective of skin modeling due to the decreasing penetration depth.
- In specific configurations (low frequency, low skin thickness, four-layer model, see Fig. 2(a)), basic restrictions are violated.

References

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