Impact of the Near-Surface Body Model on the User Exposure in mmWave 5G Bands

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***Abstract*—This paper present three different models to account for the effect of ageing, clothing and surface curvature on absorbed power density (S_{ab}). The analysis is conducted at 26 GHz and 60 GHz. The study shows that aging results in variations of the averaged absorbed power density $S_{\mathrm{ab}}^{\mathrm{av}}$ within 10% and comparable with the ones induced by inter-individual differences. When a textile is present, the variations of $S_{\mathrm{ab}}^{\mathrm{av}}$ reach 41.5% at 26 GHz, while the peak averaged absorbed power density can increase up to 72.3% for a 1 mm curvature radius at 26 GHz.**

***Index Terms*—mmW, 5G, ageing, textile, surface curvature**

I. Introduction

With the diffusion of 5G and future generations of mobile networks new frequency bands will be exploited to satisfy the requirements in terms of wide bands and high data rates. Some of these frequencies will approach or be included in the millimeter-wave (mmW) range that have never been used in the previous generations and will expose the entire population to new frequencies. At mmW, due to the high computational cost, it is almost impossible to simulate complex anatomical structures and simplified models are typically preferred. Mono-layer or multi-layer planar models are usually chosen to evaluate the exposure [1]–[3]. However these models do not fully take into account the realistic exposure conditions that may be impacted by age variations, the presence of textile in contact or in the vicinity of the skin, and the curvature radius of the surface. For this reason, in this abstract we will present different models to evaluate the exposure for such conditions with a special focus in 26 GHz and 60 GHz.

II. Materials and Methods

To account for the variations induced by age, clothing, and curvature radius, we considered the models reported in Figure 1. For age variations we used a planar multi-layer model composed by stratum corneum (SC), epidermis (E), viable dermis (D), fat and muscle (Figure 1a). The skin thickness was modified according to the typical variations associated with the ageing process [4], [5], while for the tissue permittivity variations we used the Lichtenecker's exponential law [6] that allows to relate the water content variations to the complex permittivity. The thicknesses of SC and fat were set to 15 µm and 4 mm, respectively.

For the effect of textile we used the same planar multi-layer model proposed for ageing impact evaluation, but we set the permittivity values to the ones typical for adults [7] (Figure 1b). We considered wool ($\varepsilon = 2 - j0.04$) and cotton ($\varepsilon = 1.22 - j0.036$) as reference textiles and we varied their thickness and the distance between the textile and the skin in the range 0–3 mm.

Finally, for the surface curvature variations we used a homogeneous cylindrical model with an infinite extension along its axis and with a radius varying in the range 1–15 mm (Figure 1c). This is supposed to be representative for some of the most exposed body parts including the ear and the finger.

All the models were illuminated with a normally impinging plane wave. Additionally, two different polarization were considered for the curved model.

III. Results

Figure 2a shows the effect of the variation of tissue permittivity and skin thickness with age on the averaged absorbed power density ($S_{\mathrm{ab}}^{\mathrm{av}}$). While skin thickness has a negligible impact [6], given the reduction of water content with age, the effect of permittivity and thickness combined is responsible for an increase of $S_{\mathrm{ab}}^{\mathrm{av}}$ with age. These variations are at most of 6.9% compared to a 35 years old adult and are comparable with the variations that may occur for inter-individual differences.

When adding a textile layer in contact with the skin, it may act as a matching layer and increase the absorption. $S_{\mathrm{ab}}^{\mathrm{av}}$ is maximized if the textile thickness is close to $(2n+1)\lambda/4$, n being an integer and λ the wavelength inside the material (Figure 2b). For the considered materials and frequencies, $S_{\mathrm{ab}}^{\mathrm{av}}$ is 41.5% higher than the value for nude skin at 26 GHz and 34.4% at 60 GHz. If an air gap between the textile and the skin is considered, when setting the textile thickness to its typical value (2 mm for wool and 0.2 mm for cotton), $S_{\mathrm{ab}}^{\mathrm{av}}$ is increased up to 8.6% at 26 GHz and 13.9% at 60 GHz compared to the nude skin case.

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Figure 1: Tissue models for the evaluation of EM power absorption: (a) as a function of age, (b) in presence of a textile, and (c) for curved body surfaces.

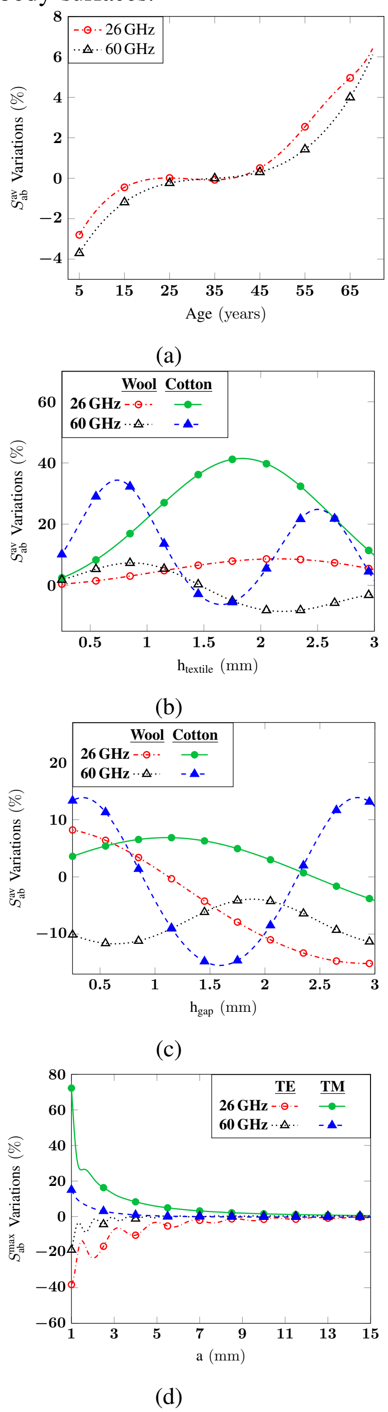

Figure 2: S_{ab} variations induced by (a) age, (b) textile in contact with the skin, (c) textile separated from the skin by an air gap, and (d) body curvature radius.

For the electromagnetic (EM) power absorption in curved body parts, we considered S_{ab}^{max} instead of S_{ab}^{av}, since for almost the whole considered range of radii (a) the circumference was shorter than 2 cm, making not possible to compute a surface average over a 4 cm^2 square area. Independently of the polarization of the impinging plane wave, as a approaches 10 mm, S_{ab}^{max} tends to the value for a planar homogeneous model. For $a = 1$ mm, S_{ab}^{max} is decreased of −38.2% for transvers electric (TE) polarization and increased of 72.3% for transvers magnetic (TM) polarization at 26 GHz compared to the planar skin homogeneous model. At 60 GHz, the S_{ab}^{max} variation is equal to −18.7% and 15% for TE and TM polarization, respectively.

IV. Conclusion

In this study, we modeled the impact of age, clothing and surface curvature on the EM power absorption. Variations of the cutaneous skin thickness and tissue permittivity with age on S_{ab}^{av} result in an enhancement up to 6.9% compared to a 35 years adult taken as a reference. A textile layer in contact with skin can result in an increase of S_{ab}^{av} up to 41.5% at 26 GHz compared to nude skin, while it can reach 72.3% for $a = 1$ mm at 26 GHz when compared to a planar skin model.

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