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# User Exposure in mmW Bands: Impact of Age, Textile and Body Curvature

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**Abstract**—With the upcoming deployment of 5G and B5G, new frequencies, absent from the natural electromagnetic (EM) spectrum, have been proposed for wireless communications. In this study, we investigate the variations of the human body exposure in real conditions at 26 GHz and 60 GHz as a function of age, textile presence, and local body curvature radius. The analysis revealed that aging induces variations of the averaged absorbed power density within 10%. At 26 GHz, the variations reach 41.5% in presence of a textile for the averaged absorbed power density and 72.3% for the peak absorbed power density when the curvature radius is of 1 mm.

**Index Terms**—5G, absorbed power density ( $S_{ab}$ ), age, clothing, curvature radius.

## I. INTRODUCTION

Following the increasing demand for high data rate communications, millimeter-wave (mmW) frequencies are increasingly used for 5G, internet of things (IoT), augmented reality, etc. [1], [2]. As a consequence, in the near future, the population will be exposed to mmW frequencies currently absent from the natural electromagnetic (EM) background. Given the shallow penetration depth of mmW, whole-body models, used at lower frequencies, cannot be directly used at mmW [3], [4]. As an alternative, in the past few years, many research groups proposed to use planar mono- or multi-layer models that locally approximate the body surface [5]–[10]. These generic models are designed to analyze local exposure, without dealing with the complexity of realistic exposure use cases. The aim of this paper is to investigate how the EM exposure varies at 26 GHz and 60 GHz when accounting for the variability of the biological tissue properties with age, presence of a textile, and body curvature.

## II. MATERIALS AND METHODS

Three different models have been considered. The distribution of the EM field was computed analytically, and validated numerically using COMSOL Multiphysics.

### A. Age

To account for age variations, a four layer tissue model composed of stratum corneum (SC), ED (viable epidermis and dermis), fat and muscle was considered (Figure 1a). A normally impinging plane wave was used as EM source. The skin thickness was modified according to the measured values available in literature [11], [12]. The permittivity as a

function of age was computed according to the Lichteneckers exponential law [13].

### B. Textile

To evaluate the exposure in presence of a textile interposed between the EM source and skin a 4-layer tissue model, similar to the one proposed for the effect of age analysis, was used. A textile layer was added, in direct contact with skin or separated by an air gap (Figure 1b). The skin thickness and tissues' permittivity were set to the typical values [9], [14], [15]. Two representative textile materials were considered (cotton and wool), and their permittivity and typical thicknesses were measured [15].

### C. Curvature Radius

If the ratio between the penetration depth and body curvature radius exceeds 5, a planar approximation of the model is no longer valid [16]. To evaluate the exposure in these specific conditions, we used a homogeneous cylinder to locally model the body surface (Figure 1c). The cylinder radius was varied in the range 1–10 mm to represent the fingers and the external portion of the ear, the most exposed parts of our body in the phone call scenario. The model was illuminated by transvers electric (TE) and transvers magnetic (TM) plane waves.

### D. Exposure Metric

Above 6 GHz, due to the shallow penetration depth (0.85 mm at 30 GHz), the specific absorption rate (SAR) is no more considered as an appropriate metric to evaluate the exposure. The new metric recently proposed by International Commission on Non-ionizing Radiation Protection (ICNIRP) and International Electrical and Electronics Engineers (IEEE) to estimate the exposure is the absorbed power density [17], [18]

$$S_{ab} = \frac{1}{A} \int_A \mathbf{E} \times \mathbf{H}^* \cdot d\mathbf{s}, \quad (1)$$

where  $\mathbf{E}$  and  $\mathbf{H}$  are the electric and magnetic fields,  $d\mathbf{s}$  is the infinitesimal normal vector, and  $A$  is the averaging area. For general public, this value should not exceed  $20 \text{ W/m}^2$  for  $A = 4 \text{ cm}^2$ . As an additional constraint, to account for narrow beams, at frequencies above 30 GHz  $S_{ab}$  should remain below  $40 \text{ W/m}^2$  for  $A = 1 \text{ cm}^2$ .

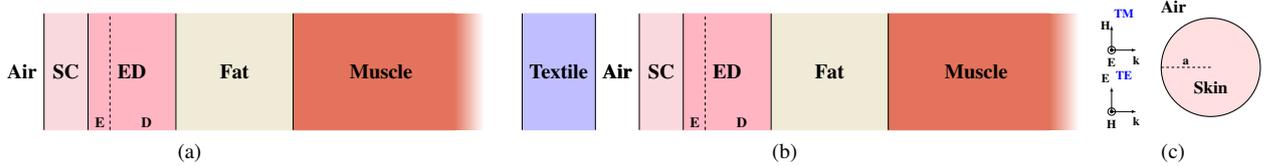


Figure 1: Tissue models used to investigate EM power absorption: (a) as a function of age, (b) in presence of a textile, and (c) for curved structures.

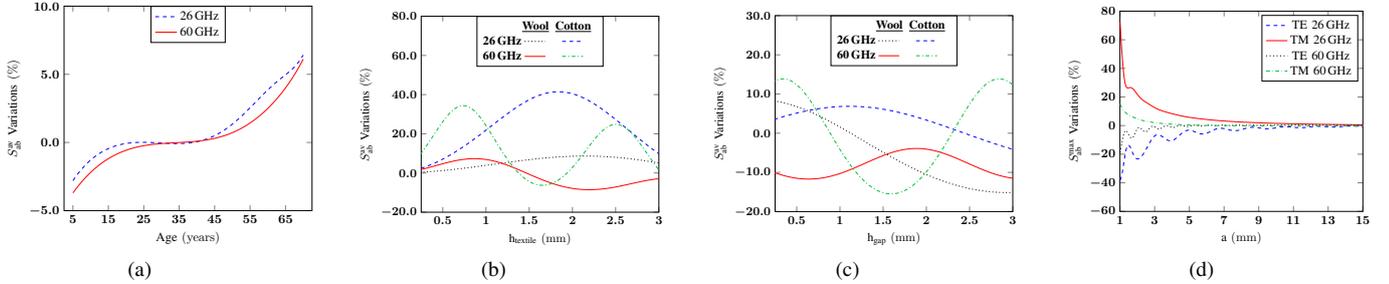


Figure 2: Variations of the  $S_{ab}$  with respect to the case of a planar homogeneous skin model (a) as a function of age, (b) textile thickness, (c) air gap thickness in presence of a textile, and (d) body curvature radius.

### III. RESULTS

#### A. Age

The effect of tissue permittivity and skin thickness variation with age on the averaged absorbed power density ( $S_{ab}^{av}$ ) is shown in Figure 2a. While the skin thickness has almost no impact [13], the combination of the two parameters results in an increase with age, due to the reduction of the water content and consequently of the contrast between skin and air. The variations are within 6.9% compared to a 35 years old adult, considered as reference.

#### B. Clothing

A textile layer in contact with skin, depending on its thickness and permittivity, can modify the matching between skin and air, leading to a potential increase in the power absorption.  $S_{ab}^{av}$  is maximized for a textile thickness close to  $(2n + 1)\lambda/4$ ,  $n$  being an integer and  $\lambda$  the wavelength inside the textile material (Figure 2b). The absorption is increased up to 41.5% at 26 GHz (for a cotton 1.84 mm thick layer) and 34.4% at 60 GHz (for a cotton 0.74 mm thick layer). When considering an air gap between the textile (2 mm for wool and 0.2 mm for cotton) and skin, the  $S_{ab}^{av}$  reaches 8.6% at 26 GHz for a wool 0.1 mm thick layer and 13.9% at 60 GHz for a cotton 2.84 mm thick layer.

#### C. Curvature radius

For the evaluation of the exposure in curved body parts, since for almost the whole considered range of  $a$  the circumference was shorter than 2 cm, averaging over a  $2 \times 2 \text{ cm}^2$  or even  $1 \times 1 \text{ cm}^2$  surface was not possible for all the considered model dimensions. To this end, we preferred to consider punctual values instead of averaged ones. As  $a$  approaches

10 mm,  $S_{ab}^{max}$  tends to that for the planar interface. The highest differences are observed for  $a = 1 \text{ mm}$  and correspond to  $-38.2\%$  for TE and  $72.3\%$  for TM polarization at 26 GHz, while they reach  $-18.7\%$  (TE polarization) and  $15\%$  (TM polarization) at 60 GHz.

### IV. CONCLUSION

In this study, we investigated the effect of ageing, textile, and body curvature radius on the absorbed power density. To evaluate the exposure, in the first case a 4-layer tissue model, accounting for the skin thickness and tissues' permittivity variations as a function of age, was used. To consider the impact of textile, an additional layer with the properties of wool or cotton was added on the top of the multi-layer tissue model in contact with it or separated by an air gap. The effect of curvature radius in the 1–10 mm range is analyzed using a cylindrical homogeneous skin model.

Variations of the cutaneous skin thickness with age has almost no impact on  $S_{ab}^{av}$ . However, variations of the tissue permittivity with age may result in a  $S_{ab}^{av}$  enhancement up to 6.9%. A textile or a curvature radius (comparable with the wavelength) can lead to a more pronounced increase. For example, for a textile in contact with skin  $S_{ab}^{av}$  can be up to 41.5% higher than for nude skin at 26 GHz, while  $S_{ab}^{max}$  can reach 72.3% at 26 GHz for  $a = 1 \text{ mm}$ .

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