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Age Dependence of Human Exposure in Emerging 5G Bands: Comparison between Plane-Wave Exposure and Multi-Beam Antennas

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Abstract

The fast development of the 5th generation (5G) mobile networks and human-centered communications is leading to the increasing proliferation of wireless devices resulting in ubiquitous exposure of people of all ages. This study investigates the effect of ageing on the power deposition at 26 GHz and 60 GHz, frequencies upcoming for 5/6G. The exposure under near-field conditions induced by multi-beam radiating structures is compared to the one induced by a plane wave. The highest variation of the averaged absorbed power density with respect to the typical value for adults is observed at 70 years and corresponds to 8.8% at 26 GHz and 6.9% at 60 GHz. The maximum decrease is obtained for children at 5 years and is of −4.5% at 26 GHz and −3.7% at 60 GHz. At 26 GHz, the plane-wave model results in an underestimation of the averaged power density variations obtained with a multi-beam antenna, while at 60 GHz the variations with the two sources of exposures are almost identical.

1 Introduction

Dictated by the need for secured communications and high data rates, the frequency bands upcoming for the 5th and future generations of wireless networks are progressively shifting towards the millimeter waves (MMW). With the increasing diffusion of wireless technologies, the number of people using radiating devices is continuously expanding. Tablets and mobile phones are entering in the daily lives of more and more children and seniors, thus requiring an accurate exposure assessment as a function of age. While at lower frequencies this has already been investigated [1–5], there remains a gap of knowledge on age-dependence at MMW, in particular for realistic sources. The ageing effect was partly discussed considering a normal impinging plane wave [6] but it is still necessary to compare this exposure condition to a scenario considering realistic antennas under near-field conditions.

With the shift towards MMW, due to the higher losses in this frequency range, phased array with multi-beam directive antennas are usually preferred to omnidirectional ones. In addition, many designs proposed in the literature prefer edge antennas than broadside ones, due to the lower shadowing effect of the user [7–10].

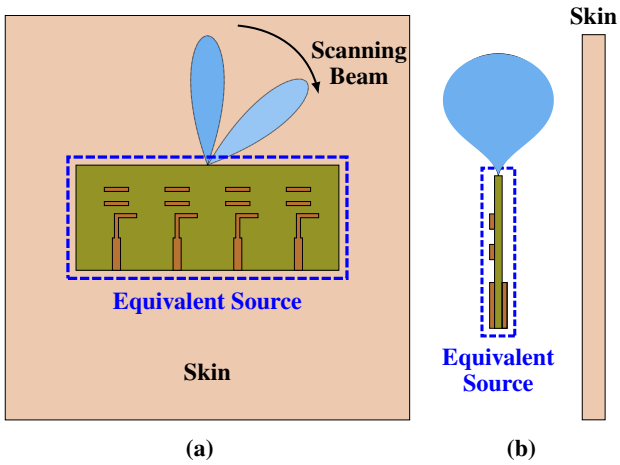


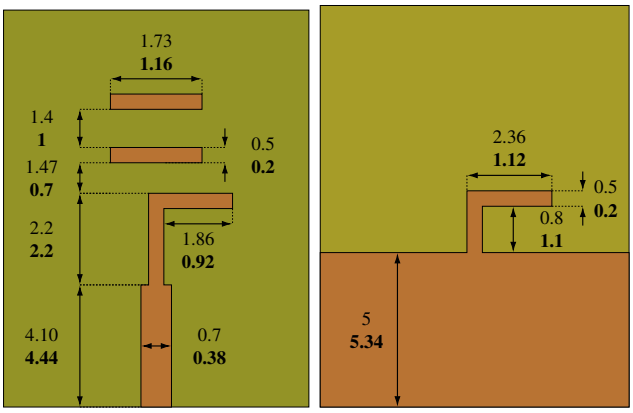
Figure 1. Exposure scenario: (a) front and (b) lateral view (the dimensions are not to scale).

In this paper, we investigate how the exposure varies as a function of age when considering a multi-beam antenna as a source at 26 GHz and 60 GHz. These results are then compared to the ones for a plane wave. For the sake of simplicity, since the power absorption mechanism at 26 GHz is similar to the one in the lower part of the MMW spectrum, 26 GHz is referred as MMW.

2 Materials and Methods

The considered exposure scenario (Figure 1) is representative of a configuration in which the wireless device is positioned next to the user (e.g., during a phone call).

Two Yagi antennas (one per frequency) inspired from the recent literature works were designed on a RO4350B substrate ($\varepsilon_r = 3.48$, $\tan\delta = 0.0037$) [11]. The chosen substrate thickness is 0.508 mm at 26 GHz and 0.254 mm at 60 GHz and the inter-element spacing is 5.77 mm at 26 GHz and 2.34 mm at 60 GHz. The remaining dimensions are reported in Figure 2. Depending on the phase shift α at the array input ports it is possible to steer the beam. Figure 3 represents the antenna radiation pattern for $\alpha = 0°$



(a) (b)

Figure 2. Yagi antenna geometry: (a) top and (b) bottom. The dimensions (in mm) in regular font refer to 26 GHz and the ones in bold to 60 GHz.

and $\alpha = 142.5°$ corresponding to a main beam direction of 0° and 45°, respectively.

To exclude from the analysis the coupling between the body and the antenna, already discussed in [12], the radiating device is replaced by an equivalent source. The currents on the equivalent source were computed in free space on the box surrounding the 4-element array ($27.33 \times 14.02 \times 2.93\,\text{mm}^3$ at 26 GHz and $17.05 \times 12.36 \times 1.39\,\text{mm}^3$ at 60 GHz).

To represent the human tissues, a planar skin model (6 cm × 6 cm × 2 mm at 26 GHz and 4 cm × 4 cm × 1 mm at 60 GHz) is used. This approximation is justified by the fact that at these frequencies the typical radius of the body curvature exceeds by five times the penetration depth [13]. The skin complex permittivity computed with the age-dependent model reported in [6] at 26 GHz and 60 GHz is represented in Figure 4.

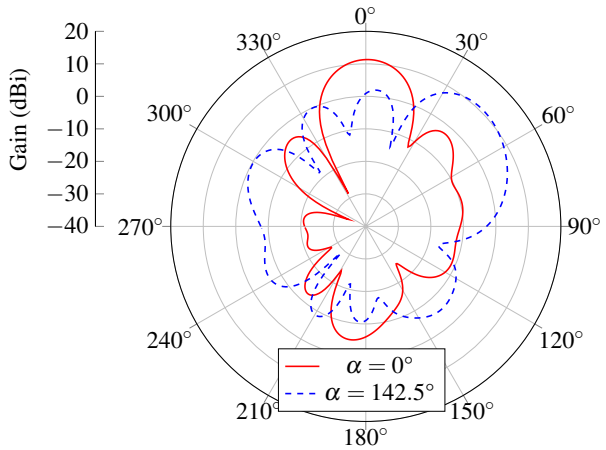
3 Results

In the 6–300 GHz range, as suggested by International Commission on Non-ionizing Radiation Protection (ICNIRP) and International Electrical and Electronics Engineers (IEEE) [14,15], the metric used to assess the exposure is the absorbed / epithelial power density

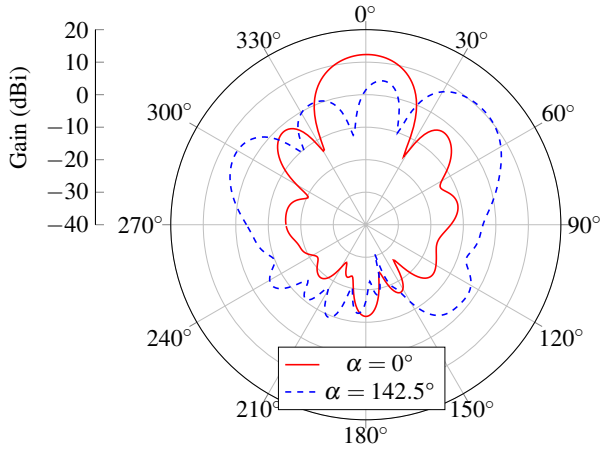
$$PD_{av} = \frac{1}{A}\int_A \frac{1}{2}\text{Re}\left[\mathbf{E}\times\mathbf{H}^*\right]\cdot d\mathbf{s}\,, \qquad (1)$$

where **E** and **H** are the electric and magnetic fields, respectively, d**s** is the normal to the surface, and $A = 4\,\text{cm}^2$ is the averaging area.

In simulations, the distance between the equivalent source and the skin model is set to 0.5 cm, corresponding to typical mobile phone thickness. The variations of the PD_{av} as a function of age and in respect to the value for a 35 years old adult [16] are represented in Figure 5.

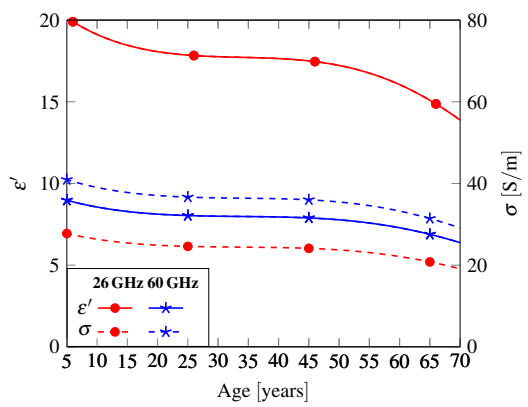


(a)



(b)

Figure 3. Radiation patterns (a) at 26 GHz and (b) 60 GHz for $\alpha = 0°$ and $\alpha = 142.5°$.



(a)

Figure 4. Permittivity ε', and conductivity σ as a function of age at 26 GHz and 60 GHz.

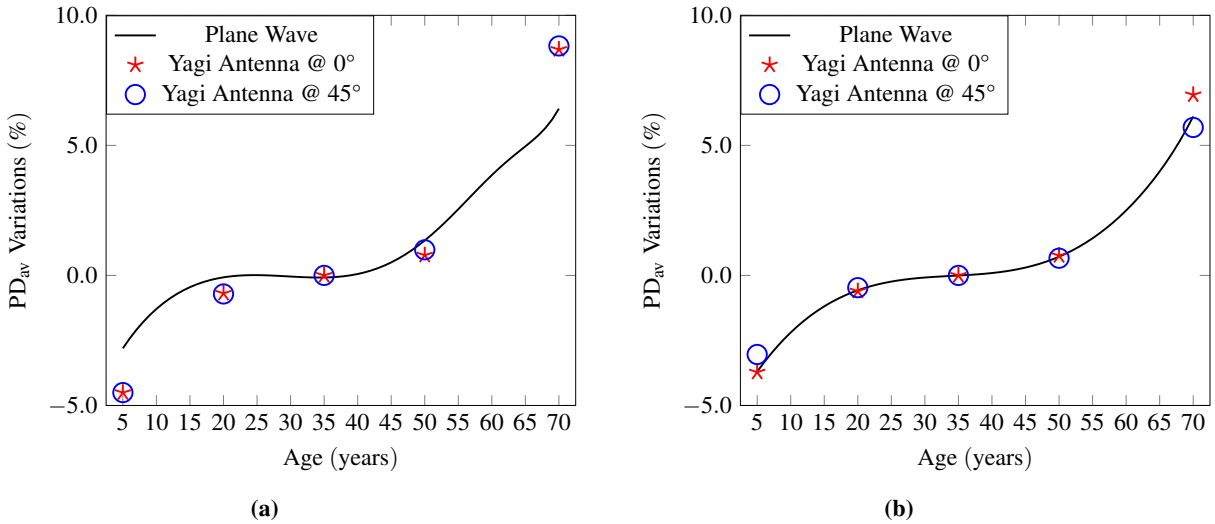


Figure 5. PD_{av} variations as a function of age with respect to the reference value (35 years) at: (a) 26 GHz, (b) 60 GHz.

PD_{av} was computed when considering the Yagi antenna pointing at the broadside (0°) and at 45°. These data are compared with the ones obtained with a plane-wave illumination [6]. Both for the Yagi antenna and plane-wave illumination, the highest increase is observed for seniors (70 years old), while the maximum decrease is for children (5 years old). A plateau is observed between roughly 20 and 50 years. The age-dependent variations can be explained by decrease of the water concentration with age responsible for decrease of the complex permittivity. The lower water concentration for older ages results in reduction of the contrast between skin and air leading to an increase with age of the absorbed power density.

The PD_{av} decrease for a 5 years old child is between −4.5% (Yagi antenna) and −2.8% (plane wave) at 26 GHz, while the variations are almost identical for the antenna and the plane wave exposure (−3 to −4%) at 60 GHz. For the 70 years old model, the PD_{av} increase is between 6.4% (plane wave) and 8.8% (Yagi antenna) at 26 GHz and between 5.7% to 6.9% at 60 GHz. Note that for all exposure conditions the PD_{av} changes are of the same order of magnitude of the typical inter-individual variations (10–15%).

4 Conclusion

This study analyses the effect of ageing on the averaged absorbed power density (PD_{av}) in a skin-equivalent model under near-field exposure conditions. A representative multi-beam radiating structure is used as a source at the frequencies upcoming for 5G and future generations wireless networks (26 GHz and 60 GHz). The results are compared with the ones obtained when considering a normal impinging plane wave as an exposure source.

For all the exposure conditions, PD_{av} increases with age. The maximum increase with respect to the reference value at 35 years corresponds to 8.8% at 26 GHz and 6.9% at 60 GHz and is reached for a senior (70 years old). The lowest decrease is at 5 year and is −4.5% at 26 GHz and −3.7% at 60 GHz.

At 26 GHz, the results for a plane-wave illumination represent an underestimation of the PD_{av} variations. At 60 GHz, the variations obtained with a plane wave and a realistic antenna are almost identical. The age-dependent variations are comparable to the typical inter-individual differences and do not exceed the safety margins suggested by the standards and the guidelines (factor of 50 for general public and 10 for occupational exposure).

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