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Variability of near-surface tissues absorbed power density at mmWave frequencies

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Abstract

The rapid deployment of 5G and the development of 6G networks have increased human exposure to millimeter-wave (mmWave) electromagnetic fields, which are largely absorbed by near-surface tissues due to their limited penetration depth. In this frequency range, the absorbed power density (S_{ab}) is the primary dosimetric quantity used to quantify energy deposition in superficial tissues. S_{ab} is influenced by several factors, including anatomical site, tissue structure and thickness, hydration, age [1], clothing [2] and environmental conditions such as skin temperature, as well as inter-individual variability. Accurate dosimetric assessment requires consideration of these factors, since assumptions of uniform adult bare skin may underestimate or overestimate exposure for specific individuals or scenarios. In this context, this study investigates the variability of S_{ab} induced by plane-wave exposure at 26 GHz and 60 GHz across three body sites palm, head, and ear under various exposure scenarios accounting for age, skin temperature, and textile layers. Near-surface tissues are modeled as planar multi-layer structures, including stratum corneum, epidermis dermis, fat, and muscle, with cartilage specifically for the ear, and tissue permittivity is adjusted according to age and temperature models reported in the literature and calculated. Prior studies have demonstrated that clothing, body site, and age can influence mmWave absorption, highlighting the need for site-specific and scenario-specific evaluations to ensure accurate human exposure assessment.

The analysis considers both individual and combined parameter effects to study the possible variations in S_{ab} . Individual parameter assessments allow identification of the contribution of age, temperature, and clothing to absorbed power variability for each on-body site. Combined scenarios, such as age with temperature and age with clothing, highlight potential interactions that can either amplify or mitigate the overall absorbed power, emphasizing that single parameter evaluations may not capture the full complexity of realistic exposure conditions. The study also explores body site specific differences in variability, showing that anatomical features, layer thicknesses, and local tissue properties can modulate the absorption pattern. By providing a systematic framework for evaluating S_{ab} variability, this work offers insights for more realistic dosimetric models and supports risk assessment in mmWave communication environments. Overall, the findings highlight the importance of incorporating coupled parameter effects, anatomical specificity, and temperature-dependent dielectric properties to accurately quantify human exposure at mmWave frequencies.

References

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