Comparison between planar multilayer vs realistic anatomical models for dosimetric analysis of plane wave propagation in biological tissues

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In the last decades, the interest towards the use of electromagnetic (EM) waves for biomedical applications with particular regard to biomedical sensors as wearable devices, is growing, supported also by the availability of increasing powerful computers able to simulate more and more realistic anatomical regions in more and more complex scenarios. The use of reliable simulation software has many advantages, such as, for example, it offers the possibility to evaluate almost in real time the performance of any electromagnetic wave-based system in the presence of biological medium, as well as the response of tissues when they are invested by radiation, in a perfectly controlled and noise-free environment.
In several cases, for example when the working frequency is in the range of millimeter waves, the various anatomical districts are modeled as a series of planar layers and the uniform plane wave approximation is used. Uniform plane waves represent, indeed, the simplest solutions of Maxwell's equations, and for this reason this approximation is used to describe the propagative behavior of electromagnetic waves, as well as their behavior in the presence of one or more media. However, a detailed study of the impact that this approximation has on the accuracy of the results obtained has not yet been addressed.
We aim to evaluate the validity limits of this approximation, as a function of anatomical region (thus different radii of curvature), frequency and different directions of EM wave propagation. Specifically, in this abstract the anatomical region of the wrist (thus, small radius of curvature compared to microwaves wavelength) was analyzed and the results simulated with two different simulation software, Sim4life and Ansys Electronics Desktop, respectively, were compared at 1.5 GHz and 24 GHz and reported in Fig. 1 for the lower frequency of interest.
In the full wave simulation with Ansys Electronics Desktop software, the wrist was modeled as a planar geometry, infinite in the plane normal to the propagation vector of the wave. The dielectric properties of the individual biological layers, at the specific frequency, were derived from the IT'IS database [1]. The area of the structure was 400 cm^2 (λ_{aria}@1.5 GHz), and the thickness of the individual layers was: skin 2.2 mm, subcutaneous fat 2.5 mm, tendon ligaments 3.3 mm, subcutaneous fat 19 mm, muscle 13.5 mm, tendon ligaments 5 mm, and skin 3 mm.
For both simulation approaches a plane wave with 1 V/m of amplitude was considered.
The simulated wrist model in Sim4life is shown in Figure 1-left. The green line passes through different tissues, each with a different thickness, corresponding to the ones also simulated in Ansys. In Figure 1-right, the comparison between the electric field amplitudes in the structure obtained with the two simulators is shown, and a similar trend can be appreciated.

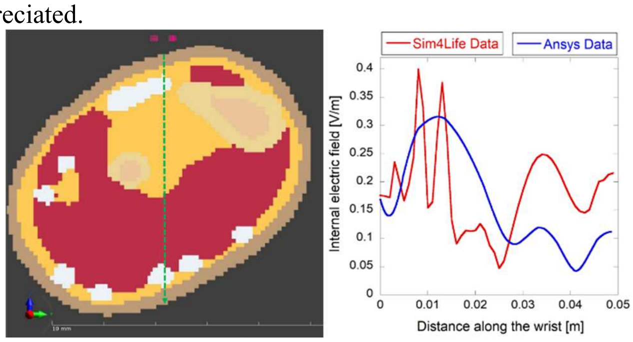

Figure 1. (Left) Simulated wrist model with sim4life. (Right) Plot of the electric field as a function of the distance with the simulated model with Ansys (blue line) and Sim4life (red line).

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References

[1] P.A. Hasgall, et al., “IT’IS Database for thermal and electromagnetic parameters of biological tissues,” Version 4.0, May 15, 2018, DOI: 10.13099/VIP21000-04-0.