Ta, Thanh Tam Julian; Schiffarth, Anna-Malin; Bornkessel, Christian; Schilling, Lisa-Marie; Hein, Matthias; Heberling, Dirk:

Ray tracing-based analysis of the influence on the scattering of the electric field caused by the measuring person at 6G frequencies

DOI: 10.22032/dbt.65211

URN: urn:nbn:de:gbv:ilm1-202520019

This publication was produced within the framework of the event:

Conference: BioEM 2024 – the 3rd annual conference of BioEM ; (Chania, Crete, Greece) : 2024.06.16-21.

Published online: 06.03.2025

Ray Tracing-based Analysis of the Influence on the Scattering of the Electric Field Caused by the Measuring Person at 6G Frequencies

Thanh Tam Julian Ta[1], Anna-Malin Schiffarth[1], Christian Bornkessel[2], Lisa-Marie Schilling[2], Matthias Hein[2] & Dirk Heberling[1,3]
[1]Institute of High Frequency Technology, RWTH Aachen University, Aachen, Germany
[2]RF & Microwave Research Laboratory, Thuringian Center of Innovation in Mobility, TU Ilmenau, Ilmenau, Germany
[3]Fraunhofer Institute for High Frequency Physics and Radar Techniques, Wachtberg, Germany

INTRODUCTION

Constantly increasing demands on mobile communications require continuous development of the network and technologies. Therefore, many institutions are already working on the next mobile network generation 6G, which is expected to work on the same frequency as 5G New Radio (410 MHz to 7.125 GHz and 25.25 GHz to 71 GHz [1]) as well as the sub-THz frequencies (90 GHz – 300 GHz) [2]. For radiation protection it is important to obtain reliable data on the actual electromagnetic exposure to ensure that the exposure safety limits according to the International Commission on Non-Ionizing Radiation Protection (ICNIRP) [3] are not exceeded. However, the person performing the measurement can be a significant source of uncertainty on the assessment of radio frequency (RF) exposure. Due to the presence of the person, the electric field can be distorted. Furthermore, reflection occurring from the body can superimpose with the incident waves and lead to a standing wave with constructive and deconstructive interferences. This may lead to a misinterpretation of the actual exposure. The uncertainty caused by reflection from a body has been estimated in [4] by simulations for the frequencies in the range from 0.3 MHz to 10 GHz. In [5] a measurement-based investigation was performed for GSM, LTE and 5G in sub-6 GHz frequency range and for 5G in frequency range 2 (FR2) at 27 GHz for an indoor and outdoor scenario. A numerical follow-up and extension of these studies for higher frequencies and different incident angles using ray tracing method in CST Studio Suite 2023 is presented here. The frequencies analysed were 27 GHz, 60 GHz, 80 GHz and 100 GHz.

SIMULATION SETUP AND MODEL

In the ray tracing simulation, the Virtual Population V2.0 Duke body model [6] was used to represent the body of the person performing the measurement. As in [4], the body model was standing on a perfectly electric conducting ground and was exposed to a vertically polarised wave. Three different scenarios for excitation angles were analysed. The first scenario is based on the same orientation as in [4]: a frontal exposure without elevation. The second scenario had an elevation angle of 25° and the third an additional lateral shift of 30°, as illustrated in Fig. 1(a) where the arrows only indicate the direction of the plane wave.

As the analysis solely considered measurement uncertainties resulting from reflection of the body, and the penetration depth is less than 1 mm at frequencies above 30 GHz [3], the simulation only considered the model's surface. Therefore, the model was defined as a full solid object and the material parameters were set to the electrical conductivity and permittivity of human skin, as provided in [7], which are based on [8].

In analogy to the sweeping method used in exposure assessment, a 'sweeping volume' was defined to evaluate the electric fields at different points within a volume, which was positioned 1 m above the ground and 50 cm from the centre of the model’s chest. The volume has been adapted to the shoulder width and height of the model and covered an area 64 cm wide, 80 cm high and 20 cm deep, which is similar to a typical measured sweeping volume. However, the CST Field Monitor has limitations when using the ray-tracing method, as it can only analyse 2D-planes. As a result, the volume was divided into multiple planes. The number of planes had to be limited to 30 in order to keep computational time and memory requirements to a reasonable level. The planes had a spacing of 0.66 cm, so that they were not multiples of half the wavelength of the chosen frequencies apart. The simulation model with the excitation angle and three evaluation planes are shown in Fig. 1 (a) and the "sweeping volume" in Fig. 1 (b).

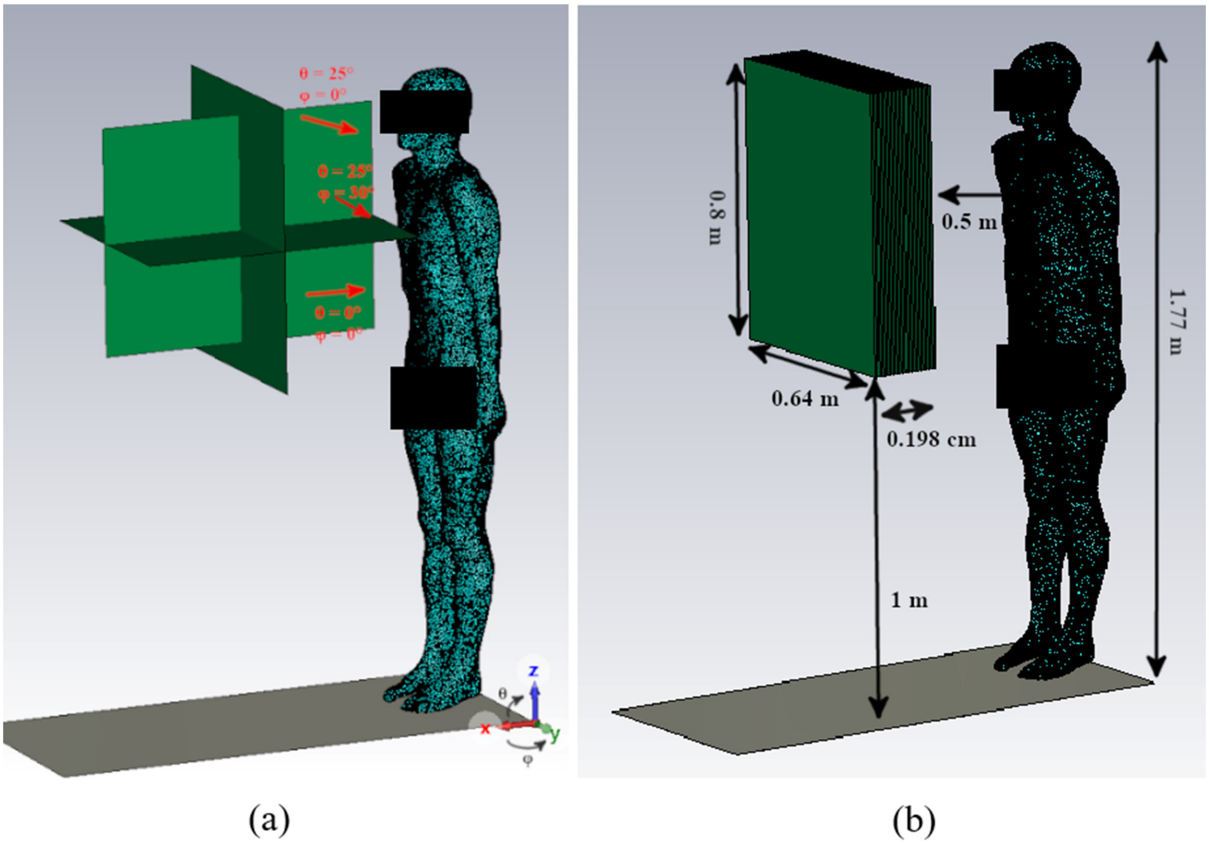

Figure 1: Simulation body model standing on a perfectly electric conducting ground with different incident angle of the electromagnetic wave and three evaluation planes (a) and the defined "sweeping volume" (b).

RESULTS

To gain insight into how the electric field can be distorted by reflection on the body model, a section of the planes perpendicular to the front of the model was first examined. On a flat surface, a standing wave would be expected. Figure 2(a) and (b) show the electric field distorted by the body model with a representation of a standing wave in the bottom right corner. The images show a distorted, very faintly pronounced standing wave pattern.

To estimate the uncertainty caused by the reflection of the measuring person, the field strength obtained from the simulation with the body model was compared with the field strength without reflections to calculate the electric field variation in dB, as done in [3]. As mentioned in [9], in practice, the root mean square (RMS) values of three collocated orthogonal antennas are measured and the isotropic value is calculated to ensure that the exposure estimate for a specific point in space is independent of the polarisation and direction of propagation of the field. Therefore, the RMS for each sampling point inside each plane was calculated with and without reflection and used to determine the highest difference across all planes.

Table 1 shows the highest electric field variation in dB for different frequencies and incident angles. The largest electric field variations were observed for the frontal exposure without elevation at 27 GHz, with 14.5 dB. By looking at the different frequencies, it can be seen that the variations are lower at higher frequencies. However, comparing 80 GHz with 100 GHz, the differences for the frontal exposure are the same. When looking at the different incident angles it can be seen that when looking at the different excitation angles of 27 GHz and 60 GHz, the electric field variations differs by up to 3.4 dB. At 80 GHz and 100 GHz, the differences between the chosen incident angles were smaller, with a maximum of 1.3 dB.

Frequency (GHz)	Highest variation in the RMS values in dB		
	θ = 0° φ = 0°	θ = 25° φ = 0°	θ = 25° φ = 30°
27	14.5	12.7	11.6
60	13.4	11.8	10.1
80	10.4	10.6	9.7
100	10.4	9.8	9.1

Table 1: Highest field variation in dB at different frequencies and incident angles across all planes.

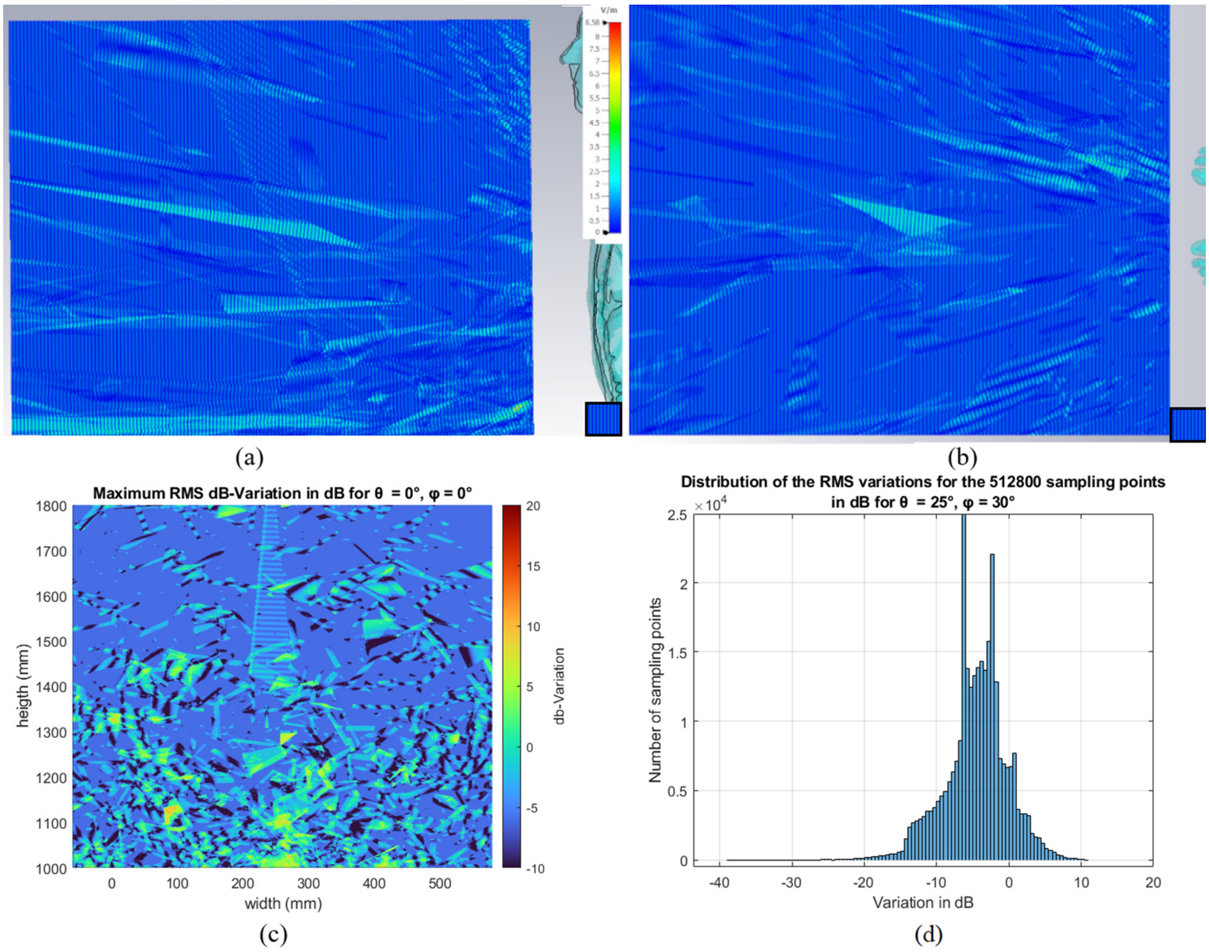

Figure 2: Top view (a) and side view (b) perpendicular to the body showing a distorted very faintly pronounced standing wave pattern caused by reflection of a frontal incident wave at 27 GHz. Electric field variations in the plane 50 cm in front of the body at 27 GHz for excitation angle at θ = 0° and φ = 0° (c) and the distribution of these variations with 249400 sampling points between -6.5 dB and -6 dB (d).

Upon looking at the highest electric field variations for each frequency and excitation angle, these were higher than 9 dB. However, at closer inspection of the single planes for each simulated frequency and incident angles, it becomes apparent that these high variations occur only in very small spots. Fig. 2 (c) illustrates the electric field variations in the plane 50 cm in front of the body model at 27 GHz for a frontal incident wave. By analysing the ray reflections in the simulations, it can be observed that more reflected rays intersect at these spots than in the remaining plane. This superpositions of multiple reflections with the incident wave are the cause of the high variations in the electric field. In Fig. 2 (d) the distribution of electric field variations of all sampling points of the plane is shown. In the sampled plane, the deviations mostly range from -7 dB to 2 dB.

CONCLUSIONS

To analyse the uncertainty due to the scattering of the field caused by the person performing a RF exposure measurement in millimetre wave spectrum, simulations were done using the ray tracing method in CST Studio. The simulations were conducted at different incident angles for frequencies of 27 GHz, 60 GHz, 80 GHz, and 100 GHz with a full body model standing on a perfect electric conducting ground. Similar to [3], the simulated field strength with the body model and without were compared for each frequency and incident angle to determine the highest possible field variation.

The results show that the field variation due to the presence of the measuring person can lead to a misinterpretation of the actual exposure. These field variations were smaller at higher frequencies. Also, the differences between the incident angles were smaller for the higher frequencies. But as only four frequencies and three different incident angles were analysed up to now, it is not possible to determine a frequency and angular dependence.

However, as the initial investigation had shown that the reflections from the body and the incident wave superimpose forming a distorted very faintly pronounced standing wave pattern that can lead to these high deviations, it is not accurate to extrapolate the calculated field variations to the actual uncertainty due to the person performing a measurement. The standing wave effect can only be observed in the case of coherent superposition, which was done here by using a mono-frequency-observation. However, communication signals are multicarrier signals and the exposure is not measured only at a single carrier frequency. As stated in [10], simulations may produce inaccurate results when compared to measured data if only one frequency are considered. It was shown that a combination of carrier frequencies reduces the deviation between simulation and measurement.

In the simulation, the planes were sampled pointwise to calculate the field strength. However, in reality, measurements are not taken at a single spatial point. Therefore, the electric field would have to be integrated over a spatial area, especially at high frequencies where the antennas are also large in comparison to the wavelength, which could average out the minima and maxima resulting in a smaller electric field variation.

Therefore, to obtain a more accurate simulation-based estimation of the uncertainty caused by the presence of the measuring person, it is necessary to extend the simulation to a combined multifrequency and volume-based analysis. Clothing, body movements, different ground properties could also be considered. The simulation's accuracy can be estimated by comparing it with a measurement-based analysis.

Acknowledgment:
This work has received funding by the German Federal Ministry of Education and Research (BMBF) in the course of the 6GEM research hub under grant number 16KISK038.

REFERENCES

[1] ETSI TS 138 104, V17.11.0, “5G; NR; Base Station (BS) radio transmission and reception (3GPP TS 38.104 version 17.11.0 Release 17)”, Technical Specification, 2023.

[2] A. Yazar, S. Dogan-Tusha, H. Arslan, "6G vision: an ultra-flexible perspective", ITU Journal on Future and Evolving Technologies - Volume 2020, Article 9, 1(1), 1-20, Dec. 2020. http://handle.itu.int/11.1002/pub/8173e1cc-en.

[3] The International Commission on Non-Ionizing Radiation Protection (ICNIRP), “Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz)”, Health Phys 118(00):000–000; 2020. Pre-print. DOI: 10.1097/HP.0000000000001210.

[4] DIN EN 62232:2017, Determination of RF field strength, power density and SAR in the vicinity of radiocommunication base stations for the purpose of evaluating human exposure (IEC 62232:2017), 2019.

[5] T. T. J. Ta, A. -M. Schiffarth and D. Heberling, "Evaluation of the influence of the measuring person on the assessment of mobile radio exposure with an isotropic measurement probe," 2023 17th European Conference on Antennas and Propagation (EuCAP), Florence, Italy, 2023, pp. 1-5, doi: 10.23919/EuCAP57121.2023.10133092.

[6] M. -C. Gosselin, E. Neufeld, H. Moser, E. Huber, S. Farcito, L. Gerber, M. Jedensjö, I. Hilber, F. Di Gennaro, B. Lloyd, E. Cherubini, D. Szczerba, W. Kainz, N. Kuster, “Development of a new generation of high-resolution anatomical models for medical device evaluation: The Virtual Population 3.0”, Physics in Medicine and Biology, 59(18):5287-5303, 2014

[7] Dielectric properties database, ITIS Foundation, https://itis.swiss/virtual-population/tissue-properties/database/dielectric-properties

[8] C. Gabriel. “Compilation of the dielectric properties of body tissues at RF and microwave frequencies”, Report N.AL/OE-TR- 1996-0037, Occupational and environmental health directorate, Radiofrequency Radiation Division, Brooks Air Force Base, Texas (USA), 1996.

[9] ITU-R, “Electromagnetic field measurements to assess human exposure,” Report ITU-R SM.2452-0, International Telecommunications Union, Radiocommunication Sector (ITU-R), Jul 2022. Spectrum Management Series. https://www.itu.int/pub/R-REP-SM.2452-1-2022

[10] L. -M. Schilling, A. -M. Schiffarth, C. Bornkessel, D. Heberling, M. Hein, “Ray tracing-based analysis of extrapolation factors for RF exposure to 5G massive-MIMO base stations”, in The Joint Annual Meeting of The Bioelectromagnetics Society and the European BioElectromagnetics Association (BioEM 2023), Oxford (UK), 2023, pp. 319-320.