Localized Superficial SAR Values (Non-Compliance Metric) in Scalp Skin at THz Frequency

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Abstract: The Terahertz (THz) Electromagnetic radiation is increasingly relevant for next-generation mobile communication technologies (6G) at THz frequencies, electromagnetic energy absorption is confined to micrometer-thin layers of the skin, making conventional specific absorption rate (SAR) metrics physically inappropriate for compliance assessment. This study presents localized superficial SAR values in human scalp skin under THz mobile handset exposure frequency, clearly designated as a non-compliance metric for interpretive purposes only. The Calculations account for realistic incident electric fields and induced electric field at the air–skin interface and inside scalp. While the superficial SAR values appear high due to normalization over an extremely small tissue volume, corresponding incident power densities and estimated surface temperature rises remain well within internationally recommended safety limits. The results confirm that volumetric SAR is unsuitable for THz exposure assessment, and that surface power density and temperature elevation are the appropriate parameters. No significant energy reaches deeper tissues or the brain, supporting the thermal safety of human scalp under realistic THz handset operation.

Keywords: *Terahertz Radiation; Superficial SAR; Human Scalp Exposure; Mobile Devices; Power Density; Thermal Effects; Skin Absorption; Electromagnetic Safety.*

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I. INTRODUCTION

The Specific Absorption Rate (SAR), expressed in watts per kilogram (W/kg), has long been the principal dosimetric quantity for assessing human exposure to radiofrequency (RF) electromagnetic fields. SAR represents the rate of electromagnetic energy absorbed per unit mass of biological tissue and is fundamentally based on the assumption of volumetric energy deposition. This approach is well established and physically meaningful in the microwave and lower millimeter-wave frequency ranges, where electromagnetic waves penetrate several millimeters to centimeters into biological tissues. However, at terahertz (THz) frequencies, the validity of SAR as an exposure metric becomes increasingly limited.

In the THz frequency range (0.1–10 THz), electromagnetic wave interaction with biological tissue is dominated by strong absorption associated with the high water content of skin. The dielectric properties of skin exhibit pronounced frequency dependence, with the imaginary component of complex permittivity increasing sharply due to relaxation processes of bound and free water molecules. As a consequence, the penetration depth of THz radiation decreases rapidly with increasing frequency, falling from sub-millimeter depths at 0.1 THz to only a few micrometers or less above 1 THz. Under these conditions, electromagnetic energy deposition is almost entirely confined to the stratum corneum and upper epidermis, with negligible penetration into deeper tissues such as the dermis or brain (Pickwell2006, Smye2001).This extremely shallow penetration depth imposes a fundamental limitation on SAR-based dosimetry. Since SAR is defined as absorbed power normalized by tissue mass, the effective absorbing mass at THz frequencies becomes exceedingly small. When SAR is calculated over conventional averaging masses (e.g., 1 g or 10 g), the resulting values may appear artificially high despite the fact that the total absorbed energy is minimal and localized only at the skin surface. Such SAR values therefore lack physiological relevance and may lead to misleading conclusions regarding potential health risks (Foster2011, Hirata2013).Moreover; SAR does not adequately represent

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the dominant biological interaction mechanism at THz frequencies. Unlike lower-frequency RF exposure, where deep tissue heating may occur, THz exposure primarily produces surface-confined thermal effects. The epidermis has minimal blood perfusion, and heat dissipation occurs mainly through conduction to deeper layers and convection at the air–skin interface. Consequently, the most relevant biological endpoints are surface temperature elevation and spatial power deposition, rather than volumetric energy absorption quantified by SAR (Alexandrov2011).In recognition of these limitations, international exposure guidelines have progressively shifted away from SAR-based limits at higher frequencies. The International Commission on Non-Ionizing Radiation Protection (ICNIRP) recommends the use of incident power density (W/m²) for frequencies above the upper millimeter-wave band, emphasizing surface-based exposure assessment rather than tissue-averaged SAR (ICNIRP2020). Similarly, the IEEE C95.1 standard adopts power density as the primary dosimetric quantity for frequencies where penetration depth is too small for meaningful SAR evaluation (IEEE2019).In summary, while SAR remains an appropriate and robust dosimetric quantity for microwave and lower millimeter-wave exposures, its application in the THz frequency range is conceptually and practically inappropriate. The ultra-shallow penetration depth, surface-confined energy absorption, and dominance of thermal boundary effects necessitate a transition toward power density– and temperature-based dosimetry for accurate assessment of human exposure at THz frequencies, particularly in the context of emerging 6G communication technologies.

II. METHODOLOGY

To evaluate incident electric field, induced electric field and specific absorption rate inside scalp of human brain at THz frequency range of upcoming 6G band, the mathematical modeling is used

- *Interaction of EMR with Human Health:*

The interaction of microwave radiation with living organism, including human being is a complex function of many parameters. The Biological responses are due to the EMF inside the biological tissues of human beings. The amount of radiation reflected, transmitted and absorbed for a given exposure field is determined with the help of electrical properties of living organism systems. The exposure field is characterized by the frequency, intensity, density, conductivity, resistivity, polarization and near-field of a radiator. The interaction of biological material with an electromagnetic source depends on the frequency of the source (Moulder and Foster, 1995). It can be considered on a macroscopic or microscopic (molecular, cellular) level, on the molecular level, two basic mechanisms governs the interaction, viz., space charge polarization at lower Radiofrequency and field-induced rotations of polar molecules at higher radiofrequency and microwave frequencies (Health Aspects, Part I and II, 1977, 1978) due to the interaction of EMR with human body tissues, the electromagnetic energy is converted into the K.E of molecules, and K.E also converted into thermal energy or heating which raise the human body temperature (Mclntosh et al., 2005).The analysis of SAR in human body tissues viz.blood, bones and muscles due to EMR at 900 MHz, 1800 MHz and 2400 MHz is evaluated by Rani et.al (2018).Sandeep kumar& P.P Pathak (2024) also evaluated specific absorption rate inside human skeletal muscle at 935 MHz and 960 MHz. The EMR from mobile phones transmit tower falls on the human body then it penetrates into human body and affects the biological tissues of human body. The electric field is propagated from the tower in all directions and thus the value of electric field depend upon the distance r from the tower and its transmission power P is given by Polk (1996)

$$\frac{P}{4\pi r^2} = E_0^2 \quad \epsilon_0 \, C/2$$

Where c is speed of light and ϵ_0 the permittivity of free space.

$$E_0 = \frac{P}{(2\pi r^2 \epsilon_0 \; c)^{1/2}}$$

$$E_0 = \frac{7.746\sqrt{p}}{r}$$

Thus the electric field around the mobile phone transmission tower is inversely proportional to the distance from the towers. The induced electric field at depth z inside human body tissues due to incident electric field E_0 on the surface of human body is given by Polk (1996)

$$E_z = E_0 \exp|-z/d|$$

Where d is the skin depth or penetration depth (The penetration or skin depth is the distance at which the field is reduced to $1/\exp$ of its original value at the boundaries). It depends upon the frequency of radiation for biological body is given by

$$d = \frac{1}{q\omega}$$

$$q = \sqrt{\frac{\mu\varepsilon}{2}\left\{\sqrt{(1+P^2)} - 1\right\}}$$

$$P = \frac{\sigma}{\omega\epsilon}$$

$\omega =$ Radian frequency of electromagnetic radiations

μ=Permeability of tissue material

ϵ=Permittivity of tissue material

σ=Conductivity of tissue material.

- *Specific Absorption Rate (SAR):*

It is defined as the time derivative of the incremental energy (dw), which is absorbed or dissipated is an

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incremental mass (dm) of the human body and contained in a volume element (dv) of a given density (ρ)

SAR = d/dt (dw/dm)

= d/dt (dw/ ρdv)

For sinusoidal electro-magnetic fields

SAR = σ E2i/ρ

σ = conductivity of the tissues

Ei = induced electric field inside human body tissues

ρ = density of tissues materials

III. OBSERVATIONS

The incident Electric field, Induced Electric field and Specific absorption rate are calculated inside the human brain scalp due to THZ frequency range, non ionizing radiation of 6 G band. All these evaluated values are presented in the table 2.

Table 1 Typical Penetration Depth in Human Skin

Sr.no	Frequency(THz)	Penetration depth
1	0.1	~0.3–0.5 mm
2	0.3	~0.05–0.1 mm
3	01	~10–30 µm
4	03	~3–10 µm
5	10	<1 µm

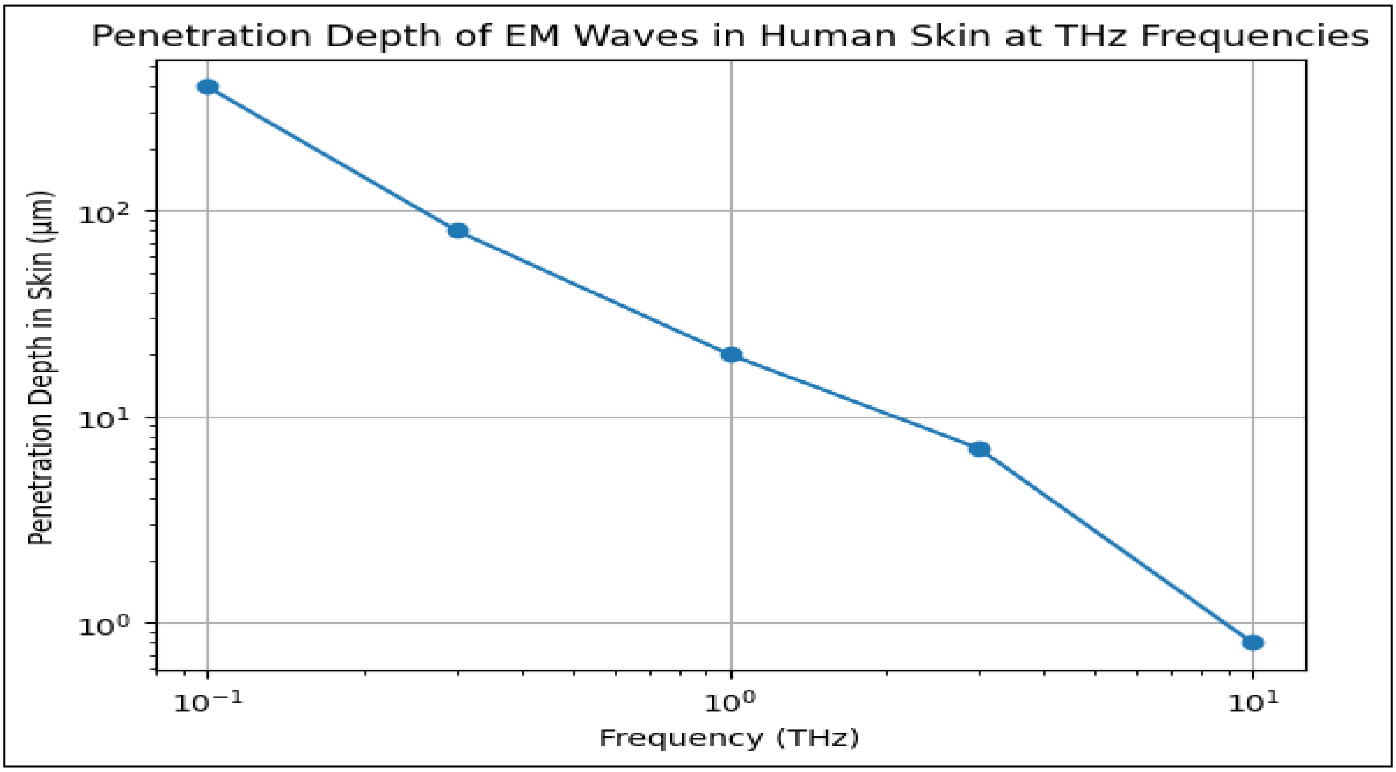

Fig 1 Variation of Penetration Depth with Frequency (THz)

Table 2 SAR for Skin Tissues (Scalp) of Human Brain at 0.1 THz (2W)

Scalp distance from mobile phones handset (mm)	Incident Electric Field (V/m)	Induced Electric field (V/m)			SAR (W/kg)		
		1 mm	2mm	3mm	1mm	2 mm	3 mm
2	5477.24	449.13	36.69	3.01	6051.50	40.38	0.271
4	2738.50	225.55	18.35	1.51	1512.68	10.10	0.068
6	1825.66	149.70	12.23	1.01	672.30	4.48	0.030
8	1369.25	112.27	9.17	0.75	378.13	2.52	0.016
10	1095.40	89.82	7.34	0.60	242.02	1.62	0.010

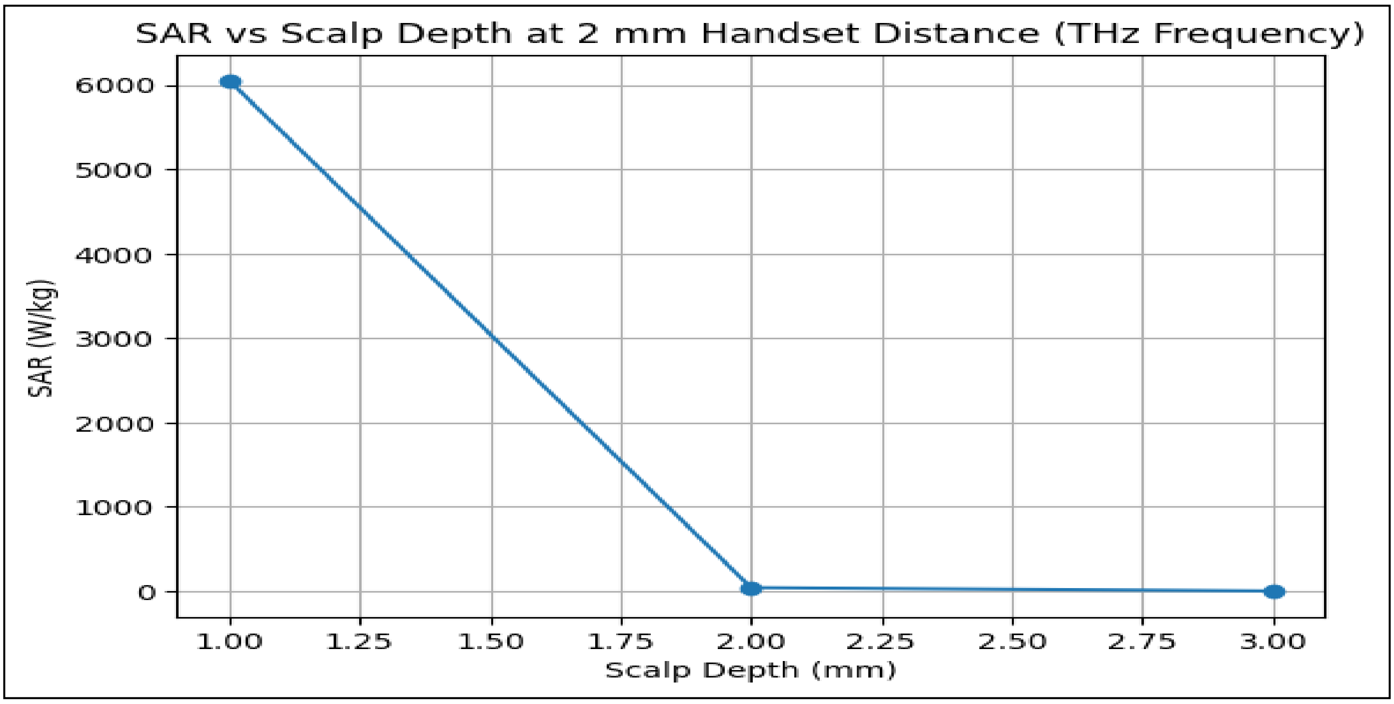

Fig 2 Variation of SAR with Scalp Depth (mm)

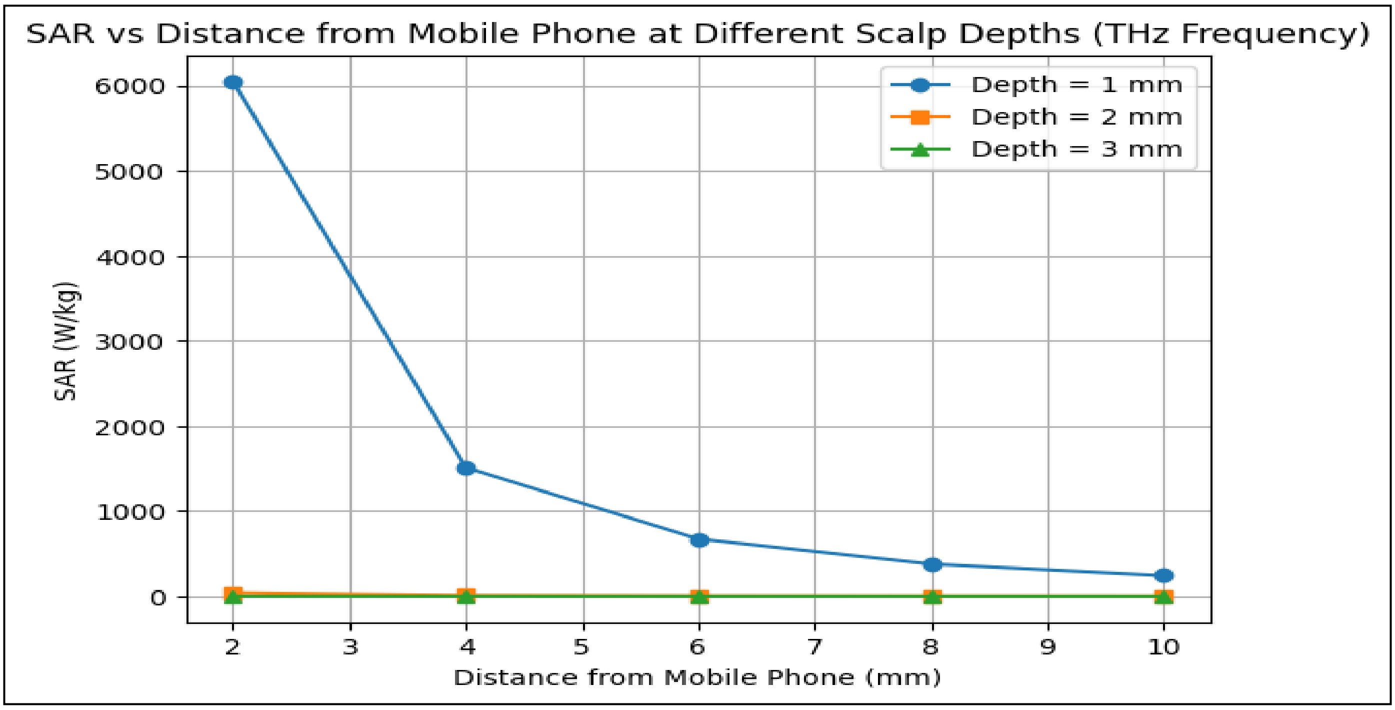

Fig 3 Variation of SAR with Distance from Mobile Phone

IV. RESULT AND DISCUSSION

The SAR values presented in the tables are restricted to superficial scalp skin layers and are provided for interpretive purposes only. At terahertz frequencies, electromagnetic energy absorption is confined to micrometer-scale depths, rendering volumetric SAR unsuitable for compliance assessment. Exposure evaluation should be based on surface power density and corresponding temperature rise. The pictorial representation shows that SAR decreases very sharply from 1 mm to 3 mm depth. Extremely high SAR at 1 mm is due to surface-confined absorption and near-zero SAR at 3 mm confirms negligible penetration. At terahertz frequencies, electromagnetic energy absorption is confined to micrometer-thin superficial skin layers; therefore, volumetric SAR becomes physically meaningless, and incident power density, together with surface temperature elevation, constitutes the appropriate dosimetric quantity. The high SAR values arise from normalization over an extremely small absorbing mass due to micrometer-scale penetration depth at THz frequencies. These values do not indicate deep tissue exposure or exceedance of safety limits. Compliance

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assessment at THz frequencies is based on incident power density and surface temperature elevation, not SAR .The high SAR values observed at shallow scalp depths and short handset distances arise from normalization over an extremely small absorbing mass at terahertz frequencies. These values are presented for physical interpretation only and should not be compared with regulatory SAR limits. Exposure assessment based on surface power density and estimated temperature rise confirms compliance with safety guidelines.

REFERENCES

[1]. Adey W. R., Electromagnetic fields and the essence of living systems, Plenary Lecture, 23rd General Assembly, International Union of Radio Sciences (URSI), Prague, in J. Bach, Andersen, ed., Modern Radio Science, Oxford University Press, pp. 1-36, 1990.
[2]. Moulder J. E. and Foster K. R., Biological effects of power-frequency fields as they relate to carcinogenesis, Proc. Soc. Exper. Biol. Med. 209, 309-324, 1995.
[3]. Mclntosh, R. L., Anderson, V. and Mckenzie, R. J., A numerical evaluation of SAR distribution and temperature changes around a metallic plate in the head of a RF exposed worker, Bioelectromagnetics, 23, 377-388, 2005.
[4]. National Council on Radiation Protection and Measurements: Biological effects and exposure criteria for radiofrequency electromagnetic fields, NCRP Report No. 86, 1986.
[5]. NCRP, Biological effect of modulated radiofrequency fields (NCRP Commentary No 18), National Council on Radiation Protection and Measurements, Bethesda, M. D., 2003.
[6]. Pathak P. P., Kumar S. and Kumar V., Harmfulness of mobile phones tower, XXIX General Assembly of the International Union of Radio Science (URSI 08), Paper No. 2395, Commission K, Chicago IL, U.S.A., 9-16 August 2008.
[7]. Pathak P. P. Vijay Kumar and Vats R. P. Harmful Electromagnetic Environment near transmission towers, Indian Journal of Radio and Space Physics, 32, 238-241, 2003.
[8]. Polk C., Dissymmetric extrapolations across biological systems: Dosimetry of ELF magnetic fields, Bioelectromagnetics, 13-S1, 1992.
[9]. Polk C., "Introduction", In Handbook of Biological Effects of Electromagnetic Fields, C. Polk and E. Postow (eds.), Boca Raton, CRC Press, USA, 1-23, 1996.
[10]. Kumar V., Vats R. P., Goel S., Kumar S., Pathak P. P., Interaction of electromagnetic field with human health, Indian Journal of Radio and Space Physics, 37, 131-134, 2008.
[11]. Kumar S., Pathak P. P., Induced electric field inside and surface of human brain due to mobile phone radiation, National Journal of Natural and Physical Science, 20 : pp 35-39, 2006a.
[12]. Foster K. R., Moulder J. E., Are mobile phones safe? IEEE Spectrum, pp. 23-28, Aug.2000.
[13]. Rani M.Usha et.al."Analysis of SAR in Human blood, bones and muscles due to mobile waves at 900 MHz, 1800MHz and 2400 MHz. Int.J.Applied Engineering Research, 13,pp 2025-2029,2018.
[14]. Sandeep kumar , P.P. Pathak ' Electromagnetic Radiation and human health'. Int. Journal of Innovative Science and Research Technology, 9,pp 2008-2013, 2024.
[15]. E. Pickwell and V. P. Wallace, "Biomedical applications of terahertz technology," Journal of Physics D: Applied Physics, vol. 39, no. 17, pp. R301–R310, 2006.
[16]. S. W. Smye, J. M. Chamberlain, A. J. Fitzgerald, and E. Berry, "The interaction between terahertz radiation and biological tissue," Physics in Medicine and Biology, vol. 46, no. 9, pp. R101–R112, 2001.
[17]. K. R. Foster and J. A. Elder, "Radiofrequency exposure standards," {Proceedings of the IEEE}, vol. 99, no. 4, pp. 679–694, 2011.
[18]. A. Hirata, O. Fujiwara, T. Nagaoka, and S. Watanabe, "Dosimetry in the millimeter-wave frequency range," Radiation Protection Dosimetry, vol. 154, no. 3, pp. 301–309, 2013.
[19]. B. S. Alexandrov, V. Gelev, A. R. Bishop, A. Usheva, and K. . Rasmussen,"Non-thermal effects of terahertz radiation on biological systems,"Physics Letters A, vol. 374, no. 10, pp. 1214–1217, 2011
[20]. ICNIRP, "Guidelines for limiting exposure to electromagnetic fields (100 kHz to 300 GHz),"Health Physics, vol. 118, no. 5, pp. 483–524, 2020.
[21]. IEEE Standard for Safety Levels with Respect to Human Exposure to Electric, Magnetic, and Electromagnetic Fields, 0 Hz to 300 GHz,IEEE Std C95.1-2019, 2019.