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Power and Current Induction in Arteries and Blood within Due to UHF Exposure

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Author's contribution

The sole author designed, analysed, interpreted and prepared the manuscript.

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ABSTRACT

The EMF effect on the arterial blood flow is investigated employing a mathematical model. The propagation of an incident electromagnetic wave in the ultra-high frequency range (*UHF*), *200MHz -100GHz,* is studied. This range covers the microwave to the millimeter wave ranges (*MW-mmW*ave), currently adopted as the *5G* mobile communications. Thermal and non-thermal possible effects, due to this *UHF* far field exposure are accounted for by the present results. These results, obtained from the proposed mathematical model, illustrate the distribution of both the induced power and the current densities versus frequency in arteries and blood within. The frequency dependence of dissipated and stored power densities is thus investigated. In addition to this, the ohmic and displacement current densities are computed. These are related to thermal and non-thermal effects as well. The present results are calculated for electric field strengths ranging from 1V/m to 1kV/m.

Keywords: Mathematical model; MW and mmWave exposure; stored and dissipated power; current density; arterial exposure.

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1. INTRODUCTION

The increase of the dependence on wireless communication has a strong impact on the scientific and engineering research world. Most of the technological applications utilize wide frequency ranges especially with the advent of the fifth generation of communication (*5G*). The *5G* that employs millimeter waves (*mmW*ave) ranging from *2.3GHz* to *3.4GHz* encourages excessive use of wireless products. Previously the use of *mmW*ave band has been exclusively kept for the military and police applications. Despite the great benefit of expanding to the *mmW*ave range, the EMF whole body exposure levels will undeniably increase as a result. Accordingly, the employment of such band requires the establishment of denser cell phone tower urban networks, estimated as five times the existing one. In addition to this, it is expected that more wireless devices, including wireless-enabled vehicles, will be commonly used. So the public are expected to receive an excessive EMF dose.

The EMF effect on the health and environment has enjoyed a considerable interest of scientific research [1-8]. Despite the extensive work on the health and safety levels of RF and MW, [9-12]; the impact on human and animal health or on the environment of such high frequency electromagnetic spectrum is still not adequately addressed by the scientific world. These safety levels are measured as *SAR* (*w/kg*) or power density (W/m^2), the effect of which in the tissues is beleived to be thermal [13-17]. It is possible that the *mmW*ave have completely different biological effects from those caused by the *MW* [18-20]. The *mmW*aves have been used as military weapons causing the temporarily sensation of skin burn [21] among other symptoms [22]. On the other hand low intensity of these waves have been used for therapeutic treatment [23].

The inconclusive reports on the non-thermal effects of EMF radiation that disregard their possible interaction mechanism with human tissue,arouse a cotroversy about the existing standards of health and safety.

The main purpose of the present work is to employ an analytical approach to calculate the average power density absorbed in the arterial tissue and blood within. The incident frequency, in the *MW* and *mmW*ave range *(200MHz-100GHz)*, is considered. The induced current densities are calculated as a function of frequency and electric field strength. Both induced power and induced current densities are related to the thermal and non-thermal effects.

2. MATHEMATICAL MODEL

The present model considers normal incidence of a polarized EM wave. The electric field of strength, E_0, is assumed to fall normal on a homogeneous $1mm^2$ arterial section, of *1mm* thickness and *4mm* radius, with blood flowing through, shown in Fig. 1.

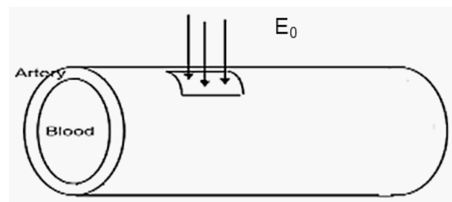

Fig. 1. The model

Maxwell's equations are applied, tracing the normal electric and magnetic fields, E_x and H_y. The incident waves penetrate the arterial section in z- direction reaching the blood within. The transmission, reflection, dispersion coefficients are calculated for the artery and the blood as complex functions of frequency.

Mathematical details of the model has been reported previously [24]. The model employs the values of the electromagnetic properties of the tissues under consideration reported in mnay researchers [25-27]. The dissipated and stored power densities, P_{diss} and P_{strd}, are calculated (W/m^2) for the artery and the blood within, in terms of ε *(f)*, σ*(f),* and μ *(f)*, as complex functionsof frequency, *f,* and field strength, E_0. In addition, the induced ohmic and displacement current densities, J_d and J_{Dis} ($\mu A/mm^2$) are calculated. These quantities are calculated for different values of E_0 ranging; *1V/m-1kV/m.* The total electric and magnetic fields in the artery and blood within are produced over the *frequency* range *(200MHz-100GHz)*. The computations of the proposed deterministic model are executed by the Maple-V computer program.

3. RESULTS

Fig. 2a and Fig. 2b illustrate the power densities, dissipated and stored, versus frequency respectively, in the artery. Fig.(2a) shows minima at *17.99GHz* and *49.89GHz* while Fig.(2b) shows a single minimum at the latter frequency for E_0<*10V/m*. Whereas Fig.(3a) and Fig.(3b) show these distributions of power densities, dissipated and stored, versus frequency for the blood. These figures show multiple minima at *f>10 GHz* for E_0*=10V/m-1kV/m.* Fig.(4a) shows the ohmic current density distribution versus freauency while Fig.(4b) shows the freauency distribution of displacement current density through the arterial section.These figures show the dissipated power distribution when subjected to different field strengths.They show multiple minima at *f>10GHz* for E_0*=10V/m-1kV/m.* Fig.(5a) and Fig.(5b) show these distributions,ohmic and displacement current densitiesin blood.

For different E_0, Table 1 illustrates the average power for three frequency ranges namely; low frequency range*, LF (30kHz-300kHz),* high frequency range, *HF (3MHz-900MHz)* and ultra-high frequency *UHF(200MHz-100 GHz)*. Table 2 and Table 3 illustrate the average value of the current densities considering these frequency ranges for the artery and blood within respectively.

4. DISCUSSION

In the light of the current wireless technology and applications there is a growing trend to employ millimeter waves. This requires not only the use of the frequency range approaching *42*GHz, but also a considerable increase in the transmitting antennae density over populated areas (*BTS*). Accordingly, *EMF* public exposure is expected to escalate. Due to the considerable number of reports concerning children vulnerability to blood diseases, due to *EMF* exposure, the present work investigates the penetration of these waves through arterial tissue to the blood.

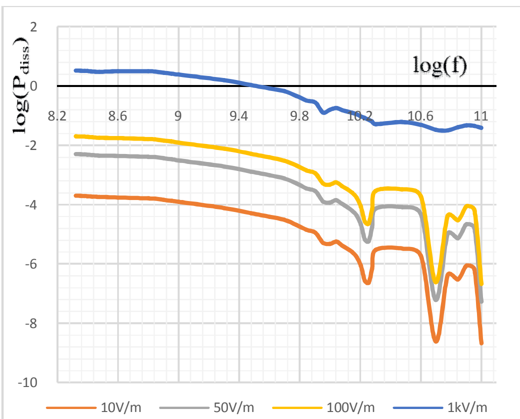

Fig. (2a). Dissipated power density in arterial section log(Pdiss) vs log(f)

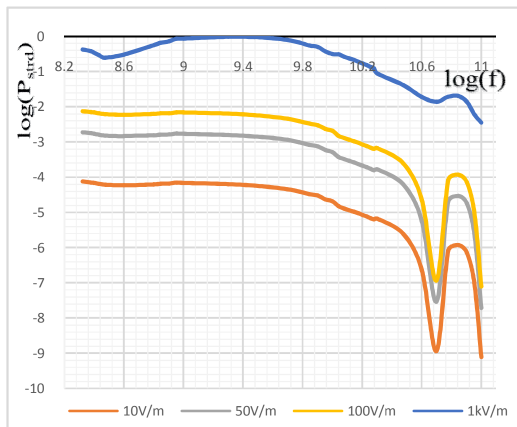

Fig. (2b). Stored power densityin arterial section log(Pstrd) vs log (f)

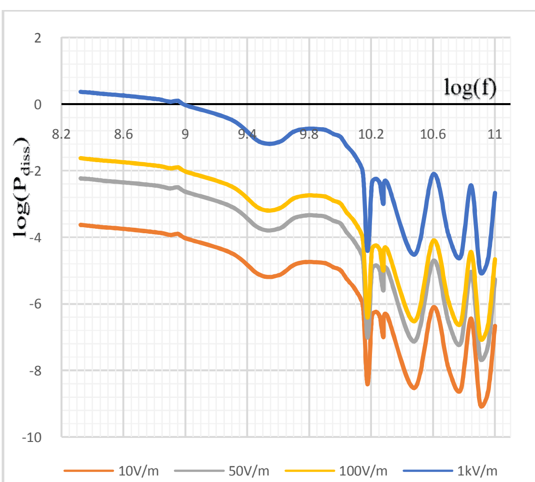

Fig. (3a). Dissipated power density in blood log(Pdiss) vs log(f)

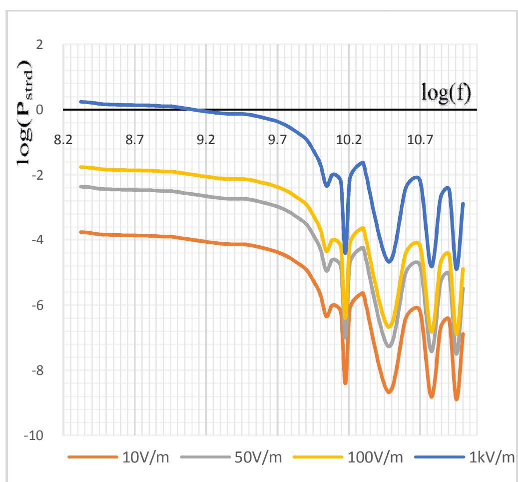

Fig. (3b). Stored power densityin blood log(Pstrd) vs log(f)

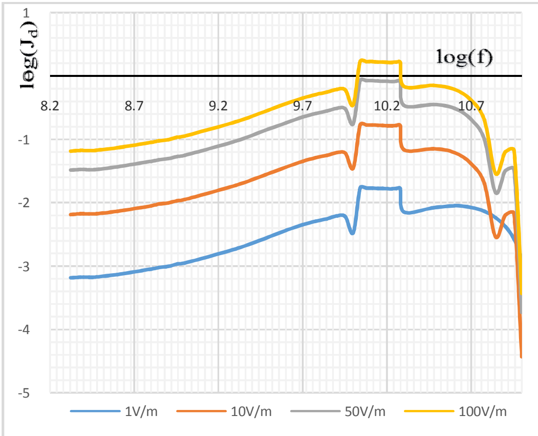

Fig. (4a). Ohmic current induced in the arterial section $\log(J_d)$ vs log(f)

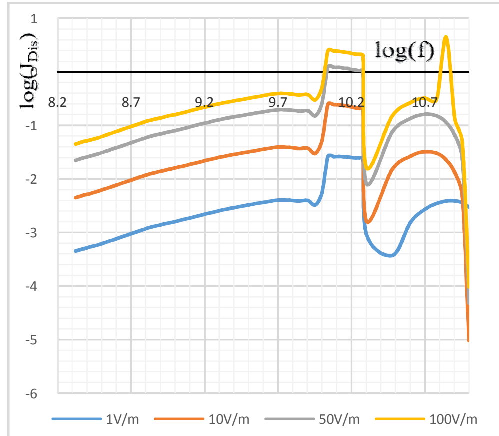

Fig. (4b). Displacement current induced in the arterial section $\log(J_{Dis})$ vs log(f)

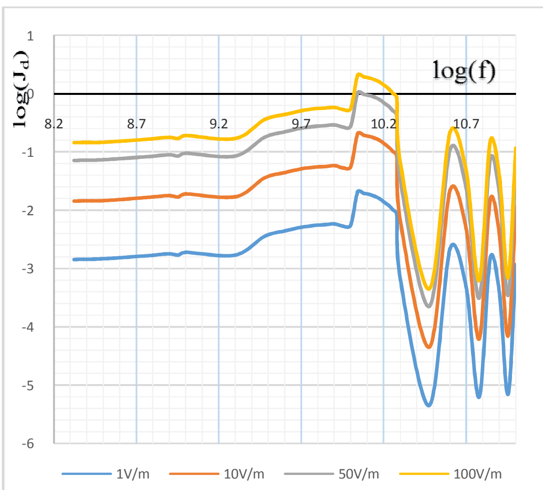

Fig. (5a). Ohmic current induced in blood $\log(J_d)$ vs log(f)

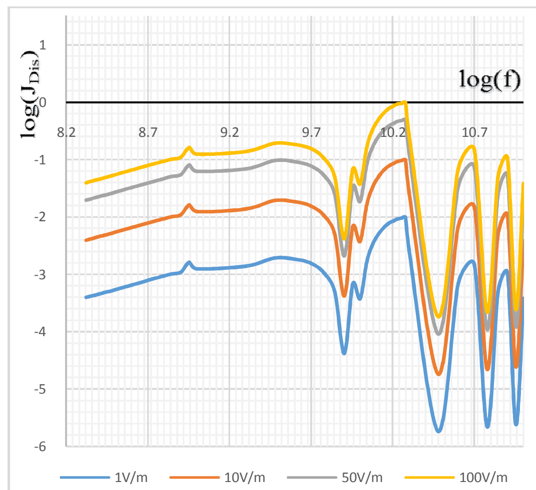

Fig. (5b). Displacement current induced in blood $\log(J_{Dis})$ vs log(f)

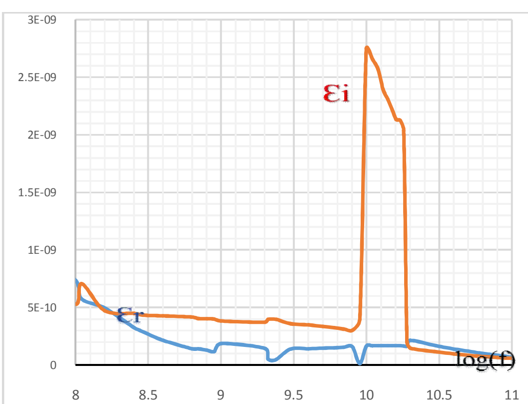

Fig. (6a). Artery permitivitty; real ($Ɛ_r$) and imaginary (Ɛi) components vs log(f)

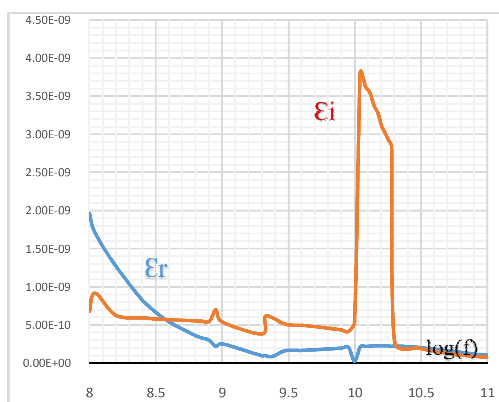

Fig. (6b). Blood permitivitty; real ($Ɛ_r$) and imaginary (Ɛi) components vs log(f)

Table 1. Comparison of induced EMF power

E_0 V/m	LF exposure (W/m^2) [26]				HF exposure (W/m^2) [26]				UHF exposure ($10^{-3}W/m^2$) (present work)			
	Artery		Blood		Artery		Blood		Artery		Blood	
	P_{diss}	P_{strd}	P_{diss}	P_{strd}	P_{diss}	P_{strd}	P_{diss}	P_{strd}	P_{diss}	P_{strd}	P_{diss}	P_{strd}
10	0.083	0.669	0.026	0.0014	0.0004	0.0003	0.0004	0.3	0.05	0.03	0.05	0.0099
50	2.565	0.7187	0.582	0.0362	0.0101	0.0076	0.0072	7.4	1.4	0.7	1.4	1.3
100	8.283	0.9547	2.609	0.145	0.04	0.03	0.0101	29.7	5.6	3.1	5.4	5
1000	828.31	294.47	260.9	14.469	4.039	3.055	4.0164	2970.1	1055	357	538	499

Table 2. Comparison of induced EMF current density in artery

E_0 V/m	LF exposure ($10^{-4}\mu A/mm^2$)		HF exposure ($10^{-4}\mu A/mm^2$)		UHF exposure ($10^{-4}\mu A/mm^2$)	
	J_d	J_{Dis}	J_d	J_{Dis}	J_d	J_{Dis}
1	1.98	0.16	3.68	0.379	3.68	0.379
10	19.79	1.6	36.79	3.79	36.8	3.79
50	116.8	8.31	183.97	16.3	183.9	16.26
100	197.9	16	368	38	367.9	37.9
1000	1979.2	160	3673.4	0.379	3.68	0.379

Table 3. Comparison of induced EMF current density in blood

E_0 V/m	LF exposure ($10^{-3}\mu A/mm^2$)		HF exposure ($10^{-3}\mu A/mm^2$)		UHF exposure ($10^{-3}\mu A/mm^2$)	
	J_d	J_{Dis}	J_d	J_{Dis}	J_d	J_{Dis}
1	0.2	0.0143	0.92	1.03	2	0.776
10	2	0.143	9.3	1.033	20	7.8
50	10.167	0.861	46.3	5.2	100.2	38.8
100	20.3	1.4	92.6	3.8	200.4	77.6
1000	203.2	14.4	926	10.31	2004	776

Hence, the present work introduced a methodology to assess the absorbed power, dissipated and stored, and the induced current in blood.

The present work results are concentrated on power and current induction in arterial tissue and blood. We believe that the thermal effects are related to the dissipated power (P_{diss}) and the ohmic current (J_d). On the other hand the non-thermal effects of these incident waves are related to the stored power (P_{strd}) and the displacement current (J_{Diss}).

The present results illustrate the power distribution with the *UHF* range, exhibiting regular behavior up to *f=10GHz*. After which considerable irregularities appear with *f*, which is believed to be the combined effect of both the characteristic variation of the permittivity as shown in Fig.(6a) and the intrinsic properties of the investigated tissue [27]. This pattern is consistent for both dissipated and stored power densities in the arterial section, as shown in Fig.(2a) and Fig.(2b). The power density level either dissipated or stored depends markedly on the electric field strength. On the other hand, for blood the regular frequency range of power, both dissipated and stored, extends only to *f=6.3GHz* as shown in Fig. (3a) and Fig. (3b). After which the irregularities become more obvious and deeper than those in case of the arterial response. Meanwhile the EM field exposure affects the power absorption in a frequency dependent behavior exhibiting minima at *f=14.97GHz*. Similar behavior has been observed in the induced thermal and non-thermal currents in both arteries and blood. The currents densities are almost regular up to *f=8.9GHz,* then they exhibit considerable irregularities that corresponds to the permittivity variation, shown in Fig.(6b). As expected the thermal and non-thermal currents depend on the field strength, E_0. It is noteworthy to point out that the current density distributions show an increase in the range 10GHz to 20GHz.

5. CONCLUSION

Most of the international safety standards, (ICNRP, WHO, IEEE) [13-17], deal with the possible thermal effects of whole body exposure to *EMF*. Usually the non-thermal effects are overlooked. In the present model, the author shed some light on the possible non-thermal energy and induced currents caused by such exposure.

The new *5G* technology, employed for the mobile network, will change from operating on *MW*, around 1GHz-*3GHz*, to operating on *mmW*ave approaching *40GHz*. Besides, it is well documented that the exposure to the *mmW*ave, similar to that proposed by the 5G communication frequency, is considered hazardous to an extent. Hence, particular consideration should be given to their effect on the different biological tissues.

In the present model, a mathematical approach is employed to study the absorption, dissipation and storage of power in biological tissue with particular interest to the induced currents in both arteries and blood. The values of these quantities are illustrated for three frequency ranges in the Tables. This is believed to contribute to thermal and non-thermal effects. The procedure of this work can be extended to study similar effects on different organs subjected to the millimeter waves.

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COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

1. Vecchia P. Exposure of humans to electromagnetic fields. Standards and regulations Ann Ist Super Sanità. 2007; 43(3):260-267.
2. International commission on non-ionizing radiation protection. ICNIRP Publication; 2009.
3. Gajšek P. D'Andrea JA, Mason PA, Ziriax JM, Walters TJ, Hurt WD, Meyer FJC, Jakobus U, Samaras T, Sahalos JN. Mathematical modeling of EMF energy absorption in biological systems. Biological Effects of Electromagnetic Fields. 2003;11.
4. Christ A, Klingenbock A, Samaras T, Goiceanu C, Kuster N. The dependence of electromagnetic far-field absorption on body tissue composition in the frequency range from 300MHz to 6GHz. IEEE Transactions on Microwave Theory and Techniques; 54.
5. Prisco MG, Nasta F, Rosado MM, Lovisolo GA, Marino C, Pioli C. Effects of GSM-modulated radiofrequency electromagnetic fields on mouse bone marrow cells. Radiat Res., Vols. 2008;170(6):803-810. DOI: 10.1667/RR1213.1
6. El Naggar MA, El Messiery MA. Evaluation of power absorption in human eye tissue. International Journal of Advanced Research. 2013;1(7):658-665. Available:http://www.journalijar.com [ISSN 2320-5407]
7. Repacholi MH. Low-level exposure to radiofrequency electromagnetic fields: Health effects and research needs. Bioelectromagnetics. 1998;19:1–19.
8. El Naggar MA. EMF power absorption in bone and bone marrow: Mathematical model. Article no. PSIJ2015.053, Science-domain International. 2015;7(2348-0130): 11-19. Available:www.sciencedomain.org
9. Foster R. Thermal and non-thermal mechanisms of interaction of radio-frequency energy with biological systems. IEEE Transactions on Plasma Science. 2000;28(1).
10. VN, et al. Effects of cell phone radio-frequency signal exposure on brain glucose metabolism. J. Am. Med. Assn. 2011;8(305).
11. HR, et al. Exposure to pulse-modulated radio frequency electromagnetic fields affects regional cerebral blood flow. Eur. J. Neurosci. 2005;1000(21).
12. A, et al. The influence of the call with a mobile phone on heart rate variability parameters in healthy volunteers, Indust. Health. 2008;409(46).
13. ICNIRP publication. International commission on non-ionizing radiation protection ICNIRP statement on the: Guidelines for limiting exposure to Time-varying electric, magnetic, and Electromagnetic fields (up to 300 GHz)," Health Physics. 2009;97(3):257-258.
14. ICNIRP guidelines for limiting exposure to time-varying electric, magnetic and electromagnetic fields (up to 300 GHz). Health Physics. 1998;74(4):494-522.
15. IEEE international committee on electro-magnetic safety (SCC39). IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electro-magnetic Fields, 3 kHz to 300 GHz," IEEE Std C95.1™, Park Avenue New York, NY 10016-5997, USA, (Revision of IEEE Std C95.1-1991); 2005.
16. C. S. b. t. I. International, "IEEE Standard for Safety Levels with Respect to Human Exposure to Radio Frequency Electro-magnetic Fields, 3 kHz to 300 GHz.," I E E E 3 Park Avenue New York, NY 10016-5997, USA; 2009.
17. IEEE Standards, "C95.6TM IEEE Standard for Safety Levels with Respect to Human Exposure to Electromagnetic Fields, 0–3 kHz," The Institute of Electrical and

Electronics Engineers, Inc. 3 Park Avenue, New York, NY 10016-5997, USA; 2002.
18. PG, et al. Current state and implication of research on biological effects of millimeter waves: A review of the literature. Bioelectromagnetics. 1998;19:393-413.
19. SLAVRL. A study of the effect of millimeter-band microwaves on the bone marrow of mice. SOV. PHIS-USP. 1974; 16(570).
20. LA S. Specific influence of millimeter waves on biological objects. In: No thermal effects of millimeter wave irradiation," (Devyatkov ND, ED.), Ussr: ACAD. Sci. Ussr. 1981;86-113.
21. JEP et al. Thermal injury in human subjects due to 94-GHz radio frequency radiation exposures. AFRL-RH-FS-TR-2016-0001, Air Force Research Laboratory, Radio Frequency Bioeffects Branch, 711th Human Performance Wing,Human Effect; 2016.
22. GS, EG. Moros. Modelling millimetre wave propagation and absorption in a high resolution skin model: the effect of sweat glands. Physics in medicine and biology, Phys. Med. Biol. 2011;56: 1329–1339. DOI: 10.1088/0031-9155/56/5/007
23. MKL et al. Effect of millimeter wave irradiation on tumor metastasis Bioelectromagnetics. 2006;27:258-264.
24. El Naggar MA. Mathematical investigation on EMF thermal and non-thermal effects on arteries with implants: LF and HF Exposure. IJSRM. Human. 2018;8(4):100-109.
25. LRGC, Gabriel S. The dielectric properties of biological tissues: Measurement in the frequency range 10Hz to 20GHz. Physics in Medicine and Biology. 1996;41(11): 2251-2269.
26. GCGS. Compilation of the dielectric properties of body tissues at RF and microwave frequencies. Dielectric properties of the body tissues; 1996.
27. Cararra N. An internet resource for the calculation of the dielectric properties of biological tissues in the frequency range of 10 Hz to 100 GHz. Available:http://niremf.ifac.cnr.it/tissprop.

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