Cellular Radiofrequency Electromagnetic Field can be measured only by Nanotechnological Methods

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***Abstract* - The eukaryotic cell is a basic unit of plants, fungi and animals and it is also a likely source of electromagnetic field whose function we would like to examine in the future. Eukaryotic cells contain various organelles and structures. It is expected that the electromagnetic activity originates mainly in cytoskeleton that is a structure that protects and organizes the cell, enables a motion of the cell and is necessary for cell division. This structure is composed of three types of filaments. Microtubules, which are one of them, fulfil all conditions for generation of cellular electromagnetic field. We approximate electrical properties of basic structure of a microtubule (tubulin heterodimer) as elementary electric dipole and then we calculate electromagnetic field around them. In this paper, we present results from calculations of power and electric intensity around two models of microtubule network.**

***Index Terms* - bioelectrodynamics, microtubule network, cellular power.**

I. INTRODUCTION

The electromagnetic field of eukaryotic cells is the topic, which assumes considerable sense in previous years. In the 1960s H. Fröhlich postulated and theoretically treated concept in which he presented the existence of mechanical vibrations of electrically polar structures in cell causing generation of electromagnetic field around and in cells [1-2]. With the advent of deeper understanding to structures of the cell microtubules emerge as hot candidates for generation of endogenous electromagnetic activity [3]. Electromagnetic field of living cells has been inspected by several authors in frequency range from kHz to the GHz region [4-7].

II. MICROTUBULE AND ITS DIPOLE MOMENT

Cytoskeleton is composed of three types of filaments and the most interesting for us are microtubules. Microtubule (Fig. 1.) resembles hollow rod with inner and outer diameter 17 nm and 25 nm, respectively.

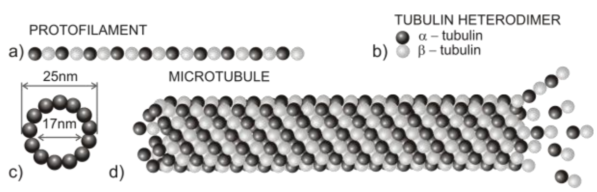

Fig. 1. a) Protofilament, b) Tubulin heterodimer, c) Cross section of microtubule, d) Single microtubule with 13 protofilaments

Microtubules are mostly composed of 13 protofilaments. The basic subunit of protofilaments is tubulin heterodimer which is highly polar structure with strong static dipole moment in direction of microtubule axis of 337 Debye ($1{,}12.10^{-27}$ Cm) [8]. Microtubules fulfil all conditions for generation of cellular electrodynamic field.

III. METHOD OF CALCULATION

We approximated electrical properties of tubulin heterodimer as elementary electric dipole which is described by these equations:

$$H_{\varphi} = -\frac{Idl}{4\pi} k^2 \sin \vartheta_p \left(\frac{1}{jkr} + \frac{1}{(jkr)^2} \right) e^{-jkr} \qquad (1)$$

$$E_r = -\frac{Idl}{4\pi} Zk^2 2 \cos \vartheta_p \left(\frac{1}{(jkr)^2} + \frac{1}{(jkr)^3} \right) e^{-jkr} \qquad (2)$$

$$E_{\delta} = -\frac{Idl}{4\pi} Zk^2 \sin \vartheta_p \left(\frac{1}{jkr} + \frac{1}{(jkr)^2} + \frac{1}{(jkr)^3} \right) e^{-jkr} \qquad (3)$$

All equations include:

$$j\omega \hat{p} = Id\vec{l} \qquad (4)$$

where E is electric field intensity, H is magnetic field intensity, I is equivalent current, dl is length of the dipole, Z is wave impedance, k is propagation constant, ω is angular frequency, p is dipole moment, j is imaginary unit ($j^2 = -1$) and other symbols are according to Fig. 2.

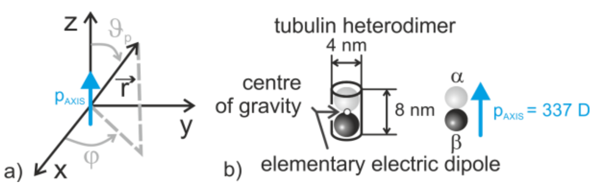

Fig. 2. a) Dipole moment in Cartesian coordinate system, b) Tubulin heterodimer (dimensions and centre of gravity)

We used program Matlab for calculations of electromagnetic field around oscillating microtubule network. We created two models of microtubule network – symmetric and asymmetric model. The symmetric model represents microtubule network of a non-dividing cell. Microtubules are distributed symmetrically on the sphere (centrosom, r = 200 nm) and axis of microtubules are situated along radius vector from centre of the sphere (Fig. 3a.). This distribution of microtubules simulates complete (phase and geometrical) symmetry in the cell. The symmetric model represents microtubule network of a dividing cell. Microtubules are distributed asymmetrically (only on poles) on the sphere and grow along radius vector from centre of the sphere (Fig. 3b.)

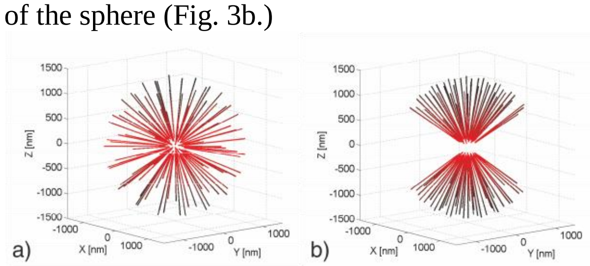

Fig.3. a) Symmetric and b) Asymmetric model of the microtubule network. Each red line represents one microtubule

Both models are composed of 100 microtubules and each model is constituted of 195 000 elementary electric dipoles. The calculation of the power and electric intensity around both models was realized by summation of contributions from all dipoles in the point in space (PoFE – points of field of evaluation). We used the distribution of PoFE on the sphere with the smallest potential energy in case of calculation of the power. We don't consider the effect of the cell wall in our calculation. The radiated power was calculated from Time-averaged Poynting vector S defined as

$$\vec{S} = \frac{1}{2} \Re\{\vec{E} \times \vec{H}^*\} \qquad (5)$$

where $\Re\{\}$ denotes real part of complex number and * denotes complex conjugate. The radiated power was calculated according to equation:

$$P = \sum_{j}^{K} \vec{S}_j A_j \qquad (6)$$

where K is number of elementary surfaces, A_j is j-th surface with S_j power density flowing through it.

III. PARAMETERS USED FOR CALCULATIONS

We took two different mediums into account; lossy [10] and lossless (Tab. 1). As longitudinal shift between neighbouring protofilaments the value of 4,92 nm is used (latice A). Longitudinal mechanical oscillations of tubulin heterodimers are represented by active dipole moment in direction of microtubule axis. We determine the value of dipole moment for frequency around kHz from work [9] as $p_{A1} = 1/8p_{AXIS}$ and for higher frequencies as $p_{A2} = 1/80p_{AXIS}$ in accordance with heat waves.

Table 1: Parameters of mediums for 8 frequencies (ε_{r1} and σ_1 - lossy medium; ε_{r2} and σ_2 - lossless medium)

f [Hz]	1 K, 1 M, 10 M & 100 M	1 G	10 G	42 G	100 G
ε_{r1} [-]	81	81	71	20	10
σ_1 [S/m]	1	1,33	17,2	39,7	68,5
ε_{r2} [-]	81	81	71	20	10
σ_2 [S/m]	0	0	0	0	0

We approximated mechanical oscillations of tubulin heterodimers in one protofimament as oscillations of the chain of rigid particles and used optical branch [11]. Optical branch is more suitable for generation of electromagnetic field. Movement of particles and corresponding oscillations of the dipole moment are described by spatial modulation function:

$$p_m = p_A \cdot \sin(mv) \qquad (7)$$

where p_m is modulated dipole moment, p_A is the active part of p_{AXIS} and mw is basically distance along the microtubule. Modulation function is specific for each mode from mode zero to max mode. The mode zero represents oscillations of all dipoles in phase and the max mode represents oscillations of neighbouring dipoles in antiphase. Higher modes resemble longitudinal wave. In the Fig.4. the modulation function of the 1st protofilament (mode 5) is depicted. Modulation functions of 2nd - 13th protofilaments are axially shifted. Each circle represents the value of dipole moment of one heterodimer.

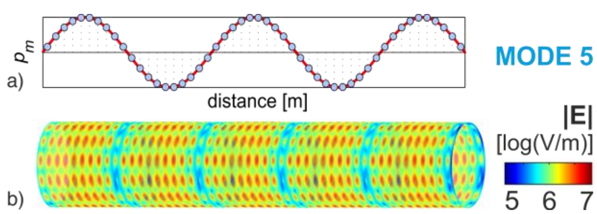

Fig.4. a) The modulation function of the 1st protofilament. b) The electric intensity in logarithmic scale on the coaxial surface 1 nm above the microtubule wall (mode 5)

IV. RESULTS

We presented selected results of calculations of radiated power from asymmetric and symmetric model of microtubule network. We used 8 frequencies (Table 2) and mode 0 for excitation of microtubules and two mediums – lossy and lossless. The mode 0 is the most effective for generation of electromagnetic field. The calculated results of power show that the values of power of microtubule network generated by mode min and mode max are little different and the values of power generated by asymmetric and symmetric model are the same. Therefore, we showed the results only from asymmetric model for case of calculation of power. Time-averaged Poynting vector computed from components of near-field $E\sim1/(jkr)^3$ and $H\sim1/(jkr)^2$ is zero in lossless medium. In contrast, the time-averaged Poynting vector calculated from components of far-field $E\sim1/(jkr)$ and $H\sim1/(jkr)$ isn't zero and has constant character. In Table 2. you can see the values of power generated by asymmetric model for all 8 frequencies in lossless medium.

Table 2: Constant values of power calculated from border of microtubule net to 1 m for all 8 frequencies, (symmetric and asymmetric model in case of lossless medium)

f [Hz]	1 k	1 M	10 M	100 M
P [log(W)]	-52,22	-40,22	-36,22	-32,22
f [Hz]	1 G	10 G	42 G	100 G
P [log(W)]	-28,22	-24,25	-22,03	-20,68

Accordingly, the values of time-averaged Poynting vector calculated from components of near-field aren't zero and are higher than components calculated in lossy medium. On one hand, the values of power in lossy medium are greater than in lossless medium and, on the other hand, the values of power in lossy medium depending on distance from cell wall descend faster than values of power in lossless medium. Fig.5. shows dependence of power of asymmetric microtubule network in lossy medium for all 8 frequencies. The value of power is the highest in proximity of cell wall and decreases fast with growing distance. The other results are calculations of intensity of electric field depending on radial distance from pole or equator of cell (Fig.6.).

Fig.7. depicts intensity of electric field in dependency on distance from pole of the cell wall for all 8 frequencies.

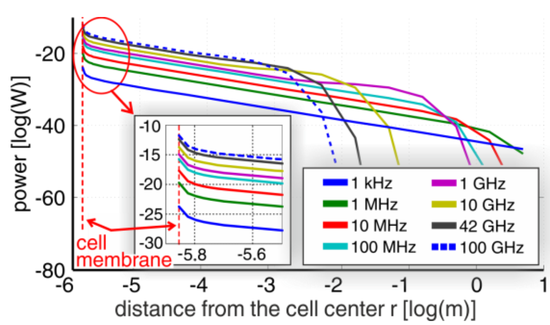

Fig.5. Power calculated from border of microtubule net to 1 m for all 8 frequencies (asymmetric model, mode 0 and lossy medium)

The difference of the electric intensity generated by mode 0 and mode 150 in dependency of radial distance from the pole of asymmetric model in lossy medium and for frequency 42 GHz is shown in the Fig.8. Mode 0 generates higher values of electric intensity than mode 150.

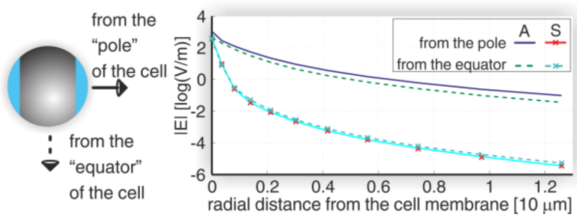

Fig.6. Electric intensity radial from the cell membrane in direction of equator (dashed lines) and pole (full lines). A - asymmetric and S - symmetric model. (mode 0, f = 42 GHz, lossy medium)

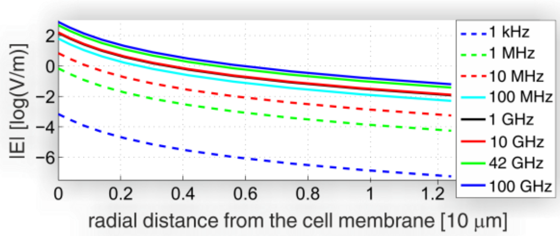

Fig.7. Electric intensity radial from the equator of the cell membrane - comparison of frequencies (asymmetric model, mode 0 and lossy medium)

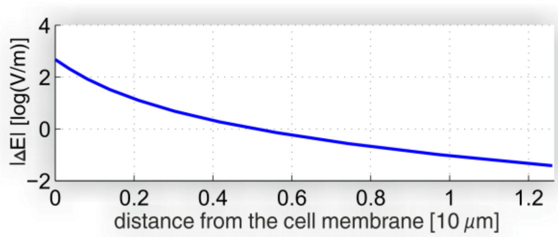

Fig.8. Difference between the electric intensity generated by mode 0 and the one generated by mode 150 in dependency of radial distance from the equator of the cell membrane ($\Delta E = E_{mode0}(r) - E_{mode150}(r)$). (asymmetric model, f = 42 GHz and lossy medium)

V. CONCLUSION

We presented results of calculations of the power and electric intensity generated by two models of microtubule network. The values of power generated by both models of microtubule network show that the small values of power in very small distances from the cell membrane (in order μm) aren't measurable by classic methods and decrease fast with growing distance. Measuring is possible by probe with special characters (length, impedance and thickness). If probe will be too thick, then the value of electric field can be averaged, because the distribution of electric intensity on the cell membrane has spatial character.

ACKNOWLEDGMENT

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