First Approach Toward a Modeling of the Impedance Spectroscopic Behavior of Microbial Living Cells

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Abstract

The subject of the interactions between electromagnetic (EM) fields and living cells is a strong issue for several decades [1]. Large number of works have been done to study the EM field penetration and inner induced currents in living microorganisms. Relevant information to be collected deals with level and frequency of the EM signal that may affect the development of the considered cells. The former because non-thermal effects are nowadays suspected to exist, altering cell's metabolism, the latter because it is well known that the spectral response of the living cell impedance exhibits some dispersion in relation with cell membrane behavior and shield effects [2].

In the battle against pathogenic microorganisms, the use of physical means is in fact a modern approach to the inhibition of bacterial growth. The use of electric current was first proven to be effective in the removal of biofilms in water. This method was reported more than 50 years ago [3], with many subsequent reports [4 - 6]. Most articles on the subject focus on improving the effectiveness of antibiotics against microbes by the application of direct currents of low amplitudes. Several mechanisms have been proposed for the inhibition [7 - 10].
It appears that these mechanisms may be partially related to shape, dimensions and orientation of bacterial cells in relation to the applied electric field orientation. The present work aims at examine this problem through the elaboration of a simplified equivalent electric circuit, supported by a prior COMSOL analysis using the AC/DC Module.

The bacterium selected to test our approach is Escherichia coli. A first model, suitable for the required level of resolution, may be a 1 to 3 micrometer long and 0.3 to 0.7 micrometer wide capsule filled with salted bound water and surrounded by a dielectric membrane of thickness 50 nm. The medium is considered as a physiological fluid (free water). Figure 1 shows the COMSOL model, assuming that the field is provided through the application of an AC voltage between two plane parallel electrodes. Next, the equivalent circuit for the overall medium, containing the suspended bacterial cells, is deduced, taking into account the concentration and the orientation of bacteria, as well as the electrodes/medium interface.

As an example of interesting result, Figure 2 shows the current lines for a bacterium longitudinally oriented with the electric field at a frequency of 1MHz. It reveals the well-known shield effect at lower frequencies.

This work will be completed in the future with a more complex approach taking into account the microstructure of the dielectric membrane (mechanical vibrations of the proteins) and the electrochemical behavior of the electrodes/water interfaces.

Reference

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Figures used in the abstract

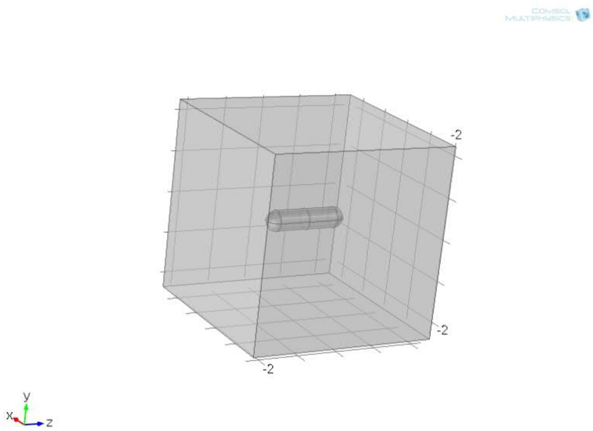

Figure 1: COMSOL model of the bacterium

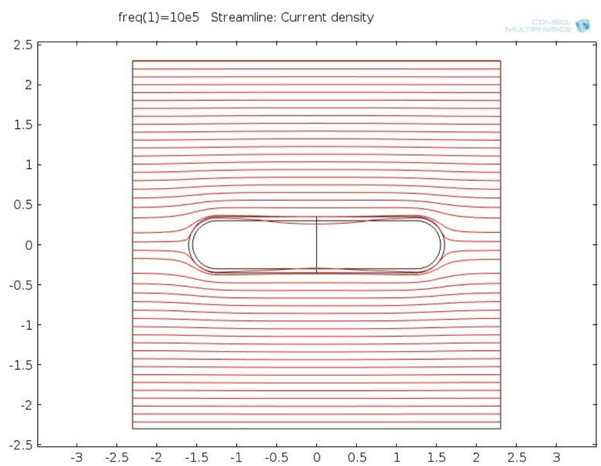

Figure 2: Current lines at 1MHz