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Modeling and Measurement of Electromagnetic Radiation from Bacterial Communities

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It is a well-known fact that biological cells, whether unicellular or multicellular organisms, do not function in isolation. Their proper function or even survival depends on their ability to interact with each other and the outside environment. Critical environmental information, that cells need to sense and process, includes temperature, pH, availability of nutrients, etc. Communication among cells can pertain to changes in the cell internal workings in response to the received information from adjacent cell by means of chemical signals. Cell signaling, in unicellular organisms, is used for coordinating tasks, and in multicellular organisms allows for formation of tissues such as muscles and nerves. Signaling by means of specific chemical particles known as "quorum sensing" has shown to be inefficient in regard to the data rate and range of communication. In this approach cells release chemical molecules to adjacent cells through the process of diffusion. As many functions within cells are mediated by electricity, we postulate that cell should also be able to communicate electromagnetically, which requires far less energy, can provide higher data rate, and longer range.

In this paper we focus on a community of unicellular organisms in the form of biofilm that contain complex organic elements called amyloid fibrils with permanent dipole moments that are characterized as elastic helical strings or beams. These amyloid fibrils are part of the extra-cellular matrix in the biofilm and are either suspended within the liquid medium of biofilms or attached to the cells. The charged strings attached to the cells can be modeled as cantilever beams with permanent dipole charges on them and can be set motion purposefully by the cell through a sudden release of heat generated from a metabolic process or accumulated stress. According to the fundamental theory of electromagnetics, any vibrating (accelerating) charges radiate electromagnetic waves at frequencies related to the natural mechanical resonances of the structure. Due to the small dimensions of cells and amyloids, the fields generated by such motions fall within radio frequencies. Reception is accomplished in the reverse order, meaning that time varying electric fields vibrate an amyloid connected to a receiving cell and the mechanical motion transferred to the cell is sensed.

To describe the theory behind the concept of electromagnetic based communication, a novel multiphysics model which we refer to as "Electromagnetically-Coupled System of Mechanical Oscillators" is proposed. This model is based on randomly oriented vibrating elastic amyloid fibrils interacting with each other electromagnetically. To accurately model the signal transmission between bacteria and find the frequency and amplitude level of such EM signaling, this research combines the equations of mechanical vibration of both cantilever beam and spring mode with Maxwell's equations. Based on initial modeling results, we predict that electromagnetic communication indeed can occur within gigahertz frequency ranges, depending on the mode of vibration. To prove the existence of such signaling within biofilms, an ultra-wideband near-zone radiative signal collector system operating from 1-50 GHz is developed for signal detection. The system consists of a specially-designed dual-polarized signal collector that is capable of focusing the field at a small area where the Petri dish is placed, broadband low-noise amplifiers, and a spectrum analyzer. Exemplary measurements show that the system can detect the change in background emission with a signal level as low as -191 dBm/Hz. A large number of bio-samples have been prepared for experiments. Some initial results indicating possible emission from such samples have been gathered and are being re-examined and retested for validation.

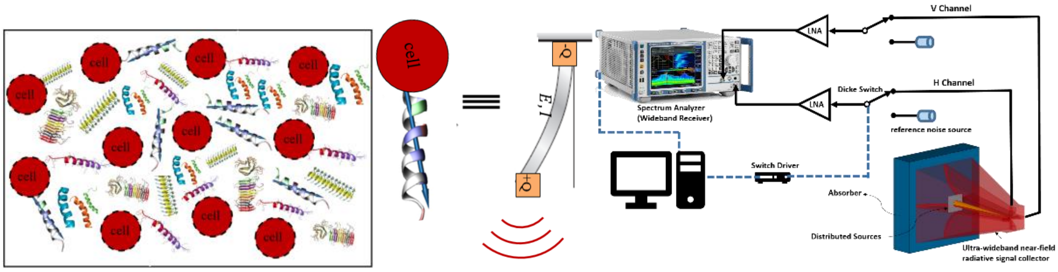

Figure 1. (a) EM signaling model and (b) the measurement system