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NEAR-FIELD RADIO-FREQUENCY PROBING METHOD CAPABILITIES FOR THE STUDY OF WATER STRUCTURAL DYNAMIC

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Living systems and free water were studied with the help of near-field radio-frequency (NFRF) probing methods. The results of this analysis suggest that processes within biological systems are comparable with those in ordinary water. The presented data suggest that near-field radio-frequency probing can be a useful diagnostic tool for the analysis of the radio-frequency fields generated by biological objects.

Keywords: radio-frequency near-field probing method, permittivity, generator frequency, wavelet transform.

1. Introduction

Recent progress in the development of radio-frequency and microwave medical equipment suggests that such instrumentation can be a useful diagnostic tool applicable in the area of internal medicine, traumatology and musculoskeletal disorders. Diagnostics based on radio-frequency and microwave probing methods offer advantages over conventional diagnostic tools e.g. probing methods offer a noninvasive diagnostic approach that allows the studying of biological tissue heterogeneity and such methods offer spatial analysis of biological organs, including the analysis of tissues located on the surface or within biological organs, as well as help define the special dimensions of these biological organs.

Despite recent progress, there is a growing understanding that new diagnostic approaches need to be transformed into more sophisticated tools which not only target symptoms of inflammatory processes, but are also successfully integrated into mainstream clinical laboratory and instrumental analyses.

Living biological objects have a complex structure of physical fields inside and outside the biological borders of the object. Spatial distribution and time dynamics of these physical fields carry important biological information that could be used for medical diagnosis.

One of the most important characteristics that describes interaction between probing electromagnetic radiation (PER) and a biological object is the complex permittivity, that is, in turn, connected with conductivity and the tangent of dielectric loss. Conductivity and dielectric loss, in turn, depend upon the physicochemical parameters of the biological object, such as water content, protein hydration, temperature, etc.

Recent studies suggest a strong connection between protein hydration and the activity of a biological system [1].

This paper presents data from the near-field radio-frequency (NFRF) probing study of biological objects as compared to ordinary water. Data suggest that the NFRF probing method is sensitive to the dynamic state of the water in a biological object, and therefore, can be used to analyze the state of that biological object.

2. The equipment and the methodology of the experiment

The main purpose of this method is to glean information about any inner structure (biological or physical) which can be surveyed from its surface. The NFRF probing method is based on the following assumptions: first, the electrodynamic state of the surface is connected with processes inside object through its dielectric permittivity (ε) and specific conductivity (σ), and second, the connection between the surface parameters and processes inside the object can be monitored by means of a compact electric antenna (sensor) that is working in the active mode.

There is one distinct property that characterizes our approach and sets it apart from conventional methods of radio-frequency (RF) diagnostics, namely, the choice of frequency for the antenna-sensor. We have previously presented the analysis of the known dispersive dependences for (ε), (σ) and full impedance (Z) which demonstrated that frequencies between 1-10 MHz were very sensitive to processes in biological systems [2]. Based on those results, 4 MHz was selected as the working frequency for the antenna-sensor.

All experiments were conducted with the help of diagnostic equipment [3] presented in Figure-1.

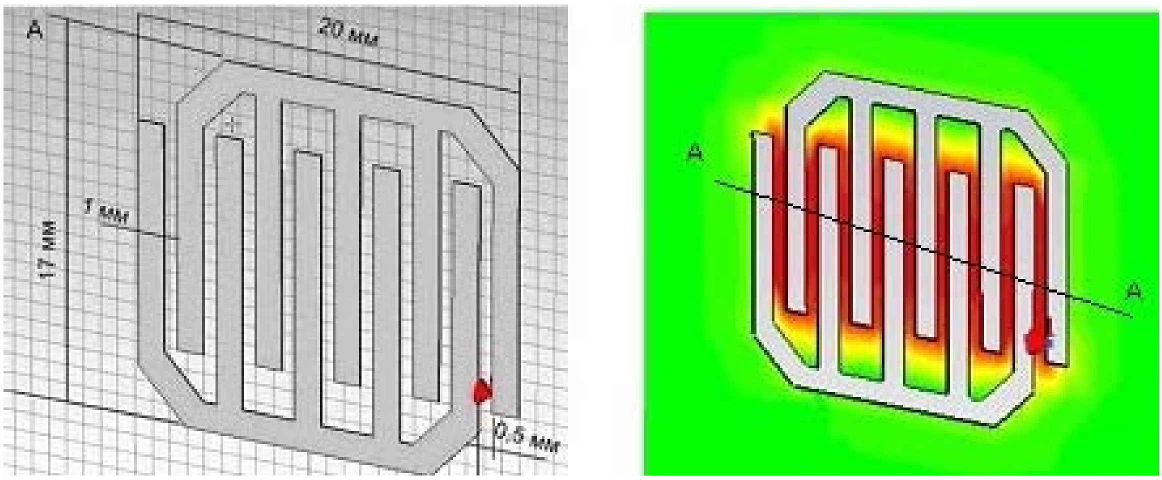
a) **b)**

Fig. 1. Diagnostic radio-frequency near-field probing equipment: a) general overview of the equipment in full assembly; b) overview of the antenna-sensor with circuit board of the RF generator

The main element of the electronic equipment is the highly sensitive detector comprised of the compact antenna connected to the RF generator oscillatory circuit with geometry presented on Figure-2-a.

During operation, the generator's aperture creates a quasi-static electric field (near-field zone) in the air. Figure-3 presents the results of the quasi-static electric field analysis conducted with the help of certified software package CST Studio Suite 2012 designated for electrodynamic modeling within a wide range of frequencies.

When the sensor is placed in contact with the surface of the physical or biological object, a quasi-static electric field generated by the sensor works as a connector between



a) **b)**

Fig. 2. Radio-frequency antenna-sensor: a) Overview of the antenna geometry; b) Quasi-static field (near-field zone) at the antenna aperture

the antenna's impedance and object's surface impedance. As a result of that connection, the general impedance of the radio-frequency generator's oscillating circuit and its frequency value ($\delta\nu$) are changed. The difference between frequencies is described according to the following equation: ($\delta\nu = \nu_0 - \nu_1$), where ($\nu_0$) is the generator's frequency when antenna is placed in air, and (ν_1) is the generator's frequency, when antenna is placed on the object's surface. During NFRF probing, the frequency difference ($\delta\nu$), recorded through computer interface, represents an analytical signal that follows the changes in the object of interest.

After an analytical signal $\delta\nu = \nu_0 - \nu_1$ is obtained by the antenna, the signal is digitized through a "frequency-code" transformation and analyzed with the help of a designated software package.

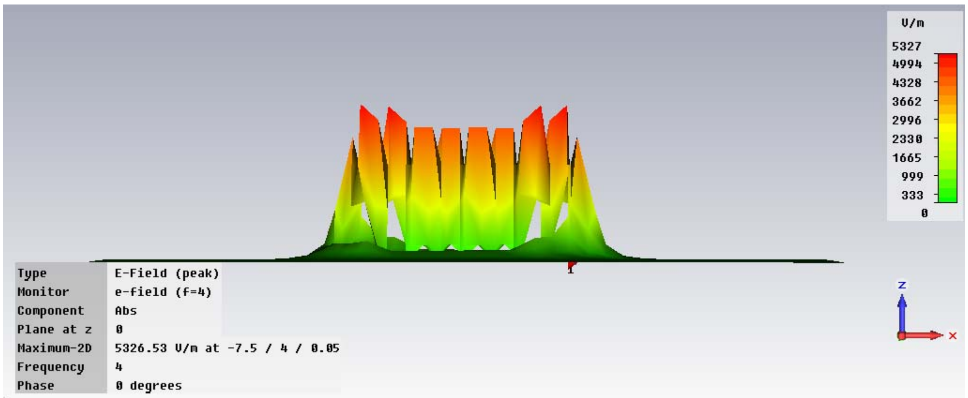
3. Experimental design

The goal of the study was to compare the NFRF probing of a healthy subject's hand and water samples.

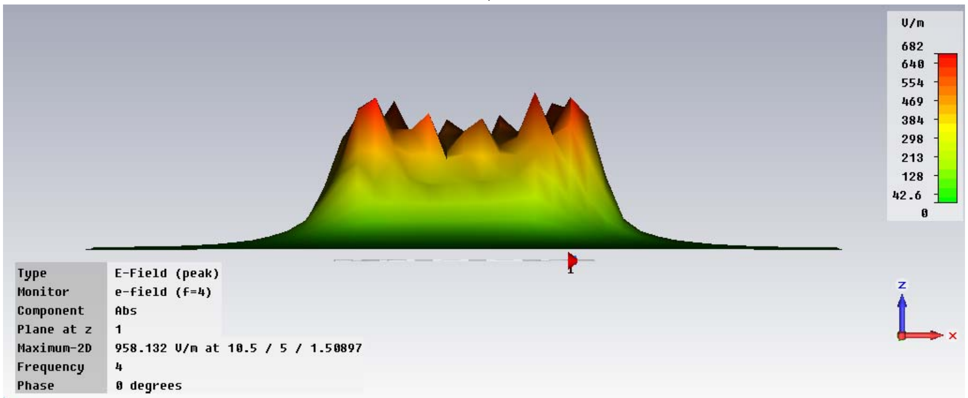
As previously mentioned, the frequency difference ($\delta\nu$) is the main source of diagnostic information of the proposed method, which allows an estimation of the object's internal structural organization.

Prior to use, the sensor was subjected to an initial calibration procedure that comprised of two processes: the first included 20 minutes of sensor operation in the air until the working temperature of the sensor was stabilized; the second process included 20 minutes of operation during which the sensor was wrapped in a plastic film and placed in water. After that, the device was re-calibrated and the frequency of the sensor was tuned in.

The initial calibration procedure was set up using the software option "Tune in" that expressed the sensor's frequency (ν_0) in relative units, and allowed the sensor's frequency to be tuned to either the "air" or "water" option. The selection between "air" and "water" options was determined by the goals of the particular experiment, since the sensor's tuning and calibration process could be carried out using any other object or different place on the object.



a)



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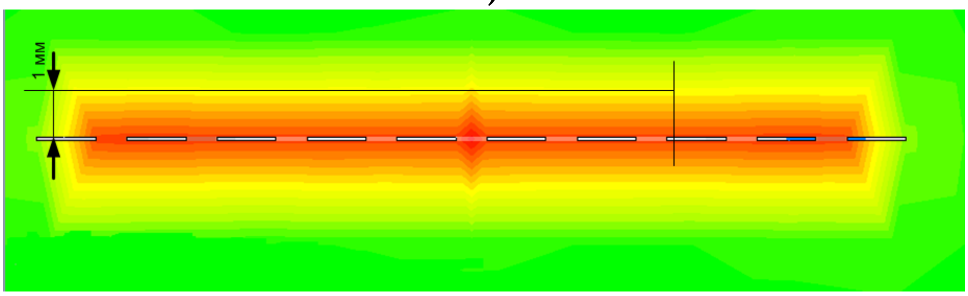

c)

Fig. 3. Quasi-static electric field distribution at the antenna aperture (near-field zone): a) field distribution at A-A cross-section (Figure 2-b). b) Distribution of the same field (a) 1mm away from antenna's aperture. Note that field amplitude is decreased by approx. 10 times. c) field distribution at 90 degrees

In order to conduct the first set of experiments (Figure-4), the sensor was tuned in the air for 20 minutes. After tuning, the sensor was placed on the volunteer's hand and the sensor's signal was recorded every three minutes for two hours without changing the position of the sensor.

The second set of experiments (Figure-5) was conducted using the same tuning in the air (20 minutes), but the sensor was then wrapped in plastic film and placed in the water ($\sigma = 4\times10^{-6}$ mOhm/cm, pH$\sim$5.6). The plastic film did not change the parameters of the sensor.

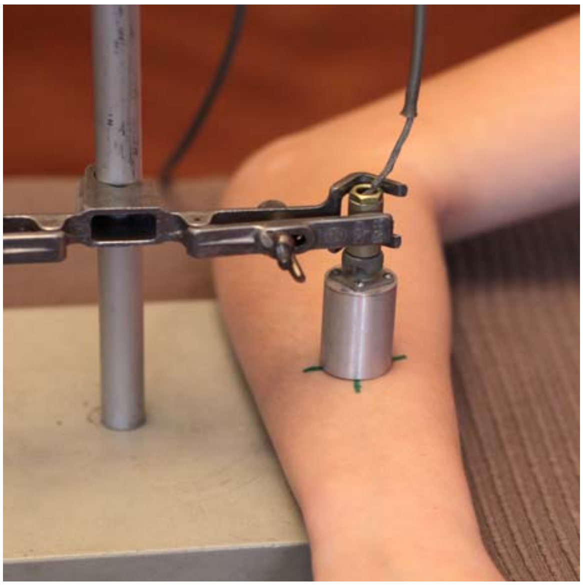

Fig. 4. The arm experiment

Fig. 5. The distilled water experiment

The final experimental step included the time-frequency analysis of the measured parameters. This analysis was carried out with the help of wavelet transformation. The wavelet transformation was chosen over a Fourier transformation because it offers two dimensional evolvement of a one-dimensional process where frequency and time values are considered to be independent variables. Therefore, this transformation allows simultaneous frequency and time analysis of the same process. The Morlet wavelet was used as the basic function.

4. Results and Discussion

Figure 6 presents data obtained with the help of radio-frequency near-field probing of the hand (a) and wavelet analysis of the data (b). Method is described in the experimental design section.

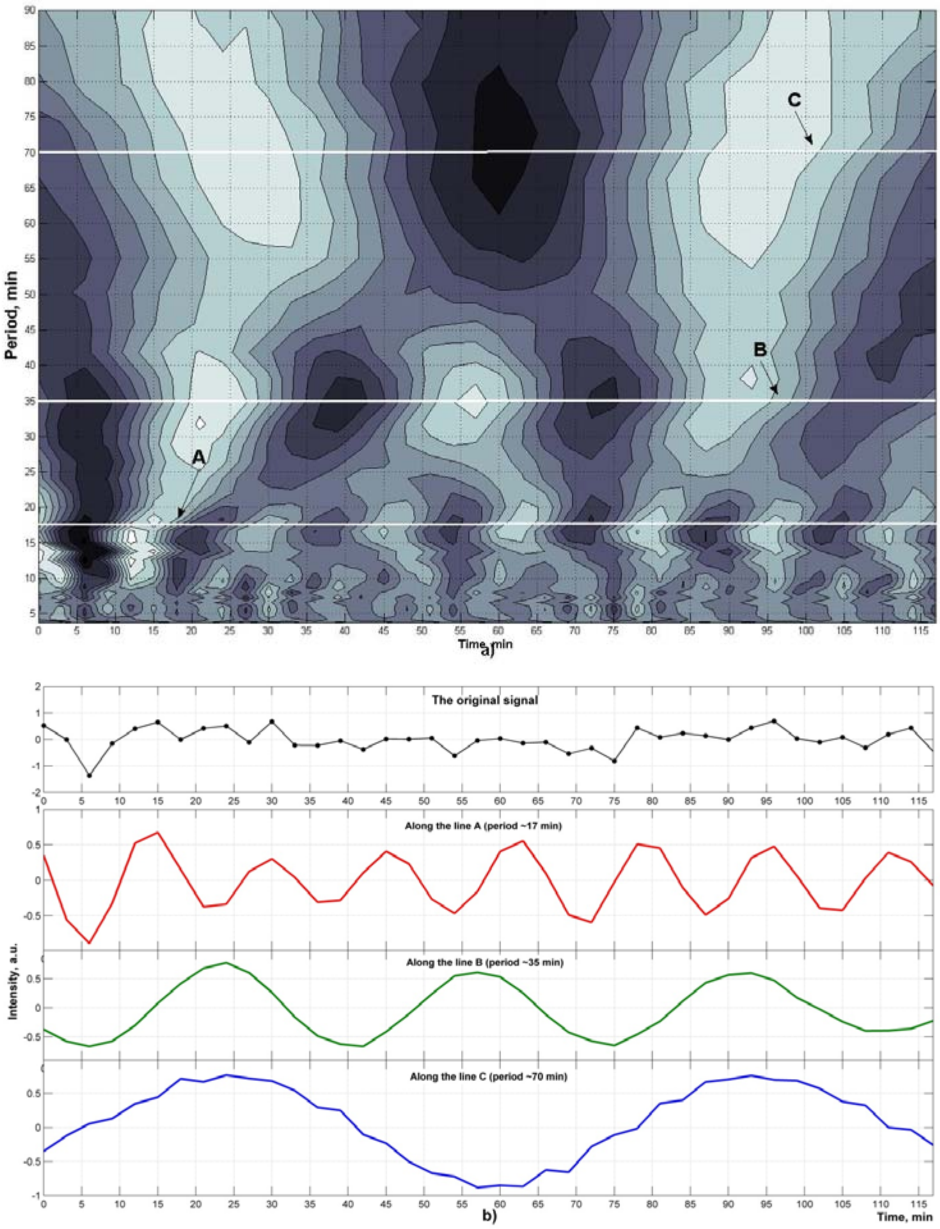

Fig. 6. Wavelet analysis of the NFRF probing signal recorded from the surface of the hand: a) wavelet transformation of the initial signal. Horizontal lines are labeled with letters A, B, and C. b) Initial signal harmonics along the lines A, B, and C on the Figure 6-a

Figure 7 presents data obtained with the help of radio-frequency near-field probing of the water. Method is described in the experimental design section.

Analysis of the experimental data allows us to conclude that, regardless of the nature of studied object, all observed dynamic changes in the NFRF probing signal showed

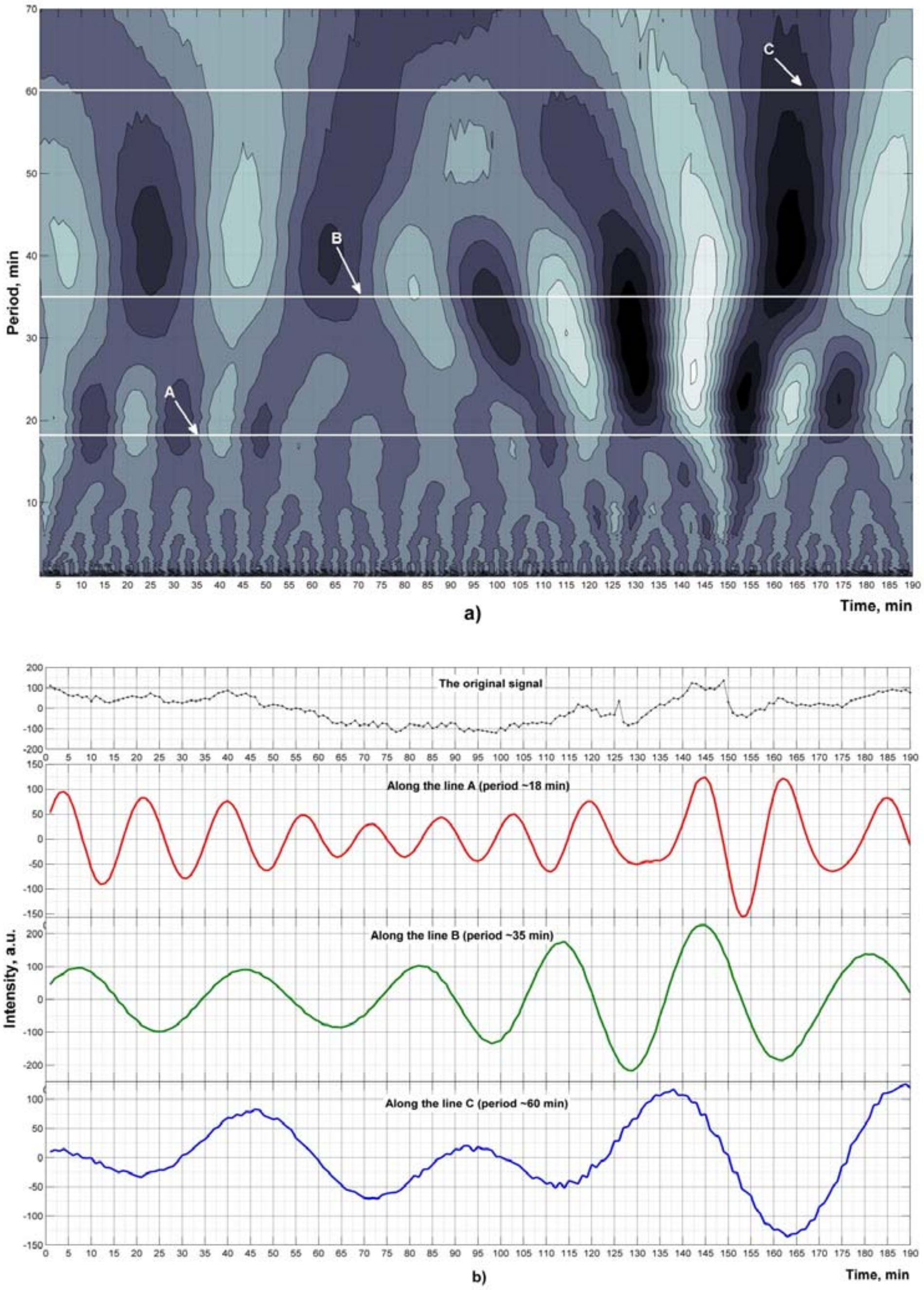

Fig. 7. Wavelet analysis of the radio-frequency near-field probing signal recorded from the sensor placed in the water: a) wavelet transformation of the initial signal. Horizontal lines are labeled with letters A, B, and C. b) Initial signal harmonics along the lines A, B, and C on the Figure 6-a

very reproducible time patterns, within which the magnitude of the changes varied up to 10% (11-19 min, 25-35 min, and 60-70 min). Similarity between patterns obtained from biological object and from ordinary water pointed out that, perhaps, NFRF probing signal was very sensitive to the degree of protein hydration, namely, the changes of the dispersive dependences for ε, σ and Z were determined by hydration shells around proteins.

Therefore, the main hypothesis is that processes within biological system are comparable with the processes in the ordinary natural water. Presented analysis of the dynamic changes of the radio-frequency near-field probing signal can be used for the development of a diagnostic method.

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