Control dynamics of biological systems under a influence of millimeter radiation

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***Abstract*— In this paper we describe a theoretical model of the interaction of millimeter electromagnetic radiation with a biological environment. The mechanism of formation of optical phonons and their interaction with the generated field by the cell system are studied. It is shown that the system displays, under certain conditions, periodic and chaotic behaviours. For certain bifurcation parameter values of the molecular system Hopf and period doubling bifurcations may occur.**

***Key Words* —Millimeter waves, dynamical control, chaotic behaviour.**

I. Introduction

The influence of electromagnetic fields on a living matter represents one of the most important problem of modern biomedicine. During recent years, it has been shown that the practical application of electromagnetic waves of the millimeter (MM) and terahertz (THZ) range is of particular interest [1-2]. Millimeter wave imaging techniques have been widely investigated for various medical applications, such as breast cancer tissues [3-5], brain tumour detection, and skin cancer detection and monitoring [6, 7], etc. A comprehensive analysis of the dielectric properties of breast tissues and the differences between normal and tumorous breast tissues at the frequency range from 0.5 to 50 GHz in terms of sensitivity and specificity is presented in [8]. On the other hand, permittivity measurements of excited canine head skin tissues in the MM wave frequency was published in [9]. A possible alternative for testing the envisaged skin cancer detection for canine samples with human skin tissues across a wider band is developed.

Although a large number of experiments confirm the therapeutical effect of MM waves on living organisms, a complete theoretical mechanism that explain their interaction is missed. There are several theories explaining the influence of MM electromagnetic waves on biomacromolecules. According to Frohlich's model [10], the living cells are able to generate electromagnetic waves in the MM range.

Other studies have shown that the production of coherent waves by living cells is a systemic process involving cell membranes, protein channels, and cellular transport pumps. Electromagnetic radiation of low intensity implies the acceleration of active transport of sodium ions, which leads to a change in the permeability of erythrocyte membranes for potassium ions [11]. An acceleration of the oxidation mechanism of liposomes has also been observed, which contributes to the amplification of ionic conductivity in the cell membrane [12, 13]. The absorption and generation of MM waves by biomolecules can stimulate their growth, a process similar to photosynthesis. Thus, a major interest of biomedicine is to study the mechanism connected to the processes of the biological systems involving the radiation of MM and THZ.

In this paper, we report studies on the dynamics of Bose-condensed dipole-active phonons and internal Fröhlich photons in biological media. The theoretical model is used to calculate the behavior of photons and phonons for different parameters of the system.

II. Theoretical Model

The investigated model is shown in Fig. 1 and consists of biological sample of length L under the influence of external pump P. Under the influence of external pump, the dipole-active phonons are created in the biological medium. The external pump comes from a millimeter wave generator of high frequency, within the range 42.2–61.2 GHz with small output power (10 mW). We mention that the MM waves generator can work in the continuous wave (CW) as well as pulse generation regimes. The diffraction losses emitted by the biological cells are used for further irradiation by using an optical feedback, τ being the propagation time of emitted photons trougth the amplifier.

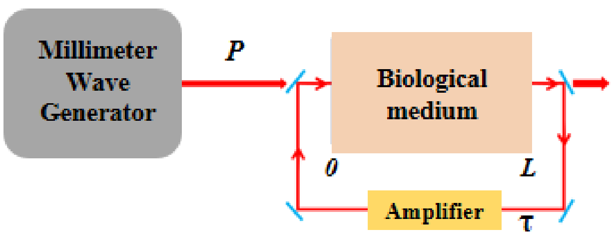

Fig. 2. Schematic representation of investigated setup.

The dynamics of molecular system irradiated by MM waves can be described by using the system of nonlinear differential equations [14] that fully describes the dynamic evolution of Frohlich millimeter electromagnetic field:

$$\frac{dY_1}{dT} = -\sigma Y_1 - (\tilde{\delta} - \tilde{\omega}_0)Y_2 + 2\alpha\tilde{\gamma}Y_3 + \alpha\left\{2\tilde{\gamma}\left[\delta - \nu\left(Y_3^2 + Y_4^2\right)\right] - 1\right\}Y_4 + \Gamma\left[\cos(\varphi)Y_1(t-\tau) + \sin(\varphi)Y_2(t-\tau)\right] + P,$$

$$\frac{dY_2}{dT} = (\tilde{\delta} - \tilde{\omega}_0)Y_1 - \sigma Y_2 + 2\alpha\tilde{\gamma}Y_4 - \alpha\left\{2\tilde{\gamma}\left[\delta - \nu\left(Y_3^2 + Y_4^2\right)\right] - 1\right\}Y_3 + \Gamma\left[\cos(\varphi)Y_2(t-\tau) - \sin(\varphi)Y_1(t-\tau)\right],$$

$$\frac{dY_3}{dT} = -\alpha Y_2 - Y_3 - \left[\delta - \nu\left(Y_3^2 + Y_4^2\right)\right]Y_4,$$

$$\frac{dY_4}{dT} = \alpha Y_1 + \left[\delta - \nu\left(Y_3^2 + Y_4^2\right)\right]Y_3 - Y_4. \quad (1)$$

In the equations (1) $Y_1^2 + Y_2^2 = I$ represents the intensity of emitted Fröhlich photons and $Y_3^2 + Y_4^2 = n$ the phonons concentration generated by biological system. For conveniences we introduced the next dimensionless variables:

$$\delta = \frac{\Delta}{\gamma},\ \tilde{\delta} = \frac{\omega^2 - c^2k^2}{2\omega\gamma},\ \alpha = \sqrt{\frac{\omega\Omega_0}{2\gamma^2}},\ \Omega_0 = \frac{4\pi d^2}{V_0\hbar},$$

$$\tilde{\omega}_0 = \frac{\Omega_0}{\gamma},\ \tilde{\gamma} = \frac{\gamma}{\omega},\ \sigma = \frac{\gamma_f}{\gamma},\ T = \gamma t,$$

where ω is the electromagnetic wave frequency, while Ω - phonon energy. $\Delta = \omega - \Omega$ represents detuning, γ - phonons attenuation coefficient, γ_f is the attenuation constant of external electromagnetic field, d – dipolar electric momentum, k - wave vector, c- speed of light in vacuum, and V_0 is cells volume. Γ and φ characterise the amplitude and phase of optical feedback, respectively.

III. Numerical Results

In this section we describe the evolution of equations (1) for different values of system parameters. The numerical calculations of the system of ordinary differential equations (1) were realized by using the Runge–Kutta method. In all our numerical calculations the following dimensionless parameter values are used: $\tilde{\delta} = 0.1$, $\tilde{\omega}_0 = 0.1$, $\sigma = 10$, $\nu = 1$, $\tilde{\gamma} = 1.1$, $\tau = 0.15$, $P = 95$, $\varphi = 3\pi/2$. The other parameter values as amplitude Γ and phase φ of optical feedback, and detuning δ are considered to vary. Figure 2 shows the influence of detuning and optical feefback strength on the dynamics of emitted Fröhlich photons, as well as phase portrait and power spectrum for different parameters.

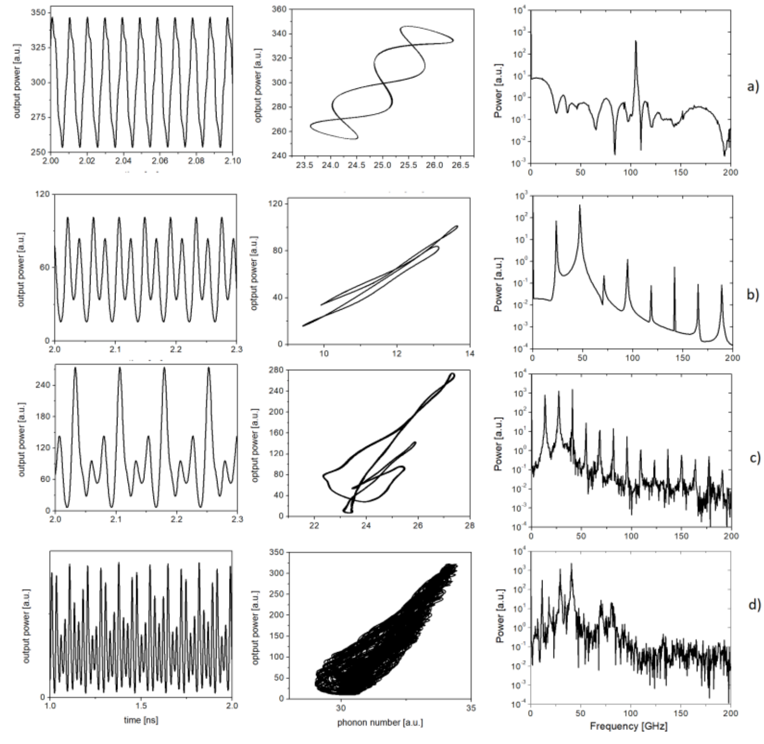

Fig. 2. Time evolution of the output power of internal Fröhlich photons (left), phase portrait (center) and power spectrum (right) for different parameters: a) $\alpha = 20.3$, $\delta = 20$, $\Gamma = 5.0$, b) $\alpha = 15$, $\delta = 10$, $\Gamma = 5.0$, c) $\alpha = 15$, $\delta = 23.3$, $\Gamma = 15.0$, d) $\alpha = 15$, $\delta = 30$, $\Gamma = 15$.

For small values of detuning and optical feedback strength the dynamics of our system shows a periodic evolution (see Fig. 2, *a*). The phase trajectories go to a stable limit cycle with time. For large values of δ and Γ period-doubling oscillations are observed that correspond to the transition of the system in a chaotic regime (see Fig. 2, b-d). The chaotic evolution is shown in Fig. 2 d. Similar evolutions can be observed and in the power spectrum.

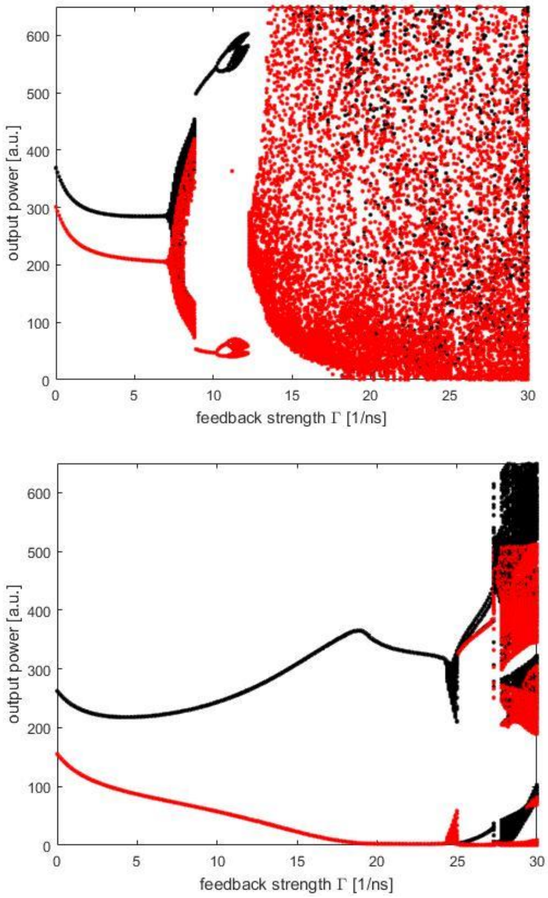

Fig. 3. Numerical bifurcation diagram of the output power for the optical feedback strength being bifurcation parameter and a) $\alpha = 15$, $\delta = 20$, a) $\alpha = 20$, $\delta = 15$.

Figure 3 shows the bifurcation diagram of the output power for the optical feedback Γ as bifurcation parameter. Each black dot represents a peak (maximum) of the output power. Red dots show the minimum of the output power. For small values of the optical feedback the system displaces a periodic oscillation regime similar to that shown in Fig. 2a). With increasing of Γ one can observe double period Hopf bifurcations and transition to chaos. Thus, for large values of bifurcation parameter (feedback strength) the dynamics of the molecule system shows a chaotic behavior.

CONCLUZIONS

In this paper we study the dynamics of Bose-condensed dipole-active phonons and internal Fröhlich photons in biological environment. Time evolution of the output power of internal emitted photons and phonons are calculated for different parameters of the system. It is shown that under certain values of detuning and optical feefback parameters the system displays periodic as well as chaotic behaviours. The bifurcation diagrams of the emitted photons as function of feedback strength Γ was obtained. Thus, in the molecular system periodic and chaotic oscillations may occur.

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