DNA as an Electromagnetic Fractal Cavity Resonator: Its Universal Sensing and Fractal Antenna Behavior

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Abstract We report that 3D-A-DNA structure behaves as a fractal antenna, which can interact with the electromagnetic fields over a wide range of frequencies. Using the lattice details of human DNA, we have modeled radiation of DNA as a helical antenna. The DNA structure resonates with the electromagnetic waves at 34 GHz, with a positive gain of 1.7 dBi. We have also analyzed the role of three different lattice symmetries of DNA and the possibility of soliton-based energy transmission along the structure.

Keywords Biological living system · Antenna · DNA vibration

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1 Introduction

An antenna is capable of transmitting and receiving electromagnetic waves (EMs). Biomaterials are insulators, whether insulators have any potential to radiate like a metallic antenna or not depends on multiple factors. An antenna emits electromagnetic signals only when the standing wave formed inside absorbs integral multiple of its energy in the cavity and only if the radiation resistance is very low. Certain fields could literally break apart DNA (fields as low as 0.18 μT) as suggested recently from studies showing associations with damage to DNA repair genes [1, 2]. Insulators like biomaterials, do not have highly reflecting metallic outer boundary that reflects and develops electromagnetic signals multiple times, and develops high-quality factor or produces high-quality standing waves. For example, DNA literally needs to breathe, else it would break apart [3]. Our attempt to theorize that biomaterials could also act as an antenna includes the factor that even such insulated biomaterials would somehow produce standing waves, which is fundamentally against the concept of physics. Such problems are not addressed seriously, and the predictions for the electromagnetic interactions continue [4, 5]. Even though claims are already been made that DNA is a fractal antenna [6], there are several questions need to be answered before we could confirm whether such a possibility could really exist. There are different kinds of antennas, but recently fractal antennas have received a lot of attention. Fractal antenna is an antenna design that uses the most important fractal characteristic known as self-similarity. The self-similarity in the DNA structure does exist; however, that alone cannot promise electromagnetic resonance in the extremely low frequency (ELF) and radio frequency (RF) ranges. The electromagnetic field interacts with DNA in the ELF range and during DNA strand break, such as described in [7]. EMF can break apart DNA [2]; that is, by maximizing its length and perimeter, they can receive or transmit electromagnetic radiation at many different frequencies simultaneously thus suitable for multiband or wideband applications. Since fractal antenna designs are tightly packed, they are very useful in telecommunication applications such as microwave communication and cellular phones.

DNA is a molecule that contains genetic information utilized by all life-forms and numerous viruses. The human DNA in form of the double helix and various models of conductions has been proposed thus far. The DNAs' interaction with the electromagnetic fields (EMFs) has a wide frequency bandwidth, which does not limit to an optimal frequency. DNA within cells has a compact structural property similar to a fractal antenna with a bandwidth lying at the RF range. By fractal behavior in the electromagnetic resonance spectrum, it is meant that the arrangement of the frequencies has a similar distribution at different scales. In this particular case, we cover a specific domain; however, in future, we would provide detailed frequency database [8–10]. Herein, we developed a new electromagnetic interaction model for the double-helix-shaped human DNA (see Fig. 1). Moreover, we have performed computer simulations in the RF range, with the help of antenna

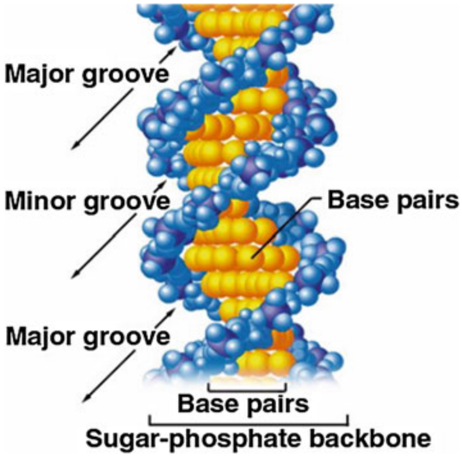


Fig. 1 DNA structure [11]

theory, and compared the results with the biological data. The human DNA is modeled as a uniform medium with a helical shape. The proposed antenna has the physical dimensions of the same order of magnitude that the original human DNA dimensions [11]. The simulated results were very close to the biological results.

The present work is divided into three parts: In Sect. 2, we present the antenna designing characteristic. Section 3 describes the analysis of the simulation and comparison with biological data. Finally, we wrap up the work with the conclusions.

2 Modeled Antenna Design

DNA is a double helix in which molecules contain two polynucleotides (nucleotide is the basic unit of the DNA structure) wrapped around one another arranged in such a way that their base pair molecules are inside and sugar phosphate molecules “backbone” are outside to form the famous double-helix structure. There are three kinds of weak interactions run in parallel in a DNA, along the linear chain; then, there are two spirals, one spiral if we consider the DNA as a normal cylinder and then if the other spiral if we consider a twisted cylinder. Therefore, we would always get three distinct kinds of transmissions along the DNA molecule simultaneously. Thus, helical structure is not absolutely regular. Superposition of three distinct dynamics would change the structure in homogeneously, and we can distinguish minor and major grooves which are shown in Fig. 1. At room temperature, the conductivity of DNA is 2.4 mho/cm. [12] and the value of the dielectric constant is 4.7 [13]. Here, the 2D view of modeled antenna is designed to take the original view of the A-DNA structure, which has the following physical structural data as shown in Table 1. The 3D view of the modeled antenna based on A-DNA structure is shown in Fig. 2.

Table 1 Dimensional scale of parameter

S. No.	Parameter	Dimension
1	Base pair diameter	0.23 nm
2	Helix packing diameter	2.55 nm
3	Base pair/turn	1
4	Base pairs per turn of helix	11
5	Tilt of base normal to the helix axis	19°
6	Distance per complete term	3.2 nm
7	Distance between base pairs	0.34 nm

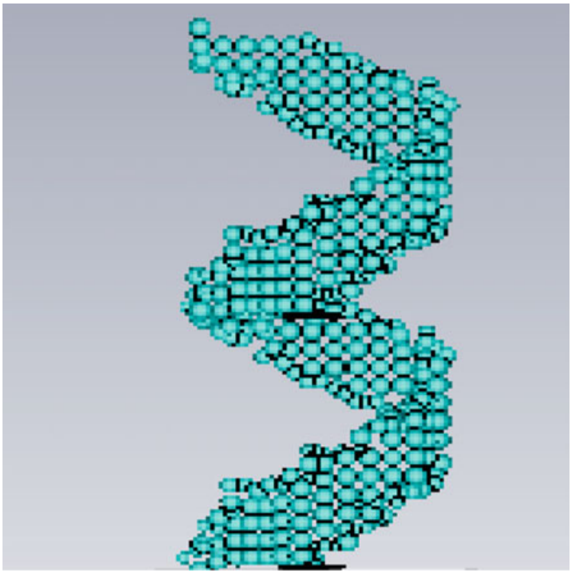


Fig. 2 Single-turn 3D view of modeled antenna

3 Analysis of Simulated and Biological Result

3.1 Radiation Analysis

The reflection coefficient S_{11} (reflection coefficient is an antenna parameter that shows the amount of lost power by the load and does not return as a reflection) of the modeled antenna is shown in Fig. 3a. The reflection coefficient indicates that modeled antenna resonates at the 34 GHz frequency and the corresponding gain is positive (1.7 dBi). The gain value of the single turn of the 3D modeled antenna swims toward the positive value as depicted in Fig. 3b.

The antenna theory suggests that if the dimension of the helix antenna is small compared to their wavelength, then the maximum radiation pattern would always be in the normal direction [14]. Here, the DNA fractal antenna consisting of a small loop where the helix packing diameter is the same as the small loop diameter and

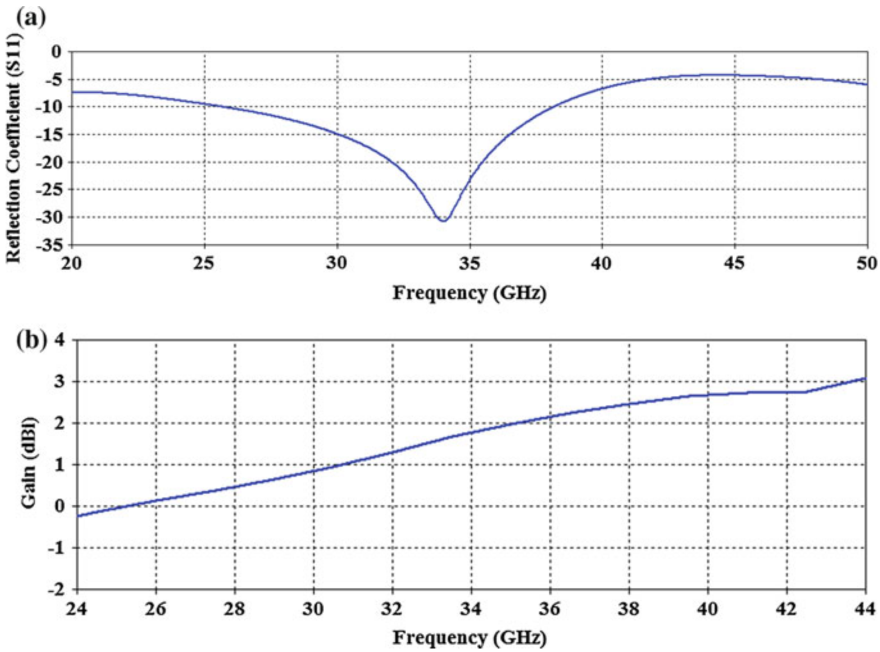


Fig. 3 **a** Variation of the reflection coefficient (dBi) versus to frequency (GHz), **b** variations of the efficiency versus to frequency (GHz)

the length of the loop is almost the same as one-turn distance ($n \cdot L < \lambda$). The modeled DNA antenna radiates with the maximum field in the normal direction to the helical axis. The simulated *E* and *H* radiation pattern plane of DNA one-turn double-helix modeled antenna is depicted in Fig. 4 which is significantly close to the theoretical assumption made by direct transmission calculation.

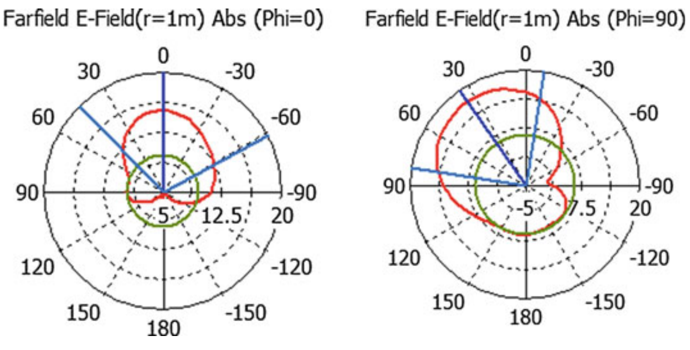


Fig. 4 *E* and *H* plane radiation patterns

3.2 Power Analysis

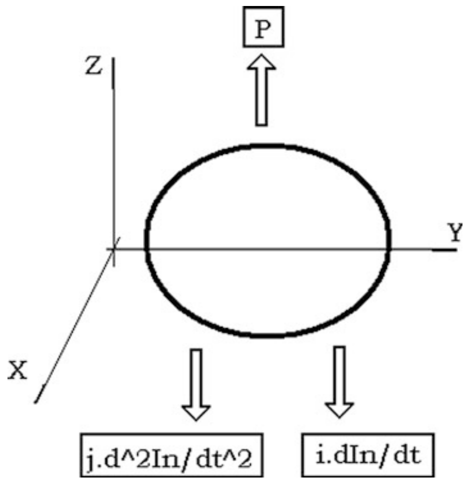
Experimentally, the actual current distribution on the helix antenna is found to be more complex. Since the total current at the end of a DNAs cylindrical surface is constant, the traveling wave's asymmetric or nonlinear terms generated by the superposition of three different kinds of transmissions would get damped due to the structural stretch in the molecular structure. Longer stretches of DNA are entropically elastic under tension; it undergoes a continuous structural variation due to the available energy, continual collisions with the water molecules. The modeled DNA antenna behaves in a way that during structural damping, the DNA molecules are cyclically stressed; as a result, the energy is dissipated internally. The dissipated energy holds the relation with the current amplitude as described in Eq. (1). The shape of the hysteresis curve remains unchanged along with the amplitude and the strain rate [14]. The loss coefficient also remains constant. The dissipated energy by the structural vibration (damping) is then given by

$$P_{\mathrm{st}} = \alpha I^2, \tag{1}$$

where α is the loss coefficient and I is the variation in the amplitude of the steady-state current.

Here, DNA helical fractal antenna may be considered as a dynamic system of the DNA molecules which undergo collisions due to structural or thermal vibration. Now, we consider the following case of energy dissipation as shown in Fig. 5, and the variation is demonstrated with the viscous damping. Let I_{n} be the small amount of the current displacement from the steady-state current (I_1) and the damping voltage in this case such that:

Fig. 5 Dynamic system



$$I_{\mathrm{n}} = I_1 \sin(\omega t - \varphi), \tag{2}$$

$$V_{\mathrm{damp}}(\mathrm{d}V/\mathrm{d}t) = j\mathrm{d}I_{\mathrm{n}}/\mathrm{d}t \tag{3}$$

The power loss per cycle ($2\pi/\omega$) of the current flow due to the applied potential say damped potential (voltage) following the interaction with the neighbor's molecule is given by:

$$P = \int V_{\mathrm{damp}} \mathrm{d}I_n \tag{4}$$

Considering Eqs. (2) and (3), we get

$$P = j\pi\omega^2 I_1^2. \tag{5}$$

where j is a constant, and then, Eq. (5) is close to Eq. (1). This means that the vibration amplitude of the current at the steady state holds the proportional relationship with the power loss. The simulated result also well followed the theoretical assumption related to the vibrational study of the DNA molecules with EM wave interaction. The VSWR curve is depicted in Fig. 6a, and we know that VSWR is equal to the ratio of the maximum and minimum current or the voltage value and its value is close to 1 at the modeled antenna's resonance frequency.

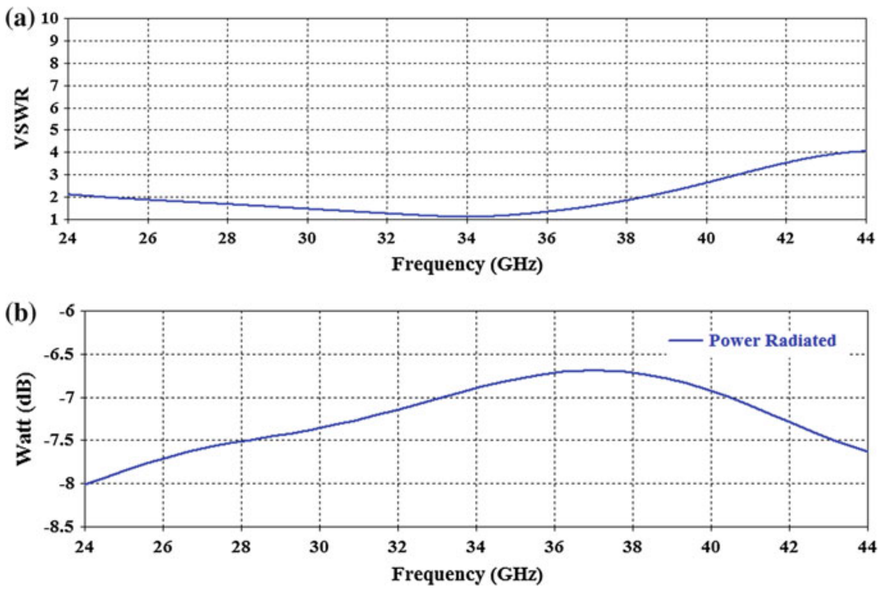


Fig. 6 **a** Variation of the VSWR versus frequency (GHz), **b** radiate power (dB) versus frequency (GHz)

Suppose the wavelength range of these structural vibration = $\lambda_{\min} - \lambda_{\max}$ mm. Let $P_{(\mathrm{vis})\max}$ and $P_{(\mathrm{vis})\min}$ correspond to the maximum and minimum power for $I_{p(\max)}$ and $I_{p(\min)}$ current amplitudes. The required value can be obtained from the depicted Fig. 6b, by using the following parameter values $P_{(\mathrm{vis})\max} = -6.6$ dB, $P_{(\mathrm{vis})\min} = -7.9$ dB, $\mathrm{VSWR}_{\max} = 4$, and $\mathrm{VSWR}_{\min} = 1$, and considering Eq. (5), we get

$$P_{(\mathrm{vis})\max}/P_{(\mathrm{vis})\min} = (\lambda_{\min}/\lambda_{\max})/\left(I_{\rho(\max)}/I_{\rho(\min)}\right)^2 = (\lambda_{\min}/\lambda_{\max})/(\mathrm{VSWR})^2$$

After putting the values, we get

$$\lambda_{\min}/\lambda_{\max} = 0.05 - 0.83$$

The theoretical models of DNA vibration and the model of related twisting vibration suggest that the frequency of such vibrations was estimated within the range $\lambda = 1 - 0.1$ mm (approximately). A model of conformational mobility of DNA, where the motion of nucleotides was considered like pendulum, has been used to obtain the vibration frequency range of $\lambda = 1 - 0.6$ mm (approximately) [15]. Following the theoretical model $\lambda_{\min}/\lambda_{\max} = 0.1$, the simulated result accepts this ratio for the wide frequency range. Here, simulated results of the modeled antenna are well matched with the theoretical results (Figure 7).

3.3 Energy Transfer Through the DNA (Protein) Molecule

Now, we assume that a nonlinear current profile of DNA lattice is composed of N molecules in the form of the helix aligned along Z direction. Let we assume that

- I the current flow between first and last element of the DNA helix chain.
- I_0 Current exits in space between the adjacent DNA molecule at equilibrium state (say, separation current)
- I_d The longitudinal displacement current from its equilibrium current system is dynamic. Now here, we assume that current flow in DNA chain originated along Z direction)

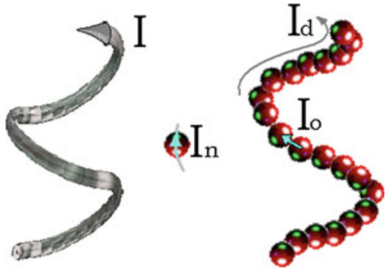


Fig. 7 Current profile of DNA molecules in helix form

I_{rd} Relative displacement current (we may define the relative displacement current between the adjacent molecules from displacement current I_{d})

We may define the relative displacement current between adjacent molecules in the form of $I_{\mathrm{d}}$and then

$$I_{\mathrm{rd}} = I_{\mathrm{d}}(n+1) - I_{\mathrm{d}}(n) \tag{6}$$

The total interaction or displacement power between two adjacent DNA molecules in dynamic states can be written in the form:

$$P_{\mathrm{rd}} = j(I_{\mathrm{rd}} + I_0)^2 - P_0 \tag{7}$$

From Eq. (7), three different cases can be discussed which is consistent with the energy or power profile of the DNA helix shape

Case 1: By using Eq. (7), the relative displacement power between the two adjacent molecules will be minimum, if the neighboring molecules tried to maintain the equilibrium states:

$$\lim_{I_{\mathrm{rd}} \to 0} P_{\mathrm{rd}} = 0 \tag{8}$$

Then, $\mathrm{d}P_{\mathrm{rd}}/\mathrm{d}I_{\mathrm{rd}} = 0, \mathrm{d}^2P_{\mathrm{rd}}/\mathrm{d}I_{\mathrm{rd}} = 0$

Case 2: Equation (8) is found to be in the increasing order if $I \to I_{\mathrm{D}}$, so

$$\lim_{I \to I_{\mathrm{D}}} P_{\mathrm{rd}}f = +\mathrm{value}$$

Case 3: If $I_{\mathrm{rd}} < 0$, then $\mathrm{d}^3P_{\mathrm{rd}}/\mathrm{d}I_{\mathrm{rd}}^3 < 0$.

By the power or energy profile, Friesecke and Pego proved that the continuous limit for relative displacement profile is:

$I(t) = [P'_{\mathrm{rd}}/P''''_{\mathrm{rd}}] \cdot [\text{amplitude. Sech (angle)}]^2$ [15, 16].

Thus, obtained equation of the current or power shows a solitonic waveform which provides the comprehensive explanation of the theoretical statement "A process of vibrational energy transfer along the protein molecule is considered on the basis of a hypothesis of the soliton" [17].

3.4 Dynamic Power Spectrum

The power spectrum of the dynamic system (in case of cherry flow) is shown in [18] which approximates very well with the simulated power curve as shown in Fig. 8. In case of absolute continuous spectrum, the finite length coverage indicates

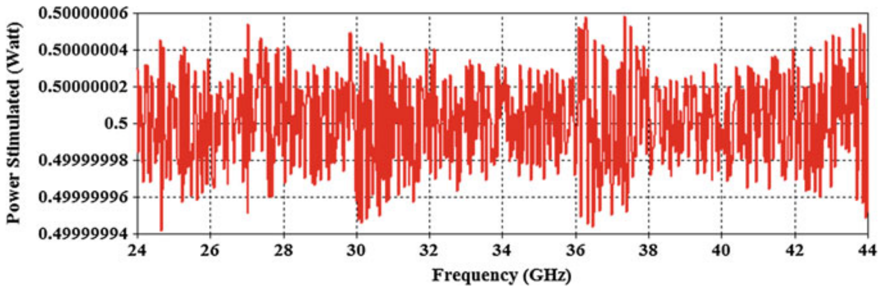


Fig. 8 Power stimulated profile of modeled fractal antenna

a bounded spectral curve, whereas the absence of such convergence indicates the presence of singularities in spectrum measure.

4 Conclusions

In this work, we report that a 3D-A-DNA structure of the human body behaves as a fractal antenna which may interact with electromagnetic fields over a wide range of frequencies. The radiation analysis showed that the modeled antenna resonated at a frequency of 34 GHz with a corresponding positive gain of 1.7 dBi. Additionally, the maximum radiation pattern is mainly in the normal direction just similar to that antenna theory predicts. From our power analysis, we found that the power loss is proportional to the vibration amplitude squared of the current at steady state, a result found before [3]. The wavelength range of these structural vibrations $\lambda_{\min} - \lambda_{\max}$ was investigated. We found that the ratio value between $\lambda_{\min}/\lambda_{\max}$ ranged from 0.05 up to 0.83. Other theoretical DNA vibrational models predicted a value of 0.1. We also found that the energy transfer through the DNA molecule can be calculated by the displacement power between two adjacent DNA molecules whose displacement current is described by a soliton waveform at equilibrium. This result was hypothesized before in [17]. Finally, we found that the simulated dynamic power spectrum of the antenna is similar to the one presented in [18].

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References

1. Xing, H., Wilkerson, D.C., Mayhew, C.N., Lubert, E.J., Skaggs, H.S., Goodson, M.L., Hong, Y., Park-Sarge, O.K., Sarge, K.D.: Mechanism of HSP 70i gene bookmarking. Science **307**, 421–423 (2005)
2. O'Carroll, M.J., Henshaw, D.L.: Aggregating epidemiological evidence: comparing two seminal EMF reviews. Risk Anal. **28**, 225–234 (2008)

3. Alexandrov, B.S., Gelev, V., Bishop, A.R., Usheva, A., Rasmussen, K.O.: DNA breathing dynamics in the presence of a terahertz field. 29 October 2009. http://arxiv.org/abs/0910.5294
4. Adair, R.K.: Vibration resonances in biological systems at microwave frequencies. Biophys. J. **82**(3), 1147–1152 (2002)
5. Meyl, K.: DNA and cell resonance: magnetic waves enable cell communication. DNA Cell Biol. **31**(4), 422–426 (2012)
6. Blank, M., Goodman, R.: DNA is a fractal antenna in electromagnetic fields. Int. J. Radiat. Biol. **87**(4), 409–415 (2011)
7. Sage C, Carpenter D (Eds.) A scientific perspective on health risk of electromagnetic fields. Published online 31 August 2007 at: http://www.bioinitiative.org/report/index.htm
8. Sahu, S., Ghosh, S., Fujita, D., Bandyopadhyay, A.: Live visualizations of single isolated tubulin protein self-assembly via tunneling current: effect of electromagnetic pumping during spontaneous growth of microtubule. Sci. Rep. **4**, 7303 (2014)
9. Sahu, S., Ghosh, S., Hirata, K., Fujita, D., Bandyopadhyay, A.: Multi-level memory-switching properties of a single brain microtubule. Appl. Phys. Lett. **102**, 123701 (2013)
10. Sahu, S., Ghosh, S., Ghosh, B., Aswani, K., Hirata, K., Fujita, D., Bandyopadhyay, A.: Atomic water channel controlling remarkable properties of a single brain microtubule: correlating single protein to its supramolecular assembly. Biosens. Bioelectron. **47**, 141–148 (2013)
11. Watson, J.D., Crick, F.C.H.: Molecular structure of nucleic acids, a structure for deoxyribonucleic acids. Nature **171**, 737–738 (1993)
12. Dewarrat, F. C.: Electric characterization of DNA thesis (2002). https://nanoelectronics.unibas.ch/…/theses/Dewarrat-PhD-Thesis.pdf
13. Flock, S., Labarbe, R., Houssier, C.: Dielectric constant and ionic strength effects on DNA precipitation. Biophys. J. **70**, 1456–1465 (1996)
14. Thomson William, T., Dahleh Dillon, M.: Theory of vibration with applications. 5th edition (1998)
15. Moleron, M., Leonard, A., Daraio, C.: Solitary waves in a chain of repelling magnets. J. Appl. Phys. **115**, 184901 (2014)
16. Friesecke, G., Pego, R.: Nonlinearity **12**, 1601 (1999)
17. Reshetnyak, S.A., Shcheglov, V.A., Blagodatskikh, V.I., Gariaev, P.P., Maslov, MYu.: Mechanisms of interaction of electromagnetic radiation with a biosystem. Laser Phys. **6**(4), 621–653 (1996)
18. Zaks, M.: Fractal fourier spectra in dynamic system. Instituted fur Physik (2001). https://publishup.uni-potsdam.de/opus4-ubp/files/145/zaks.pd