

## Closed Electrical Transmission Line as a Ring Waveguide for Interacting Waves of Electron and Phonon Currents

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### Abstract

As a result of mathematical modeling it has been shown that any closed electrical line can be interpreted as a ring waveguide where the Fermi-Pasta-Ulam recurrences of the electron and phonon currents interact with each other on the transversal and longitudinal periodical structures of the line conductor's crystalline lattice as well as on the structures of the wire insulation. An electronic circuit simulating the mathematical model through the dynamics of magnons and phonons in a closed ferrite core with two different coils switched into the shoulders of a multivibrator has been developed. It has been demonstrated that the interacting ferromagnetic and ferroacoustic resonances excited simultaneously in a ferrite core qualitatively correspond to the dynamics of the electron and phonon currents interaction process in a closed electrical line.

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## Introduction

In the earlier paper [1] there was discussed an idea that an electric current represents a quantum recurrence between the energies of its electron and phonon components. Similar hypothesis was put forward by British scientist Heaviside who supported a concept that the "energy current" propagates in an electrical line not along conductors but in the layers of their insulation [2,3]. The purpose of the study was to work out a mathematical model of an electric current in a transmission line as well as to elaborate a physical device that would support the developed theoretical notions.

### Theoretical Model of Electric Current in a Transmission Line

First consider a closed electrical transmission line as a ring waveguide. We define the amplitude of electron current in the transversal plane of the waveguide as  $I_{electron}$  and the amplitude of phonon current in the longitudinal plane of the waveguide as  $I_{phonon}$ . Using the results of the paper [1] we can describe the interaction process between the two currents within the framework of two parametrically coupled Hill's type differential equations. Some properties of these equations including their ability to absorb the energy of a random perturbation force were discussed in [4]:

$$\frac{d^2 I_{phonon}}{dx^2} + k_{\perp}^2 (1 + \beta I_{electron}) I_{phonon} = a_1 F_1 + a_2 F_2$$

$$\frac{d^2 I_{electron}}{dy^2} + k_{\parallel}^2 (1 + \beta I_{phonon}) I_{electron} = a_1 F_1 + a_2 F_2$$

..... (1)

Where  $x$  - is the longitudinal coordinate along the waveguide and  $y$  - is the transversal coordinate across the waveguide,  $k_{\parallel}$ ,  $k_{\perp}$  - are the longitudinal and transversal spatial frequencies.  $F_1$  and  $F_2$  are the random functions reflecting the short and long wave heat oscillations along the conductor lattice correspondingly.

The interaction process between the two currents takes place both on a quantum scale [1] and on a classical one. In order to unify the processes of interaction between electron and phonon currents in the

line-waveguide on both high and low frequency levels we made the following substitutions and assumptions. For a quantum scale the energy balance between electrons and phonons in a crystalline lattice of a waveguide can be written like this:

$$\hbar \omega_{\parallel} (k_{\parallel})_{phonon} = \hbar \omega_{\perp} (k_{\perp})_{electron} \quad \dots\dots(2)$$

The distance  $a$  between the neighboring atoms in the longitudinal lattice represents a diffraction slot for an electron current. That brings a dispersion ratio for the electron wave in a form:

$$\omega_{\perp} = \frac{2\sqrt{2\pi}c}{a} \left| \frac{\sin \frac{k_{\perp} a}{2}}{k_{\perp}} \right| \quad \dots\dots (3)$$

Now equalizing the energies of electron and phonon waves and using a quantum ratio  $p = \hbar k$ , we can put:

$$\frac{2\hbar\sqrt{2\pi}c}{a} \left| \frac{\sin \frac{P_{\perp} a}{2\hbar}}{\frac{P_{\perp}}{\hbar}} \right| = 2\hbar\sqrt{\frac{\chi}{m}} \sin \left| \frac{P_{\parallel} a}{2\hbar} \right| \quad \dots\dots(4)$$

Where  $\chi$  - is the elastic force acting between neighboring atoms,  $m$  - is the mass of an atom

For a macro scale we can use the dispersion ratio for electromagnetic waves in a cylinder adjustable waveguide [5] imagining that such a waveguide represents a cylinder in a spherical resonator with an adjustable radius  $R=y$ . Considering only a diameter cross section of the sphere, we get:

$$\omega_{\perp} = ctgk_{\perp} y \quad \dots\dots (5)$$

And for longitudinal waves in a ring line the dispersion ratio looks like follows:

$$\omega_{\parallel} = \left| \frac{\sin k_{\parallel} x}{2} \right| \quad \dots\dots(6)$$

We can reduce the system (1) to the form in which the interaction process between electron and phonon currents taking place on both short and long spatial scales depends only on the temporal coordinate by means of introducing the time lags. So the new system looks like:

$$\frac{d^2 I_{phonon}}{dt^2} + \left| \frac{\sin z(t)}{z(t)} \right|^2 (1 + \beta \exp I_{electron}) I_{phonon} = a_1 F_1 + a_2 F_2$$

$$\frac{d^2 I_{electron}}{dt^2} + (ctgw(t))^2 (1 + \beta \exp I_{phonon}) I_{electron} = a_1 F_1 + a_2 F_2$$

.....(7)

$$I_{phonon} / 2 = z(t) + T_0 \frac{dz(t)}{dt}$$

$$I_{electron} = w(t) + T_2 \frac{dw(t)}{dt} \quad \dots\dots(8)$$

Where  $T_0, T_2$  are the periods of the time lags.

$$1 < \beta \leq 1, a_1, a_2 = 1$$

The functions  $z(t)$  and  $w(t)$  were introduced as time lag ones to unify the processes of dispersion on short and long scales reflecting the dissipation on the crystalline lattice and its non homogeneity:

For long scale (100-200steps) counting of the system (7) the expression for the frequency

$$\omega_{II} = \left| \frac{\sin k_{II} x}{2} \right|$$

whereas for shot scale (10 -20 steps) counting it looks like

$$\omega_{II} = \left| \frac{\sin k_{II} x}{2k_{II} x} \right|$$

since a small section of the transmission line in the transversal plane can be considered as a resonator excited by a number of sources consisting of vertical chains of atoms in the crystalline lattice [5]. Exponential parametric multipliers in (7) come from the mutual transformation process between the energies of the electron and phonon currents.

*Computer Study of the Electric Current Model*

Computer study of the model system (7) shows that on a ring scale (100 steps and more) the dynamics of the currents demonstrates a resonant interaction between their Fermi-Pasta-Ulam recurrences [6] since they are formed on the periodical structures of the crystalline lattices. Fig.1 shows one of the forms of the FPU interacting recurrences appearing in the dynamics of the phonon current whereas Fig.2 depicts same for the electron current., Fig.3,4, demonstrate some middle states of both FPU recurrence and Fig.5,6 - the return to the initial states.

Computer study of the electric current model system (7) along a restricted part of the waveguide (10-20steps) shows a presence of the FPU recurrence only in the dynamics of the electron current (Fig.8,10,12). Whereas the frequency dynamics of the

phonon current remains stable on a restricted length of the waveguide (Fig.7,9,11). Mentioned groups of graphs were obtained during a number of different runs of the system (7) on a computer.

Some more graphs were obtained during the study of the system (7) under different initial conditions for  $I_{electron}$  and  $I_{phonon}$ . For convenience of comparing with experimental oscillographs there are placed later in the paper.

*Experiment*

The main purpose of experiment was to visualize the results of the theoretical model through a physical simulation of the system (7). First it was interesting to observe a resonant interaction between two FPU recurrences in the dynamics of the electron and phonon currents obtained as a result of the computer study of the system (7) on a long and short scales of counting (Fig.1-12.). Since the real frequencies of the currents are determined by the scale of the crystalline lattices and lie in a band of  $10^{13} - 10^9$  Hz it was decided to use a closed ferromagnetic core with two different coils as a model of a transmission line. For that purpose there was used a commercial fly back transformer (Fig.14) which coils were switched into the multivibrator's shoulders (Fig13).

Two resonant processes of transformation of photons into magnons under a ferromagnetic resonance [7] as well as magnons into phonons under ferroacoustic resonance [8] were used as main parameters of the physical model. Consider the details of this approach. As it is known the magnetizing vector dynamics of a ferromagnetic is described within the framework of the Landau Lifshitz [9] equation which in one dimensional case looks as follows:

$$\frac{\partial \vec{S}(y,t)}{\partial t} = \vec{S}(y,t) \frac{\partial^2 \vec{S}(y,t)}{\partial t^2} \quad \dots\dots(9)$$

Where the density of the spin energy is[9]:

$$E(y,t) = \frac{1}{2} \left| \frac{\partial \vec{S}}{\partial y} \right|^2 \quad \dots\dots(10)$$

And the current density is:

$$j(y,t) = \vec{S} \left( \frac{\partial \vec{S}}{\partial y} \times \frac{\partial^2 \vec{S}}{\partial t^2} \right) \quad \dots(11)$$

As it was shown [9] the equation (9,10,11) can

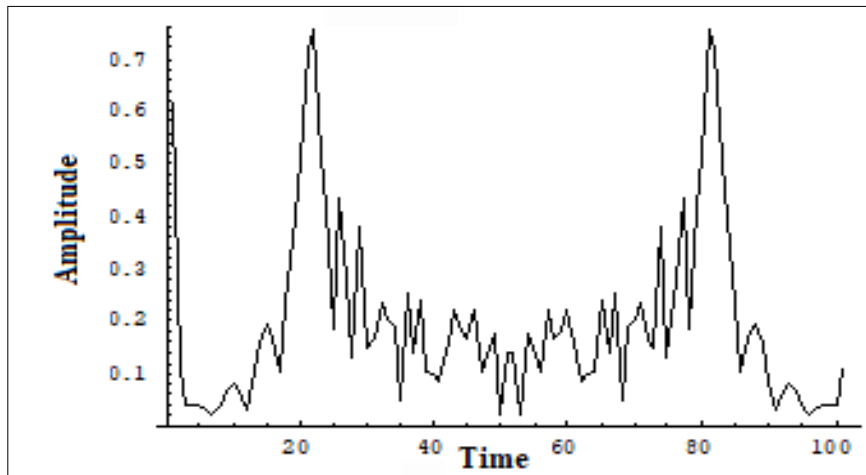


Figure 1. Initial Fourier image of the  $I_{phonon}$  in a number of solutions of (7) on a long scale. Vert. axis – amplitude, horiz. axis – time (units are conditional)

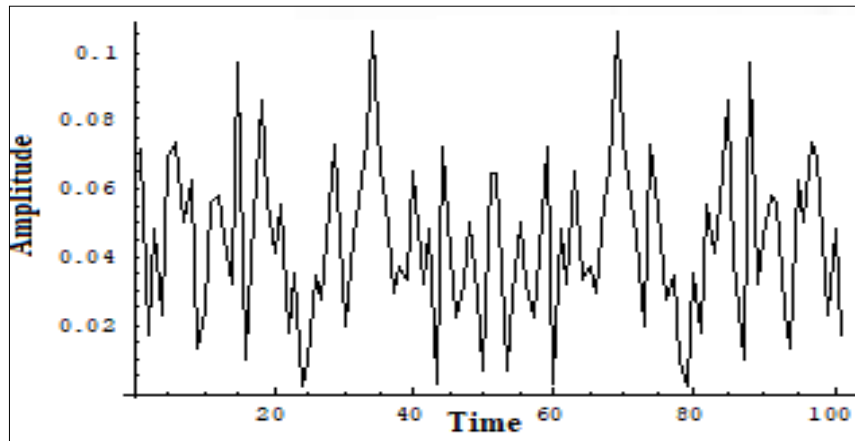


Figure 2. Initial Fourier image of the  $I_{electron}$  in a number of solutions of (7) on a long scale. Vert. Axis-amplitude, horiz. Axis-time (units are conditional)

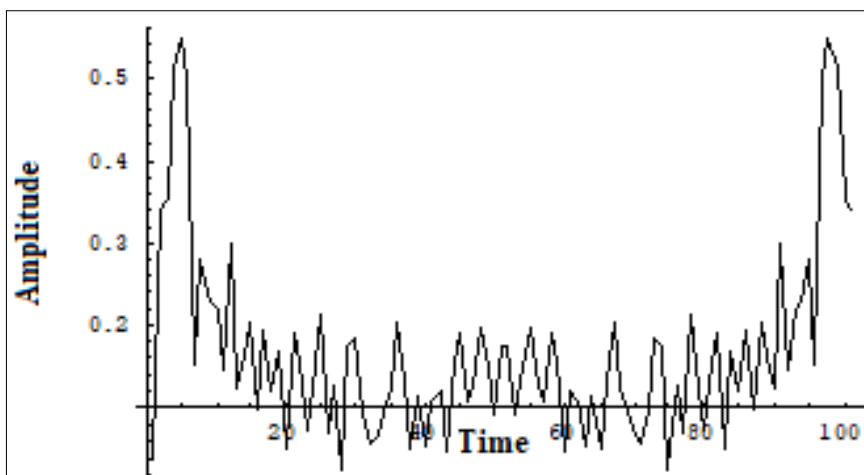


Figure 3. Middle Fourier image of the  $I_{phonon}$  in a number of solutions of (7) on a long scale. Vert. axis – amplitude, horiz. axis – time (units are conditional)

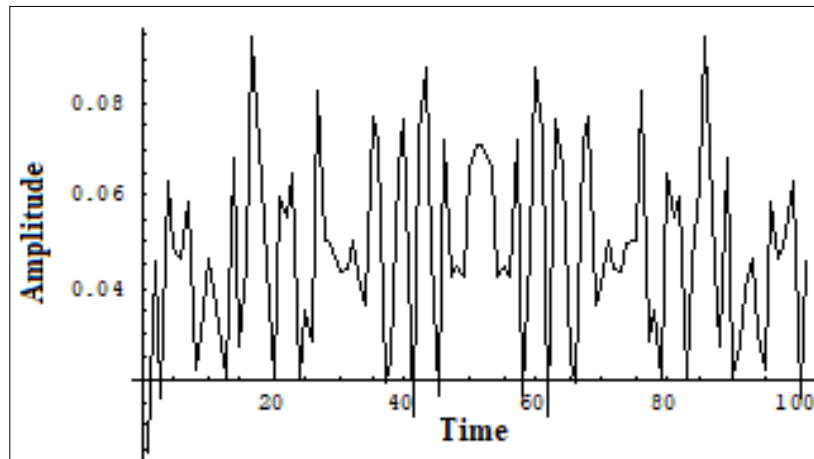


Figure 4. Middle Fourier image of the  $I_{electron}$  in a number of solutions of (7) on a long scale. Vert. axis – amplitude, horiz. axis – time (units are conditional)

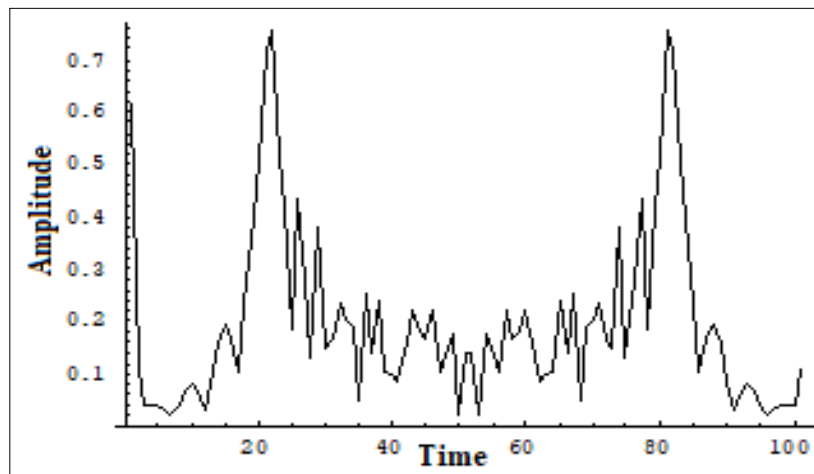


Figure 5. The recurrence of the initial Fourier image of the  $I_{phonon}$  in a number of solutions of (7) on a long scale. Vert. axis - amplitude, horiz. axis – time (units are conditional)

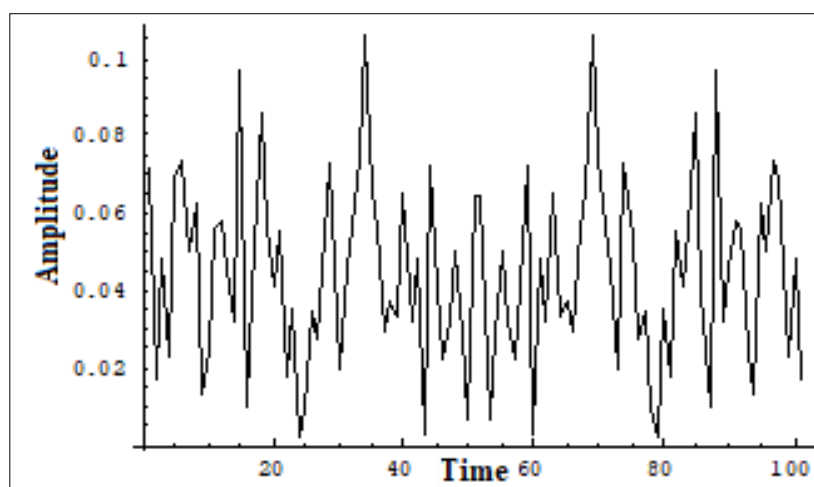


Figure 6. The recurrence of the initial Fourier image of the  $I_{electron}$  in a number of solutions of (7).on a long scale. Ver. axis – amplitude, horiz. axis – time (units are conditional)

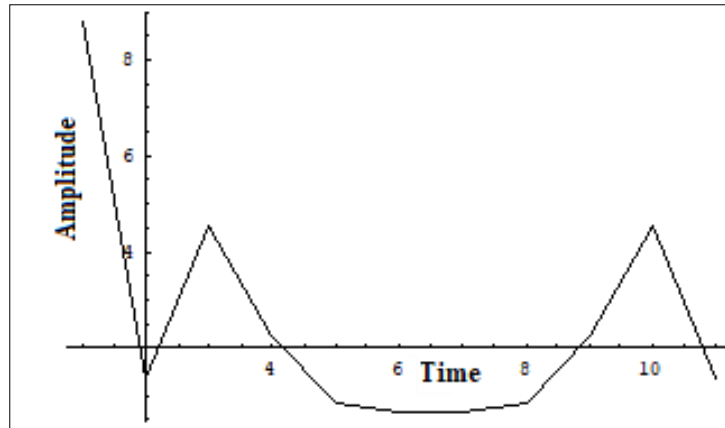


Figure 7. Unchangeable Fourier image of the  $I_{phonon}$  in a number of solutions of (7) on a short scale. Ver. axis – amplitude, horiz. axis – time (units are conditional)

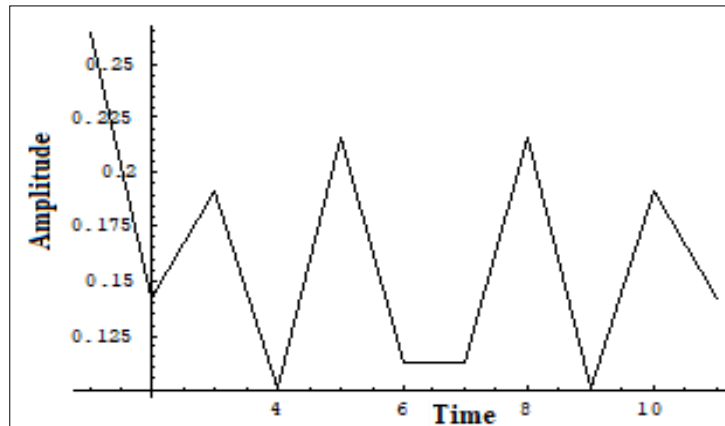


Figure 8. Initial Fourier image of the  $I_{electron}$  in a number of solutions of (7) on a short scale. Vert. axis – amplitude, horiz. axis – time (units are conditional)

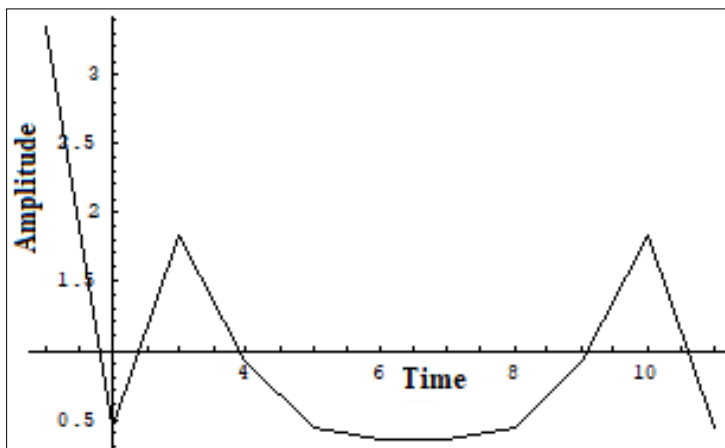


Figure 9. Unchangeable Fourier image of the  $I_{phonon}$  in a number of solutions of (7) on a short scale. Ver. axis – amplitude, horiz. axis – time (units are conditional)

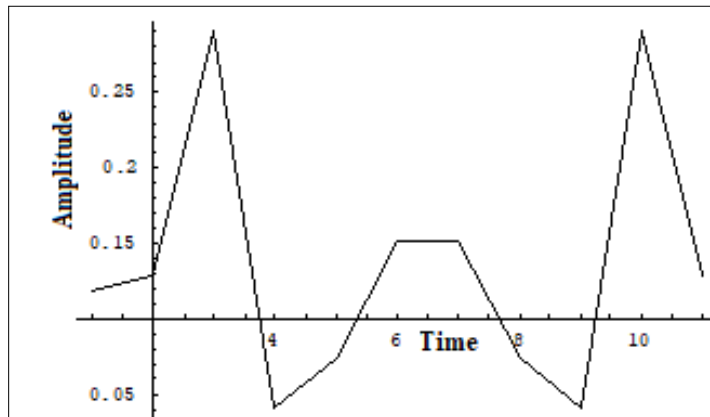


Figure 10. Middle Fourier image of the  $I_{electron}$  in a number of solutions of (7) on a short scale. Vert. axis – amplitude, horiz. axis – time (units are conditional)

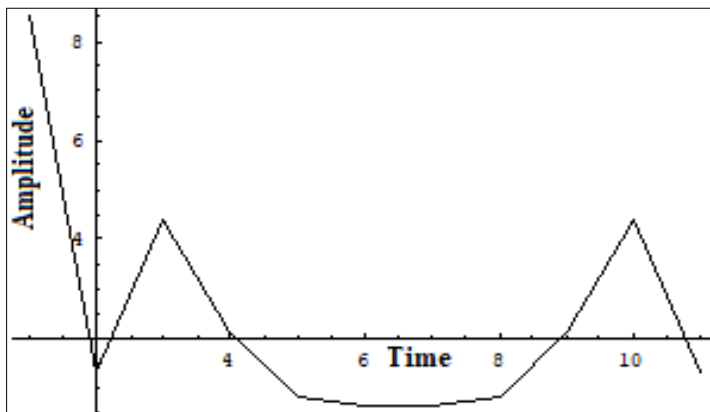


Figure 11. Unchangeable Fourier image of the  $I_{phonon}$  in a number of solutions of (7) on a short scale. Ver. axis – amplitude, horiz. axis – time (units are conditional)

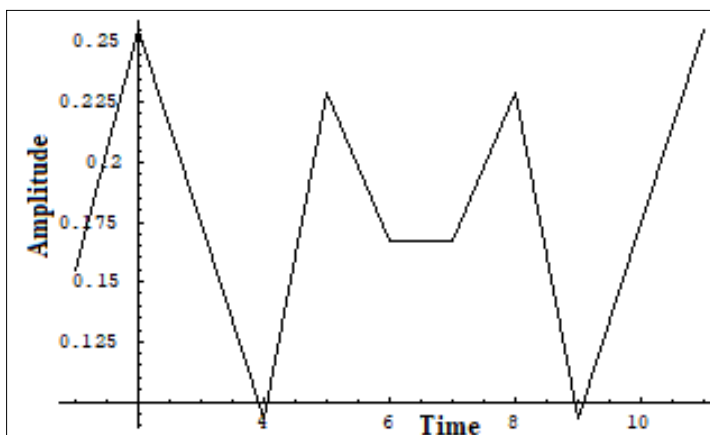


Figure 12. The recurrence of the initial Fourier image of the  $I_{electron}$  in a number of solutions of (7) on a short scale. Ver. axis – amplitude, horiz. axis – time (units are conditional)

be reduced to the non linear Shrodinger equation having the following solution for E and j :

$$E(y,t) = \frac{1}{2} \chi^2 = 8\eta^2 \sec h^2 \{2\eta(y - y_0) + 8\eta\xi t\}$$

$$j(y,t) = \chi^2 \tau = 32\xi\eta^2 \sec h^2 \{2\eta(y - y_0) + 8\eta\xi t\} \dots\dots (12)$$

Where as a result of transformation of the vector to the Serre-Frene vectors  $\chi$  - is the curvature and  $\tau \bar{S}$  - is twisting. The expressions (12) represent the canonical forms of the non linear Shrodinger equation solution and mean that in the periodical structure of a crystalline lattice there will be a number of solutions for the current j. As it was demonstrated theoretically [10 ] and experimentally [11] that the dynamics of the solution of the non linear Shrodinger equation manifests the Fermi-Pasta-Ulam recurrence. In order to visualize such a solution for our model of electric current it was necessary to lower the frequency which was the order of  $10^{13}$  Hz. That could be possible to provide a transformation of photons into magnons in a ferromagnetic. Any ferromagnetic has a magnetic moment which can have a certain precession. The frequency of such precession usually is a few megahertz. At the same time the frequency of the magnetic moment  $\omega$  is the energy of a staying magnon [8].

..... (13)

$\hbar\omega = \varepsilon_0$  Eq. (13) means that under a ferromagnetic resonance a photon transforms into a magnon. The energies of a photon and a magnon are equal with the same impulse:

$$\varepsilon_0 + \frac{p^2}{2m^*} = cp$$

which gives a following equation:

$$\varepsilon_0 + \frac{(\hbar\omega)^2}{2m^*c^2} = \hbar\omega \dots\dots(14)$$

Where  $m^*$  is the effective mass of a magnon:

$$m^* \approx \frac{\hbar}{Aa^2} \approx m_e \frac{10^2}{T_c K} \dots\dots(15)$$

The electron mass has been introduced into the (15) for better evaluation. So when  $T_c \approx 10^2$  K

The magnon has an effective mass close to that of an electron. If to apply a magnetic field to the

ferromagnetic and when  $\mu H = kT$  and  $H = 10^4$  oersted, then the magnon velocity  $V_0 = (\varepsilon_0 / 2m^*)^{1/2}$  will be  $V_0 \approx 3 \times 10^5$  cm/sec

This evaluation means that it is possible to "observe" the picture of the non linear Shrodinger equation together with the FPU recurrence just by exciting in a ferrite core a transversal magnetic wave by an electric impulse in a coil having a small number of turns. It was realized by a symmetric multivibrator circuit (Fig.13) in one shoulder of which there was switched the above mentioned coil  $L_1$  of 12 turns  $d=1$ mm wire on a ferrite core of the fly back transformer (Fig.14). The other shoulder was loaded by a coil having the same numbers of turns which was not on a core but in the air. The resulting impulse is shown in Fig.16. As it can be seen its form is close to the non linear Shrodinger equation solution and corresponds to one of the computer solutions of the current model system (7) shown in Fig.15.

On the other hand the dynamics of the phonon current along the ring waveguide in the structure of the crystalline lattice by analogy with sound waves can be described within the framework of the Korteweg de Vries equation [12]. That brings the problem to the Fermi-Pasta-Ulam recurrence first described by Zabusky and Kruskal [13] who have demonstrated that periodical initial conditions in a ring chain described by the KdV equation can result in manifestation of some specific dynamics of the KdV equation solution. For that study there was used the same fly back transformer (Fig.14) with two coils in 12 turns (left in the Fig.14) and in 400 coils (right in the Fig.14) switched into the shoulders of the multivibrator (Fig.13). Between the collectors of the transistors (Fig.13) there was switched an air variable capacitor  $C^1$  which played the role of a variable spatial waveguide. with periodical structure. This circuit realized interacting of the two FPU recurrences: one within the framework of the non linear Shrodinger equation [11] and the other – within the KdV equation [13]. The KdV solution was obtained in the dynamics of electrical signal on the high voltage coil (right in the Fig.13) of the fly back transformer (Fig.14). The oscillograph in Fig.18 shows a typical solution of the KdV equation which corresponds to one of the solutions of the system (7) shown in Fig.17.



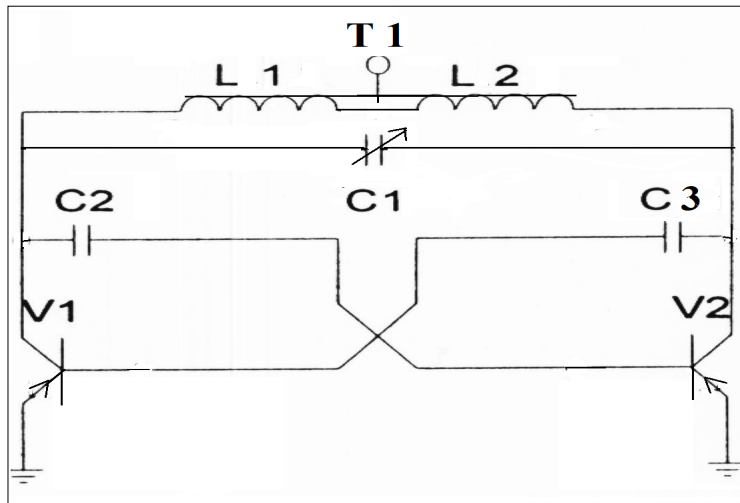


Figure 13. Electronic circuit physically modeling system (7).  $T_1$ - standard fly back transformer with a closed ferrite core  $L_1$  has 12 turns,  $L_2$  has 400 turns,  $C_1$  - air variable capacitor,  $C_2$  - 800 pF,  $C_3$  - 0.25  $\mu$ F,  $V_1$   $V_2$  - transistors of NTE33 type.

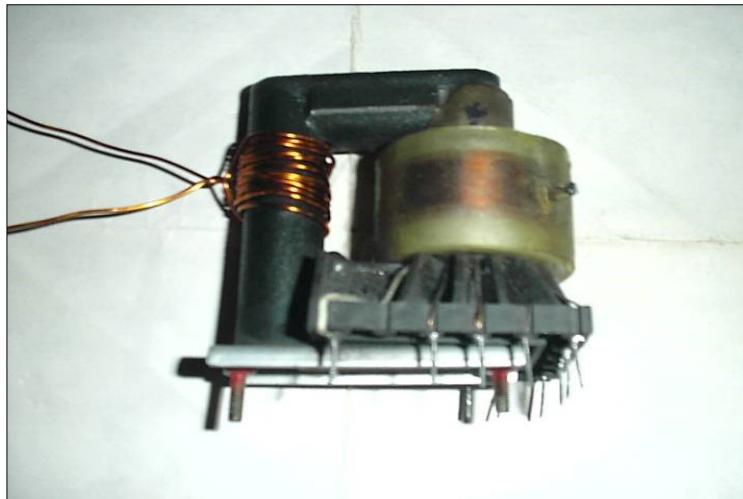


Figure 14. Commercial fly back transformer used in the experiment (Fig.13). Left coil (12 turns) served for simulation of the electron current  $I_{electron}$  whereas the right one (400 turns) served for simulation of the phonon current  $I_{phonon}$ .

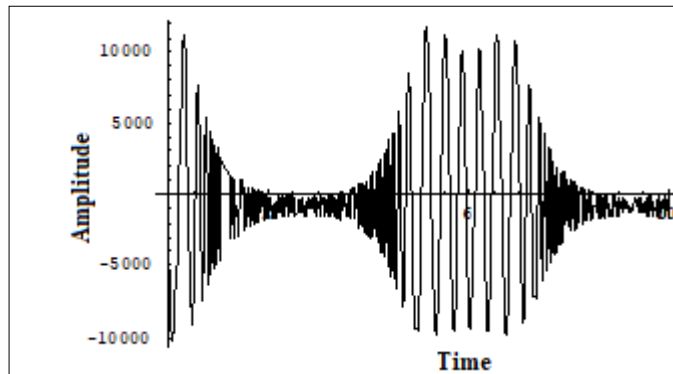


Figure 15. One of the solutions of the system (7) for the electron current  $I_{electron}$  corresponding to the non linear Srodinger equation solution. Vert. axis – amplitude, horiz –time (units are conditional).

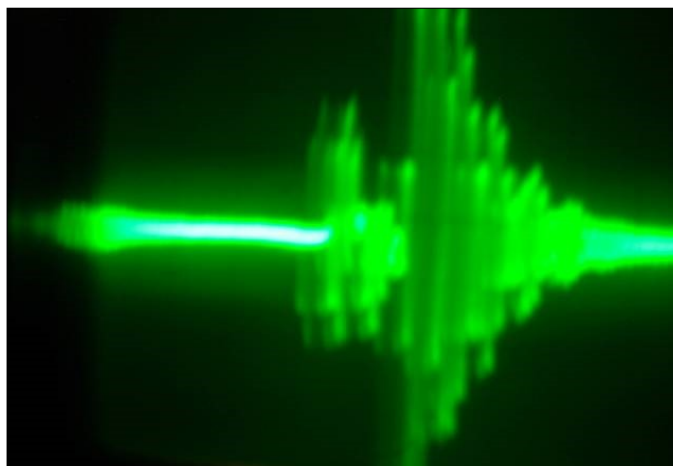


Figure 16. Oscillograph of the collector voltage in the physical model of the system (7) with two identical coils in two shoulders of the multivibrator – one on the ferrite core, the other – in the air.(Fig.13). Corresponds to the solution of (7) in Fig.15.Vert axis  $\mu\text{sec/cm}$  , Horiz axis-2volts per cm.

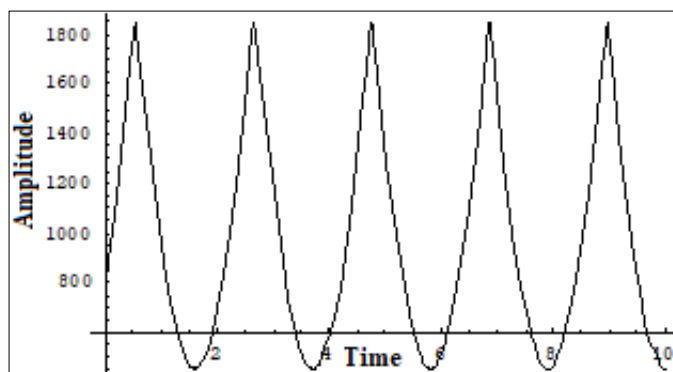


Figure 17. One of the solutions of the system (7) for the phonon current  $I_{phonon}$  corresponding to the solution of the KdV equation. Vert. axis –amplitude, horiz –time (units are conditional).

Differently loaded both shoulders of the multivibrator (Fig.13) simulate the two unified solutions of the non linear Shrodinger equation and that of the KdV equation. As in can be seen on the graphs (Fig.20,21,23,26,29) the two solutions are unified in the experimental circuit. Dependently on the position of the variable capacitor  $C_1$  (Fig.13) there prevailed either the KdV solution (Fig.20,21) or the non linear Shrodinger one (Fig.23,26,29.). These graphs correspond to the different solutions of the system (7) under different initial conditions (Fig.19,22 and Fig.24,25,27,28 correspondingly). So the two resonantly interacting FPU recurrences describing the dynamics of the electron current or the phonon current of the model can be in a high frequency part of the FPU spectrum or in a low frequency one developing a new FPU recurrence in accordance with the laws of the interaction between FPU recurrences [6]. In terms of an electric current that means that there can be a large current circuit or a high voltage one. It has to be emphasized that working for about five minutes in the high frequency spectrum of the FPU recurrence that is mostly in a region of the Shrodinger equation solution (Fig.25,26 ) caused an irreversible damage of the circuit including mains transformer, rectifier circuit, both transistors, feedback capacitors and all light diode indicators. But a very surprising subsequence of the experiment was a partial burning of the mains cord and a durable glowing of the cord's insulation at a distance over 10 meters from the experiment place accounting that the consumed power of the model circuit didn't exceed 10 watts.

## Results

The research has resulted in developing a mathematical model of an electric current in a closed transmission line. The waveguide approach used in modeling pointed at a much more sophisticated nature of an electric current than it has been generally assumed. An electric current either AC or DC represents within the framework of the proposed model a complex resonant interaction process between the dynamics of the transversal electron current and longitudinal phonon current in the structure of a conductor as well as in an insulation layers. A physical model developed for evaluating possible solutions of the mathematical model

allowed to propose a basis for constructing the FPU recurrence generators that were later used for medical purposes.

## Discussion

The problem of interaction of nonlinear resonances has always been a sophisticated one. The more complex proved to be the analysis of interaction between the spectra of the FPU recurrences [6]. The first mathematical modeling of two parametrically coupled temporal and spatial electromagnetic waves [4] showed their unusual property of interacting its solutions with the white noise that induced the further research in the sphere. .So, the developed mathematical model of an electric current in a transmission line as well as the elaborating a physical model of this process based on interacting ferromagnetic and ferro acoustic resonances allowed to analyze the problem in a more profound way/ And the quantum mechanic consideration of the electric current phenomenon [1] proved to be helpful for developing of the two interacting electron and phonon currents model.

## Conclusion

According to developed mathematical and physical models, a considerable regrouping of energy in favor of the electron current takes place in current transformers, in electrical motors, in the points of wire connections, in the structure of heating alloys whereas the phonon current is characteristic for lightning and for some Tesla's long distance experiments when the frequency of generated electrical current lied in a band of hundreds of kilohertz. The electron current mode in a transmission line causes prevailing of a high frequency FPU recurrence not only in a conductor but in the insulation material as well, which could result in considerable damage of the electrical networks.

## Acknowledgements

The author is thankful to the museum of Russian composer Piotr Chaykovsky in Klin Moscow Region which visiting has helped him to insight the idea of the electric current experimental model. The author is also thankful to the library of Princeton University for help.



Figure 18. Oscillograph of the collector voltage in the physical model of the system (7) corresponding to the solution of the KdV equation. Vert axis *milli sec/cm*, Horiz axis-3volts per cm.

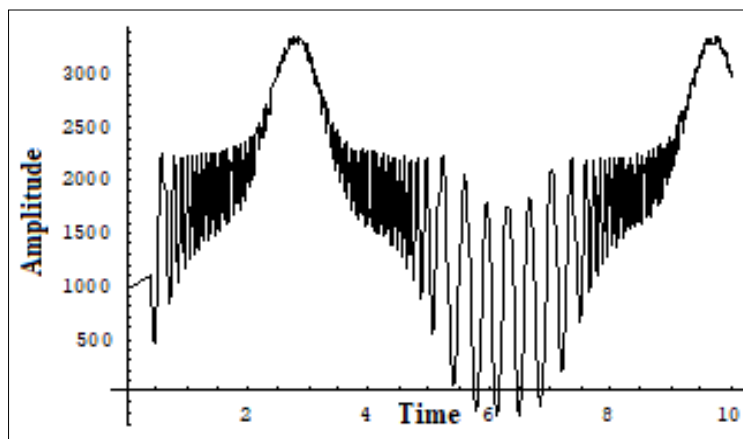


Figure 19. One of the solutions of the system (7) for the sum of the phonon current  $I_{phonon}$  and electron current  $I_{electron}$  corresponding to the snapshot of the interaction of the FPU recurrences – formed on the transversal structure of the crystalline lattice (non linear Shrodinger equation solution) and formed on the longitudinal structure of the crystalline lattice (the KdV equation solution). Vert. axis –amplitude, horiz –time (units are conditional).

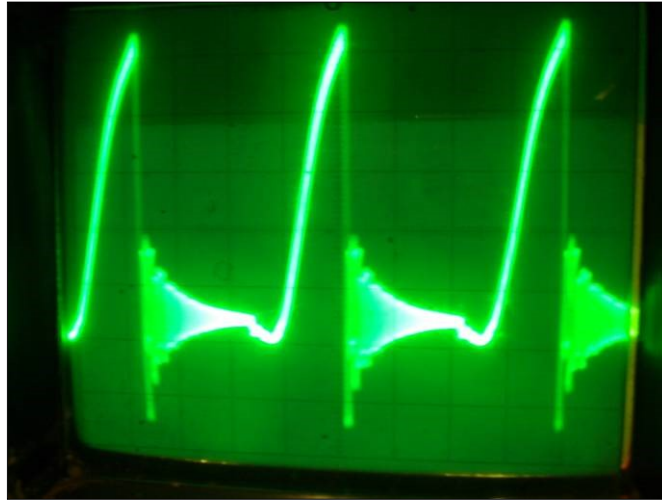


Figure 20. Oscillograph of the voltage on both transistors collectors in the physical model of the system (7) corresponding to the interaction process between two FPU recurrences corresponding to the interaction dynamics of the electron current  $I_{electron}$  and that of the phonon current  $I_{phonon}$ . The phonon current energy prevails. Vert axis *milli sec/cm*, Horiz axis-3volts per cm.

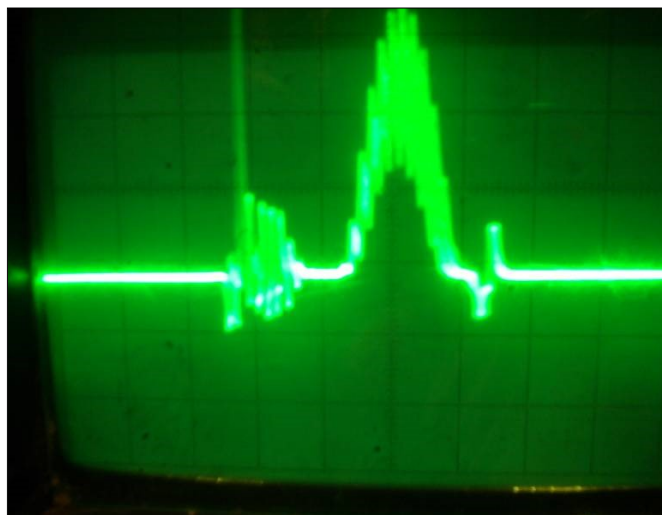


Figure 21. Oscillograph of the both transistors collector voltage in the physical model of the system (7) corresponding to the interaction process between two FPU recurrences corresponding to the interaction dynamics of the electron current  $I_{electron}$  and that of the phonon current  $I_{phonon}$ . The electron current energy prevails. Vert axis *milli sec/cm*, Horiz axis-3volts per cm.

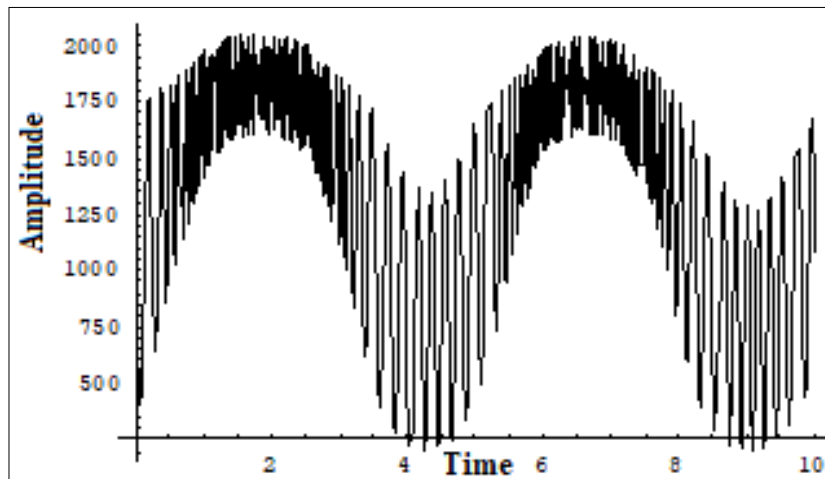


Figure 22. One of the solutions of the system (7) for the sum of the phonon current  $I_{phonon}$  and electron current  $I_{electron}$  corresponding to the snapshot of the interaction of the FPU recurrences – formed on the transversal structure of the crystalline lattice (non linear Shrodinger equation solution) and formed on the longitudinal structure of the crystalline lattice (the KdV equation solution). Corresponds to the balanced case. Vert. axis –amplitude, horiz –time (units are conditional).

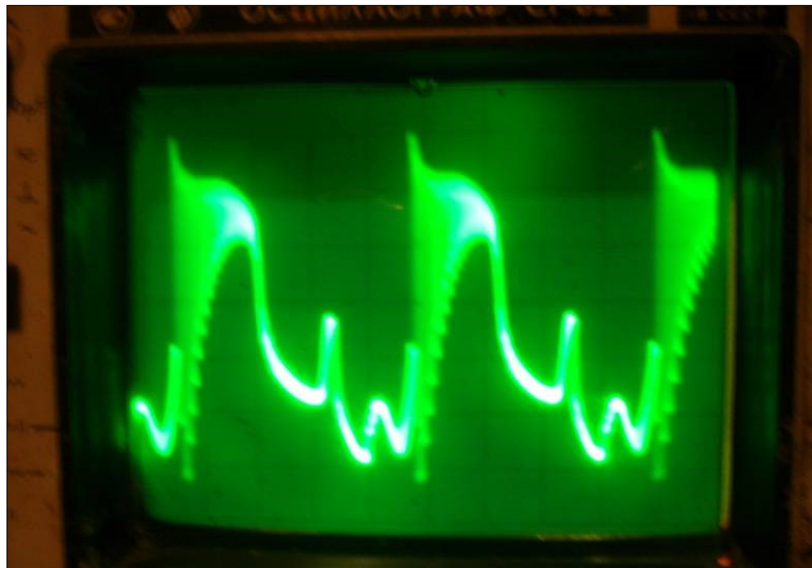


Figure 23. Oscillograph of the both transistors collector voltage in the physical model (Fig.13) of the system (7) corresponding to the interaction process between two FPU recurrences corresponding to the interaction dynamics of the electron current  $I_{electron}$  and that of the phonon current  $I_{phonon}$ . Corresponds to the balanced case.. Vert axis *milli sec/cm*, Horiz axis-3volts per cm.

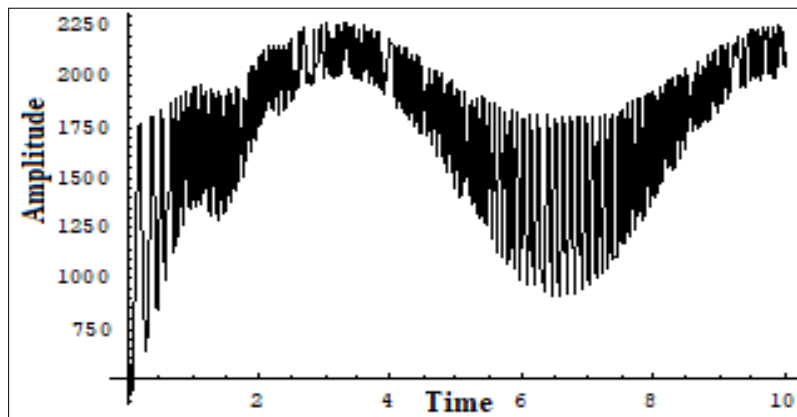


Figure 24. One of the solutions of the system (7) for the sum of the phonon current  $I_{phonon}$  and electron current  $I_{electron}$  corresponding to the snapshot of the interaction of the FPU recurrences – formed on the transversal structure of the crystalline lattice (non linear Shrodinger equation solution) and formed on the longitudinal structure of the crystalline lattice (the KdV equation solution). Corresponds to the prevailing of the electron current energy. Vert. axis –amplitude, horiz –time (units are conditional).

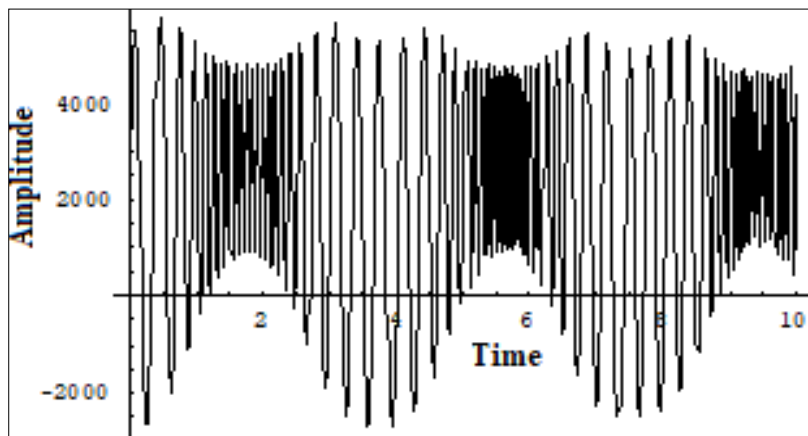


Figure 25. One of the solutions of the system (7) for the sum of the phonon current  $I_{phonon}$  and electron current  $I_{electron}$  corresponding to the snapshot of the interaction of the FPU recurrences – formed on the transversal structure of the crystalline lattice (non linear Shrodinger equation solution) and formed on the longitudinal structure of the crystalline lattice (the KdV equation solution). Corresponds to the to the prevailing of the electron current energy. Vert. axis –amplitude, horiz –time (units are conditional).

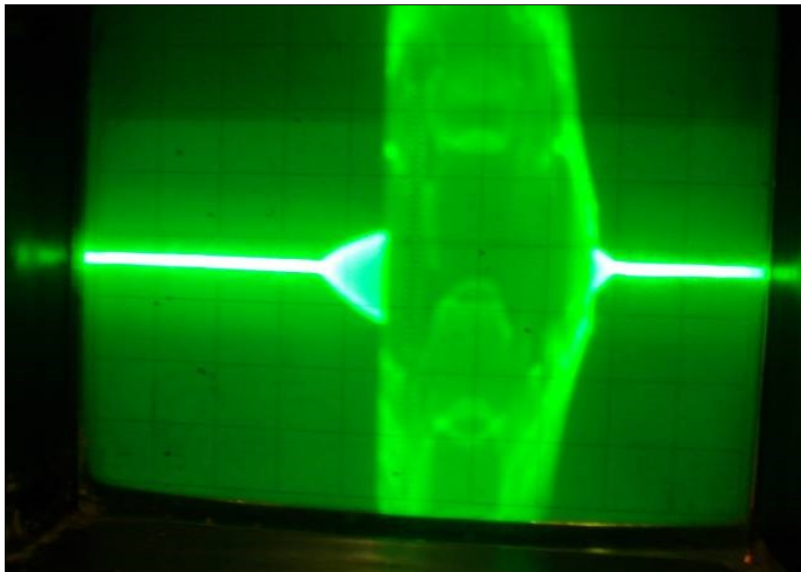


Figure 26. Oscillograph of the both transistors collector voltage in the physical model of the system (7) corresponding to the interaction process between two FPU recurrences corresponding to the interaction dynamics of the electron current  $I_{electron}$  and that of the phonon current  $I_{phonon}$ . Corresponds to prevailing of the electron current. The pulse has a complex intrinsic structure of the high frequency FPU recurrence (few GigaHertz). Vert axis  $0.5 \mu sec/cm$ , Horiz axis-2volts per cm.

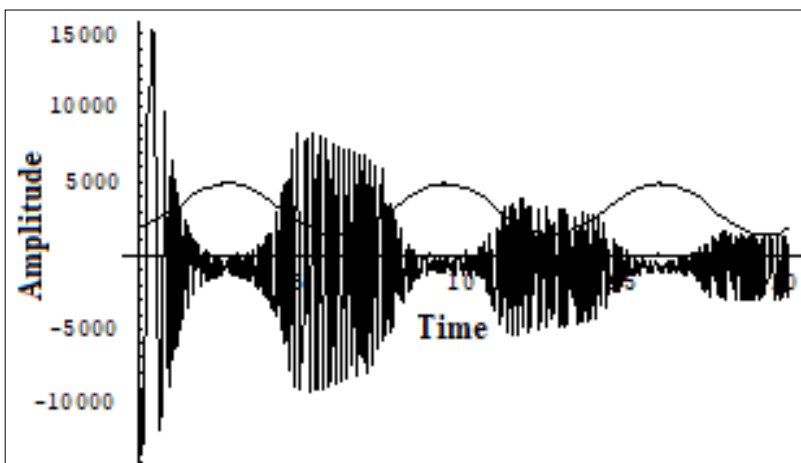


Figure 27. One of the solutions of the system (7) for the sum of the phonon current  $I_{phonon}$  and electron current  $I_{electron}$  corresponding to the snapshot of the interaction of the FPU recurrences – formed on the transversal structure of the crystalline lattice (non linear Shrodinger equation solution) and formed on the longitudinal structure of the crystalline lattice (the KdV equation solution). Corresponds to the prevailing of the electron current energy and a long period of longitudinal dynamics. Vert. axis –amplitude, horiz –time (units are conditional).



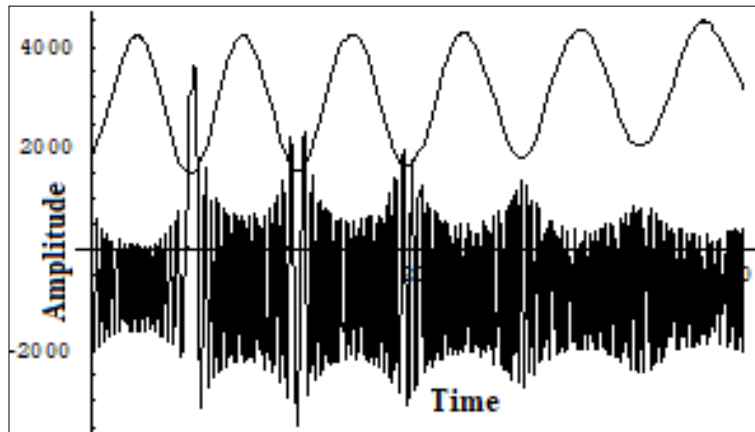


Figure 28. One of the solutions of the system (7) for the sum of the phonon current  $I_{phonon}$  and electron current  $I_{electron}$  corresponding to the snapshot of the interaction of the FPU recurrences – formed on the transversal structure of the crystalline lattice (non linear Shrodinger equation solution) and formed on the longitudinal structure of the crystalline lattice (the KdV equation solution). Corresponds to the balanced case of both currents energies and a long period of longitudinal dynamics. Vert. axis –amplitude, horiz –time (units are conditional).

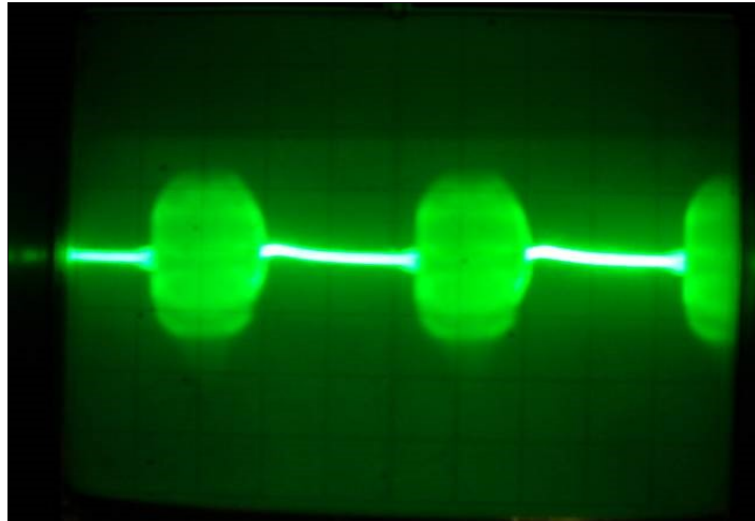


Figure 29. Oscillograph of the both transistors collector voltage in the physical model of the system (7) corresponding to the interaction process between two FPU recurrences corresponding to the interaction dynamics of the electron current  $I_{electron}$  and that of the phonon current  $I_{phonon}$ . Corresponds to prevailing of the electron current. The pulses have a complex intrinsic structure of the high frequency FPU recurrence (few Gigahertz). Vert axis  $1.5 \mu sec/cm$ , Horiz axis-1volt per cm.

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