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Influence of the Composite Materials Nonlinear Properties with Radioisotope Inclusions on Reflected Radiation

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ABSTRACT

The study results of the composite materials nonlinear properties with radioisotope inclusions (CMNP), which are materials with irregular and unsteady in homogeneity leading to the appearance of nonlinear properties, are presented. It is proposed to present the CMNP structure with unsteady conductivity because of a change in the internal structure due to the appearance of more and more tracks from the decay products of radioisotope inclusions in the form of an equivalent radio circuit with a change in the number of links in the circuit simulating this structure.
Based on the long-line model, the influence of the CMNP nonlinear properties on the surface currents formation excited by electromagnetic waves incident on the material (EMW) surface is shown.
It is proposed to carry out a description of the EMW randomization processes in the CMNP based on the iterated functions (IFS) system apparatus.
It is shown that the IFS allows us to simulate the secondary radiation of objects with the CMNP, determined by the geometric dimensions of the tracks, inclusions themselves, their conductivity and the nature of the spatial distribution.

Key words: composite materials with radioisotope inclusions, nonlinear properties, equivalent radio circuit, long line, α-particle tracks, secondary radiation, apparatus of the iterated functions system.

1. INTRODUCTION

One of the most important properties of radar absorbing materials (RAP) and radar absorbing coatings (RAC) created on their basis, which are used, for example, to solve the problems of reducing the objects radar visibility is their non-linearity. With the RAC having this property, the frequency spectrum of

the incident electromagnetic waves incident on the surface is transformed, as a result of which the secondary radiation spectrum is transferred and, accordingly, the probability of detecting an object with a coating of non-linear properties is reduced.

Materials with nonlinear properties include CMNP [1-3].
The radioactive material spots deposited on the surface of the semiconductor layer, radioisotope inclusions in the semiconductor layer, as well as a-particles tracks lead to the formation of in homogeneous and unsteady in the structure of the CMNP conductivity, which leads to an increase in the scattering of incident electromagnetic waves [4-5]. In addition, the CMNP nonlinear properties can lead to significant changes in the reflected signal properties. This is both due to the randomization of electromagnetic currents, and to a significant change in the frequency spectrum, primarily due to the material unsteady structure.

1.1 Problem analysis

Because of the spatial in homogeneity presence that are irregular and unsteady due to ionization processes in the charged particle tracks region, induced by the radioisotope inclusions decay, and also due to the radioisotope inclusions themselves, the CMNP have the non linearity property. The CMNP non linearity can lead to the randomization of electromagnetic currents and a significant change in the frequency spectrum of the secondary radiation. However, in the well-known works [1–5] devoted to the study of the CMNP absorbing and reflecting properties, the questions of assessing the nonlinear properties influence that are non-stationary in nature did not find proper coverage.

The article purpose is to determine the CMNP nonlinear properties influence of the on the secondary radiation.

2. MAIN MATERIAL

2.1 The CMNP equivalent scheme

The α-particles tracks, which are metallic inclusions, can be considered as regions that have inductance, and dielectric regions between tracks are the capacitance.
It is necessary to take into account that the nonstationarity of the conductivity of the CMNP semiconductor layer is caused by a change in its internal structure due to the appearance of more and more new tracks from the decay products of radioisotope inclusions.
This approach gives possibility to the unsteadiness conductivity of the CMNP semiconductor layer due to the change in its internal structure due to the appearance of more and more tracks from the decay products of radioisotope inclusions, to qualitatively represent by changing the number of links in the circuit modeling this structure.
The equivalent radio engineering scheme of the CMNP spatio-temporal structure conductivity is shown in fig. 1.

Presented in fig. 1 is a ladder-type chain. The impedance of an infinite staircase can be represented as follows [1]:

$$z_{n+1} = z_1 + \frac{z_n z_2}{z_n + z_2}, \quad n = 1, 2, ..., \infty, \qquad (1)$$

where z_1, z_2 – complex resistances - conductance of circuit elements.

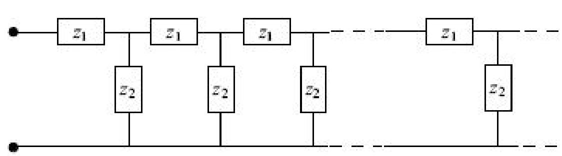

Figure 1: The equivalent radio circuit diagram of the CMNP conductivity spatio-temporal structure: z_1 – inductive component of impedance; z_2 – capacitive component of impedance.

2.2 The CMNP nonlinear properties Influence on the secondary radiation

The CMNP unsteady conductivity structure, which determines the non-stationary nature of the nonlinear properties, will lead to the randomization of electromagnetic currents and a significant change in the reflected radiation frequency spectrum.
An adequate tool is the apparatus of the iterated functions system (IFS) [6] to describe the processes of signal randomization during their propagation through the CMNP surface layer structure.

Let us consider an example of the IFS appearance in the chain simplest link shown in fig. 2, which is the circuit element of the CMNP modelling structure (fig. 1).

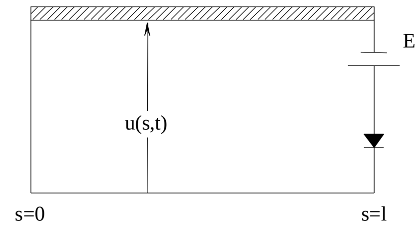

Fig.ure 2: The long line scheme with a nonlinear diode, illustrating the attractor appearance during the successive reflection of a short pulse from the line ends and the CVC diode in the line

The current and voltage oscillations in the long line electric circuit with a nonlinear element are described by a system of telegraph equations, which, assuming zero line losses, is reduced to a simple form:

$$i_s + Cu_t = 0, \quad u_s + Li_t = 0$$

where s – is the coordinate of the long line point;
t– time;
L and C – are the specific long line inductance and capacitance.
The boundary and initial conditions have the form:

$$u(0,t) = 0; \quad i(l,t) = g(u(l,t) + E);$$

$$i(s,0) = i_0(s); \quad u(s,0) = u_0(s),$$

where $i = g(u)$ – is the current-voltage characteristic (CVC) of the nonlinear element;
E – bias voltage;
$i_0(s)$, $u_0(s)$ – current and voltage initial distribution in the line.
Suppose that the working area of the CVC shown in fig. 3, lies near the small voltage values and is linear (almost linear) i.e. $g(u) = \alpha u + \beta$.

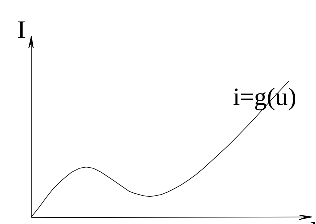

Figure 3: The working section of the CVC is in fact its initial linear section

The pulse current values dynamics i_k at the line input with the diode can be represented determined by a linear display that is uniquely associated with the characteristic of the diode, namely:

$$i_{k+1} = \frac{\alpha z - 1}{\alpha z + 1} i_k + 2\frac{\alpha E + \beta}{\alpha z + 1}, \qquad (2)$$

where $z = \sqrt{\frac{L}{C}}$ – is the specific line.

Suppose now that at the pulse arrival moment to nonlinear inclusion, the system can be (randomly) in one of the states that differ by a small shift of the bias (Fig. 3.), and then propagates to the next scattering. Then the momentum values dynamics on the radioisotope inclusions is uniquely described by a system of the form iterate linear functions:

$$f_k(x) = Jx + b_k,\ k = 1,\ldots, N. \qquad (3)$$

These functions have the same Jacobians $J = \frac{\alpha z - 1}{\alpha z + 1} < 1$ and different offsets, determined in accordance with the expression:

$$b_k = 2\frac{\alpha E_k + \beta}{\alpha z + 1}. \qquad (4)$$

The current values sequence is fractal with dimension:

$$D_f = \frac{\ln(N)}{|\ln(J)|}. \qquad (5)$$

It can be seen from this relation that the current values generated series fractal dimension is controlled by the line parameters and the set of possible displacements.

2.3 The fractal dimension determination of the CMNP surface layer

The secondary radiation vector potential is determined by the expression [7]:

$$\vec{A}(\omega) = \frac{e^{i\vec{k}\vec{R}_0}}{R_0} \int e^{i(\vec{k}\ \vec{r} - \omega t)} I(\omega) dl; \qquad (6)$$

$$\vec{R} = \vec{r} + \vec{R}_0. \qquad (7)$$

The fractal contour impedance has a power dependence on the form frequency [8]:

$$Z(\omega) \propto \omega^{D_f - 3}, \qquad (8)$$

where $1 < D_F < 2$ – is the conductivity distribution fractal dimension.
The amplitude of the current in the radiating circuit is equal to:

$$I(\omega) = U(\omega)/Z(\omega). \qquad (9)$$

It can be seen that the potential substantially depends on the fractal system geometry forming the secondary radiation.
First of all, the expression for the electromagnetic field through the above power law dependence of the impedance on the frequency includes the fractal dimension.
In addition, the radiating circuit geometry determines the phase term in the expression for the potential.

To determine the fractional derivative index, we use the regularization method [9, 10].
By analyzing the CMNP conductivity distribution based on the regularization method, it can be assumed that the fractional derivative index value is related to the coating surface layer fractal dimension by the ratio:

$$D_f = 2 - \nu, \qquad (9)$$

where ν – is the fractional derivative index describing the memory in the oscillatory system.
The fractional derivative exponent is determined on the basis of the following considerations.
The CMNP, as a heterogeneous system in the conductivity structure, is a metal-semiconductor structure.
The current fluctuations in such a structure can be represented by the equation, which under the weak quadratic non linearity of the load conductivity $(\beta << 1)$ is the equation for the Van Der Pol simplest model generator [11].
An essential metal feature – semiconductor fractal system is its irreversibility (the absorbed electromagnetic energy is released only in the form of heat) and the memory existence.
When electromagnetic waves EMW decay on a-particle tracks, the memory in the system is determined by the relaxation time, which depends on the material characteristics.
The equation solutions behavior with fractional derivatives without dissipation and the equations of a conventional oscillator with dissipation are similar, which allows us to make a statement about the equivalence in a sense of the oscillations damping degree and the derivative deviations of the integer

value order. Having found the relationship between the energy dissipation degree and the fractional order of the differentiation operator, approximating the process with real dissipation, the process with memory without dissipation, we can determine the fractal dimension of the surface CMNP layer.

We present it in the graph in fig. 4. The final results of the desired dependence calculations.

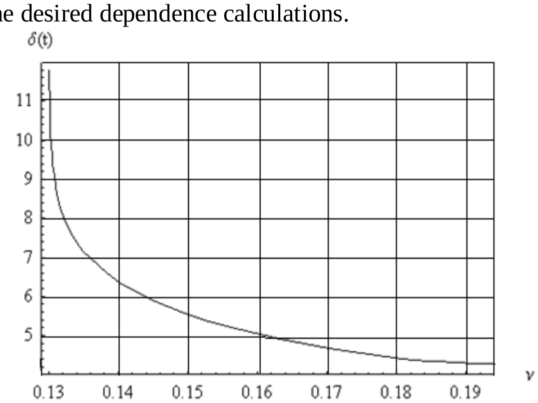

Figure 4: The attenuation coefficient dependence on the fractional derivative index that describes the memory in the system

It can be seen that the maximum attenuation of EMW in the CMNP is achieved at $\nu = 0.13$.

he EMW attenuation coefficient value is determined by the relaxation time, the activity magnitude, and the nature of the radioisotope inclusions distribution in the CMNP semiconductor layer.

In accordance with the numerical calculations shown in the form of a graph in fig. 4, in order to obtain the maximum EMW attenuation value on the CMNP coating, it is necessary that the material fractal dimension be of the order. $D_f = 1,87$. In this case, to ensure the EMW attenuation on a-particle tracks, it is necessary to choose a semiconductor material with a long relaxation time.

The CMNP radiation simulating spectrum with the fractal conductivity in homogeneity dimension $D_f = 1.87$ is shown in fig. 5.

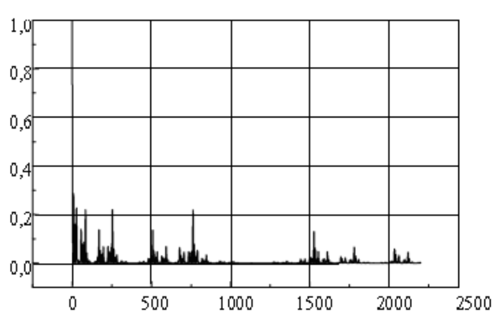

Figure 5: The emitters system emission spectrum simulating the CMNP conductive elements with a fractal dimension in homogeneity conductivity $D_f = 1.87$

The IFS implementation for the CMNP with a fractal dimension of conductivity heterogeneity $D_f = 1.87$ is shown in fig. 6.

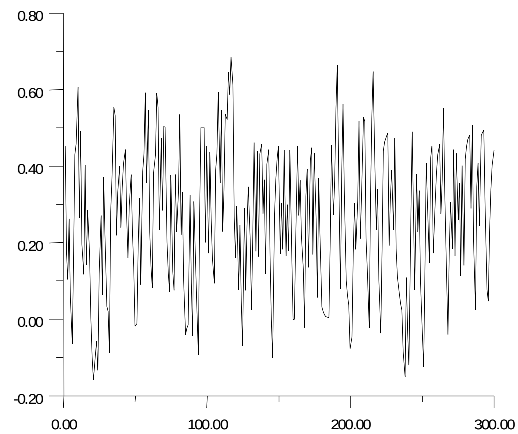

Figure 6: The IFS four linear functions implementation with $J = 0.45$ and $D_f = 1.87$

In fig. 7 it also shows the current realization initial section at the different initial values, and fig. 8 - the corresponding current values distribution function in the implementation.

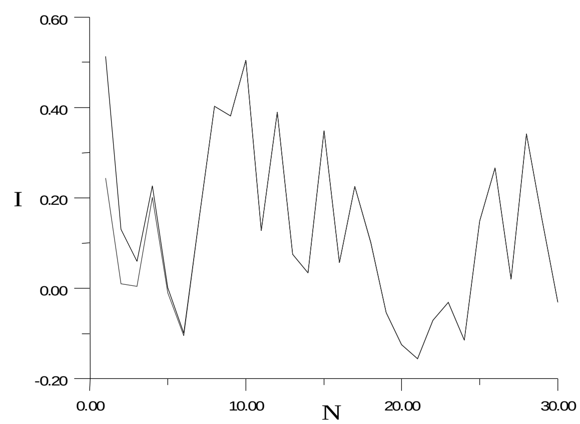

Figure 7: The IFS implementation initial section for two different initial current values

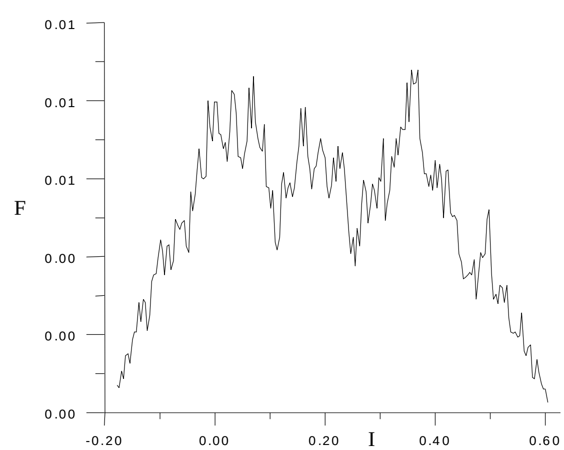

Figure 8: The current value distribution function in the implementation shown in Fig. 7

It can be seen that already after 3-4 iterations, the implementation reaches the attractor.

Distribution functions on show the excitation of large-scale chaos in the CMNP during the external signals propagation.

The line parameters that models the currents propagation over the coating surface (and, consequently, the secondary radiation) are determined by the tracks geometric dimensions, the inclusions themselves, their conductivity, and the nature of the spatial distribution.

It should be emphasized that the specific probability distribution type of the bias values on inclusions or the initial conditions values does not change the limit set structure.

The limit set structure is determined only by the specific values of the linear mappings coefficients associated with the covering geometry and inclusions in them.

Thus, the proposed approach based on the IFS apparatus allows one to simulate the secondary objects radiation with the CMNP, determined by the tracks geometric dimensions, inclusions themselves, their conductivity, and the spatial distribution nature.

3. CONCLUSION

As a result of the CMNP nonlinear properties studies associated with the presence of irregular and unsteady in homogeneity in the material due to the radioisotope inclusions, it was found that by selecting the inclusions geometric dimensions themselves, their spatial distribution, and also the size of the tracks of α-particles, secondary radiation can be controlled.

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