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About direct radiation of ultrashort electromagnetic pulses and fractal space-time geometry

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Abstract: **Theoretical and experimental investigations of propagation of ultrashort electromagnetic pulses (US EMP) are needed to develop new technologies of creation of modern special engineering. The analytical method of field calculation of travelling antenna waves taking into account reflection of fracture and redistribution of currents in wires because of losses of radiation energy from fractures is considered. The calculations of V-antenna, the field of radiation of a horn system and the pulse radiation of the antenna with a reflector are presented. Experimental investigations of UWB EMP propagation carried out on the basis of the theory developed by S.A. Podosenov are the base of creation of modern radiotechnical complexes. Simultaneously the main conceptions of space-time fractal geometry of deterministic structures are introduced.**

Keywords: **ultrashort pulses, antenna structures, fractal, space-time, new technologies**
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This article is dedicated to the bright memory of
Stanislav Alexandrovich Podosenov
(1.09.1937 – 1.03.2022)
who made a great contribution to development
of modern and classical theory of radiation of
pulse electromagnetic fields

Contents

1.INTRODUCTION

This work is dedicated to the bright memory of Ph.D. (phys.-math. sci.) Stanislav Alexandrovich Podosenov (1.08.1937-1.03.2022). He graduated from the Physical Department of the M.V. Lomonosov Moscow State University in 1963 (the chair of statistical physics and quantum mechanics, the chairman was academician N.N. Bogolubov). His speciality is the theoretical physicist. He is a winner of the prize of RF Government 2002 in the field of science and engineering. He made a great contribution to development of modern and classical field radiation of pulse electromagnetic fields appreciated by the world scientific community. In 1972 S.A. Podosenov (at the University of Peoples Friendship, in the theoretical physics chair of prof. Ya.P. Terletskiy) defended his Ph.D. thesis. The speciality is theoretical and mathematical physics. The subject is "Relativistic mechanics of deformable medium in the tetrade formulation." The thesis is connected with the scientific school of known prof. of MSU D.D Ivanenko, V.I. Rodichev and academician L.I. Sedov.

Ultrashort pulses (US) of electromagnetic field have wide practical application in radiophysics, radiolocation, metrology, nuclear physics (for explosion investigations), antenna engineering, medicine etc.

In radiolocation US pulses of electromagnetic field are used for transmission of energy and information. Transmission of information by means of US EMP is realized during the short time intervals. This permits to diminish power of radio communication means, their dimensions and mass and consequently their cost. Application of US EMP for information transmission diminishes harmful influence of electromagnetic field on environment. It is possibly to transmit information concerning sizes, location and structure of the object by means of reflected US EMP. That permits rapid and exact determination of necessary target characteristics [1-5]. At pulse duration 10^{-10} *s* the resolution of the order of a few centimeters can be achieved.

US pulses of electromagnetic field are widely applied in the field of ensuring of the unity of measurements – state verification schemes, state special standards, reference and working measuring instruments and standard settings [6-9].

S.A. Podosenov began working at the laboratory of generation and measurement of parameters of electromagnetic pulses VNIIOFI in 1989 jointly with prof. A.A. Sokolov. The problem of creation of the theory of pulse radiation from fieldforming systems was set by prof. A.A. Sokolov. By means of formulae derived by S.A. Podosenov one can calculate the radiation field applying computers that do not have big power [10].

In the laboratory of generation and measurement of parameters of electromagnetic pulses VNIIOFI works for creation new measurement technologies and application of US EMP to investigate physical processes in heterogeneous media [11-47] and pulse interaction strip lines in printed circuit boards are successfully carried out [12].

Measurement technologies are successfully applied to struggle with electromagnetic terrorism [17]. Experimental investigations of influence of US EMP in the systems of monitoring of access to rooms are important [20,39]. Measuring complex for investigation of electromagnetic environment, when propagating of US EMP indoors, was created [41]. Methods and means of monitoring of electromagnetic radiation in ultrashort duration range [45,46] are used to investigate stability of video supervision systems against power US EMP [43], in particular, when investigating of functioning of typical complex security system devices [44].

Ultrashort pulse standard radiators are used for metrological ensurance of telecommunication techniques [22]. Measuring instruments for test of radioelectronic equipment for US EMP impact resistance are developed [26]. Investigations of functioning of personal computers in condition of US EMP impact are carried out [30]. When creating of means of resistance ensurance of information systems for impact of ultrawide band electromagnetic radiation (UWB EMP) investigations of functioning of local computer networks in conditions of UWB EMP impact are of great importance [33]. Investigation of US EMP propagation has great importance to estimate resistance of on-board computers in conditions of impact of US electromagnetic fields [38].

At the laboratory of generation and measurement of parameters of electromagnetic pulses VNIIOFI works for creation of new methods and measuring instruments of US EMP parameters in the picosecond range are successfully carried out [48]. On the basis of US EMP application in VNIIOFI the measuring system for express-diagnostics of electromagnetic parameters of radio absorbing materials in the range of 0.1…4.0 GHz having great practical importance was created [49].

US electromagnetic pulses are applied in medicine. Using of electromagnetic radiation assists to effective therapy when treatment of cancer diseases. Ultrawide band pulse periodic microwave radiation on mouse tumors was investigated in vivo [50]. Using of such radiation in combination anticancer therapy permitted to get inhibition of the growth rate of Lewis lung carcinoma on 70-80% as compared with the only action of chemotherapy drug (cyclophosphamide).

Miniature appliances operating on the basis of US EMP permit contactless controlling of pulsations of inner human organs that essentially improves diagnostics.

Such pulses can be effectively applied to transmit energy and information. This permits qualitative improvement of technical and ecological characteristics of radioelectronic devices and decreasing of their cost. Information transmitting by means of US EMP has profit as compared with methods of modulation of radio waves because energy is radiated during very short time interval.

The purpose of this work is brief representation of mathematical apparatus created by S.A. Podosenov. On the basis of this one it is possibly to calculate fields from travelling current waves taking into account fracture reflections and the basis of fractal space-time geometry of deterministic structures created jointly with prof. A.A. Potapov.

2.ANALYTICAL METHOD OF FIELD CALCULATION FROM TRAVELLING CURRENT WAVES TAKING INTO ACCOUNT FRACTURE REFLECTIONS

When creating the theory of pulse radiation from fieldforming systems S.A. Podosenov got a set of integro-differential equations for charge and current densities of charged metallic bodies and wires locating in external heterogeneous and nonstationary electromagnetic field. Created new simple calculation method of pulse radiation in time domain is based on direct finding of tensor of electromagnetic field from travelling current waves of arbitrary form.

Line fractures are the secondary radiation sources of anisotropic TEM waves. Energy losses stipulated for radiation have to change the amplitude and form of the signal passing through the fractures of transmission lines. The method of predetermined currents was modified taking into account the fracture reflection coefficients. Rounded wires were replaced by fractures (**Fig. 1**).

Reflection and transmission coefficients of current pulses from line fractures depending on parameters of pulse and time of their transmission through fractures permit to determine the form of reflected and transmitted pulses as compare with incident ones.

The simple method of analytical calculation of radiation from travelling current waves propagating on the curvilinear wires proposed by S.A. Podosenov can be applied to calculate radiation of *V*-antenna, linear one and the antenna constituted with rectilinear cuts.

This new analytical method of field calculation from travelling current waves with fractures takes into account redistribution of currents in wires stipulated for losses of fracture radiation energy. The correlation between transmission coefficient γ and reflection coefficient β and fracture angles and wire geometry is determined. The radiation field from angles is described with spherical TEM waves with

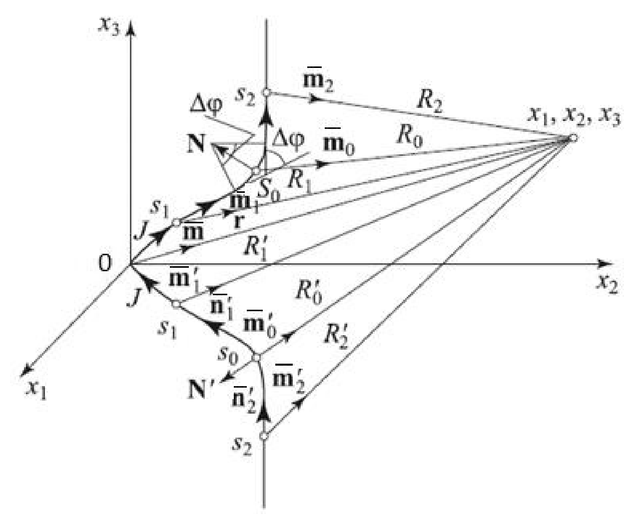


Fig. 1. *Geometry of symmetrical sections with fractures.* $\vec{m}_0$ *is the unit vector directed from the fracture to the observation point,* R_0 *is the distance from the fracture to the observation point,* s_1 *and* s_2 *are the distances from the antenna excitation point along the wire to points 1 and 2,* R_1 *and* R_2 *are the distances from points 1 and 2 to the observation point.*

centres on fractures. Proposed calculation method is close with the experiment.

The main formulae for calculation of electric and magnetic radiation fields at known reflection β and transmission γ coefficients through fractures in the vector form are presented below [1]:

$$\begin{aligned}
\vec{E} = \frac{\eta_0}{4\pi}\Bigg\{ & \gamma\cdot\frac{J(t-s_0/c-R_0/c)}{R_0}\left(\frac{\vec{n}_1-\vec{m}_0}{1-\vec{m}_0\cdot\vec{n}_1}-\frac{\vec{n}_2-\vec{m}_0}{1-\vec{m}_0\cdot\vec{n}_2}\right)+ \\
& +\beta\cdot\frac{J(t-s_0/c-R_0/c)}{R_0}\left(\frac{\vec{n}_1-\vec{m}_0}{1-\vec{m}_0\cdot\vec{n}_1}+\frac{\vec{n}_1+\vec{m}_0}{1+\vec{m}_0\cdot\vec{n}_1}\right)+ \\
& +\gamma\cdot\frac{J(t-s_2/c-R_2/c)}{R_2}\frac{\vec{n}_2-\vec{m}_2}{1-\vec{m}_2\cdot\vec{n}_2}-\frac{J(t-s_1/c-R_1/c)}{R_1}\frac{\vec{n}_1-\vec{m}_1}{1-\vec{m}_1\cdot\vec{n}_1}+ \\
& +\gamma\cdot\frac{J(t-s_0/c-R'_0/c)}{R'_0}\cdot\left(\frac{\vec{m}'_0+\vec{n}'_1}{1+\vec{m}'_0\cdot\vec{n}'_1}-\frac{\vec{m}'_0+\vec{n}'_2}{1+\vec{m}'_0\cdot\vec{n}'_2}\right)+ \\
& +\beta\cdot\frac{J(t-s_0/c-R'_0/c)}{R'_0}\cdot\left(\frac{\vec{m}'_0+\vec{n}'_1}{1+\vec{m}'_0\cdot\vec{n}'_1}-\frac{\vec{m}'_0-\vec{n}'_1}{1-\vec{m}'_0\cdot\vec{n}'_1}\right)+ \\
& +\gamma\cdot\frac{J(t-s_2/c-R'_2/c)}{R'_2}\frac{\vec{n}'_2+\vec{m}'_2}{1+\vec{m}'_2\cdot\vec{n}'_2}-\frac{J(t-s_1/c-R'_1/c)}{R'_1}\frac{\vec{n}'_1+\vec{m}'_1}{1+\vec{m}'_1\cdot\vec{n}'_1}\Bigg\},
\end{aligned} \tag{1}$$

$$\begin{aligned}
\vec{H} = \frac{1}{4\pi}\Bigg\{ & \gamma\cdot\frac{J(t-s_0/c-R_0/c)}{R_0}\left(\frac{\vec{m}_0\times\vec{n}_1}{1-\vec{m}_0\cdot\vec{n}_1}-\frac{\vec{m}_0\times\vec{n}_2}{1-\vec{m}_0\cdot\vec{n}_2}\right)+ \\
& +\beta\cdot\frac{J(t-s_0/c-R_0/c)}{R_0}\left(\frac{\vec{m}_0\times\vec{n}_1}{1-\vec{m}_0\cdot\vec{n}_1}+\frac{\vec{m}_0\times\vec{n}_1}{1+\vec{m}_0\cdot\vec{n}_1}\right)+ \\
& +\gamma\cdot\frac{J(t-s_2/c-R_2/c)}{R_2}\frac{\vec{m}_2\times\vec{n}_2}{1-\vec{m}_2\cdot\vec{n}_2}-\frac{J(t-s_1/c-R_1/c)}{R_1}\frac{\vec{m}_1\times\vec{n}_1}{1-\vec{m}_1\cdot\vec{n}_1}+ \\
& +\gamma\cdot\frac{J(t-s_0/c-R'_0/c)}{R'_0}\cdot\left(\frac{\vec{m}'_0\times\vec{n}'_1}{1+\vec{m}'_0\cdot\vec{n}'_1}-\frac{\vec{m}'_0\times\vec{n}'_2}{1+\vec{m}'_0\cdot\vec{n}'_2}\right)+ \\
& +\beta\cdot\frac{J(t-s_0/c-R'_0/c)}{R'_0}\cdot\left(\frac{\vec{m}'_0\times\vec{n}'_1}{1+\vec{m}'_0\cdot\vec{n}'_1}+\frac{\vec{m}'_0\times\vec{n}'_1}{1-\vec{m}'_0\cdot\vec{n}'_1}\right)+ \\
& +\gamma\cdot\frac{J(t-s_2/c-R'_2/c)}{R'_2}\frac{\vec{m}'_2\times\vec{n}'_2}{1+\vec{m}'_2\cdot\vec{n}'_2}-\frac{J(t-s_1/c-R'_1/c)}{R'_1}\frac{\vec{m}'_1\times\vec{n}'_1}{1+\vec{m}'_1\cdot\vec{n}'_1}\Bigg\},
\end{aligned} \tag{2}$$

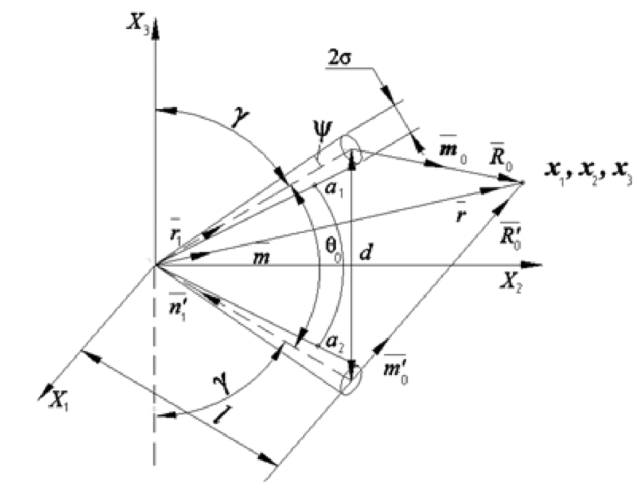
where $\eta_0 = (\mu_0/\varepsilon_0)^{1/2}$ is the wave impedance of vacuum [51-57].

3. CALCULATION OF PULSE RADIATION OF ANTENNA BASIC STRUCTURES

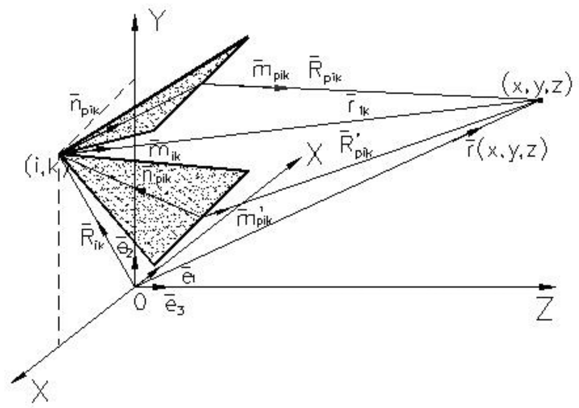
On the basis of the method proposed by S.A. Podosenov pulse radiation of the main for US EMP radiation fieldforming systems: *V*-antenna (**Fig. 2***a*) [58], a radiation field of a horn system (Fig. 2*b*) [59], and pulse radiation of an antenna with a reflector (Fig. 2*c*) [60] are calculated.

3.1. Calculation of V-antenna

Solution of problems connected with investigation of nonstationary radiation is necessary to ensure defense of electronics from nonstationary electromagnetic fields. The investigation of fields from non-sinusoidal current waves in near zone is needed. *V*-antenna radiates a spherical electromagnetic wave and has high sensibility and widebandness that permits measuring nanosecond EMP.



a



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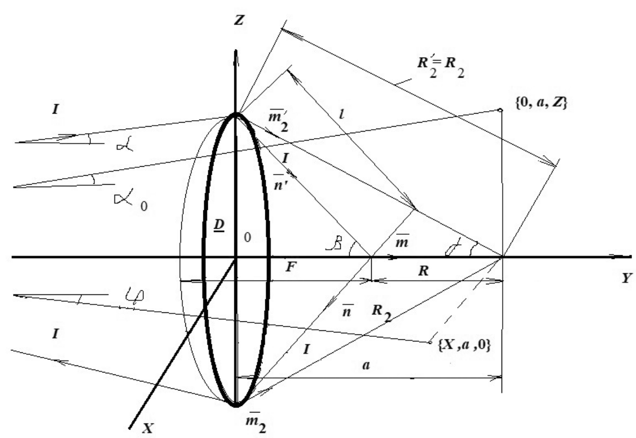

c

Fig. 2. *Calculation of concrete antenna basis structures: V-antenna (a), radiation of a horn system (b), image of V-antenna in a reflector (c).*

Let us consider radiation of *V*-antenna formed with two thin cones originated from one point with the angle θ_0 between axes (Fig. 2*a*).

We will consider two cases:

a) Infinite antenna

Infinite *V*-antenna radiates TEM wave. Formulae for calculation radiation fields have the vector form [1,58]:

$$\vec{E} = -\frac{\eta_0}{4\pi}\frac{J\left(t-r/c\right)}{r}\left(\frac{\vec{n}-\vec{m}}{1-\vec{m}\cdot\vec{n}}+\frac{\vec{n}'+\vec{m}}{1+\vec{m}\cdot\vec{n}'}\right), \quad (3)$$

$$\vec{H} = -\frac{1}{4\pi}\frac{J\left(t-r/c\right)}{r}\left(\frac{\vec{m}\times\vec{n}}{1-\vec{m}\cdot\vec{n}}+\frac{\vec{m}\times\vec{n}'}{1+\vec{m}\cdot\vec{n}'}\right), \quad (4)$$

where $\vec{m}$ and $\vec{n}$ are the unit vectors, t is the time, c is the light velocity in vacuum, J is the current value.

b) Finite antenna

Let *V*-antenna with finite length has an arm l. We will consider that the current in such an antenna propagates on a line with a fracture at the end on 180° and flows further to the load. The antenna is matched with the generator load. We will take into account reflections only one time.

One can represent formulae for calculation of radiation fields in the vector form [1,58]:

$$\begin{aligned}\vec{E} = -\frac{\eta_0}{4\pi}\Bigg\{&\frac{J\left(t-r/c\right)}{r}\left(\frac{\vec{n}_1-\vec{m}}{1-\vec{n}_1\cdot\vec{m}}+\frac{\vec{n}'_1+\vec{m}}{1+\vec{n}'_1\cdot\vec{m}}\right)+\\ &+\frac{J\left(t-2l/c-r/c\right)}{r}\left(\frac{\vec{n}_1+\vec{m}}{1+\vec{n}_1\cdot\vec{m}}+\frac{\vec{n}'_1-\vec{m}}{1-\vec{n}'_1\cdot\vec{m}}\right)-\\ &-\frac{J\left(t-l/c-R_0/c\right)}{R_0}\left(\frac{\vec{n}_1-\vec{m}_0}{1-\vec{n}_1\cdot\vec{m}_0}+\frac{\vec{n}_1+\vec{m}_0}{1+\vec{n}_1\cdot\vec{m}_0}\right)-\\ &-\frac{J\left(t-l/c-R'_0/c\right)}{R'_0}\cdot\left(\frac{\vec{n}'_1-\vec{m}'_0}{1-\vec{n}'_1\cdot\vec{m}'_0}+\frac{\vec{n}'_1+\vec{m}'_0}{1+\vec{n}'_1\cdot\vec{m}'_0}\right),\end{aligned} \quad (5)$$

$$\begin{aligned}\vec{H} = -\frac{1}{4\pi}\Bigg\{&\frac{J\left(t-r/c\right)}{r}\left(\frac{\vec{m}\times\vec{n}_1}{1-\vec{m}\cdot\vec{n}_1}+\frac{\vec{m}\times\vec{n}'_1}{1+\vec{m}\cdot\vec{n}'_1}\right)+\\ &+\frac{J\left(t-2l/c-r/c\right)}{r}\left(\frac{\vec{m}\times\vec{n}_1}{1+\vec{m}\cdot\vec{n}_1}+\frac{\vec{m}\times\vec{n}'_1}{1-\vec{m}\cdot\vec{n}'_1}\right)-\\ &-\frac{2J\left(t-l/c-R_0/c\right)}{R_0}\left(\frac{\vec{m}_0\times\vec{n}_1}{\left(1-\vec{n}_1\cdot\vec{m}_0\right)\left(1+\vec{n}_1\cdot\vec{m}_0\right)}\right)-\\ &-\frac{2J\left(t-l/c-R'_0/c\right)}{R'_0}\left(\frac{\vec{m}'_0\times\vec{n}'_1}{\left(1-\vec{n}'_1\cdot\vec{m}'_0\right)\left(1+\vec{n}'_1\cdot\vec{m}'_0\right)}\right)\Bigg\}.\end{aligned} \quad (6)$$

Here $2l/c$ is the phase shift of spherical waves. It is equal to time of interaction propagation to ends of the antenna and back. It follows from formulae (5) and (6) that radiation contains the sum of four spherical waves. The first two ones originate from the centre with the phase shift $2l/c$ that is equal to time of interaction propagation to ends of the antenna and back. Two other waves are formed from antenna ends at the moment of signal coming from the excitation point [55-58].

3.2. Calculation of a radiation field of a horn system

Knowing the induced electric current on the horn surface one can determine the radiation field created with the horn.

Finding of the horn radiation field in time domain is come down to the theory of radiation of travelling wave wire antenna. The antenna form can be arbitrary. The radiating system with the radiation field based on the theory [59] is presented schematically in Fig. 2*b*.

Let in plane *YOX* the coordinates of the excitation points of the horn system are specified. $R'_{i,k}$ is the radius-vector connecting the origin and the excitation point of the cell with numbers $\{i, k\}$. We will substitute each horn on N *V*-antennae and let p is the number of the antenna in $\{i, k\}$ cell. Electric radiation field of *V*-antenna with number p locating in the horn with numbers $\{i, k\}$ in the observation point $\{x, y, z\}$ in the time moment t has the form [1,59]:

$$\begin{aligned}\vec{E}_{p,i,k} = -\frac{\eta_0}{4\pi}\Bigg\{&\frac{J_p\left(t-r_{i,k}/c\right)}{r_{i,k}}\left(\frac{\vec{n}_{p,i,k}-\vec{m}_{i,k}}{1-\vec{m}_{i,k}\cdot\vec{n}_{p,i,k}}+\frac{\vec{n}'_{p,i,k}+\vec{m}_{i,k}}{1+\vec{m}_{i,k}\cdot\vec{n}'_{p,i,k}}\right)-\\ &-\frac{J_p\left(t-l_p/c-R_{p,i,k}/c\right)}{R_{p,i,k}}\left(\frac{\vec{n}_{p,i,k}-\vec{m}_{p,i,k}}{1-\vec{m}_{p,i,k}\cdot\vec{n}_{p,i,k}}+f\frac{\vec{n}_{p,i,k}+\vec{m}_{p,i,k}}{1+\vec{m}_{p,i,k}\cdot\vec{n}_{p,i,k}}\right)-\\ &-\frac{J_p\left(t-l_p/c-R'_{p,i,k}/c\right)}{R'_{p,i,k}}\left(\frac{\vec{n}'_{p,i,k}+\vec{m}'_{p,i,k}}{1+\vec{m}'_{p,i,k}\cdot\vec{n}'_{p,i,k}}+f\frac{\vec{n}'_{p,i,k}-\vec{m}'_{p,i,k}}{1-\vec{m}'_{p,i,k}\cdot\vec{n}'_{p,i,k}}\right)+\\ &+f\frac{J_p\left(t-2l_p/c-r_{i,k}/c\right)}{r_{i,k}}\left(\frac{\vec{n}'_{p,i,k}-\vec{m}_{i,k}}{1-\vec{m}'_{i,k}\cdot\vec{n}'_{p,i,k}}+\frac{\vec{n}_{p,i,k}+\vec{m}_{i,k}}{1+\vec{m}_{i,k}\cdot\vec{n}_{p,i,k}}\right)\Bigg\},\end{aligned} \quad (7)$$

where $R_{p,i,k}$ and $R'_{p,i,k}$ are the distances from the ends of straight and back wires of number p cell $\{i, k\}$ to the observation point, and $\vec{m}_{p,i,k}$ and $\vec{m}'_{p,i,k}$ are the corresponding unit vectors directed from the wire ends to the observation point.

Let the current at the ends of the horn of *V*-antenna is completely absorbed that is equivalent to zero reflection coefficient f. Reflection of the current at the end of the horn is equivalent to presence of fractures at the end of the horn of *V*-antenna on 180° and the reflection coefficient f is equal to unit. In practice reflection coefficient f is the function of time and its value is in the range between zero and unit. Resulting formula for the calculation of the radiation field from the horn system has the form

$$\vec{E}(t,x,y,z)=\sum_{k=1}^{v}\sum_{i=1}^{u}\sum_{p=1}^{N}\vec{E}_{p,i,k}(t,x,y,z), \tag{8}$$

where u is the number of horizontal horns, and v is the number of vertical ones.

A horn antenna array can be considered as superposition of radiators, its field is additive in accordance with the numbers of horns. Experimental results of the field calculation of the systems containing 36, 64 and 144 horns carried out confirm correctness of the theory [56].

3.3. Calculation of pulse radiation of an antenna with a reflector

When calculating the radiation field of an antenna with a reflector the radiation field of the parabolic mirror is substituted with the radiation field of V-antenna reflected in a mirror. The method permits to determine the field at any distance from the reflector.

As the excitation point of V-antenna is in the focus of the parabolic reflector then the image of the excitation point in the mirror will be imaginary and it will be located in the infinitely remoted point behind the mirror. The ends of the exiting antenna and its mirror imagination will be coincided each other and they will be located at the generatrix of the mirror. The distance between the ends is equal to the mirror diameter (Fig. 2*a*).

Thus, instead of V-antenna – reflector system we obtain two V-antennae with different opening angles θ_0. The antenna opening angle substituting the reflector will tend to zero. Field superposition of these antennae gives the search field.

The symmetrical parts of the antenna with a fracture formed by crossing of two rectilinear parts are presented in Fig. 1. The beginning of the rectilinear section is located on the distance s_1 measured along the wire, the end is located on the distance s_2 and the fracture is located on the distance s_0 from the excitation point of the antenna. Omitting simple but cumbersome transformations we present the general expression for determination of the full electric field for points with arbitrary coordinates $\{x, y, z\}$ [1,60]:

$$\begin{aligned}
E_{tz}=\frac{1}{2f_g\pi}\Bigg\{&\frac{V(t-R/c)}{2R}\cdot\left(\frac{\sin\beta+z/R}{1+\frac{(y-\cot\beta D/2)\cos\beta+z\sin\beta}{R}}+\right.\\
&\left.+\frac{\sin\beta-z/R}{1+\frac{(y-\cot\beta D/2)\cos\beta-z\sin\beta}{R}}\right)-\\
&-\frac{V(t-l/c-R_2/c)}{2R_2}\cdot\frac{\sin\beta-\frac{z-D/2}{R_2}}{1+\frac{y\cos\beta+(D/2-z)\sin\beta}{R_2}}-\\
&-\frac{V(t-l/c-R'_2/c)}{2R'_2}\cdot\frac{\sin\beta+\frac{z+D/2}{R'_2}}{1+\frac{y\cos\beta+(D/2+z)\sin\beta}{R'_2}}-\\
&-\frac{4V(t-2F/c-y/c+(D/2c)\cot\beta)}{D}\cdot\frac{1+k^2-p^2}{1+2k^2-2p^2+2k^2p^2+k^4+p^4}+\\
&+\frac{V(t-l/c-R_2/c)}{2R_2}\cdot\frac{D/2-z}{R_2-y}+\frac{V(t-l/c-R'_2/c)}{2R'_2}\cdot\frac{D/2+z}{R'_2-y}\Bigg\}.
\end{aligned} \tag{9}$$

On the basis of the theory developed by S.A. Podosenov experimental investigations of propagation of UWB pulse signals were carried out. These investigations confirmed its correctness. The main formulae were checked up experimentally in the laboratory of generation and measurement of parameters of electromagnetic pulses VNIIOFI. Obtained results are matched with theoretical results [60]. Experimental investigations were carried out using nonsymmetrical strip lines. Strip transducer was located in heterogeneous field of GTEM-cell. GTEM-cell is a section of matched cone line with a flat inner electrode and rectangular external one. By means of it one can create TEM waves with a homogeneous field in a cross section in the area between electrodes. A spherical TEM wave is formed in GTEM-cell. Such a cell has a transmittance bandwidth 5 GHz by level 3 dB. In investigation a pulse generator with front 70 ps and amplitude 5.3 V was used. The method proposed by S.A. Podosenov can be used for calculation of pulse interaction of strip lines in print circuit boards.

The theory of interaction of line two-wire transmission line with external electromagnetic field was experimentally confirmed and applied for calculation of interaction of transmission lines with nonstationary heterogeneous electromagnetic fields. It was ascertained that two-wire (strip) lines can be used both for measurement of local intensity of electromagnetic pulses and for measurement of space heterogeneities of pulse electromagnetic fields.

4. ABOUT FRACTAL GEOMETRY OF SPACE-TIME OF DETERMINISTIC STRUCTURES

S.A. Podosenov interested in not only theory of radiation of pulse electromagnetic fields. Many works of S.A. Podosenov were devoted to investigations in the field of the relativity theory – investigation of space-time and classical fields of bound structures. In particularly, jointly with prof. A.A. Potapov he investigated fractal space-time geometry of deterministic structures [4,5,53]. Briefly essence of this problem consists in following.

Usually when describing properties of arbitrary deformed systems in the form of continuum that in general case can be represented by fractals [2,3] either the field of 4-velocities (Euler's view point) or the continuum motion law establishing the connection between Euler and Lagrangian variables is prescribed. Space-time is considered either flat in the case of the special relativity theory (SRT) or the Riemannian one in the case of the general relativity theory (GRT). In other words it is considered that any external non-gravitational fields do not curve space-time of fractal deterministic structures. Its space-time geometry is remained flat. Only "space sections" are bent. Geometry of that in general case is not a Euclidian one. Such a view point is the most spread in scientific literature on the relativity theory and it is supported by majority of investigators.

V.I. Rodichev's [61] and A.A. Vlasov's [62] works differ from the standard interpretation. In [62, p. 326-327] considering the theory of growth of crystal, plasma and biological structures keeping their similarity the author concluded that growth of such structures (fractals!) is possible in non-Eucledian space-time.

Our approach is based on the development of Rodichev's and Vlasov's ideas. It consists in following. Let in a flat Minkowsky space-time with signature (+ - - -) continuum is at rest. In some moment force field of any nature switches on (except the gravitational one) and continuum begins moving. In accordance with the classical version space-time properties remain unchanged.

Our version depends on the location of the observer. If the observer considers motion of the medium from inertial reference frame (IRF) then for him fractal space-time geometry will be unchanged. For the observer connected with moving continuum that is being in noninertial reference frame (NRF) properties of fractal space-time in general case can be changed. We admit that applying of a force field for the observer locating in NRF can change space-time properties transforming it in a curved one in the world tube.

Thus, for the NRF observer after application of the force field continuum will move in some space-time. We want to determine the structure of this space-time in accordance with the specified structure of a force field and the continuum characteristics: a deformation velocity tensor $\Sigma_{\mu\nu}$, an angular velocity tensor $\Omega_{\mu\nu}$, a first curvature tensor of world lines of medium particles F_μ.

For moving continuum in four-dimensional space-time with signature (+ - - -) the expansion is right

$$\nabla_\mu V_\nu = \Sigma_{\mu\nu} + \Omega_{\mu\nu} + V_\mu F_\nu, \tag{10}$$

where V_μ is the field of 4-velocity satisfying the normalization condition

$$g_{\mu\nu} V^\mu V^\nu = 1, \tag{11}$$

$g_{\mu\nu}$ is the metric tensor in the Euler frame of reference,

$$\Sigma_{\mu\nu} = \nabla_{(\mu} V_{\nu)} - V_{(\mu} F_{\nu)}, \tag{12}$$

$$\Omega_{\mu\nu} = \nabla_{[\mu} V_{\nu]} - V_{[\mu} F_{\nu]}, \tag{13}$$

$$F_\mu = V^\nu \nabla_\nu V_\mu. \tag{14}$$

Parentheses arounds indices are the symmetry sigh, and square brackets are the alternation sign. Greek indices are changed from zero to three, latin ones are changed from unit to three.

One can interpret expansion (10) from two view points.

1. We consider that the field of 4-velocity V_μ is known, for example, as a result of integration of relativistic Euler's or Navier-Stokes's equation at specified flat metric. In this case the continuum characteristics $\Sigma_{\mu\nu}$, $\Omega_{\mu\nu}$, F_μ can be obtained in accordance with formulae (12-14), and expansion (10) is a mathematical identity.
2. We consider functions $\Sigma_{\mu\nu}$, $\Omega_{\mu\nu}$, F_μ are specified. In this case expansion (10) turns into a system of differential equations relatively V_ν and $g_{\mu\nu}$. As the number of equations of system (10) and (11) exceeds the number of unknown functions, integrability conditions should be fulfilled. Relation (15) will be an integrability condition for components of 4-velocity

$$\frac{\partial^2 V_\nu}{\partial x^\varepsilon \partial x^\sigma} = \frac{\partial^2 V_\nu}{\partial x^\sigma \partial x^\varepsilon}. \quad (15)$$

To obtain the connection between geometrical and kinematic characteristics of continuum we will calculate expression (16) in an explicit form

$$2\nabla_{[\varepsilon}V_{\sigma]}V_\nu = 2\partial_{[\varepsilon}\partial_{\sigma]}V_\nu + \\ +\left(\frac{\partial\Gamma^\mu_{\varepsilon\nu}}{\partial x^\sigma} - \frac{\partial\Gamma^\mu_{\sigma\nu}}{\partial x^\varepsilon} + \Gamma^\mu_{\sigma\rho}\Gamma^\rho_{\varepsilon\nu} - \Gamma^\mu_{\varepsilon\rho}\Gamma^\rho_{\sigma\nu}\right)V_\mu, \quad (16)$$

where $\Gamma^\mu_{\varepsilon\nu}, \Gamma^\mu_{\sigma\nu}, \Gamma^\mu_{\sigma\rho}, \Gamma^\rho_{\varepsilon\nu}, \Gamma^\mu_{\varepsilon\rho}, \Gamma^\rho_{\sigma\nu}$ – are the Christoffel's symbols expressed by the metric coefficients. From expression (16) taking into account (10-15) the structure equation of deterministic fractal has the form:

$$R^\mu_{\varepsilon\sigma,\nu}V_\mu = 2\nabla_{[\varepsilon}\Sigma_{\sigma]\nu} + 2\nabla_{[\varepsilon}\Omega_{\sigma]\nu} + 2\nabla_{[\varepsilon}(V_{\sigma]}F_\nu). \quad (17)$$

Integration of system (10) and (17), where $R^\mu_{\varepsilon\sigma,\nu}$ is the Riemann-Christoffel's curvature tensor, gives the solution of the problem about space-time geometry where NRF with prescribed structure is realized.

Transition into the rotating reference frame (deterministic fractal) as it is proved in [1,53,63-66], also results in pseudo-Riemannian space-time geometry.

However variety of fractals can not be described only by Riemannian geometry. In [1,63] the structure equation for spaces of metric connectivity with the curvature tensor differed from zero was obtained.

Thus, at the early 2000s owing to our works first a new problem area arose. It was called "Fractal geometry of space-time of deterministic structures" [1,4,5,53,63-66].

In our works [53,67-70] the Hausdorff-Colombeau measure for negative fractal dimensions was introduced. Space-time is modelled as multifractal subset with positive and negative fractal measurements. The axiomatic quantum field theory in space-time with negative fractal dimensions is proposed. We showed that fractal nature of quantum space-time with negative Hausdorff-Colombeau dimensions can solve the problem of cosmological constant.

Works concerning the rotor Mössbauer experiment [71,72] were one of the last works of S.A. Podosenov.

5.CONCLUSION

Theory of pulse radiation from field-forming systems developed by S.A. Podosenov is the base for the analytical calculation of radiation from travelling current waves.

A new analytical method of field calculation in time domain permitting to determine electromagnetic fields from complex structures both in near zone and far one is proposed.

Developed method of analytical calculation of fields from travelling current waves taking into account reflections from fractures and redistribution of currents in wires due to loss of radiation energy was experimentally confirmed.

Simple analytical relations for calculation of antenna constructions of main basic structures are presented. Developed mathematical apparatus can be used for calculation of fields in EMP simulators and calculation of *V*-antenna, radiation field of a horn system, and for the calculation of pulse radiation of an antenna with a reflector. Ordinary personal computer can be used for these calculations.

An investigation of propagation of UWB pulses confirmed correctness of the theory. Presented method has a great practice value and can be used to calculate of pulse interaction of strip lines in printed circuit boards.

The theory of interaction of a linear two-wire transmission line with an external electromagnetic field created by S.A. Podosenov was confirmed experimentally. It was used for calculation of interaction of transmission lines with nonstationary heterogeneous electromagnetic fields. Two-wire (strip) lines can be used both for the measurement of local EMP field strength and for the measurement of space heterogeneities of pulse electromagnetic fields.

Besides that at the early 2000s owing to our works first a new problem area arose. It was called "Fractal geometry of space-time of deterministic structures" [1,4,5,53,63-66] for problems of electrodynamics. In our works [53,63-66] Hausdorff-Colombeau measure concerning negative fractal dimensions was introduced. Space-time is modelled as a multifractal subset with positive and negative fractal measurements. The axiomatic quantum field theory in space-time with negative fractal dimension is proposed.

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