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# The principle of organizing an underwater radio communication channel using spherical antennas

© A.K. Tomilin

Tomsk Polytechnic University,
Tomsk, Russia
e-mail: aktomilin@tpu.ru

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The principle of operation of spherical antennas, which were used in experiments on the transmission of a short-wave radio signal in the marine environment, is theoretically described. A solution of a spherically symmetric electrodynamic problem based on the experimentally found potential component of the magnetic field is proposed. The characteristics of a potential wave process in an electrically conductive medium are determined. The law of transformation of an electromagnetic wave at the „conductor-dielectric"interface has been established.

**Keywords:** generalized electrodynamics, longitudinal electromagnetic waves, potential magnetic field.

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## Introduction

The papers [1,2 ]present the results of full-scale experiments on the transmission of short-wave (HF) radio signal in the marine environment within half a kilometer using special spherical antennas. The carrying capacity of the radio communication channel is estimated, its spectral and energy characteristics are obtained. It is concluded that it is possible to create a two-way voice radio communication channel between mobile underwater objects at a distance of several kilometers. The results obtained can lead to the creation of breakthrough technologies that allow solution of the urgent scientific and technical problem of organizing high-speed radio communication channels with mobile underwater objects. The scientific basis for these experiments was the developing generalized theory of electromagnetic waves [3].

The purpose of this work is to theoretically describe the process of radio wave generation by spherical antennas and their free propagation in the marine environment, as well as at the „conductor-dielectric„ interface.

## 1. Generalized theory of electromagnetic waves

The theory, which was formed at the end of the XIXth century as a result of studies by Maxwell, Lorentz, Heaviside, Hertz, describes the electromagnetic wave as a sequence of changes in the vortex electric and magnetic fields. It received universal recognition and allowed the creation of modern means of radio and telecommunications. Nevertheless, this theory has certain inconsistencies that contradict physical concepts: the in-phase change in the strength functions of electric $\mathbf{E}(\mathbf{r}, t)$ and magnetic $\mathbf{H}(\mathbf{r}, t)$ fields in the description of free electromagnetic wave, periodic zeroing of its energy density function, the need to use mathematical calibrations. Obviously, numerous problems and paradoxes of electrodynamics are connected with this, the theory is not able to explain them.

One of the problems arises when considering a spherically symmetric electrodynamic problem given in the article by B.M. Bolotovsky and V.A. Ugarov [4], published in 1976. It is proposed to determine the electromagnetic field of the expanding ball, on the surface of which an electric charge is uniformly distributed. As the charges move, radial electric currents arise. What is the configuration of the electromagnetic field in this case? The authors of the article conclude that the electric field outside the expanding ball will be constant, and the magnetic fields created by neighboring radial currents will be completely compensated. Thus, the electrodynamic process does not occur, and all comes to electrostatics. They agree with the opinion of Ya.B. Zel'dovich and I.A. Yakovlev that the charge conservation law prohibits the formulation of the nonstationary problem itself.

The problem formulated above models the situation that arises in a nuclear explosion, when, as it is known, strong electromagnetic radiation is detected. In this case, the radial flows of charged particles create open currents. What configuration does the field of the vector electrodynamic potential $\mathbf{A}$ have in this case? Is it possible in this case to represent it as a purely vortex, i.e., without sources and drains? These issues require a theoretical study, taking into account the results of experiments with spherical antennas.

In the experiments described in the articles [1,2] the spherical antennas with a diameter of 60 mm made of copper were used. They were loaded on kapron halyards into the sea to a depth of 6 to 10 m. An amplitude-modulated or frequency-modulated non-stationary electric potential $\phi(t)$ with a carrier frequency of 27 MHz was created on the transmitting antenna, and the receiving spherical antenna recorded this signal. The maximum distance between the antennas (470.7 m) by many times exceeded the length of the electromagnetic wave, therefore, in the marine environment a free electromagnetic wave process propagated between the antennas, which must be described analytically. There is a need to obtain an adequate solution for a spherically symmetric electrodynamic problem similar to that considered above. In this case, two fundamental problems arise: firstly, it turns out that non-stationary spherically symmetric problem cannot be reduced to a stationary case, as the authors of the article [4] suggest, and secondly, it is known that radio communication channel in the marine environment in HF band cannot be organized using free transverse electromagnetic waves.

There is a need for a critical analysis of some of the ideas developed in electromagnetism. It is customary to identify the magnetic field with a picture of iron shavings and consider it purely vortex. This does not correspond to the general field theory, or more accurately — to the Helmholtz decomposition theorem [3], which requires that any vector field be represented as a superposition of the solenoidal and potential components. This discrepancy is due to the use of calibrations for the vector electrodynamic potential $\mathbf{A}$, which do not consider the potential electromagnetic processes.

Let's expand the electrodynamic theory, refusing from artificial restrictions, first of all, the prohibition of the potential component of the vector electrodynamic potential $\mathbf{A}_p$, especially since this component is implicitly present in the theory using the Lorentz calibration:

$$\nabla\cdot\mathbf{A}+\varepsilon'\varepsilon_0\mu'\mu_0\,\frac{\partial\phi}{\partial t}=0, \qquad (1)$$

where $\mu_0, \varepsilon_0$ — magnetic and electric constants, respectively, $\mu', \varepsilon'$ — relative magnetic and electric permeability of the medium, $\phi$ is the potential of the electric field. Obviously, in (1) $\nabla\cdot\mathbf{A}\neq 0$, hence $\mathbf{A}_p\neq 0$. Thus, the Lorentz condition simultaneously excludes two potential components: magnetic and electric. For this reason, under such theory only vortex vector functions are used to describe the wave process. If instead of (1) we write a more general relation:

$$H^*(x',y',z',t)=-\frac{1}{\mu'\mu_0}\,\nabla\cdot\mathbf{A}-\varepsilon'\varepsilon_0\,\frac{\partial\phi}{\partial t}, \qquad (2)$$

then it becomes possible to take into account the so-called potential magnetic field (PMF), the intensity of which is determined by the scalar function $H^*(x',y',z',t)$. The conditions of PMF occurrence and numerous experiments with it, performed by various researchers, are described in the monograph [3]. The concept of PMF is associated with the consideration of open electric current, examples of which can be a separate moving charged particle or a linear Hertz oscillator, which is a linear conductor of finite length. Besides, potential magnetic fields are formed in complex electrical and magnetic systems of the toroidal type [5]. They serve as sources $(-H^*)$ and drains $(+H^*)$ of field of vector $\mathbf{A}$. By the way, the relation (2) is not calibration relation, it should be considered as an expression of the PMF strength in potentials.

d'Alembert wave equation

$$\Delta\mathbf{A}-\varepsilon'\varepsilon_0\mu'\mu_0\,\frac{\partial^2\mathbf{A}}{\partial t^2}=-\mu'\mu_0\mathbf{j} \qquad (3)$$

in this approach contains a superposition of the solenoidal $(\mathbf{A}_s)$ and potential $(\mathbf{A}_p)$ components of the electrodynamic potential:

$$\mathbf{A}=\mathbf{A}_s+\mathbf{A}_P.$$

Using closed $(\mathbf{j}_s)$ and open $(\mathbf{j}_p)$ electric conduction currents, we obtain from (3) two wave equations for the vortex and potential components of the magnetic field of vector $\mathbf{A}$ respectively

$$\Delta\mathbf{A}_s-\varepsilon'\varepsilon_0\mu'\mu_0\,\frac{\partial^2\mathbf{A}_s}{\partial t^2}=-\mu'\mu_0\mathbf{j}_s, \qquad (4)$$

$$\Delta\mathbf{A}_p-\varepsilon'\varepsilon_0\mu'\mu_0\,\frac{\partial^2\mathbf{A}_p}{\partial t^2}=-\mu'\mu_0\mathbf{j}_p. \qquad (5)$$

Equations (4), (5) should be supplemented with the wave equation for the scalar potential:

$$\Delta\phi-\varepsilon'\varepsilon_0\mu'\mu_0\,\frac{\partial^2\phi}{\partial t^2}=-\frac{\rho}{\varepsilon'\varepsilon_0}, \qquad (6)$$

where $\rho=\rho(r,t)$ is the electric charge density.

Differentiating (2) with respect to time, we obtain

$$\frac{\partial B^*}{\partial t}=-\nabla\cdot\frac{\partial\mathbf{A}}{\partial t}-\varepsilon'\varepsilon_0\mu'\mu_0\,\frac{\partial^2\phi}{\partial t^2}. \qquad (7)$$

Here the relation $B^*=\mu'\mu_0H^*$ is used. Jointly considering (6) and (7), taking into account the expression of the electric field strength in potentials

$$\mathbf{E}_p=-\nabla\phi-\frac{\partial\mathbf{A}_P}{\partial t}, \qquad (8)$$

we get the equation

$$\nabla\cdot\mathbf{D}=\rho+\varepsilon'\varepsilon_0\,\frac{\partial B^*}{\partial t}. \qquad (9)$$

It follows from (9) that the potential electric field can be generated not only with the help of electric charge, but also due to non-stationary potential magnetic field. The process of changing PMF $B^*(\mathbf{r},t)$ at some point in space is similar to electric charge of a certain density, since at this point a source or drain of the electric field is created. This can be called the phenomenon of vortex-free electromagnetic induction. It is confirmed by several experiments given in the monograph [3]. Thus, equation (9) describes the process of non-stationary PMF transformation into non-stationary potential electric field.

Applying the operator „gradient" to relation (2), taking into account (3) and (9), we obtain the equation

$$\nabla\times\mathbf{H}+\nabla H^*=\mathbf{j}+\frac{\partial\mathbf{D}}{\partial t}. \qquad (10)$$

It takes into account both vortex and potential processes of generation by conduction currents and displacement of the magnetic field, which in the general case is represented by 4-vector $(\mathbf{H}, H^*)$, which corresponds to the Helmholtz theorem.

Equations (9), (10), which form the basis of generalized electrodynamics, were obtained in different ways by several authors independently of each other [6–16]. A rather complete analysis of the problems of electrodynamics and the foundations of the generalized theory with various Appendices are contained, for example, in the monograph by Professor B. Zohuri (USA, University of New Mexico), published in 2019 [17]. The earliest of the found articles containing the equations of generalized electrodynamics was published in 1956 and belongs to the Japanese physicist T. Ohmura [18]. For a complete description of four-component electrodynamic processes, it is convenient to use quaternions as, for example, in the article [19].

## 2. Spherically symmetric wave process

Separating the potential and vortex components we obtain from (10) two independent equations:

$$\nabla \times \mathbf{H} = \mathbf{j}_s + \frac{\partial \mathbf{D}_s}{\partial t}, \tag{11}$$

$$\nabla H^* = \mathbf{j}_p + \frac{\partial \mathbf{D}_p}{\partial t}. \tag{12}$$

To describe electromagnetic wave emitted by the spherical antenna, it is sufficient to jointly consider equations (9) and (12), which determine the interconversion of radial conduction currents $\mathbf{j}_p$ and/or displacement currents $\partial \mathbf{D}_p/\partial t$ into a potential magnetic field and vice versa. These processes form a free electromagnetic wave. Its propagation occurs along the direction of the vectors $\mathbf{D}_p$ and $\mathbf{j}_p$, therefore such waves are usually called longitudinal. Sometimes they are called electroscalar because they are described using the current density vector $\mathbf{j}_P$ and the scalar intensity function $H^*$. Experiments with such waves in the atmosphere and outer space are described in publications [3,8,20,21]. However, in the atmosphere and in outer space radio communication using transverse waves works much more efficiently. Using longitudinal waves you can solve the problem of radio communication with mobile underwater objects [1,2], and also it can be used to transmit radio signal in mine workings [22].

To describe a free longitudinal electromagnetic wave in an unrestricted medium with electrical conductivity $\sigma$ the equations (9) and (12) should be represented as

$$\nabla \cdot \mathbf{j}_p = \sigma \frac{\partial B^*}{\partial t}, \tag{13}$$

$$\nabla H^* = \mathbf{j}_p. \tag{14}$$

When writing (13) Ohm law is used in differential form:

$$\mathbf{j}_p = \sigma \mathbf{E}_p. \tag{15}$$

From equations (13), (14) one can obtain the corresponding differential equations for a free longitudinal wave and write them in spherical coordinates:

$$\frac{\partial^2 j_p}{\partial r^2} + \frac{2}{r}\frac{\partial j_p}{\partial r} - \varepsilon'\varepsilon_0\mu'\mu_0 \frac{\partial^2 j_p}{\partial t^2} = 0, \tag{16}$$

$$\frac{\partial^2 H^*}{\partial r^2} + \frac{2}{r}\frac{\partial H^*}{\partial r} - \varepsilon'\varepsilon_0\mu'\mu_0 \frac{\partial^2 H^*}{\partial t^2} = 0. \tag{17}$$

Let us consider the process of propagation of the free spherical longitudinal electromagnetic wave with a cyclic frequency $\omega$ and length $\lambda$ in unrestricted electrically conductive medium. As follows from the wave equations (16), (17), the propagation speed of the longitudinal electromagnetic wave in each medium is the same as that of the transverse one:

$$V_{\parallel} = V_{\perp} = \frac{1}{\sqrt{\varepsilon'\varepsilon_0\mu'\mu_0}}.$$

Let's start the review of the wave process from the moment of time $t = 0$, when the wave front has a radius $r_0$, and write down the initial conditions:

$$H^*(r_0, 0) = -H_0^*, \quad j_p(r_0, 0) = 0. \tag{18}$$

It is convenient to divide the wave period $T$ into quarters, and, accordingly, discriminate four concentric spherical layers with a thickness of a quarter of the wavelength each. The temporal and spatial arguments of the functions describing the process in neighboring layers are shifted relative to each other by $T/4$ and $\lambda/4$, respectively. Differential equations (16), (17), taking into account the conditions (18) have corresponding solutions:

$$j_p(r, t) = \frac{r_0 j_p^{(\max)}}{r} \exp i[\omega t - k(r - r_0)], \tag{19}$$

$$H^*(r, t) = \frac{r_0 H_0^*}{r} \exp i\left[\left(\omega t - \frac{\pi}{2}\right) - k\left(r - r_0 - \frac{\lambda}{4}\right)\right], \tag{20}$$

where $k = \omega\sqrt{\varepsilon'\varepsilon_0\mu'\mu_0}$ — wavenumber, $j_p^{(\max)}$ — the maximum amplitude value of the conduction current density.

The longitudinal electromagnetic wave propagating in an arbitrarily chosen radial direction is conventionally shown in Fig. 1. It is a spatiotemporal sequence of generation of non-stationary PMF $H^*$ by non-stationary conduction currents $\mathbf{j}_p$ and vice versa. The vortex magnetic field is not shown in this Figure, since, as noted above, such fields created by neighboring currents are compensated.

It follows from solutions (19), (20) that the longitudinal wave in the conductor decays according to the law $1/r$. Note that in the dielectric medium instead of the current density function $j_p(r, t)$ the electric field strength $E_p(r, t)$ should be used. The coefficient of proportionality between these values is the specific electrical conductivity of the medium $\sigma$ in accordance with Ohm law (15). For sea water depending on salinity and temperature $\sigma = 3{-}7$ S/m.

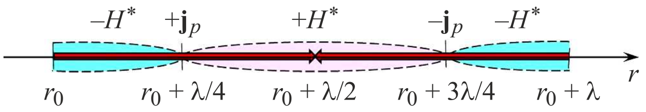


**Figure 1.** Schematic representation of longitudinal electromagnetic wave in linear conductor.

This contributes to increase in the range of the radio communication channel using longitudinal waves in the marine environment by $\sigma$ times compared to the atmospheric channel with the same transmitter power.

The energy density at the spherical front of the longitudinal electromagnetic wave is determined by the function transformed taking into account (15):

$$w(r,t) = \frac{1}{2}(\mu'\mu_0 H^{*2} + \varepsilon'\varepsilon_0 E_p^2) = \frac{1}{2}\left(\mu'\mu_0 H^{*2} + \frac{\varepsilon'\varepsilon_0 j_p^2}{\sigma^2}\right). \quad (21)$$

Note that this function does not have zero values, since the characteristics of the electromagnetic wave included in it are shifted in phase. This corresponds to the physically meaningful idea of the energy conversion of the conduction current into the energy of the potential magnetic field and vice versa. Using (21) and the initial condition (18) for the function $H^*$, as well as the initial value of the energy density: $w(r_0,0) = w_0$, we can determine the maximum the amplitude value of the conduction current present in the solution (19):

$$j_p^{(\max)} = \sigma\sqrt{\frac{2w_0}{\varepsilon'\varepsilon_0}}.$$

This ratio imposes a certain limitation on the power of underwater radio power supplies, since it is necessary to ensure the electrical safety of scuba divers and marine animals.

## 3. Boundary conditions

The boundary conditions for the generalized electromagnetic theory are formulated in [3]. It follows from them that the longitudinal electromagnetic wave with wave vector $\mathbf{k}_{\|}$, propagating in the conductor and incident normally on flat interface „conductor-dielectric", is converted into the transverse electromagnetic wave with wave vector $\mathbf{k}_{\perp}$, which propagates in the dielectric along the interface plane, i.e. in this particular case $\mathbf{k}_{\|} \perp \mathbf{k}_{\perp}$. The tangential component of the longitudinal electromagnetic wave at the interface „conductor-dielectric" is continuous, it generates the transverse wave in the dielectric, the wave vector of which is directed normally to the interface. This means that at the interface „conductor-dielectric" there is a transformation of the longitudinal wave into the transverse one and vice versa in accordance with the general law (Fig. 2):

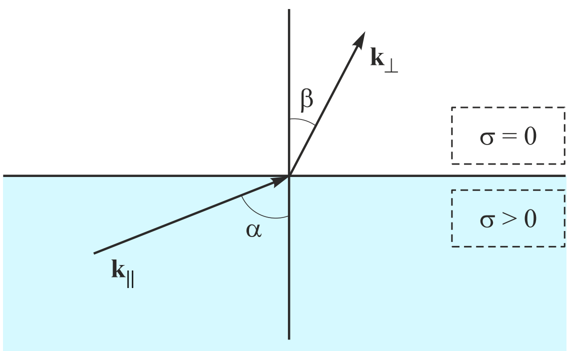


**Figure 2.** Transformation of electromagnetic wave at the interface „conductor—dielectric".

$$\mathbf{k}_{\|}\cos\alpha = \mathbf{k}_{\perp}\cos\beta, \quad \beta = \pi/2-\alpha,$$

or

$$\operatorname{tg}\alpha = k_{\|}/k_{\perp}. \quad (22)$$

The boundary condition (22) indicates the fundamental possibility of organizing a communication channel for a ground radio station operating on conventional transverse waves with the mobile underwater object whose antenna is capable of receiving longitudinal waves. This conclusion was indirectly confirmed by analyzing the signals recorded with the help of the underwater spherical antenna in the course of the experiments described in the articles [1,2]. In the power density spectrum of the received signal the narrow-band harmonics were found, the presence of which cannot be explained, for example, by multiple frequencies „of the tone call". Presumably, this is explained by the boundary condition formulated above: the sources of these radio signals are in the air, and the signals themselves, being transformed, pass through the interface „air—water" and then propagate under water in the form of longitudinal waves. However, this hypothesis requires additional study, and a series of special experiments must be performed for the final conclusion.

## 4. Spherical antenna design

To create non-stationary electric potential on the transmitting spherical antenna, it is proposed to use an open oscillatory circuit with a spiral coil, which is the secondary winding of a Tesla transformer (Fig. 3). Both coils of the transformer are located in the same plane.

Electromagnetic processes occurring in the spiral coil are determined by equations (9), (11), (12) and are described in detail in the monograph [3]. The conduction current flowing in the spiral coil has two components: a vortex (circular) $\mathbf{j}_s$ and a potential (radial) $\mathbf{j}_p$, i.e., (Fig. 4, $a$). The corresponding electric field can be represented as a superposition of the vortex and potential components: $\mathbf{D} = \mathbf{D}_s + \mathbf{D}_p$ (Fig. 4, it b).

Radial currents $\mathbf{j}_p$ create PMF of strength $H^*$ in accordance with equation (12). The PMF of the primary coil is transformed into the PMF of the secondary coil due to

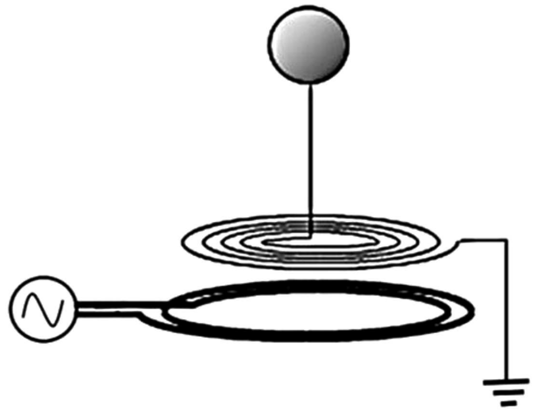

**Figure 3.** Schematic diagram of spherical antenna.

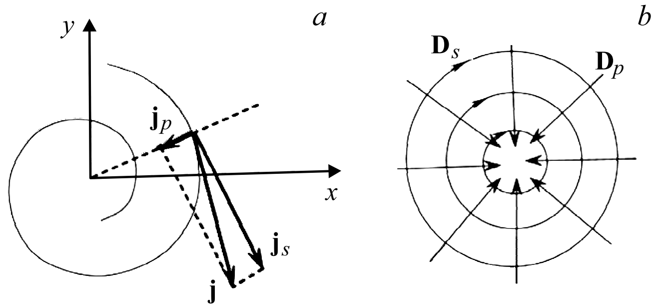


**Figure 4.** Configuration of conduction currents ($a$) and electric field ($b$) in spiral Tesla coil.

radial displacement currents $\partial \mathbf{D}_p/\partial t$. A non-stationary PMF creates electric potential in the center of the secondary coil in accordance with the law (9). This potential is transmitted to the spherical antenna connected to the center of the secondary coil.

In [3] a method for calculating the inductance of the spiral coil and resonant frequencies of the spherical antenna is given, taking into account its electric capacitance. It was used in the design, manufacture and setting of antennas, which were used in the experiments described in the articles [1,2]. Note that the resonant setting of the spherical antenna with spiral coil is complex process. In such oscillatory circuit the so-called „three-humped" resonance arises [3]. To detect the maximum resonant peak it is necessary to carefully examine a sufficiently wide frequency range using a special antenna analyzer. Besides, capacitive couplings occur between the turns of the helical coil, which can affect the resonant peaks.

## Conclusion

Thus, both problems identified at the beginning of the study were successfully solved under the generalized electrodynamic theory: a wave electromagnetic process is described in the spherical electrodynamic problem, and it is shown that free longitudinal (electroscalar) electromagnetic waves propagate in electrically conductive medium. These provisions make it possible to design special antennas for organizing radio communication channels with mobile underwater objects. One of the possible types of antennas for longitudinal electromagnetic waves — spherical antennas — was used in experiments, the results of which are described in articles [1,2]. The conditions obtained at the interface „conductor-dielectric" indicate the transformation of longitudinal waves into transverse waves and vice versa, i.e. there is fundamental possibility of connecting atmospheric and underwater radio communication channels without special repeaters.

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### Conflict of interest

The author declares that he has no conflict of interest.

## References

[1] A.K. Tomilin, A.F. Lukin, A.N. Gulkov. Tech. Phys. Lett., **47** (6), 577 (2021). DOI: 10.1134/S1063785021060146
[2] A.F. Lukin, A.K. Tomilin, A.N. Gulkov, K.A. Krems. Techn. Phys., 2022, vol. 92, No. 9. P. 1232–1236. DOI: 10.21883/TP.2022.09.54688.43-22
[3] A.K. Tomilin. *Obobshchennaya elektrodinamika* (Triumf, M., 2020). (in Russian) DOI: 10.32986/978-5-93673-270-6-2020-04
[4] B.M. Bolotovsky, V.A. Ugarov. UFN, **119**, 2 (1976). (in Russian).
[5] V.M. Dubovik, L.A. Tosunyan. Physika elementarnykh chastits i atomnogo yadra, **14** (5), (1983) (in Russian).
[6] N.P. Khvorostenko. Izv. vuzov. Fizika, **35** (3), 24 (1992) (in Russian).
[7] A.A. Protopopov. *Fizilo-matematicheskie osnovy teorii prodol'nykh elektromagnitnykh voln.* Pod obsch. red. E.I. Nefedov, A.A. Yashin. (TulGU, Tula, 1999) (in Russian)
[8] C. Monstein, J.P. Wesley. Europhys. Lett., **59** (4), 514 (2002). DOI: 10.1209/epl/i2002-00136-9
[9] K.J. van Vlaenderen, A. Waser. Hadronic J., **24**, 609 (2001).
[10] D.A. Woodside. Am. J. Phys., **77** (5), 438 (2009). DOI: 10.1119/1.3076300
[11] A.I. Arbab, Z.A. Satti. Progr. Phys., **2**, 8 (2009).
[12] P.A. Zhilin. *Trudy XXIII shkoly-seminara „Analiz i sintez nelineynykh mekhanicheskikh kolebatel'nykh sistem"* (IPMash AN, SPb., 1996) (in Russian)
[13] L.M. Hively. Patent № US 9,306,527 B1, Apr. 5, 2016.
[14] S.B. Klyuev, E.I. Nefedov. Fizika volnovykh protsessov i radiotekhnicheskiye sistemy, **11** (4), 26 (2008) (in Russian).
[15] E.I. Nefedov. *Elektromagnitnyye polya i volny* (Izdat. tsentr „Akademiya", M., 2014), (in Russian)

[16] E.I. Nefyodov, S.M. Smolskiy. *Understanding of Electrodynamics, Radio Wave Propagation and Antennas* (Scientific Research Publishers, USA, 2012)

[17] B. Zohuri. Scalar Waves. In book: *Scalar Wave Driven Energy Applications* (Springer, 2019), p. 443–491, DOI:10.1007/978-3-319-91023-9_6

[18] T. Ohmura. Prog. Theor. Phys., **16** (6), 684 (1956).

[19] L.A. Alexeyeva. J. Modern Phys., **7**, 1351 (2016). DOI: 10.4236/jmp.2016.711121

[20] K. Meyl. J. Scientific Exploration, **15** (2), 199 (2001).

[21] O.A. Zaimidoroga. J. Modern Phys., **7** (8), 806 (2016). DOI: 10.4236/jmp.2016.78074

[22] D.V. Fedosov, A.V. Nikolaev, A.V. Kolesnikov. Zhurnal radioelektroniki (elektronny zhurnal), **9**, 1684 (2021). (in Russian). DOI: 10.30898/1684-1719.2021.9.11


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