Installation for studying the parameters of localization of an electromagnetic wave in a waveguide of variable cross-section in the framework of the predictions of the 5-D extended space model

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Abstract: **The paper describes the creation and testing of an experimental setup for studying the parameters of localization of electromagnetic microwave radiation with a power of 0.001-0.004 W in the range of 36.0-79.0 GHz when propagating radiation in metal waveguides of variable cross-section. Measurements will also be carried out under conditions of filling the waveguide with dielectric materials with refractive indices from 1.46 to 4.0 for microwave radiation of the specified range. The installation is designed to measure the parameters of the localization of microwave radiation when it passes through a waveguide of variable cross-section, filled with materials with different refractive indices. Interpretation of the results will be carried out within the framework of the 5-D extended space model (ESM). The extended space model is formulated in (1+4)-dimensional space time-coordinate-interval. An additional spatial coordinate in the ESM is the interval. In the conjugate 5-D space, the energy-momentum-mass interval in the ESM corresponds to mass. In the ESM formalism, the question of the appearance of a nonzero variable mass in a photon and its localization under the influence of an external field is studied.**

Keywords: **localization of the electromagnetic field, waveguide, microwave radiation, (1+4)D extended space model, variable photon mass, interval**

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CONTENTS

1. INTRODUCTION

In modern science, the problem of combining gravitational and electromagnetic fields into one is actively discussed. Historically, this topic has been discussed for over 100 years.

Most of the attempts to build a unifying field model are implemented by constructing geometric models of physical interactions and interpreting physics within the framework of geometry in spaces of a larger number of dimensions. A review of the literature on the topic of multidimensional theories can be found, for example, in [1].

At the very beginning of the 20th century, Felix Klein [2] considered the Hamilton-Jacobi theory as optics in spaces of a greater number of dimensions. Klein's ideas did not receive further development at the time of creation. Interest in the problem of the geometrization of physics was again caused by the creation of the General Theory of Relativity (GR) [3]. Efforts have been made by researchers to describe electromagnetism in geometric terms similar to gravity. The authors of these works tried to expand the already created general relativity scheme in various ways instead of creating new models.

The models of Klein [4] and O. Kaluza [5] became famous. We can also mention the work of Fock [6] and Mandela [7]. Note that a 5-dimensional space was used to build these models. Nevertheless, no clear physical interpretation of the fifth coordinate was made in these works. In the future, attempts to develop 5-dimensional models were undertaken by many scientists, including Einstein, de Broglie, Gamow and Rumer [8,9], however, some interesting results did not work out.

We believe that the reason for the relative failure of these approaches was the lack of new physical hypotheses and the basis for a formal generalization of the existing models.

An interesting opinion about the reasons for the failures in the creation of a unified theory of the Fock field is from his letter to Rumer on February 14, 1950: "The success of the idea of geometrization in Einstein's theory of bodies with a sufficiently small mass move according to the same law. The movement of charged bodies in an electromagnetic field depends on the ratio of charge to mass. Therefore, the geometrization of the corresponding concepts can be successful only for one particle. This is also the reason for the complete failure of all “unified” field theories"[10, p. 78].

We also note Einstein's opinion regarding the shortcomings of the 5-dimensional Rumer theory (the Extended Space Model - ESM model [14-18] is close to Rumer's idea, but differs significantly from it in that the ESM considers the interval S as a non-compactified 5th coordinate), expressed in Einstein's letter M.Born from 12/14/1929: "I really liked Mr. Rumer. His idea of attracting multidimensional sets is original and formally well implemented. The weakness is rooted in the fact that the laws found in this way are not complete and the paths for logical support and completeness are not foreseen"[10, p. 163; 11].

Although in Rumer's 5-optics the fifth coordinate is introduced in the form of an action and a 5-dimensional space with the metric (+, -, -, -, -) is considered, but no transformations in this space that would confuse the coordinate with the other four coordinates of the Minkowski space, he does not consider. Accordingly, in the conjugate 5-dimensional space with coordinates, the mass also remains constant and is not converted into energy and momentum.

It is also necessary to note the theory of gauge fields, in which electromagnetism, gravity and other interactions are considered from a single geometric point of view [12]. In the work of Landau [13], estimates of the value of the "radius" of elementary particles were obtained, proceeding from the limit of applicability of electrodynamic representations in quantum mechanics. Note that the "radius" of the electron in this case turned out to be equal to zero.

The approach proposed in the ESM [14-18] is fundamentally different from all the above and similar theories. The ESM is based on the physical hypothesis that mass (rest mass) and its conjugate value - action (interval) are dynamic variables. The magnitude of these variables is determined by the interaction of fields and particles. In this respect, such a model is a direct generalization of the Special Theory of Relativity (SRT). In SRT, the interval and rest mass of particles are invariants, and they can vary in the ESM. In particular, a photon can acquire a mass, both positive and negative. This mass can appear and change due to electromagnetic interaction and generate gravitational forces. It is this circumstance that allows us to consider gravity and electromagnetism as a single field in the ESM.

A similar ESM 5-dimensional model was developed by Paul Wesson et al. [19-22]. P. Wesson suggested using "mass" as the fifth coordinate, complementary to time and three spatial coordinates: [19, p.10]. "We ... consider mass on the same basis as time and space ..." [19, p. 191, equation (7.40)]. "This means that the role of the uncharged 4D mass in the 5D geometry is played by an additional coordinate".

This approach seems counterintuitive to us. In this case, this leads to difficulties in generalizing the 4D energy-momentum tensor to the 5D energy-momentum-mass tensor in 5-dimensional space.

Of course, mass can be used as a fifth coordinate, but not in coordinate space. Mass should be considered in momentum space, i.e., as an additional quantity to the energy and three components of the momentum. And in coordinate space, the fifth coordinate must be another value related to mass. As a result of considering mass as the fifth coordinate in addition to time and space in [19-22], it was difficult to establish a connection between m and real experiments.

Recently James Overduin (co-author Paul Wesson) and R.C. Henry in [23] proposed the same idea of introducing the 5th coordinate as Tsipenyuk D.Yu. and Andreev V.A. in 2000 [14].

The presented work is devoted to the description of the experimental setup we created and its subsequent testing. The installation is designed to study the parameters of localization of electromagnetic microwave radiation with a power of 0.001-0.004 W in the range of 36.0-79.0 GHz during propagation of radiation in metal waveguides of variable cross-section. These parameters of the facility should allow experimentally testing the prediction of the ESM in the region of localization of electromagnetic waves when they hit media with a high refractive index.

2. POTENTIALS AND CURRENTS IN THE FRAMEWORK OF THE ESM APPROACH

Within the framework of the extended space model, the process of localization of the electromagnetic field was described when an electromagnetic wave from a vacuum enters an external field (for example, an electron) or into a converging waveguide.

In the ESM, the assumption is made that the relationship between energy, momentum and mass is 5-dimensional if we take into account the possibility of mass change in physical processes:

$$E^2 - c^2 p_X^2 - c^2 p_Y^2 - c^2 p_Z^2 - m^2 c^4 = 0. \qquad (1)$$

The generalization of Einstein's special theory of relativity (STR) to (1+4)D-dimensional space $(T, \vec{X}, S)$, with the metric (+ - - - -), where the fifth coordinate is the interval S, which has the physical meaning of action, is considered. The basis for this generalization is the fact that in SRT the masses of particles are scalars and do not change during their elastic interactions. It is well known that a photon can be considered a massless particle and described by a plane wave only in infinite empty space. If a photon enters a medium or finds itself in a limited space (in a resonator or waveguide), then it acquires a nonzero mass.

The length of the Lorentz-covariant 5-vector corresponding to objects satisfying (1) in the ESM is equal to zero:

$$(ct)^2 - x^2 - y^2 - z^2 - s^2 = 0. \qquad (2)$$

In contrast to (1+3)D Minkowski space, where the particle is associated with a 4-dimensional isotropic for massless particles and anisotropic for massive particles, the energy-momentum vector (*E/c*; *P*(*x*), *P*(*y*), *P*(*z*)), in the (1+4)D ESM particle is assigned an isotropic Lorents-covariant for all particles 5-dimensional energy-momentum-mass vector (*E/c*; *P*(*x*), *P*(*y*), *P*(*z*), *mc*) whose length is zero.

The 5-dimensional current vector generating a single electromagnetic-gravitational field has the form:

$$\vec{\rho} = (\mathrm{j}_0, \vec{\mathrm{j}}, \mathrm{j}_4) = \left[\frac{\mathrm{emc}}{\sqrt{1\text{-}\beta^2}}, \frac{\mathrm{em}\vec{\mathrm{v}}}{\sqrt{1\text{-}\beta^2}}, emc \right]. \qquad (3)$$

This is an isotropic vector $\vec{\rho}^2 = 0$.

The equation of continuity, as in the usual case, is expressed by the equality to zero of the 5-divergence of the 5-current

$$\sum_{\mathrm{i}=0}^{4} \frac{\partial \mathrm{j}_\mathrm{i}}{\partial \mathrm{x}_\mathrm{i}} = 0. \qquad (4)$$

If the charge is at rest, then the continuity equation takes the form

$$\frac{\partial m}{\partial t} + \frac{\partial m}{\partial x_4} = 0. \qquad (5)$$

Current (3) generates an electromagnetic-gravitational field in the expanded space G(1,4). This field is given by the 5-vector potential A:

$$A = (A_\rho, A_x, A_y, A_z, A_s) = (A_0, A_1, A_2, A_3, A_4) \qquad (6)$$

Here and below, we use the notation $t = x_0$, $x = x_1$, $y = x_2$, $z = x_3$, $s = x_4$.

The components of this vector potential are determined by the equations

$$\Pi_{(5)}\, \mathrm{A}_0 = -4\pi\rho, \qquad (7)$$

$$\Pi_{(5)}\, \vec{\mathrm{A}} = \frac{-4\pi}{c} \vec{j}, \qquad (8)$$

$$\Pi_{(5)}\, \mathrm{A}_5 = \frac{-4\pi}{c} j_S. \qquad (9)$$

Here

$$\prod_{(5)} = \frac{\partial^2}{\partial \mathrm{s}^2} + \frac{\partial^2}{\partial \mathrm{x}^2} + \frac{\partial^2}{\partial \mathrm{y}^2} + \frac{\partial^2}{\partial \mathrm{z}^2} - \frac{1}{c^2} \frac{\partial^2}{\partial \mathrm{t}^2}. \qquad (10)$$

Note that in the case when there is no dependence on the coordinate *s* and the mass m entering the current components (3) is constant, the system of equations (7)-(9) splits into two independent parts. Equations (7), (8) specify the usual potentials of the electromagnetic field, and equation (9) specifies the potential of the scalar gravitational field. These fields exist independently of each other. They are combined into one field only when the mass m becomes variable and there is a dependence on the variable *s* [18].

2.1. Localization of fields and particles within the framework of the ESM approach

Localization of fields and particles within the framework of the ESM approach is considered in detail in [17,18]. Some of the results of this work are presented below. Note that the approach is based on an analogy when comparing the dispersion relation of a free particle

$$E^2 = (c\vec{p})^2 + m^2c^4. \quad (11)$$

and the dispersion relation of the wave in the mode of a hollow metal waveguide

$$\omega^2 = \omega^2_{kr} + (c\xi)^2. \quad (12)$$

Here, ω_{kr} is the critical frequency of the waveguide mode, and ξ is the wave propagation constant. De Broglie, Feynman, and other authors drew attention to the similarity of relations (11) and (12). The critical frequency ω_{kr} is associated with a parameter that has the dimension of mass

$$m = \frac{\hbar\omega_{kr}}{c^2}, \quad (13)$$

The mass that an electromagnetic field acquires when it enters a waveguide.

In particular, if the waveguide has a square shape with a side of size *a*, then this connection has the form

$$a = \frac{\sqrt{2}\pi\hbar}{mc}. \quad (14)$$

We propose to consider this value as a linear parameter associated with a massless particle when it acquires mass *m*. We believe that at the same time as, when hitting an external field, a massless particle acquires a nonzero mass, the corresponding infinite plane wave is compressed to a finite size. And this final size is characterized by the localization parameter

$$l = \frac{2\pi\hbar}{mc}. \quad (15)$$

In appearance, quantity (15) resembles the Compton wavelength of an electron, however, its physical meaning is completely different. In the formula for the Compton wavelength of an electron, the parameter *m* - is the electron rest mass, and in formula (15) *m* - is the mass that a photon acquires when it is exposed to external influences.

In the ESM, the external influence is described by means of rotations in the expanded space G(1,4). Since the linear parameter l is expressed using formula (14) in terms of the photon mass, it can be used to find the dependence of this parameter on the quantities that specify these rotations.

So, in the case of hyperbolic rotations in the plane (*TS*), the dependence of the photon mass on the rotation angle θ is determined by the formula $mc^2 = \hbar\omega sh\theta$. Substituting this expression into formula (15), we obtain an expression for the parameter *l* through the angle θ

$$l = \frac{2\pi c}{\omega \cdot sh\theta}. \quad (16)$$

In the case of Euclidean rotations in the (*XS*) plane, the dependence of the photon mass on the rotation angle ψ is determined by the formula $mc^2 = \hbar\omega sin\psi$.

With its help, we obtain an expression for the parameter *l* through the angle ψ.

$$l = \frac{2\pi c}{\omega \cdot \sin\psi}. \quad (17)$$

The speed of propagation of a wave *c* in vacuum is related to the propagation of speed in a medium or a waveguide *v* refractive index *n* by the ratio $v = c/n$.

In the case of rotations (*TS*), a photon under the influence of an external field acquires a mass related to the refractive index by the relation

$$m_{(TS)} = \frac{\hbar\omega}{c^2} \cdot sh\theta = \frac{\hbar\omega}{c^2}\sqrt{n^2 - 1}. \quad (18)$$

The physical meaning of turns (*TS*) is that we do not make spatial movements, we are always at the same point, but the optical density at this point changes over time. Thus, in this case, the transformation

(*TS*) means a transition to a different point in time and a different optical density. This can be interpreted in such a way that an external field arises in space, which, acting on a particle and performing work, changes its energy and mass. All movements occur along cones and hyperboloids and are transitive in nature. Since there is no spatial motion, the momenta of the particles must be conserved.

In the case of rotations (*XS*), a photon under the influence of an external field acquires a mass related to the refractive index by the relation

$$m_{(XS)} = \frac{\hbar\omega}{c^2}\cdot\sin\psi = \frac{\hbar\omega}{c^2 n}. \qquad (19)$$

The rotation (*XS*) corresponds in the ESM to the transition from a space with one optical density to a space with a different optical density. In this case, no time processes occur, everything is considered at the same time. Therefore, the energy of the particles is conserved, and all processes occurring with them are reduced to internal rearrangements. Conventionally, this can be understood so that a particle, falling into a denser medium, is deformed in an elastic manner, and leaving it, restores its characteristics. In this case, there is no exchange of energy and momentum between the medium and the particle.

So, from the point of view of the ESM, the transition from a medium with one refractive index to a medium with a different refractive index can be interpreted as a movement along the fifth coordinate of the Expanded space. In other words, this (1+4)-dimensional space can be understood as a set of 1+3-dimensional Minkowski spaces, each of which is characterized by some parameter, such as the refractive index n. And the transition from a medium with an index n_1 to a medium with a refractive index n_2 can be interpreted as a transition in 1+4-dimensional space from one 1+3-dimensional subspace to another 1+3-dimensional subspace. Thus, the geometry of the Expanded Space turns out to be related to the physics of the processes that we study in each specific problem. Namely, with fields and environments that participate in these processes. The distribution of these media and fields in our ordinary Minkowski space determines the distribution of the "refractive index" in the Expanded space, i.e. its geometry.

In [36], a solution to the system of equations (7)-(10) was found in the form

$$U(s,x,y,z,t) = u(s,x,y,z)\cdot e^{-iks}\cdot e^{i\omega t},\ k = \frac{2\pi}{\lambda}, \qquad (20)$$

Assuming that the sought-for function is stationary in time and varies slowly along the s-axis in comparison with the change along the x, y, z axes. In this case, the solution has the form of a 3-dimensional Gaussian wave

$$u = u_0\left(\frac{w_0}{w}\right)^{3/2}\exp\left[-i(ks+\varphi) - \right.$$
$$\left. -(x^2+y^2+z^2)\left(\frac{1}{w^2}+\frac{ik}{2R}\right)\right]. \qquad (21)$$

Here w_0 is the minimum radius of the wave at a point $s = 0$; w - is the diameter of the wave at point s_1 and R is the radius of curvature of the wavefront at this point.

When a plane electromagnetic wave hits a medium or an external field, the ESM predicts that, in accordance with (21), the plane wave is localized into a sphere of radius ω_0, taking into account the above assumptions.

3. DESCRIPTION OF INSTALLATION AND METHODS OF MEASUREMENT

To experimentally check the correctness of the ESM predictions about the parameters of the localization of an electromagnetic wave in a waveguide with a variable cross section, we assembled a specialized experimental microwave setup. This setup is also supposed to measure the microwave localization parameter when radiation hits dielectric media with a refractive index greater than unity.

The installation diagram is shown in **Fig. 1**.

Radiation in the microwave frequency range from 36 to 79 GHz is generated by interchangeable generators 1 model Г4-141 (generation region 36-54 GHz) or Г4-142 (generation region 53-79 GHz). The instability of the output frequency is not more than 10^{-3}, the adjustable output signal power is up to $4\cdot10^{-3}$ W, the range of the output power level is not less than 30 dB. The limit of instability of the output power level is ±0.3 dB. Standard operating modes of generators: 1) continuous generation; 2) internal modulation by rectangular symmetric pulses with a repetition rate 1 ± 0.2 kHz and a duty cycle of 2 ± 0.4; 2) electrical remote frequency tuning by digital code.

After the generator, microwave radiation propagates through a silver-plated copper waveguide having a rectangular cross-section of $a\times b$ = 5.5×2.5 mm for the case of the Г4-141 generator (option 3.8×1.9 mm when using the Г4-142 generator) with a length l = from 30 to 50 mm.

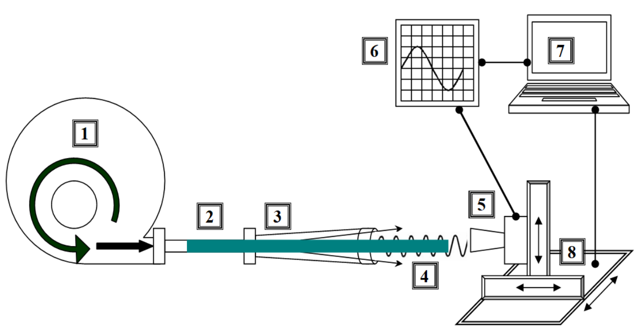

Fig. 1. *Installation diagram. 1 - microwave generator 36-79 GHz, 2 - rectangular waveguide, 3 - output horn/sectoral antenna, 4 - Teflon or silicone dielectric insert of variable cross-section, 5 - microwave receiver, 6 - digital oscilloscope, 7 - computer, 8 - receiver 3D positioning system.*

Inside the waveguide 2, if necessary, a dielectric rod 4 made of Teflon or silicone and completely filling the waveguide can be installed and, if necessary, coming out from the waveguide by 150-200 mm outside. At the same time, we made a series of dielectric rods with a length having both a constant cross-section along the length and converging evenly in one or two directions. For example, to work with the Г4-141 generator (the generation region is 36-54 GHz, which approximately corresponds to the microwave radiation wavelength from 8.32 to 5.55 mm), Teflon rods of various profiles were made: No. 1 with a cross-section of 5.5×2.5 mm at the beginning up to 2.2×1.6 mm at the end of a rod 200 mm long; No. 2 with a section from 5.5×2.5 mm at the beginning to 0.5×2.5 mm at the end of a 180 mm long rod and No. 3 with the same section 5.4×2.4 mm along the entire rod 200 mm long.

Further, the installation has the ability to install a horn antenna 3, as well as a waveguide 2 with a wall thickness of 1.2 mm, made of copper and silver-plated from the inside. We have the ability to install various horn antennas at the output 3 or at the input of the receiver 5. We have horn antennas of the following types and sizes: 1) horn antennas of the pyramidal type, measuring the length of the horn - 90 or 75 mm and the size of the output aperture 45×45 mm or 40×40 mm; 2) horn antennas with a circular output section with dimensions (length x output diameter): 55×36; 110×44; 116×51 and 160×50 mm.

The received modulated low frequency 1 kHz microwave signal from the receiver 5, after digitizing its parameters on the DS-1052 oscilloscope, is transmitted for recording and further processing to the computer 7. The receiver 5 can be precisely moved in three spatial directions using the 3-dimensional positioning system of the receiver 8.

Direct measurement by the parameter of a high-frequency signal in the continuous generation mode with a resolution in the range of 36-79 GHz on the assembled installation is impossible. For this reason, it was decided to measure the parameters of the microwave signal resulting from internal modulation by rectangular symmetric pulses with a repetition rate 1 ± 0.2 kHz and a duty cycle of 2 ± 0.4. A low-frequency modulated microwave signal is confidently recorded by a receiver coupled to a digital oscilloscope at a distance of 10-800 mm from the output waveguide. When the maximum signal output power level is set at $4 \cdot 10^{-3}$ W, the amplitude of the recorded useful signal reaches 700 mV at a distance of about 100 mm.

Measurement of the useful signal with an accuracy of less than 0.1 mV on the created setup seems to be impractical. This conclusion was made based on the results of experimentally measured signal fluctuations caused by various factors in total. Such factors can be the instability of the signal from the generator (the level of parasitic amplitude low-frequency modulation of the output signal is about 1% according to the technical description), mechanical vibrations of the installation, air flows, etc.

Thus, we have a range of the useful signal of the order of 10^4, which seems to be sufficient for the purposes of our experiment. The positioning accuracy of the receiver of our installation is not worse than 0.1 mm, is sufficient taking into account the characteristic distances at which there is a significant change in the signal for microwave waves in the 3-8 mm range.

4. RESULTS OF CALIBRATION AND TEST MEASUREMENTS

On the created experimental stand, in the period from April to June 2021, we carried out several series of test and calibration measurements, the results of which are described below.

The power of the output signal of the Г4-141 and Г4-142 generators can be changed with a special regulator, while the signal level indicator shows current changes in the range of 0-100 mV. The connection between the readings of the dial indicator and the real level of the output signal was measured. In **Fig. 2** shows the data showing the measured relationship between the readings of the dial indicator installed on the Г4-141 generator with the level of the microwave signal recorded at a distance of 200 mm. The measurements were carried out at two frequencies at frequencies of 36 and 52 GHz.

Changes in the linearity of the connection between the indicator readings and the real output signal level were carried out for two frequencies 36 and 52 GHz. It can be seen that changes in the output signal occur with

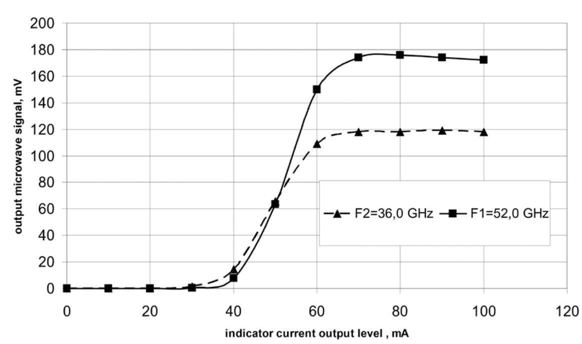

Fig. 2. *The linearity level of the measured output microwave signal at a distance of 200 mm from the output waveguide, depending on the readings of the dial gauge of the output level installed on the Г4-141 generator.*

changes in the regulator current in the range of 30-70 mA. The measurement accuracy of the microwave signal is from 0.1 to 2.0 mV at various signal amplitudes.

Fig. 3 shows the change in the signal with a linear shift of the receiver along the direction of propagation of the microwave signal by 50 mm relative to the Teflon insert.

The receiver moves towards the emitter relative to a 200 mm long Teflon insert of constant cross-section partially inserted into the output waveguide, see Fig. 1. The frequency of the emitter in two series of measurements was 36.0 and 52.0 GHz, the current set on the output power regulator was 70 mA, which corresponds to the maximum output power, see Fig. 2. The measurement accuracy of the microwave amplitude in this signal series was 0.5-2.0 mV.

It can be seen that the number of periods of stationary microwave waves established in the receiving waveguide is proportional to the frequencies of the initial radiation: the ratio of the initial frequencies 52.0/36.0 = 1.44 coincides, taking into account the accuracy of the measurements, with the ratio of the number of periods measured when the receiver is moved to a length of 51 mm 16/11 = 1.45.

We also measured the number of maxima of a steady-state microwave wave in air in the absence of a dielectric rod. In these measurements, the sensor was moved along the axis of wave propagation at a distance of 70 mm. The frequency range for which the number of maxima in the air is investigated is from 37 to 52 GHz. The results are shown in **Fig. 4**.

The achieved measurement accuracy in this experiment is estimated at 0.4 mm and is displayed on the graph. The microwave radiation power in this series was $2\cdot10^{-3}$ W, the distance of the source to the receiver was from 100 to 180 mm.

From the results shown in Fig. 4 it can be seen that a good qualitative and quantitative agreement has been achieved between the calculated and experimentally measured graphs of the change in the microwave wavelengths depending on the frequency.

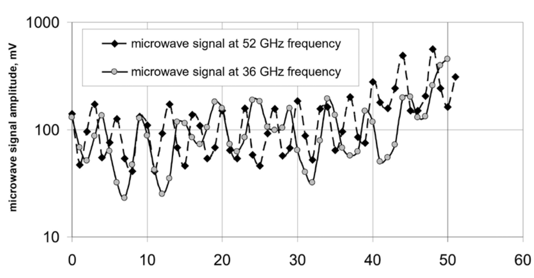

Fig. 3. *The structure of standing waves generated in the waveguide connected to the receiver input when the receiver is moved towards the emitter by 0-51 mm. The measurements were carried out at two radiation frequencies of 36.0 and 52.0 GHz.*

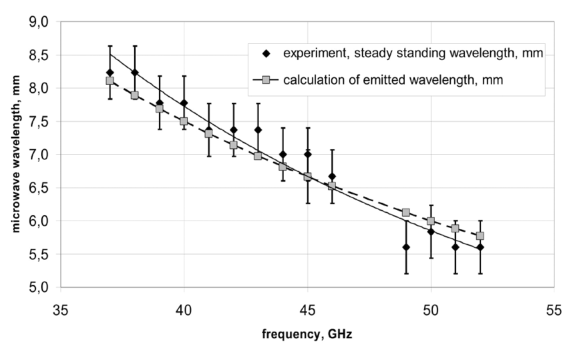

Fig. 4. *The lengths of the steady-state microwave wave in the air obtained by counting the number of maxima measured when the receiver is shifted by 70 mm, depending on the frequency of 36-52 GHz. Also, for comparison, the calculated graph of the wavelength emitted by the generator versus frequency is shown.*

We plan to compare the results of measurements carried out on the created experimental stand with the calculations of the electromagnetic field for microwave antennas, carried out using programs based on the method of moments. For example, the common programs NEC2 and MININEC3. It is also possible to use a more modern program for modeling MMANA-GAL - this is a program for calculating and analyzing antennas. Any antenna that can be thought of as an arbitrary set of thin wires. The computational basis of the program is MININEC3 (revised and modified for modern means) [32,33]. The possibility of using the electrodynamic modeling and design system HFSS (High Frequency Structure Simulator), IE3D, Microwave Office, Microwave Studio [34,35] will also be studied.

5. CONCLUSION

Let us formulate the main provisions of the ESM, which lead to the localization of the photon and the appearance of new fields in it. According to the ESM, a photon, falling into a medium, or into an external field, acquires mass. Simultaneously with this, its localization takes place. In empty Minkowski space, an infinite plane wave is associated with a photon, which contains components of both electric and magnetic fields. After a photon is exposed to an external influence, it localizes, acquires mass and, in addition to the fields and, it has new field components: a vector field and a scalar field. These 10 fields form a single object, they satisfy the extended system of Maxwell's equations and can transform into each other. Each of them interacts with the environment in its own way and, due to the presence of additional components, they can penetrate such barriers that are inaccessible to a conventional electromagnetic field. In this case, an important role is played by the fact that photons have mass, and in addition to electromagnetic interaction, there is also a gravitational interaction between photons and the external environment.

The appearance of a nonzero mass in a photon and a simultaneous change in the mass of other particles leads to a change in the picture of their interaction. The developed formalism of the ESM makes it possible to take these changes into account.

The developed setup for measuring the parameters of the microwave field when radiation hits waveguides of variable cross-section or an external field will make it possible to compare the experimental results with the predictions made within the framework of the ESM. The experimental data that we plan to obtain on the created installation will allow us to compare the predictions of the (1+4)D ESM with standard calculations made in the framework of classical calculations carried out in the (1+3)D Minkowski space.

REFERENCES

1. Vladimirov YuS. Prostranstvo-vremya: yavnye i skrytye razmernosti [Space-Time: Explicit and Hidden Dimensions]. Moscow, LIBROKOM Publ., 2010, 208 p.
2. Klein Felix. Über neuere englische Arbeiten zur Gesammelte matematische Abhandlungen. *Zeitschrift für Mathematik und Physik,* 1901, 46:375.
3. Einstein A. Die Grundlage der allgemeinen Relativitätstheorie. *Annalen der Physik*, 1916, 49:769-822.
4. Klein Oskar. Quantentheorie und fünfdimensionale Relativitätstheorie. *Zeitschrift für Physik,* 1926, 37(12):895-906; doi: 10.1007/BF01397481.

5. Kaluza Th. Zum Unitätsproblem in der Physik. *Sitzungsberichte der Koniglich Preussischen Akademie der Wissenschaften*, 1921:966-972.
6. Fock VA. Über die invariante Form der Wellen und der Bewegungsgleichungen für einen geladenen Massenpunkt. *Zeitschrift für Physik,* 1926, 39:226-232.
7. Mandel H. Über den Zusammenbang zwischen der Einsteinischen Theorie des Fern. Parallelismus und der Fünfdimensionalen Fieldtheorie. *Zeitschrift für Physik,* 1926, 39:136-145.
8. Einstein A, Bergmann P. Generalization of Kaluza's Theory of Electricity. *Ann. Math*., Ser. 2, 1938, 39:683-701.
9. Rumer YuB. *Issledovaniya po pyatimernoy optike* [Studies on five-dimensional optics]. Moscow, URSS Publ., 2010, 152 p.
10. Kraineva IA et.al. *Yuri Borisovich Rumer: Physics, XX century.* Novosibirsk, ARTA Publ., 2013, 592 p.; https://www.iis.nsk.su/files/b ook/file/rumer.pdf.
11. Frankfurt UI (ed.). *Einstein sbornik-1972*. Moscow, Nauka Publ., 1974, p. 15.
12. Rubakov VA. *Klassicheskie kalibrovochnye polya. Bozonnye teorii* [Classical gauge fields. Bosonic theories]. Moscow, URSS Publ., 1999, 336 p.
13. Landau LD. On the "radius" of elementary particles. *Soviet Physics JETP*, 1940, 10:718-722.
14. Tsipenyuk DYu, Andreev VA. Structure of Extended Space. *Bulletin of the Lebedev Physics Institute,* 2000, 6:23-34; arXiv:gr-qc/0106093, 2001; doi: 10.24412/0455-0595-2000-6-23-34.
15. Tsipenyuk DYu, Andreev VA. Elektrodinamika v rasshirennom prostranstve [Electrodynamics in extended space]. *Preprint IOFAN-1999*, No 9, 26 p.; doi: 10.24412/FhlTben9-y4 (in Russ.).
16. Andreev VA, Tsipenyuk DYu. Mechanism of the Dark Matter and Condensed Bubble Objects Formation in the Model of Extended Space. *Bulletin of the Lebedev Physics Institute*, 2004, 9:13-25; arXiv:physics/0506002.
17. Andreev VA, Tsipenyuk DYu. The Mass and Size of Photons in the 5-Dimensional Extended Space Model. *Journal of Modern Physics*, 2016, 7:1308-1315; doi: 10.4236/jmp.2016.711116.
18. Andreev VA, Tsipenyuk DYu. Electromagnetic field in the extended space 5-dimensional model, its localization and interaction with waveguide. *RENSIT: Radioelectronics. Nanosystems. Information technologies*, 2019, 11(2):93-102; doi: 10.17725/rensit.2019.11.093.
19. Wesson PS. *Space, Time, Matter: modern Kaluza-Klein theory*. Singapore, World Scientific Publ., 1999, 209. Available: https://archive.org/details/spacetimematterm0000wess.
20. Wesson PS. *Five-Dimensional Physics. Classical and Quantum Consequences of Kaluza-Klein Cosmology.* Singapore, World Scientific Publ., 2006, 232 p.
21. Wesson PS. *Int. J. Mod. Phys. D,* 2015, 24:1530001.
22. James Overduin, Paul Wesson. Kaluza-Klein Gravity. *Physics Reports,* 1997, 283:303-378.
23. Overduin J, Henry RC. *Physics and the Pythagorean Theorem*. arXiv:2005.10671v2; 2020.
24. Andreev VA, Tsipenyuk DYu. Properties of the 5-Dimensional Extended Space Model with Variable Photons Mass and Size. *New Insights into Physical Science*, 2020, 7(12); doi: 10.9734/bpi/nips/v7.
25. Tsipenyuk DYu. Non-isotropic objects in extended space. *Engineering Physics,*

2017, 6:20-26; http://infiz.tgizd.ru/en/arhiv/16434.

26. Tsipenyuk DYu, Belayev WB. Bubble structures in microphysical objects in 5-D extended space model. *RENSIT: Radioelectronics. Nanosystems. Information technologies*, 2019, 11(3):249-260; doi: 10.17725/rensit.2019.11.249.
27. Tsipenyuk DYu, Belayev WB. Dependence of universe deceleration parameter on cosmological constant: mechanism of vacuum pressure excitation by matter. *Romanian Reports in Physics*, 2020, 72:113; http://www.rrp.infim.ro/2020/AN72113.pdf.
28. Tsipenyuk DY, Belayev WB. Astrophysical and microcosm's applications of 2hv photon gravitational mass. *Indian J Phys,* 2021; doi: 10.1007/s12648-021-02104-2.
29. Voropinov AV, Tsipenyuk DYu, Shevchenko MA et.al. *Laser Phys. Lett.,* 2021, 18:075301; doi: 10.1088/1612-202X/ac063a.
30. Pshirkov M, Vasilyev V, Postnov K. Fermi bubbles around the M31 galaxy. *EPJ Web of Conferences*, 2016, 125:03010; doi: 10.1051/epjconf/201612503010.
31. Predehl P, Sunyaev RA, Becker W. Detection of large-scale X-ray bubbles in the Milky Way halo. *Nature*, 2020, 588:227-231; doi: 10.1038/s41586-020-2979-0.
32. Description MMANA-GAL program. *Web-cite MMANA-GAL, DL2KQ & DL1PBD*; http://gal-ana.de/basicmm/ru/.
33. Goncharenko IV. *Antenny KV i UKV. Part 1. Komp'yuternoe modelirovanie. MMANA*. Moscow, IP RadioSoft, Journal "Radio", 2004, 126 p. (in Russ.).
34. *High Frequency Structure Simulation*. Manuals, Agilent, 2000.
35. Sirkeli AI, Drach VE. Obzor SAPR modelirovaniya SVCH-ustrojstv. *Interaktivnaya nauka*, 2017, 1(11):139-141, doi: 10.21661/r-116149 (in Russ.).
36. Andreev VA, Tsipenyuk DYu. The 5-dimensional Extended space model. Localization of a plane wave and its interaction with a point charged particle. *Pramana-J. Phys, 2021*, in press; https://www.ias.ac.in/Journals/Pramana%E2%80%93 Journal of Physics/.