Scientific Research Publishing

Journal of Modern Physics, 2024, 15, 2422-2445
https://www.scirp.org/journal/jmp
ISSN Online: 2153-120X
ISSN Print: 2153-1196

On the Constancy of the Speed of Light in All Directions: A Proposed Experiment to Measure the One-Way Speed of Light

Konstantinos Patrinos

Physics Department, School of Applied Mathematical and Physical Sciences, National Technical University of Athens, Athens, Greece
Email: kpatr@central.ntua.gr

How to cite this paper: Patrinos, K. (2024) On the Constancy of the Speed of Light in All Directions: A Proposed Experiment to Measure the One-Way Speed of Light. *Journal of Modern Physics*, **15**, 2422-2445.
https://doi.org/10.4236/jmp.2024.1513100

Received: October 30, 2024
Accepted: December 23, 2024
Published: December 26, 2024

Abstract

The self-rotating motion of the earth makes it possible to test the constancy of the speed of light in all directions by measuring the one-way speed of light. The review of the implemented experiments to test the constancy of the speed of light, based on the theory of the absolute system of reference, yields some indications that the speed of light is affected by the self-rotational motion of the earth. The newest experiments based either on the methodology of standing waves or on the Compton edge effect cannot contribute in this field of research. A proposed experiment to measure the one-way speed of light, and the corresponding relativistic predictions, are discussed.

Keywords

Constancy of the Speed of Light, Ether-Drift Experiment, Michelson-Morley Experiment, One-Way Speed of Light, Anisotropies of the Speed of Light

1. Introduction

The purpose of the present study is to test the constancy of the speed of light in all directions. It should be mentioned, although it is widely known, that the history of this effort goes back a long time, more than a century ago. The experiments of the period 1881-1930, described in [1]-[15], were intended to confirm the view that light propagates at a constant speed in the ether and that the ether is the medium of propagation of electromagnetic radiation, based on the electromagnetic theory of light formulated by James Maxwell in 1861. The first attempt was made in 1881 by Albert Abraham Michelson, who devised a new method to achieve this goal, in which no appreciable displacement of the interference fringes was observed, so the experiment was repeated in 1887 by Albert Abraham Michelson and Edward Williams Morley, this time with greater precision.

All attempts to measure the speed of the earth relative to the ether were based on measurements of the displacement of the interference fringes proportional to the ratio v^2/c^2. This is mainly due to Fresnel's theory predicting a positive result of ether drift experiments only to second order in v/c, because Fresnel's dragging coefficient would cause a negative outcome of all optical experiments capable of measuring effects to first order in v/c.

Experimental experience has shown that the speed of light emitted by a light source placed in a rotating frame and observed from the inertial frame of the laboratory is equal to the speed of light emitted by a light source stationary in the laboratory. This experimental result is consistent with the basic principle of special relativity that the speed of light is constant in any inertial frame of reference regardless of the speed of the light source. However, there is no corresponding experimental experience to confirm the principles of relativity, regarding the constancy of the speed of light in all directions, according to the estimates of an observer who is on a self-rotating frame with a small angular velocity. Such a test of the constancy of the speed of light could be made with respect to a reference frame of a geographic location on the surface of the earth, given the angular velocity of the earth's self-rotation.

There are two conflicting views in the scientific community on the constancy of the speed of light. One view is that derived from direct measurements, using interferometers in which light propagates bidirectionally in each arm, *i.e.* in each arm there are two beams, an incident and a reflected, with opposite directions. The experimental results obtained from the use of interferometers, regarding the calculation of the upper limit on ether drift velocity, range from 1.5 km/s to 20 km/s. Also a simple re-analysis of the old results (1887) from the Michelson-Morley interferometer experiment has been done by Reginald T. Cahill and Kirsty Kitto, motivated by developments in a new information-theoretic modelling of reality, known as Process Physics, as reported in [16]. This analysis takes into account the refractive index of the optical medium, in this case, air, and the Lorentz-Fitzgerald contraction, so the calculated velocity with respect to a preferred frame of reference is multiplied by a factor of $1/\sqrt{n-1}$. However, the analysis by Reginald T. Cahill and Kirsty Kitto does not take into account the Fresnel drag coefficient. In the paper by J. Shamir and R. Fox, ref. [15], in which all these factors are taken into account and the optical material used has a refractive index of 1.49, the authors state the following

> "We make three assumptions here which are included in most of the rival theories to STR:
>
> 1) There exists a preferred frame of reference ("ether") with respect to which we can (in principle, at least) measure velocities and accelerations.
>
> 2) The Lorentz contraction of length is a real physical process.

3) The Fresnel drag coefficient is given exactly by

$$b = 1 - \frac{1}{n^2},$$

where n is the refractive index of a transparent material."

The experimental result is $v \le 6.64\ \text{km/s}$, and is commented by the authors as follows

> "The upper limit to the velocity of the earth through the ether (6.64 km/s) that was obtained in this experiment is much less than the orbital velocity of the earth around the sun (about 30 km/s). The experimental basis of special relativity is thus enhanced by this negative result."

The other view is based on the claim that the experimental errors resulting from the use of interferometers are large and also on the newer experimental methodologies of searching for anisotropies of the speed of light, namely, on the measurement of the frequency change during the change of orientation of a resonator, and on the experimental measurements derived from the Compton edge effect. The claim that the experimental errors resulting from the use of interferometers are large comes from the experimental experience of those involved with such experiments using Michelson's methodology and on this subject we cite a small part of the paper by Albert Abraham Michelson and Edward Morley, described in [2], where the authors state the following

> "In the first experiment, one of the principal difficulties encountered was that of revolving the apparatus without producing distortion; and another was its extreme sensitiveness to vibration. This was so great that it was impossible to see the interference fringes except at brief intervals when working in the city, even at two o'clock in the morning. Finally, as before remarked, the quantity to be observed, namely, a displacement of something less than a twentieth of the distance between the interference fringes may have been too small to be detected when masked by experimental errors."

The experimental result obtained following the methodology for measuring the frequency change of a resonator, with respect to the upper bound on ether drift velocity, during the period 1958-1964 is ~30 m/s. As of 2015, optical and microwave resonator experiments have improved this limit to $\Delta c/c \simeq 10^{-18}$. Also, in 2018, as the authors V. G. Gurzadyan and A. T. Margaryan stated in [17] for the case of Compton edge effect,

> "to probe the light speed invariance with respect to the velocity of the apparatus, namely, with respect to the beam electron reference system and the reference system of the calorimeter, we use the data of GRAAL's Laser Compton Backscattered (LCB) experiment."

and the result obtained from the data analysis is $\delta c/c = 7.1 \times 10^{-12}$.

However, based on the theory of the absolute reference system, the present study demonstrates that these newer experimental methodologies cannot contribute to this field of research.

In order to remove this contradiction between the experimental results derived from the use of interferometers on the one hand and the results derived from the newer experiments based on the methodology of standing wave and the measurements of GRAAL's Laser Compton Backscattered (LCB) experiment on the other hand, the most effective way is to test the constancy of the speed of light by directly measuring the one-way speed of light. The one-way measurement of light speed experiment proposed in the present study aims to test not only the constancy of the speed of light for a light source and an observer located in a rotating frame of reference, but also the effect on the speed of light due to a supposed preferred system of reference.

The Lorentz-Fitzgerald contraction, in its classical description, is mentioned in the literature mainly for rectilinear motions of bodies, with respect to inertial frames of reference. In a self-rotating frame of reference, difficulties arise in applying this classical view of the contraction of bodies due to their motion with respect to the ether.

A relevant example is worth mentioning. Imagine a circular homogeneous metal disk, rotating around an axis of rotation perpendicular to its plane, passing through its center of mass. You will realize that you cannot apply this Lorentz-Fitzgerald contraction theory unless you accept that the radius of the disk also decreases and furthermore that it is no longer a homogeneous body since its density will depend on the radial distance.

Let us denote by ρ_0 the density of the circular disk when it is stationary. The density of the rotating disk will be a function of $\rho(r)$, that is, it will depend on the radial distance r. A stationary annular differential mass of the circular disk is expressed by the relation $\mathrm{d}M = 2\pi\rho_0 r\mathrm{d}r$. The radius of the annular differential mass, when the disk rotates with angular velocity ω decreases by a factor $\gamma(r) = \left(1-\omega^2 r^2/c^2\right)^{-1/2}$, so the annular differential mass takes the form $\mathrm{d}M = 2\pi\rho(r)\left(r/\gamma(r)\right)\mathrm{d}\left(r/\gamma(r)\right)$. Finally, for the density $\rho(r)$ we obtain an expression of the form $\rho(r) = \rho_0\Big/\left(1-2\omega^2 r^2/c^2\right)$.

The cause of radius reduction of the circular disk cannot be attributed to the Lorentz-Fitzgerald contraction, since the vector velocity, due to the rotational motion, of each elementary mass $\mathrm{d}m = \rho_0 r\mathrm{d}r\mathrm{d}\varphi = \rho(r)\left(r/\gamma(r)\right)\mathrm{d}\left(r/\gamma(r)\right)\mathrm{d}\varphi$ of this disk is perpendicular to the radial straight line segment of length $r/\gamma(r)$. In summary, the classical concept of Galilean kinematics, when studying phenomena that evolve in a compact rotating frame of reference, cannot include the Lorentz-Fitzgerald contraction.

However, these results do not appear in the case of a rectilinear and uniformly accelerated body, in which at a given moment in time it can be considered that the body in question constitutes a momentarily physical inertial frame of reference, since at that moment in time all the elementary masses of this body are in the same kinetic state, with the same instantaneous vector velocity.

According to the theory of the absolute system of reference, the main part of which is formulated in [18]-[22], when the light source and the observer are in a momentarily inertial reference system, the measured phase velocity of the light beam propagating in a vacuum is the known from the literature. Also, according to this theory, in the case where the physical frame of reference in which the light source and the observer are located is rotating, the phase velocity of the light beam is obtained based on the rules of Galilean kinematics. Based on the theory of the absolute system of reference, we will examine the topics of the following sections.

There is today a widespread concern in the scientific community regarding the constancy of the speed of light in all directions, so such a test is necessary. We would thus test the principle of the theory of relativity, on the constancy of the speed of light, which in this case is expressed by the formulation that the measurement of the speed of light is nearly independent of the self-rotational motion of the Earth.

2. Review of the Searching for Anisotropies of the Speed of Light Behaving as the First and Third of the Legendre Polynomials

The analysis of the shifts of the fringe position is made in [23] for anisotropies that behave as

$$\frac{1}{c(\phi)} = \frac{1}{c_0}\left[1 + b_1 P_1(\cos\phi) + b_3 P_3(\cos\phi)\right],$$

where $P_1(\cos\phi) = \cos\phi$, $P_3(\cos\phi) = \frac{1}{2}\left(5\cos^3\phi - 3\cos\phi\right)$, and $c(\phi)$ is the vacuum phase velocity of light in a direction that makes an angle ϕ with a presumed single preferred direction in space.

Dr. Arthur I. Miller pointed out to the authors a crucial Lorentz theorem, namely that no interferometer can detect an ether wind in first order in the earth's velocity. [H. A. Lorentz, Theory of Electrons (Teubner, Leipzig, 1909)]. After that, in [24], the authors retracted the claim that their experiment is able to detect an aether wind (if the ether effect can be described by a Fresnel drag coefficient).

However, by correctly applying the laws of Galilean kinematics to this subject under consideration, based on the experimental result, we can determine the order of magnitude of the velocity with respect to the earth's orbital reference system.

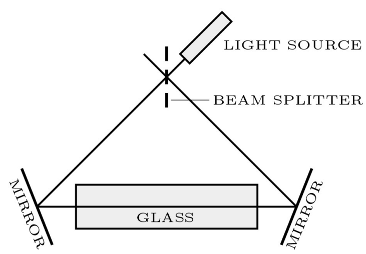

Figure 1. A diagram of the interferometer used.

Figure 1 shows the operating principle of the interferometer used. Light entering the interferometer from the light source is split by the beam splitter into two beams which travel around the interferometer in opposite directions. These two beams recombine on the beam splitter, and a fringe pattern is formed by the lens.

When the glass is present, both beams pass through the glass.

The optical path of each of the two beams, which travel in opposite directions, is the isosceles triangle of **Figure 1**, with interior angles 45˚, 90˚, 45˚. The length of the two equal arms is $\ell = 12\ \text{cm}$. The glass is 12 cm long and is made of crown glass with a refractive index of 1.5. The line segment passing through the glass has a length equal to $2d + \ell = \sqrt{2}\ell \simeq 17\ \text{cm}$.

According to Galilean kinematics, a path of vector length $\boldsymbol{\ell}$ of an optical beam in an earth laboratory moving with vector velocity $\boldsymbol{v}$ with respect to the earth's orbital reference system is defined by the equation

$$\boldsymbol{\ell} + \boldsymbol{v}t = \boldsymbol{c}t$$

where t is the time required for the wavefront to travel the vector length $\boldsymbol{\ell}$, and $\boldsymbol{c}$ is the vector phase velocity of light with respect to the earth's orbital reference system. We denote by $\boldsymbol{v}_\perp$ and $\boldsymbol{c}_\perp$ the components of $\boldsymbol{v}$ and $\boldsymbol{c}$ which are perpendicular to the plane of the interferometer, and with $\boldsymbol{v}_\parallel$, $\boldsymbol{c}_\parallel$ the parallels to it, so we get the equations

$$\boldsymbol{v}_\perp = \boldsymbol{c}_\perp \tag{1}$$

$$\boldsymbol{\ell} + \boldsymbol{v}_\parallel t = \boldsymbol{c}_\parallel t \tag{2}$$

The time t is given by equation

$$t = \frac{\ell}{\left|\boldsymbol{c}_\parallel - \boldsymbol{v}_\parallel\right|} = \frac{\ell / c_\parallel}{\sqrt{1 + \left(v_\parallel / c_\parallel\right)^2 - 2\left(v_\parallel / c_\parallel\right)\cos\varphi}} \tag{3}$$

where φ is the angle between the vectors $\boldsymbol{v}_\parallel$ and $\boldsymbol{c}_\parallel$. The dot product of the vector $\boldsymbol{v}_\parallel$ with both sides of Equation (2) yields the equality

$$\boldsymbol{\ell} \cdot \boldsymbol{v}_\parallel + v_\parallel^2 t = \boldsymbol{c}_\parallel \cdot \boldsymbol{v}_\parallel t$$

so

$$\ell v_\parallel \cos\theta + v_\parallel^2 t = c_\parallel v_\parallel t \cos\varphi$$

where θ is the angle between the vectors $\boldsymbol{\ell}$ and $\boldsymbol{v}_\parallel$, so substituting $\cos\varphi$ into the Equation (3) we get the following quadratic equation

$$\left(1 - \frac{v_\parallel^2}{c_\parallel^2}\right)t^2 - \frac{2 v_\parallel \ell \cos\theta}{c_\parallel^2} t - \frac{\ell^2}{c_\parallel^2} = 0 \tag{4}$$

and the solution is

$$t(\theta) = \frac{\ell}{c_\parallel} \frac{\left(v_\parallel / c_\parallel\right)\cos\theta + \sqrt{1 - \left(v_\parallel^2 / c_\parallel^2\right)\sin^2\theta}}{1 - v_\parallel^2 / c_\parallel^2} \tag{5}$$

Substituting $v_\parallel$ and $c_\parallel$ into Equation (5) we get the following generalized form

$$t(\theta) = \frac{\ell}{\sqrt{c^2 - v_\perp^2}} \frac{\left(\sqrt{v^2 - v_\perp^2} / \sqrt{c^2 - v_\perp^2}\right)\cos\theta + \sqrt{1 - \left(\left(v^2 - v_\perp^2\right)/\left(c^2 - v_\perp^2\right)\right)\sin^2\theta}}{1 - \left(v^2 - v_\perp^2\right)/\left(c^2 - v_\perp^2\right)} \tag{6}$$

If the vector velocity $\boldsymbol{v}$ is perpendicular to the plane of the interferometer, then the Equation (6) yields the following equality

$$t = \frac{\ell}{\sqrt{c^2 - v^2}} = \frac{\ell/c}{\sqrt{1 - v^2/c^2}} \tag{7}$$

in which the time t is independent of the angle θ, so no displacement of the interference fringe pattern is observed during the rotation of the interferometer. The maximum displacement during interferometer rotation is observed when the vector velocity $\boldsymbol{v}$ is parallel to the interferometer plane, so the Equation (6) yields the following equation

$$t(\theta) = \frac{\ell}{c} \frac{(v/c)\cos\theta + \sqrt{1 - (v^2/c^2)\sin^2\theta}}{1 - v^2/c^2} \tag{8}$$

In order to identify any effect of the earth's self-rotating motion on the studied experiment, at least the order of magnitude of the velocity v, which obtained from the measured displacement of the interference fringe pattern, must be calculated. Because the vector velocity of the laboratory due to the self-rotating motion of the earth is parallel to the plane of the interferometer, we have to calculate the displacement of the interference fringe pattern using Equation (8).

Since in this case $\boldsymbol{v}_{\parallel} = \boldsymbol{v}$, and $\boldsymbol{c}_{n_{\parallel}} = \boldsymbol{c}_n$, inside the glass Equation (2) takes the form

$$\boldsymbol{\ell}_n + \boldsymbol{v} t_n = (\boldsymbol{c}/n + f\boldsymbol{v}) t_n \tag{9}$$

where f is the Fresnel drag coefficient, n is the refractive index of glass, and $\ell_n = \ell$. Therefore, defining that θ is the angle between the horizontal arm and the vector velocity $\boldsymbol{v}$, we obtain

$$t_n(\theta) = \frac{\ell}{c/n} \frac{(v\cos\theta)/(nc) + \sqrt{1 - (v^2\sin^2\theta)/(n^2c^2)}}{1 - v^2/(n^2c^2)} \tag{10}$$

Also for the two small parts of the horizontal arm, of length $d = (1/2)\times(17\text{ cm} - 12\text{ cm}) = 2.5\text{ cm}$,

$$t_d(\theta) = \frac{d}{c} \frac{(v/c)\cos\theta + \sqrt{1 - (v^2/c^2)\sin^2\theta}}{1 - v^2/c^2} \tag{11}$$

In each arm of the triangular interferometer, due to the opposite directions of the two beams, $\sin\theta_i$ and $\cos\theta_i, i = 1,2,3$, of one direction are opposite to those of the other direction. Based on the geometry of **Figure 1**, the arrival time difference of the wavefronts of these two beams is

$$\begin{aligned} \Delta t(\theta) &= \left[4d\cos\theta + 2\ell\cos(\theta + 3\pi/4) + 2\ell\cos(\theta + 5\pi/4)\right]\frac{v/c^2}{1 - v^2/c^2} \\ &\quad + 2\ell\cos\theta \frac{v/c^2}{1 - v^2/(n^2c^2)} \\ &= -2\ell\cos\theta \frac{v/c^2}{1 - v^2/c^2} + 2\ell\cos\theta \frac{v/c^2}{1 - v^2/(n^2c^2)} \\ &\simeq -2\ell f \frac{v^3}{c^4}\cos\theta \end{aligned} \tag{12}$$

Therefore, the maximum time difference which corresponds to the maximum displacement of the interference fringe pattern is

$$\Delta t_{max} = 4\ell f \frac{v^3}{c^4} \tag{13}$$

and the maximum displacement of the interference fringe pattern is

$$\delta = 4 f \frac{\ell}{\lambda} \frac{v^3}{c^3} \tag{14}$$

where λ is the wavelength. Unfortunately, there are no data, the existence of which would allow a reanalysis, but we can use the values of b_1 and b_3 (Equation (9), p. 3324, in [23]), considering very small the angles ϕ_i, so the Legendre polynomials $P_1(\cos\phi_i)$ and $P_3(\cos\phi_i)$ are approximately equal to unity. Also the scale factor F can be considered to be of the order of magnitude of unity, so the experimental value of δ is $\delta_{exp} \simeq 3(b_1 + b_3)n\ell = 1.3\times10^{-11}$. Substituting this experimental value of δ into Equation (14), for $\lambda = 5\times10^{-7}$ m, yields a value for the velocity v of approximately 0.87 km/s, which is of the order of magnitude of the earth's equatorial speed of 0.4651 km/sec.

3. A Review of Experiments Implemented Using New Technologies

On January 9, 1954, a proposal by H. Littman Furth for a new ether drift experiment published. This proposal, described in [25], had as its main objective an experiment for testing whether second-order effects predicted by classical (non-relativistic) optics as results of an "aether drift" could be detected with standing electromagnetic waves.

The theoretical part of this proposal in brief is that in the absence of an ether drift one has $\nu = nc/(2\ell)$, where ν is the resonance frequency, ℓ is the length of resonator tube, n is the integral multiple of the periodic time T of the oscillator, and c is the phase velocity of electromagnetic wave. But if the tube points in the direction of translational movement (velocity v) of the earth with respect to the ether, the condition for resonance is $nT_1 = 2\ell c/(c^2 - v^2)$, and the resonance frequency will be:

$$\nu_1 = \frac{n(c^2 - v^2)}{2\ell c} = \nu\left(1 - \frac{v^2}{c^2}\right) \tag{15}$$

and if the tube is at right angles to the direction of v the resonance frequency is:

$$\nu_2 = \frac{n}{2\ell}\sqrt{c^2 - v^2} = \nu\sqrt{1 - \frac{v^2}{c^2}} \tag{16}$$

A few months later, on April 17, 1954, L. Essen describes with positive comments the previous article of H. Littman Furth in a new article in the same scientific journal, as seen in [26]. In the following year, on May 7, 1955, L. Essen carried out the first experiment following this new methodology. As he states in [27] "A cylindrical cavity resonator of length 16.866 cm. and diameter 8.075 cm. was used to control the frequency of an oscillator at approximately 9200 Mc./s. The resonator was mounted with its axis horizontal and was rotated continuously in a horizontal plane at a rate of about one turn per minute, the frequency of the oscillator being measured by comparison with a quartz standard at intervals of 45˚ during the rotation."

Following this experiment, a series of experiments were carried out using this methodology, some of which date from 2003 to 2015. Earth's direction and velocity (ca. 368 km/s (229 mi/s)) relative to the CMB (cosmic microwave background) rest frame are ordinarily used as references in these searches for anisotropies. The experimental results during the period 2003-2004, as stated in [28]-[31] are $\Delta c/c \leq 10^{-15}$, during the period 2005-2007, as stated in [32]-[36] are $\Delta c/c \leq 10^{-16}$, in 2009, as stated in [37] [38] are $\Delta c/c \leq 10^{-17}$ and in 2015 as stated in [39] the experimental result is $\Delta c/c \simeq 9.2 \pm 10.7 \times 10^{-19}$ (95% confidence interval). However, as we will demonstrate below, these experimental results are in agreement with the theory of the absolute reference system, according to which the measurement of the speed of light by an observer who is stationary in a rotating reference system is that obtained from Galilean kinematics.

According to a related study in [40] (7.4. STANDING WAVES), the Cartesian components of the electric vector $\boldsymbol{E}^{(i)}$ of the incident wave, for incidence perpendicular to the xy plane *i.e.* along the z axis, are obtained by the equations

$$E_x^{(i)} = -A_{\parallel} \mathrm{e}^{-\imath\tau_i}, \ E_y^{(i)} = A_{\perp} \mathrm{e}^{-\imath\tau_i}, \ E_z^{(i)} = 0 \tag{17}$$

where $A_{\parallel}$, $A_{\perp}$ are the amplitudes of the components of $\boldsymbol{E}^{(i)}$ parallel and perpendicular respectively to the plane of incidence,

$$\tau_i = \omega\left(t + \frac{z}{u}\right) \tag{18}$$

$\omega = 2\pi\nu$, and u is the velocity of propagation. The Cartesian components of the electric vector $\boldsymbol{E}^{(r)}$ of the reflected wave are

$$E_x^{(r)} = R_{\parallel} \mathrm{e}^{-\imath\tau_r}, \ E_y^{(r)} = R_{\perp} \mathrm{e}^{-\imath\tau_r}, \ E_z^{(r)} = 0 \tag{19}$$

where

$$\tau_r = \omega\left(t - \frac{z}{u}\right) \tag{20}$$

We suppose that in this case the reflectivity may be taken as unity, so, by the Fresnel Formulae we obtain $R_{\parallel} = A_{\parallel}$ and $R_{\perp} = -A_{\perp}$, and if A_x, A_y are the amplitude components of the electric vector, we may write $A_{\parallel} = -A_x$, $A_{\perp} = A_y$. The x-component of the electric vector of the total field is

$$\begin{aligned} E_x &= E_x^{(i)} + E_x^{(r)} \\ &= -2A_x \sin\left(\frac{\tau_i - \tau_r}{2}\right) \mathrm{e}^{-\imath((\tau_i+\tau_r)/2-\pi/2)} \end{aligned} \tag{21}$$

Similarly,

$$\begin{aligned} E_y &= E_y^{(i)} + E_y^{(r)} \\ &= -2A_y \sin\left(\frac{\tau_i - \tau_r}{2}\right) \mathrm{e}^{-\imath((\tau_i+\tau_r)/2-\pi/2)} \end{aligned} \tag{22}$$

and

$$E_z = 0 \tag{23}$$

Let v be the velocity of the laboratory relative to the earth's orbital reference system S in the z-direction. In the reference system S' of the laboratory, we assume that one end-plate of the resonator tube is on the side of the microwave generator at position $(x', z') = (0, \ell)$, while the other end-plate is at position $(x', z') = (0, 0)$, where $x' = x$ and $z' = z - vt$. For refractive index equal to unity the phase velocity is $u = c$. According to relevant study in [41] the Doppler effect is expressed by the relation $\omega = \omega' - \boldsymbol{k}' \cdot \boldsymbol{v}'$, where $\boldsymbol{v}' = -\boldsymbol{v}$, $\boldsymbol{k}' = \boldsymbol{k}$, and equivalently $\omega' = \omega - \boldsymbol{k} \cdot \boldsymbol{v}$. The phase velocity transformation is $\boldsymbol{u}' = \boldsymbol{u} - (\boldsymbol{v} \cdot \hat{\boldsymbol{u}})\hat{\boldsymbol{u}}$, where $\hat{\boldsymbol{u}}$ is a unit vector in the direction of $\boldsymbol{u}$. In S' for the incident wave we obtain $u_i' = c + v$ and $\omega_i' = \omega_i (c + v)/c$, while for the reflected wave $u_r' = c - v$ and $\omega_r' = \omega_r (c - v)/c$, where $\omega_i = \omega_r = \omega$, indicating that the observer of S' receives frequencies like the derived from phase velocities of the incident and reflected electromagnetic wave in a resonator tube stationary with respect to the S reference system. This result is consistent with our initial assumption that the absolute value of the phase velocity is constant at S, equal to c, despite the microwave generator and end-plates being stationary with respect to the self-rotating system S'.

According to Equations (18), (20), (21), the components of the electric vector are

$$E_x = -2A_x \sin\left(\frac{\omega z}{c}\right) \mathrm{e}^{-\imath(\omega t - \pi/2)} \tag{24}$$

$$E_y = -2A_y \sin\left(\frac{\omega z}{c}\right) \mathrm{e}^{-\imath(\omega t - \pi/2)} \tag{25}$$

$$E_x = 0 \tag{26}$$

and in a strictly analogous manner, using the equation $\boldsymbol{H} = n\hat{\boldsymbol{s}} \times \boldsymbol{E}$, where $\boldsymbol{H}$ is the magnetic vector, n is the refractive index of medium, and $\hat{\boldsymbol{s}}$ denoting a unit vector in the direction of propagation, we obtain the following expressions for the components of the magnetic vector of the total field:

$$H_x = 2A_y \cos\left(\frac{\omega z}{c}\right) \mathrm{e}^{-\imath\omega t} \tag{27}$$

$$H_y = -2A_x \cos\left(\frac{\omega z}{c}\right) \mathrm{e}^{-\imath\omega t} \tag{28}$$

$$H_z = 0 \tag{29}$$

so standing waves are created in the resonator tube with resonance frequency ν.

If the tube is at right angles to the direction of v, *i.e.* the tube is perpendicular to x-direction, we assume that one end-plate of the resonator tube is on the side of the microwave generator at position $(x', z') = (0, \ell)$, while the other end-plate is at position $(x', z') = (0, 0)$ of reference system S', where $x' = x - vt$ and $z' = z$. In the S reference system the incidence must be perpendicular to the end-plate to generate standing waves, so at S' the phase velocity is $\boldsymbol{u}' = \boldsymbol{u} - (\boldsymbol{v} \cdot \hat{\boldsymbol{u}})\hat{\boldsymbol{u}} = \boldsymbol{u}$. The Doppler effect in this case is expressed by the relation $\omega' = \omega - \boldsymbol{k} \cdot \boldsymbol{v} = \omega$, *i.e.*, there is not a Doppler effect. The components of the electric and magnetic vector are given by the Equations (24) to (29).

We observe that following the experimental methodology of standing waves the theoretical results based on Galilean kinematics are the same as the relativistic ones. This methodology differs from that of Michelson. Also the results of the Kennedy-Thorndike experiment, stated in [42], and of the experimental data analysis based on the methodology of testing the constancy of the speed of light from measurements derived from the Compton edge effect, stated in [17], are in agreement with the theory of the absolute system of reference.

4. Test of the Constancy of the Speed of Light in All Directions on the Surface of the Earth

The vector velocity $\boldsymbol{v}$ due to the self-rotating motion of the Earth has a direction towards the east, so the experimental setup should have the corresponding orientation, determined according to the cardinal points on the horizon. In this case, the vector velocity $\boldsymbol{v}$ is parallel to the plane of the interferometer. One such experiment, which actually has a somewhat satisfactory experimental resolution, is that of Illingworth which we will study.

We will review the experimental work of Illingworth in 1927, described in [9], focusing our observations on the points of interest. This experimental research is a repetition of the Michelson-Morley experiment according to a new methodology that Dr. R. J. Kennedy, National Research Fellow at the California Institute of Technology, had applied a year earlier.

The total time between departure and return of the wavefront in each arm of the Michelson-Morley interferometer, based on Equation (8) is

$$t_{arm}(\theta) = t(\theta) + t(\theta + \pi) = \frac{(2\ell/c)\sqrt{1-\beta^2 \sin^2\theta}}{1-\beta^2} \tag{30}$$

where $\beta = v/c$.

According to Equation (30), it follows that if the vector velocity $\boldsymbol{v}$ is parallel to the vector length ℓ, then $t = (2\ell/c)/(1-\beta^2)$, while if the vector velocity $\boldsymbol{v}$ is perpendicular to the vector length ℓ we get $t = (2\ell/c)/\sqrt{1-\beta^2}$, as expected.

In an experimental setup Michelson-Morley, which is located inside the Earth laboratory, the return time difference of the wave fronts of the two perpendicular light beams at the point of observation, according to Equation (30), will be equal to $t_{arm}(\theta) - t_{arm}(\theta + \pi/2)$. If the experimental setup is rotated by 90˚ this time difference will have changed by Δt, so

$$\begin{aligned} \Delta t &= \left(t_{arm}(\theta) - t_{arm}(\theta + \pi/2)\right) - \left(t_{arm}(\theta + \pi/2) - t_{arm}(\theta + \pi)\right) \\ &= 2\left(t_{arm}(\theta) - t_{arm}(\theta + \pi/2)\right) \end{aligned} \tag{31}$$

therefore, the displacement of the interference fringe pattern is obtained from the relation

$$\delta = \frac{2c}{\lambda}\left(t_{arm}(\theta) - t_{arm}(\theta + \pi/2)\right) \tag{32}$$

In his paper, Illingworth states "The purpose of the present investigation is to make a study of the sensitivity obtainable by Kennedy's method and to make further investigations as to the presence of an ether drift using Kennedy's apparatus". Based on the initial finding that a small weight of 14 g caused a displacement equal to 1/500 of the fringe, starting with the field of view exactly balanced, it was noted each time how many such small weights were removed or added to bring it back into balance after from rotation 90˚. The measurement procedure and the way of calculating the average displacement, due to orientation, in terms of weight are mentioned in Tab. 2 in [9].

In **Table 1**, the measurements of the average displacements, due to orientation, in terms of weight, obtained by the process in which, as Illingworth states, "the observer stopped the apparatus and took a reading when he was looking north, west, south, east and north, the readings being taken every 30 seconds". This choice was made under the assumption of a displacement of the interference fringe pattern, due to the eastward motion of the earth laboratory, so these orientations give the maximum possible displacements.

Table 1. Readings that were taken at 5 A.M., 11 A.M., 5 P.M., and 11 P.M. July 9, with the procedure in which "the observer stopped the apparatus and took a reading when he was looking north, west, south, east and north". Data are from Tab. 3 in [9].

5 *A.M.*	11 *A.M.*	5 *P.M.*	11 *P.M.*
N,S-E,W	*N,S-E,W*	*N,S-E,W*	*N,S-E,W*
0.12	0.35	0.12	−0.05
0.57	−0.21	−0.28	0.09
0.00	−0.03	−0.72	−0.63
0.10	−0.15	−0.08	−0.22
0.32	−0.11	0.09	0.00
−0.01	0.24	0.15	−0.20
	−0.07	0.15	
	−0.03	0.18	
	−0.03	0.03	
	0.00	−0.05	

According to this hypothesis, if in the initial placement, one of the two vertical arms of the interferometer is parallel to the east-west direction, based on (32), the displacement of the interference fringe pattern in a rotation of the interferometer by 90˚ is

$$\delta = \frac{2c}{\lambda}\left(t_{arm}(0) - t_{arm}(\pi/2)\right) \simeq \frac{2(v/c)^2}{\lambda/\ell}$$

so, as Illingworth states in [9], in this case, the velocity, which by the way is referred to as "ether velocity", for this experiment yields a velocity value

$$v = 112\sqrt{\delta}\ \text{km/s} \tag{33}$$

The average value of the measurements listed in Table 1 is

$$\overline{w} = \frac{1}{32}\sum_{i=1}^{32} w_i = -0.0113$$

where w_i is each measurement, so, since the experimental value of the displacement of the interference fringe pattern is $\delta = \overline{w}/500$, the absolute value of the velocity, according to relation (33), is

$$v = 112\sqrt{\left|\overline{w}/500\right|} = 0.53\ \text{km/s} \tag{34}$$

If the procedure is followed in which, as described by Illingworth, "the directions were changed to north-east, north-west, south-west, south-east and north-east", then the two perpendicular arms form angles 45˚ with the vector velocity $\boldsymbol{v}$, so according to the relation (32), the displacement in a rotation of the interferometer by 90˚ is

$$\delta = \frac{2c}{\lambda}\left(t_{arm}\left(\pi/4\right) - t_{arm}\left(3\pi/4\right)\right) = 0$$

In this case the displacement is zero, so this procedure is not suitable for determining the requested speed. In Table 2, which records only the average displacement in terms of weights, there appears to be a tendency toward zero in the columns headed NW, SE-SW, NE.

Table 2. Average displacement in terms of weights. Data taken from Tab. 3 in [9].

5 *A.M.*		11 *A.M.*		5 *P.M.*		11 *P.M.*	
N,S-E,W	*NW,SE-SW,NE*	*N,S-E,W*	*NW,SE-SW,NE*	*N,S-E,W*	*NW,SE-SW,NE*	*N,S-E,W*	*NW,SE-SW,NE*
+0.18	−0.08	−0.004	−0.001	−0.041	−0.025	−0.17	+0.025

5. Predictions of General Theory of Relativity on Light Speed Measuring in a Rotating Frame

In a rotating system of reference the expression for $\mathrm{d}s^2$, in cylindrical coordinates r, ϕ, z, as stated in [43] (§89. Rotation, p. 254), is given by the relation:

$$\mathrm{d}s^2 = \left(c^2 - \Omega^2 r^2\right)\mathrm{d}t^2 - 2\Omega r^2 \mathrm{d}\phi\mathrm{d}t - \mathrm{d}z^2 - r^2\mathrm{d}\phi^2 - \mathrm{d}r^2 \tag{35}$$

where Ω is the angular velocity of rotation. Denoting by x^0, x^1, x^2, x^3, respectively, the coordinates ct, r, ϕ, z, we have for the nonzero components of the metric tensor the expressions

$$g_{00} = 1 - \Omega^2 r^2/c^2,\ \ g_{11} = -1,\ \ g_{22} = -r^2,\ \ g_{33} = -1,\ \ g_{02} = -\Omega r^2/c. \tag{36}$$

Also as stated in [43], "As in every stationary field, clocks on the rotating body cannot be uniquely synchronized at all points. Proceeding with the synchronization along any closed curve, we find, upon returning to the starting point, a time differing from the initial value by an amount [see (88.5)]…", so the time difference, due to lack of uniquely synchronization, along a path AB is equal to

$$\Delta t = -\frac{1}{c}\int_A^B \frac{g_{0\alpha}}{g_{00}}\mathrm{d}x^\alpha = \frac{1}{c^2}\int_A^B \frac{\Omega r^2 \mathrm{d}\phi}{1-\Omega^2 r^2/c^2}$$

or, assuming that $\Omega r/c \ll 1$ (*i.e.* that the velocity of rotation is small compared with the velocity of light),

$$\Delta t = \frac{2\Omega}{c^2}\int_A^B \frac{r^2}{2}\mathrm{d}\phi \tag{37}$$

As the integral $\int_A^B \frac{r^2}{2}\mathrm{d}\phi$ is independent of z, it is defined as a plane surface, S, at any plane perpendicular to the axis of rotation, z, according to the equation $S = \frac{1}{2}\int_{A'}^{B'} r^2\mathrm{d}\phi$, defining by $A'B'$ the projection of the path AB on this plane, so, we obtain the relation

$$\Delta t = \pm\frac{2\Omega}{c^2}S \tag{38}$$

and the sign + or - holding according as we traverse the path $A'B'$ in, or opposite to, the direction of rotation.

Let us assume that a ray of light propagates along a straight-line path, which is the path AB. As stated in [43], the velocity of light, by definition, is always equal to c, if the times are synchronized along the given path and if at each point we use the proper time. Since the difference between proper and world time is of the order v^2/c^2, then in calculating the required time interval t to terms of order v/c this difference can be neglected. Therefore, we have

$$t = \frac{\ell}{c} \pm \frac{2\Omega}{c^2}S \tag{39}$$

where ℓ is the length of the path AB. From this, it follows that the calculated speed of light, ℓ/t, is equal to

$$c \pm 2\Omega\frac{S}{\ell} \tag{40}$$

However, the phase velocity of the light ray is not given by the expression (40). Let us assume that at points A and B there are two observers who record the time of emission of an electromagnetic signal and the time of its reception respectively. In order to calculate the phase velocity of propagation of the electromagnetic signal based on the length and time measurements, the observer located at point B must take into account the time difference due to the inability to synchronize the clocks in a rotating system and correct the indication of his clock so that the term $\pm\left(2\Omega/c^2\right)S$ in the relation (39) to be canceled. Then the phase velocity will be given by the relation

$$c = \frac{\ell}{t_p} \tag{41}$$

where t_p is the calculated propagation time of the signal from point A to point B, after the correction of the time of clock at point B.

A direct way to calculate the phase velocity of the electromagnetic signal, stated in [44], is that of transforming the expression of a plane electromagnetic wave from the inertial reference system to the rotating one. From this calculation, it follows that the phase velocity of the electromagnetic signal in the rotating reference frame is equal to that estimated in the inertial reference frame, c.

Let us consider the case where a light beam is emitted by a source that is stationary with respect to the surface of the earth at a geographical location and propagates parallel to the earth's equatorial plane, along the aforementioned straight-line path AB of length ℓ. We denote by Ω the angular velocity of the earth. Also we denote by $\boldsymbol{v}$ the vector velocity of the light source due to the rotational motion of the earth and by R the distance of point A from the axis of rotation of the earth, as shown in **Figure 2**.

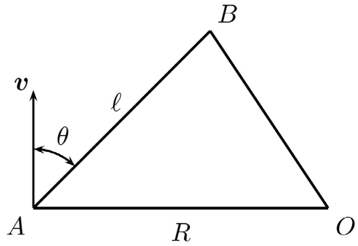

Figure 2. The light beam is directed from point A to point B. We denote by $\boldsymbol{v}$ the vector velocity of the light source due to the rotational motion and by R the distance of point A from the axis of rotation of the earth. We also denote by ℓ the length of the path AB and by θ the angle between the vector velocity of the light source and the direction of the light beam.

In this case the velocity vector, $\boldsymbol{v}$, and the straight line segments OA and AB lie in a plane which is parallel to the equatorial plane, that is, they are perpendicular to the axis of rotation of the earth. Therefore the aforementioned surface S will be equal to the area of the triangle OAB and will be given by the relation $S=\frac{1}{2}R\ell\cos\theta$, where θ is the angle between the vector velocity of the light source and the direction of the light beam. Therefore, the relation (39), substituting the Ω by v/R, takes the form

$$t(\theta)=\frac{\ell}{c}+\frac{v\ell\cos\theta}{c^2} \quad (42)$$

If the light beam propagates eastward, then $\cos\theta=1$, so we obtain the equation

$$t(0)=\frac{\ell}{c}\left(1+\frac{v}{c}\right) \quad (43)$$

whereas, if it propagates westward

$$t(\pi)=\frac{\ell}{c}\left(1-\frac{v}{c}\right) \quad (44)$$

However, as mentioned above, the times obtained from Equations (43), (44), are not those predicted by the phase velocity of the light beam. The phase velocity of the light beam is equal to that estimated in the inertial reference frame and the corresponding time is given by the relation

$$t_p = \frac{\ell}{c} \tag{45}$$

Equation (8), which is derived based on Galilean kinematics, especially in the case where beam propagates eastward or westward, is the corresponding of Equation (42). When the propagation direction of the light beam is towards the east, according to the relation (8) the required time interval for the propagation of the light beam from point A to point B, is:

$$t_e = \frac{\ell}{c-v} \simeq \frac{\ell}{c}\left(1+\frac{v}{c}\right) \tag{46}$$

and when it propagates west it is:

$$t_w = \frac{\ell}{c+v} \simeq \frac{\ell}{c}\left(1-\frac{v}{c}\right) \tag{47}$$

Despite the fact that the times obtained from the relations (43), (44), agree with those resulting from the relations (46), (47), respectively, the phase velocities of the light beam obtained from the relations (46), (47), *i.e.* based on Galilean kinematics, differ from the relativistic one which is constant and equal to that of the inertial reference frame.

If the light beam propagates northward or southward, or, in the general case, if the path AB of the beam and the earth's axis of rotation are in the same plane, then, since the angle ϕ remains constant, from the relation (37) it follows that the time difference Δt is zero, so $t = \ell/c$. According to Galilean kinematics, that is, according to the relation (8) the required time interval, $t(\theta)$, for the propagation of the light beam to the north or south, is:

$$t_{n,s} = \frac{\ell}{\sqrt{c^2 - v^2}} \tag{48}$$

thus, in this case, too, the Galilean phase velocity of the beam does not agree with the relativistic one.

In the case in which the path of the light beam is a closed contour, the surface S is the projected area of the contour on a plane perpendicular to the axis of rotation. Therefore, the two-way speed of the light, measured by an earthly observer will be equal to c, that is, it will have the same value as the estimated in an inertial reference frame. This means that in a rotating reference frame, the estimated time from the departure to the return of a light ray to the same point is always $2\ell/c$, that is, independent of the speed v.

6. Measuring the One-Way Speed of Light

The purpose of the study in this section is to propose a method of measuring the speed of light in a single direction, without reflection. The proposed experiment is theoretically studied in the case of classical velocities addition, based on Galilean kinematics, namely in the case where the earth's equatorial speed and the well-known from the literature light speed in vacuum being classically added, and it is found that the measuring of the difference between the light speed that based on Galilean kinematics and the relativistic one gives visible results.

6.1. Experimental Setup

Let us consider the case of a laser source and a horizontal rotating circular frame on which are placed two plates in each of which there is a thin slit (**Figure 3**). The laser source is a uniform intensity distribution one, and through two contacts appropriately placed on the rotating frame and on the laser it sends a pulse of short duration of wavelength in the visible range, whose wavefront is very close to the thin slit of the plate closest to the laser when the two thin slits and the laser are aligned.

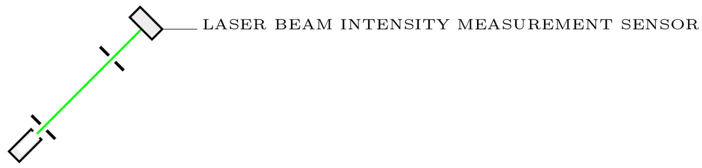

Figure 3. A diagram of the experimental arrangement.

The laser and the sensor are stationary with respect to the laboratory, but it is possible to orient this laser in any direction, determined according to the cardinal points on the horizon. When the circular frame is stopped moving, having made the required placements of the laser source and the two plates, we consider that a small part of the laser beam can pass through the two equal width thin slits and so it can incident on the laser beam intensity measurement sensor. The number of rotations in a time period can be measured through the mechanism of emission of short-duration laser pulses.

6.2. Basic Theory

We denote by d the width of the two thin slits. We also denote by ℓ the radial distance of the two thin slits. The vector velocity $\boldsymbol{v}$ due to the self-rotating motion of the Earth has a direction towards the east, so the experimental setup should have the corresponding orientation, determined according to the cardinal points on the horizon. In this case, the vector velocity $\boldsymbol{v}$ is parallel to the plane of the circular frame. According to Galilean kinematics the time required for the wavefront of the light beam to travel along a path equal to ℓ is given by the relation (8).

Let us consider the power of the outgoing beam, which comes from the emitted laser pulse at the exact moment of alignment of the thin slits and the laser. Let P_0 be the power of the outgoing beam when the circular frame is stationary and the laser and the thin slits are aligned. We denote by f the rotation frequency of the circular frame. Also we denote by R_i the distance of the inner slit from the axis of rotation, and by u_o, u_i the velocities of the outer and inner slits respectively, so we obtain the equalities $R_o - R_i = \ell$, $u_o = 2\pi f R_o$, and $u_i = 2\pi f R_i$. Because the width of the slits is small and the time in which the photons exit from the outer slit is also short, the movements of the two slits can be considered rectilinear.

The wavefront of the emitted laser pulse reaches the outer slit in time $\tau = t(\theta)$. In a time less than τ no photons exit the outer slit, so the power of the outgoing beam is zero along this slit, while at time τ, due to the displacement of the outer slit by a length of $u_o\tau$, a part of the outgoing beam of width $d - u_o\tau$ with the corresponding power exits. Therefore, the power function of the outgoing beam with respect to time is discontinuous.

If we assume that the circular frame rotates clockwise, then, after the specific time τ the right edge of the inner slit allows the passage of more photons due to its movement to the right, while the left edge of the outer slit due to its movement also to the right limits the number of outgoing photons. The time interval of the increase in the width of the outgoing beam on its right side begins at time τ and we consider that it is estimated at time t. Suppose that during the time interval $\Delta t = t - \tau$, due to the movement of the inner slit, the width of the outgoing beam on its right side increased by a length x_i. The length x_i will be equal to the length of displacement of the inner slit in time Δt, so $x_i = u_i \Delta t$. We denote by x_o the decrease in the width of the outgoing beam from the left side, so $x_o = u_o \Delta t$. The total decrease in the width of the outgoing beam is equal to $x_o - x_i = (u_o - u_i)\Delta t$, so its total width at time t is $d - u_o\tau - (u_o - u_i)\Delta t$. Therefore, the time of zeroing of the width of the outgoing beam is

$$t_{max} = \frac{d}{u_o - u_i} - \frac{\tau R_i}{R_o - R_i}$$

The power of the outgoing beam, for $\tau \le t \le t_{max}$, is $P = P_o\left(d - u_o\tau - (u_o - u_i)\Delta t\right)/d$. For $0 \le t < \tau$ there is no outgoing beam. The power function shown in **Figure 4** is given by the following relation

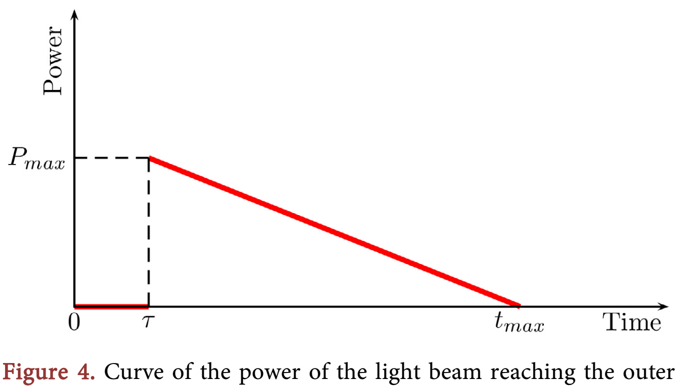

Figure 4. Curve of the power of the light beam reaching the outer thin slit versus time, which is taken once per revolution. The time τ is equal to $t(\theta)$.

$$P = \begin{cases} 0 & \text{if } 0 \le t < \tau, \\ P_o\left(1 - u_i\tau/d - (u_o - u_i)t/d\right) & \text{if } \tau \le t \le t_{max}. \end{cases}$$

The maximum power of the outgoing beam is obtained at time τ, so

$$P_{max} = P_0\left(1 - \frac{2\pi fR_o t(\theta)}{d}\right) \tag{49}$$

The required frequency of rotation of the circular frame in order to prevent the light beam from exiting the thin slit of the outer plate is:

$$f_o = \frac{d}{2\pi R_o t(\theta)} \tag{50}$$

If the frequency f_o is measured experimentally then the time $t(\theta)$ of the beam's propagation from the slit of the inner plate to the slit of the outer one is obtained from the relation (50).

The Relativistic Prediction

In the present experimental procedure, no clocks are used to measure the time interval $t(\theta)$, nor is any clock synchronization required. The physical quantities used are the distances and velocities in the space of the experimental arrangement, which can be estimated by an inertial observer who watches this experimental proceeder, since the differences in the proper time, the measured lengths and the measured velocities in the inertial and the rotating reference frames are of the order of v^2/c^2. Therefore, the value of the time interval $t(\theta)$ predicted by the theory of relativity, for example in the case in which the laser beam propagates eastward or westward is not that obtained from the relations (43), (44), but from the equation $t = \ell/c$.

6.3. An Example

Assume that $\ell = 1\ \text{m}$, $R_o = 1.2\ \text{m}$, $d = 10\ \mu\text{m}$, and that the beam propagates east. As speed v we will consider the earth's equatorial speed of 0.4651 km/sec. Transit time is:

$$t_e = \frac{1}{299792458 - 465}\ \text{s} \simeq 3.335646126 \times 10^{-9}\ \text{s} \tag{51}$$

and when the beam propagates west the transit time is:

$$t_w = \frac{1}{299792458 + 465}\ \text{s} \simeq 3.335635778 \times 10^{-9}\ \text{s} \tag{52}$$

Also assume that $P_0 = 50\ \text{mW}$. In our example, the maximum power of the outgoing beam during the rotation of the circular frame is given by the relation

$$P_{max} = P_0\left(1 - \frac{2\pi fR_o t_e}{d}\right) \tag{53}$$

In this case, the curve of the outgoing beam maximum power versus frequency is plotted in Figure 5.

The required frequency of rotation of the circular frame in order to prevent the light beam from exiting the thin slit of the outer plate, when the beam propagates east, is:

$$f_{oe} = \frac{10\times10^{-6}}{2\pi\times1.2\times3.335646126\times10^{-9}}\,\mathrm{s}^{-1} \simeq 23856.689\ \mathrm{rpm} \tag{54}$$

while, when the beam propagates west, is:

$$f_{ow} = \frac{10\times10^{-6}}{2\pi\times1.2\times3.335635778\times10^{-9}}\,\mathrm{s}^{-1} \simeq 23856.763\ \mathrm{rpm} \tag{55}$$

Therefore, in 1000 minutes of rotation with frequencies f_{oe} and f_{ow}, a difference of 74 revolutions arises.

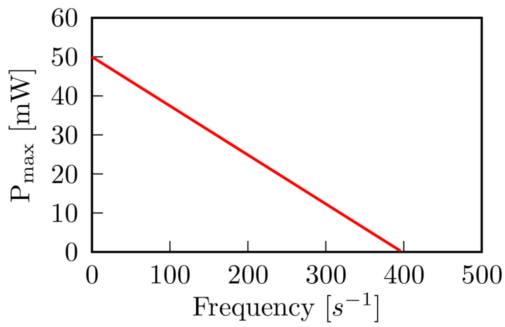

Figure 5. The power versus frequency curve.

7. Discussion

As references in the test of the constancy of light speed, Earth's direction and velocity (ca. 368 km/s (229 mi/s)) relative to the cosmic microwave background (CMB) rest frame are ordinarily used. As stated in [22], "The spherical electromagnetic wave, which consists of free photons of gravitational field force carriers, comes from the continuous conversion of bound photons into free photons (and vice versa), and their frequency spectrum is the spectrum of the 'mass frequency' of bound photons from which they originate…". The photons of the CMB are the force carriers of the gravitational attraction field, as correctly stated in [45]. Therefore, the CMB rest frame is the absolute reference system. However, based on the theory of the absolute reference system, the "absolute reference system" is not the one referred to in the literature as "preferred system of reference", with respect to which any light ray propagates with a constant phase velocity c. According to the theory of the absolute reference system, the "preferred system of reference" for a laboratory anywhere in the universe is a corresponding inertial reference system which is characterized by specific "transport frequencies" of the structural elements of the matter of the laboratory, and these "transport frequencies" the light ray in question also has.

The Earth's orbital motion is considered inertial during measurements of the displacement of the interference fringe pattern. The tests of the Michelson-Morley experiment show that this movement of the Earth does not affect the speed of light in any direction. But the Earth's self-rotating motion is a field of research, in terms of testing the constancy of the speed of light in all directions, for an observer in a self-rotating frame of reference. Due to the very low Earth's equatorial speed compared to the speed of light the use of an interferometer to test the constancy of the speed of light in this reference system requires a corresponding experimental resolution. Illingworth's measurements, analyzed based on the revision of the origin of the interference fringe pattern displacement phenomenon in the present study, seem to approach this goal.

The value of the speed obtained from the relationship (34), if not interpreted as the speed of the Earth with respect to the ether, but as a speed due to the Earth's self-rotation, approaches the value of Earth's equatorial speed reported in the literature. Although the statistical errors are large, the result of the relationship (34) is an indication, prompting us to examine the correctness of this hypothesis by repeating the experiment with a more accurate experimental setup.

Conflicts of Interest

The author declares no conflicts of interest regarding the publication of this paper.

References

[1] Michelson, A.A. (1881) The Relative Motion of the Earth and of the Luminiferous Ether. *American Journal of Science*, **3**, 120-129. https://doi.org/10.2475/ajs.s3-22.128.120

[2] Michelson, A.A. and Morley, E.W. (1887) On the Relative Motion of the Earth and the Luminiferous Ether. *American Journal of Science*, **3**, 333-345. https://doi.org/10.2475/ajs.s3-34.203.333

[3] Morley, E.W. and Miller, D.C. (1904) Extract from a Letter dated Cleveland, Ohio, August 5th, 1904, to Lord Kelvin from Profs. Edward W. Morley and Dayton C. Miller". *Philosophical Magazine*, **8**, 753-754. https://doi.org/10.1080/14786440409463248

[4] Morley, E.W. and Miller, D.C. (1905) Report of an Experiment to Detect the Fitzgerald-Lorentz Effect. *Proceedings of the American Academy of Arts and Sciences*, **41**, 321-328. https://doi.org/10.2307/20022071

[5] Miller, D.C. (1925) Ether-Drift Experiments at Mount Wilson. *Proceedings of the National Academy of Sciences*, **11**, 306-314. https://doi.org/10.1073/pnas.11.6.306

[6] Tomaschek, R. (1924) Über das Verhalten des Lichtes außerirdischer Lichtquellen. *Annalen der Physik*, **378**, 105-126. https://doi.org/10.1002/andp.19243780107

[7] Miller, D.C. (1933) The Ether-Drift Experiment and the Determination of the Absolute Motion of the Earth. *Reviews of Modern Physics*, **5**, 203-242. https://doi.org/10.1103/revmodphys.5.203

[8] Kennedy, R.J. (1926) A Refinement of the Michelson-Morley Experiment. *Proceedings of the National Academy of Sciences*, **12**, 621-629. https://doi.org/10.1073/pnas.12.11.621

[9] Illingworth, K.K. (1927) A Repetition of the Michelson-Morley Experiment Using Kennedy's Refinement. *Physical Review*, **30**, 692-696. https://doi.org/10.1103/physrev.30.692

[10] Piccard, A. and Stahel, E. (1926) L'expérience de Michelson, réalisée en ballon libre. *Comptes Rendus*, **183**, 420-421.

[11] Piccard, A. and Stahel, E. (1927) Nouveaux résultats obtenus par l'expérience de

Michelson. *Comptes Rendus*, **184**, Article 152.

[12] Piccard, A. and Stahel, E. (1927) L'absence du vent d'éther au Rigi. *Comptes Rendus*, **184**, 1198-1200.

[13] Michelson, A.A., Pease, F.G. and Pearson, F. (1929) Results of Repetition of the Michelson-Morley Experiment. *Journal of the Optical Society of America*, **18**, Article 181. https://doi.org/10.1364/josa.18.000181

[14] Joos, G. (1930) Die Jenaer Wiederholung des Michelsonversuchs. *Annalen der Physik*, **399**, 385-407. https://doi.org/10.1002/andp.19303990402

[15] Shamir, J. and Fox, R. (1969) A New Experimental Test of Special Relativity. *IL Nuovo Cimento B Series* 10, **62**, 258-264. https://doi.org/10.1007/bf02710136

[16] Cahill, R. and Kitto, K. (2002) Michelson-Morley Experiments Revisited and the Cosmic Background Radiation Preferred Frame. https://doi.org/10.48550/arXiv.physics/0205065

[17] Gurzadyan, V.G. and Margaryan, A.T. (2018) The Light Speed versus the Observer: The Kennedy–Thorndike Test from Graal-ESRF. *The European Physical Journal C*, **78**, Article 607. https://doi.org/10.1140/epjc/s10052-018-6080-x

[18] Patrinos, K. (2019) The Physics of an Absolute Reference System. *Journal of Applied Mathematics and Physics*, **7**, 431-475. https://doi.org/10.4236/jamp.2019.73033

[19] Patrinos, K. (2019) Classical Quantum Field Theory Based on the Hypothesis of the Absolute Reference System. *Journal of Applied Mathematics and Physics*, **7**, 747-780. https://doi.org/10.4236/jamp.2019.74052

[20] Patrinos, K. (2020) The Confirmation of Hypothesis of the Absolute Reference System. *Journal of Applied Mathematics and Physics*, **8**, 999-1015. https://doi.org/10.4236/jamp.2020.86078

[21] Patrinos, K. (2021) Gravitation Theory Based on the Physics of an Absolute Reference System. *Journal of Applied Mathematics and Physics*, **9**, 1194-1214. https://doi.org/10.4236/jamp.2021.96082

[22] Patrinos, K. (2021) Quantum Gravity. *Journal of Modern Physics*, **12**, 1387-1403. https://doi.org/10.4236/jmp.2021.1210087

[23] Trimmer, W.S.N., Baierlein, R.F., Faller, J.E. and Hill, H.A. (1973) Experimental Search for Anisotropy in the Speed of Light. *Physical Review D*, **8**, 3321-3326. https://doi.org/10.1103/physrevd.8.3321

[24] Trimmer, W.S.N., Baierlein, R.F., Faller, J.E. and Hill, H.A. (1974) Erratum: Experimental Search for Anisotropy in the Speed of Light. *Physical Review D*, **9**, 2489-2489. https://doi.org/10.1103/physrevd.9.2489.2

[25] Furth, H.L. (1954) Proposal for a New Æther Drift Experiment. *Nature*, **173**, 80-81. https://doi.org/10.1038/173080b0

[26] Essen, L. (1954) Proposal for a New Æther-Drift Experiment. *Nature*, **173**, 734-734. https://doi.org/10.1038/173734a0

[27] Essen, L. (1955) A New Æther-Drift Experiment. *Nature*, **175**, 793-794. https://doi.org/10.1038/175793a0

[28] Wolf, P., Bize, S., Clairon, A., Luiten, A.N., Santarelli, G. and Tobar, M.E. (2003) Tests of Lorentz Invariance Using a Microwave Resonator. *Physical Review Letters*, **90**, Article 060402. https://doi.org/10.1103/physrevlett.90.060402

[29] Müller, H., Herrmann, S., Braxmaier, C., Schiller, S. and Peters, A. (2003) Modern Michelson-Morley Experiment Using Cryogenic Optical Resonators. *Physical Review*

Letters, **91**, Article 020401. https://doi.org/10.1103/physrevlett.91.020401

[30] Wolf, P., Tobar, M.E., Bize, S., Clairon, A., Luiten, A.N. and Santarelli, G. (2004) Whispering Gallery Resonators and Tests of Lorentz Invariance. *General Relativity and Gravitation*, **36**, 2351-2372. https://doi.org/10.1023/b:gerg.0000046188.87741.51

[31] Wolf, P., Bize, S., Clairon, A., Santarelli, G., Tobar, M.E. and Luiten, A.N. (2004) Improved Test of Lorentz Invariance in Electrodynamics. *Physical Review D*, **70**, Article 051902. https://doi.org/10.1103/physrevd.70.051902

[32] Antonini, P., Okhapkin, M., Göklü, E. and Schiller, S. (2005) Test of Constancy of Speed of Light with Rotating Cryogenic Optical Resonators. *Physical Review A*, **71**, Article 050101. https://doi.org/10.1103/physreva.71.050101

[33] Stanwix, P.L., Tobar, M.E., Wolf, P., Susli, M., Locke, C.R., Ivanov, E.N., *et al*. (2005) Test of Lorentz Invariance in Electrodynamics Using Rotating Cryogenic Sapphire Microwave Oscillators. *Physical Review Letters*, **95**, Article 040404. https://doi.org/10.1103/physrevlett.95.040404

[34] Herrmann, S., Senger, A., Kovalchuk, E., Müller, H. and Peters, A. (2005) Test of the Isotropy of the Speed of Light Using a Continuously Rotating Optical Resonator. *Physical Review Letters*, **95**, Article 150401. https://doi.org/10.1103/physrevlett.95.150401

[35] Stanwix, P.L., Tobar, M.E., Wolf, P., Locke, C.R. and Ivanov, E.N. (2006) Improved Test of Lorentz Invariance in Electrodynamics Using Rotating Cryogenic Sapphire Oscillators. *Physical Review D*, **74**, Article 081101. https://doi.org/10.1103/physrevd.74.081101

[36] Müller, H., Stanwix, P.L., Tobar, M.E., Ivanov, E., Wolf, P., Herrmann, S., *et al*. (2007) Tests of Relativity by Complementary Rotating Michelson-Morley Experiments. *Physical Review Letters*, **99**, Article 050401. https://doi.org/10.1103/physrevlett.99.050401

[37] Eisele, C., Nevsky, A.Y. and Schiller, S. (2009) Laboratory Test of the Isotropy of Light Propagation at the 10-17 Level. *Physical Review Letters*, **103**, Article 090401. https://doi.org/10.1103/physrevlett.103.090401

[38] Herrmann, S., Senger, A., Möhle, K., Nagel, M., Kovalchuk, E.V. and Peters, A. (2009) Rotating Optical Cavity Experiment Testing Lorentz Invariance at the 10-17 Level. *Physical Review D*, **80**, Article 105011. https://doi.org/10.1103/physrevd.80.105011

[39] Nagel, M., Parker, S.R., Kovalchuk, E.V., Stanwix, P.L., Hartnett, J.G., Ivanov, E.N., *et al*. (2015) Direct Terrestrial Test of Lorentz Symmetry in Electrodynamics to 10-18. *Nature Communications*, **6**, Article No. 8174. https://doi.org/10.1038/ncomms9174

[40] Born, M. and Wolf, E. (1975) Principles of Optics. Electromagnetic Theory of Propagation. Interference and Diffraction of Light" 5th Edition, Pergamon Press.

[41] Fernandez-Diez, J.L.J. and McDonald, K.T. (2019) Galilean Transformation of Wave Velocity. http://kirkmcd.princeton.edu/examples/wave_velocity.pdf

[42] Kennedy, R.J. and Thorndike, E.M. (1932) Experimental Establishment of the Relativity of Time. *Physical Review*, **42**, 400-418. https://doi.org/10.1103/physrev.42.400

[43] Landau, L. and Lifshitz, E. (1975) The Classical Theory of Fields. Pergamon Press Ltd.

[44] Sfarti, A. (2017) Electrodynamics in Uniformly Rotating Frames the Central Observer Point of View. *Theoretical Physics*, **2**, 177-187.

https://doi.org/10.22606/tp.2017.24004

[45] Cui, Q. (2022) Possible Relations of Cosmic Microwave Background with Gravity and Fine-Structure Constant. *Journal of Modern Physics*, **13**, 1045-1052. https://doi.org/10.4236/jmp.2022.137058