A New Ether Drift Experiment

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It is well known that no fringe shifts are expected when an interferometer at rest in the laboratory is rotated. We propose an experiment where fringe shifts can be observed when a 'one-way interferometer' at rest in the laboratory is rotated. Since the predicted results obviously contradict the postulates of the Special Theory of Relativity, these can be considered as a new test to the validity of the STR. The laboratory is assumed in inertial motion relative to a preferred reference frame where light's speed is isotropic and equal to 'c'. Fringe shifts are shown to be proportional to the speed of the laboratory relative to the preferred frame, as well as to the divergence of the source and the misalignment of the beams that interfere.

Introduction

The Special Theory of Relativity has been one of the most successful theories of the last century. There has been a tremendous effort during the past decades to test the validity of Lorentz Invariance [1]. The vast number of experimental results should make clear to the reader that such a violation has not been detected. It is generally accepted that the STR is fully verified experimentally [2]. More than one hundred years after Michelson and Morley's famous experiment, articles are still being published on the matter. The anisotropy $\frac{\Delta c}{c}$ has been reduced in the last five years from 10^{-14} [3] to 10^{-17} [4] using optical resonators. Many of these results use the two-way speed of light, leaving questions on the constancy of the speed of light in one direction [5]. Also recently, authors have claimed that substituting the vacuum in these resonating cavities with a dielectric gaseous media should increase the limit imposed on $\frac{\Delta c}{c}$ by several orders of magnitude [6], although other authors have performed similar experiments still reporting null results [2]. Others defend a "special system of reference experimentally inaccessible" as a non contradiction to STR postulates. Clearly, Einstein's ideas still promote an active debate [7] among the modern physicists' community.

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It is argued that the reason for choosing STR over other rival theories is its elegance and relative simplicity rather that its better agreement with experimental results [2]. Mostly, classical theories differ from STR fundamentally in the interpretation of experimental results, rather than in their outcomes.

We propose a new test to the existence of a preferred reference frame where light's speed is isotropic and equal to 'c'.

In what follows, we first show that although there is no phase change when an interferometer at rest in the laboratory is rotated, if a one-way interferometer is used then fringe shifts should be observed. This is because the time it takes light to travel the distance between the source and the observer in one orientation *differs* to the time it takes light to travel the distance between the source and the observer in other orientation; in general, this difference in travel times when the interferometer is rotated cause the observer to *perceive* fringe shifts if the laboratory is in motion relative to the preferred frame. We emphasize that these observed fringe shifts are not due to a phase change, but to the effect of relative motion between the observer and light, or equivalently between the observer and the preferred frame. Finally, we show that the magnitude of the fringe shifts is proportional to the *divergence* of the source of light used and the *misalignment* of the interferometer, as well as to the velocity of the laboratory relative to a preferred reference frame.

Theory

It will be shown that fringe shifts can be observed when a one-way interferometer is rotated. Classical pre-relativistic concepts such as the Lorentz-Fitzgerald contraction of bodies in the direction of motion are used in order to preserve two-way Lorentz Invariance and Michelson and Morley's reported null result. Velocities are considered relative to a preferred referential frame where the speed of light is isotropic and has a constant value of 'c'.

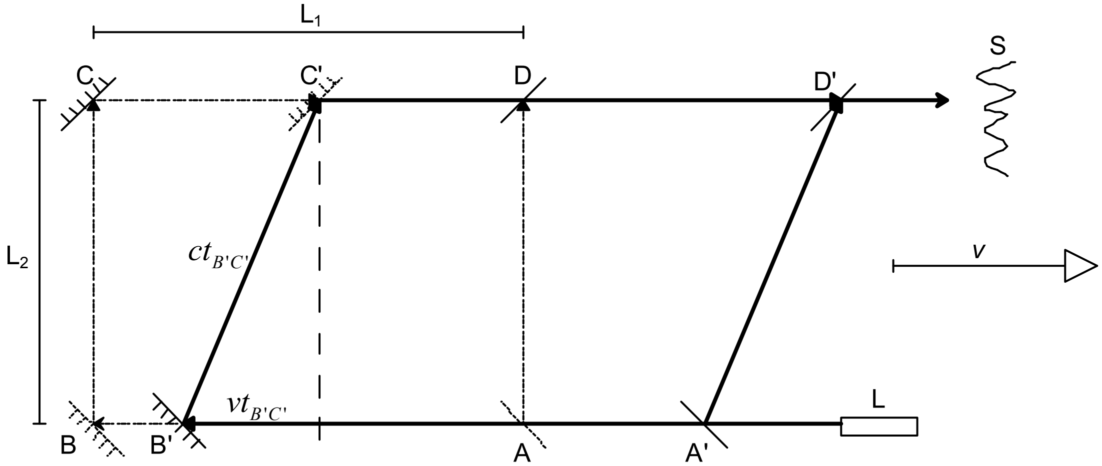

Figure 1 Interferometer by which calculations are made. Thin dotted lines represent the path light travels when the interferometer at rest (v=0), thick solid lines represent the path light travels when the interferometer moves with v>0, the dashed line help visualize a right triangle of sides $vt_{B'C'}$ and L_2 and hypotenuse c $t_{B'C'}$.

Consider an interferometer as the one shown schematically in Figure 1, with arms of length L_1 and L_2. Dotted lines represent the path traveled by light when the interferometer is at rest. At rest, light emitted by the source located at L reaches beam splitter located at A. One beam travels the optical path between points $ABCD$, while the other travels AD. Both beams recombine at D, and the interference pattern can be seen on the screen S.

When the interferometer travels at a speed v with respect to the preferred frame (solid dark lines in Figure 1), while the beam of light travels from A to B, the mirror at B moves to position B'. In this fashion, one beam travels the distances between points $AB'C'D'$. For both beams to recombine at D' at the same time so that an interference can be seen, the second beam must travel the path $A'D'$.

For the sake of simplicity and without loss of generality, for all purposes it can be considered the screen S as located at D', and the source of light as located adjacent of the first beam splitter, thus no extra distance is traveled by the beams other than between points $AB'C'D'$ and $A'D'$.

In order to obtain the time taken by each beam to reach D', we consider Lorentz-Fitzgerald contraction of bodies in the direction of their motion. This consideration ensures that we preserve Michelson & Morley's and most modern experimental results. We express this factor with the parameter $\alpha = \sqrt{1 - \frac{v^2}{c^2}} < 1$, where c is the speed of light, and v is the speed of the interferometer, both relative to the preferred frame.

We will analyze the interferometer in two different orientations. For all subsequent formulations, the superscript $i=1,2$ denotes the first and second orientation (0º and 90º relative to v), respectively; the subscript $j=1,2$ denotes the paths $AB'C'D'$ and $A'D'$, respectively.

For the first orientation, we can find the value of the time $t^1_{B'C'}$ that takes light to travel the distance between points B' y C' using Pythagoras's theorem with the relation

$$\left(vt^1_{B'C'}\right)^2+\left(L_2\right)^2=\left(ct^1_{B'C'}\right)^2 \tag{1}$$

We obtain,

$$t^1_{B'C'}=\frac{L_2}{\sqrt{c^2-v^2}}=\frac{L_2}{\alpha c} \tag{2}$$

We also have that

$$t^1_{AB'}+t^1_{C'D'}=\frac{\alpha L_1}{c-v}+\frac{\alpha L_1}{c+v}=\frac{2\alpha c L_1}{c^2-v^2}=\frac{2L_1}{\alpha c} \tag{3}$$

From equations (1), (2), (3), and using the fact that $t^1_{B'C'}=t^1_{A'D'}$, we have that the time taken by light to travel paths $AB'C'D'$ and $A'D'$ is given by:

$$t^1_1=\frac{2L_1}{\alpha c}+\frac{L_2}{\alpha c} \tag{4}$$

$$t^1_2=\frac{L_2}{\alpha c} \tag{5}$$

$$\Delta t_1=t_1-t_2 \tag{6}$$

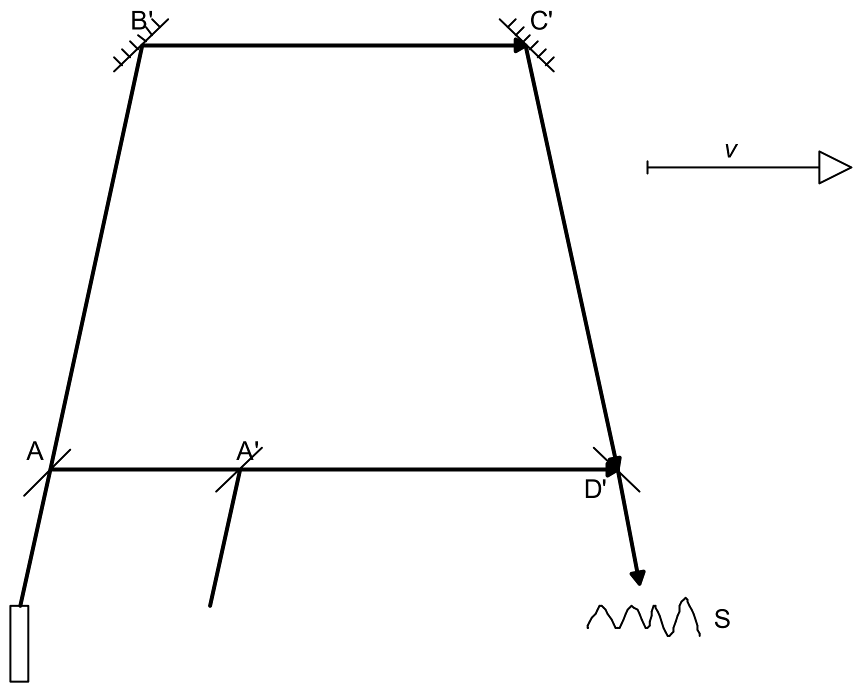

Figure 2 Second orientation of the same interferometer, after a 90º rotation.

Using Figure 2, when the interferometer is rotated 90º (second orientation), we have that for the travel times:

$$t_1^2 = \frac{2L_1}{\alpha c} + \frac{\alpha L_2}{c - v} \tag{7}$$

$$t_2^2 = \frac{\alpha L_2}{c - v} \tag{8}$$

$$\Delta t_2 = t_1^2 - t_2^2 \tag{9}$$

From equations (6) and (9), we find that

$$\Delta t = (\Delta t_2 - \Delta t_1) = 0 \tag{10}$$

The result obtained in equation (10) is the expected one, and is a direct consequence of considering Lorentz-Fitzgerald contraction α. This result means that, at D', *there is no phase change as a consequence of rotating the interferometer*.

However, it is important to notice that, although $\Delta t = 0$,

$$t_1^2 > t_1^1 \tag{11}$$

And that

$$t_2^2 > t_2^1 \tag{12}$$

That is, the time taken by light to travel the distance between points $AB'C'D'$ (or $A'D'$) in the first orientation *is smaller* than the time taken to travel the same paths in the second orientation of the interferometer.

Given that the distance r traveled by light can be calculated as $r = ct$, we have from equations (11) and (12) that the distance traveled by light in the first orientation *is smaller* than the distance traveled in the second orientation of the interferometer.

It is important to emphasize that the results obtained in equations (11) and (12) *are not obtained* if a M&M type interferometer is used, because light travels each arm of the interferometer in a *two-way fashion*, thus obtaining $t_1^2 = t_1^1$ and $t_2^2 = t_2^1$.

The results of equations (11) and (12) enables us to explain why the proposed interferometer is sensible to anisotropies in the speed of light when it is rotated. Although equation (10) states the fact that there is no phase change in the interference pattern that forms in D', the equations (11) and (12) say that the distance traveled by light from the source to D' (the observer) is different in each orientation of the interferometer.

The change ΔS in this distance is,

$$\Delta S = c\left(t_2^2 - t_2^1\right) = c\left(t_1^2 - t_1^1\right) = cL_2\left(\frac{\alpha}{c-v} - \frac{1}{\alpha c}\right) \tag{13}$$

For the proposed interferometer, it can be verified that ΔS is identically equal to zero just in the case when $v = 0$. For a M&M interferometer $\Delta S = 0$ for all v because $t_2^2 = t_2^1$ and $t_1^2 = t_1^1$: the distance traveled by light from the source to D' remains constant when the interferometer is rotated.

As it was already said, for both beams to arrive simultaneously at D', we have to consider that one beams traverses A and that the other is reflected at A' when the beam splitter initially located at A has moved to A'.

We can see that $\overline{AA'} = v\frac{2L_1}{\alpha c}$ has the same value in both orientations. This expression means that the interferometer has moved with velocity v during the time $\frac{2L_1}{\alpha c}$.

For an observer at D', the interference pattern is produced by the interference of two beams: one beam transmitted at A and another one reflected at A', both arriving simultaneously at D'. The difference of the distance traveled by light is $r_2^i - r_1^i = \frac{2L_1}{\alpha}$.

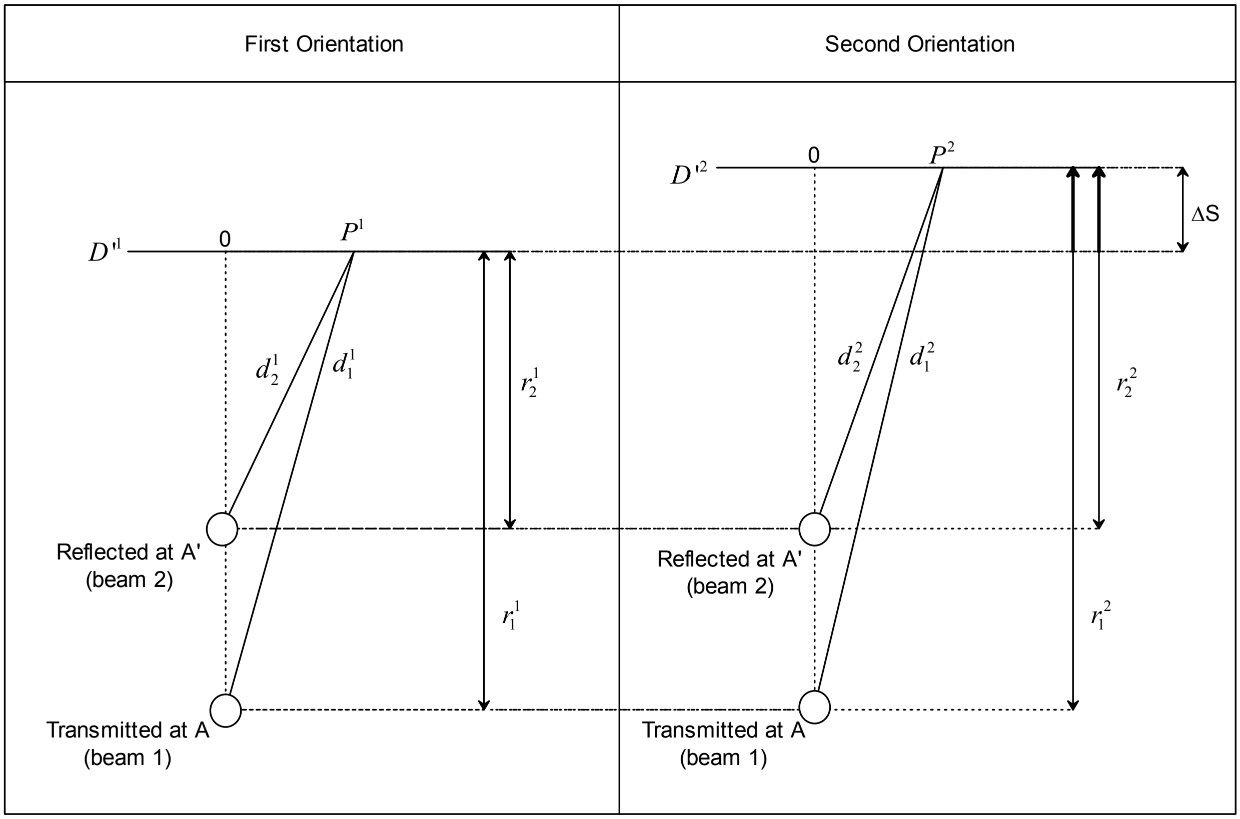

Figure 3 In each orientation, the interference pattern is formed by two beams: one that is transmitted at A, and another that reflects at A', arriving both beams simultaneously at D'. The *difference* between the distances traveled by light is greater than zero and of constant value in both orientations. In the second orientation, both beams have to travel an additional distance ΔS to arrive to D'.

In reference to Figure 3, P^1 and P^2 represent a fixed distance from the origin 0 in the visualization screen (D'). They represent the position of the observer with respect to the source of light for each orientation. The distances $r_j^i = ct_j^i$ correspond to the perpendicular distances from the source to the beam splitter D', for each orientation. The $\overrightarrow{d_j^i}$ represents the distance traveled by light from the source to the observer in each orientation.

It is a known fact that the phase Φ^i in a point P^i on D'^i can be calculated as

$$\Phi^i = k\left(\left|\overrightarrow{d_1^i}\right| - \left|\overrightarrow{d_2^i}\right|\right) \tag{14}$$

where $k = \dfrac{2\pi}{\lambda}$ is the wave number, and λ is the wavelength of the light used.

Because in the second orientation the beams have to travel an additional distance ΔS to reach the observer, it should be clear that $d_j^2 > d_j^1$.

We define

$$\Delta\Phi = \Phi^2 - \Phi^1 \tag{15}$$

As can be verified, in general, $\Delta\Phi \neq 0$, the value depending greatly on the divergence of the beam.

We see then that, in general, *from the point of view of the observer* there *is* a fringe shift. The observed fringe shift is not due to a change in the difference of travel times (phase change), but to a change in the total distance that light travels from the source to the observer when the interferometer is rotated.

This doesn't contradict the result obtained in equation (10), which states that the relative phase between the beams that form the interference pattern *is the same in both orientations*. That is, that the interference pattern doesn't change.

We shall notice that for an *ideal* perfectly aligned interferometer as shown in Figure 3, if *ideal* perfectly plane waves are used $\Delta\Phi$ is equal to zero all over D'.

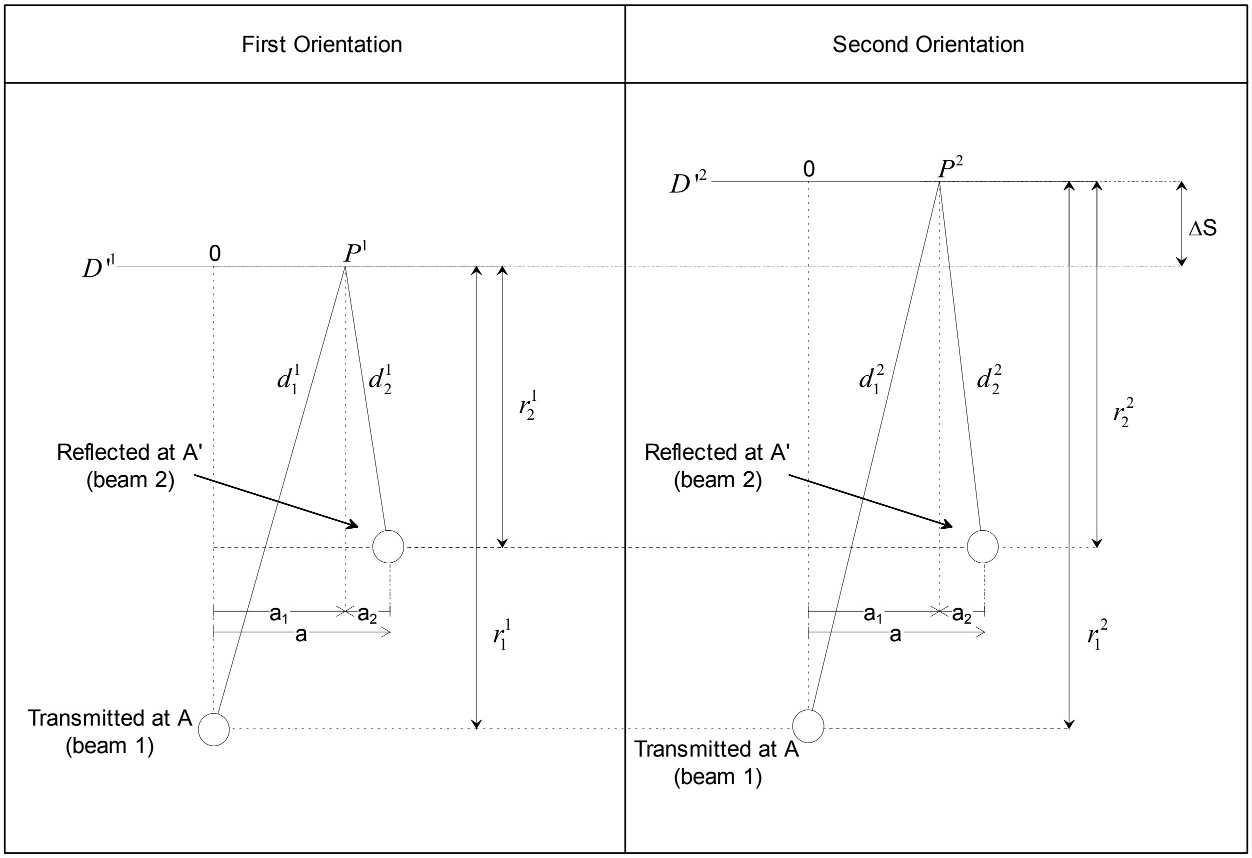

Figure 4 Schematic behavior of the interference pattern formed by the two beams. The points P1 y P2 represent the position of the observer in each orientation. In this figure, we consider also a misalignment, represented by the lateral (vectorial) distance a=a_1-a_2 between the beams.

Figure 1, Figure 2 and Figure 3 represent a perfectly aligned interferometer. In practice, in order to observe interference fringes, the interferometer must be slightly unaligned. That is, the angles of the mirrors and beam splitter don't have exact 45º inclinations and the beams that interfere at D' are not parallel. Figure 4 show an interferometer slightly unaligned. The misalignment is represented in the figure with the lateral distance between beams $\overrightarrow{a} = \overrightarrow{a_1} - \overrightarrow{a_2}$. The distances $\left|\overrightarrow{a_j}\right|$ correspond to the modulus of the projection of $\overrightarrow{d_i^i}$ over $\overrightarrow{a}$.

The points P^i correspond to the fixed position of the observer with respect to the origin 0.

The distances $\left|\overrightarrow{d_j^i}\right|$ from the source of light to the observation point are equal to $\left|d_j^i\right| = \sqrt{\left|\overrightarrow{r_j^i}\right|^2 + \left|\overrightarrow{a_j}\right|^2}$, where $\left|\overrightarrow{r_j^i}\right| = ct_j^i$.

The phase change that an observer measures when the interferometer is rotated (and thus passing from P^1 to P^2) is given by

$$\Delta\Phi = k\left(\left|\overrightarrow{d_1^2}\right| - \left|\overrightarrow{d_2^2}\right|\right) - \left(\left|\overrightarrow{d_1^1}\right| - \left|\overrightarrow{d_2^1}\right|\right) \tag{16}$$

Where λ is the wavelength of light. This is equivalent to a number of fringes $N = \frac{\Delta\Phi}{2\pi}$.

From equation (16) it can be seen that the more unaligned the interferometer or the more divergent the source of light, the greater fringe shift must be measured.

The effect described in this paper can be visualized in the next figure:

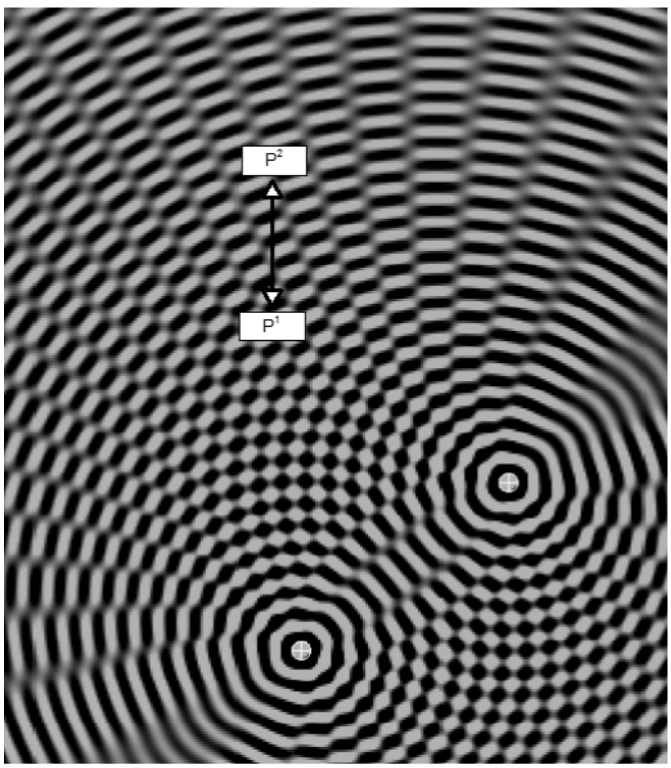

Figure 5 Unaligned interferometric setup. This figure represents a snapshot of spheres of light propagating away from a point like source. The two beams that form the interference pattern are one transmitted at A and the other reflected at A'. When the interferometer is rotated the observer measures the pattern at different distances from the source of light (points P^1 and P^2), thus measuring a fringe shift. In this figure, the observer measures N≅1,5.

Figure 5 represents a snapshot of spheres of light propagating away from a point like source (the two sources that are seen in the figure correspond to the beams reflected and refracted at A' and A, respectively). When the interferometer is rotated, the observer measures the interference pattern at different distances from the source of light (points P^1 and P^2), thus measuring a fringe shift.

In the case of an M&M type interferometer, in Figure 5 the distance between P^1 and P^2 is equal to zero.

Conclusions

It has been described and analyzed an interferometer sensitive to motion relative to the preferred reference frame (PRF) where the speed of light is isotropic and equal to ‘c’. That is, the proposed interferometer can be used to determine if motion relative to the PRF is possible or not. As it has been explained, since we take into account Lorentz-Fitzgerald contraction of bodies in the direction of motion, there is no contradiction with the classical M&M type results nor with all equivalent modern refinements.

The most important difference between the proposed interferometer and a M&M type interferometer is that light travels the distances between $A'D'$ and $B'C'$ in a *one way fashion*. Assuming the possibility of motion relative to the PRF, when the interferometer is rotated (Figure 1 to Figure 2), the distance traveled by the beams of light between the source and the observer increases. Fringe shifts are observed without any phase change occurring. The interference pattern remains constant while the interferometer is rotated.

Because in a M&M type interferometer light travels each arm in a *two way fashion*, the distance between the source of light and observer remains constant when the interferometer is rotated, as does the relative phase between the beams of light, thus no fringe shifts are seen.

In this paper we have considered a rotation of the interferometer from the first to a second orientation (0º to 90º). However, it can be verified that the maximum fringe shift occurs during a rotation from the second orientation to the “fourth” (90º to 270º).

Since there is no relative motion between parts of the interferometer, according to the Special Theory of Relativity (STR) no fringe shifts are expected when the interferometer is rotated. However, it is shown that although there is no relative motion between parts of the interferometer, inertial motion relative to the PRF can be detected.

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