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# Measurable Experimental Difference between Relativity and FitzGerald–Lorentz length contraction

By Robert te Winkel<sup>1</sup> and An Michel Rodríguez<sup>2</sup>

(April-24<sup>th</sup> 2013)

*We describe an experimental setup sensible to the fundamental difference between STR and LF-contraction theories: the existence of a privileged frame of reference where light's speed is isotropic and equal to 'c'. The setup consists of a one-way interferometer (no mirrors reflecting the light back over the same path), with no moving parts and at rest in the laboratory. If this fundamental preferred frame exists then, if the laboratory moves with respect such a frame, a fringe displacement should be observed when the interferometer's orientation is changed with respect to this velocity. Importantly, this fringe shift is only apparent to the observer, as the phase difference between beams remains always constant (as expected) during the rotation. It is also shown why a Michelson-Morley interferometer (or any two-way interferometer) is incapable of measuring the effect.*

## Introduction

The Special Theory of Relativity (STR) 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. Important to notice is that 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, some 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 similar experiments have been performed 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 than its better agreement with experimental results [2]. Mostly and importantly, classical theories differ from STR in the interpretation of experimental results, rather than in their outcomes.

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

In what follows, we show an experimental setup consisting of a one-way interferometer at rest in the laboratory. Assuming the laboratory moves with velocity 'v' relative to the aforementioned preferred frame, when this interferometer is rotated relative to some fixed arbitrary axis (not parallel to 'v'), fringe shifts should be *observed*. As it will be also show, *it is very important to emphasize* that the fringe movement is only *apparent* to the observer, *in the same way* that a movie is seen smaller or bigger when the projection screen is moved farther or nearer from the projector (it is the *same movie*). In this example, the projector would be the laser and the movie would be the interference fringes (the *same pattern* would be seen bigger or smaller).

## Theory

In what is next, we will analyze the interferometer in only two different orientations. For all subsequent formulations, the superscript  $i = 1, 2$  denotes the first and second orientation: an arbitrary angle of  $\Theta$  and  $\Theta + 90^\circ$  relative to  $v$ , respectively. The subscript  $j = 1, 2$  denotes the path each beam of light travels in the interferometer.

In order to obtain the time taken by each beam to reach the projection screen, as previously said we have to consider Lorentz-Fitzgerald contraction of bodies in the direction of their motion in order *to ensures that we preserve Michelson & Morley's and most modern experimental results*. We express this

contraction factor with the parameter  $\alpha = \sqrt{1 - \frac{v^2}{c^2}} \leq 1$ , where  $c$  is the speed of light, and  $v$  is the speed of the interferometer, both relative to the preferred frame.

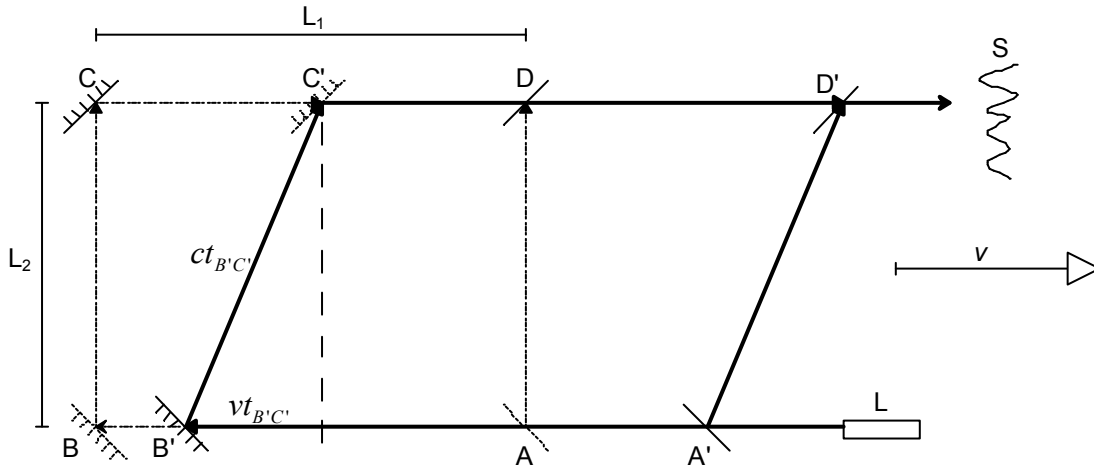


Figure 1 Schematic interferometer by which calculations are made. If a preferred frame doesn't exist, solid lines would coincide with the dotted lines, because the interferometer is at rest in the laboratory. If a preferred frame exists, the dotted lines represent the path light travels when the interferometer is at rest ( $v=0$ ) with respect to the preferred frame, thick solid lines represent the actual path light travels when the interferometer moves with  $v>0$  with respect to the preferred frame. The dashed line help visualize a right triangle of sides  $vt_{B'C'}$  and  $L_2$  and hypotenuse  $ct_{B'C'}$ .

Consider an interferometer as the one shown schematically in Figure 1, with arms of length  $L_1$  and  $L_2$  (as measured at rest with respect to the the laboratory). Dotted lines represent the path traveled by light when the interferometer is at rest. When the interferometer is at rest (or if a preferred frame doesn't exists), 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  $A'D'$ . For this orientation, we find that the time taken by light to travel paths  $AB'C'D'$  and  $A'D'$  is given by:

$$t_1^1 = \frac{2L_1}{\alpha c} + \frac{L_2}{\alpha c} \quad (0)$$

$$t_2^1 = \frac{L_2}{\alpha c} \quad (0)$$

We now analyze the times when the interferometer has been rotated 90° with respect to the first orientation.

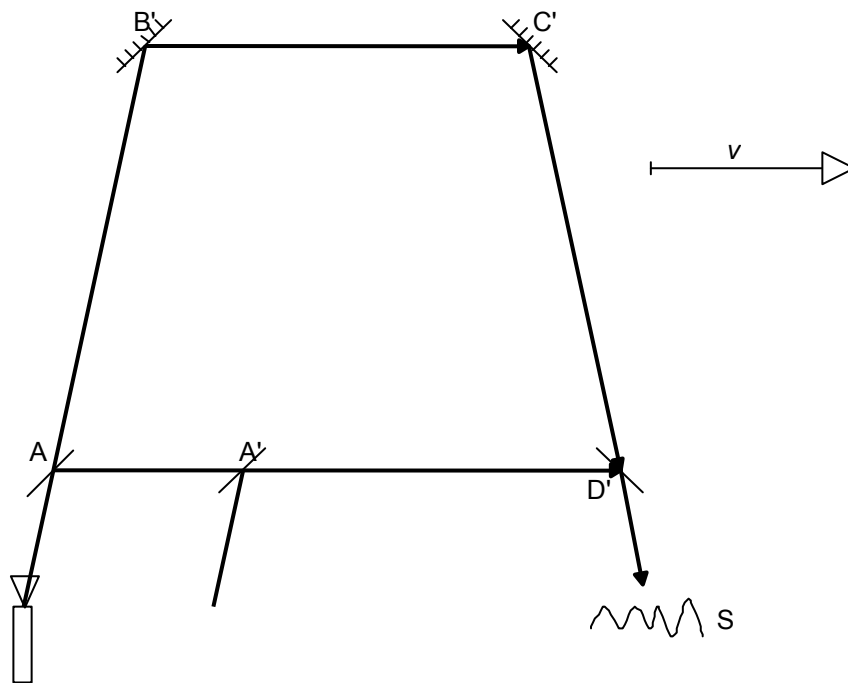


Figure 2 Second orientation of the same interferometer, after a 90° rotation. Notice that the laser emits a 'cone' of light. For the sake of the drawing, we have exaggerated the angle of the beam that actually arrives at B'.

Using Figure 2 (analogous to Figure 1, after a rotation of 90°), when the interferometer is rotated 90° (second orientation), we have that for the travel times:

$$t_1^2 = \frac{2L_1}{\alpha c} + \frac{\alpha L_2}{c - v} \quad (0)$$

$$t_2^2 = \frac{\alpha L_2}{c - v} \quad (0)$$

As expected, we see that

$$\Delta t = (\Delta t^2 - \Delta t^1) = (t_2^2 - t_1^2) - (t_2^1 - t_1^1) = 0 \quad (0)$$

The result obtained in equation (0) is the expected one, and is a direct consequence of considering Lorentz-Fitzgerald contraction  $\alpha$ .

Being the phase of the beam proportional to the time of travel, this result means that, at  $D'$ , *there is no phase change as a consequence of rotating the interferometer.*

However, the main point of this paper is to notice that, although  $\Delta t = 0$ ,

$$t_1^2 > t_1^1 \quad (0)$$

And that

$$t_2^2 > t_2^1 \quad (0)$$

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.

Given that the distance  $r$  traveled by light can be calculated as  $r = ct$ , we have from equations (0) and (0) that the distance traveled by light in the first orientation *is smaller* than the distance traveled in the second orientation of the interferometer. Hence the analogy of the projection screen being farther or nearer from the projector.

It is important to emphasize that the results obtained in equations (0) and (0) **are not obtained** if a Michelson-Morley type (or any two-way) 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 (0) and (0) enables us to explain why the proposed interferometer is sensible to anisotropies in the speed of light when it is rotated.

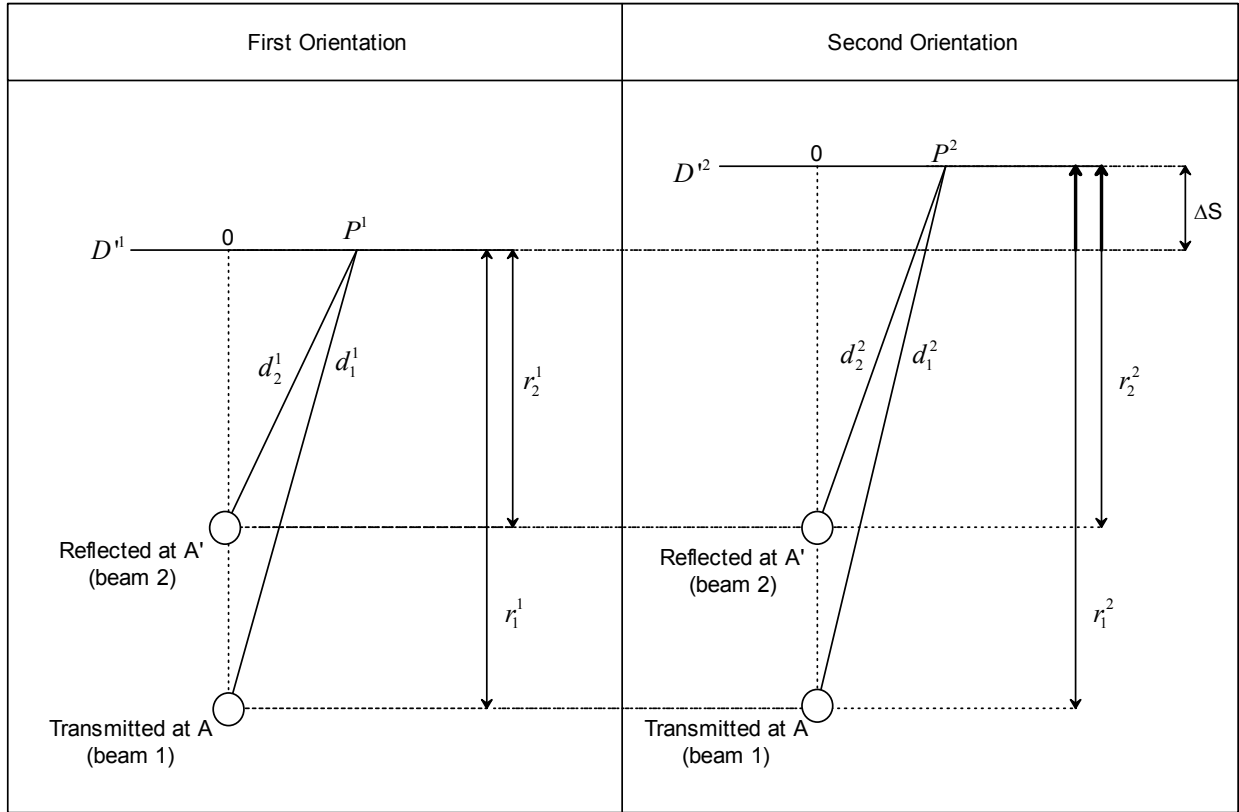


Figure 3 In each orientation, the interference pattern is formed by two beams: one that is transmitted at A, and another that reflects at A', arriving both beams simultaneously at D'. The difference between the distances traveled by light is greater than zero and of constant value in both orientations.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

In reference to Figure 3, the change  $\Delta S$  in this distance is,

$$\Delta S = c(t_2^2 - t_2^1) = c(t_1^2 - t_1^1) = cL_2 \left( \frac{\alpha}{c-v} - \frac{1}{\alpha c} \right) \quad (0)$$

It can be verified that  $\Delta S$  is identically equal to zero just in the case when  $v = 0$ .

Describing Figure 3,  $P^1$  and  $P^2$  represent a fixed distance from the origin 0 in the visualization screen ( $D^1$ ). 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  $D^i$ , for each orientation. The  $\overline{d_j^i}$  represents the distance traveled by light from the source to the observer in each orientation.

It is a known fact that the phase  $\Phi^i$  in a point  $P^i$  on  $D^i$  can be calculated as

$$\Phi^i = k \left( \left| \overline{d_1^i} \right| - \left| \overline{d_2^i} \right| \right) \quad (0)$$

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

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

We define

$$\Delta\Phi = \Phi^2 - \Phi^1 \quad (0)$$

As can be verified, in general,  $\Delta\Phi \neq 0$ .

This result tells us that *the observer* could see the interference pattern “move”. These fringe shifts are not due to a change in the difference of phase when the beams meet, 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 (0), 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 space-wise.

## Slightly unaligned one-way interferometer

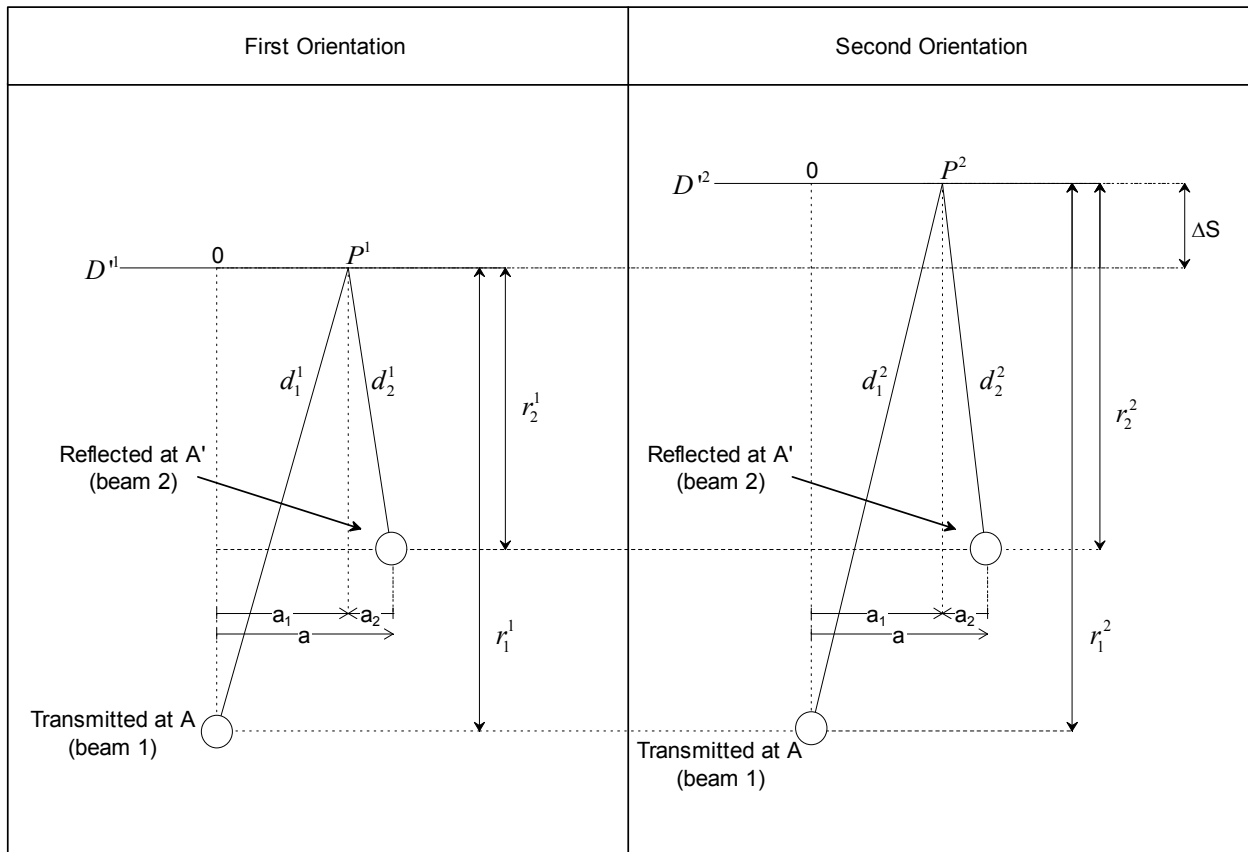


Figure 4 Schematic behavior of the interference pattern formed by the two beams. The points  $P_1$  y  $P_2$  represent the position of the observer in each orientation. In this figure, we consider also a misalignment, represented by the lateral (vectorial) distance  $a = a_1 - a_2$  between the beams.

Figure 1, Figure 2 and Figure 3 represent a perfectly aligned interferometers. As it is well know, in practice, in order to observe interference *fringes*, the interferometer must be slightly unaligned (if not, just a plain bright or dark pattern is seen). That is, the angles of the mirrors and beam splitter don't have exact  $45^\circ$  inclinations and the beams that interfere at  $D'$  are not parallel. In this case, the previously described effect is greater.

Figure 4 shows an interferometer slightly unaligned. The misalignment is represented in the figure with the lateral displacement between beams  $\vec{a} = \vec{a}_1 - \vec{a}_2$ . The distances  $|\vec{a}_j|$  correspond to the modulus of the projection of  $\vec{d}_i^j$  over  $\vec{a}$ .

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

The distances  $|\vec{d}_j^i|$  from the source of light to the observation point are equal to  $|\vec{d}_j^i| = \sqrt{|\vec{r}_j^i|^2 + |\vec{a}_j|^2}$ , where  $|\vec{r}_j^i| = ct_j^i$ .

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

$$\Delta\Phi = k\left(|\vec{d}_1^2| - |\vec{d}_2^2|\right) - \left(|\vec{d}_1^1| - |\vec{d}_2^1|\right) \quad (0)$$

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

From equation (0) it can be seen that the more unaligned the interferometer the greater fringe shift must be measured.

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

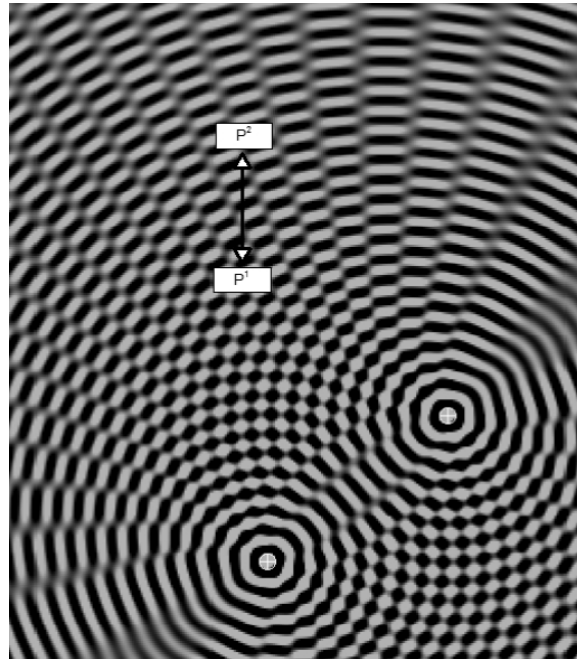


Figure 5 Schematic diagram of a snapshot of spheres of light propagating in a slightly unaligned one-way interferometer. Notice that there is only one source of light that is reflected from the same mirror at different moments in time. The two beams that form the interference pattern are one transmitted at A and the other reflected at A' (both encounter at D' to make the interference). 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 example figure, the observer would measure  $N \cong 1,5$ .

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

Since there is no relative motion between parts of the interferometer, according to the Special Theory of Relativity (STR) no fringe shifts are expected to be seen 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 could be detected if a preferred frame exists, relative to which light's speed is isotropic and equal to 'c'.

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 all involved distances 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. Analogous to a movie being seen smaller or bigger when projection screen is moved farther or nearer the projector, fringe shifts are *observed* without any phase change occurring. In this paper we have considered a rotation of the interferometer of  $90^\circ$ . However, it can be verified that the maximum fringe shift occurs during a  $180^\circ$  rotation.

If this experiment is realized and the effect is not seen, it can almost definitely rule out the possibility of the existence of a preferred frame. On the contrary, if the effect is seen, a paradigm shift is to be expected, with a lot of obvious implications in EM forces, General Relativity, and Copenhagen's interpretation of quantum physics (think for example in the EPR paradox).

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