Is detection of Fitzgerald-Lorentz contraction possible?

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August 7, 2008

Abstract

Visual perception of Fitzgerald-Lorentz contraction is known to be theoretically impossible, and this can be demonstrated pedagogically with the aid of simple spacetime diagrams of one spatial dimension. Such diagrams also demonstrate, simply and directly, that the apparent length of a moving meter stick changes as it passes by and can even look elongated. In addition, measurement of a moving meter stick with instruments, as opposed to visual perception, must be inherently ambiguous, as the length measured depends on clock synchronization, which is widely considered to be conventional. In fact, for some synchronization choices, a moving meter stick would be measured as greater than one meter. Thus, the well known Fitzgerald-Lorentz contraction factor \( \sqrt{1 - \frac{v^2}{c^2}} \) would generally not be seen visually, and would only be measured in a system employing one particular (Einstein) synchronization convention.

1 Introduction

1.1 Background

Although statements such as “... the experimental evidence for relativity is so overwhelming that physicists now regard ... [length contraction and time dilation] as commonplace”, (Kleppner and Kolenkow[1]), and “... special relativity theory represents a theory experimentally checked in all of its aspects” (Brumberg[2]) are widespread, they are not 100% true.

Certainly, time dilation, mass-energy equivalence, and the invariance of two way light speed were verified early on by the Michelson-Morley,[3] Kennedy-Thorndike,[4] Ives-Stilwell,[5] and various cyclotron experiments. Many later experiments greatly improved on the accuracy of the earlier ones (see Haugen and Will,[6] and Klauber.[7])

Somewhat obscured in summaries of experiments testing special relativity theory (SRT) is the fact that Fitzgerald[8]-Lorentz contraction of moving bodies has never been directly observed. The reason often cited is one of practicality. At low speeds, the effect is simply too small to detect. At high speeds, the effect may be greater, but monitoring length on an object zipping by at close to the speed of light is well beyond the capability of real-world instruments.

One might therefore pose a reasonable question. If instruments of sufficient accuracy could one day exist, could we then witness Fitzgerald-Lorentz contraction? The answer reveals some intriguing facets of SRT.
1.2 Seeing vs. Measuring: Framing the Question

In SRT we often refer to an “observer”, and concomitant with that term is the tendency to think of someone who “observes” (i.e., “sees” with the eyes) such things as moving rods looking shortened. Unfortunately, the term is misleading.

What we are really referring to in SRT when we speak of an observer, is a “measurer”. The equations of SRT incorporate quantities an experimentalist would measure at a given event. If we are distanced from certain events, what we see are the light rays emanating from them. These do not reach our eyes instantaneously, of course, but travel to us at the speed of light. So, light from two events which occur simultaneously, but are located at different distances from an observer, will be seen at different times by that observer. So from the point of view of “seeing” the events, they do not appear simultaneous, though from the point of view of “measuring” the events with clocks at their respective locations, they are. As first noted by Lampa[9] and Terrell[10], this has significant implications for Fitzgerald-Lorentz contraction.

So we have to concern ourselves with two different questions.

1. Could we ever see Fitzgerald-Lorentz contraction?
2. Could we ever measure it?

After a brief review of Fitzgerald-Lorentz contraction in SRT in Section 2, we will address the first question in Section 3, the second in Section 4, related issues in Sections 5 and 6 and for completeness, concomitant issues regarding time dilation observation in Section 7. The central theme of Section 3 is known, though certainly not widely, and has not before, I submit, been presented in as simple and pedagogic a manner as it is herein.

2 Fitzgerald-Lorentz Contraction Reviewed

The contraction of length of moving objects is traditionally deduced from the Lorentz transformation,

\[ cT' = \gamma \left( cT - \frac{v}{c} X \right) , \quad (a) \]

\[ X' = \gamma \left( X - \frac{v}{c} cT \right) , \quad (b) \]

(1)

where two spatial dimensions are suppressed, primed and non-prime coordinates represent two different coordinate frames with common origin at \( T = 0, v = |v| \) is the speed of either frame measured in the other, spatial axes are collinear and aligned with \( v, c \) is the speed of light, and \( \gamma = \frac{1}{\sqrt{1 - v^2/c^2}} \). The length of a moving rod is determined as the distance between endpoints of the rod provided the determination is made when the endpoints are at the same moment in time (i.e., they are simultaneous in the observer/measurer’s coordinate system.)

Thus, we consider two events A and B which occur simultaneously in the \( X - T \) coordinate system and are located at opposite ends of a meter stick fixed in the \( X' - T' \) system. From (1)(b),

\[ X_B' - X_A' = \gamma \left( X_B - X_A - \frac{v}{c} (cT_B - cT_A) \right) , \quad (2) \]

where the time terms drop out because of simultaneity of A and B \( (T_A = T_B) \). Thus a distance of one meter measured as \( X_B' - X_A' \) in the primed frame is less than one meter by \( 1/\gamma \) as measured in the unprimed frame.
This is shown graphically in Fig. 1, where, as is well known, orthogonality in Minkowski space comprises space and time axes with inverse slopes. Note in the figure that the meter stick fixed in the primed frame has length as measured therein, with simultaneous endpoints ($T'_C = T'_A$), as $X'_C - X'_A = 1$ m, and since $X'_C = X'_B$, then $X'_B - X'_A$ also equals unity in (2).

We, in the unprimed frame, have grid lines at one meter intervals laid out along our X axis. Events A and D are on two of these grid lines, one meter apart. We record the location at which each endpoint of the moving meter stick is passing (events A and B) when the clock at each location has the same reading ($T = 0$ in Fig. 1). The distance between these locations is less than 1 meter (i.e., $X_B - X_A < 1$ m), so we consider the moving meter stick to be contracted.

In the unprimed frame, the simultaneity events at the endpoints are different events than they are in the primed frame, and this results in the famed Fitzgerald-Lorentz contraction.

### 3 Visual Images of Moving Meter Sticks and Fitzgerald-Lorentz Contraction

The result of the previous section has everything to do with measurement, particularly the measurement of the local clock readings at events A and B, and nothing to do with what an observer would see with her eyes.

#### 3.1 Relativistic “Seeing” Historically

In a seminal, but little appreciated article, Lampert [9] first addressed the issue of visual appearance of a relativistically moving rod. In further ground breaking work, Terrell [10] showed that a three dimensional object traveling at relativistic speed would appear in a photograph as rotated and changed in scale. Many authors subsequently expanded on Terrell’s work. Among these, Weinstein [11], Scott and Viner [12], Hickey [13], and Deissler [14] noted the particular phe-
nomenon addressed in the present Section 3, though none, I contend, have done so in a manner as pedagogically suited for presentation to new students of relativity. Specifically, we take a simpler tack and consider only one dimensional moving meter sticks, portrayed in spacetime diagrams of only one spatial dimension, such as that of Fig. 1.

3.2 Defining “Seeing”

By “see” herein, we mean the following. A stationary observer close to the line of travel of a moving meter stick looks at one end of that meter stick and sees which grid line in her coordinate system that end looks coincident with. By doing likewise with the other end at the same moment (on her local clock), she can count the grid lines between endpoints and thus determine the length she is seeing. This eliminates the need to correct for apparent diminution, visually, of objects that are more distant, as well as the need for considering more than one dimension for viewing perspective. Further, it parallels the method we have for measuring any length or velocity non-locally. That is, we consider length or velocity to be that which would be measured by meter sticks proximate to the object being measured.

The following analysis is ideal, however, in that, being one dimensional (spatially), it assumes the viewer is coincident with the line of travel of the moving meter stick. In the real world, the observer would then only be able to see the front face of the meter stick and unable to see which grid lines the ends are adjacent to. Fuller, and more complicated, analyses by Scott and Viner[12], Hickey[13], and Deissler[14] show that a viewer close to, but not precisely aligned with, the line of travel will see, to high approximation, the meter stick behavior described in the simplified, single spatial dimension case considered herein.

3.3 Relativistic Seeing Via Spacetime Diagrams

As can be gleaned from Fig. 2, due to the requirement that light photons must travel to an observer’s retina, and this takes time, two observers (O₁ and O₂) fixed at different locations in the unprimed frame will not actually see the same length for a meter stick moving relative to them. Fig. 2 shows the paths taken by light rays from each end of the moving meter stick that both reach an observer’s eyes at the same time (same event) and demonstrates that each observer will generally not see a moving meter stick contracted by 1/γ.

As Gamba[15] noted, “No one will ever see the Lorentz contraction. [To be able to do so], one has to assume an infinite velocity of light...”. Fitzgerald-Lorentz contraction is not something an observer simply sees visually.

It should also be noted that the length seen changes as the object moves past the seer. This can be understood by making other sketches similar to Fig. 2 in which one of the observers is shown at a different time (same X, different T). It can also be understood from Fig. 3 by simply noting that an observer (O₁RH) nearer the leading end of the moving object sees a longer length than an observer (O₁LH) near the trailing end, and that as the object moves by, the relative positioning of an observer to the moving object changes.

Surprisingly, for certain observers at certain times, such as O₁RH in Fig. 3, the moving meter stick length can not only look greater than the Lorentz contracted length, but greater than one meter.

Fig. 4 is physical depiction of this, showing a “stationary” observer situated ahead of a meter stick mounted on a moving train. Light from the trailing end of the moving meter stick
Figure 2: Contraction Seen Varies with Observer Position

Figure 3: Elongation Seen by Some Observers
must be released before light from the leading edge, in order for both to arrive at the observer at the same instant. But during the time between departures of the two light pulses, the meter stick moves. Hence, it appears longer than one meter to the observer shown in the figure.

With a modicum of thought, one can convince oneself that an approaching, non-accelerating meter stick looks longer than one meter by a constant value, until the moment we see the leading edge coincident with us. Then the meter stick starts looking shorter and shorter, for an instant (when we see ourselves as midway between the ends) looks contracted by the Lorentz factor, and then looks like it continues to shrink, until the trailing edge passes by us. Thereafter, the moving meter stick, looking more contracted than $1/\gamma$ m, continues to look this same constant length as it recedes.

### 3.4 Quantifying visual perception

We can use Fig. 5 to determine the precise length $l_0$ we would see for an approaching meter stick having speed $v$. A stationary observer at event M, when she is coincident with the meter stick leading edge, sees light from the trailing edge that left at event N. The length such observer would see would equal the spatial distance between events Q and M. To find this, we need to find the distance $|X_N|$, the magnitude of the spatial coordinate of event N, and add that to $\sqrt{1 - v^2/c^2}$, the spatial coordinate of event M. To do this, we need only to find the intersection of two world lines, that of the light ray and that of the trailing edge.

The trailing edge world line is

$$cT = \frac{c}{v} X, \quad (3)$$

and the light ray world line is

$$cT = X - \sqrt{1 - v^2/c^2}. \quad (4)$$
Solving simultaneously, we find

\[ X_N = -\frac{v \sqrt{1 - v^2/c^2}}{c} \left( 1 - \frac{v}{c} \right), \]  

(5)

and thus

\[ l_a = |X_N| + \sqrt{1 - v^2/c^2} = \frac{\sqrt{1 - v^2/c^2}}{1 - v/c}. \]  

(6)

In similar fashion, one can derive the comparable relation for the length \( l_r \) of a receding meter stick,

\[ l_r = \frac{\sqrt{1 - v^2/c^2}}{1 + v/c}, \]  

(7)

which differs from (6) only in the sign before the speed term in the denominator. These relations are plotted in Fig. 6.

3.5 Conclusion: Visual Perception of Length

We conclude that Fitzgerald-Lorentz contraction is not something that is actually seen by physical observers, and that the length change seen varies with observer position and as the observed
object moves.

4 Fitzgerald-Lorentz Contraction and Conventionality of Synchronization

One might then ask if Fitzgerald-Lorentz contraction is, in theory, readily measurable, even though it cannot be visually seen. The answer to this question is both subtle and interesting, and involves a contemporary issue in relativity theory, conventionality of synchronization.

4.1 Conventionality of Synchronization

Synchronization in SRT involves the setting of standard clocks at different locations within a given reference frame. Since any number of settings on a given clock are possible, one must decide on a convention to use. The most common of these is the Einstein synchronization convention.

In Einstein synchronization, the one-way speed of light is assumed invariant, isotropic, and equal to $c$. One starts with a clock at one’s own location, and at time $t_1$ on that clock, sends a pulse of light to a second location, whose distance $d$ from the first is known. The time elapsed during the flight of the light pulse is $d/c$, so one sets the time on the second location clock such that at the instant it received the light flash, it would have read

$$t_2 = t_1 + d/c.$$  (8)
Note this ensures that any one-way measurement of light speed will result in a value of \( c \), given that we use the local clocks at the emission and reception points to measure \( \Delta t = t_2 - t_1 \).

Note also that the two-way (back and forth, reflected) speed of light is measured using only the clock at the first location, so no synchronization convention is needed to do that. The invariance of two-way light speed has been measured in many experiments, beginning with Michelson-Morley, and, for inertial systems at the least, has always been found invariant and equal to \( c \).

However, as has been argued by many (see references in Anderson et al\[16\]), there is an interrelationship between one-way light speed and synchronization convention. Synchronize your clocks in a different way, and the one-way speed of light is different (and not equal to \( c \).) Conversely, assume a different one-way speed of light, and you get a different synchronization scheme for the clocks in your coordinate system.

The class of acceptable alternative synchronization schemes is limited to those for which the two-way speed of light remains invariant and equal to \( c \), as has been proven experimentally. That is, the one-way speed of light in one direction would be less than \( c \); in the other direction, greater than \( c \); and the dependence would be such that the average round trip speed remains \( c \).

Much work has been done on this, and most who have done that work believe that non-Einstein synchronizations, though more cumbersome mathematically, predict the very same observable quantities as traditional Einstein synched SRT. That is, there is no way to discern, via experiment, between synchronizations. They are merely different conventions, any one of which can be considered a valid representation of the physical world, and in this sense, synchronization is merely a gauge. (See Ohanian,\[17\] Choy,\[18\] Martinez,\[19\] Macdonald,\[20\] and Klauber\[21\] for a debate over the opposing position.)

### 4.2 Synchronization Convention and Fitzgerald-Lorentz Contraction

Fig. 7 is a graphical illustration of the effect of an alternative synchronization in the stationary frame. Note that since simultaneity means having the same time on two different clocks, for the \( X-cT \) system, the \( X \) axis represents events which are all simultaneous (all with \( T = 0 \)). This is an Einstein synched coordinate system, which results in horizontal space and vertical time axes. For an alternative synchronization convention (\( x-ct \) coordinate system with dashed coordinate grid lines) in the same frame, different events are simultaneous, so the set of such events with \( t = 0 \) (the \( x \) axis) is no longer horizontal (though the time axis remains vertical.)

Now, consider deducing the contraction effect for two different synchronization schemes. We use the same criterion as commonly used in traditional SRT, i.e., the endpoint events of the moving rod are measured when they are simultaneous.

As can be seen in Fig. 7, each synchronization convention (spatial axis slope) results in a different measured length. That is, the intersection point of the moving meter stick’s right end worldline with the spatial axis will be different for different simultaneities in the stationary frame, and thus the length seen in that frame would depend on the simultaneity chosen therein.

So if synchronization is a convention, then measurement of the contraction of a moving rod is also conventional\[22\] \[23\]. That is, we are hard pressed to say that there really is an absolute physical effect, agreed to by everyone and witnessed in the real world, whereby moving objects contract by a particular factor \( 1/\gamma \).

Fig. 8 demonstrates another surprising feature of conventionality of synchronization. That is, not only can the \textit{measured} length of a moving meter stick be greater than \( 1/\gamma \) m, it can, for
some synchronization choices (such as the $x-ct$ coordinates in Fig. 8), actually be greater than 1 m. The moving meter stick does not have to be measured as contracted, it can be elongated.

Note, from Fig. 2 and Fig. 3, that the eyes of any particular observer will see the same thing as an object moves by him, regardless of the synchronization convention chosen (i.e., of the slope of the $X$ axis.) The only things that matter, as far as visual observation is concerned, are where the observer is located and the slope of the world lines of points in the object.

4.3 Conclusion: Measurement of Length

So, consistent with many other analyses of conventionality in synchronization, no physical world effect occurs from which one can select one synchronization scheme as more fundamental than another. And, the famed moving rod “contraction” effect varies with synchronization choice.

5 Revisiting the “Seeing” of Fitzgerald-Lorentz Contraction

Sherwin[24] describes a means to correct for the speed of light using a pulsed radar system, so that the map, plan-position display for such a system would show what one would see if one could see the rod endpoints instantaneously, rather than time delayed by the light travel times. In contemporary times, one could envisage a computer program that could also do this, and display an image of the “true” Fitzgerald-Lorentz contracted meter stick.
Figure 8: Elongation Measured in Non-Einstein Synched Coordinate System

However, these approaches determine time delays by assuming a one-way light speed of \( c \), i.e., Einstein synched observer coordinates. With an alternative, equally valid, observer synchronization scheme, and concomitant different one-way light speeds, one would see an image with a different length for the moving meter stick. So, there really is no “true” Fitzgerald-Lorentz contracted length factor.

6 The Dewan-Beran-Bell Spaceships

Dewan\[25\][26], Beran\[25\], and Bell\[27\] describe what has become a classic thought experiment in favor of the reality of Lorentz contraction. In it, two spaceships, \( S_1 \) and \( S_2 \), are connected by a taut thread, and for a period of time, carry out identical acceleration histories, as measured by a “stationary” observer. That is, as measured by the stationary observer, the two ships increase speed until they reach a constant common velocity, all the while keeping the same distance between them.

From the point of view of Fitzgerald-Lorentz contraction, the thread tries to contract, but the motion of the two ships prevents it. Stresses form and increase as the ships’ speed increases, until the thread breaks. Though many of Bell’s CERN colleagues originally thought the thread would not break, it is now universally agreed that it, indeed, will. One might then presume that this generally accepted result “proves” the physical reality of Fitzgerald-Lorentz contraction.

However, the problem, as stated, presupposes Einstein synchronization. Consider the same experiment with different synchronization in the stationary observer’s frame, such that for the
final constant velocity of the two ships, there would be no contraction measured on a moving, free thread/meter stick. This is a synchronization choice precisely between the two regimes wherein a meter stick moving at the final velocity would be measured to contract or elongate. While one might naively expect no broken thread in this case, one would find the exact same result, a broken thread, though the reason is now different. With this synchronization, the lead ship $S_1$ would be measured to start accelerating before the trailing ship $S_2$. Thus, the distance between them would not be measured in the stationary frame as constant, but increasing. And the increasing distance would break the thread.

Any other synchronization scheme would produce the same effect, though the degree of length change and difference in starting times would vary. Once again, we find the same measurable physical effects, though the conventional quantities vary, and there is no way to determine a preferred synchronization. The resulting stresses are physically real. But since Fitzgerald-Lorentz contraction varies with convention, we would be hard put to say that it is physically real.

7 Time Dilation

Note that, like length contraction, we cannot generally “see” time dilated by the Fitzgerald-Lorentz factor either, as an approaching clock (atomic or otherwise) will appear to beat faster than a receding clock, due to the Doppler effect. Subtracting this effect out of an observation will, of course, give us the appropriate time dilation result. But we could not see the effect directly with our eyes.

Nevertheless, if a clock were to be passing by us transversely (direction of travel perpendicular to our line of sight), we would see, at least to high approximation, a pure time dilation by $1/\gamma$. Hasselkamp et al. seems to be the only inertial experiment to date that has verified this effect for a detector actually aimed at 90 degrees to the object’s velocity.

With regard to certain means of measurement, however, we run into a similar difficulty as with length contraction. If a clock moves from 3D point $p$ to 3D point $q$ in our frame, we can compare the time on that clock with the local clocks at $p$ and $q$ as it passes by them. But the local clock settings depend on our choice of synchronization. So, in this regard, a measurement of this type for time dilation on the moving clock with respect to time in our system must also be ambiguous.

However, round trip clock time, like round trip light speed, has no ambiguity associated with it, as we measure the departure and arrival times of the moving clock with the same local clock. And experimentally, this has always shown the traveling clock time to be dilated by $1/\gamma$.

Time dilation and length contraction are further similar in that viewers of both located half way between the sides/ends of a moving clock or meter stick will find time and length to be altered in the familiar way by a factor of $\gamma$.

8 Summary and Conclusions

The question posed in the title of this article must be answered with care. As seen by the eyes, a moving meter stick does appear to have length unequal to one meter. But, due to the finite speed of light, it is not generally different by the factor $1/\gamma = \sqrt{1 - v^2/c^2}$, the length looks different to different observers, the length can appear greater than 1m, and the length appears
to change as the object moves by. However, at the specific instant when an observer sees himself as midway between the meter stick endpoints, he will see a length of \( \frac{1}{\gamma} \) m.

Further, Fitzgerald-Lorentz contraction cannot be measured, in the sense that the specific factor by which an object can be considered physically contracted depends on the choice of synchronization. In fact, for some synchronization conventions, the object would be measured as *elongated*. The famous contraction factor of \( \frac{1}{\gamma} \) is only valid for one synchronization convention (Einstein) and thus has no independent physical reality.

We must therefore be cautious in 1) promoting time dilation and Fitzgerald-Lorentz contraction as similar phenomena that have both been verified experimentally, and 2) attempting to extrapolate Fitzgerald-Lorentz contraction by assuming it applies directly to certain physical situations. The latter include the well known traditional approach to relativistic rotation, in which it is often assumed that rods on the circumference of a rotating disk contract physically by a factor of \( \frac{1}{\gamma} \). Certain extant controversies in relativistic rotation (Rizzi and Ruggiero[29]) may have their roots in this assumption[30] (Klauber[31]).

Fitzgerald-Lorentz contraction is unlike round trip time dilation, mass-energy dependence, and two-way light speed invariance, which are manifestly convention independent. It is also unlike visual observation of moving objects, which is also convention independent. In contrast, it is much like, and closely linked to, one-way light speed and synchronization gauge.[32]

9 Acknowledgements

I thank Alan Macdonald, John Mallinckrodt, and Robert Krotkov for helpful comments, and Alan Macdonald and John Mallinckrodt for bringing to my attention certain references with which I was unfamiliar.

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[32] Readers wishing to pursue this topic further may find the following articles of interest. W. Rindler, “Length contraction paradox”, Am. J. Phys. 29(6), 365-366 (June 1961). E. Marx, “Lorentz Contraction”, Am. J. Phys. 35(12), 1127-1130 (Dec 1967). D. W. Lang, “The meter stick in the match box”, Am. J. Phys. 38(10) 1181-1184 (Oct 1979). A. Macdonald, “Clock synchronization, a universal light speed, and the terrestrial redshift experiment”, Am. J. Phys. 51(9), 795-797 (Sept 1983). R. A. Sorensen, “Lorentz contraction: A real change in shape”, Am. J. Phys. 63(5), 413-415 (May 1995). A. Gjurchinovski, “Reflection of light from a uniformly moving mirror”, Am. J. Phys. 72(10), 1316-1324 (Oct 2004). A. Gjurchinovski, “Relativistic addition of parallel velocities from Lorentz contraction and time dilation”, Am. J. Phys. 74(9), 838-839 (Sept 2006). D.V. Black, M. Gop, F. Wessel, R. Pajarola, and F. Kuester, “Visualizing flat spacetime: Viewing optical versus special relativistic effects”, Am. J. Phys. 75(6), 540-545. (June 2007). E. Pierce, “The lock and key paradox and the limits of rigidity in special relativity”, Am. J. Phys. 75(7), 610-614 (July 2007). C.M. Savage, A. Searle, and L. McCalman, “Real time relativity: Exploratory learning of special relativity”, Am. J. Phys. 35(9) 791-798 (Sept 2007).