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Not peer-reviewed version

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Posted Date: 15 April 2026

doi: 10.20944/preprints202603.2291.v3

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Communication

Recovering Absolute Time in the Lorentz Transformation -The Apparent Nature of Relative Simultaneity

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Abstract

Special Relativity holds that the relativity of simultaneity is an inescapable physical consequence of the Lorentz Transformation (LT). This study shows that the phenomenon disappears when a position 4-vector from the stationary frame S is transformed into a fully covariant form in the moving system S' , which means the transformed 4-vector is not expressed by coordinates of S . This step is mandatory if S and S' are to be physically equivalent. Standard LT matrix multiplication yields a 'mixed-coordinate' representation in which the stationary time t remains the evolution parameter. An additional functional step is required to replace t with expressions in terms of the local time t' . When this procedure is applied to any two simultaneous events in S , the resulting time interval in S' is zero ($\Delta t' = 0$). This demonstrates that the textbook claim of relative simultaneity is tied to the intermediate mixed-coordinate stage and does not reflect a physical effect once full coordinate homogeneity is enforced in the moving frame. The resulting physical effects' predictions remain fully consistent with all observable consequences of special relativity and are equivalent to those obtained in the Tangherlini framework. We argue that absolute-like simultaneity emerges naturally as a formal necessity for the consistent transformation of the position 4-vector into a fully covariant form.

Keywords: coordinate homogeneity; Lorentz invariance; relative simultaneity; equations of motion; temporal relations

"there is more to structure in special relativity than meets the eye."

Jose G. Vargas [1]

1. Introduction

Relative simultaneity became a hallmark of Special relativity since 1905 Einstein released his seminal paper [2] (first widely available 1923 translation in English). Einstein derived Lorentz transformation mapping the moving system S' coordinates x', y', z' and t' in terms of x, y, z and t of the stationary system S . The overwhelming interpretation was that every observer has their own timeline in which they judge events happening elsewhere such that they may disagree on whether simultaneous events that really happened in another system are factually simultaneous or not. The summary of this peculiar and counterintuitive phenomenon has been captured by Eddington [3], (p. 49) who famously declared: "There is no absolute Now, but only the various relative Nows differing according to the reckoning of different observers...". We found it illuminating to analyse this situation using the LT matrix approach transforming 4-vectors from a stationary system S vector to their image in the moving system S' . We demonstrate how the matrix approach may clear potential misunderstandings regarding relative simultaneity.

The following LT matrix representation in standard axes' configuration is used in subsequent considerations. The matrix approach restores the direct algebraic route and reveals an intermediate 'mixed-coordinate' stage that is usually not highlighted in textbook treatments of relative simultaneity:

$$\Lambda_v = \begin{bmatrix} \gamma_v & -v\frac{\gamma_v}{c} & 0 & 0 \\ -v\frac{\gamma_v}{c} & \gamma_v & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \end{bmatrix} \quad (1)$$

$$\gamma_v = 1/\sqrt{1 - v^2/c^2}$$

2. Methods

2.1. Lorentz Transformation Procedure

There are two approaches to LT. The traditional one, in the simplest case uses explicit algebraic expressions of LT corresponding to the original Einstein-derived form as shown in Equation 2, to which we refer as 'direct Lorentz transformation' (DLT)¹.

$$\begin{cases} t' = \gamma_v(t - vx/c^2) \\ x' = \gamma_v(x - vt) \end{cases} \quad (2)$$

The 'inverse Lorentz transformation' (ILT) can be obtained by solving the system presented in Equation (2) for variables x and t which was not shown in [2], is:

$$\begin{cases} t = \gamma_v(t' + vx'/c^2) \\ x = \gamma_v(vt' + x') \end{cases} \quad (3)$$

The other approach uses the LT matrix from Equation (1) applied to the 4-vectors. This method was not in common use in 1905 and the change of coordinates was accomplished frequently by substituting time and space coordinates with expressions from ILT Equations (2). This was first demonstrated by Einstein, who must have used the ILT while proving that the speed of light is invariant in all inertial frames [2], (p.46). The DLT-based method continued to be used and still is today in many publications and textbooks to present a proof of relative simultaneity, for example Tolman [4], (p. 51), Feynman [5], (p. 15-13), Ugarov [6], (p. 73) and University of California lecture notes². However, the difference is that Einstein's spherical wave transformation was not presented in detail but summarised by "after a simple calculation" [2], (p.46). The derivation process was reconstructed in the book of French [7], (p.81) where in fact the ILT in Equation (3) was explicitly utilised to substitute x and t in the equation of the spherical wave: $x^2 + y^2 + z^2 = c^2 t^2$ then after simplifications and grouping, the covariant form emerges: $x'^2 + y'^2 + z'^2 = c^2 t'^2$. The LT matrix approach is elegant, more robust and less error-prone hence eliminating hand-picked substitutions in a series of algebraic equations. Educational approach to the matrix method can be found in the book of Steane [8].

The typical use of the LT matrix in physics is as follows: $\Lambda_v \mathbf{K} = \mathbf{K}'$ where $\mathbf{K}, \mathbf{K}'$ are wave 4-vectors are before and after the transformation respectively. For many physical problems this is a one-step complete matrix multiplication. The problem becomes more complicated when the 4-vector is an explicit function of time. The matrix multiplication result contains the stationary system time t , which makes it a 'mixed-representation'. It is not immediately clear how to obtain the homogenous representation of the original vector in the general case. In classical mechanics using Galilean matrix the problem does not exist because $t = t'$. We propose that the second step must be added after the matrix multiplication, where the first component is used to convert time t to t' by equating the

¹ The terms 'Direct Transformation' and 'Inverse transformation' are used by Ugarov [6], (p.67) as introduced above.

² Keith Fratus, The Lorentz Transformation - Lecture Notes, University of California, Santa Barbara (updated in 2025) Page 3 within

temporal component as: $ct'=(\mathbf{X}'_c)_0$ as shown in Equation (60). This procedure immediately recovers the covariant form of the equations of motion (EOM) for all explicit EOMs in the 4-vector form. However, this becomes debatable because the relativity of simultaneity no longer appears. We formulate a hypothesis and attempt the proof in the following section.

3. The Hypothesis of Coordinate Homogeneity

The Lorentz Transformation process is typically treated as a sequence of coordinate substitutions or as a single-step LT matrix multiplication by a 4-vector. While the latter is sufficient for vectors not containing an explicit time variable, the resulting vector has a 'mixed-representation' of coordinates—containing the variable t remaining present, where t' could be reasonably expected—causing significant interpretation problems. To address this issue, we put forward the following hypothesis.

Hypothesis: For an inertial system S' to be functionally equivalent to S , its physical state must be expressed as a homogeneous 4-vector, reflecting the original representation in system S . Furthermore, there is only one, unique mathematically consistent form possible for each vector to maintain this functional equivalence.

Problem: Standard 'raw' result of the LT matrix multiplication yields a mixed-coordinate representation containing the stationary frame variable t .

Necessity: Because observers in S' have no direct awareness of time variable the other system, t must be eliminated.

Objective: Achieving true covariance requires that all components of the transformed vector are explicit functions of the local time t' .

The most reliable EOM of light emitted from the origin in S is represented by the following 4-vector:

$$\mathbf{X}_c = \begin{bmatrix} ct \\ ct \\ 0 \\ 0 \end{bmatrix}. \quad (4)$$

The transformation of the EOM 4-vector $\mathbf{X}_c$ using the LT matrix yields:

$$\mathbf{X}'_c \equiv \Lambda_v \mathbf{X}_c = \Lambda_v \begin{bmatrix} ct \\ ct \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \gamma_v ct - \gamma_v vt \\ \gamma_v ct - \gamma_v vt \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \gamma_v (c - v)t \\ \gamma_v (c - v)t \\ 0 \\ 0 \end{bmatrix}. \quad (5)$$

The result does not yet constitute a functional EOM for moving observers. There is no explicit t' coordinate and the spatial component $\gamma_v (c - v)t$ does not immediately imply the invariant speed of light. It is still a representation of the light propagation 4-vector in S' ; however, it is not in the covariant form directly comparable to $\mathbf{X}_c$. The presence of the other system's time variable t , of which S' has no direct awareness, makes it a 'mixed-representation'. Traditionally, it would require some narrative and algebraic manipulation to demonstrate that the speed of light is invariant. To achieve full coordinate homogeneity in S' , we must eliminate the stationary parameter t . A simple two step conversion makes this straightforward. The equation $(\mathbf{X}'_c)_0 = ct'$ validly introduces the t' variable and can be solved for t from the first temporal element as follows:

$$(\mathbf{X}'_c)_0 = ct' \Rightarrow t = \frac{ct'}{\gamma_v (c - v)}. \quad (6)$$

Substituting t using the formula from Equation (6) is the only possible way to make the resulting 4-vector covariant. Therefore, it is unique as stated in the hypothesis. The truth of the hypothesis is demonstrated, however; this is only one specific case, and this is not a formal proof, which is physically valid in general case. After substituting t to equation (5) the covariant form of the light vector in S' is:

$$\mathbf{X}'_c(t') = \begin{bmatrix} ct' \\ ct' \\ 0 \\ 0 \end{bmatrix}. \quad (7)$$

This confirms the postulates of special relativity. Therefore, when the 4-vector is expressed using explicit time t , the presented conversion is a necessary step. Now we can apply the same methodology to events. Since the interpretation of the intermediate form of the EOM in Equation (5) was initially problematic, we can anticipate difficulties in interpretation after transformation of events coordinate

Coordinates of events in the stationary frame S and locations x_1 and x_2 are:

$$\mathbf{E}_1 \equiv \begin{bmatrix} ct \\ x_1 \\ 0 \\ 0 \end{bmatrix}, \quad (8)$$

$$\mathbf{E}_2 \equiv \begin{bmatrix} ct \\ x_2 \\ 0 \\ 0 \end{bmatrix}. \quad (9)$$

For the event $\mathbf{E}_1$ and $\mathbf{E}_2$ LT matrix transformation yields:

$$\mathbf{E}'_1 \equiv \Lambda_v \mathbf{E}_1 = \Lambda_v \begin{bmatrix} ct \\ x_1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \gamma_v ct - \gamma_v vx_1/c \\ -\gamma_v vt + \gamma_v x_1 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \gamma_v (ct - \frac{vx_1}{c}) \\ \gamma_v (-vt + x_1) \\ 0 \\ 0 \end{bmatrix}. \quad (10)$$

$$(\mathbf{E}'_1)_0 = ct't \Rightarrow t = \frac{t'c^2 + \gamma_v x_1}{\gamma_v c^2}, \quad (11)$$

$$\mathbf{E}'_2 \equiv \Lambda_v \mathbf{E}_2 = \Lambda_v \begin{bmatrix} ct \\ x_2 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \gamma_v ct - \gamma_v vx_2/c \\ -\gamma_v vt + \gamma_v x_2 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} \gamma_v (ct - \frac{vx_2}{c}) \\ \gamma_v (-vt + x_2) \\ 0 \\ 0 \end{bmatrix}, \quad (12)$$

$$(\mathbf{E}'_2)_0 = ct't \Rightarrow t = \frac{t'c^2 + \gamma_v x_2}{\gamma_v c^2}. \quad (13)$$

After substituting the time expression from Equation (11), the covariant form of the first event vector in S' is:

$$\mathbf{E}'_1(t') = \begin{bmatrix} ct' \\ -vt' + \gamma_v x_1 - \frac{\gamma_v x_1 v^2}{c^2} \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} ct' \\ -vt' + x_1/\gamma_v \\ 0 \\ 0 \end{bmatrix}. \quad (14)$$

For the event $\mathbf{E}_2$ by the same process we get:

$$\mathbf{E}'_2(t') = \begin{bmatrix} ct' \\ -vt' + \gamma_v x_2 - \gamma_v x_2 v^2/c^2 \\ 0 \\ 0 \end{bmatrix} = \begin{bmatrix} ct' \\ -vt' + x_2/\gamma_v \\ 0 \\ 0 \end{bmatrix}. \quad (15)$$

While Equation (10) represents the standard coordinate mapping, Equation (14) represents the functionally complete state where relative simultaneity vanishes. Similarly for equations (12) and

(15).

Note that the conventional mixed-coordinate subtraction of the raw transformed time components from Equations (10) and (12), immediately yields the familiar non-zero result $\Delta t' = -\gamma_v(vx_2/c^2 - vx_1/c^2)$. However, once each event is expressed in the fully covariant form by solving the temporal component for the time t variable and substituting back yielding Equations (14) and (15), both events naturally acquire the same value of t' . Consequently $\Delta t' = t' - t' = 0$. This shows that the textbook claim of relative simultaneity arises from the intermediate mixed-coordinate representation, whereas the completed covariant representation enforces coordinate homogeneity naturally. The apparent disappearance of $\Delta t'$ is therefore a direct consequence of demanding that every component of the transformed 4-vector be an explicit function of the local time t' of the moving frame including relative concurrent motion of light signal $X'_c(t')$ as in Equation (7) and that of the system S itself at $-v$ velocity. The relative simultaneity claim approved by overwhelming consensus does not mean this is an error but rather one aspect of the more nuanced interpretation of conventional simultaneity.

The term 'conventional' does not carry a negative connotation because it was a deliberate stipulation which Einstein admitted deciding on the definition of simultaneity of his own free will [9] (p.28). Strohm [10] (p.109) confirms the convention as the correct classification, because there are other valid alternatives including the Tangherlini transformation (TT) operating in absolute time, also known as the absolute transformations.

The $\Delta t' = 0$ conclusion appears to be at variance with the standard interpretation of simultaneity first presented by Einstein [2], (p.42). Our approach may be questioned, because of what seems as a deliberate choice of assigning different events the same value of ct' . However, assigning x_1 to the first spatial component in the event coordinate 4-vector is not different than having an equation of motion but with zero velocity, which is perceived like any other relative motion in S'. The fact that without the discussed substitution there would be no valid equation of motion, is compelling. We now attempt to falsify the assertion about absolute simultaneity of distant events. It is natural to assume that in system S two concurrent light beams emitted from the origin at a delay δ_1 and δ_2 can generate events simultaneously expressed as:

$$X_{c1} = \begin{bmatrix} ct \\ c(t - \delta_1) \\ 0 \\ 0 \end{bmatrix}, X_{c2} = \begin{bmatrix} ct \\ c(t - \delta_2) \\ 0 \\ 0 \end{bmatrix}. \quad (16)$$

The LT applied to those EOMs using the previously described procedure yields:

$$X'_{c1}(t') = \begin{bmatrix} ct' \\ -\gamma_v(v + c)\delta_1 + ct' \\ 0 \\ 0 \end{bmatrix}, X'_{c2}(t') = \begin{bmatrix} ct' \\ -\gamma_v(v + c)\delta_2 + ct' \\ 0 \\ 0 \end{bmatrix}. \quad (17)$$

From the above we see that, for any pair of delays δ_1 and δ_2 , the two originally simultaneous events can be re-expressed in S' such that both occur at the same local time t' . This confirms that the time difference vanishes ($\Delta t' = t' - t' = 0$) once the full covariant representation is enforced. The construction demonstrates that absolute simultaneity can be recovered in the homogeneous 4-vector form while remaining fully consistent with the Lorentz transformation and all its empirical predictions. However, how do we know this solution is physically meaningful? Is Lorentz time absolute?

There seems to be no doubt that the systems S and S' are properly configured covariant systems. In this representation the temporal component is always ct or ct' , where t and t' represent the local master origin clock proper time initially projected to all clocks, which remain synchronised in the idealised scenario. Even in conventional synchronisation every clock state is the same as the master clock. All with an implicit assumption, that both local system clocks ensembles along the axes are synchronised by light signals enforcing Einstein's synchronisation. Only then, does the

application of the LT matrix yield a physically valid transformed event. The idealised master clocks in uniform motion instantaneously synchronised to 0 when coinciding, subsequently carry their own proper time evolving from the synchronised value onwards, together with their later synchronised local clock ensembles. The clocks on x and x' axes can be synchronised at the speed of light immediately after $t = 0$, well before an experiment is conducted. Although in relative motion and different rates, they remain in continuous temporal relation predictable by the theory of relativity. For any location there can always be two independent clocks running at different rates in the respective systems. Any event can be simultaneously recorded by them, providing a lasting record of what and when it happened, in which system.

The apparent absence of relative simultaneity requires further discussions to gain a wider consensus or falsification. We can use traditional LT equations allowing more than one choice. For relative simultaneity, one of the most common methods in literature [4], (p.51), [5], (p.15-13), [6], (p.73), lecture notes², (page.2) and [7], (p.93), use the original Einstein's DLT formulation, in other cases by substituting explicit variable t with the equivalent expression from the ILT as in Equation (3), most common in the position 4-vector conversions for example by French], (p.81).

To convert the E_1 4-vector's x component manually, we need to equate the this component content (x_1) to the x variable: $(E_1)_2=x_1 \Rightarrow x = x_1$, then using the ILT from Equation (3) results in $x_1=\gamma_v(vt' + x')$. Solving this for x' , the final outcome becomes $x' = -vt' + x_1/\gamma_v$. This is exactly what happened after the second transformation step: $(E'_1)_1 = -vt' + x_1/\gamma_v$ in Equation (15). Using the manual method, if there is any time variable left in spatial components, we need to substitute t with the first ILT equation content, thus introducing x' in the middle of the transformed equation. Then it must be solved for x' again. The operation equivalent to the second step transformation after the LT matrix multiplication is 'automatically' completed. Now, in the temporal component ct we can substitute the formula for t from the Equation (3). However, it becomes a 'mixed representation' and it is not possible to represent the 4-vector in the covariant form. Therefore, the only choice is to put ct' where it belongs, thus securing a covariant representation. We have just demonstrated that the second step concludes the covariant Lorentz transformation equivalent to using Equation (3) in the manual mode.

The disappearance of relative simultaneity is the result of demanding covariant representations in the equivalent systems, and the 'mixed-representation' contains all necessary information to accomplish this process. So, the moving observer's time found its way out of the shell of synchronisation convention. We can see it as an emergence of the 'absolute-like' time came naturally. The nature of this time is yet to be revealed. Absolute time is not fiction. It is explicit in independently developed Tangherlini's theory [11] from Einstein's field equations of General Relativity (GR) which preserves all relativistic effects as Einstein's theory. Both theories are equivalent by the virtue of GR coordinate independent formulation; it is not then a surprise that 'absolute-like' time had to emerge somewhere in special relativity as demonstrated.

For more than one hundred years physicists derive correct relativistic equations of motion this way or another, not being aware of what kind of time they are dealing with. It is also not surprising that relative simultaneity has no physical effect because in Tangherlini's theory it is inherently absent. Until this moment it was unthinkable these two theories could ever agree on relative simultaneity, but they did eventually. Furthermore, the TT (or absolute transformation) can be derived using Reichenbach synchronisation approach as demonstrated by Strohm [10] which is the second non-arbitrary alternative.

The absolute appearance of Lorentz time which we named 'absolute-like' requires more decisive determination. The only way to approach the problem is to compare it with Tangherlini time directly. Tangherlini framework requires one special absolute rest frame (ARF) where one-way velocity of light isotropy holds. For all other inertial frames only the empirically valid, round trip average speed of light is enforced, unlike in the special theory of relativity (STR) which postulated equivalence of all inertial frames.

It is noteworthy that the absolute-like time emerging from the two-step procedure yields physical predictions identical to those obtained in Tangherlini's absolute-time formulation, which is known to reproduce all observable relativistic effects. A detailed mathematical comparison is left for future work.

4. Discussion

The investigation of the Lorentz transformation reveals that the long-standing debate over relative simultaneity is based on an intermediate algebraic stage of the transformation rather than on a completed covariant physical representation. By changing the way LT is applied in the traditional and matrix approach, the rationale of coordinate homogeneity establishes a unified procedure applicable to both continuous 4-vector EOMs and discrete, distant events.

The transition from a 'mixed-coordinate' form to a fully covariant representation is not merely an optional interpretation but a mathematical necessity to maintain the functional equivalence of inertial frames. Because the local time t cannot be explained in terms of the relatively moving spatial coordinate x without circularity, it becomes evident that the 'absolute-like' time is naturally encoded within the structure of special relativity, being still the relativistic time and independent of coordinates convention. Special relativity is not physically affected but becomes stronger.

Ultimately, the apparent interval $\Delta t \neq 0$ is identified as a coordinate artefact of the manual processing of the LT, not elevated to achieve full covariance of the two systems. When the transformation is fully resolved, the time interval between distant events returns to $\Delta t = 0$, suggesting that while the Relative "Now" has served as a prominent academic narrative, it does not reflect the underlying physical reality of a covariant universe.

The invariant form of the light propagation equation $x' = ct'$ indicates that if the emission from the stationary source is continuous for a period of time and then stop, then in S and S' the leading and trailing edges of the propagating 'light stick' continue to move simultaneously in both systems. This implies that the same is true for a moving rigid rod, often discussed in textbooks. In fact, no special proof is necessary noting that the moving system x axis can be seen as segmented by adjacent one-meter rigid sticks. This is justified by the relevant Einstein's statement [2], (p. 43) :

Let each system be provided with a rigid measuring-rod and a number of clocks, and let the two measuring-rods, and likewise all the clocks of the two systems, be in all respects alike.

The special relativity is founded on the rigid body concept stated in the preamble of [2], (p. 38)

The theory to be developed is based—like all electrodynamics— on the kinematics of the rigid body, since the assertions of any such theory have to do with the relationships between rigid bodies (systems of co-ordinates), clocks, and electromagnetic processes.

As far as the covariant representation of the relative moving systems is concerned, a correction of well-known opinions that rigid rods in relative motion have their ends at different times may be required. Einstein [2], (p. 42) described this as follows:

Observers moving with the moving rod would thus find that the two clocks were not synchronous, while observers in the stationary system would declare the clocks to be synchronous. So we see that we cannot attach any absolute signification to the concept of simultaneity,"

The length contraction is preserved in both, the special relativity and Tangherlini frameworks. We concluded our investigation with a surprising result that in the special case under investigation, the emerging 'absolute-like' behaves like Tangherlini absolute time, both capable of describing physical processes correctly in inertial frames in relative uniform motion and the spatial offset present in conventionally synchronised clocks has no effect in this description.

5. Conclusions

1. The covariant Lorentz transformation of two simultaneous events gives the interval $\Delta t = 0$ in the moving frame. The phenomenon of relative simultaneity is found to be an artefact of the intermediate mixed-coordinate representation and vanishes in the complete covariant form.
2. The apparent relative simultaneity $\Delta t' \neq 0$ of the standard interpretation arises from reading the temporal components of the incomplete, ‘mixed-coordinate’ intermediate result, which retains the stationary frame variable t in the 4-vector components, as if it represented a physical measurement. However, in a system-specific observation only the local homogeneous variable t' possesses physical measurable significance.
3. This result may need to revive a debate on Eddington’s abolition of absolute “Now” and is offered for broader discussion by the community.
4. The Hypothesis of Coordinate Homogeneity has been proven within the limited scope of special cases under analysis but requires general validation and mathematical rigour.
5. The findings presented here do not suggest an error in the empirical successes of relativistic physics, as incomplete transformations and possible side-effects are unlikely to survive the rigorous experimental verification or practical application. Rather, this correction applies the academic and philosophical narratives that have grown around the ‘mixed-representation’ of the Lorentz transformation. While these narratives—such as the abolition of an absolute “Now”—are prominent in theoretical debate, they appear to be inconsequential artefacts of a specific mathematical representation, with no impact on the underlying physical reality.

Author Contributions: The author contributed to all aspects of the work.

Funding: This research received no funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: No data were generated.

Conflicts of Interest: The author declares no conflicts of interest.

Abbreviations

The following abbreviations are used in this manuscript:

ARF	Absolute Rest Frame
DLT	Direct Lorentz Transformation
EOM	Equation of Motion
GR	General Relativity
ILT	Inverse Lorentz Transformation
LT	Lorentz Transformation
STR	Special Theory of Relativity
TT	Tangherlini Transformation

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