Applied Physics Research; Vol. 6, No. 6; 2014
ISSN 1916-9639 E-ISSN 1916-9647
Published by Canadian Center of Science and Education

# Time Transfer and the Sagnac Correction in the GPS

Stephan J.G. Gift[1]

[1] Department of Electrical and Computer Engineering, The University of the West Indies, St Augustine, Trinidad and Tobago, West Indies

Correspondence: Stephan J.G. Gift, Department of Electrical and Computer Engineering, The University of the West Indies, St Augustine, Trinidad and Tobago, West Indies

*Dedicated to the memory of Franco Selleri, 1936-2013*

Received: September 9, 2014 Accepted: September 15, 2014 Online Published: October 14, 2014

doi:10.5539/apr.v6n6p1 URL: http://dx.doi.org/10.5539/apr.v6n6p1

**Abstract**

Time transfer from a GPS satellite to a receiver fixed on the surface of the rotating Earth is investigated. Using experimentally confirmed GPS light signal transfer time and a simple kinematic calculation, light speed variation is demonstrated for light travelling between the satellite and the ground-based receiver. This variable speed is also determined using classical principles applied to light transmission relative to the terrestrial receiver moving as a result of the rotating Earth, all within the Earth-Centred Inertial (ECI) frame. These results produce the accurate time transfer algorithm without any correction and lead to the re-interpretation of the "Sagnac correction" considered by the ITU to be a necessary time correction in GPS time transfer. They also lead to a revision of the Lorentz Transformations that yields the Selleri Transformations which better accord with the observed light speed variation and confirmed relativistic phenomena in the physical world.

**Keywords:** time transfer, GPS, ECI frame, Selleri Transformations, special relativity, light speed variation

## 1. Introduction

Time Transfer is the process of communicating time information by way of electromagnetic signal transmission across space. It is necessary for example to maintain coordination of time and frequency in systems operating at or close to the Earth and beyond. The method by which this is accomplished is based on an algorithm published by the International Telecommunications Union (2012) that has been rigorously tested and verified. It involves the transmission of a signal from one station to another such that system synchronization can be effected. Today it is part of the standard procedure employed in time comparisons between separated laboratories on the rotating Earth and is widely accepted (Nelson, 2011; Ashby, 2010; Petit & Wolf, 2005; Blanchet, Salomon, Teyssandier, & Wolf, 2001).

The approach described in the ITU recommendation (2012) and supported by Nelson (2011), Ashby (2010), Petit and Wolf (2005) and Blanchet et al. (2001) is to use light (electromagnetic) signal transmission in the Earth-Centred Inertial (ECI) frame where it travels at speed $c$ to determine the travel time from a satellite to a ground receiver which is moving at speed $v$. Because light speed in the ECI frame is known, this computation is very straightforward and yields a transfer time given by

$$\Delta t = \frac{R}{c} + \frac{\overline{v}.\overline{R}}{c^2} \tag{1}$$

where $R$ is the initial distance between the satellite and the receiver. This result has been experimentally confirmed. The publications by the ITU (2012) and several authors (Nelson, 2011; Ashby, 2010; Petit & Wolf, 2005; Blanchet et al., 2001) interpret the first term $R/c$ in (1) as the time for the light to traverse the distance $R$ at constant speed $c$ while they interpret the second term $\overline{v}.\overline{R}/c^2$ as the "correction" necessary for accurate time arising because of the movement of the ground receiver as a result of the rotation of the Earth. These researchers refer to this latter time adjustment as the "Sagnac correction" and this interpretation is widely accepted as being correct. In the ITU recommendation it is also stated that "The speed of light is $c$ in every inertial frame of reference". This claim of light speed constancy for one-way light speed in all inertial frames is a foundation principle in special relativity that has however not been confirmed (Zhang, 1997).

Light travel between a GPS satellite and a receiver on the surface of the Earth has been considered by Sato (2010). He concluded that for such light transmission there is light speed variation relative to an observer on the surface of the rotating Earth. Phipps (2006, p42) has also made reference to this phenomenon. These variable light speed results cast doubt on the interpretation by the ITU of constant light speed *c* with the "Sagnac correction". After careful examination of this situation, we have arrived at the conclusion that this interpretation of the time transfer equation (1) contained in the ITU recommendation and enjoying wide support is invalid and these results form the subject of this paper. We show using elementary analysis that the actual physical situation involves variable light speed for light travelling between the satellite and the moving ground receiver with no "Sagnac correction" being necessary for accurate results. These findings are reconciled with results previously presented by Selleri (2010) and the implications for space-time physics are thoroughly discussed.

## 2. Time Transfer in the GPS

In this section transfer time is derived following the approach by Ashby (2010). This is done by considering an electromagnetic pulse transmitted from a GPS satellite at position $\bar{r}_T$ and GPS time $t_T$ travelling at speed $c$ relative to the ECI frame to a ground receiver whose position at GPS time $t_T$ is $\bar{r}_R$ and whose velocity because of the rotation of the Earth is $v$ relative to the ECI frame. Let $\theta$ be the angle between the direction of propagation of the signal and $v$ which, because $v \ll c$ can be represented as shown in Figure 1. If the signal arrives at the receiver at time $t_R$ then for the signal transmission interval $\Delta t = t_R - t_T$ the receiver experiences a displacement $\bar{v}\Delta t$. For signal travel within the ECI frame from satellite to receiver at speed $c$ in time $\Delta t$, the signal displacement $c\Delta t$ is given by

$$c\Delta t = \bar{R} + \bar{v}\Delta t \tag{2}$$

where $\bar{R} = \bar{r}_R - \bar{r}_T$. Ashby proceeds by squaring both sides of equation (2) and truncating the resulting expansion to leading order in $v$ giving

$$(c\Delta t)^2 = (\bar{R} + \bar{v}\Delta t)^2 \approx R^2 + 2\bar{v}.\bar{R}\Delta t \tag{3}$$

From this and again for leading order in $v$,

$$c\Delta t = R\left(1 + \frac{2\bar{v}.\bar{R}\Delta t}{R^2}\right)^{1/2} \approx R + \frac{\bar{v}.\bar{R}}{R}\Delta t \tag{4}$$

Solving equation (4) approximately for $\Delta t$ yields

$$\Delta t = \frac{R}{c} + \frac{\bar{v}.\bar{R}}{c^2} \tag{5}$$

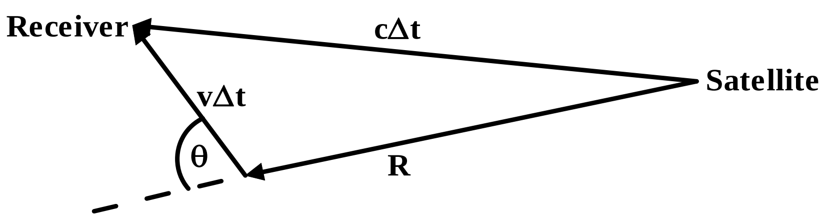


Figure 1. Light Transmission in the ECI Frame from GPS Satellite to ECEF Receiver

The interpretation of the transfer time in equation (5) presented by the ITU and several researchers is that the first term $R/c$ is the time for the light to travel the distance $R$ at speed $c$ as it travels toward the receiver fixed on the surface of the Earth and the second term is the "Sagnac correction" necessary because of the rotation of the Earth and consequent movement of the receiver. We now show using two approaches both involving elementary analysis that this interpretation is wrong.

### *2.1 Light Speed Determination Using GPS Transfer Time Measurement*

The transfer time $\Delta t$ in (5) for light travelling from the orbiting satellite to a ground-based receiver has been fully tested and experimentally verified and is routinely used in time comparisons. It is therefore accurate and can be used to evaluate the light speed $c_R$ relative to the ground receiver. Using the distance $R$ between the satellite and the receiver at the time of transmission of the signal, light speed $c_R$ is given by

$$c_R = \frac{R}{\Delta t} = \frac{R}{\frac{R}{c} + \frac{\bar{v}.\bar{R}}{c^2}} \tag{6}$$

But from Figure 1, $\bar{v}.\bar{R} = vR\cos\theta$ and hence (6) becomes

$$c_R = \frac{R}{\frac{R}{c} + \frac{vR\cos\theta}{c^2}} = \frac{c^2}{c + v\cos\theta} = \frac{c^2(c - v\cos\theta)}{c^2 - v^2\cos^2\theta} \approx c - v\cos\theta, v << c \tag{7}$$

Therefore elementary kinematics using the experimentally confirmed transfer time $\Delta t$ and the initial separation $R$ yields a light speed $c_R = c - v\cos\theta$ relative to the receiving station and not $c_R = c$ as claimed in the ITU recommendation. This result contradicts the principle of light speed constancy requiring light speed $c$ relative to the receiver but is consistent with variable light speed results previously presented (Gift, 2013).

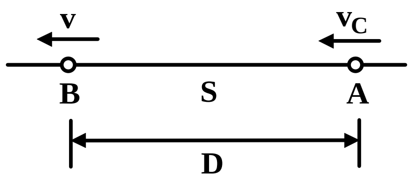


Figure 2. Vehicle at A and Pedestrian at B on the surface S

In order to remind the reader of the legitimacy of this light speed calculation, we examine in Figure 2 the case of an automobile at position $A$ moving at velocity $v_C$ relative to the surface $S$ (corresponding to light travel at velocity $c$ relative to the ECI frame) and a pedestrian a distance $D$ away at $B$ walking at velocity $v$ in the same direction as the automobile such that $v << v_C$ (corresponding to the receiver a distance $R$ away from the satellite moving at speed $v << c$ relative to the ECI frame). If $T$ is the time for the automobile to intercept the pedestrian, then from simple kinematics

$$v_C T = vT + D \tag{8}$$

where $vT$ is the distance moved by the pedestrian before interception. Equation (8) corresponds to Ashby's equation (2). Solving for time $T$ gives

$$T = \frac{D}{v_C - v} \tag{9}$$

Therefore velocity $v_{CR}$ of the automobile relative to the pedestrian is found by dividing the initial distance $D$ between the automobile and the pedestrian by the time to interception $T$ which gives

$$v_{CR} = \frac{D}{T} = \frac{D}{D/(v_C - v)} = v_C - v \tag{10}$$

This is the well-known result for relative velocity in classical mechanics and the elementary calculation in (10) is exactly that employed in (7) giving relative light speed $c_R = c - v\cos\theta = c - v$ for $\theta = 0^o$ the corresponding situation in Figure 1.

To further demonstrate the correctness of the relative light speed $c_R = c - v\cos\theta$ the transfer time $\Delta t$ is calculated using this speed. Thus

$$\Delta t = \frac{R}{c_R} = \frac{R}{c - v\cos\theta} = R\frac{c + v\cos\theta}{c^2 - v^2\cos^2\theta} = \frac{R}{c^2}(c + v\cos\theta), v << c \tag{11}$$

Equation (11) gives

$$\Delta t = \frac{R}{c} + \frac{Rv\cos\theta}{c^2} = \frac{R}{c} + \frac{\bar{v}.\bar{R}}{c^2} \tag{12}$$

which is exactly the transfer time (5) given in the ITU recommendations that has been rigorously tested and confirmed. It follows therefore that the GPS transfer time is $R/(c - v\cos\theta)$ and not $R/c$ with a "Sagnac correction" since the light travels toward the receiver at relative speed $c - v\cos\theta$ and not $c$. The interpretation that transfer time $\Delta t$ in (5) is really a travel time $R / c$ with a "Sagnac correction" $\bar{v}.\bar{R} / c^2$ simply promotes the illusion that light travels at speed $c$ relative to the receiver in the Earth-Centred Earth Fixed (ECEF) frame when in fact the light speed relative to the receiver is $c_R = c - v\cos\theta$.

*2.2 Light Speed and Time Transfer Using Relative Velocity in the ECI Frame*

The relative light speed $c_R$ can be determined in another way. The ECI frame is a frame that moves with the Earth in its orbit around the sun but does not share its rotation. In this frame GPS signals propagate in straight lines at constant speed $c$ relative to the frame. We can use the ECI frame and classical velocity composition to determine the relative light speed $c_R$ for light propagating from the GPS satellite to the ground receiver. Thus consider again the light pulse from the GPS satellite travelling at speed $c$ in the ECI frame and received by the ground receiver where the surface velocity is $v$ at angle $\theta$ relative to the direction of light propagation as shown in Figure 3.

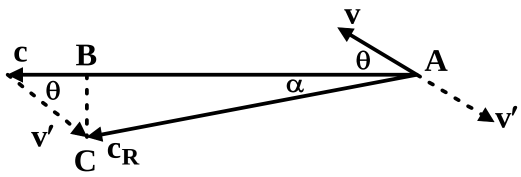


Figure 3. Light Speed in the ECI Frame and Receiver Speed due to the Earth's Rotation

In order to determine the velocity of the light relative to the moving receiver, a velocity $v'$ that is equal and opposite to the surface velocity $v$ is applied in order to bring the receiver to rest relative to the ECI frame (Sadler, 1983). The light speed $c_R$ relative to the ground-based receiver is then the resultant of $c$ and $v'$ given by

$$c_R{}^2 = c^2 + v^2 + 2vc\cos(180 - \theta) = c^2 + v^2 - 2vc\cos\theta = (c - v\cos\theta)^2 + (v\sin\theta)^2 \qquad (13)$$

For $v << c$, $c - v\cos\theta >> v\sin\theta$ and therefore

$$c_R{}^2 = (c - v\cos\theta)^2 + (v\sin\theta)^2 \approx (c - v\cos\theta)^2 \qquad (14)$$

from which

$$c_R = c - v\cos\theta, v << c \qquad (15)$$

Note that this light speed is the speed relative to the receiver fixed in the ECEF frame and not speed relative to the ECI frame which is $c$. It is exactly the speed obtained in the kinematic calculation in (7). In order to determine the angle $\alpha$ between the relative light speed $c_R$ and $c$, consider the right-angled triangle ABC in Figure 3 in which $AB = (c - v\cos\theta)$ and $BC = v\sin\theta$. Then

$$\tan\alpha = \frac{BC}{AB} = \frac{v\sin\theta}{c - v\cos\theta} \approx 0, v << c \qquad (16)$$

from which $\alpha \approx 0, v << c$. It follows therefore that the velocity of the light $c_R$ relative to the ground-based receiver on the surface of the rotating Earth is $c_R = c - v\cos\theta, v << c$ at an angle $\theta$ relative to the receiver velocity $v$. The light transfer time to travel the distance $R$ at speed $c_R = c - v\cos\theta$ is as shown before given by

$$\Delta t = \frac{R}{c_R} = \frac{R}{c - v\cos\theta} \approx \frac{R}{c} + \frac{\bar{v}.\bar{R}}{c^2} \qquad (17)$$

which is the transfer time $\Delta t$ presented in (5) and published by the ITU.

To further elucidate the arguments, consider the situation in the ECI frame where the surface velocity $v$ is oriented in the direction of the light transmission corresponding to $\theta = 0^o$ in Figure 1. Then light transmission in the ECI frame yields

$$c\Delta t = R + v\Delta t \qquad (18)$$

This corresponds to equation (2) given by Ashby. Solving for $\Delta t$ we get

$$\Delta t = \frac{R}{c - v} \tag{19}$$

Therefore the light speed relative to the receiver is given by

$$c_R = \frac{R}{\Delta t} = \frac{R}{R/(c - v)} = c - v \tag{20}$$

The expansion of (19) to first order in $v/c$ gives

$$\Delta t = \frac{R}{c} + \frac{vR}{c^2} \tag{21}$$

Now compare this with the case of the automobile in Figure 2 at position $A$ moving at velocity $v_C$ relative to the surface $S$ (corresponding to light travel at velocity $c$ relative to the ECI frame) and the pedestrian a distance $D$ away at $B$ walking at velocity $v$ in the same direction as the automobile such that $v << v_C$ (corresponding to the receiver a distance $R$ away from the satellite moving at speed $v << c$ relative to the ECI frame). Then as shown previously, classical mechanics gives the speed of the automobile relative to the pedestrian as simply $v_C - v$. Therefore as evaluated in equation (9) the time $T$ for the automobile to intercept the pedestrian is given by

$$T = \frac{D}{v_C - v} \tag{22}$$

Expanding equation (22) to first order yields

$$T = \frac{D}{v_C} + \frac{vD}{v_C^{\,2}} \tag{23}$$

Considering (23) and (21) it can be seen that the two situations are completely analogous. In the case of the moving automobile however, equation (23) is not interpreted as the time $D / v_C$ for the automobile to travel at speed $v_C$ relative to the pedestrian with a "correction" $Dv / v_C^{\,2}$ necessary because of the movement of the pedestrian. Instead the accepted and correct interpretation of (23) is this is the time $D/(v_C - v)$ for the automobile to travel to the pedestrian at speed $v_C - v$ relative to the moving pedestrian. In the same way in time transfer in the GPS, equation (21) should not be interpreted as the time $R / c$ for the light to travel at speed $c$ relative to the receiver in the ECEF frame with a "Sagnac correction" $Rv / c^2$ necessary because of the rotation of the Earth as advanced in the ITU recommendation and by several authors. Instead, as demonstrated for the automobile and the pedestrian, the correct interpretation of (21) is that it is the time $R/(c - v)$ for the light to travel to the receiver at speed $c - v$ relative to the receiver.

It should be noted that the relative speed $c - v$ is exactly the relative speed in (15) and (7) for $\theta = 0^o$. Similarly receiver movement in a direction opposite to the direction of light transmission yields relative light speed $c + v$ corresponding to $\theta = 180^o$ in (15) and (7). The possibility of demonstrating light speed variation $c \pm v$ relative to the rotating Earth by employing a GPS satellite operating in the ECI frame and transmitting to a receiver on the surface of the Earth was also pointed out by Phipps (2006, p42) and later demonstrated by Sato (2010).

### 3. Time Transfer and Space-Time Physics

The results of this research unmistakably demonstrate variable light speed $c_R = c - v\cos\theta$ for light transmission from a GPS satellite to a ground-based receiver, contrary to the principle of light speed constancy invoked in the ITU recommendation and by several authors. This light speed variation was determined firstly based on elementary kinematics utilizing confirmed GPS transfer time and a general distance measurement. This light speed value was then verified by using it to derive the experimentally confirmed value of time transfer. Light speed $c_R = c - v\cos\theta$ relative to the receiver was also determined using classical velocity composition for light transmission in the ECI frame. This then yielded the transfer time (5) by simple calculation. It means therefore that the GPS transfer time is $R/(c - v\cos\theta)$ with no "correction" and not $R / c$ with a "Sagnac correction" since the light travels toward the receiver at relative speed $c - v\cos\theta$ and not $c$. The interpretation in the ITU Recommendation that the time transfer is $R / c$ with a "Sagnac correction" encourages the belief that light travels at speed $c$ relative to the receiver when the speed is really $c - v\cos\theta$ as has been conclusively demonstrated.

Thus the detection of light speed variation is an objective fact validated by observational experience using accurate atomic clocks in the actual time measurement of travelling light. It follows therefore that the principle of light speed constancy is falsified on the surface of the Earth as well as in the immediate surrounding region within the ECI frame. Since the principle directly yields the Lorentz Transformations in space-time physics (Rindler, 2006), the invalidity of the principle implies that these transformations do not represent the physical world. Towards resolving this difficulty Selleri (1996, 2011), using experimentally confirmed time dilation (Zhang, 1997) and two-way light speed constancy (Zhang, 1997) determined the set of "equivalent" transformations which contains all possible space-time transformations that connect two inertial frames $S(t, x, y, z)$ and $S'(t', x', y', z')$ under a set of reasonable assumptions that include light speed $c$ in $S(t, x, y, z)$. The transformations are "equivalent" in the sense that they have the same spatial transformations

$$x' = \gamma(x - vt),\ y' = y,\ z' = z \tag{24}$$

but have temporal transformations that differ by a clock synchronization parameter $e_1$ such that

$$t' = t / \gamma + e_1(x - vt) \tag{25}$$

where $\gamma = 1 / \sqrt{1 - v^2 / c^2}$. Interestingly Selleri (2011) has shown that despite the synchronization difference these transformations make the same predictions for a broad range of phenomena including Michelson-Morley, Romer, Doppler, Fizeau, and the International Atomic Time. However these transformations make different light speed predictions for light travel in the "moving" frame $S'(t', x', y', z')$ given by (Selleri, 1996, 2011)

$$c(S') = \frac{c}{1 + (\beta + ce_1\sqrt{1 - \beta^2})\cos\theta} \tag{26}$$

where $\beta = v / c$ and $\theta$ is the angle between the direction of light propagation and $v$. Spavieri (2012) discussed the two significant members of this "equivalent" set namely the Lorentz transformations corresponding to $e_1 = -v\gamma / c^2$ and whose time transformation is

$$t'_L = \gamma(t - vx / c^2) = t / \gamma - vx' / c^2 \tag{27}$$

and the Selleri transformations corresponding to $e_1 = 0$ whose time transformation is

$$t'_S = t / \gamma \tag{28}$$

The difference between the two transformations is clearly the single term $vx' / c^2$.

Starting with the classical Galilean transformations given by

$$x' = x - vt,\ y' = y,\ z' = z,\ t' = t \tag{29}$$

Levy (2003) has shown that the incorporation of experimentally confirmed clock retardation and length contraction yields the Selleri transformations

$$x' = \gamma(x - vt),\ y' = y,\ z' = z,\ t'_S = t / \gamma \tag{30}$$

Guerra and de Abreu (2006) refer to these transformations as synchronized transformations since the clocks in $S'(t', x', y', z')$ measuring $t'_S$ can be externally synchronized using synchronized clocks in $S(t, x, y, z)$ where the light speed is $c$. They appropriately describe as "true speeds" the speeds calculated in $S'$ using these synchronized clocks and ordinary rulers that measure $t'_S$ and $x'$ respectively. This "true speed" of light as predicted by the Selleri transformations can be determined by setting $e_1 = 0$ in (26) giving light speed

$$c_S(S') = \frac{c}{1 + \beta\cos\theta} \tag{31}$$

in the "moving" frame $S'$ (Selleri, 1996). This speed in (31) reduces to $c_S(S') = c - v\cos\theta, v << c$ which is exactly the light speed $c_R = c - v\cos\theta, v << c$ determined in this paper in the time transfer process using two methods in (7) and (15). Selleri (2010) used this variable light speed (31) to calculate the time for an electromagnetic signal to travel between two points on the surface of the earth via a geostationary satellite and thereby fully accounted for the "Sagnac correction" unnecessarily introduced by others in the time transfer process (ITU, 2012; Nelson, 2011; Ashby, 2010; Petit and Wolf, 2005; Blanchet et al., 2001). He argued therefore that "The procedure which we suggest to experimentalists is to avoid using a wrong velocity of light [ $c_R = c$ ] and correcting the result with an ad hoc term, but rather to use from the beginning the velocity of light [ $c_R = \frac{c}{1 + \beta\cos\theta}$ ] of the [Selleri] transformations." This is fully consistent with the arguments presented in section 2 of this paper where we show that the light travels toward the receiver at relative speed $c - v\cos\theta$ and not $c$. We therefore completely support Selleri's position.

Guerra and de Abreu describe the effect of the introduction of the term $vx' / c^2$ in the time component of the Selleri transformations (28) resulting in in the time component of the Lorentz transformations (27) as delaying the synchronized moving clocks "by a factor that is proportional to their distance $x'$ to the reference position $x' = 0$". We entirely agree with their description of this process as "de-synchronizing" the synchronized measuring clocks which now measure time $t'_L$ in $S'$. They unfortunately consider the resulting Lorentz transformations as mathematically equivalent to the original Selleri transformations which is incorrect since the two transformations predict different light speeds as given in (26). We nevertheless embrace their description "Einstein speeds" of the speeds calculated in $S'$ using these "de-synchronized" clocks and ordinary rulers to measure $t'_L$ and $x'$ respectively. This speed of light corresponding to that predicted by the Lorentz transformations can be determined by setting $e_1 = -v\gamma / c^2$ in (26) giving "Einstein" light speed

$$c_L(S') = c \tag{32}$$

in the "moving" frame $S'$. This result (32) predicted by the Lorentz transformations constitutes light speed constancy that is a quite different speed from the variable light speed (31) derived from the Selleri transformations and is directly contradicted by the light speed $c_R = c - v\cos\theta, v << c$ determined in the GPS signal transmission calculations in sections (2.1) and (2.2).

It is clear therefore that the introduction of the "de-synchronizing" term $vx' / c^2$ results in the false prediction of light speed constancy in all moving frames. It constitutes an ad hoc mathematical convention which realizes non-existent light speed constancy that is unconnected to the real world. Almost any "speed" can be similarly obtained by suitably "de-synchronizing" the clocks through variation of $e_1$ in (26) and Will (1992) has observed that "a particularly perverse choice of [de-] synchronization can make the apparent speed…infinite"! This particular choice corresponds to $e_1 = -\gamma(1 + \beta\cos\theta) / c\cos\theta$ in light speed equation (26) above which yields infinite light speed. These "apparent" speeds represented in general by (26) for $e_1 \neq 0$ are therefore fictitious. They are falsified by the observed light speed $c_R = c(S') = c - v\cos\theta, v << c$ detected using GPS time transfer technology as reported in this paper and corresponding to $e_1 = 0$ in (26). These results are entirely in accordance with the findings of Gift (2009a) and Selleri (2004, 2011) who identified the Selleri transformations given by

$$x' = \gamma(x - vt),\ y' = y,\ z' = z \tag{33a}$$

$$t' = t / \gamma \tag{33b}$$

as those that accord with the physical world and not the Lorentz transformations represented by

$$x' = \gamma(x - vt),\ y' = y,\ z' = z \tag{34a}$$

$$t' = t / \gamma - vx' / c^2 \tag{34b}$$

which are invalid.

## 4. Conclusion

The main contribution of this paper is the demonstration of light speed variation in the time transfer process in the GPS which contradicts the principle of light speed constancy. This was effected using light travel times based on the GPS time transfer algorithm and simple kinematics as well as classical mechanics involving velocity composition in the ECI frame. Both approaches yielded the relative light speed $c_R = c - v\cos\theta, v << c$ for light travelling at an angle $\theta$ with respect to the surface velocity at the receiver. This result is consistent with light speed $c_R = \frac{c}{1 + (v/c)\cos\theta}$ predicted by Selleri's transformations since $\frac{c}{1 + (v/c)\cos\theta}$ reduces to $c - v\cos\theta$ for $v << c$ but is inconsistent with the light speed invariance principle which requires $c_R = c$. This expression $c - v\cos\theta$ for light speed relative to the surface of the rotating Earth was used to derive the confirmed GPS time transfer algorithm that is published in the ITU recommendation. It was shown that accurate GPS time transfer uses $R / (c - v\cos\theta)$ with no "correction" and not $R / c$ with a "Sagnac correction" since the light travels toward the receiver at relative speed $c - v\cos\theta$ and not $c$. Selleri completely accounted for the "Sagnac correction" by applying the light speed $c_R = \frac{c}{1 + (v/c)\cos\theta}$ on the surface of the Earth, thereby rendering any "correction" completely unnecessary (Selleri, 2010).

The failure of the principle of light speed constancy means that the Lorentz Transformations which are derived from this principle cannot represent the physical world and must be replaced. Selleri derived the "equivalent" set of transformations which provides the framework for the determination of the correct transformations from all those that are allowable. This turns out to be the Selleri transformations which differ from the Lorentz transformations by a single term $vx'/c^2$ in the time component of the Lorentz transformations. The elimination of this term effectively provides reconciliation with observed light speed variation while still satisfying all the experimentally confirmed predictions in special relativity as demonstrated by Selleri (2004, 2011). The Lorentz transformations and special relativity have been at the center of ongoing controversy since the inception of the theory (Essen, 1971; Dingle, 1972; Bethell, 2009). In light of the elementary but unassailable results derived in this paper as well as the considerable contradicting evidence now available (Sato, 2010; Marmet, 2000; Kelly, 2005; Hayden, 1991; Gift, 2010a, 2010b, 2010c, 2012a, 2013; Wallace, 1969; Navia et al., 2007; Nodland & Ralston, 1997), the continuing use of the Lorentz transformations and special relativity lacks intellectual integrity and is scientifically indefensible.

The rejection of the Lorentz transformations along with special relativity and the introduction of the Selleri transformations into mainstream physics are likely to open new and interesting areas of space-time research. For example the relaxation of the Lorentz covariance requirement of relativity theory has resulted in the development of the elements of a new quantum theory of magnetic interaction that offers plausible explanations for chemical reactivity, the covalent bond and the Pauli Exclusion Principle (Gift, 2009b). Another interesting development is the provision of a theoretical foundation for the existence of a preferred frame by the new transformations (Selleri, 2004, 2011), the detection of which has been reported by several researchers (Galaev, 2002; Demjanov, 2010; Gift, 2006, 2012b). Finally, these new transformations may assist in the development of an improved gravitational theory as attempted by Logunov (1998) and thereby cast new light on the major unsolved problem of the past century which is the unification of gravity and quantum theory (Smolin, 2006). The recent failure to verify supersymmetry (Wolchover, 2012; Lykken & Spiropulu, 2014) emphasizes the need for action.

**References**

Ashby, N. (2010). The Sagnac Effect in the Global Positioning System. In G. Rizzi & M. L. Ruggiero (Eds.), *Relativity in Rotating Frames*. London: Kluwer Academic Publishers.

Bethell, T. (2009). *Questioning Einstein: Is Relativity Necessary*? Colorado: Vales Lake Publishing.

Blanchet, L., Salomon, C., Teyssandier, P., & Wolf, P. (2001). Relativistic Theory for Time and Frequency Transfer to Order $c^{-3}$. *Astronomy and Astrophysics, 370*, 320-329. http://dx.doi.org/10.1051/0004-6361:200 10233

Demjanov, V. V. (2010). Physical interpretation of the fringe shift measured on Michelson interferometer in optical media. *Physics Letters A*, *374*, 1110-1112. http://dx.doi.org/10.1016/j.physleta.2010.03.058 [Retracted by Editor]

Dingle, H. (1972). Science at the Crossroads, Martin Brian & O'keefe, London.

Essen, L. (1971). The Special Theory of Relativity: A Critical Analysis, Oxford University Press, Oxford.

Galaev, Y. M. (2002). The Measuring of Ether-Drift Velocity and Kinematic Ether Viscosity Within Optical Wavebands. *Spacetime & Substance, 3*(5,15), 207-224.

Gift, S. J. G. (2006). The Relative Motion of the Earth and the Ether Detected. *Journal of Scientific Exploration, 20*, 201-214.

Gift, S. J. G. (2009a). Separating Equivalent Space-Time Theories. *Apeiron, 16*, 408-418.

Gift, S. J. G. (2009b). A Quantum Theory of Magnetism. *Progress in Physics, 1*, 12-19.

Gift, S. J. G. (2010a). One-Way Light Speed Measurement Using the Synchronized Clocks of the Global Positioning System (GPS). *Physics Essays, 23,* 271-275. http://dx.doi.org/10.4006/1.3361840

Gift, S. J. G. (2010b). Light Speed Invariance is a Remarkable Illusion. *Physics Essays, 23,* 1-4. http://dx.doi.org/10.4006/1.3280803

Gift, S. J. G. (2010c). Doppler Shift Reveals Light Speed Variation. *Apeiron, 17*, 13-21.

Gift, S. J. G. (2012a). A Simple Demonstration of One-Way Light Speed Anisotropy Using GPS Technology. *Physics Essays, 25*, 387-389. http://dx.doi.org/10.4006/0836-1398-25.3.387

Gift, S. J. G. (2012b). Successful Search for Ether Drift in a Modified Michelson-Morley Experiment Using the GPS. *Applied Physics Research, 4*, 185-192. http://dx.doi.org/10.5539/apr.v4n1p185

Gift, S. J. G. (2013). Light Transmission and the Sagnac Effect on the Rotating Earth. *Applied Physics Research, 5*, 93-106. http://dx.doi.org/10.5539/apr.v5n5p93

Guerra, V., & de Abrue, R. (2006). On the Consistency between the Assumption of a special system of reference and Special Relativity. *Foundations of Physics*, *36*, 1826-1845. http://dx.doi.org/10.1007/s10701-006-9085-5

Hayden, H. C. (1991). Is the Velocity of Light Isotropic in the Frame of the Rotating Earth? *Physics Essays, 4*, 361-367. http://dx.doi.org/10.4006/1.3028918

International Telecommunication Union. (2012). *Relativistic Time Transfer in the Vicinity of the Earth and in the Solar System*. Recommendation ITU-R TF.2018, August.

Kelly, A. (2005). Challenging Modern Physics. Florida: BrownWalker Press.

Levy, J. (2003). From Galileo to Lorentz . . . and Beyond, Apeiron, Montreal, Quebec, Canada.

Logunov, A. A. (1998). *Relativistic Theory of Gravity*. New York: Nova Science Publishers.

Lykken, J., & Spiropulu, M. (2014). *Supersymmetry and the Crisis in Physics* (pp. 22-27). Scientific American, May.

Marmet, P. (2000). The GPS and the Constant Velocity of Light. *Acta Scientiarum, 22*, 1269-1279.

Navia, C. E., Augusto, C. R., Franceschini, D. F., Robba, M. B., & Tsui, K. H. (2007). Seach for Anisotropic Light Propagation as a Function of Laser Beam Alignment Relative to the Earth's Velocity Vector. *Progress in Physics, 1*, 53-60.

Nelson, R. A. (2011). Relativistic Time Transfer in the Vicinity of the Earth and in the Solar System. *Metrologia, 48*, S171-S180. http://dx.doi.org/10.1088/0026-1394/48/4/S07

Nodland, B., & Ralston, J. P. (1997). Indication of Anisotropy in Electromagnetic Propagation over Cosmological Distances. *Physical Review Letters*, *78*, 3043-3046. http://dx.doi.org/10.1103/PhysRevLett.78.3043

Petit, G., & Wolf, P. (2005). Relativistic Theory for Time Comparisons: a Review. *Metrologia, 42*, S138-S144. http://dx.doi.org/10.1088/0026-1394/42/3/S14

Phipps, T. E. (2006). *Old Physics for New*. Apeiron, Montreal.

Rindler, W. (2006). *Relativity Special, General and Cosmological* (2nd ed.). New York: Oxford University Press.

Sadler, A. J., & Thorning, D. W. S. (1983). Understanding Mechanics. Oxford: Oxford University Press.

Sato, M. (2010). The Velocity of Electromagnetic Wave is Observed Differently Depending on the Observer's Velocity. *Physics Essays, 23*, 405-412. http://dx.doi.org/10.4006/1.3452472

Selleri, F. (1996). Noninvariant One-Way Velocity of Light. *Foundations of Physics, 26*, 641-664. http://dx.doi.org/10.1007/BF02058237

Selleri, F. (2004). Recovering the Lorentz Ether. *Apeiron, 11*, 246-281.

Selleri, F. (2010). Sagnac Effect: End of the Mystery. In G. Rizzi, & M. L. Ruggiero (Eds.), *Relativity in Rotating Frames* (pp. 55-78). London: Kluwer Academic Publishers.

Selleri, F. (2011). *La Relativita Debole*. Milano: Edizioni Melquiades.

Smolin, L. (2006). *The Trouble with Physics*. New York: Houghton Mifflin.

Spavieri, G. (2012). On Measuring the One-way Speed of Light. *The European Physics Journal D, 66*, 76-81. http://dx.doi.org/10.1140/epjd/e2012-20524-8

Wallace, B. G. (1969). Radar Testing of the Relative Velocity of Light in Space. *Spectroscopy Letters, 2*, 361-367. http://dx.doi.org/10.1080/00387016908050941

Will, C. M. (1992). Clock Synchronization and Isotropy of the One-Way Speed of Light. *Physical Review D, 45*, 403-411. http://dx.doi.org/10.1103/PhysRevD.45.403

Wolchover, N. (2012). As Supersymmetry Fails Tests, Physicists seek new Ideas. *Quanta Magazine*, November 20. Retrieved from http://www.simonsfoundation.org/quanta/20121120-as-supersymmetry-fails-tests-physicists-seek-new-ideas/

Zhang, Y. Z. (1997). Special Relativity and its Experimental Foundations. *World Scientific*. Singapore. http://dx.doi.org/10.1142/3180