GPS III

History of Relativity in GPS

GPS AND RELATIVITY: AN ENGINEERING OVERVIEW

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Abstract

We give and explain in detail the formulas for the relativistic corrections to be implemented in high-speed aircraft, or when using other satellites in connection with GPS, or when using GPS from another satellite. *We explain how to use these formulas in various scenarios, give numerical examples, and itemize the pitfalls to be avoided by (for example) receiver manufacturers.*

Note: Relativistic corrections to be implemented

Fliegel, H. F. and R. S. DiEsposti (1996). GPS and Relativity: An Engineering Overview. Proceedings of the 28th Annual Precise Time and Time Interval Systems and Applications Meeting.

https://apps.dtic.mil/sti/pdfs/ADA516975.pdf
https://adsabs.harvard.edu/pdf/1997ptti.conf..189F

INTRODUCTION

The Operational Control System (OCS) of the Global Positioning System (GPS) does not include the rigorous transformations between coordinate systems that Einstein's general theory of relativity would seem to require – transformations to and from the individual space vehicles (SVs), the Monitor Stations (MSs), and the users on the surface of the rotating earth, and the geocentric Earth Centered Inertial System (ECI) in which the SV orbits are calculated. There is a very good reason for the omission: the effects of relativity, where they are different from the effects predicted by classical mechanics and electromagnetic theory, are too small to matter – less than one centimeter, for users on or near the earth. However, a new class of users, who employ satellites that obtain time and position in space from GPS, cannot be satisfied with the approximations in the current OCS. Furthermore, because those approximations have not been publicly analyzed and presented, there is much confusion in the GPS literature. Eminent scientists have been divided amongst themselves, wondering whether the OCS software does not need to be rewritten, expecially since the Department of Defense is now requiring that the current specifications – 6 meters in User Range Error (URE) – are to be tightened under the Accuracy Improvement Initiative (AII). In this paper, we compare the predictions of relativity to those of intuitive, classical, Newtonian physics; we show how large or small the differences are, and how and for what applications those difference are large enough to make it necessary to correct the formulas of classical physics.

Note:

The classical effect of electromagnetic retardation suddenly require Relativistic corrections when the instrument accuracy is increased.

The causal mechanism for electromagnetic retardation in classical mechanics would be due to an energy exchange with a medium.

What they're saying is: the exact same effect (em retardation), but to a smaller degree is actually due to divergent time due to relative velocity between observers and gravitational effects

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$$dt = \gamma \, [dt' + \frac{1}{c^2}(\vec{\omega} \times \vec{R}) \cdot d\vec{\rho}\,] \tag{17}$$

Eq. (17) "is just what one would expect by a Lorentz transformation from the center of rotation to the instantaneous rest frame of the accelerated origin" ([6], p. 23). Except for the leading γ factor, it is the same as the formula derived in classical physics for the signal travel time from the GPS satellite to the ground station. As we have shown, introducing the γ factor makes a change of only 2 or 3 millimeters to the classical result. In short, there are no "missing relativity terms." They cancel out.

The paper then goes on to show how GR and SR relativity cancel out, but their terms are "included", so their argument is because the equation is there, the effect exist, even though it cancels out and you wouldn't know either way.

I would like to make another point. When one looks at differential GPS, the correction that needs to be made primarily is the difference between the radial distance in the ephemeris and the time reading on the satellite. And I believe this comes in because of a mix-up, or aliasing if you will, between these two quantities in the iteration procedure that the Kalman filter is following. And that if one perhaps does the explicit recognition of the special relativistic effects – I mean, it took a long time to get general relativity down properly, but I think that is more or less correct now. But it's the absence of any explicit acknowledgment of special relativistic effects due to the speed of light being the same whenever measured by an observer, leading to the relativity of simultaneity and the associated Lorentz transformation physics – there's nothing of that at all modeled in the current system, and I think it should be. Thank you.

Note:

After the citations there's a convo with several GPS lads, Carrol Alley mentions the most devastating piece of evidence against Relativity theory.

The Principle of Relative Simultaneity not being a factor in GPS completely falsifies the justification to even do a Lorentz transformation in the first place to even suggest to another grown man that time dilates relative to proper time and that distances contract hyperbolically in the direction of motion relative velocity.

GPS up until 1996 (at minimum) did not account for

1. The Principle of Simultaneity
2. Equal-gravitational potential effects
3. Time dilation relative to proper time

In fact, the fact that 2) and 3) are inherently missing means that 1) isn't even the cause of any of these effects. The system could not be synchronized to a cohesive timeline (GPS Time) without never ending cascades of transformations to calculate the differences from 2) and 3) relative each person that uses GPS simultaneous to anyone else who uses it.

This is actually a full stop meta argument for relativity. If there's no substantiation of the principle of relative simultaneity, then that's game over in and of itself.

GPS Simultaneity vs Relative Simultaneity

Global simultaneity vs. the relativity of simultaneity.

In any debate about the speed of light, the problem of simultaneity is always a focus. Special Relativity claims the relativity of simultaneity which states that two events occurring at two different places which are viewed as simultaneous for an observer in a system, usually will not be simultaneous if viewed for an observer in another system. But contrary to this, simultaneity is the key to GPS operations. GPS is a Timing – Ranging system: it does not directly measure the distance between two places where two events, i.e. signals transmitting and receiving, occur. It measures the difference of the two instants when these two events happen and then, the distance is calculated using the range measurement equation. GPS, especially its space segment and control segment, makes a huge effort to establish and maintain a GPS system time, or simply, GPS time [4]. In a scope where GPS is applied, roughly a scope with diameter of 50,000 km or bigger, if one is using GPS, one is using GPS time and therefore the concept of simultaneity of GPS: two events happened at two different places, (x_1, y_1, z_1, t_1) and (x_2, y_2, z_2, t_2), are simultaneous if $t_1 = t_2$. This is true no matter who the observer (receiver) is, where the receiver is, what its status is, or what its speed is. This is the basic operational principle of GPS. We can call it Global Simultaneity.

In the books about Special Relativity, the most commonly cited example about the relativity of simultaneity is the example about the railway platform and the moving train [5]. It says that two events (e.g., the two strokes of lightning A and B) which are simultaneous with reference to the platform are not simultaneous with respect to the moving train and vice versa. But now GPS receivers have been utilized extensively on railway platforms and moving trains, and lightning at two different places, A and B, conceptually is the same as the emissions of GPS signals from two satellites or two DGPS stations. In fact, if two signals are emitted from two satellites or two DGPS stations at the same GPS time, both the GPS receiver on the railway platform and the GPS receiver in the moving train would acknowledge the two events, the emissions of the signals, to be simultaneous. Without this basic acknowledgement, the GPS receivers can not function at all.

The range measurement equation and the crucial experiment of Special Relativity.

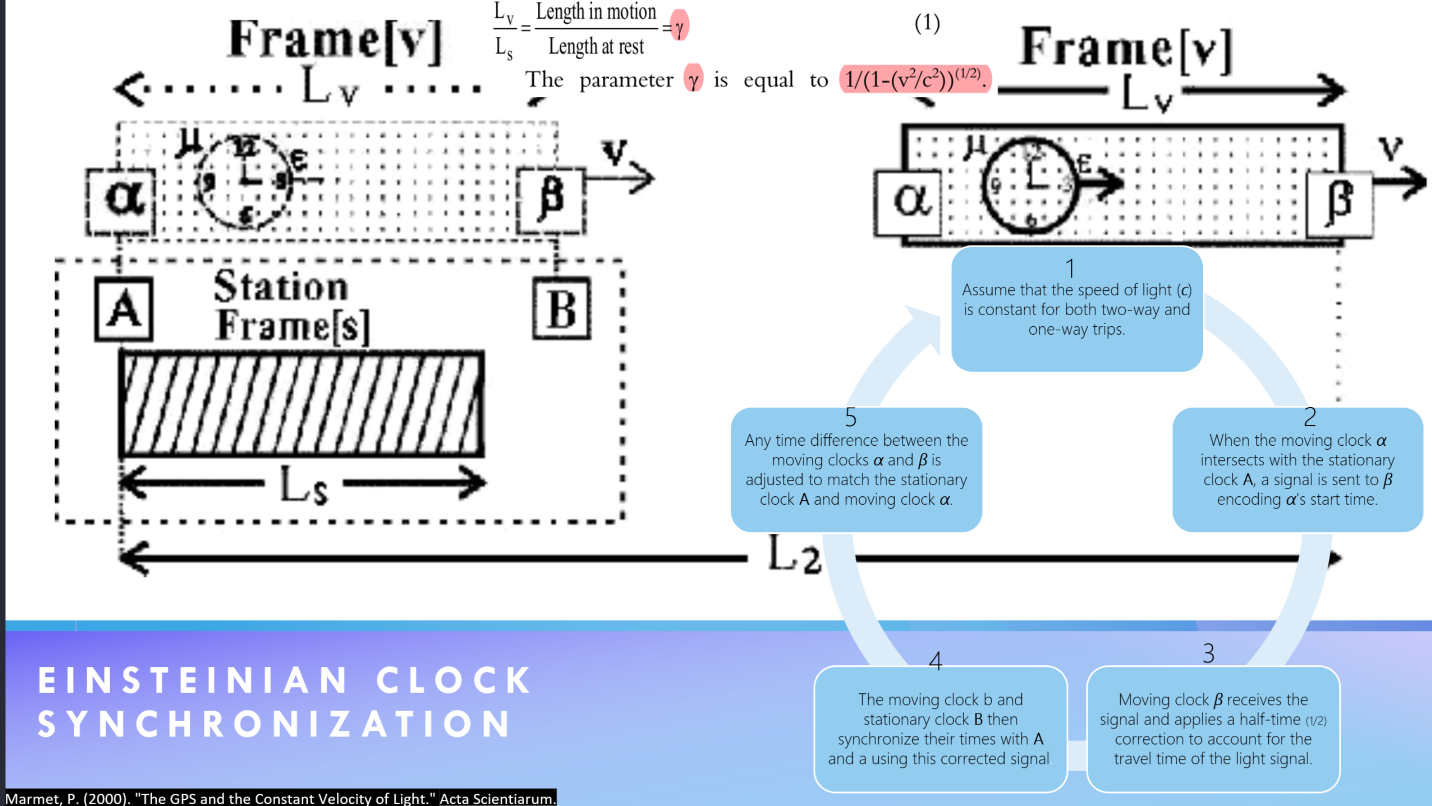
We have shown that the correctness of the range measurement equation contradicts the principle of the constancy of the speed of light which asserts that light in vacuum always has a definite speed of propagation that is independent of the state of the motion of the observer [6]. We have also indicated that the relativity of simultaneity contradicts the purpose of GPS system time and the basic operational principle of GPS. Due to the popularity of Special Relativity, a lot of people still will not accept these. Therefore, we would examine a crucial experiment, in which the result can be used to refute or verify Special Relativity from everybody's point of view. More importantly, in this experiment, simultaneity, or the synchronization of the clocks, is not a concern.

We mount two atomic clocks with the same construction, signal transmitter, reflector, and receivers on the two ends, points A and B, of a vehicle, with distance L between A and B. First (fig. 4a), the vehicle is stationary relative to the earth

Note: Because the Principle of Relative Simultaneity aren't present in GPS corrections, it's already over. People just wont accept it. Think about how fascinating that is. The core tenant of their belief is absent from a relative motion situation that explicitly demands it.

Wang purposing an further experiment is an oil branch.

Atomic Clock Synchronization



Note:

Marmet, P. (2000). "The GPS and the Constant Velocity of Light." Acta Scientiarum.

Full Credentials: Paul Marmet, Professor, Physics, Laval University, Québec, Canada 1962-83, Senior Research Officer, National Research Council of Canada 1983-90

Based on Relativity theory, once these clocks are in motion, theoretically as they free-fall around the Earth, the the oscillation rate shouldn't retarded 1:1 to the velocity of the craft. Relativity dictates that c = c in an inertial frame.

Between 1978 and 1998, the author also published several other papers related to the fundamental principles in physics. Several of these papers are presented on this web site. In 1997-99, physicists of the establishment showed fierce disagreement with the fact that Marmet's research implied that the fundamental principles of physics were being questioned. Although the experimental work, which could determine the energy of numerous quantum stated was highly appreciated and even honored, the physics establishment required that the author should stop questioning the fundamental principles of physics. The author was first informed by NSERC (Natural Science and Engineering Research Council of Canada) to stop doing that fundamental research despite the fact that, being theoretical, it required no research funds – all research grants were used for the experimental work needed for the electron impact apparatus. Since the fundamental research was still going on the following year, the grant was cut to zero, putting an end to experimental work using the monoenergetic electron beams.

In May 1999, the head of the physics department came to Marmet's office and said: "*Ce n'est pas ton bureau que nous voulons, ton problème est que tu remets en question les principes fondamentaux de la physique*." ("We do not want your office, your problem is that you keep questioning the fundamental principles of physics.") Three months later, a letter was sent requiring Marmet's office to become unoccupied before the end of the month. Without research grant and being expelled from his office, Dr. Marmet continued his research alone at home.

This was the irrevocable death of a unique instrument in the world, which was able to measure the electronic structure of negative ions and their ionization efficiency curve using a high resolution monoenergetic electron beam. A few months later, the instrument was destroyed. Also, this shows that physics is not only a science, it is a doctrine. Therefore, there are heretics. It's not different from Galileo's time!

Paul Marmet

Note: Additional info about Marmet

A past president of the Canadian Association of Physicists (1981-2), he also served as a member of the executive committee of the Atomic Energy Control Board of Canada. Dr. Marmet has been elected Fellow of the Royal Society of Canada and was made an Officer of the Order of Canada. He was awarded the Herzberg prize, the Rutherford prize, the Parizeau medal and a Service Award from the Royal Astronomical Society of Canada. He is the author of over a hundred journal papers, four books and 200 presentations at scientific meetings.

https://web.archive.org/web/20210226183310/https://www.mysticmedicine.com/the-divine-for-a-critical-mind-resources/paul-marmet

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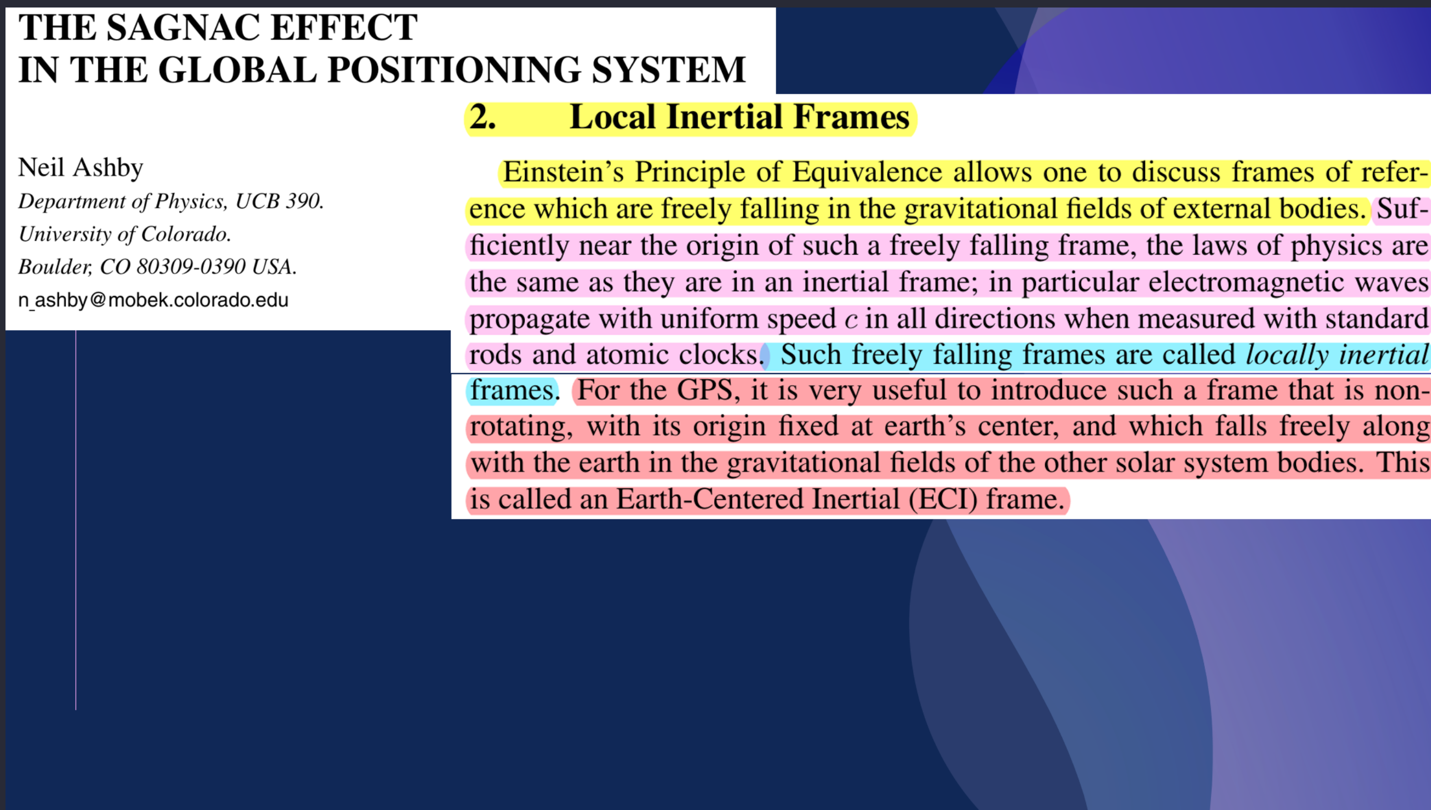

THE SAGNAC EFFECT
IN THE GLOBAL POSITIONING SYSTEM

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2. Local Inertial Frames

Einstein's Principle of Equivalence allows one to discuss frames of reference which are freely falling in the gravitational fields of external bodies. Sufficiently near the origin of such a freely falling frame, the laws of physics are the same as they are in an inertial frame; in particular electromagnetic waves propagate with uniform speed c in all directions when measured with standard rods and atomic clocks. Such freely falling frames are called *locally inertial frames*. For the GPS, it is very useful to introduce such a frame that is non-rotating, with its origin fixed at earth's center, and which falls freely along with the earth in the gravitational fields of the other solar system bodies. This is called an Earth-Centered Inertial (ECI) frame.

Note: Ashby, N. (2004). The Sagnac Effect in the Global Positioning System.

Neil defining an the free fall orbit of a satellite a "local inertial frame"

Special note; Ashby is the lad they brought in to parade the variance in c around like's proof of Relativity theory.

Keep in mind the difference between "Sagnac Effect" and "Sagnac Correction" It will be extremely important later when reading Wang's work and AG Kelly.

PUBLIC RELEASE VERSION

NAVSTAR GPS

USER EQUIPMENT

INTRODUCTION

SEPTEMBER 1996

PUBLIC RELEASE VERSION

Note:

7.5 AIDING TO MAINTAIN SATELLITE TRACK

In normal receiver operation, the code and carrier tracking loops are both being tracked in phase lock. There is a symbiosis between the code and carrier tracking loops where each loop aids the other. In a high jamming environment, the receiver may lose its ability to track the carrier. Subsequent accelerations will cause the carrier frequency of the received GPS signal to vary due to a change in the Doppler shift. The Doppler shift of the frequency of the received carrier signal is proportional to the relative velocity of the receiver with respect to the satellite along the line-of-sight from the receiver to the satellite.

Note: Now they're saying here that they're getting the velocity correction to add to the receiver from Doppler shift in the signal with respect to the receiver's velocity.

There is where it gets crazy the Range Measurement Equation derives distance based on the variance of c. What are the odds the variance in c (distance measured with the RME wrt the ECI) magically derives the distance accurate down to the millimeter and that variance is also the same as the Doppler freq.

Obviously they can't say it straight forward that c != c, but they also need to explain how they get the velocity of the receiver. This is how they do it.

In later additions to the ICDs, they show flow chart diagram which will be in the next slide.

NAVSTAR GLOBAL POSITIONING SYSTEM

INTERFACE SPECIFICATION
IS-GPS-200
Revision D
IRN-200D-001
7 March 2006

Navstar GPS Space Segment/Navigation User Interfaces

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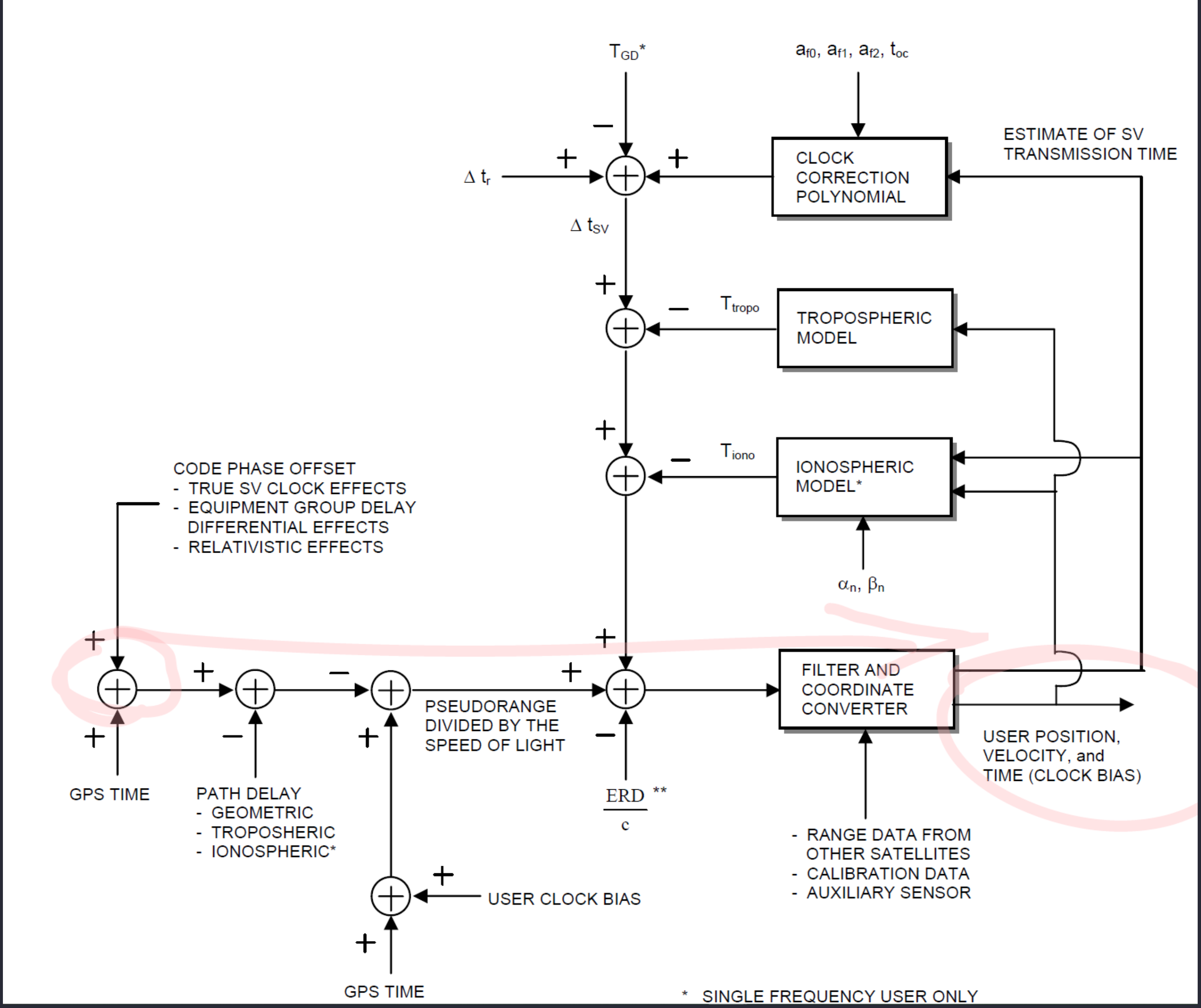
Note: 2006 ICD



Note:

Range Measurement equation

A. Navigation

Keeping these caveats in mind, the constancy of c leads to the following idealized conception of a navigational system. Referring to Fig. 2, suppose four transmitters, each with its own standard clock, are placed at known locations $\boldsymbol{r}_j$. Assume the clocks are synchronized by the Einstein procedure. There is a receiver at unknown position $\boldsymbol{r}$ carrying a standard clock which has not been synchronized. Let these transmitters rapidly transmit synchronized pulses which are tagged with the transmitter's position and time, so that a receiver can determine the time t_j and the location $\boldsymbol{r}_j$ of the pulse from transmitter j. The receiver's position $\boldsymbol{r}$ and clock time t can then be determined by solving four simultaneous propagation delay equations:

$$|\boldsymbol{r} - \boldsymbol{r}_j| = c(t - t_j); \qquad j = 1, 2, 3, 4, \tag{3}$$

for the unknowns $\boldsymbol{r}$ and t. These equations just express the principle of the constancy of c in an inertial frame. Clearly a timing error of one nanosecond would lead to an error of about 30 cm in position determination.

Note: Ref. from Wang's paper regarding the Range Measurement Equation.

Ashby, N. (1994). "Relativity in the Future of Engineering." IEEE Transactions on Instrumentation and Measurement 43(4): 505-514.

https://ieeexplore.ieee.org/abstract/document/310159

PDF Download: https://sci-hub.hkvisa.net/10.1109/19.310159

Some people [1] think that the range measurement equation is based on the constancy of the speed of light. On the surface, this may appear to be true: c, the speed of light, is the only velocity term that appears within the equation. Expressions such as c-v and c+v, which are often seen in discussions of Special Relativity and classical physics, do not exist in the equation. Therefore, some people would conclude that if this equation is correct, Special Relativity is correct; if this equation has been proved with a high degree of accuracy, Special Relativity has been proved with a high degree of accuracy. For example, it has been concluded [3] that Special Relativity had been confirmed to the limit of $\delta c/c < 5 \times 10^{-9}$.

But we should not judge things by their appearance; we must try to grasp their essences. If we analyze the implication of the range measurement equation carefully, we will find that, contrary to what its appearance tells us and what some people think, the correctness of the GPS' range measurement equation actually leads to the incorrectness of the principle of the constancy of the speed of light, and furthermore, the principle of relativity. This may seem unexpected, but it is quite understandable if we compare it with Sonar systems. Recall that in underwater navigation, Sonar uses the same range measurement equation in a reference frame based on water to calculate the distance traveled by sound even though the sound receiver is moving relative to water. The difference there is that the speed of sound in water, a, is used instead of the speed of light in vacuum, c. However, no one would emphasize the constancy of the speed of sound, and contrarily, every one thinks the speed of sound is dependent on the motion of the sound receiver.

Note: The equal itself is misleading because it already accounts for a variance in c relative to velocity inherently.

Two examples of the Sagnac correction in GPS.

The transformation from ECI to ECEF when investigating the propagation from a satellite to a ground station. With the around-the-world Sagnac experiment [10], it is well known that the signal propagation eastward from a satellite to a ground station will take a longer time compared to the signal propagation westward because of the rotation of the earth. As we mentioned above, this Sagnac effect will be included automatically and we do not need a Sagnac correction if we utilize the range measurement equation correctly, i.e., utilize the range as the distance in ECI between the source at the transmission time and the receiver at the reception time. If we define the range not as the distance in ECI, but as the distance in ECEF, then we need to add a Sagnac correction, like in the rotating disk case mentioned above.

Note: Because the equation already accounts for c +- v, there's no need for any additional Sagnac corrections.

The Sagnac effect, the Sagnac correction and the translational motion including uniform motion.

There is a misconception that the Sagnac effect, a first order effect, uniquely belongs to the rotational motion. Although it is true that for an interference experiment, the necessary condition of the Sagnac effect is the rotation. It is because for an interference experiment, the light path is a closed one and for this closed light path, the possible Sagnac effects caused by the translation motion are cancelled with each other like in the Michelson-Morley experiment which only detected the second order effect. Now the signal propagation in GPS is a one-way propagation, there will not be a cancellation and therefore, rotation is not a necessary condition for a first order Sagnac effect anymore. Besides, we should notice that the motions of the ground station and the satellite in the previous examples are not purely rotational, but circular motions, which are the combination of the translational motion and the rotational motion. Here, we will show that for purely translation motions, including uniform motions, all the discussions about the Sagnac effect and the Sagnac correction are suitable too. That is, there is a Sagnac effect when the receiver is in a uniform motion, and we need to add a Sagnac correction if we use the range measurement equation not in its original meaning.

Note: The Sagnac EFFECT in c is a first-order effect in the one-way speed of light.

The one-way speed being the signal sent from the Satellite and to a receiver. The signal encodes its time down to the 9.192 billionths of a second.

Each signal sent to you in trilateration is a one-way first-order measurement of c.

If a GPS receiver is in rotational, translational or uniform motion, that velocity will be reflected in the variance in the one-way measurement in relation to the time sent and time received relative to the assumed constant speed.

The measurement is taken in the ECI frame. The ECI is a hypothetical stationary frame wrt to the center of Earth (i.e. not moving).

How can the measurement be taken in a hypothetical frame but it instantaneously derives the distance with no transforms or corrections.

In my opinion, this can only be explained if all motion is relative to the medium electromagnetic waves propagate in. The mechanism for the variance is the observer's motion relative to the medium. It's the only way c change for the observer.

It works just like any other wave. That's why Wang gives the analogy about the Range Measurement Equation and sonar.

A. G. Kelly Exposes Atomic Clock Fraud

FLYING CLOCKS

Haffle and Keating (**20**), in 1972, conducted tests with four cesium clocks, where the clocks were flown Eastward and Westward in aeroplanes around the Earth. The results of these investigations are often quoted as proof that time changes with speed, as predicted by the Theory of Special Relativity. It will be shown here that the tests were of insufficient accuracy to draw the conclusion that time is altered. They used the Theory of Special Relativity to forecast a difference in time between that recorded by flying clocks, and the time recorded by a standard station at Washington, USA.

All four clocks were predicted to lose time flying Eastward; two of the four did so, one gained time, and one showed no significant change. On the Westward journey, the clocks were required by the theory to gain time; two did so, one lost time, and one showed no significant change (the same clock that showed no difference on the Eastward journey)

It is normal for a particular cesium clock to show a drift rate relative to a standard clock station, which records the average of several very accurate clocks. Indeed, individual clocks can display inexplicable gradual, or sudden, *changes* in drift rate. Sudden drift changes can be, in extreme instances, as large as 1 μs per day; the differences forecast by the authors over the total flight time of six days were of the order of one-tenth of that.

The behaviour of the clocks during the ten days prior to the tests, and during the five days after the tests, showed that the results were highly dependent on the period in which the tests were actually performed. The changes during the flight periods were radical for three of the clocks. A clock that had been gaining time prior to flight was seen to be losing time after the flight. Other clocks suffered changes in their rate of drift during the flight period, by a factor of two or three. It is not known at what stage of any flight such changes in behaviour occurred, because no clock could be compared with the ground reference station during flight.

Despite the fact that one of the four clocks on each of the Eastward and Westward journeys showed time changes of opposite sign to those predicted by the Theory, Haffle and Keating still took the average of all four clocks; **the average turned out to be of the same order, but of opposite sign, to the time changes of the aforementioned aberrant clocks.** Taking the average of the time changes recorded by the four clocks does not provide evidence, on which a conclusion may be based.

Realising the somewhat disparate behaviour of the four clocks, the authors proceeded to make corrections to these results. Whenever, during flight, one clock displayed a sudden change in drift rate relative to the other three, its rate change was ignored. Had but one such correction been made, there could have been some credibility in this procedure; but fourteen such sudden rate changes were ignored, with seven of these on one clock. These corrections changed the results derived by the average method from -66ns to -59ns going Eastward, and from +205ns to +273ns going Westward. It was not possible for the authors to make corrections to offset possible *gradual* changes in drift pattern. The results predicted by their theory were -40ns and +275ns, which were very close to the published experimental results.

It is of interest to note that a previous test, carried out over some weeks in 1970, and referred to in the Haffle and Keating paper, resulted in no discernible gain or loss during the flights. It is evident that tests of a far more

accurate nature are required to discern the effect, if any, of transportation on cesium clocks.

Note: Moving atomic clocks around the world did not give agreement with Relativistic prediction.

2 of the 4 clocks gained time when they were supposed to lose time and vice versa with respect to the direction around the Earth, with and against assumed rotation.

Kelly, A. G. (1995). Time and the Speed of Light: A New Interpretation, Institution of Engineers of Ireland.

Hafele-Keating Paper (1971):

Although the final analysis of our data is not yet completed, we have established, with an intermediate level of analysis, that portable cesium beam clocks are capable of showing relativistic effects with relatively inexpensive commercial jet flights. The results of this analysis are in reasonable agreement with theoretical predictions. However, those who doubt the validity of conventional relativity theory, and there are many people in this category, probably will not be converted by the results shown in Figure 4. Indeed, the difference between theory and measurement in Figure 4 is disturbing, and if our final analysis does not improve agreement, an improved version of this experiment should be given serious consideration. The standard deviation on the measurement could be reduced considerably, probably by a factor of ten, with such improvements as the use of dual beam clocks and circumnavigations with less ground time. In any event, this experiment verifies unequivocally the existence of the predicted east-west directional asymmetry; only more precise magnitudes remain to be established.

Note: Hafele's own commentary on the experiment and discrepancy between prediction and result.

Hafele, J. and R. Keating (1971). Performance and Results of Portable Clocks in Aircraft, US Naval Observatory.

Hafele-Keating (1972)

Relativity prediction:

Table 1. Predicted relativistic time differences (nsec).

Effect	Direction	
	East	West
Gravitational	144 ± 14	179 ± 18
Kinematic	—184 ± 18	96 ± 10
Net	−40 ± 23	275 ± 21

Corrected data set with no explanation of corrections and now the clocks match Relativity's prediction despite the massive discrepancies that should have invalidated the experiment when the clocks were out of synch at varying amounts, especially in the wrong direction.

Table 1. Observed relativistic time differences from application of the correlated rate-change method to the time intercomparison data for the flying ensemble. Predicted values are listed for comparison with the mean of the observed values; S.D., standard deviation.

Clock serial No.	$\Delta\tau$ (nsec) Eastward*	Westward
120	− 57	277
361	− 74	284
408	− 55	266
447	− 51	266
Mean ± S.D.	− 59 ± 10	273 ± 7
Predicted ± Error est.	− 40 ± 23	275 ± 21

* Negative signs indicate that upon return the time indicated on the flying clocks was less than the time indicated on the MEAN(USNO) clock of the U.S. Naval Observatory.

Hafele-Keating: Performance and Results of Portable Clocks in Aircraft (Original Data, 1971)

The original data from the Hafele-Keating experiment showed that three of the four clocks were unreliable and had significant variations in their drift-rates, which should have been steady in order to make accurate measurements.

Table 1 shows the drift-rates of the clocks before and after the eastward and westward tests: before and after, difference, mean.

The conclusion from the data is that the huge swings in drift rates made the results of the experiment unreliable and inconclusive. The accuracy of the clocks would have to be better by two orders of magnitude in order to reach a meaningful conclusion on the test.

Take note of the mean values, as we'll be comparing the original recorded results before and after the "post-analysis and consolidation" was conducted which brings the results more in line with relativity theory's predictions.

TABLE III. FLYING CLOCK DATA - RATES RELATIVE TO U.S. NAVAL OBSERVATORY MEAN

CLOCK (ser. no.)	R_i (ns/hr)	R_f (ns/hr)	$\overline{R}$ (ns/hr)	ΔR (ns/hr)	$\Delta\tau_i$ (ns)	$\Delta\tau_f$ (ns)	$\Delta\tau$ (ns)
Eastward flight $\tau = 65.42$ hr							
361	+2.66	+4.38	+3.52	+1.72	1790	1910	-110
408	-1.78	+3.22	+0.72	+5.00	-20	30	+3
120	-4.50	-8.89	-6.70	-4.39	-290	-780	-52
447	-7.16	-8.41	-7.78	-1.25	-1140	-1705	-56
				$\overline{\Delta R} = +0.27$ ns/hr; $\sigma_{\Delta R} = 3.8$ ns/hr			$\overline{\Delta\tau} = -54$ ns; $\sigma_{\Delta\tau} = 46$ ns
Westward flight $\tau = 80.33$ hr							
361	+6.89	+3.97	+5.43	-2.93	2880	3390	+74
408	+4.84	+2.16	+3.50	-2.68	490	980	+209
120	-8.88	-4.56	-6.72	+4.31	-2100	-2400	+240
447	-7.17	-9.42	-8.30	-2.25	-2840	-3390	+116
				$\overline{\Delta R} = -0.89$ ns/hr; $\sigma_{\Delta R} = 2.6$ ns/hr			$\overline{\Delta\tau} = +160$ ns; $\sigma_{\Delta\tau} = 78$ ns

1 ns/hr = 2.78×10^{-13} sec/sec

$$\sigma = \left[\frac{\Sigma(\Delta\tau - \overline{\Delta\tau})^2}{3}\right]^{\frac{1}{2}}$$ (standard deviation)

Note:

Hafele, J. and R. Keating (1972). "Around the World Atomic Clocks: Predicted Relativistic Time Gains."

Corrected comparison:

Hafele-Keating: Published Data in *Science* After Post-Analysis and Consolidation (1972)

Here we compare of the original data and the data after a post-analysis and consolidation was done. In their published paper, it is mentioned that corrections were made to include the relevant information (flight speed and altitude, not counting take off / landing altitude changes, etc.) and suddenly the results are brought in line with the predictions by relativity. It should be noted that no source of what exactly was changed or how it was accounted for can be found.

	Eastward dt_{total} [us/trip]	Eastward dt_{total} residual [%]	Westward dt_{total} [us/trip]	Westward dt_{total} residual [%]
HK predicted	-40 ± 23	--	275 ± 21	--
HK measured #1	-54 ± 46	25.9%	160 ± 78	41.8%
HK measured #2	-59 ± 10	32.2%	273 ± 7	0.7%

Relativity wins again.

A. G. Kelly Exposes Sagnac Correction a NOT a Relativisitc correction in GPS

One of the most familiar arguments for the validity of special relativity is that the Global Positioning System (GPS) navigation system would not achieve high accuracy without making special relativistic corrections. The principal correction cited is a first-order timing adjustment to compensate for signal propagation time variations arising from the motions of the satellites and ground receiver in the local Earth-centered Earth-fixed (ECEF) frame due to the Sagnac effect. But the Sagnac effect is a purely classical, first-order effect that has somehow been incorrectly re-classified in this application as a special relativistic effect (see, *e.g.*, Allen, Weiss and Ashby 1985; Ashby 2002). So a first-order timing correction must be made for the accurate performance of the GPS system, just the amount attributable to the velocity component of the satellite constellation along the line-of-sight in the ECEF frame. The fact that this first-order timing correction is required at all is in direct conflict with special relativity.

Wolf and Petit (1997) tested the isotropy of the one-way speed of light by analyzing the GPS satellite network timing signal database and found no dependency on source-receiver motion, which they interpreted as evidence that c was isotropic. However, Wolf and Petit noted that the data set they analyzed had been pre-processed and corrected for the Sagnac effect (in this case, a first-order change in the time of flight of radio signals between satellites and receivers), and justified making this correction by claiming that the Sagnac effect was a relativistic effect that was "second-order in c" and therefore that the correction had negligible consequences in their analysis. But the correction that was made was first-order in the velocity component of the line-of-sight between each satellite and the ground receiver in the ECEF frame. Thus, while the affect of the first-order line-of-sight velocity component of the GPS satellites is clearly evident in the raw timing signal data, this first-order component had been removed from the dataset that Wolf and Petit analyzed to show that c was isotropic.

Note: At the highest level of raw data, the data is corrected to make c +- v = c in the most egregious way.

Mislabeling the Sagnac effect as a second-order Relativistic effect is legit insane.

The entire +- v corrections is swept up as"Earth rotation" and that gives the appearance that c = c.