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Gravitational frequency shift and transverse Doppler effect in GPS

In 1959, the Pound-Rebka experiment proved that a receiver tuned strictly to the transmitter's frequency ceases to receive a signal and its setting must be changed if the receiver or transmitter is at different heights from the Earth's surface. The need to tune the frequency with a change in the height at which the transmitter or receiver is located is confirmed with very high accuracy by all subsequent experiments. This phenomenon, called the gravitational frequency shift, and the transverse Doppler effect in general relativity are explained by the slowing down of time in moving systems and in regions with a higher gravitational potential [1, 2, 3]. The correction for the gravitational time dilation and the speed of movement is introduced into the on-board clocks of the GPS satellites, since it is believed that in the orbit of 20 184 km, the clock without correction runs 38 microseconds per day faster than on Earth [4, 5, 6]. This phenomenon, called the gravitational frequency shift, and the transverse Doppler effect are explained in general relativity by the slowing down of the time in moving systems and in areas with a higher gravitational potential [1, 2, 3]. The correction for the gravitational time dilation and the speed of movement is introduced into the on-board clocks of the GPS satellites, since it is believed that in the orbit of 20 184 km, the clock without correction runs 38 microseconds per day faster than on Earth [4, 5, 6].

In this work, the need for clock correction is explained on the basis of purely classical concepts without using the statements of the theory of relativity about time dilation and the constancy of the speed of light. It is shown that, in fact, the speed of electromagnetic radiation does not remain constant in the gravitational field but changes, and the signal from a satellite to a receiver on Earth comes faster than from a source on Earth to a satellite. Time in orbit does not change and clocks run at the same speed as clocks on Earth. The receiver on Earth sees an increased signal frequency not because of the acceleration of the satellite's atomic clock, but because of the increase in the speed of the photons and the resulting Doppler effect.

According to general relativity, photons, moving away from the gravitating mass, lose energy and, due to the fact that their speed remains constant and equal to C, the wavelength of the photons increases and, therefore, the frequency decreases [2, 7]. To reconcile the change in the frequency of photons with the constancy of the speed of light, Einstein, on the basis of his principle of equivalence, concluded that at different altitudes the frequency of photons changes not due to changes in the speed of photons, but because of changes in time and speed of clock. Therefore, in accordance with the theory of relativity, three relativistic effects arise in moving frames:

slowing down time when speed increases (SRT effect),
acceleration of time with increasing altitude (gravitational effect of general relativity),
Sagnac effect in rotating systems

All relativistic calculations of changes in time and frequency are carried out only under the condition that the speed of light does not change when the light source and the receiver are at different heights from the Earth's surface.

Below we consider the first two effects - gravitational frequency shift and relativistic time dilation. The Sagnac effect is discussed in detail in the next article.

The Pound-Rebka Experiment

Descriptions of this experiment and calculations can be found in many works [8, 9], and therefore we will not dwell on them, but will only show that the same change in the radiation frequency is obtained in a purely classical calculation if to assume that the photons moving in a gravitational field accelerate and change their speed

In the Pound-Rebka experiment, photons pass in the vertical direction a distance of 22.5 meters. If we imagine that gravity does not affect the speed of movement of photons, they pass a distance of 22.5 meters at a speed of 299 792 458 / n = 299 702 547.2358 m / s in a time of 22.5 n / 299 792 458 = 7.50744369 e-8 sec, where the refractive index n = 1. 0003.

In an absolute vacuum in the absence of gravity, photons must pass a distance of 22.5 meters,in 22,5 / 299 792 458 = 7.505 192 1419 e-8 s.

In a gravitational field, photons move in vacuum with an acceleration of 9.8 m/s2 and on the way from top **to bottom** their speed increases by 7.505 192 1419 e-8 x 9.8 = 7.355 088 e-7 м/сек to avalue (299 702 547. 2358 + 7.355 088 e-7) m / s .

To **upward**, photons move with an acceleration of 9.8 m / s2 and their speed turns out to be less by the same value 0. 000 000 7.355 088 m / s .

The relative gravitational change in velocity in this experiment turns out to be
0. 000 000 7.355 088 / 299 792 458 = **2.453** 393 e-15 .

In accordance with the Doppler effect, a change in the speed of photons leads to a proportional change in their frequency: when moving down, the frequency of photons increases by **2.453** 393 e-155 and when moving up decreases by **2.453** 393 e-15 .

This gravitational red shift of **2.453** 393 e-15, caused by a change in the speed of photons in the Earth's gravitational field, turns out to be quite close to the value of **2.57** (+- 0.26) e-15, obtained in the Pound-Rebka experiment and predicted by general relativity [9].

The frequency change in GPS

If, in the Pound-Rebka experiment, the source is at rest relative to the receiver and is only at a different altitude, in the GPS system the source moves relative to the receiver, and therefore two effects simultaneously arise here, which relativists explain as a time dilation. Below these two effects are considered from the classical point of view, provided that the speed of light does not have the property of invariance and the time in orbit does not depend on either gravity or the speed of the satellite.

Gravitational frequency shift in GPS

In the GPS system, the signal from the satellite to the receiver on Earth passes a much greater distance than in the Pound-Rebka experiment, and at this distance the value of the gravitational potentil changes several times. Accordingly, the gravitational frequency shift is also much larger. The correction for the gravitational redshift of the frequency in the GPS system is introduced based on the same predictions of general relativity:

- time at the altitude of the orbit of satellites flows faster than on Earth.
- the signal from a satellite at different heights from the Earth goes with the same constant speed,
- when approaching the Earth's surface, the frequency of electromagnetic radiation increases,
- when moving in a gravitational field, the energy of photons changes not due to a change of the speed of the photons, but because of the change in their frequency [2]

If the atomic clock before launch into orbit was tuned to a frequency of 10, 230, 000, 000 Hz, due to gravitational displacement, the receiver on Earth receives a signal with a frequency of 10,230,000,004.574856 1 Hz, by 4.574856 Hz higher than the original frequency of 10.23 GHz, resulting a positioning error arises . In order for the receiver on Earth to receive a signal with a frequency of 10.23 GHz, a correction is introduced in the atomic clock before launch: their frequency is reduced by 4.574856 Hz. General relativity explains the introduction of this correction by the fact that time flows faster in orbit, the clock frequency at this altitude increases by 4.574856 Hz, and **therefore**, without introducing this correction, a signal with a frequency greater than 10.23 GHz arrives at the receiver. Relativists regard the necessity of introducing a gravitational correction in the GPS system as the first engineering confirmation of the validity of the predictions of the theory of relativity [10].

It is shown below that the gravitational frequency shift arises not because of the "acceleration" of time in orbit or its "deceleration" on the Earth's surface, but because of the change in the speed of the photons in the gravitational field and Doppler effect. Time in orbit flows at the same speed as on the surface of the Earth, and the speed of the atomic clock does not depend on how high they are and at what speed they move in orbit.But nevertheless, the receiver on Earth sees that the frequency of the electromagnetic signal coming from the satellite is geater. What happens to the signal when it propagates in the gravitational field? This question can be answered on the basis of purely classical concepts, rejecting the dogma of the special theory of relativity of the "invariance" of the speed of light.

If to not take into account the effect of gravity, the distance of 20 184 km from the satellite orbit to the receiver on Earth, photons travel with a speed close to 299 792 458 m / s . To simplify the calculation, we neglect the speed reduction in a dense layer of the atmosphere (this layer is less than 1% of the entire path). Reducing the speed in this section is not of fundamental importance and does not significantly affect the resulting speed.

Photons from the satellite to the Earth move in the gravitational field and, like all material objects, are accelerated by this field, increasing the speed of movement. The speed increases in the same way as under the influence of gravity in a rarefied atmosphere increases the speed of a bullet directed from the satellite to the Earth. The increase in speed is proportional to the intensity of the field and the time of movement

The acceleration of gravity varies from 9.8 m / s2 at the Earth's surface to 0.5650 m / s2 at an altitude of 20,184 km of the satellite's orbit. The dependence of the acceleration of the earth's gravity on the height above the Earth's surface, we built with a fairly high accuracy in Visio 7 (Fig. 1). Provided that photons move in absolute vacuum, they pass a distance of 20 184 km in a time of 20 184 / 299792.4581617 = 0.067 326 576 9 sec. Dividing the area under the curve into 10 sections (2000 km each) and approximating them with rectangles and triangles, using the areas under the curve, we calculated the changes in the speed of the photons at different heights.

For example, for section 8:

speed change is [2000 / 299,792, 458] x bc + 0.5 x ef x ab / 299 792. 458 =

= 0.021 025 545612625118140897327043 5 m / s,

where: ab / 299 792. 458 - the time the photons pass the distance ab = 2000 km,

bc = ad = 2.6019 m / s2 - acceleration of gravity in area 8,

ef = bf – be, где bf = 3.7014 - acceleration of gravity in the next section 9.

Changes in the speed of movement of photons in the gravitational field for each section are shown in Fig. 1. Full calculations are given in the Appendix.

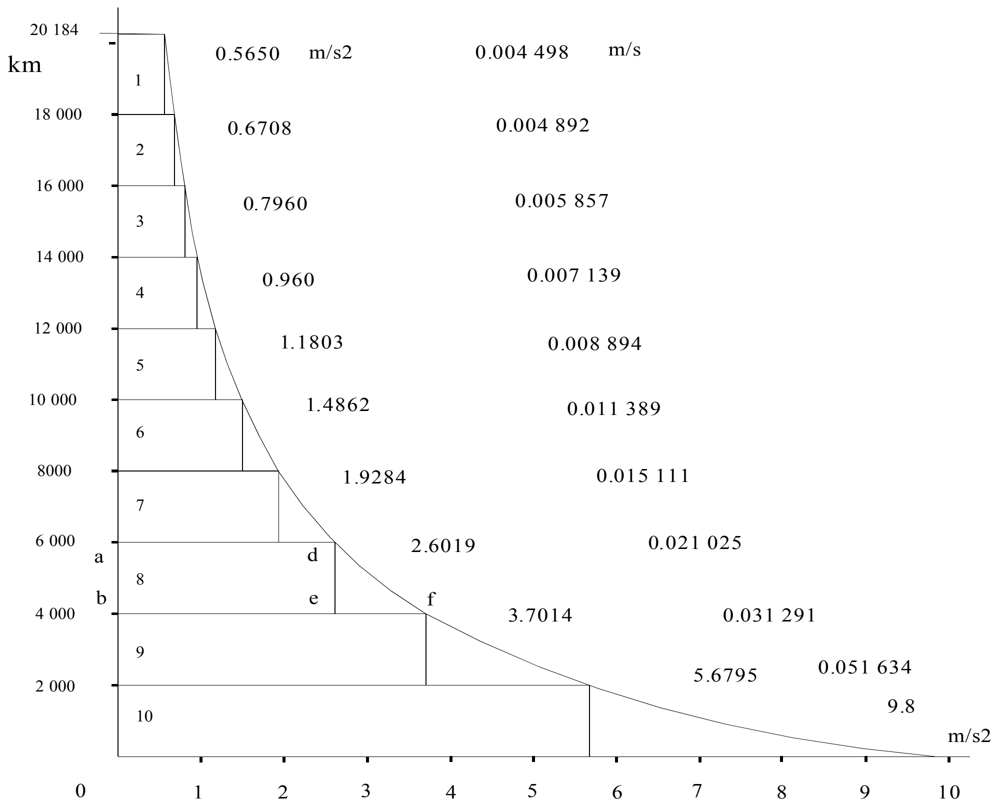

Fig.1

The change in the speed of the photons can be approximately determined by calculating the integral $\int_0^{20184} f(h)dh$, where f (h) is the dependence of the acceleration on the distance h from the Earth's surface, provided that the photons move at a constant speed and the time of movement is proportional to the distance, but such calculation also turns out to be approximate and not so clear/

The total increase in the speed of movement of photons on the way from the satellite to the receiver is given in the Appendix and turns out to be equal to 0.161 734 622423356627604020645509 35 m / s.

By such a value of 0.161 734 m / s, the speed of photons should increase under the action of gravity if we assume that the distance of 20 184 km from the satellite to the receiver of the photons is in absolute vacuum. In this case, the speed of movement increases to a speed of 299 792 458.1617 m / s, which is greater than C = 299 792 458 m / s.

In relative terms, the change in the speed of the photons turns out to be equal to

0.161 7 / 299 792 458 = 5.3948862990861707269507308789386e-10 or 5.3948 e-10 .

An increase in the speed of movement of photons by 5.3948 e-10 leads to a proportional increase in the signal frequency:

10 230 000 000 x 5.3948e-10 = 5.5189686839651526536705976891542 Гц

and therefore instead of the signal emitted by the satellite at a frequency of10.23 МГц , the receiver on Earth sees a high frequency signal 10 230 000 005.5189 Hz.

Accordingly, the signal from the receiver to the satellite travels at a speed of 299792457.8382 m / s, which is 0.161 7 m / s less than C = 299792458 m / s, and the satellite instead of a frequency of 10.23 GHz sees a frequency 10 229 999 994.4810 Hz lower by 5.5189 Hz.

Since in fact the signals do not travel in an absolute vacuum, but in a rarefied atmosphere, the signal from the satellite to the receiver on Earth does not come in time

20 184 / 299792.4581617 = 0.067 326 576 9 sec, but in time

20 184 x n / 299792.4581617 = 0.067 346 774 9 sec, that is more by 20 μs.

An additional time of 20 microseconds is spent on the re-emission of photons by the atoms of the medium, but the speed of the photons changes under the influence of gravity only in the intervals of time, when they move between the re-emitting atoms in absolute vacuum.

Thus, if before launching into orbit, you do not enter a correction in the atomic clock and the satellite emits a frequency of 10.23 MHz, a signal of an increased frequency of 10 230 000 005.5189 Hz arrives at the receiver on Earth.

The receiver sees an increased frequency not due to the fact that the clocks in orbit go faster, as stated by general relativity, but due to the fact that the frequency of electromagnetic radiation is increased when moving from the satellite to the Earth. The increase in photon frequency by 5.5189 Hz is explained not by the "acceleration of time" and the acceleration of the atomic clock but by an increase of 0.161 734 m / s in the speed of the photons.

To eliminate the effect of **only gravitational** frequency shift, a correction of 5.3948 e-10 should be introduced in the satellite clock before launching into orbit, reducing the signal frequency by 5.5189 Hz to a value of 10 229 999 994.4810 Hz. In orbit, neither the time nor the speed of the atomic clock changes, and the clock emits a frequency of 10,229,999,994.4810 Hz. Due to the fact that on the way from the satellite to the receiver the speed of the photons increases, a signal comes to the receiver on Earth with a frequency of 10.230 000 000 Hz.

Unlike the longitudinal Doppler effect, which is different for different satellites, since it depends on the angle at which the receiver sees it, the gravitational change in the signal frequency is the same for all GPS satellites, since it depends only on the difference in altitude between the satellite and the receiver. For example, although the S2-R distance to the S2 satellite (Fig. 2) is greater than the distance S1-P and the signal goes to the receiver longer, the speed of the photons on the S2-R path changes by the same amount 0.161 734 m / s as on the S1-R path from the S1 satellite. The increase in the distance to the satellite S2 is compensated by the decrease in the effect of gravity on the speed of the photon, since as it approaches the receiver, the direction of the gravitational vector, as shown by the arrows in Fig. 2, deviates from the direction of motion of the photons.

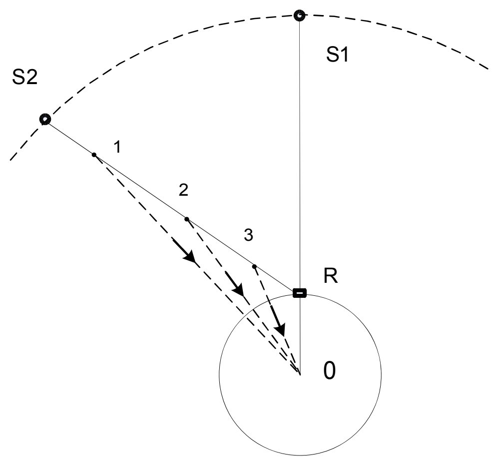

Рис.2

The frequency shift because of the satellite movement

Depending on the angle at which the receiver sees the satellite, a longitudinal Doppler effect occurs. This effect and the rotation of the Earth relative to the orbits of the satellites is taken into account in the receiver when solving equations and a corresponding correction is introduced to it.

However, in addition to this, the so-called correction for the deceleration of time due speed of the satellite movement is also introduced, since according to the SRT in all moving systems, time slows down and the speed of the clock decreases. Relativistic time dilation is the most famous effect of SRT (it is enough to recall the "paradox of twins") and a corresponding correction is introduced to it in the GPS system [6].

When the light source approaches the receiver or moves away from it, the receiver sees that the signal frequency is increasing or decreasing. But when the source moves perpendicular to the "source-receiver" line, the receiver should see light, the frequency of which, it would seem, should be exactly equal to that which the source emits, as is the case, for example, in acoustics. However, when source moves in transverse direction, the receiver sees light of smaller frequency. Special relativity explains this decrease in the frequency with the slowing down of time in moving systems The first attempt to experimentally confirm “time dilation” by measuring the frequency of light in the transverse direction was made in 1938 by Ives and Stilwell [13]. Subsequent experiments with very high accuracy confirmed the "time dilation" in the moving frame itself, but without direct measurement of the frequencies of the transverse rays. As we know, the experiment in which direct transverse observation was successfully carried out for the first time was carried out in 1979: the second-order Doppler shift was determined from the spectrum of hydrogen atoms moving at a speed of 9.28e8 cm / s [14]].

The transverse Doppler effect has been experimentally confirmed with high accuracy and therefore a corresponding correction is introduced in the GPS system. Relativists claim that it is impossible to explain the transverse effect from the classical point of view and consider it as confirmation of time dilation in moving systems.

In the article "Stellar aberration and the transverse Doppler effect" we explained why the frequency of light emitted in the transverse direction decreases [15]. Because the article was published more than 15 years ago, many could not find it, and therefore we will allow ourselves to briefly repeat the explanation given there.

Figure 2 shows the changes in the directions of movement of photons when the light source moves perpendicular the direction to the receiver.

If the source S is at rest, only the photons that were emitted exactly in the direction 0 to the arrive to the receiver R (Fig. 2, a). The photons emitted in directions 1 and 2 obviously do not arrive tot the receiver.

Let us imagine that the source and the receiver are in an ideal vacuum and the source with a speed V moves perpendicular to the SR line (Fig. 2, b). At the moment of emission, all photons receive an additional speed V, and the direction of movement and their speed relative to the receiver change. Those photons that the source emits in the direction of 0, now, due to the additional speed, do not come to the receiver.

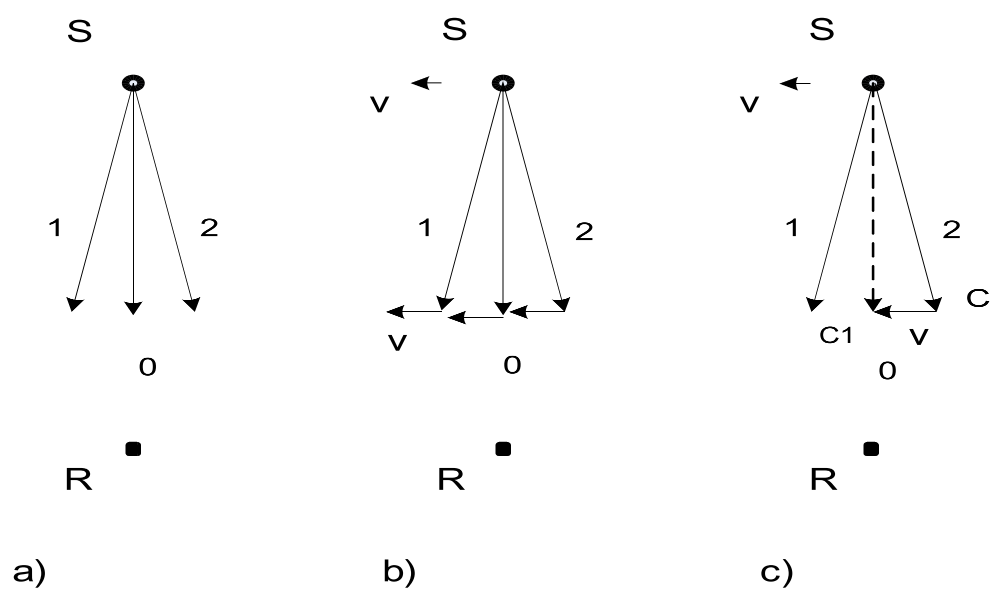

Fig.2

Instead of these photons, photons emitted in direction 2 come to the receiver, that is, photons emitted a little back: when the vector addition of the velocity V with the velocity C, the resulting velocity C1 (shown by the dotted line in Fig. 2) turns out to be directed towards the receiver and is less than C. In an ideal vacuum, the photons move toward the receiver at a speed C1 less than C, and therefore the receiver sees light at a reduced frequency.

In a real situation, photons always move not in an ideal vacuum, but in a gaseous medium, and their speed is determined by the refractive index of the medium (Fig. 2, c). But at the first moment after radiation before meeting with the atoms of the medium, the photons - just as in the case of motion in absolute vacuum - move relative to the source with a velocity C and the velocity V is added to this velocity C vectorially. Due to the added velocity, the photons emitted in the direction of 0 change direction and do not arrive at the receiver R. Photons emitted in direction 2 ("backward") change the direction of movement towards the receiver and after the first re-radiation by the atoms of the medium go towards the receiver. Just as in the case of motion in a vacuum, photons, before being re-emitted by the atoms of the medium, travel with a speed C1, which is less than C. A photon meets an atom of the medium at a speed $C1<C$ and its frequency decreases. The re-emitted photon with respect to the atom

moves with a speed C until it meets the next re-emitting atom and with an average speed C / n and with a reduced frequency goes to the receiver.

The same happens when a signal is emitted by a GPS satellite. If no correction is made to the satellite clock, the signal is emitted at a frequency of 10.23 GHz. The photons move relative to the satellite with a speed C, but since the satellite moves with an orbital speed of 3.874 km / s, due to the vector addition of this speed with a speed C, the speed of the photons relative to the receiver and the atmosphere changes from C to C1 <C:

$$C1 = \sqrt{C^2 - V^2}^2 = \sqrt{299792458^2} = \sqrt{299792458^2 - 3.874^2} = 299\,792\,457.\,974\,969557105024765046 76 \text{ м/сек}$$

and C – C1 = 299 792 458 - 299 792 457. 974 96955710502476504676 = 0.02 503 044289497523495324 m / s

The speed C1 turns out to be 0.02 503 044289497523495324 m / s less than the speed C.
The relative decrease in speed is

0.02 503 044289497523495324 / 299 792. 458 = 8.349 257 0366714278560136426113828e-11.

At a speed of 299 792 457. 974 m / s, the photons emitted by the satellite travel until the first re-emission by the atoms of the medium. Meeting with the atoms of the medium, the photons decrease the frequency and move relative to the medium at a speed C / n.

The relative reduction in frequency is the same as that of the C1 speed and equals 8.349 e-11. Therefore, in the absence of a correction for the clock rate, a signal arrives at the receiver with a frequency lower than the frequency of 10.23 GHz, at

10.230 000 000 x 8.349 257 0366714278560136426113828e-11 = 0.854 128994851487069670195639144446 Hz

and the receiver sees the frequency

10 230 000 000 - 0.854 128994851487069670195639144446 = 10 229 999 999. 145 87100514851293033 Hz.

In order for a 10.23 GHz signal to arrive at the receiver on Earth, a correction of 0.854 Hz must be introduced in the satellite clock before launching into orbit, and the clock must emit a signal with a frequency of 10 230 000 000. 854 Hz.

Thus, the decrease in signal frequency due to speed is explained not by the mythical "time dilation" in moving systems, but by the decrease in the speed of the photons at the moment of the emission by a moving satellite. The atomic clock, tuned before launch at an increased frequency of 10,230,000,000. 854 Hz, goes in orbit with the same frequency and the satellite emits a signal of this very frequency. Immediately after emission, the photons change the frequency by 0.854 Hz and the signal goes to the receiver on Earth at a frequency of 10.23 GHz

The assertion of relativists that at a speed of several kilometers per second, time slows down and the atomic clock decreases its speed, looks simply ridiculous, since even an acceleration of 1019g, as shown by cyclotron experiments, does not affect the speed of an atomic clock [11].

Resulting shift of the frequency

Above, we considered separately the effect of gravitational displacement and the velocity effect. The GPS system introduces one resulting correction for both "relativistic" effects. Due to the speed of the satellite's orbital motion, the signal frequency decreases by 8.349 e-11, and due to the change in the gravitational potential, it increases by 5.3948 e-10. The resulting effect is determined by the difference

5.3948e-10 – 8.349e-11 = 4.45599e-10

The frequency of the signal emitted by the satellite is increased by 4.45599×10−10,

10 230 000 000 x 4.45599×10−10 = 4. 664 7777 GHz

and therefore the atomic clock before launching into orbit is tuned to the frequency

10 230 000 000 - 4. 664 7777 = 10 229 999 995. $33_{5\ 222\ 3}$ Hz.

The GPS satellite emits a signal with a frequency of 10 229 999 995.33 Hz. During the time 0.067 seconds, while the signal travels from the satellite to the receiver on Earth, the signal frequency increases by 4.664 Hertz and the receiver receives a frequency of 10.23 GHz.

The frequency shifts we obtained (8.349e-11 - from the satellite speed, 5.3948e-10 - from the change in gravitation, 4.45599e-10 - from the combined effect, and 10 229 999 995.33 Hz) we compared with the data published by relchtivists, and found rather large discrepancies. For example, in [1, 5, 10], in contrast to our obtained values of 8.349e-11 and 5.3948e-10, the values of 2.5046 × 10−1 and 6.9693 × 10−10 are given, but practically the same values are indicated 4.4647 × 10−10 and 10.229 999 995 43 GHz.

Later articles indicate values close to those obtained by us: 8.349 × 10−11, 5.307 × 10−10, and 4.472 × 10−10 at the same frequency of 10.229 999 995 43 GHz [16]. The work [6] indicates the frequency of 10.229 999 995 453 GHz.

The rather good coincidence of the results obtained by us on the basis of classical concepts with the latest published data allows us to assert that when analyzing the operation of the GPS system, the theory of relativity with its mystical assertion about time dilation in moving systems is simply redundant.

Conclusion

The introduction of the so-called "relativistic" corrections in the GPS system is considered as confirmation of the validity of the main consequences of the theory of relativity - gravitational redshift and time dilation in moving systems.

In this article, we have shown that a receiver on Earth receives a signal of a changed frequency not due to a mystical change in time on the satellite, but due to a change in the frequency of electromagnetic radiation on the way from the satellite to the receiver. And such explanation becomes possible only under the condition that the main postulate of SRT - the postulate of "invariance" of the speed of light is erroneous and the speed of light in vacuum can vary in magnitude and be greater or less than C. This postulate is "confirmed" only by erroneous explanations of the Michelson experiment and De Sitter's observations of binary stars - in both cases, light does not propagate in vacuum, as is assumed, but in air (Michelson) or in a rarefied interstellar gaseous medium (De Sitter), where the velocity light is determined by the refractive index of the medium and therefore does not depend on the movement of the source. And on the basis of this experiment and this observation, a conclusion is made about the independence of the speed of light from the movement of the source! And not a single experiment, not a single observation prove the independence of the speed of light from the movement of the observer, while the postulate of invariance states that the speed of light does not depend either on the movement of the source, or on the movement of the observer who measures this speed.

In our previous work [17], on the basis of classical concepts, we were able to explain Fizeau's experiment with moving water - one of the most important "confirmations" of the theory of relativity. In this, as in all our other works [18], studies were carried out under the condition that the speed of light does not possess the mystical property of invariance and in an ideal vacuum depends on the speed of the source.

And the question always arises: why should we analyze all phenomena only taking into account the constancy of the speed of light and only therefore agree that time can slow down, that body weight increases with increasing speed, and so on?

And instead of analyzing such an achievement of humanity as the GPS system, assuming that time flows faster or slower, wouldn't it be better to conduct a direct experiment to measure the time of signal propagation in one direction? To conduct despite the fact that such an experiment is not possible due to the "clock synchronization according to Einstein" rule. It was impossible in 20 century but not in 21.

The experiment is possible and requires only that two GPS satellites moving in the same orbit have one regular, for $ 100 GPS receiver and make the satellites exchange signals. The clocks of the satellites are synchronized and therefore each receiver immediately determines the time of traveling of the signal from the second satellite. And they will immediately see that the signal from the first satellite to the second travels longer than from the second to the first. Because the speed of propagation of the signal relative to satellite 2 is less than the speed relative to satellite 1.

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Appendix

1 0.5650 x 2 184 / 299 792. 458 + 0.5 x 0.1050 x 2 184 / 299 792. 458
0.5650 x 0.00728503983912764076273059544413 + 0.5 x 0.1050 x 0.00728503983912764076273059544413
0.00411604750910711703094278642593 + 0.0003.82464591554201140043356260816 83
0.00449851210066131817098614268675

2 0.6708 x 2 000 / 299 792. 458 + 0.5 x 0.1252 x 2 000 / 299 792. 458
0.6708 x 0.0066712819039630409915115342895 + 0.5 x 0.1252 x 0.0066712819039630409915115342895
0.0044750959011784078971059372014 + 4.1762224718808636606862204 65226e-4
0.0048927181483664942631745592 4792

3 0.7960 x 0.0066712819039630409915115342895 + 0.5 x 0.164 x 0.0066712819039630409915115342895
0.0053103403955545806292431812 9444 + 5.4704511612496936130394581 1739e-4
0.0058573855116795499905471271 0618

4 0.960 x 0.0066712819039630409915115342895 + 0.5 x 0.2203 x 0.0066712819039630409915115342895
0.0064044306278045193518510729 1792 + 7.3484170172152896521499550198843e-4
0.0071392723295260483170660684 1991

5 1.1803 x 0.0066712819039630409915115342895 + 0.5 x 0.3059 x 0.0066712819039630409915115342895
0.0078741140312475772822810639219 + 0.0010203725672111471196516891 6958
0.0088944865984587244019327530 9148

6 1.4862 x 0.0066712819039630409915115342895 + 0.5 x 0.4422 x 0.0066712819039630409915115342895
0.0099148591656698715215844422 6105
0.0113898795946360998848076424 9246

7 1.9284 x 0.0066712819039630409915115342895 + 0.5 x 0.6735 x 0.0066712819039630409915115342895
0.0128649000236023282480308427 2387 +
0.0151114542047618823019223518 9586

8 2.6019 x 0.0066712819039630409915115342895 + 0.5 x 1.0995 x 0.0066712819039630409915115342895
0.0173580083859214363558138610 6785 +
0.0210255456126251181408973270 435

9 3.7014 x 0.0066712819039630409915115342895 + 0.5 x 1.9781 x 0.0066712819039630409915115342895
0.0246930828393287999259807930 1916 +
0.0312913142064434456186352760 0819

10 5.6795 x 0.0066712819039630409915115342895 + 0.5 x 4.1205 x 0.0066712819039630409915115342895
0.0378895455735580913112897589 9722 +
0.0516340541161979465140513975 1716

Resulting change is equal to **0.161 734 6224233566276040206455093 5** m / s