One-Way Speed of Light Using GPS Clocks

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Abstract. One-way light speed is determined using the synchronizing algorithm of the GPS clocks.

Keywords: GPS clocks, one-way light speed, special relativity

1. Introduction

The principle of the constancy of the speed of light is a key postulate in special relativity [1]. This idea followed from the essentially null result of the celebrated Michelson-Morley experiment of 1887 [2] and is today a fundamental concept in modern physics and metrology. Over the past 100 years, numerous experiments have been conducted (in the non-inertial frame of the rotating Earth) to test the validity of this postulate [3]. These experiments, which have searched for light speed variations resulting from directional, diurnal and seasonal changes have progressively lowered the limit on light speed anisotropy to a value of $\delta c / c < 10^{-17}$ where δc is the measured change in light speed. The result has been the wide acceptance of light speed isotropy on the surface of the Earth, with the speed of light being defined as a constant in the 1983 SI definition of the unit of length applicable in the frame of the rotating Earth.

Despite this almost universal acceptance of light speed constancy, Zhang [3] has shown that what these many experiments have established is two-way light speed constancy and that one-way light speed constancy remains unconfirmed. The measurement of one-way light speed generally requires synchronized clocks and the identification of the ECI frame in the latter part of the 20th century in which light travels at constant speed, allowed such clock synchronization to be realized. As a result, accurate synchronized atomic clocks are today deployed in the global positioning system (GPS) and are available for the measurement of one-way light speed on the surface of the Earth [4]. Marmet [5] and Kelley [6] were among the first to observe time differences using these synchronized clocks, between light travelling eastward as compared with light travelling westward over the same distance. From these light travel time differences these researchers deduced light speeds $c-v$ eastward and $c+v$ westward relative to the surface of the Earth where v is the speed of rotation of the Earth's surface at the particular latitude.

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Saburi [7] demonstrated transmission time differences of electromagnetic signals sent in two directions between ground stations in the USA and Japan via the geostationary satellite ATS-1. Unequal travel times for electromagnetic signals travelling in opposite directions around the surface of the Earth were also directly shown by Allan et al. using signal reflections off orbiting satellites [8], but these researchers did not associate this with anisotropic light speed. This result contradicting light speed constancy has been directly confirmed by this author using light travel time derived from the CCIR clock synchronization algorithm [9]. Since most physicists believe that one-way light speed constancy has been confirmed, in this paper we summarize the determination of one-way light speed using the GPS clocks.

2. One-Way Light Speed

Consider two points A and B fixed on the surface of the Earth with B east of A.

Eastward Transmission

The total time Δt for light to travel the path from point A to point B as measured by synchronized GPS clocks is given by [4]

$$\Delta t = \int_{path} \frac{d\sigma'}{c} + \frac{2\omega_E}{c^2} \int_{path} dA'_z \tag{1}$$

where $d\sigma'$ is infinitesimal distance in the moving frame, ω_E is the angular velocity of the rotating Earth and dA'_z is the infinitesimal area in the rotating coordinate system swept out by a vector from the rotation axis to the light pulse and projected onto a plane parallel to the equatorial plane. This equation has been experimentally confirmed in the operation of the GPS. Carrying out the simple integration involved in (1) gives

$$\Delta t_{AB} = \frac{l}{c} + 2A'_z \frac{\omega_E}{c^2} \tag{2}$$

where l is the distance between the two points both moving at speed v the speed of the Earth's surface at that latitude. Let the circumference of the Earth at that latitude be l_C and let the corresponding radius be r . Then the area A'_z is given by

$$A'_z = \frac{l}{l_C} \pi r^2 \tag{3}$$

Noting that $\omega_E = v / r$ and $l_C = 2\pi r$, equation (3) in (2) gives

$$\Delta t_{AB} = \frac{l}{c} + \frac{lv}{c^2} \tag{4}$$

Thus, if an observer at point A sends a light signal eastward to an observer at point B, the time interval Δt_{AB} between the transmission and reception of the signal is given in (4). This is the time that synchronized GPS ground-station clocks at A and B would measure. Since the distance between the two points is l, it follows that the one-way speed of light c_{AB} for light traveling eastward from A to B is given by

$$c_{AB} = \frac{l}{\Delta t_{AB}} = \frac{l}{\frac{l}{c} + \frac{lv}{c^2}} = c(1+\frac{v}{c})^{-1} = c(1-\frac{v}{c}+...) = c - v, v << c \qquad (5)$$

Westward Transmission

Similarly, the total time Δt_{BA} for light to travel the path from point B to point A as measured by synchronized GPS clocks is given by

$$\Delta t_{BA} = \frac{l}{c} - 2A'_z \frac{\omega_E}{c^2} \qquad (6)$$

which yields

$$\Delta t_{BA} = \frac{l}{c} - \frac{lv}{c^2} \qquad (7)$$

Thus, if an observer at point B sends a light signal westward to an observer at point A, the time interval Δt_{BA} between the transmission and reception of the signal is given in (7). Since the distance between the two points is l, it follows that the one-way speed of light c_{BA} for light traveling westward from B to A is given by

$$c_{BA} = \frac{l}{\Delta t_{BA}} = \frac{l}{\frac{l}{c} - \frac{lv}{c^2}} = c(1-\frac{v}{c})^{-1} = c(1+\frac{v}{c}+...) = c + v, v << c \qquad (8)$$

3. Conclusion

Thus, the travel time (4) gives a one-way eastward light speed measurement of $c_{AB} = c - v$ relative to the surface of the Earth and the travel time (7) gives a one-way westward light speed of $c_{BA} = c + v$. These results confirm that light travels faster West than East between fixed points on the surface of the Earth and therefore that one-way light speed is not the same in all directions as required by the light speed constancy postulate of special relativity. Importantly, these light speed tests revealing light speed anisotropy have been performed in the same frame as the many Michelson-Morley-type and other tests and also where the standard for length measurement using the light speed constancy postulate is routinely applied. These negating tests cannot therefore be discounted by claims of inapplicability because the Earth's surface is not inertial. This is an escape route often used by relativists whenever a test yields results that contradict special relativity. Finally, there have been attempts for example by Edwards [10] to overcome this difficulty presented by light speed anisotropy by deriving the Lorentz transformations of special relativity using two-way instead of one-way light speed constancy. This however does not resolve the problem for the theory since these transformations predict one-way light speed constancy which as shown is falsified by the GPS clocks. Selleri [11-12] has derived a set of transformations which predict anisotropic light speed and we believe these transformations better accord with the physical world.

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