# A Simple Demonstration of One-Way Light Speed Anisotropy Using GPS Technology

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**Abstract.** The one-way speed of light in an East-West direction over short distances is examined by exploiting the successful operation of the Global Positioning System. This system has been rigorously and extensively tested and verified in the Earth-Centred Inertial frame, a frame that moves with the Earth as it revolves around the Sun but does not share the Earth's rotation. The result is a simple demonstration of one-way light speed variation depending on the direction of propagation that indicates the need for a change in the practice of the routine application of the principle of light speed constancy in the frame of the Earth

**Keywords: one-way speed of light, GPS, range equation, ECI frame, special theory of relativity, principle of light speed constancy.**

## 1. Introduction

The GPS is a modern navigation system that employs accurate synchronized atomic clocks in its operation [1]. Based on the IS-GPS-200E Interface Specification [2], GPS signals propagate in straight lines at the constant speed $c$ in an Earth-Centered Inertial (ECI) frame, a frame that moves with the Earth but does not share its rotation. This isotropy of the speed of light in the ECI frame is utilized in the GPS range equation given by [1, 2]

$$\left|\overline{r_r}(t_r) - \overline{r_s}(t_s)\right| = c(t_r - t_s) \quad (1)$$

Here $t_s$ is the time of transmission of an electromagnetic signal from a source, $t_r$ is the time of reception of the electromagnetic signal by a receiver both times determined using synchronized clocks, $\overline{r_s}(t_s)$ is the position of the source at the time of transmission of the signal and $\overline{r_r}(t_r)$ is the position of the receiver at the time of reception of the signal.

Equation (1) allows accurate determination of the instantaneous position of objects which are stationary or moving on the surface of the Earth. It has been extensively and rigorously tested and verified and the system's very successful operation has resulted in the world-wide proliferation of GPS technology. It has recently been used to accurately determine distance and its clock synchronization technique utilized to accurately measure time of travel over that distance in a major experiment involving the claimed detection of superluminal neutrinos [3].

Light speed isotropy in the ECI frame and the appearance of $c$ in the range equation has sometimes been interpreted as a demonstration of the principle of light speed constancy of special relativity. This principle requires that light travel at a constant speed $c$ in all inertial frames [4-6]. Even though the principle is stated as applying in inertial frames, the vast majority of light speed experiments claim confirmation of the principle in the non-inertial frame of the Earth where anisotropy arising from rotational or orbital motion was investigated [7-16]. Zhang [7] has established that two-way light speed constancy in this frame has been confirmed while however one-way light speed constancy has not despite attempts in a few experiments to do so [14-16].

Notwithstanding the failure of this array of experiments to reveal any light speed changes, one-way light speed anisotropy induced by the Earth's rotational motion has been demonstrated for East-West light travel using GPS technology [17-20] and has been reported by Hatch for light transmission between the GPS receivers on two Gravity Recovery and Climate Experiment satellites [21]. Additionally light speed variation resulting from the Earth's orbital motion has been detected using occultations of Jupiter's satellite Io observed from the moving Earth [22] and apparently by Shtyrkov in the tracking of geostationary satellites [23]. These results if valid bring into question the application of the principle of light speed constancy in the frame of the rotating Earth.

In this paper we again test one-way light speed isotropy in the terrestrial frame utilizing GPS technology. Specifically we consider light traveling between two adjacent points fixed on the surface of the Earth at the same latitude and use the full functionality of the synchronized clocks and the range equation in the GPS to again establish the value of the one-way speed of light in an East-West direction.

## 2. One-way Light Speed on the Earth's Surface

Consider two adjacent GPS stations A and B at the same latitude and fixed on the surface of the Earth a distance $D$ apart with B East of A. Since the Earth is rotating, the stations are moving eastward at speed $v$ which is the Earth's surface speed at that latitude. Let $D$ be arbitrarily small relative to the surface of the Earth (stations A and B in the same building as occurs in the majority of light speed experiments) such that the stations are moving uniformly in the same direction at speed $v$ relative to the ECI frame.

### 2.1 Eastward Transmission

Let station A transmit a light signal eastward at time $t_I$ at a speed $c_E$ to station B which receives it at time $t_F$. Since these clocks are synchronized, the difference in these times $t_F - t_I$ is the time for the light to travel between the stations and is given by

$$t_F - t_I = \frac{D}{c_E} \tag{2}$$

On an axis fixed in the ECI frame along the line joining the two stations with the origin West of station A, let $x_A(t)$ be the position of station A at time $t$ and $x_B(t)$ be the position of station B at time $t$. Then from the range equation (1),

$$x_B(t_F) - x_A(t_I) = c(t_F - t_I) \tag{3}$$

where $x_B(t_F)$ is the position of station B at time $t_F$ and $x_A(t_I)$ is the position of station A at time $t_I$. Substituting (2) into (3) gives

$$x_B(t_F) - x_A(t_I) = c\frac{D}{c_E} \tag{4}$$

Since the stations are moving uniformly in the same direction at speed $v$ relative to the ECI frame, it follows that in light travel time $t_F - t_I$ the stations have moved eastward by a distance $v(t_F - t_I) = v\dfrac{D}{c_E}$ and hence

$$x_B(t_F) - x_A(t_I) = D + v(t_F - t_I) = D + v\frac{D}{c_E} \tag{5}$$

From equations (4) and (5) we get

$$c\frac{D}{c_E} = D + v\frac{D}{c_E} \tag{6}$$

which yields

$$c_E = c - v \tag{7}$$

This result means that on the basis of the verified operation of the GPS light travelling eastward over a short distance from clock A to clock B travels at a speed $c_E = c - v$ and not $c$ as is universally accepted.

## 2.2 Westward Transmission

Let station B transmit a light signal westward at time $t_I$ at a speed $c_W$ to station A which receives it at time $t_F$ . Since these clocks are synchronized, the difference in these times $t_F - t_I$ is the time for the light to travel between the stations and is given by

$$t_F - t_I = \frac{D}{c_W} \tag{8}$$

Then using the range equation (1) and noting that $x_B(t_I) > x_A(t_F)$ ,

$$x_B(t_I) - x_A(t_F) = c(t_F - t_I) \tag{9}$$

where $x_B(t_I)$ is the position of station B at time $t_I$ and $x_A(t_F)$ is the position of station A at time $t_F$ . Substituting (8) into (9) gives

$$x_B(t_I) - x_A(t_F) = c\frac{D}{c_W} \tag{10}$$

Since the stations are moving uniformly in the same direction at speed $v$ relative to the ECI frame, it follows that in light travel time $t_F - t_I$ the stations have moved eastward by a distance $v(t_F - t_I) = v\frac{D}{c_W}$ and hence

$$x_B(t_I) - x_A(t_F) = D - v(t_F - t_I) = D - v\frac{D}{c_W} \tag{11}$$

From equations (10) and (11) we get

$$c\frac{D}{c_W} = D - v\frac{D}{c_W} \tag{12}$$

which yields

$$c_W = c + v \tag{13}$$

This result means that based on the confirmed operation of the GPS light travelling westward over a short distance from clock B to clock A travels at a speed $c_W = c + v$ and not $c$ as is the universal belief.

## 2.3 Discussion

From (7) and (13) it follows that successful GPS operation demands that light travel faster West than East relative to the surface of the Earth. In particular the accurate operation of the synchronized clocks and range equation of the GPS demonstrates that a light signal sent eastward travels at speed $c$ minus the rotational speed of the Earth $v$ at that latitude giving $c - v$ as presented in (7). The accurate operation of the synchronized clocks and range equation of the GPS also demonstrates that a signal sent westward travels at speed $c$ plus the rotational speed of the Earth $v$ at that latitude giving $c + v$ as presented in (13).

These speeds are exactly the East-West light speeds $c \pm v$ found in independent investigations using GPS technology [17-21] and have here been demonstrated for short distances and hence approximately inertial frames. This obviates any objections relating to rotating frames which in general are not raised in the numerous light speed experiments, the vast majority of which are performed in the same (terrestrial) frame as this test and where light speeds $c$ are claimed [7-16]. These tests [7-16] which directly searched for light speed anisotropy resulting from the Earth's rotational and orbital motion did not detect one-way East-West light speeds $c \pm v$ here detected using the GPS.

These changed light speed values $c \pm v$ indicate the invalidity of the application of the principle of light speed constancy in the terrestrial frame where the principle requires constant light speed $c$ for light traveling westward or eastward between the two adjacent stations. Not only are these varying light speeds established using the GPS, the timing differences arising from these varying light speeds on the surface of the Earth are actually programmed in the GPS computers in order to produce accurate global positioning, further confirming the validity of the observed light speed anisotropy [18, 19].

## 3. Conclusion

In this paper, the successful operation of the GPS was used to demonstrate one-way light speed anisotropy $c \pm v$ for light traveling between two adjacent points at the same latitude and fixed on the surface of the Earth. The values $c \pm v$ represent an unmistakable variation in the speed of light arising from the rotation of the Earth as the light travels in the east-west direction and are consistent with light speed anisotropy results obtained previously [17-21]. In view of these revelations, the practice of the routine application of the principle of light speed constancy in the frame of the surface of the Earth needs to be reexamined. Additionally these light speed anisotropy results add another dimension to the intense discussion now taking place as a result of the recent observations at CERN [3].

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