

# Detection of absolute motion through measurement of synchronization offsets

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## Abstract

An absolute reference frame may be defined as the one which is stationary with respect to the center of mass of the Universe and in which speed of propagation of light is an isotropic constant. Any motion with respect to this frame may be referred as absolute motion. In this paper we examine the Sagnac effect of absolute motion in the context of clock synchronization through GPS satellites in common view mode. The e-synchronization of two clocks A and B amounts to introduction of time offsets such that the time taken by a light pulse to propagate between A and B will be measured to be the same in both directions. Synchronization of two clocks through a GPS satellite in common view mode is effectively equivalent to e-synchronization of these clocks and introduces an absolute synchronization mismatch proportional to the absolute velocity and length of the baseline. Measurement of this synchronization offset between the GPS synchronized clocks at the ends of a long baseline will enable the practical detection of absolute motion of earth. Here we propose a simple experiment for detection of absolute motion through measurement of absolute synchronization offsets between two timing laboratories maintaining UTC time.

**Keywords:** e-synchronization; absolute motion, Sagnac effect; synchronization offset; Relativity.

## 1. Introduction

According to special theory of relativity (SR) all motion is relative and existence of an absolute inertial frame of reference which could be practically distinguished from all other inertial frames, is ruled out. However, as per the Newtonian notion of absolute time and length, we may define an absolute or universal reference frame as the one which is at rest with respect to the center of mass of the universe, is non-rotating, and assume the speed  $c$  of light propagation to be an isotropic universal constant in that frame. Any motion with respect to such a reference frame will be called absolute motion.

The second postulate of SR depicts an assumption that the speed of light in vacuum is the same isotropic constant  $c$  in all inertial reference frames (IRF) in relative uniform motion. It is well known from Maxwell's theory that the speed of light in vacuum depends on the permittivity  $\epsilon_0$  and permeability  $\mu_0$  of the physical space. Since permittivity and permeability are properties of the physical space, the speed of light in vacuum is also a property of physical space and cannot be derived from the metric properties of coordinate space. Hence the speed  $c$  of light in vacuum can be an isotropic constant only with respect to a reference frame which is at rest or fixed in the physical space; that is, with respect to an absolute reference frame. It is therefore, wrong to define the speed of light as the same isotropic constant in different IRF in relative motion.

Kozynchenko (2006) had proposed an experiment for measuring the absolute velocity of the Earth by using two

atomic clocks. However, that experiment required much better time resolutions than currently available in atomic clocks and hence could not be practically feasible. Sandhu (2010) has shown that detection of such an absolute motion is practically feasible by measuring the up-link and down-link signal propagation times between two fixed points on the surface of earth by using pre-synchronized precision atomic clocks. Dong, J. and Dong, B. (2011) have proposed a novel method of measuring the one-way speed of light without using the atomic clocks. Here we show that detection of absolute motion is also feasible by measuring the synchronization offset between two GPS synchronized clocks located at the ends of a long baseline.

To illustrate the effect of absolute motion on signal propagation times, let us consider two points A and B in space, with a constant separation distance  $D$ . Let us assume that the line segment AB is moving in the universal reference frame with a common uniform velocity  $U_{ab}$  along AB. At an instant  $t_1$  let a signal pulse be emitted from point A when the instantaneous locations of A and B are  $A_1$  and  $B_1$  in space (figure 1). Let the signal pulse reach B at an instant  $t_2$  when the instantaneous locations of A and B are  $A_2$  and  $B_2$  respectively. The total time of flight of the pulse will now depend on the instantaneous separation distance  $A_1B_1$  (or  $D$ ) as well as the distance  $B_1B_2$  which represents the motion of point B during the pulse propagation time. The total distance traveled by the signal pulse (or light path) will be given by the relation,

$$c.(t_2-t_1) = D + U_{ab}.(t_2-t_1) \quad (1)$$

Therefore, for  $U_{ab} \ll c$ , the total pulse propagation time  $T_p$  is given by,

$$T_p = t_2 - t_1 = \frac{D}{c - U_{ab}} = \frac{D}{c} + \frac{D \cdot U_{ab}}{c^2} \quad (2)$$

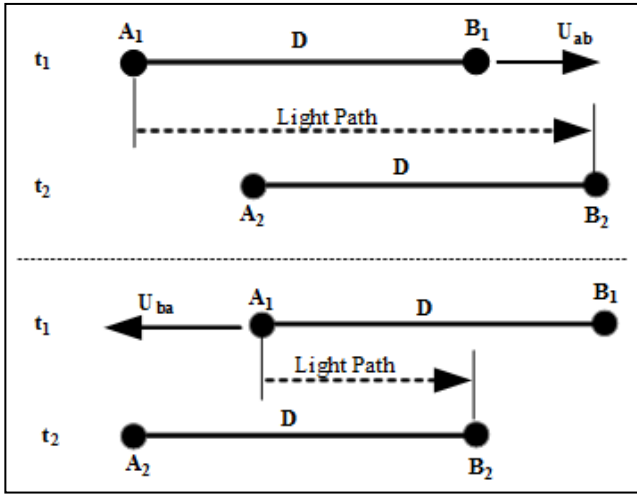
When the receiver is moving in the same direction in which the pulse propagates, the pulse propagation time will be longer than  $D/c$ , by an amount  $\delta t$  given by,

$$\delta t = T_p - \frac{D}{c} = \frac{D \cdot U_{ab}}{c^2} \quad (3)$$

If the common velocity of segment AB is from B to A ( $U_{ba}$ ), while the signal pulse still propagates from A to B, then the pulse propagation time will be shorter than  $D/c$ , by an amount  $\delta t$  given by,

$$\delta t = T_p - \frac{D}{c} = -\frac{D \cdot U_{ba}}{c^2} \quad (4)$$

The essence of Sagnac effect is to take into account the motion of receiver during the propagation time of the pulse. It is implied however, that the motion of receiver must be measured in the same inertial reference frame in which the speed  $c$  of signal propagation is an isotropic constant. Hence, the Sagnac effect associated with absolute motion must be considered in an absolute or universal reference frame.



**Fig. 1.** Effect of absolute motion of target on pulse propagation time.

## 2. Effect of Absolute Motion on GPS Position Determination

As per the currently accepted procedure for GPS position determination, the speed  $c$  of light propagation under vacuum conditions is assumed to be an isotropic constant in the Earth Centered Inertial (ECI) reference frame. To determine the position of a GPS receiver in an Earth Centered Earth Fixed (ECEF) reference frame, it requires specific coded signals from four or more GPS

satellites. The GPS receiver position  $\mathbf{R}$  in ECEF reference frame is not measured directly. The receiver records the time of reception  $T_{ri}$  of the  $i^{\text{th}}$  satellite signal and determines the time of signal transmission  $T_s$  and the satellite position  $\mathbf{S}_i$  in the ECEF frame by decoding the signal contents. If  $\mathbf{D}_i = \mathbf{R} - \mathbf{S}_i$  is the vector distance from  $i^{\text{th}}$  satellite to the receiver,  $T_{di}$  is the estimated or computed signal propagation delay, and  $t_{pi}$  is the signal propagation time for distance  $D_i$  in vacuum conditions, under assumed isotropy of light speed in ECI frame, then

$$|\mathbf{D}_i| = c t_{pi} \quad (5)$$

$$T_i = T_{ri}(\text{clock}) - T_s(\text{GPS}) - T_{di} = t_{pi} + t_{off} \quad (6)$$

where  $t_{off} = T_{\text{clock}} - T_{\text{GPS}}$  is the receiver clock offset from the GPS time and  $T_i$  is the only timing data available with the receiver for further computations. Here  $T_i$  is sum of two unknowns  $t_{pi}$  and  $t_{off}$  out of which the signal propagation time  $t_{pi}$  governs the range equation (5) and  $t_{off}$  enables synchronization of the receiver time with GPS system time. In GPS timing receivers, where the receiver coordinates are known,  $t_{pi}$  is computed from known signal path  $D_i$  and the receiver clock offset  $t_{off}$  gets computed as REFGPS in the CCGTTS file format from the available  $T_i$  data. Let  $\mathbf{u}_i$  be the unit vector along signal path  $\mathbf{D}_i$  such that,

$$\mathbf{u}_i = \frac{\mathbf{D}_i}{|\mathbf{D}_i|} \quad (7)$$

Since the satellite and receiver positions are defined in the ECEF frame, the Sagnac effect associated with the rotation of earth during the propagation time  $t_{pi}$  is normally accounted for (Ashby, 2003). Here we shall only discuss the Sagnac effect, associated with the light speed anisotropy in the ECI frame, induced by the absolute motion of earth during the signal propagation time from satellite to the receiver. If  $\mathbf{U}$  is the absolute velocity of earth, then the light speed anisotropy in the ECI frame can be accounted for (as  $c - U_{ab}$  in equation 2) by specifying the speed of light propagation along the signal path  $\mathbf{D}_i$  as,

$$c_i = c - \mathbf{U} \cdot \mathbf{u}_i \quad (8)$$

In the absolute frame, let  $\mathbf{D}_i'$  be the signal path vector from the satellite position at the instant of signal transmission to the receiver position at the instant of signal reception, such that absolute signal propagation time, under vacuum conditions, is given by,

$$T_{pi} = \frac{|\mathbf{D}_i'|}{c} \quad (9)$$

Viewing this signal propagation in the ECI frame, the signal path  $\mathbf{D}_i$  remains unchanged but the speed of signal propagation along  $\mathbf{D}_i$  becomes anisotropic  $c_i$ . Therefore, the absolute time of signal propagation along  $\mathbf{D}_i$  in the ECI frame will be given by,

$$T_{pi} = \frac{|\mathbf{D}_i|}{c_i} = \frac{|\mathbf{D}_i|}{c - \mathbf{U} \cdot \mathbf{u}_i} = \frac{|\mathbf{D}_i|}{c} \left\{ 1 + \frac{\mathbf{U} \cdot \mathbf{u}_i}{c} \right\} = t_{pi} + \frac{\mathbf{U} \cdot \mathbf{D}_i}{c^2} \quad (10)$$

The second term of equation (10) represents the change in signal propagation time from  $i^{\text{th}}$  satellite, induced by the Sagnac effect of absolute motion. Depending upon the orientations of the absolute velocity vector  $\mathbf{U}$  and the signal path vector  $\mathbf{D}_i$  these Sagnac terms will be positive for two or three satellites in view and negative for the remaining two or three satellites in view. A number of techniques have been developed to solve the nonlinear pseudo-range equations to calculate the receiver position  $\mathbf{R}$  iteratively, using Iterative Least Squares (ILS) algorithm. As the final solution converges to the correct position  $\mathbf{R}$ , the signal propagation time converges to  $t_{pi}$  for distance  $D_i$  when range equations (5) are based on the assumed isotropy of light speed in the ECI frame. However, if the range equations are based on the anisotropy of light speed in the ECI frame, the signal propagation time will converge to  $T_{pi}$  of equation (10) as the final solution converges to the correct position  $\mathbf{R}$ . The difference in propagation time in the two cases will get passed on to the receiver clock offset  $t_{\text{off}}$ . Of course the absolute velocity of earth  $\mathbf{U}$  and hence the anisotropy of the light speed  $c_i$  in the ECI frame are not known. Therefore, at present the range equations (5) are always based on the assumed isotropy of light speed in the ECI frame and the resulting errors in the signal propagation time get passed on to the receiver clock offset  $t_{\text{off}}$ . Since there is no other method to separate the unknown propagation times and the receiver clock offset from the available timing data  $T_i$ , most of the errors in  $T_i$  are passed out to the values of receiver clock offset while iteratively solving the pseudo-range equations using ILS algorithm. Hence, the effect of light speed anisotropy in ECI or ECEF frame manifests itself in the receiver time offset errors and not in the position errors.

### 3. OPERA Neutrino Experiment

The OPERA Collaboration (2011), in their paper titled “*Measurement of the neutrino velocity with the OPERA detector in the CNGS beam*”, described the measurement of neutrino velocity over a known baseline of about 730 km. At CERN, the accelerator chain is time stamped with UTC time obtained from GPS receiver XL-DC, whereas a GPS receiver ESAT-2000 provides the UTC time at LNGS. In July 2007, the synchronization mismatch between CERN and LNGS clocks was found to be about 424 ns with a portable atomic clock. “*The phase of the Cs4000 had been measured with respect to the XL-DC before leaving CERN and it was measured again with respect to Clock2 once arrived at LNGS. The two phases were within 424 ns.*” (Brunetti, 2011). This was an important result showing an absolute synchronization mismatch between the two GPS receivers located at the ends of the baseline. This measured synchronization mismatch between the two GPS receivers presented first evidence of Sagnac effect associated with absolute motion.

In 2008, two new PolaRx2e GPS receivers, with Cesium (Cs) clocks, were installed as additional systems at CERN and LNGS to correct the purported erratic behavior

of the two old GPS systems. The PolaRx2e receivers are geodetic time receivers with an accuracy of one ns. In the LNGS and CERN timing system, the PolaRx2e receivers provide precise offset values ( $\text{REF}_{\text{GPS}}$ ) between the local reference clock and the GPS time. As per the reports of METAS, (2008) and Feldmann, (2011), the receiver, antenna and cables were differentially calibrated for hardware delays before and after the data acquisition period. The time offset  $\Delta t$  between the reference clock ( $T_{\text{Pol}}$ ) and the local UTC time ( $T_{\text{UTC}}$ ) is logged into the monitoring computer every second. The local UTC time ( $T_{\text{UTC}}$ ) is related to the GPS system time ( $T_{\text{GPS}}$ ) at both locations through following relations.

$$\Delta t = T_{\text{UTC}} - T_{\text{Pol}} \quad (11)$$

$$\text{REF}_{\text{GPS}} = T_{\text{Pol}} - T_{\text{GPS}} \quad (12)$$

$$T_x = \text{REF}_{\text{GPS}} + \Delta t = T_{\text{UTC}} - T_{\text{GPS}} \quad (13)$$

Using equation (13), we can correlate the CERN system time  $T_{\text{UTC}}(\text{C})$  with the OPERA time  $T_{\text{UTC}}(\text{G})$  as,

$$T_{\text{UTC}}(\text{C}) - T_{\text{UTC}}(\text{G}) = T_x(\text{C}) - T_x(\text{G}) = C_r. \quad (14)$$

Essentially, the  $C_r$  of equation (14) represents the synchronization mismatch between the system times of CERN and LNGS. However, as shown at figure 9.1 of the PhD Thesis of Brunetti, (2011) the OPERA event times are being corrected for the synchronization mismatch of the order of 240 ns between CERN and LNGS. Such an high order of mismatch between the UTC times at CERN and LNGS, with diurnal fluctuations of about 60 ns, presented second evidence of Sagnac effect associated with absolute motion.

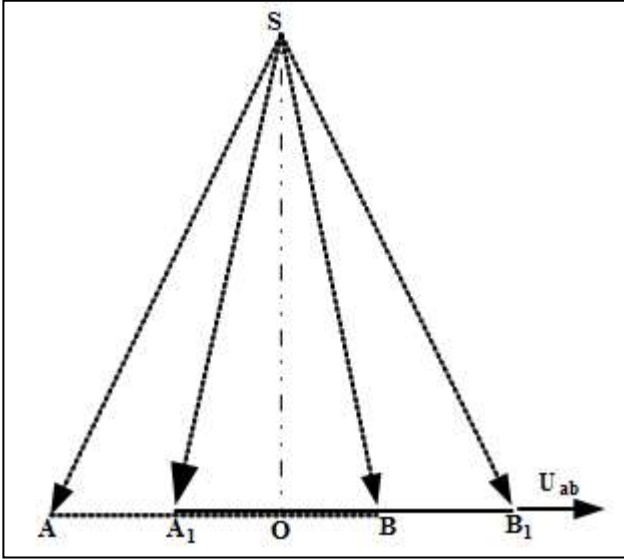
### 4 Sagnac Effect of Absolute Motion

When the UTC time at CERN and LNGS is obtained through synchronization with the GPS time, any mismatch between the two must be commensurate with the measured accuracy of the two GPS receivers. A larger value of synchronization mismatch or offsets between the UTC times of the two sites can be attributed to the Sagnac effect of absolute motion.

#### 4.1 Clock offsets in e-synchronization

Quoting Albert Einstein, from his 1905 paper, (Einstein, 1905) “...we establish by definition that the ‘time’ required by light to travel from A to B equals the ‘time’ it requires to travel from B to A.” This arbitrary definition of time constitutes a fundamental departure from the Newtonian notion of absolute time. Of course, this departure was required to support the assumed isotropy of light speed  $c$  in all IRF in relative motion. Consequent to this definition, which became Einstein’s famous clock synchronization (e-synchronization) convention, clock times of clocks in motion had to be readjusted by introducing time offsets as a function of position and velocity. This was required to ensure that the speed of light measured with e-synchronized clocks will always be  $c$ , regardless of the motion of the clocks.

Let  $U_{ab}$  be the component of absolute velocity along the baseline AB, of length D, and let a pulse of light propagate from A to B (figure 1). When the receiver is moving in the same direction in which the pulse propagates, the pulse propagation time will be longer than  $D/c$  by an amount  $D.U_{ab}/c^2$ . If we adjust the offset between the two clocks in such a way that the leading end clock (B) is set behind the trailing end clock (A) by an amount  $D.U_{ab}/c^2$ , then on arrival of the pulse at B the clock (B) will measure the event time to be less by  $D.U_{ab}/c^2$  than the true time. This will ensure that the pulse of light will be *measured* to propagate the distance from A to B in time  $D/c$ . On the other hand when the pulse is emitted from B towards A, the emission time of the pulse recorded by clock (B) will be  $D.U_{ab}/c^2$  earlier than the true time. This will again ensure that the pulse of light will be measured to propagate the distance from B to A in time  $D/c$ . This in essence is the e-synchronization of clocks in SR.



**Fig. 2.** Illustration of the Sagnac effect of absolute motion of baseline AB during the pulse propagation time from satellite S. The point A moves to  $A_1$  during the pulse propagation time of  $SA_1/c$  and B moves to  $B_1$  during pulse propagation time of  $SB_1/c$ .

#### 4.2 Clock synchronization through GPS satellites

Next, we show that synchronization of two clocks A and B, through a GPS satellite in common-view mode, is equivalent to e-synchronization of these clocks. Let us assume that  $U_{ab}$  is the component of absolute velocity of the baseline AB along A to B, and distance  $AB=D$ . Let S be the satellite in common view of A and B, such that its normal distance SO to the baseline is about 20200 km. Let a signal pulse be transmitted from S at an instant  $t_s$ , when the baseline is at AB (figure 2). Assume all atmospheric and hardware propagation delays (d) are properly accounted for. Let  $t_r(A)$  be the actual reading of clock (A) at the instant of arrival of pulse at A from S. From this clock reading, the

estimate of satellite time ( $t_{SE}$ ) at the instant of pulse transmission will be given by,

$$t_{SE} = t_r(A) - d_A - SA/c \quad (15)$$

Therefore, the normal synchronization correction  $REFGPS_{norm}(A)$  to be added to all clock (A) readings, for synchronization of this clock with the satellite system time will be given by  $t_s - t_{SE}$  as,

$$REFGPS_{norm}(A) = t_s - t_{SE} = t_s - t_r(A) + d_A + SA/c \quad (16)$$

Similarly, if  $t_r(B)$  is the actual reading of clock (B) at the instant of arrival of the pulse at B, the normal synchronization correction  $REFGPS_{norm}(B)$  to be added to the clock (B) readings, for synchronization of this clock with the satellite time will be given by,

$$REFGPS_{norm}(B) = t_s - t_r(B) + d_B + SB/c \quad (17)$$

However, equations (15) to (17) are valid only if the points A and B do not move along AB during the pulse propagation time. But when we consider absolute motion, the points A and B do move to positions  $A_1$  and  $B_1$  during the propagation time (figure 2). As such, the true propagation times will change from  $SA/c$  and  $SB/c$  to  $SA_1/c$  and  $SB_1/c$  in equations (15) to (17). Therefore the absolute synchronization corrections  $REFGPS_{abs}(A)$  and  $REFGPS_{abs}(B)$  for absolute synchronization of these clocks with the satellite time will be given by,

$$REFGPS_{abs}(A) = t_s - t_r(A) + d_A + SA_1/c \quad (16A)$$

$$REFGPS_{abs}(B) = t_s - t_r(B) + d_B + SB_1/c \quad (17A)$$

Normal synchronization correction  $REFGPS_{norm}$  is the value of  $REFGPS$  which normally gets computed in the CCGTTS files during time transfer through GPS satellites in common view mode. This computation is based on the normal assumption of isotropy of light speed in the ECI frame. Difference between the normal synchronization correction and the absolute correction represents the synchronization error or offset  $T_a$  or  $T_b$  and is obtained from equations (16), (16A) and (17), (17A) as,

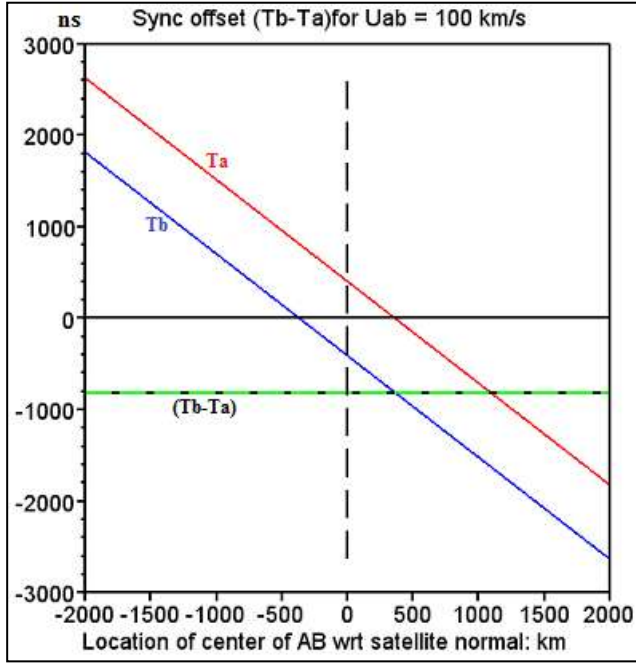
$$T_a = REFGPS_{norm}(A) - REFGPS_{abs}(A) = SA/c - SA_1/c \quad (18)$$

$$T_b = REFGPS_{norm}(B) - REFGPS_{abs}(B) = SB/c - SB_1/c \quad (19)$$

Positive value of  $T_a$  will imply that in the normal synchronization procedure, clock (A) gets advanced or leads the true time by an amount  $T_a$ . For different positions of the center of baseline with respect to the satellite normal SO (figure 2), we can compute the values of  $T_a$  and  $T_b$ , by using equations (18) and (19). Figure 3 shows the plot of  $T_a$  and  $T_b$ , for a typical velocity  $U_{ab}=100$  km/s of a 730 km baseline. The difference between  $T_b$  and  $T_a$  is also shown in figure 3 and significantly  $(T_b - T_a)$  remains constant for all positions of the baseline. The magnitude of  $(T_b - T_a)$  represents the time offset between clocks (A) and (B), induced by the Sagnac effect of absolute motion ( $U_{ab}$ ) of the baseline. The value of  $(T_b - T_a)$  shown in figure 3 is -811 ns for  $U_{ab}$  of 100 km/s. Negative value of  $(T_b - T_a)$  implies that clock (B) lags clock

(A). In general the value of  $(T_b - T_a)$  computed from equations (18) and (19) is given by,

$$T_b - T_a = -D \cdot U_{ab} / c^2 \quad (20)$$



**Fig. 3.** Satellite common view synchronization offsets of clocks at ends A and B of 730 km baseline.

This effect is precisely equivalent to the standard e-synchronization of the clocks A and B. Hence, the Sagnac effect of absolute motion of the baseline AB, induces a GPS synchronization time offset of  $D \cdot U_{ab} / c^2$  between the two clocks.

### 5. Measurement of Synchronization Phase Offset at two Timing Laboratories

The International Atomic Time (TAI) and Coordinated Universal Time (UTC) are maintained at the BIPM using data from some two hundred atomic clocks in over fifty national laboratories. The GPS data sent to the BIPM is formatted in accordance with CGGTTS specifications. The clock comparisons that provide the data for the calculation of TAI are mainly carried out using GPS satellites. Physical realizations of  $UTC(k)$  are maintained in national metrology institutes contributing with their clock data to the BIPM.

Consider two such national timing institutes or laboratories (Labs) which are regularly conducting clock comparisons through GPS satellites and designate them as Lab A and Lab B. We may ensure that the selected pair of timing Labs are separated by a long baseline D (say more than 500 km). Let the UTC time maintained at the Labs A and B, with their primary standard Cesium atomic clocks, be  $T_{UTC}(A)$  and  $T_{UTC}(B)$  respectively. In the normal process of conducting clock comparisons through GPS satellites in

common view mode, the Labs record their measurement data in CGGTTS format (Banerjee, 2007). The CGGTTS file format at the recording Labs contains information regarding satellite number (PRN), satellite track time (STTIME) and the *normal* time difference (REFGPS) between the laboratory reference clock ( $T_{UTC}$ ) and the satellite GPS time ( $T_{GPS}$ ) as,

$$REFGPS(A) = T_{UTC}(A) - T_{GPS} \quad (21)$$

$$REFGPS(B) = T_{UTC}(B) - T_{GPS} \quad (22)$$

The recorded timing data in CGGTTS format can be periodically exchanged between the recording Labs to compute the normal synchronization offset for a common PRN and STTIME as,

$$REFGPS(A) - REFGPS(B) = T_{UTC}(A) - T_{UTC}(B) \quad (23)$$

A zero value of this synchronization offset will imply e-synchronization between the clocks at A and B Labs. To evaluate the absolute synchronization mismatch between the clocks at A and B, we need to compare them with a portable pre-synchronized precision atomic clock. We can use Symmetricom's SA.45s CSAC, with an accuracy of 5 ns, as a portable clock mainly for ease of transportation and overall portability. To begin with, for detection of absolute motion we don't need to measure the absolute velocity vector of earth with great precision. Therefore, we can tolerate small inaccuracies in the measurement of phase shifts between the master clocks at two timing Labs. For certain Labs with greater separation distance, the absolute phase shift is expected to be of the order of a few hundred nanoseconds.

For comparing the phase of two clocks, first synchronize the portable clock with UTC time of master clock at Lab B in close by position, such that,  $T_{port} = T_{UTC}(B)$ . After ensuring the stability of synchronization between the portable clock and clock B for a week or two, shift the portable clock to Lab A and connect it to the fixed master clock through a time interval counter. Let the phase difference between the fixed master clock at A ( $T_{UTC}(A)$ ) and the portable clock ( $T_{port}$ ) be,

$$T_{UTC}(A) - T_{port} = \Delta t(A) \quad (24)$$

Since  $T_{port} = T_{UTC}(B)$ , from equations (21), (22) and (24) we get,

$$REFGPS(A) = T_{port} + \Delta t(A) - T_{GPS} \quad (21A)$$

$$REFGPS(B) = T_{port} - T_{GPS} \quad (22A)$$

Subtracting equation (22A) from (21A), we get,

$$REFGPS(A) - REFGPS(B) - \Delta t(A) = 0 \quad (25)$$

However, equation (25) cannot be true when computation of REFGPS is based on the normal assumption of isotropy of light speed in the ECI frame. Equation (25) will hold only when REFGPS is computed by taking into account the Sagnac effect of absolute motion, as in  $REFGPS_{abs}$  of equations (16A) and (17A). Therefore, using



equations (18) and (19), we may re-write equation (25) in terms of REFGPS<sub>norm</sub> as,

$$\text{REFGPS}_{\text{norm}}(A) - T_a - \text{REFGPS}_{\text{norm}}(B) + T_b - \Delta t(A) = 0$$

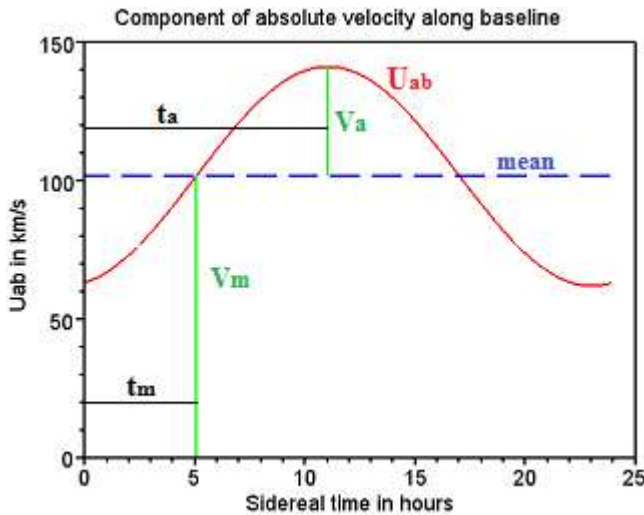
or,

$$T_b - T_a = \text{REFGPS}_{\text{norm}}(B) - \text{REFGPS}_{\text{norm}}(A) + \Delta t(A) \quad (26)$$

This  $(T_b - T_a)$  represents the absolute synchronization offset caused by the Sagnac effect of absolute motion, which can be measured and correlated with the absolute velocity of earth through equation (20).

### 5.1 Correlation between absolute velocity and synchronization offsets

As indicated in figure 3, the synchronization corrections  $(T_b - T_a)$  of the order of about -800 to -1000 ns could be feasible if the component  $U_{ab}$  of the absolute velocity along the baseline AB, is of the order of 100 km/s or so. Let the absolute velocity vector of earth be  $\mathbf{U}$ . Knowing the exact coordinates of Lab A (say LNGS) and Lab B (say CERN), the component  $U_{ab}$  of the absolute velocity will be given by the dot product of  $\mathbf{U}$  with a unit vector along AB. Hence, from the measured data of synchronization corrections  $(T_b - T_a)$  obtained from equation (26) over a period of at least 24 hours, it is feasible to make a fair assessment of the absolute velocity  $\mathbf{U}$  of earth. To demonstrate this feasibility, let us use a geocentric coordinate system with polar spherical and Cartesian coordinates. Let the Z-axis point towards north pole and let the X-axis point towards Greenwich or prime meridian in the equatorial plane. The Y-axis then points towards 90 degree east meridian in the equatorial plane to complete the right handed Cartesian coordinate system.



**Fig. 4.** Variation of  $U_{ab}$  with sidereal time for an assumed  $U=250$  km/s,  $\theta_u=\pi/18$  and  $\phi_u$  of 75 degrees.

Let the  $\mathbf{U}$  vector, originating from the center of earth, make an angle  $\theta_u$  with the Z axis and let the projection of  $\mathbf{U}$  in the equatorial plane make an angle  $\phi_u$  with the X axis. In

this configuration the direction cosines  $L_u$ ,  $M_u$  and  $N_u$  of vector  $\mathbf{U}$  are given by  $\sin(\theta_u)\cos(\phi_u)$ ,  $\sin(\theta_u)\sin(\phi_u)$ , and  $\cos(\theta_u)$  respectively. Let the polar coordinates of points A and B be  $(R_e, \theta_a, \phi_a)$  and  $(R_e, \theta_b, \phi_b)$  respectively, where  $R_e$  is the radius of earth. Cartesian coordinates of the endpoints  $[X_a, Y_a, Z_a]$  and  $[X_b, Y_b, Z_b]$  of the baseline AB are related to the polar spherical coordinates as,  $[R_e\sin(\theta_a)\cos(\phi_a), R_e\sin(\theta_a)\sin(\phi_a), R_e\cos(\theta_a)]$  and  $[R_e\sin(\theta_b)\cos(\phi_b), R_e\sin(\theta_b)\sin(\phi_b), R_e\cos(\theta_b)]$  respectively. The length D of the baseline AB can be computed as,

$$D = \sqrt{(X_b - X_a)^2 + (Y_b - Y_a)^2 + (Z_b - Z_a)^2} \quad (27)$$

To simulate the daily rotation of earth about its axis, with respect to a fixed vector  $\mathbf{U}$ , we can add  $2\pi/86164$  to the  $\phi_a$  and  $\phi_b$  coordinates, where  $t$  represents Greenwich sidereal time in seconds. The time dependent Cartesian coordinates of A and B will therefore be represented as,

$$X_a(t) = R_e \sin(\theta_a) \cos(\phi_a + 2\pi t/86164) \quad (28A)$$

$$Y_a(t) = R_e \sin(\theta_a) \sin(\phi_a + 2\pi t/86164) \quad (28B)$$

$$Z_a(t) = R_e \cos(\theta_a) \quad (28C)$$

$$X_b(t) = R_e \sin(\theta_b) \cos(\phi_b + 2\pi t/86164) \quad (29A)$$

$$Y_b(t) = R_e \sin(\theta_b) \sin(\phi_b + 2\pi t/86164) \quad (29B)$$

$$Z_b(t) = R_e \cos(\theta_b) \quad (29C)$$

From these time dependent Cartesian coordinates of A and B, the time dependent direction cosines of AB will be given by,

$$L_{ab}(t) = (R_e/D) \{ \sin(\theta_b)\cos(\phi_b + 2\pi t/86164) - \sin(\theta_a)\cos(\phi_a + 2\pi t/86164) \} \quad (30A)$$

$$M_{ab}(t) = (R_e/D) \{ \sin(\theta_b)\sin(\phi_b + 2\pi t/86164) - \sin(\theta_a)\sin(\phi_a + 2\pi t/86164) \} \quad (30B)$$

$$N_{ab} = (R_e/D) \{ \cos(\theta_b) - \cos(\theta_a) \} \quad (30C)$$

Therefore, the component  $U_{ab}$  of the absolute velocity vector  $\mathbf{U}$  along the baseline AB can be computed as,

$$U_{ab} = U \cdot \{ L_u \cdot L_{ab}(t) + M_u \cdot M_{ab}(t) + N_u \cdot N_{ab} \} \quad (31)$$

Variation of  $U_{ab}$  of LNGS–CERN baseline with sidereal time is illustrated in figure 4 for an assumed  $U$  of 250 km/s, and  $\theta_u$  of 10 degrees. All terms in  $L_{ab}$  and  $M_{ab}$  are sinusoidal with a time period of 86164 seconds. Last term in equation (31) gives the mean value of  $U_{ab}$  whereas the first two terms give rise to the diurnal variation of  $U_{ab}$ . Since the magnitude of  $U_{ab}$  directly influences the magnitude of relative time offset  $(T_b - T_a)$  in the e-synchronization of clocks at the ends of the baseline AB, measurement of such synchronization offsets can yield all information regarding the absolute velocity vector  $\mathbf{U}$ . A plot of measured diurnal variation of relative time offset  $(T_b - T_a)$  in the GPS synchronized clocks A and B will be directly correlated with the corresponding plot of  $U_{ab}$  through equation (20). Thereafter the magnitude ( $U$ ) and direction ( $\theta_u, \phi_u$ ) of the

absolute velocity vector  $\mathbf{U}$  can be computed from such a diurnal plot of  $U_{ab}$  with respect to sidereal time  $t$  as illustrated below.

Let the mean value of  $U_{ab}$  obtained from its computed diurnal plot be  $V_m$  and let the amplitude of its diurnal variation be  $V_a$ . Further, let  $t_m$  be the instantaneous value of sidereal time when  $U_{ab}$  in the computed diurnal plot crosses the mean value during its increasing phase and let  $t_a$  be the value of  $t$  when  $U_{ab}$  reaches its maximum. Then from equations (30) and (31), following relations can be easily established.

$$\begin{aligned} U \cdot N_u \cdot N_{ab} &= N_{ab} U \cdot \cos(\theta_u) = V_m \\ \text{Or } U \cdot \cos(\theta_u) &= V_m / N_{ab} \end{aligned} \quad (32)$$

$$\text{For } t = t_m, \quad U \cdot \{ L_u \cdot L_{ab}(t_m) + M_u \cdot M_{ab}(t_m) \} = 0$$

$$\text{Or } U \sin(\theta_u) \cdot \{ L_{ab}(t_m) \cos(\phi_u) + M_{ab}(t_m) \sin(\phi_u) \} = 0$$

$$\text{Or, } \tan(\phi_u) = -L_{ab}(t_m) / M_{ab}(t_m)$$

Substituting  $\tau_m = 2\pi t_m / 86164$  and using equations (30A) and (30B),

$$\tan(\phi_u) = \frac{\sin(\theta_a) \cos(\phi_a + \tau_m) - \sin(\theta_b) \cos(\phi_b + \tau_m)}{\sin(\theta_b) \sin(\phi_b + \tau_m) - \sin(\theta_a) \sin(\phi_a + \tau_m)} \quad (33)$$

Further, when  $t = t_a$ , and  $\tau_a = 2\pi t_a / 86164$

$$U \cdot \{ L_u \cdot L_{ab}(t_a) + M_u \cdot M_{ab}(t_a) \} = V_a$$

$$\text{Or, } U \sin(\theta_u) \cdot \{ L_{ab}(t_a) \cos(\phi_u) + M_{ab}(t_a) \sin(\phi_u) \} = V_a$$

$$\text{Or, } U \sin(\theta_u) = \frac{V_a}{L_{ab}(t_a) \cos(\phi_u) + M_{ab}(t_a) \sin(\phi_u)} \quad (34)$$

Using equations (32), (33) and (34), we can compute the values of  $U$ ,  $\theta_u$  and  $\phi_u$  and establish the absolute velocity vector  $\mathbf{U}$ .

## 6. Conclusion

Under the current procedures of satellite based time transfers and time comparisons, the speed of light  $c$  is assumed to be an isotropic constant in the ECI frame, due to which an e-synchronous time gets distributed to the clocks located all over the globe. That is, the master clocks in all timing Labs tend to get e-synchronized in time whereas the intention is to get them in absolute synchronization. The absolute synchronization mismatch between two e-synchronized clocks is given by the relation  $(\mathbf{D} \cdot \mathbf{U})/c^2$ , where  $\mathbf{D}$  is the separation distance (vector) between the two clocks and  $\mathbf{U}$  is the absolute velocity vector (unknown) of the earth. This absolute synchronization offset between the master clocks at two distant timing Labs can be physically measured with an appropriate portable clock and such measurements can in fact be used to determine the unknown absolute velocity vector  $\mathbf{U}$  of earth. By incorporating the absolute velocity vector  $\mathbf{U}$  in the time transfer software, we can account for the anisotropic speed of light in the ECI reference frame and thereby ensure the distribution of absolute time to different clocks all over the globe. In that case it should even be possible to achieve absolute synchronization in space clocks in deep space flights.

The major obstacle to be overcome for implementing the above mentioned absolute timing protocol, is the *mesmerizing influence* of Relativity which rules out the possibility of absolute synchronization of clocks. Detection of absolute motion through measurement of synchronization offset between the GPS synchronized clocks at any pair of timing Labs, say NIST and PTB, will invalidate the second postulate of SR. Since the second postulate of SR effectively functions as the lynchpin of Relativity (Sandhu, 2011), its experimental invalidation may call for a paradigm shift in fundamental physics.

## References :

- Ashby, N. (2003). Relativity in the Global Positioning System. *Living Rev. Relativity* 6 (2003), 1  
<http://www.livingreviews.org/lrr-2003-1>
- Banerjee, P. et al. (2007). Improvements of Indian standard time at NPL, New Delhi, maintained through GPS network. *Indian Journal of Radio & Space Physics*, Vol. 36, Feb. 2007, pp. 20-26.  
[http://nopr.niscair.res.in/bitstream/123456789/2816/1/IJRSP%2036\(1\)%2020-26.pdf](http://nopr.niscair.res.in/bitstream/123456789/2816/1/IJRSP%2036(1)%2020-26.pdf)
- Brunetti, G. (2011). Neutrino velocity measurement with the OPERA experiment in the CNGS beam. *PhD Thesis*  
[http://operaweb.lngs.infn.it:2080/Opera/ptb/theses/theses/Brunetti-Giulia\\_phdthesis.pdf](http://operaweb.lngs.infn.it:2080/Opera/ptb/theses/theses/Brunetti-Giulia_phdthesis.pdf)
- Dong, J. & Dong, B. (2011). A theory on measuring the one-way speed of light and a method of verifying the invariance of light speed. *Physics Essays: June 2011*, Vol. 24, No. 2, pp. 294-300.  
doi: <http://dx.doi.org/10.4006/1.3579492>
- Einstein A. (1905). On the electrodynamics of moving bodies. *Annalen der Physik*. 17, 891 (1905).  
<http://www.fourmilab.ch/etexts/einstein/specrel/www/>
- Feldmann, T. (2011). Relative calibration of the GPS time link between CERN and LNGS, Report calibration CERNLNGS 2011. *OPERA public note 134* (2011)  
<http://operaweb.lngs.infn.it:2080/Opera/publicnotes/note134.pdf>

- Kozynchenko, A. I. (2006). The terrestrial one-way experiment on measuring the absolute velocity of the Earth using two atomic clocks. *Europhysics Lett.* 74, Issue 2, pp. 202 (2006).  
**doi:** <http://dx.doi.org/10.1209/epl/i2005-10537-8>
- METAS, (2008). Differential calibration of matched GPS receiver, antenna and cable against reference GPS link METAS WAB2 CH01 for P3 common-view time transfer. *Measurement Report No 119-00210* (2008)  
[ftp://ftp.stben.net/pub/time/Report\\_No\\_119-00210.pdf](ftp://ftp.stben.net/pub/time/Report_No_119-00210.pdf)
- OPERA Collaboration (T. Adam, *et al.*) (2011), Measurement of the neutrino velocity with the OPERA detector in the CNGS beam  
[arXiv:1109.4897v4](https://arxiv.org/abs/1109.4897v4) [hep-ex]
- Sandhu, G. S. (2010). Proposed experiment for detection of absolute motion. *Physics Essays: September 2010, Vol. 23, No. 3*, pp. 442-450.  
**doi:** <http://dx.doi.org/10.4006/1.3454849>
- Sandhu, G. S. (2011). Relativity: a pillar of modern physics or a stumbling block. *Proc. of SPIE Vol. 8121, 812109* (2011)  
**doi:** <http://dx.doi.org/10.1117/12.904607>