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External Clock Synchronization and Clock Synchronization with Subluminal Signals are Equivalent

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Abreu and Guerra[1] present the so called *external clock synchronization* of the clocks C(x) and C'(x') of the inertial reference frames S and S' in relative motion. The axes of the two frames are parallel to each other. At the origin of time in the two frames (t=t'=0) the corresponding origins O and O' are located at the same point in space and the corresponding axes are parallel to each other. S' moves relative to S with constant speed V in the positive direction of the overlapped OX(O'X') axes. Following Einstein's philosophy the clocks of the two involved inertial reference frames could be synchronized using a light signal that propagates with the invariant speed c but also using a signal that propagates with a subluminal signal $c_f < c$; $(c'_f < c)$ respectively both emitted at t=t'=0 from the common origin in the positive direction of the overlapped axes.

Following the external clock synchronization procedure, consider that as a result of an Einstein clock synchronization procedure (c) all the clocks of the S frame read t=0. The clocks of the S' frame, $C'(x')$ are set to read t'=0 when they pass in front of a clock of the S frame, which reads t=0 as well. The situation is sketched in Figure 1.a. After a given time of motion the clock C'_1 reading t' arrives in front of clock C_2 that reads t. By definition $\Delta t = t - 0$ represents a *coordinate time interval* whereas $\Delta t' = t' - 0$ represents a *proper time interval, the two time intervals being related by*[2,3]

$$\Delta t = \gamma \Delta t' \qquad (1)$$

where γ stands for the Lorentz factor $\gamma=(1-V^2/c^2)^{-1/2}$. [2,3]. The readings of the pair of clocks of S and S' instantly located at the same point in space are related by

$$t = \gamma t' \qquad (2)$$

and we say that they are synchronized following the external clock procedure.

The same result could be obtained following a synchronization procedure performed in the S' frame, which goes as follows. Consider the clocks $C'_1(x')$ and $C'_2(x')$ of that frame, located at the same point in space M'(x') of the OX(O'X') axes. Clock $C'_1(x')$ is synchronized to clock $C'_o(0)$ located at the origin O' in such a way as to make the speed of light in empty space isotropic when measured using clocks $C'_o(0)$ and $C'_1(x')$, i.e.

$$t'_E = \frac{x'}{c} \qquad (3)$$

t'_E being the time measured by clock $C'_1(x')$ when a photon is received at M'(x') that was emitted from the origin O' when $C'_o(0)$ time was zero. Clock $C'_2(x')$ is synchronized to $C'_o(0)$ in such a way as to make the speed of light from O' to M' an-isotropically, equal to c'_f (one way speed) when measured using the clocks $C'_o(0)$ and $C'_2(x')$

$$t'_a = \frac{x'}{c'_f} \qquad (4)$$

t'_a being the time measured by $C'_2(x')$ when the signal propagating with c'_f is received at M'(x') that was emitted from O' when $C'_o(0)$ time was zero. The clock readings t'_E and t'_a are therefore related by

$$t'_E = t'_a + \frac{x'}{c}\left(1 - \frac{c}{c'_f}\right). \qquad (5)$$

The anisotropic light signal generates the event

$$E'[x', t'_E = t'_a + \frac{x'}{c}\left(1 - \frac{c}{c'_f}\right). \qquad (6)$$

Taking into account that the time t'_E is displayed by an Einstein synchronized clock, we obtain performing the Lorentz-Einstein transformations of the time coordinate of event E' to the I frame, the result is

$$t_E = \gamma\left[t'_a + \frac{x'}{c}\left(1 - \frac{c}{c'_f} + \frac{V}{c}\right)\right]. \qquad (7)$$

Comparing (2) and (7) we see that the clock synchronization procedure performed above, in accordance with Einstein's philosophy lead to the same result if

$$c'_f = \frac{c}{1 + \frac{V}{c}} \qquad (8)$$

i.e. using a subluminal signal $c'_f < c$.

Our approach underlines the fact that using the Lorentz-Einstein transformation we can show that the two synchronization procedures are equivalent, leading to the same result. Even if they one way speeds are not measurable, making the assumption that they are, we recover the results of the "theories" based on the invariance of the round trip speed of light in empty space.

References

[1]Rodrigo de Abreu and Vasco Guerra, arXiv/051296v1[physics.ed-ph] 21 Dec. 2005

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[3]R.A. Serway and R.J.Beichner, *Physics for Scientists and Engineers 5th Edition* (Saunders, College Publishers)