20th IMEKO TC4 International Symposium and
18th International Workshop on ADC Modelling and Testing
Research on Electric and Electronic Measurement for the Economic Upturn
Benevento, Italy, September 15-17, 2014

About the conventionality of simultaneity and synchronization

Luigi Maxmilian Caligiuri[1], Alfonso Nastro[2]

[1] Department of Chemistry and Chemical Technology, University of Calabria, Arcavacata di Rende (CS), Italy, max.caligiuri@gmail.com
FoPRC – Foundation of Physics Research Center, Celico (CS), Italy, caligiuri@foprc.org
[2] Department of Chemistry and Chemical Technology, University of Calabria, Arcavacata di Rende (CS), Italy, a.nastro@unical.it

Abstract **– The conceptual and operative definition of simultaneity is fundamental not only from a purely theoretical point of view but also in order to ensure the correctness of metrological practices, because of its implication upon synchronization procedures. In this paper we'll critically analyze the main possible definitions of simultaneity, discussing the consequence of each of them upon the synchronization process and how the choice of the right method is far from obvious.**

I. INTRODUCTION

The correct definition and understanding of simultaneity are aspects of primary importance in metrology both from a theoretical and applicative point of view. The measurement and expression of fundamental physical quantities as time and length, as well as all the other ones derived from these, strongly depend upon the measurements of simultaneous events. The concept of simultaneity in science has gotten, during the centuries, different formulations from the Classical Physics (CP) to Relativistic Physics (RP) in this undergoing radical modification. In CP time is absolute and the definition of simultaneity presents no conceptual issues since it supposes the presence, in every point of universal space, of a clock synchronized with every others in the Universe. This synchronization is not altered by the physical events and the clock rate is the same for all the clocks. Einstein's Special Theory of Relativity (STR) introduces, as known, a radical change in this paradigm introducing the concept of a relative simultaneity by which the simultaneity of two events is not yet absolute but depends upon the relative motion of the inertial frames used for the description. STR is commonly considered as an unquestionable truth nevertheless, despite its several experimental confirmations, it is based upon a clocks synchronization procedure (and consequently a concept of simultaneity) whose choice is quite conventional.

In particular, the standard formulation of STR is based on the postulate of light velocity isotropy in all the possible inertial frames [1], whose origin is substantially "electrodynamics" because it describes a specific property of light arising from Maxwell equations and it is not required by the internal consistence of STR itself [1]. It has been shown, in fact, that it is possible, by considering only homogeneity of empty space and time and the Relativity Principle (RP), to build "alternative" versions of Special Theory of Relativity (STR), without assuming the invariance of light velocity in vacuum [1].

When these alternatives are considered they give rise to different conceptual and operative versions of definition of simultaneity (as, absolute simultaneity or non standard simultaneity) with deep consequences upon the meaning of time [1] and then on metrology procedures.

In this paper we'll discuss the most important alternative definitions of simultaneity, considering their main consequences.

II. SIMULTANEITY AND SYNCHRONIZATION

The simultaneity of two physical events, happening in the same point of space A, doesn't present particular operative problems, since it can be determined by placing a clock in A and simply reading the time at which the two events occur. The problem arises when we must evaluate the simultaneity of two events occurring at separate locations A and B, namely when we face with the question of the synchronization of distant clocks. The Einstein' solution to this problem represents one of the foundations of STR and is known as "Einstein's synchronization procedure" [2].

He considers two clocks measuring local time placed at two distant points A and B. At time t_A a light beam starts from A, is reflected at B and the comes back to A at time t'_A according to clock A. The time of arrival of light at B is then given by (see fig. 1)

$$t_B = t_A + 1/2\left(t'_A - t_A\right) \quad (1)$$

namely the time light takes in going from A to B is one half of the time it takes in going there and back to A.

Nevertheless, this apparently obvious statement is far from foregone. It in fact based upon the implicit assumption that velocity of light is the same in all the space direction in initially considered inertial frame. The RP then extends this property to all the other inertial frames in relative motion with respect the first one.

The above definition of simultaneity determines two important consequences: its *relativity* and its *conventionality*. The first one is well know and "easily" accepted while the second one has been wrongly almost ignored by the most part of scientists although, as we'll see, it is crucial for a correct understand of simultaneity.

A. Relativity of simultaneity

It is a direct consequence of the postulate of the isotropy of light velocity and of its extension to all the possible inertial frames. According to it, two spatially separated events that are simultaneous in a given inertial frame don't appear necessarily simultaneous in another inertial frame in relative motion with respect to the first one, namely the simultaneity depends upon the observer state of motion.

More generally, two observers in relative motion can consider, depending on their relative velocity, two events A and B as simultaneous in one case, as A preceding B in another case and as A following B in another case anymore. In the standard formulation of STR each of the three above statements has the same level of truth and there is no way to establish an absolute succession of events holding for all the observers in uniform relative motion.

In any case if two events are related by a causal relationship in a given inertial frame, namely if A causes B, the mathematical structure of STR keeps the same causal relation in every inertial frame.

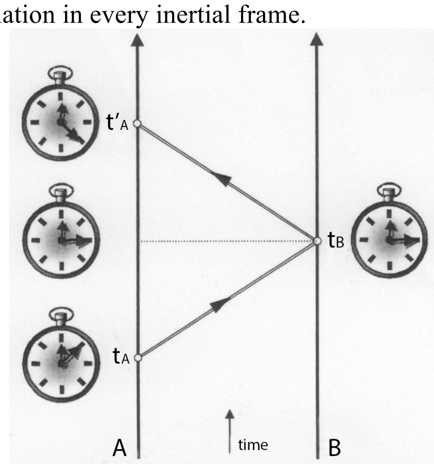

Fig. 1. Einstein's synchronization of clocks.

B. Conventionality of simultaneity

The conventionality of simultaneity is related to the arbitrariness of the choice of the synchronization procedure of distant clocks and doesn't depend upon the state of motion of the observers. In the Einstein's procedure this arbitrariness is overcome assuming the postulate of invariance of light velocity. Nevertheless, as known to Einstein itself [2], this invariant velocity cannot be measured without adopting a convenient procedure concerning the synchronization of distant clocks [3] that is not necessarily related to true properties of physical states [4] but is only conventional. In order to explain this conventional nature of the postulate of invariance of light velocity Einstein wrote, in 1916, considering the middle point of a segment AB whose extremes have been "simultaneously" stroked by two lightning: "That light requires the same time to traverse the path $A \to M$ as for the path $B \to M$ is in reality neither a *supposition nor a hypothesis* about the physical nature of light, but a *stipulation* which I can make of my own free will in order to arrive at a definition of simultaneity " [2].

Poincare already expressed this concept in 1989 writing: "The simultaneity of two events should be fixed in such a way that the natural laws become as simple as possible. In other words all these rules, all these definitions are only the result of an implicit convention" [3]. This synchronization is then substantially conventional and is not necessarily related to true properties of physical reality [2,4].

The definition of simultaneity is then equivalent to synchronization of distant clocks and to the question of the measurement of the one – way velocity of light.

C. One – way velocity of light

The question about the epistemological validity of the postulate of isotropy of light velocity is related to other three assumptions: a) the finiteness of light velocity; b) the insuperability of its value in vacuum; c) the possibility of measuring its value. The test of light velocity finiteness could be performed by using only one clock and measuring, for example, the finite time light takes to be reflected back from a mirror and deducing from this the finiteness of its value. Nevertheless this deduction is not necessary since light could move at infinite speed in one direction (towards the mirror) and at finite speed only in the opposite direction (towards the receiver) then keeping constant the total time interval required.

For this reason, the deduction of finiteness of light velocity already presupposes its finiteness. The second question cannot be experimentally addressed and it has been theoretically shown that this constraint could be also purely conventional [1]. The third question about the measurement of light velocity could appear the most simple, since it would be sufficient to directly measure the distance AB covered by light in a given time interval Δt_{AB} and simply obtain $v = d_{AB} / \Delta t_{AB}$. Nevertheless, even in this case, the measurement of $\Delta t_{AB} = t_B - t_A$ implies the synchronization of the clocks placed at A and B.

Then, as we have seen, the measurement of one – way velocity of light is equivalent to find a method of synchronization of two distant clocks so we are in a virtuous circle. The only way to experimentally measure the value of light velocity is to use only one clock but this implies to make the measurement on closed paths where light comes back to the starting point where the clock is placed (as it happens, for example, in the Michelson – Morley interferometers measurements or in the classical Fizeau's and Foucault's measurements using rotating mirrors and cogwheels).

Then we can in a no way measure the one – way velocity of light but only the two – way velocity of light, being the former in principle not measurable and so purely conventional.

However, from a theoretical point of view, there is another way to synchronize two distant clocks, namely to synchronize them when we are close and the move one of the clock away. This approach is nevertheless not a valid solution since the relative motion would alter, according to the STR, the clock rate so de-synchronizing the clocks.

A cleverer proposal could be to synchronize the two clocks A and B in the same point O and to push away the two clocks in opposite directions. In this way the clock rate of the two clocks would be altered of the same amount so remaining synchronized. But even in this case the conclusion supposes the isotropy of light in the two directions of motion. In fact even if the two clocks would be pushed with the same force and have the same inertial mass m this wouldn't ensure they will have the same velocity. This is because the relationship between quantity of motion p and velocity v in STR, namely

$$p = mv \Big/ \sqrt{1 - v^2/c^2} \tag{2}$$

is valid only if we already assume the isotropy of light velocity (or, equivalently, the Lorentz transformations for space and time).

Just a last chance remains: to move the clock away from each other so slowly ($v \to 0$) to nullify the relativistic effect, but this means to wait a considerable time ($\Delta t \to \infty$) to get the clock synchronized and, above all, it doesn't conceptually solve the problem, since it would just represent another possible synchronization procedure.

III. NON STANDARD SIMULTANEITY

The above discussion has shown we cannot define an rule to determine the simultaneity of distant events or, equivalently, a synchronization method of distant clocks if not assuming, by postulate, some experimental unverifiable fact about light. More precisely it can be shown [5] that the most general requirement required in order to construct a coherent STR is given by the equation

$$t_2 = t_1 + \alpha\left(t_3 - t_1\right) \tag{3}$$

where α is the "synchronization" parameter, introduced by Reichenbach [5] and $0 < \alpha < 1$. The commonly accepted version of STR then corresponds to the particular choice $\alpha = 1/2$ and has been chosen simply because it leads to simpler mathematical relations within the theory itself [5]. Later, Max Jammer [6], discussing the Reichenbach parameter, strongly pointed out that "One of the fundamental ideas underlying the conceptual edifice of relativity, as repeatedly stressed by Hans Reichenbach and Adolf Grunbaum is the conventionality ingredient of intrasystemic distant simultaneity". This thesis, also known as "conventionality thesis", states that the value of α must not to be necessarily equal to $1/2$ but could be any real number such as $0 < \alpha < 1$, without contrasting with any of the experimental previsions of Relativity [6,7]. Nevertheless, different values of α correspond to different values of one – way velocity of light, this resulting in a non invariant one – way velocity of light.

This also means that any clocks synchronization procedure, being based on the value of one - way velocity of light, is also related to the choice of α and the principle of the constancy of light velocity is only a useful human convention, able to simplify some mathematical relationship and not a requirement of Nature. Then different choices of $\alpha \neq 1/2$ will determine different synchronization relations and, correspondingly, different non-standard definitions of simultaneity.

In general, each different choice of $0 < \alpha < 1$, will determine a different structure of simultaneity surfaces in a space and time representation able to cause deep consequences on the meaning of the fundamental physical laws themselves and whose discussion is beyond the aim of this paper. We can finally observe that there is no prescription about the constancy of α that, in general, could be also a function of other variables, so introducing new possible classes of simultaneity definitions.

IV. THE INERTIAL TRASNFORMATIONS AND THE ABSOLUTE SIMULTANEITY

As already demonstrated [1], different synchronization procedures with $\alpha \neq 1/2$, lead to alternative versions of STR, all experimentally equivalent, but characterized by very deep differences in the interpretation of physical time and, consequently, by effects on metrological procedures. Among these alternatives one of the most important is that based on Inertial Transformations (IT) of time and space, in which the "traditional" Lorentz transformations are replaced by the following relations given space and time in two different inertial frames S_0 and S in relative motion [8]

$$\begin{cases} x' = (x - \beta ct)/R \\ y' = y \\ z' = z \\ t' = Rt \end{cases} \quad (4)$$

where $\beta = v/c$, $R = \sqrt{1-\beta^2}$ and c is the speed of light measured in S_0.

One of the most important features of the IT given by (4) is the introduction [8] of a "preferred" inertial frame S_0 S_0, that is the system in which the first synchronization of clocks is made according to the "classical" Einstein's procedure, and the definition of the "absolute" synchronization, by which two events that are simultaneous (taking place at different spatial locations) in the inertial frame S are considered to be like that also in every other inertial systems S' (S and S' being two inertial frames moving with respect to the preferred system S_0). This is a consequence of the absence, in the time transformation, of spatial variables. In fact, if we consider two events A and B taking place in S_0 at times t_A and t_B, we have in the system S

$$t'_A - t'_B = R(t_A - t_B) \quad (5)$$

and then if they are simultaneous in A, namely $t_A = t_B$, they will be simultaneous in every other inertial frame since, from eq. (5), we have $t'_A = t'_B$.

Furthermore, a clock at rest in S runs slower if viewed from S_0 but a clock at rest in S_0 runs faster if observed from S. Then both the observes agree that the relative motion with respect to S_0 slows down the clock rate.

V. CONCLUSIONS

The concept of simultaneity is of fundamental importance in metrology. We have discussed the equivalence between simultaneity and synchronization, showing that its theoretical definition and experimental evaluation are far from obvious and pose some very deep questions. In particular, with the elaboration of Einstein's STR, the concept of simultaneity became relative to the observer, depending on its state of motion. Nevertheless not all the hypothesis upon which it is founded has a logical or empirical necessity as, in particular, the postulate of isotropy of the one – way velocity of light.

This assumption, as we have shown, is only conventional implying the definition of simultaneity to be conventional as well. This means that many alternative choices are possible and the selection between one or another of these cannot be simply done by means of a logical or empirical rules but considering other criteria.

Every different definition of simultaneity potentially allows the realization of an alternative version of STR, among which a very special role is played by that based upon IT. In this case the equation for time transformation between inertial frames doesn't contain spatial variables determining an absolute simultaneity in all the inertial frames.

In this way two events that are simultaneous in a the "preferred" inertial frame defined by IT, are simultaneous in all the other inertial frame in relative motion and the synchronization procedure between clocks can be easily achieved one for all in this "privileged" system.

It is then remarkable that, thanks to the conventionality inbuilt in the concepts of simultaneity and synchronization, it has been possible to recover a definition of absolute simultaneity able to radically modify the meaning of physical time and its measurement methods especially in the application where the relative velocity is important or when high measurement precision are required [8].

REFERENCES

[1] L. M. Caligiuri, A. Sorli, "Special Relativity postulated on homogeneity of space and time and on relativity principle", Am. J. of Mod. Phys., Vol.2 No.6, November 2013, pp. 375 – 382.

[2] A. Einstein, "Ueber die spezielle und die allgemeine Relativitaetstheorie", Vieweg, Braunschweig (1988).

[3] H. Poincare, Rev. Metaphys. Morale, 6 1(1898).

[4] R. A. Nelson et al., "Experimental comparison of time synchronization techniques by means of light signals and clock transport on rotating earth", in: Proceedings of 24th Precise Time and Time Interval Meeting (1993).

[5] H. Reichenbach, "The Philosophy of Space and Time", Dover, New York (1958).

[6] M. Jammer, "Some fundamental problems in the special theory of relativity, in *Problems in the Foundations of Physics"*, G. Toraldo di Francia, ed., North – Holland, Amsterdam, pp. 202 – 236 (1979).

[7] H. Bondi, Observatory, 82, 133 (1962).

[8] D. Grimaldi, F. Lamonaca, "Analysis of the Synchronization Delay in the Path PC-DSO Co-operating into the W-DMS", Proc. of IDAACS 2007 – IEEE International Workshop on Intelligent Data Acquisition and Advanced Computing Systems: Technology and Applications, Dortmund, Germany, 6-8 September 2007, pp. 114-119. DOI: 10.1109/IDAACS.2007.4488386.