

GLOBAL SYSTEM OF UNIVERSAL TIME BASED ON RECEIVING SIGNALS FROM PERIODICAL PULSATING STARS

M. Konkanov

Kazakhstan Institute for Metrology, Time & Frequency, Kazakhstan, marconzenti@bk.ru

Abstract: This paper contains results of researches of possible ways for providing a synchronization of space navigations systems' time scales. The variant of construction of common time system in which basic the time scale formed by using characteristics of strictly periodic radio emission's galactic sources — pulsars — is put is suggested in the article.

Keywords: Universal time, pulsar, pulsar time scale.

1. Introduction

Among the seven base units of the SI, the SI second has the best realization [1]. Today, the best time and frequency standards can reproduce the second according to the SI with uncertainty near $1 \cdot 10^{-15}$ [2]. Physical realizations of other physical units have much larger uncertainties as presented in table 1. Therefore, it is quite natural to express other base units through the definition of the second using only physical laws and fundamental physical constants involved in their definition.

Table 1 Uncertainties of physical realizations of the SI base units

| Physical unit | Physical quantity | Uncertainty |
|---------------------------|-------------------|--------------------|
| Luminous intensity | candela | $1 \cdot 10^{-4}$ |
| Thermodynamic temperature | kelvin | $3 \cdot 10^{-7}$ |
| Amount of substance | mole | $8 \cdot 10^{-8}$ |
| Electric current | ampere | $4 \cdot 10^{-8}$ |
| Mass | kilogram | $1 \cdot 10^{-8}$ |
| Length | metre | $1 \cdot 10^{-12}$ |
| Time | second | $1 \cdot 10^{-15}$ |

If adopting the postulate that those constants really exist (Einstein's principle of equivalence), then the entire accuracy in the realization of the second may, thus, basically be imparted to other units as well (for example, realization of the ampere and the metre).

Beyond usage in fundamental researches, time measurement is used to verify structures of space and gravitation [3, 4].

2. Spacecraft clocks

Other most common scopes for time and frequency measurements include positioning and navigation. Moreover, functional areas of time measurement and navigation are so closely interrelated that one of them can be used to meet the challenges in the other and vice versa: "Creation of space-based radio navigation systems of global coverage which is one of the humanity's technological triumphs would not be possible if there is no frequency standards or the highest level of accuracy and unitization of time measuring. On the other hand, apart of its direct task of navigational support, this tool serves as a superior instrument for intercomparison of remote timescales which, in turn, allows forming and establishing reference time systems of unparalleled accuracy and stability that can also be used both to improve navigation systems themselves and to transfer the time, through them, to wider consumers" [5]. So, international comparisons of timescales are held by using satellite radio navigation systems (further – SNS). On the other hand, one of the central problems of developing SNS to ensure non-inquiry navigation sighting simultaneously for several satellites is the problem of mutual synchronization of satellite timescales to the nearest nanosecond as the disalignment of satellite-radiated navigation signals of 10 ns brings about additional error in users' positioning up to 10-15 m. Answering the challenge of highly accurate alignment of on-board timescales required the satellites to be equipped with highly constant on-board cesium frequency standards with relative instability of $1 \cdot 10^{-13}$ and ground-level hydrogen standard with relative instability of $1 \cdot 10^{-14}$ as well as production of ground-level scale comparison tools of 3-5 ns error. Technical features of on-board timekeepers are given in table 2.

Table 2 Technical features of on-board clocks

| Feature | Quartz standard of purity | Atomic standard of purity | | |
|---|---------------------------|--------------------------------|-------------------------------------|--------------------|
| | | Rubidium | Cesium | H-maser |
| Mass, kg | 1.35 | 2.25 | 13.5 | 33.7 |
| Consumption, Wt | 2.0 | 13.0 | 25.0 | 30.0 |
| Volume, dm ³ | 1.13 | 1.13 | 11.3 | 28 |
| Relative frequency instability (for a day) | $(1-5) \cdot 10^{-10}$ | $1 \cdot 10^{-12}$ | $1 \cdot 10^{-13}$ | $1 \cdot 10^{-14}$ |
| Temperature coefficient of frequency (1/°C) | $2 \cdot 10^{-11}$ | – | – | – |
| Life limiting factors | Ageing of the quartz | Lamp performance deterioration | Noise level in the atomic beam tube | Hydrogen reserve |

The comparative analysis of on-board clocks mounted on each spacecraft of GLONASS and GPS groups shows that as the accuracy of frequency standards increases from $1 \cdot 10^{-10}$ to $1 \cdot 10^{-14}$, the weight of sources grows significantly from 1.35 kilogram to 33.7 kilogram and energy consumption for their operation grows as well. Besides, all the navigation systems, with no exception, have defects the main of which are the following:

- the need to synchronize own spacecraft on-board clock among themselves and with the standard clock situated on the earth;

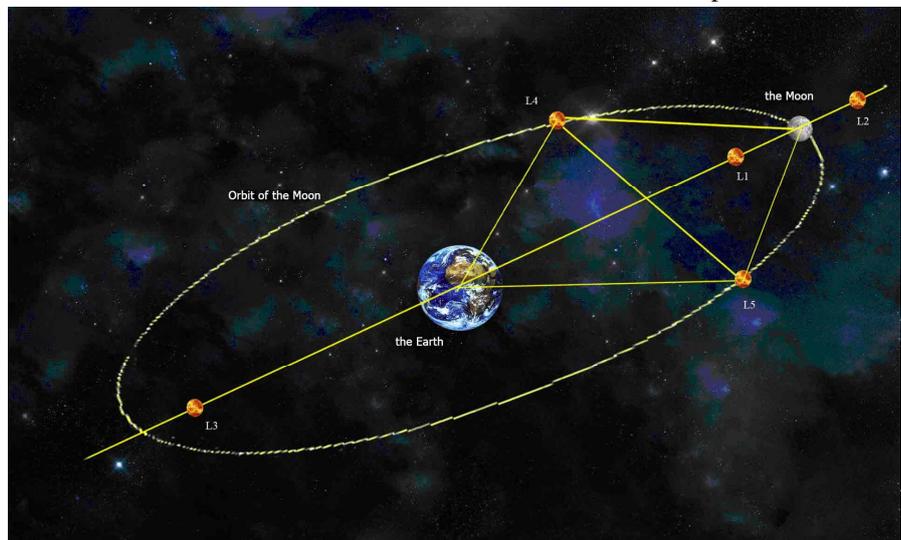
- the information signal being transmitted through the ionosphere that distorts it. In its turn, the development and production of frequency and time measures according to traditional, classic patterns can only improve their features to some extent but they will be unable to meet any modern requirements of time-and-frequency assurance [6]. As to this, activities have developed recently on formation of timescales by unconventional methods based on using some features of galactic sources of strictly periodic radio emission – the pulsars. The properties of the latter such as high stability of periods and pulse nature of radiation as well as durability and reliability allowed to suppose the

opportunity of using pulsars as keepers of a timescale being independent of earthly environment and available in various points of the land surface.

3. Time scale by pulsars

As a solution for the task of increasing the accuracy of developing a systemic timescale and maintaining it (storing) during the entire period of a spacecraft operation, an option of a Global universal time coordination system is offered based on receiving signals of pulsars. The basic idea of this system concerns in-space placement of

adjustment stations. Due to the technical complexity of receiving pulsars' signals on the Earth's surface as the very process of receiving depends on the planet's rotation; moreover, a part of the pulsar's radiation spectrum cannot be accepted on the surface due to the atmosphere, the Earth's magnetic field and several other factors, therefore, the receiving equipment is reasonable being placed to spacecrafts. Spacecrafts are launched to the circumterrestrial space, to the so-

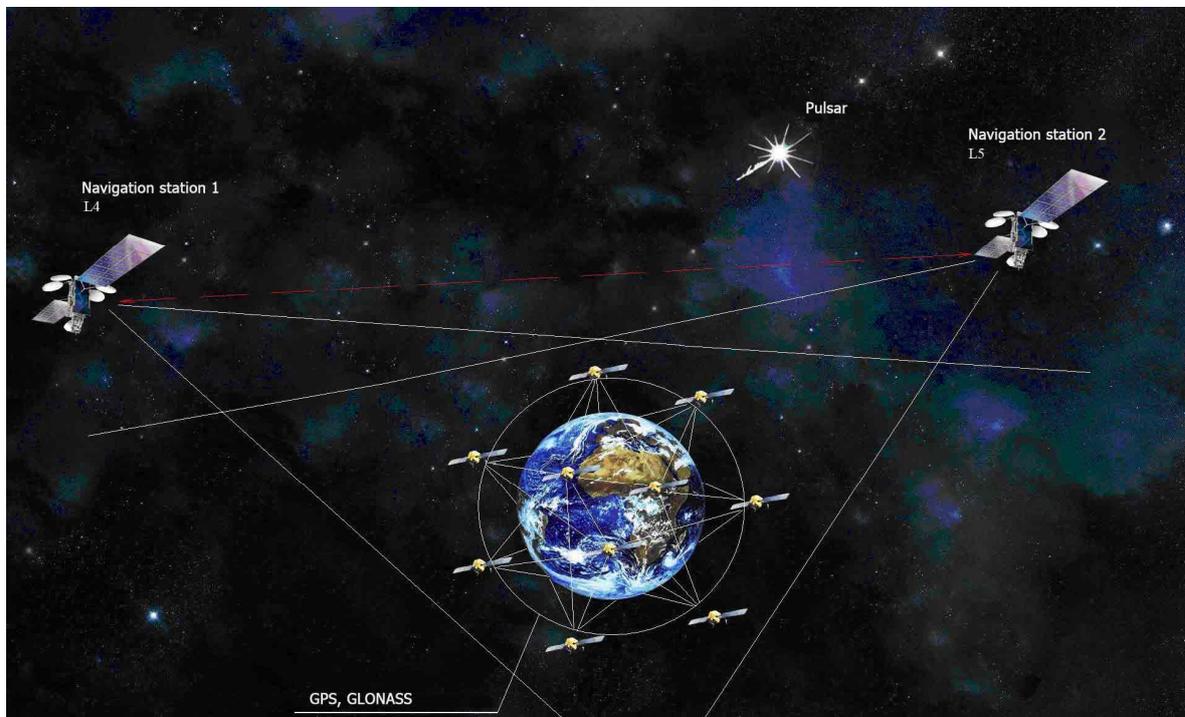


Drawing 1 — The Lagrange points in the Earth-Moon system

called libration points (The Lagrangian points), and it enables them being there for infinitely long periods of time. Libration points are points where the disposition of a small mass, for example, a spacecraft, does not change against two large masses such as the Earth and the Moon moving relative to each other.

X-ray detectors mounted on the boards of scientific spacecrafts, along with the special-purpose apparatus, will accept and transform the events of a millisecond pulsar into ultra-stable radio signals of time and frequency to be translated within the radiofrequency range to middle-orbital radio navigation systems which, given an appropriate software, will result in considerably increased accuracy of their positioning that can reach fractions of millimetre. Moreover, information derived when treating the signals of any active radio station of the space stations can raise, to a certain extent, the accuracy and reliability of navigation-time definitions. Synchronization of radiation of all the radio navigation facilities via signals of the global space system of universal time will be able uniting private radio navigation fields into a single radio navigation field allowing to supply the navigation and time services, in a more flexible manner, to different consumers in target areas.

- [1] C. Audion, B. Guinot, *The Measurement of Time: Time, Frequency and the Atomic Clock* Cambridge University Press, Cambridge, 2001.
- [2] M. A. Lombardi, "Fundamentals of time and frequency", in: Robert. H. Bishop (Editor-in-Chief), "The Mechatronics handbook", Ch. 17-1 p. 1229, 2002.
- [3] C.M. Will *Theory and experiment in gravitational physics*. Cambridge University Press, Cambridge, p. 400, 1993.
- [4] T. Damour, in "Gravitation and Quantizations", in Proc. of the LVIIIth Les Houches Summer School, pp. 1-62, 1995.
- [5] A. Kirillov (Editor-in-Chief), "Development of new satellite navigation system", *Measurement world*, Vol.9, September, 2008.
- [6] B.I. Loboyko, "Condition and trends of development of time and frequency standards", "Navigation and hydrography", Vol. 10, pp. 63 — 70, 2000.



Drawing 2 — Location of Global system of Universal time

4. Conclusion

As mentioned above, the establishment of the Global system of Universal time assurance based on receiving signals of periodic electromagnetic sources will solve the task of increasing accuracy of a systemic timescale formation and its maintaining (storing) during the entire operation period of a spacecraft. Along with that, it will solve the tasks of enhancing accuracy of synchronization of timescales of various SNS spacecrafts, coordinating systemic timescales and reducing the cost of placing SNS' spacecrafts in orbit.

5. References