COMPARATIVE ANALYSIS OF HIGH-PRECISION TIME AND FREQUENCY SYNCHRONIZATION METHODS

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ABSTRACT

This paper contains comparative analysis of high-precision time and frequency synchronization methods. Methods, which provide now the highest accuracy and are widely used for solving of the scientific and technical tasks - TQC, RMS, time signals transmission via satellite communication channels and SRNS are reviewed and estimated. The recommendations concerning the combination of these methods for the best performance are given.

COMPARISON, TIME, FREQUENCY, STANDARDS, METHODS.

THE TASK OF TIME AND FREQUENCY STANDARDS SYNCHRONIZATION

Comparison of the distant time and frequency standards is the basis for the contemporary time and frequency methods realisation. These methods allow to solve urgent scientific, technical and defence tasks in the ranging, metrology, radioastronomy, radiolocation, digital communication systems etc.

Successful accomplishment of such tasks is defined by the stability of time and frequency standards and by the their comparison accuracy. High rates of the standards enhancement (the relative instability of the modern standards is 10^{-13}...10^{-14}, and in future - 10^{-15}...10^{-16}) determine the urgency of the improvement in comparison methods accuracy task. First comparison methods were proposed by Albert Einstein in time of the relativistic theory development (task of clock synchronization). In one of these methods radio signals from the common equidistant radiation source are received in synchronization points. In another one the time signal from the first point is received in the second point and reradiated back (duplex method). In the papers concerning the relativity theory the variant of the usage of transported clocks is mentioned.

By this time the complex of the comparison methods and their technical realization is sufficiently increased. In a basis of all synchronization methods (SM) lays transfer of the information about time scales. Depending on transfer algorithms, possible to divide SM into three groups.

Oneway information transfer methods from one point to another concern the first group. Shift of time scales can be determined, if known delay between points. Examples of realization SM of the first group - transported quantum clocks (TQC); MW, LW and satellite radionavigating systems (SRNS) GLONASS and GPS (Navstar); the system using reflection of signals from the Moon; TV; cable, laser and optical fibre lines. Methods of the first group are accepted for naming passive.

Second group SM is based on bilateral radiation. Delay between points can be unknown, required only high stability and convertibility. Methods of the second group are accepted for naming active. Active SM are realized in radiometeoric, satellite and optical liaison channels.

Additional highly stable scale which signals are accepted in synchronizable points is used in third group of SM. Shift of time scales is determined in view of known difference of signals delays between point of an additional scale and the given points. Methods of this group are realized in SRNS (a differential mode), and also in radio-interference-meters with superlong bases (RSLB). In SRNS additional scale is formed by the standard onboard the satellite. In RSLB a role of an additional scale play highly stable signals of space sources (pulsars, kvazars).

Now the maximum accuracy is provided with following SM:

- TQC;
- radiometeoric method of synchronization (RMS);
- the methods based on use SRNS and telecommunication AES.

A perspective method is RSLB as it has not only high potential accuracy, but in the future can become as basis for new type of standards of time (relative instability of kvazar signals and is no worse than pulsars of pulsars 10^{-14}).

The basic parameter of quality SM is the error of scales shift measurement.

The common error sources for all the comparison methods (excluding TQC) are:

- instability and nonreciprocality (for the active methods) of the signals delay in the channel;
- hardware delays instability ;
- internal noises and disturbance of the communication channel;
- the dynamics of the measured value because of the standards instability.

Every method has its own specific error sources caused by the characteristics of the channel, comparison algorithms, hardware implementation, relativistic effects etc.

EXISTING METHODS AND SYSTEMS

Skipping the detailed comparative analysis of the mentioned methods we can define four of the methods, which provide now the highest accuracy and are widely used for solving of the scientific and technical tasks, - TQC, RSDB, RMS, time signals transmission via satellite communication channels and SRNS.

It should be noted that RSDB is a perspective method, cause it has not only high potential precision, but may become a base for new time standard type in future: relative instability of the quasar and pulsar signals are better 10^{-14}.

TRANSPORTED QUANTUM CLOCK

In present passive hydrogen time and frequency standards like F1-76 and small-size hydrogen active type standard with sapphire resonator are used as TQC. Modern hydrogen TQC provide nanosecond accuracy of measurements. For the transportation time decreasing the plane with "none-ground comparison" is used ("flying TQC").

Organization of the TQC method is rather complicated and is expensive, that is why it is rarely used, mainly in metrology or for controlling of other methods measurement results.

SATELLITE COMMUNICATION CHANNELS

The merits of this method are global coverage area, the possibility of points synchronization in difficult of access northern and highland areas, the high accuracy. The drawbacks of the method – active mode and rather high cost.

In ref. 1 the rubidium standards synchronization via geostationary satellites ATS-1 and ATS-3 results are presented. Duplex algorithm was used. Results check with TQC gave the estimation of the error with the value of 50 ns.

In ref. 2 time and frequency standards synchronization via satellite communication channel results, conducted by United States Naval Observatory, the Research Council of Canada and COMSAT are presented. Time scales synchronization discrepancy achieved in fact was less then 5 ns.

RADIOMETEOR COMPARISON METHOD

The meteor is a phenomenon occurring in the middle layer of the Earth atmosphere during entering of the small hard space pieces with the weight less than 10^{-9} g and not more than 10 g. This event consists in the evaporation of these pieces and initiation of the plasma formation – the meteor path, appearing as a result of the impact of evaporated meteor atoms with the molecules and atoms of the Earth atmosphere gases. It happens mostly in heights from 80..85 to 105..110 km. The average meteor path has the length about 15 km with the initial radius about 1..2 m.

Mirroring character of UHW reflection from meteor path allows its using for information transmission and time scales comparison. The length of such communication radio channel is determined by the height of reflecting meteor path, by the antenna heights in receiving points and by the refraction of radiowaves in troposphere. Maximum range is about 2000 km.

In the basis of RMS lies high stability and reversibility of signal delay during meteor radiowaves propagation.

RMS exceeds other methods in such showings as measurements performance (receiving of the single measure takes about 10 s), autonomy, efficiency, economy, secrecy, stability to ionospheric disturbance.

As drawbacks it should be noted that this method is active, that is it demands the radio signal radiation in the both measurement points.

The most perspective way for reducing RMS errors is using of the complex signals and phase principles in the equipment design.

By now time synchronization accuracy constitutes about 10 ns when using signal wave shape, and about 0,1..1 ns when using signal phase.

GLOBAL SATELLITE RADIONAVIGATION SYSTEMS

Usage of satellite ranging systems GPS and GLONASS signals is one of the most precise of time and frequency synchronization methods in global scope.

There are four main time synchronization methods via satellite ranging systems signals (ref. 3):

- direct synchronization;
- mutual synchronization;
- flying TQC;
- radio interferential measurements on short base.

Now the leading role is taken by two global satellite radionavigation systems (SRNS) based on onboard quantum generators synchronization - GPS (Global Positioning System), aka Navstar (Navigaion System with Time and Ranging), and GLONASS (Global Navigation Satellite System).

New possibilities are opened by European GNSS (Global Navigation Satellite System). GNSS will be the natural extension of GPS and GLONASS, providing compatibility with the main ranging signals structure. Its signals will be structurally equal to the signals of GPS and GLONASS, but unsimilar to the latter, information about ranging system integrity and the range of other data, that contribute to increase in the determination accuracy, will be added.

In SRNS GPS and GLONASS navigation space crafts (NSC) on circle earth-centered orbits with height of 20000 km above Earth are used. Thanks to quantum standards using onboard of NSC, the mutual synchronization of navigation radio signals radiated by orbital group of NSC is provided. In the user equipment (UE) during navigation time radio signals from not less than four "radio-visible" NSC are received and used for measurement of three distances and three radial velocity differences relatively to four NSC. The measurement results and ephemeral information, received from each NSC, allow to determine (ensure) three coordinates and three components of the moving object velocity vector and determine object's time scale shift (TS) relative to system time scale shift.

As a result of research ref. 4 two cycles of measurement were conducted.

In the first cycle inaccuracy of synchronizing on comparatively short time intervals was researched - 1000 measurements for each receiver with 3 seconds interval.

In the second cycle measurements were conducted for the whole week. For each of receivers 10 measurements of the difference in time scales with the break at 2 minutes was made and the average of the results was taken. Thereby 240 averaged measurements for one day was accumulated for each of the receivers.

The First cycle Measurements have shown that for the short time intervals main contribution to inaccuracy of forming time scales is determined by internal quartz generators frequency instability. STD came to 16,6-55,4 ns.

When using external master signal with the frequency 10MHz, instead of the built-in quartz generator, STD came to 0,55 ns. The systematic mistake of time scales, formed by GPS receivers constituted from 531,7 ns to 1406,9 ns (for different receivers). The Second cycle of measurements have confirmed presence of systematic error, which is possible to avoid by calibration of the each GPS receiver.

CONCLUSION

Comparison SM on accuracy is possible only at identical design procedures of errors and comparisons SM, besides accuracy, on a lot of other quality parameters (cost, efficiency, an operative range etc.).

As presented above, virtually all the methods provide the time and frequency standards comparison accuracy in the nanoseconds limits. But there are different complications in the usage of some or the other methods. That's why one should always be guided not only by the considerations of achieving the maximum accuracy, but by the practicability of the usage of some of the methods in the particular situation when choosing the synchronization method. In order of increasing the reliability of the results it is advisable to unite several methods. For example, it is recommended to combine RMS and SRNS time and frequency scales synchronization systems. The mutual calibration and examination of the both of the systems results allows to achieve higher synchronization precision.

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