XXI IMEKO World Congress "Measurement in Research and Industry"
August 30 – September 4, 2015, Prague, Czech Republic

THE EFFECT OF GPS-SIGNAL QUALITY ON TIMING ACCURACY OF SEA 9724 AND NI 9467 GPS MODULES SYNCHRONIZATION

Y. Kononov [1], *M. Ospishchev* [2], *V. Rudnev* [1,2], *S. Mikhaylov* [1],

[1] North-Caucasus Federal University, Stavropol, Russia, kyg@ncstu.ru, stas.mikhaylov@rosintecs.com
[2] RosIntecS LLC, Stavropol, Russia, m.osp@rosintecs.com, slava.rudnev@rosintecs.com

Abstract – The work results from the research of PPS-signals mistiming derived from SEA 9724 and NI 9467 GPS receiver modules. Effect of the number of satellites being tracked and tracking time has been studied. The mistiming value does not exceed PPS 0.1 µs at number of satellites greater than 5 for SEA 9724 and greater than 3 for NI 9467. It is proposed to use the value of co-ordinates as the initial information which will allow oscillating PPS at the number of satellites fewer than 4.

Keywords: synchronization, PPS, GPS, cRIO, PXI

1. INTRODUCTION

The phasor measurement units (PMUs) [1] are an integral part of modern Smart Grid, effectively complementing traditional SCADA-systems. PMUs allow to measure synchronously not only operating values of voltage and currents with frequency of up to two samples per period of the network principal frequency but also their phase. It considerably expands the scope of their application compared to SCADA, allowing to solve problems of transient phenomenon monitoring, power system parameters identifications and a number of topical application tasks [2, 3].

In addition to the PMU, the technology of the synchronous measurements in electrical systems is used in digital substations of intellectual electronic devices (IEDs), optical current and pressure transformers and Merging Units (MUs). These measuring devices use PPS-signals from GPS receivers as synchronization signals. For the device measurements results to meet the PMU IEEE Std C37.118-2011 [4], the accuracy of a synchronization (clock) source must comply with certain requirements.

Initially, GPS receivers were intended, first of all, to determine the geographical coordinates. However the algorithm of a GPS receiver operation assumes simultaneous determination with the high accuracy (less than 1 µs) of the current Universal Time Coordinate (UTC). It should be noted, that not all GPS receivers have a PPS-signal output. However, currently available in sufficiently large variety models are intended to generate a PPS-signal. Among them the C-series modules are of interest being designed for operation in measuring systems based on cRIO, since the measuring systems built on NI cRIO platform, are often used for prototyping PMU, IED and Smart Meter [5]. One of the first such units in the market was presented by S.E.A, a German company [6]. Starting 2012, National Instruments, an American company, began to produce its own NI 9467 GPS-module for cRIO. Unfortunately, there is no data on the accuracy of a PPS-signal in SEA 9724 module (unit) technical specifications. [7] The results of experimental studies show that the measurements mistiming value with SEA 9724 module application does not exceed ±250 ns. As for NI 9467 module, the manufacturer cites the value of PPS accuracy equal ±100 ns.

The application of technology of the synchronous measurements in distributive networks [3] demands a study of feasibility of GPS receivers' synchronization in cramped urban environment with a limited number of satellites tracked. The study results [8] show inversely proportional dependency of a GPS receiver synchronization accuracy on the number of satellites being tracked. Unfortunately, the authors do not cite the brand name (make) of the tested GPS receiver.

This article presents the results of the GPS-signal quality impact on the GPS receivers timing accuracy synchronization of the experimental PMU-device. The description of the testing unit developed for the studies, is presented in Section 2. The theoretical substantiation of the problem is given in Section 3. The plan and the experiment results are described in Section 4. Section 5, Summarizes conclusions drawn on the basis of the research results.

2. THE TESTING UNIT DESCRIPTION

To study the influence of a GPS-signal quality on the synchronization accuracy, a testing unit has been developed. It consists of a GPS-signal generator, GPS-signal receivers and an oscilloscope to evaluate the accuracy. The testing unit architecture is shown in Fig. 1.

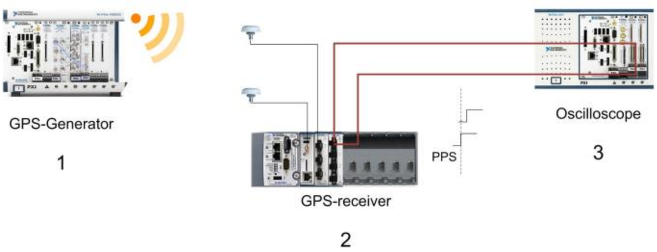

Fig. 1. Architecture of the Testing Unit.

The GPS-signal generator (1 in Fig. 1) has been developed on PXI platform of National Instruments. It consists of NI PXIe-8115 controller, NI PXIe-1062Q chassis and NI PXIe-5673E, a vector RF signal generator producing a high frequency-signal in a range from 500 kHz to 6,6 GHz. The generator Software is developed using NI LabVIEW graphic programming environment and NI GNSS Simulation Toolkit. The generator allows to emulate a GPS system signals completely identical to the real satellite signals. During the experiments conducted the generator was configured to emulate a various number of satellite signals (from 4 to 11).

The GPS-signal receiver (2 in Fig. 1) is built on NI CompactRIO platform. It consists of an NI cRIO-9024 controller, NI cRIO-9118 FPGA-chassis, two SEA 9472 modules receiving a GPS-signal, two NI 9467 modules receiving a GPS-signal and an NI 9402 digital input-output module. The receiver Software is developed using NI LabVIEW environment and NI LabVIEW FPGA module. GPS-modules generated PPS pulses at the moment of GPS-signal reception. These pulses were commutated to the terminals of the digital input-output module through FPGA-chassis resources.

The oscilloscope (3 in Fig. 4) is developed on NI PXI platform and used to evaluate the synchronization accuracy. It consists of an NI PXIe-8115 controller, NI PXIe-1071 chassis and an NI PXIe-6545 logical analyzer module. The oscilloscope Software is developed using NI Signal Express environment. PPS pulses from digital input-output GPS-signal receiver module terminals were transmitted to the logical analyzer input terminals. The mistiming value between PPS signals from different modules receiving GPS-signals was rated on the oscilloscope screen by comparing the time of the pulses rising front emergence.

3. THE PROBLEM DESCRIPTION

GPS is widely used in electrical networks as an accurate time source. Along with UTC precise values of time, the GPS receiver generates PPS pulses used as a reference signal in the synchronous phasor measurements systems (PMU).

Under the conditions of a GPS-signal consistent reception, the PPS pulses from two different receivers have a mistiming value of no more than 100 ns. The GPS-signal quality deterioration, and, in particular, decrease in the number of satellites tracked by a GPS receiver leads to increase in mistiming between PPS.

Since PPS is used as a reference signal to measure a phase in the PMU-device, the increase in mistiming between PPS in various PMUs results in occurrence of an error in the phase measurement between these devices. As a general rule [4], it is estimated that the value of mistiming between PMU-devices is that that the error in measurement of a phase does not exceed 2 π.

Hence, for networks with a frequency of 50 Hz, the error in phase measurement ε_θ correlates with the value of mistiming Δt between PMU as follows:

$$\varepsilon_\theta = 50 \cdot 360 \cdot \Delta t \qquad (1)$$

It follows therefrom that the change in PMU-devices mistiming of 1 μs leads to an increase in error in phase measurement at 0,018 °.

At the same time, the studies presented in [3], showed that value of mistiming between GPS receivers may depend on the number of satellites tracked by every receiver. Therefore, the value of the error in measurement of the PMU phase, equipped with GPS receivers, will depend on the number of satellites being tracked.

4. THE EXPERIMENT RESULTS

To evaluate the GPS-signal quality effect on the PPS pulses synchronization accuracy generated by modules receiving GPS-signals, experiments were conducted in which the number of GPS satellite signals imitated by the generator were being changed and the value of mistiming between NI 9467 module PPS pulses and SEA 9472 module PPS pulses was analyzed. The experiment was conducted under conditions shown in Table 1.

Table 1. Experiment Conditions.

Number of Satellites	SEA 9472 - SEA 9472	NI 9467 - NI 9467	SEA 9472 - NI 9467
4	Yes	Yes	Yes
5	Yes	Yes	Yes
6	Yes	Yes	Yes
8	Yes	Yes	Yes
11	Yes	Yes	Yes

For S.E.A. 9472 modules, the value of mistiming was assessed every 30 seconds for 5 minutes. Each experiment was repeated 5 times. The results are shown in Fig. 2-6.

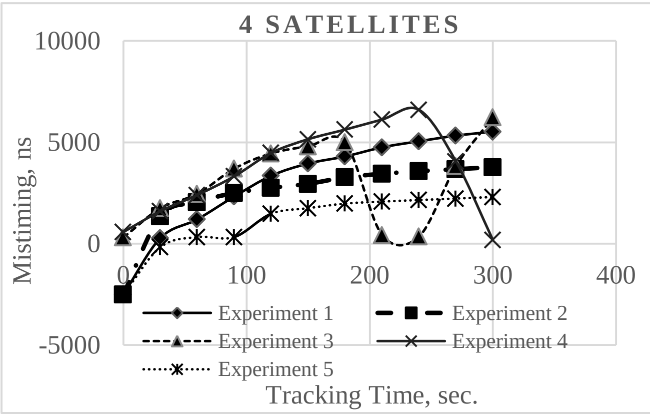

Fig. 2. Value of Mistiming at 4 Tracked Satellites.

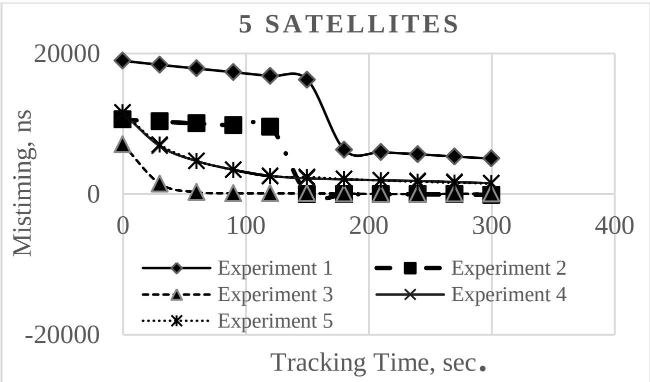

Fig. 3. Value of Mistiming at 5 Tracked Satellites.

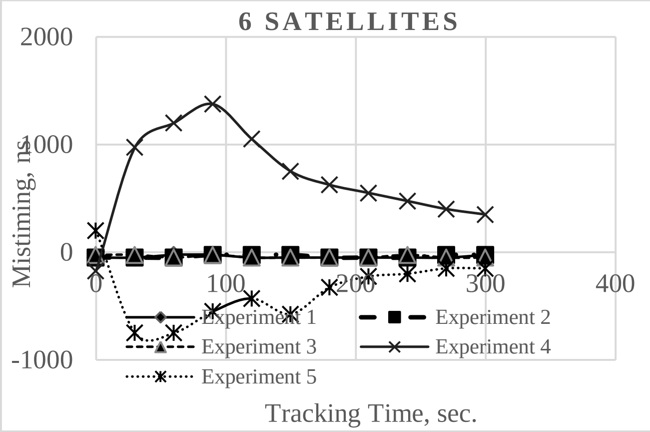

Fig. 4. Value of Mistiming at 6 Tracked Satellites.

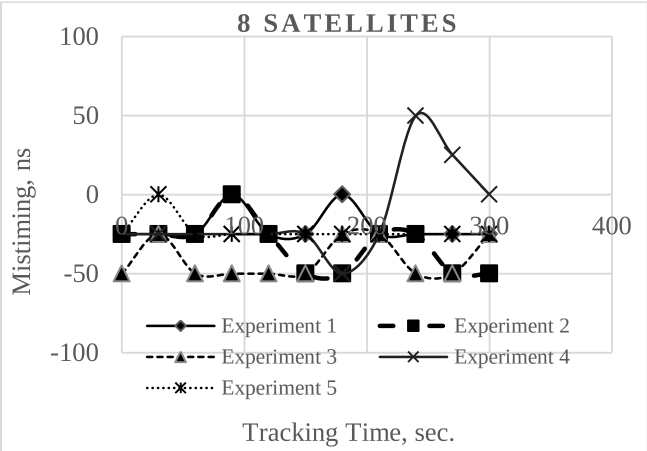

Fig. 5. Value of Mistiming at 8 Tracked Satellites.

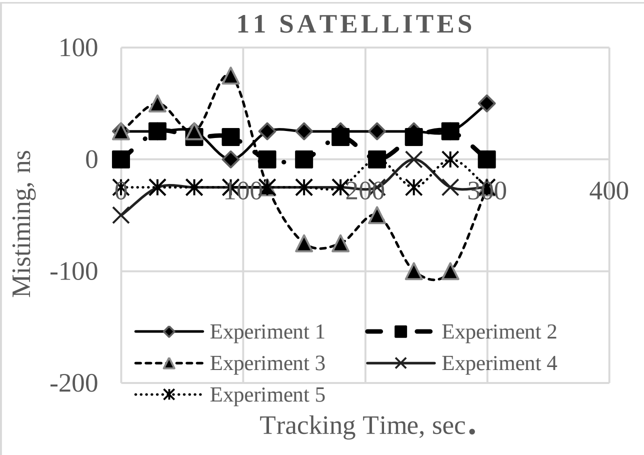

Fig. 6. Value of Mistiming at 11 Tracked Satellites.

The research results of NI 9467 modules PPS pulses mistiming did not reveal relation of its value to the number of satellites. The value of mistiming at 4 to 6 tracked satellites does not exceed 100 ns. The results are shown in Fig. 7.

There were also conducted an experiment to assess SEA 9472 mistiming at 4 tracking satellites during long period of time (70 minutes).The results are shown in Table 2.

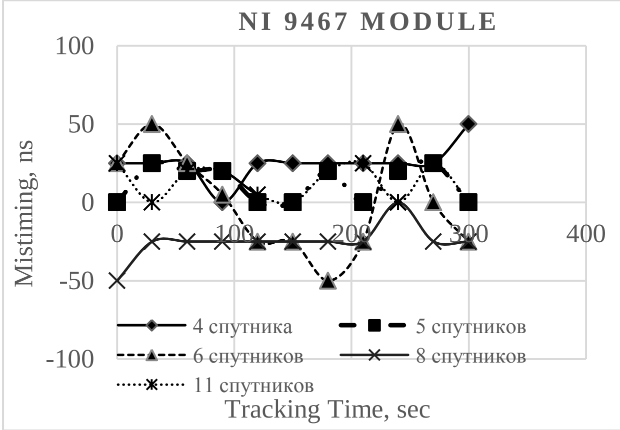

Fig. 7. Value of Mistiming of NI 9467 Modules PPS Pulses.

Table 2. Results of SEA 9472 mistiming during long period of time.

Tracking time, minutes	Mistiming, ns	Tracking time, minutes	Mistiming, ns
10	425	46	50
15	1450	50	100
20	750	55	500
25	-1875	61	350
30	-2625	65	0
35	-550	68	-625
40	-150	70	-1000
43	0	71	-1025

The representation of experimental results is snow in on Fig. 8.

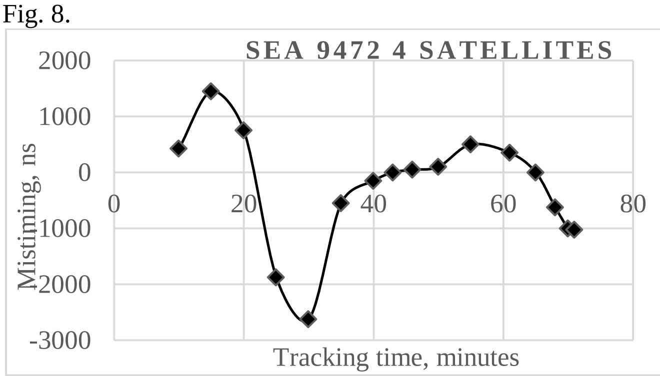

Fig. 8. Value of Mistiming of SEA 9472 Modules PPS Pulses during long period of time.

The experiment shows if 4 satellites are used than the PPS mistiming doesn’t become lower than that of the minimal value and continues to oscillate with amplitude up to 3 μs.

In addition, experiments were conducted to assess the NI 9467 and SEA 9472 «cold start» time (the time from switching the module on up to the PPS signal output start time). The evaluation of this parameter was produced at 4 and 11 tracked satellites. The results are shown in Table 3.

Table 3. Modules «Cold Start» Time at (in seconds).

Number of Satellites	SEA 9472	NI 9467
4	28	900
11	12	120

Based on the analysis of the results obtained it can be concluded that the SEA and NI modules implement standard algorithm for GPS receivers. The algorithm requires data from at least 4 satellites to determine the position coordinates and time. Obviously, the synchronization accuracy of the stationary set modules can be increased if the receiver's antenna coordinates are used as precisely given initial information. In order to do that, one-time measurements can be used produced at the initial installation using high-precision GPS receivers or other geodetic methods. If this is not possible, the averaged coordinate's information from its own receiver can be used at a considerable number of the tracked satellites when the error is minimal. In this case, the PPS pulses can be oscillated at any number of tracked satellites, greater than zero.

Development of the specialized receivers that implement this algorithm and having capable to receive signal from GPS/GLONASS/GALILEO, will improve reliability and accuracy of the measurements synchronization in electric networks. In addition to that, to eliminate the effect of the "time skew" [7] in such receivers, it is expedient to provide generation of a signal synchronized with an atomic clock signal [9] which can be used as a setting oscillator for ADC of the IED, PMU and MU.

5. CONCLUSIONS

The following conclusions have been drawn as a result of the studies conducted.

1. The generation of the PPS is feasible by the reviewed GPS receiver modules at the minimum of 4 satellites being tracked.

2. The NI 9467 module provides the best accuracy of synchronization at a small number of satellites (fewer than 6). At 4-6 tracked satellites, the PPS pulses mistiming value of these two modules does not exceed 100 ns. The NI 9467 and SEA 9472 modules synchronization timing accuracy of PPS pulses is identical and amounts to no more than 100 ns. at a considerable number of satellites being tracked (8 and more).

3. The SEA 9472 modules PPS pulses maximum mistiming value reaches 7 μs at 4 satellites tracked and does not depend on tracking time. The PPS pulses maximum mistiming value for these modules does not exceed 0.1 μs at 8 or more satellites being tracked. At 4 to 6 satellites, the SEA 9472 modules PPS pulses mistiming value decreases if the number of tracked satellites and tracking time over the satellites increase. At five tracked satellites the maximum mistiming value decreases from 18 μs to 5 μs, and at 6 satellites, it decreases from 1.5 ms to 0.35 ms.

4. The NI 9467 module search time for a GPS-signal is maximal and peaks 15 minutes at a small number of satellites (4). The GPS-signal search time is 10 minutes at 6 satellites. The search time is 1 minute at 8 satellites. The SEA 9472 module search time for a GPS-signal does not depend on the number of satellites and ranges from 15 to 30 seconds.

The suggested results have shown that the NI 9467 Module meets the required characteristics to be used in stationary electroenergetics. This module provides the timing accuracy up to 100 ns even with fewer number of satellites. The greater value of «cold start» time compared to SEA 9472 module doesn't make a noticeable impact on GPS-Synchronization modules if used in stationary conditions.

Thus, the research results have shown that it is essential for the GPS receiver of the device to track not fewer than 8 satellites to support the maximum accuracy of a phase measurement with the PMU-device. To ensure that, it is necessary to provide 360 ° visibility of the firmament at the antenna setting and to take into account a possible decrease in quality of a GPS-signal due to the atmospheric phenomena or surrounding vegetation.

ACKNOWLEDGMENTS

This work was supported by the Ministry of Education and Science of the Russian Federation under the agreement No. RFMEFI57814X0017.

REFERENCES

[1] A.G. Phadke and J.S. Thorp, *Synchronized Phasor Measurements and Their Applications*, Springer, New York, 2008.

[2] J. De La Ree, V. Centeno, J.S. Thorp, and A.G. Phadke, "Synchronized phasor measurement applications in power systems", *IEEE Trans. Smart Grid*, vol. 1, nº. 1, pp. 20-27, Jun. 2010.

[3] G. Sanchez-Ayala, J.R. Aguerc, D. Elizondo, M. Lelic, "Current trends on applications of PMUs in distribution systems", *Innovative Smart Grid Technologies (ISGT)*, 2013 IEEE PES, pp.1-6, 24-27 Feb. 2013.

[4] IEEE Standard for Synchrophasor Measurements for Power Systems, *IEEE Std C37.118.1-2011 (Revision of IEEE Std C37.118-2005* , pp. 1-61, Dec. 28 2011.

[5] B. Pinte, M. Quinlan, A. Yoon, K. Reinhard and P.W. Sauer, "A one-phase, distribution-level phasor measurement unit for post-event analysis", *Power and Energy Conference at Illinois (PECI)*, pp. 1-7, Feb. - March 2014.

[6] "SEA 9724 3G/GPS Communication Module", URL: http://www.sea-gmbh.com/en/products/compactrio-products/mobile-communications/sea-9724-3ggps/

[7] Y. G. Kononov, M.A. Ospishchev, V.Y. Rudnev "Current and voltage synchronous measurements using NI cRIO system with sigma-delta ADC NI 92xx and S.E.A. GPS modules", *XX IMEKO World Symposium*, pp. 25-30, Benevento, Italy, Sept. 2014.

[8] H. Toyoizumi and M. Genda, "Precise 1PPS signal by GPS," *IEEJ Transaction on Electronics Information and Systems*, vol. 125, nº. 8, pp. 1217–1222, 2005.

[9] M.Caciotta, A. Di Liberto, F. Leccese, S. Pisa,; E. Piuzzi, "A system for obtaining a frequency reference constantly locked to L1 GPS carrier for distributed power quality assessment", *ICEMI '09. 9th International Conference on*, pp. 2-7,2-10, Aug. 2009.