Eksakta : Berkala Ilmiah Bidang MIPA
VOLUME 21 NO 02 2020, pp 77-84
ISSN : Print 1411-3724 — Online 2549-7464
DOI : https://doi.org/10.24036//eksakta/vol21-iss2/241

Eksakta
Berkala Ilmiah Bidang MIPA
http://www.eksakta.ppj.unp.ac.id/index.php/eksakta

Article

Algorithm of Time and Frequency Remote Calibration System of SNSU-BSN

Article Info

Article history :

Received September 11, 2020
Revised September 27, 2020
Accepted September 27, 2020
Published September 30, 2020

Keywords :

Remote, cesium, calibration, atomic clock

A.Mohamad Boynawan*, Ratnaningsih, Windi Kurnia P., Yulita Ika P., Asep Hapiddin, Muhammad Azzumar

Center for Research and Human Resources Development, National Standardization Agency of Indonesia and National Measurement Standards Laboratory, National Standardization Agency of Indonesia

Abstract. National Measurement Standards- National Standardization Agency of Indonesia (SNSU-BSN) as the National Metrology Institute of Indonesia has provided time and frequency calibration services for customers. Time and frequency equipment should be calibrated to traceable to the SI units. The calibration process can be carried out in a calibration laboratory. However, some measuring devices cannot be sent to the calibration laboratory. One of the devices that cannot be sent to the calibration laboratory is Cesium atomic clock. The Cesium atomic clocks must be calibrated to get the time difference with the local coordinated universal time (UTC), namely UTC(IDN). Therefore, to calibrate the Cesium atomic clock, a remote calibration method is needed. The remote system is also intended to conduct the calibration more effective and efficient. This method requires two Global Positioning System (GPS) receiver devices placed on the client-side and a calibration laboratory. For this reason, an algorithm for remote calibration has been developed. The algorithm has been tested to calibrate Cesium-3 of SNSU-BSN against UTC(IDN). The time difference between Cesium-3 and UTC(IDN) was 5.8 microseconds by using the algorithm. Based on the algorithm that has been built, it was concluded that the algorithm can be used to perform remote calibration for the related customer.

This is an open acces article under the CC-BY license.

This is an open access article distributed under the Creative Commons 4.0 Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided the original work is properly cited. ©2020 by author.

Corresponding Author :
A. Muhamad Boynawan
Center for Research and Human Resources Development, National Standardization Agency of Indonesia and National Measurement Standards Laboratory, National Standardization Agency of Indonesia
Email : boynawan.eksakta@gmail.com

1. Introduction

Atomic clock Cesium(1-23) HP 5071A is a time and frequency standard managed by the National Standardization Agency (BSN), symbolized as Coordinated Universal Time UTC(IDN). Has followed international comparisons, so that UTC(IDN) traceability is maintained as Indonesia's national time and frequency standard.

Dissemination of the standard time and frequency values that has been carried out by BSN is through the calibration service for measuring time and frequency as well as time synchronization services through the Network Time Protocol (NTP). Based on the results of evaluations conducted through audits by experts in the field of time and frequency metrology and stakeholder input, the time dissemination system at BSN has not been able to serve optimally especially stakeholders who have an atomic clock source. Problems encountered are that the equipment cannot be moved or brought to the SNSU - BSN laboratory. For this reason, it is necessary to develop a remote calibration system for atomic clock sources against the Indonesian national time UTC(IDN) standard.

To build a remote calibration system, it is necessary to develop an infrastructure in the form of procurement of a remote calibration system, which is a GPS Receiver and data processing software from the remote calibration [24]

2. Time Standard System

2.1 Cesium Atomic Clock

The Cesium atomic clock is a source of time and frequency that has a very accurate and stable output [25]. As explained in 26th CGPM (November 2018) at BIPM "The second, symbol s, is the SI unit of time. It is defined by taking the fixed numerical value of the cesium frequency, the unperturbed ground-state hyperfine transition frequency of the caesium-133 atom, to be 9 192 631 770 when expressed in the unit Hz, which is equal to s-1". Based on these definitions, the Cesium atomic clock is the primary standard for time and frequency.

The primary standard of time and frequency managed by SNSU - BSN is the HP 5071A (Cs-1) cesium atomic clock. In addition to maintaining the traceability of the HP 5071A (Cs-1) cesium atomic clock time and frequency standards internationally, SNSU - BSN disseminates the 1 pps value and the 10 MHz frequency produced by the HP 5071A cesium atomic clock through calibration and synchronization. Synchronization of Indonesian national standard time UTC(IDN) is disseminated through an NTP server where the server gets a 1 pps reference signal as the time that will be distributed to all time regions in Indonesia, namely Indonesian Time.

2.2 GPS Receiver

GPS time and frequency receiver is high-precision time and frequency instrument that generates time and frequency outputs from its GPS [26]. GPS receivers consist of the antenna, RF front end, local oscillator, and navigation processor. An antenna is the first part of the GPS receiver that must be able to receive right-hand circularly polarized (RHCP) signals because this is the type of signal transmitted by GPS satellites [27]. GPS time and frequency transfer is a method for sharing a precise reference time using a GPS receiver. GPS time is a precise time standard that is related to UTC. A GPS receiver has the output of 1 PPS that can be used for remote application. The GPS receiver should be calibrated to ensure the accuracy and long-term stability of time transfer. A GPS receiver and its antenna with cable can be sent to a time laboratory for the calibration. Signals of GPS satellite are steered to UTC and it result an excellent of the long-term accuracy of a GPS receiver. GPS receiver provides an automated time transfer that used by time laboratories to compare theirs standards [28].

3. Time Interval Measurement

Base of remote calibration is time interval measurement. Time interval is the time that shows the duration of an event. For example a runner runs 100 meters for 9.6 seconds or baking a cake is required time for 30 minutes. On devices such as electronic time counters, time interval measurement is measuring the time taken between the START event and the STOP event. Time interval counter can measure electric delay, pulse width and other time events.

In general, measurements using a time interval counter requires two signals that function as START and STOP and a signal a reference used to calculate the time interval between START and STOP like shown in Fig. 1. The START signal will open the gate to indicate start time calculation, while the STOP signal will close the gate indicates the cessation of the time calculation process [29]. And the measurement results obtained by calculating the accumulated clock pulses when the gate is open. Good result of time interval measurement have a big effect to guarantee the remote calibration accuracy [30].

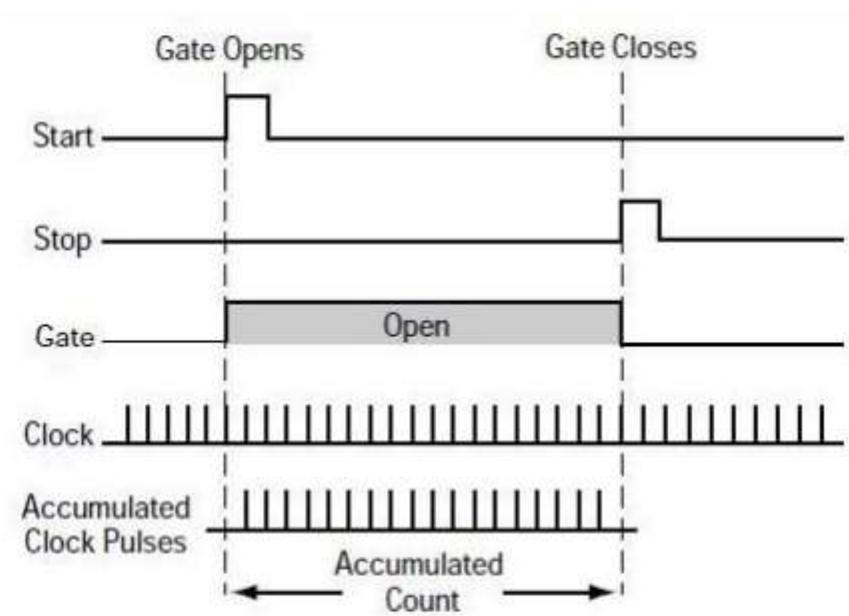

Figure. 1. Time Interval Measurement.

4. Algorithm

Algorithm of time and frequency remote calibration required Common GNSS Generic Time Transfer Standard (*CGGTTS*) file. CGGTTS is a GPS receiver output in certain file format. The resulting CGGTTS file format can be seen in Fig. 2.

```
CGGTTS GPS DATA FORMAT VERSION = 01
REV DATE = 2004-02018
RECV = Freqtime remote calibration receiver  ver.1.23BVA
CH = 12
IMS = 2573025
LAB = ID0058
X = -1817478.88m
Y = +6073156.57m
Z = -701362.93m
FRAME = WGS-84
COMMENT =
INT DLY =        0.0 ns
CAB DLY =        0.0 ns
REF DLY =        0.0 ns
REF = INTERNAL
CKSUM = AA

PRN CL  MJD  STTIME TRKL ELV AZTH   REFSV      SRSV     REFGPS    SRGPS  DSG IOE MDTR SMDT MDIO SMDI CK
             hhmmss  s  .1dg .1dg    .1ns     .1ps/s     .1ns    .1ps/s .1ns     .1ns.1ps/s.1ns.1ps/s
 22 FF 58325 000200  780 300 1617   +4692079     +9         +27    +126  136  56  159   +2   88   +0 E2
 23 FF 58325 000200  780 648 2396   +2138937    -20         +48     -24   72  78   88   +1   53   +1 CC
 11 FF 58325 000200  780 872 1486   +7282794    +60         +47     +42   72  63   80   +0   50   +0 B9
  1 FF 58325 000200  780 581 1586    +695243    -27         -27     +12   90  70   94   -6   57   -3 A5
  8 FF 58325 000200  780 341   39   +1094157    +70         -68     +83  103   7  142  +25   81  +10 B2
  9 FF 58325 000200  780 441 2905   -5129360    +65         -63     +73  205  69  115   -7   68   -3 DD
 18 FF 58325 000200  780 614 1026    -380323   +197         -43    +150  155  71   91   +0   55   +0 CF
  3 FF 58325 000200  780 289 1892   -1114123   +165         -50    +104  155  68  165   +0   90   +0 E5
 22 FF 58325 001800  780 298 1539   +4692182   -287         +43    -169  172  56  160   +1   88   +0 1F
```

Figure. 2. CGGTTS file

The *CGGTTS* data format above explains the name of the tracked satellites, for example PRN 22 produces a time comparison of 1 pps UTC(IDN) with satellite 22 of 4692079 ns. Measurements were taken at MJD 58325 (July 26, 2018), date in Modified Julian Date format [31] at 00.02.00 UTC. The file is then saved with the names xxxxx.txt.

Algorithm of CGGTTS file calculation:

- Get the files from two receivers(receiver 58 and receiver 57) that have the same MJD (same file name)
- Select a STTIME segment
- Take the REFSYS value with the same STTIME and PRN
- Make sure that besides STTIME and PRN are the same, they also have the same IOE value
- Correct the REFSYS value using the below equation
  REFSYS (corrected) = REFSYS - INT DLY - CAB DLY + REF DLY………….. (1)
- Subtract the REFSSY (STD) value with the REFSYS (UUT) value
- Calculate the average of the previous calculated values, then the time difference is obtained when a certain STTIME
- Do steps 2 through 6 for the other STTIME segments
- Calculate the average of all STTIME to get the time difference in one MJD

5. Results and Discussion

Algorithm of remote calibration used to calculate time interval difference between atomic clock Cs-3 and UTC(IDN). Each clock was connected to GPS receiver after two GPS receiver running, CGGTTS data was downloaded from each GPS receiver. Then using algorithm above, the result of remote calibration between Cs-3 and UTC(IDN) shown in Table 1. And fig. 3 below shown result time difference between Cs-3 and UTC(IDN) against time.

Table 1. Data comparison between Cs-3 and UTC(IDN)

Cs-3				UTC(IDN)		
satellite	STTIME	value		satellite	STTIME	value
9	200	44770		G01	200	-13847
1	200	44738		G03	200	-13897
22	200	44728		G06	200	-13985
6	200	44760		G07	200	-13987
19	200	44825		G09	200	-13996
7	200	44657		G11	200	-13824
28	200	44810		G17	200	-13843
23	200	44821		G19	200	-13873
3	200	44743		G22	200	-13869
17	200	44770		G23	200	-13997
30	200	44723		G28	200	-13789
				G30	200	-13905
9	1800	44825		G01	1800	-13832
1	1800	44783		G03	1800	-13868
22	1800	44819		G06	1800	-13984
6	1800	44763		G07	1800	-14004
19	1800	44826		G09	1800	-14011
7	1800	44704		G17	1800	-13852
28	1800	44812		G19	1800	-13845
23	1800	44787		G22	1800	-13864
3	1800	44752		G23	1800	-13973
17	1800	44777		G28	1800	-13803
30	1800	44693		G30	1800	-13935

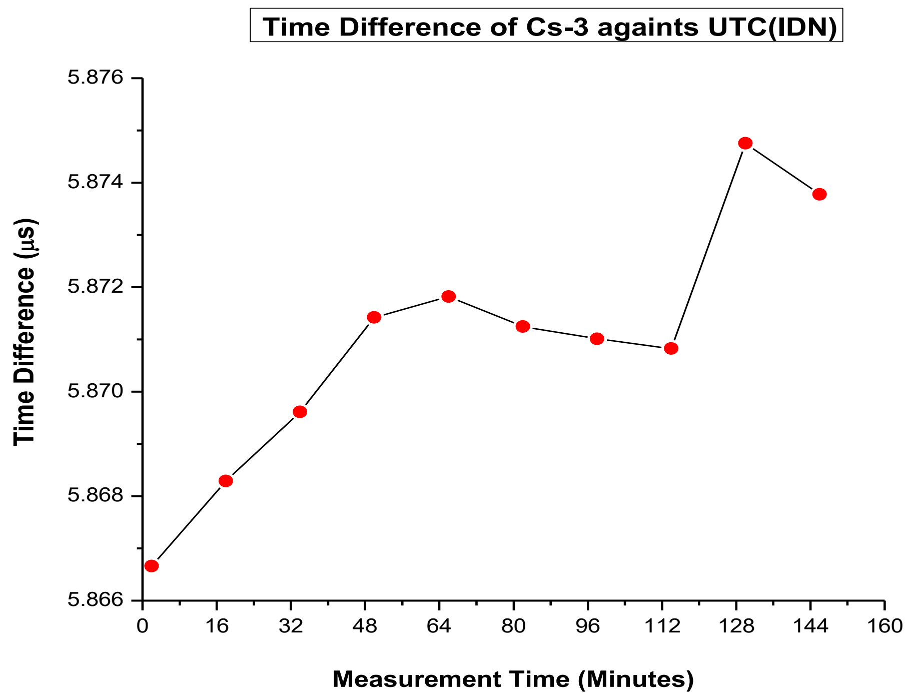

Figure. 3. Measurement result of time difference of Cs-3 against UTC(IDN)

From the table 1 shown that each STTIME GPS receiver received signal from 11 GPS satellite averaged. Indonesia can received many signal satellite in one time due to Indonesia position in equator. Time difference between STTIME was 16 minutes because GPS receiver need time to tracked GPS receiver and to calculate value and created CGGTTS file.

Figure 3 shown that time difference between Cs-3 and UTC(IDN) increased against time. Time difference increased more than 40 ps each STTIME. The biggest factor was from Cs-3. Because Cs-3 is newest atomic clock in SNSU-BSN. And it never been fine adjusted before. From figure 3 also shown that averaged time difference between Cs-3 and UTC(IDN) was 5.8 microseconds at MJD 58720(August 25, 2019).

6. Conclusion

National Measurement Standards-National Standardization Agency of Indonesia (SNSU-BSN) has developed algorithm of time and frequency remote calibration to calibrate atomic clock on remote area. The algorithm has been tested to calibrate Cesium-3 of SNSU-BSN against UTC(IDN). The time difference between Cesium-3 and UTC(IDN) was 5.8 microseconds by using the algorithm. The algorithm can be used to perform remote calibration for the related customer.

References

1. Ahmed M, Magalhaes DV, Bebeachibuli A, Muller ST, Alves RF, Ortega TA, et al. (2008). The Brazilian time and frequency atomic standards program. Anais da Academia Brasileira de Ciencias.80(2):217-52.
2. Appel J, Windpassinger PJ, Oblak D, Hoff UB, Kjaergaard N, Polzik ES. (2009). Mesoscopic atomic entanglement for precision measurements beyond the standard quantum limit.

Proceedings of the National Academy of Sciences of the United States of America.106(27):10960-5.

3. Borish V, Markovic O, Hines JA, Rajagopal SV, Schleier-Smith M. (2020). Transverse-Field Ising Dynamics in a Rydberg-Dressed Atomic Gas. Physical review letters.124(6):063601.
4. Burt EA, Diener WA, Tjoelker RL. (2008). A compensated multi-pole linear ion trap mercury frequency standard for ultra-stable timekeeping. IEEE transactions on ultrasonics, ferroelectrics, and frequency control.55(12):2586-95.
5. Chang CY, Chang EC, Huang CW. (2019). In Situ Diagnosis of Industrial Motors by Using Vision-Based Smart Sensing Technology. Sensors.19(24).
6. Clivati C, Cappellini G, Livi LF, Poggiali F, de Cumis MS, Mancini M, et al. (2016). Measuring absolute frequencies beyond the GPS limit via long-haul optical frequency dissemination. Optics express.24(11):11865-75.
7. Devenoges L, Stefanov A, Joyet A, Thomann P, Di Domenico G. (2012). Improvement of the frequency stability below the Dick limit with a continuous atomic fountain clock. IEEE transactions on ultrasonics, ferroelectrics, and frequency control.59(2):211-6.
8. Francois B, Calosso CE, Danet JM, Boudot R. (2014). A low phase noise microwave frequency synthesis for a high-performance cesium vapor cell atomic clock. The Review of scientific instruments.85(9):094709.
9. Gensemer SD, Martin-Wells RB, Bennett AW, Gibble K. (2012). Direct observation of resonant scattering phase shifts and their energy dependence. Physical review letters.109(26):263201.
10. Gill P. (2011). When should we change the definition of the second? Philosophical transactions Series A, Mathematical, physical, and engineering sciences.369(1953):4109-30.
11. Godun RM, Nisbet-Jones PB, Jones JM, King SA, Johnson LA, Margolis HS, et al. (2014). Frequency ratio of two optical clock transitions in 171Yb+ and constraints on the time variation of fundamental constants. Physical review letters.113(21):210801.
12. Hachisu H, Petit G, Nakagawa F, Hanado Y, Ido T. (2017). SI-traceable measurement of an optical frequency at the low 10⁻¹⁶ level without a local primary standard. Optics express.25(8):8511-23.
13. Hagemann C, Grebing C, Lisdat C, Falke S, Legero T, Sterr U, et al. (2014). Ultrastable laser with average fractional frequency drift rate below 5 x 10(-)(1)(9)/s. Optics letters.39(17):5102-5.
14. Matveev A, Parthey CG, Predehl K, Alnis J, Beyer A, Holzwarth R, et al. (2013). Precision measurement of the hydrogen 1S-2S frequency via a 920-km fiber link. Physical review letters.110(23):230801.
15. Mishra S, Stumpf RP, Schaeffer BA, Werdell PJ, Loftin KA, Meredith A. (2019). Measurement of Cyanobacterial Bloom Magnitude using Satellite Remote Sensing. Scientific reports.9(1):18310.
16. Parthey CG, Matveev A, Alnis J, Bernhardt B, Beyer A, Holzwarth R, et al. (2011). Improved measurement of the hydrogen 1S-2S transition frequency. Physical review letters.107(20):203001.

17. Portalupi SL, Widmann M, Nawrath C, Jetter M, Michler P, Wrachtrup J, et al. (2016). Simultaneous Faraday filtering of the Mollow triplet sidebands with the Cs-D1 clock transition. Nature communications.7:13632.
18. Reitz D, Sayrin C, Mitsch R, Schneeweiss P, Rauschenbeutel A. (2013). Coherence properties of nanofiber-trapped cesium atoms. Physical review letters.110(24):243603.
19. Shang H, Zhang T, Miao J, Shi T, Pan D, Zhao X, et al. (2020). Laser with 10(-13) short-term instability for compact optically pumped cesium beam atomic clock. Optics express.28(5):6868-80.
20. Shi H, Ma J, Li X, Liu J, Li C, Zhang S. (2018). A Quantum-Based Microwave Magnetic Field Sensor. Sensors.18(10).
21. Szymaniec K, Lea S, Liu K. (2014). An evaluation of the frequency shift caused by collisions with background gas in the primary frequency standard NPL-CsF2. IEEE transactions on ultrasonics, ferroelectrics, and frequency control.61(1):203-6.
22. Windpassinger PJ, Oblak D, Petrov PG, Kubasik M, Saffman M, Alzar CL, et al. (2008). Nondestructive probing of Rabi oscillations on the cesium clock transition near the standard quantum limit. Physical review letters.100(10):103601.
23. Zhuang W, Chen J. (2014). Active Faraday optical frequency standard. Optics letters.39(21):6339-42.
24. M. A. lombardi, (2019). The Reach and Impact of the Remote Frequency and Time Calibration Services at NIST, NCSLI Measure J. Meas. Sci.
25. D. Piester, M. Rost, M. Fujieda, T. Feldmann, and A. Bauch (2011), Remote atomic clock synchronization via satellites and optical fibers, Adv. Radio Sci., Vol. 9, , pp. 1–7.
26. J. L. Wang, S. Y. Huang, C. S. Liao, (2013). Time and Frequency Transfer System using GNSS Receiver," Asia-Pacific Radio Science Conference.
27. M. Tamazin, M. Karaim and A. Noureldin, (2018). GNSSs, Signals, and Receivers," IntechOpen.
28. G. Petit, P. Defraigne, B. Warrington, and P. Uhrich, (2006). Calibration of dual frequency GPS receivers for TAI, Proceedings of the 20th EFTF.
29. J. Kalisz (2013). Review of methods for time interval measurements with picosecond resolution, Metrologia 41,. pp. 17-32
30. X. Hong, G. Liu, Z.i Wu, D. Xipeng, (2010). Remote calibration system for frequency based on in-place benchmark," Front. Mech. Eng. China,Vol. 5, no. 3. pp. 316–321.
31. James R. Clynch, (2006), Time Systems and Dates: Universal Time, GPS Time, Julian Dates, February.