ICIC Express Letters
Part B: Applications
Volume **7**, Number **9**, September **2016**

ICIC International ©2016 ISSN 2185-2766
pp. 1969–1974

AUTONOMOUS INTEGRITY MONITORING OF THE REFERENCE FREQUENCY ONBOARD NAVIGATION SATELLITE

Sheng Tang[1], Lei Ji[2], Ya Liu[3], Tianxiang Wang[1] and Haodan Lei[1]

[1]School of Information Science and Technology
Northwest University
No. 1, Xuefu Avenue, Xi'an 710127, P. R. China
tangsheng@nwu.edu.cn

[2]School of Life Science
Beijing Institute of Technology
No. 5, Zhongguancun South Street, Beijing 100081, P. R. China

[3]National Time Service Center
Chinese Academy of Sciences
No. 3, Shuyuan East Street, Xi'an 710600, P. R. China

Received January 2016; accepted April 2016

Abstract. *The conventional methods of evaluating the integrity of the reference frequency onboard navigation satellite are difficult to meet the requirement of failure isolation. A method of autonomous integrity monitoring based on oscillator intervention technique is proposed in this paper, which can detect the anomalies of the master or backup reference frequency onboard navigation satellite and identify the anomaly source simultaneously. Simulation experiment results demonstrate the improvement of the proposed method. It is shown that small accidental jumps or jitters of the 10.23MHz reference frequency which are greater than 8mHz can be accurately identified in one second.*
Keywords: Navigation satellite, Reference frequency, Integrity, Autonomous monitoring

1. **Introduction.** The reference frequency of navigation satellite is a special signal with fixed frequency value usually produced by the Time Keeping System (TKS) onboard satellite. For example, both reference frequencies of GPS Block IIR and Galileo IOV are 10.23MHz [1,2]. It is very necessary to monitor integrity of the reference frequency onboard navigation satellite, since its accuracy and stability will directly affect the performance of the whole satellite navigation system [3-5]. Although the integrity monitoring of the reference frequency onboard navigation satellite has received a great deal of attention in recent years, the interest has been focused mainly on detection of frequency jump or phase jump; however, the frequency resource configuration has not been taken into account [6-11]. One problem in engineering practice is that the abnormal reference frequency signal chain could not be identified easily by the way of comparing the measurement of the master and backup reference frequencies, even though the frequency jump or phase jump can be accurately detected by a phase meter onboard the satellite.

In order to solve the problem mentioned above, a method of autonomous integrity monitoring based on oscillator intervention technique is proposed in this paper, which can accurately detect the small anomaly of the master or backup reference frequency chain, and make a correct judgment of the anomaly source simultaneously onboard the navigation satellite.

The rest of this paper is organized as follows. Section 2 introduces the principle of autonomous integrity monitoring of the reference frequency onboard navigation satellite and presents the design scheme of the system. Section 3 gives a simulation experiment to verify the the proposed method. Section 4 concludes this paper.

2. **Principle of Autonomous Integrity Monitoring.** In a more simplified and reasonable TKS scheme, only two atomic clocks are powered up to drive two individual frequency synthesizers respectively. One of the two signal chains produced by the synthesizers is selected as the reference frequency of the satellite payloads. The selected signal chain can be called master chain, and the other can be called backup chain. The backup chain must be adjusted as the same frequency and the same phase with the master chain, which enables stable switching to the backup chain when anomaly of the master chain occurs and thus not suitable for providing the standard reference frequency signal for the navigation satellite.

The comparison measurement between the master chain and the backup chain can help to detect the frequency jump or phase jump, but it is unable to find the failure source. Each of the signal quality degradation derived from the master chain or the backup chain can lead to a jump display. In order to isolate the abnormal reference frequency source, an oven controlled crystal oscillator (OXLN38D-S-KP-V, 10.2299MHz) is introduced into the comparison measurement in our design. Firstly, the oscillator can be used to realize high precision frequency measurement. Secondly it can help to construct three-party voting logic and isolate the abnormal reference frequency source.

2.1. **Design and implementation of data acquisition and processing system.** As shown in Figure 1, the circuit structure of our comparison measurement system has similarity with the classical DMTD (Dual Mixer Time Difference) measurement equipment [2,12], but the conventional counter is abandoned and replaced by a dual channel simultaneous acquisition module and a digital processing module in the measurement of two sine-beat signals. Such practice can not only help to realize the high precision measurement, but also make it possible to integrate digital multi-algorithm into the basic measurement system, such as the frequency anomaly detection algorithm, and the anomaly isolation algorithm. And in the design, three sets of measurement data are selected as the basis data of autonomous integrity monitoring, which can be obtained by calculating the simultaneous sampled data of two sine-beat signals.

(1) $\Delta f_{ab}(n)$: relative frequency difference of master chain and backup chain.
(2) $\Delta f_{ac}(n)$: relative frequency difference of master chain and intervention oscillator.
(3) $\Delta f_{bc}(n)$: relative frequency difference of backup chain and intervention oscillator.

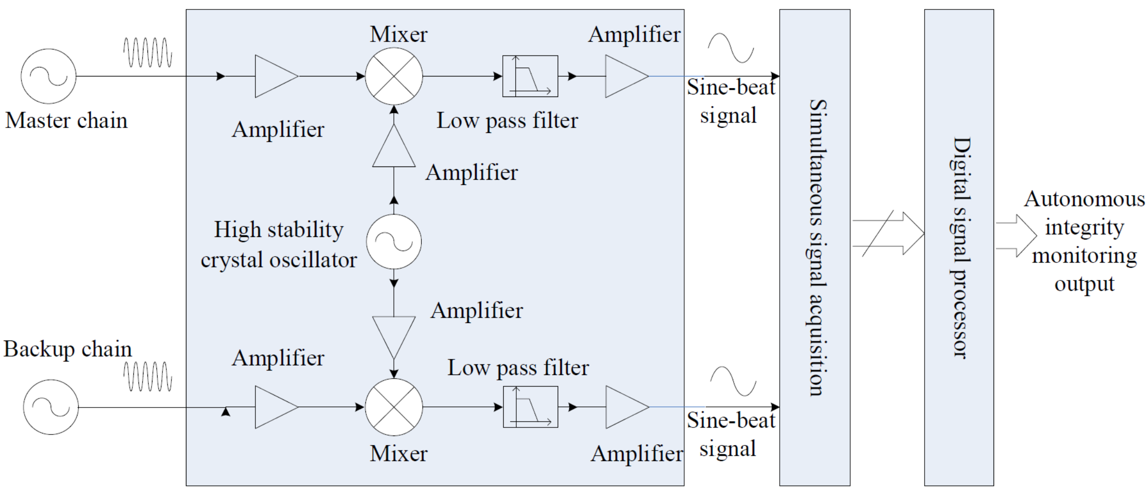

FIGURE 1. Structure of the basic frequency measurement system

2.2. **Detection and isolation of frequency anomaly.** Compared with other predicted tracking algorithm (e.g. Kalman filter method), the least square method has the virtues of the simple principle, good real-time performance and is easy to realize. In our design, several previous measurement results are used to predict the trend of the frequency difference. As shown in Figure 2, the frequency jump detection is carried out by comparing the Least Square Prediction (LSP) of the previous measurement results and the current measurement result where "g" is a detection threshold and it will affect the detection rate and false alarm rate. If the threshold value is too large, it will lead to missing report of some frequency anomalies. On the other hand, too small threshold value may cause bigger false alarm rate. Therefore, the selection of the detection threshold should be according to the demand on the detection rate and the false alarm rate in a practice project.

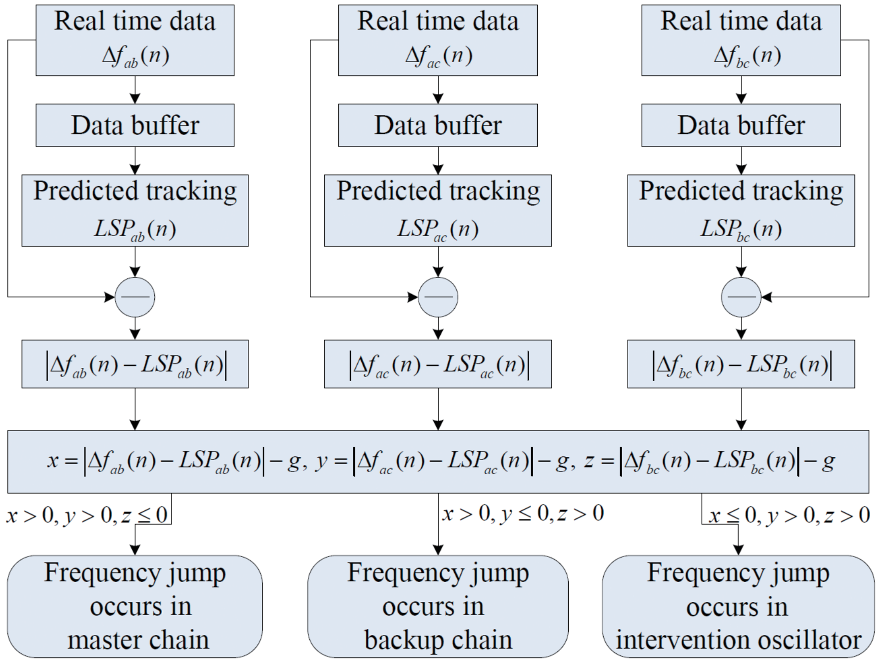

Figure 2. Algorithm of frequency anomaly detection and isolation

The procedure of the frequency anomaly isolation could be illustrated by an example as follows. The original frequency difference measurement data of a certain type of TKS principled sample machine are shown as Figures 3(a)-3(c). It is apparent that the master chain has been adjusted by a frequency offset of 1mHz at the moment of 45th second, which is used to simulate a relative frequency jump about 9.7E-11. The Figures 3(d)-3(f) show the detecting result of the frequency jump, among which both Figure 3(d) and Figure 3(e) have abnormal peaks at the moment of 45th second. And at the same time, Figure 3(f) has no apparent abnormal peak. According to the algorithm illustrated in Figure 2, we can come to the conclusion that a frequency jump occurred in master chain at the moment of 45th second. It can also be seen that two simultaneous smaller abnormal peaks appeared in Figure 3(e) and Figure 3(f) at the moment of 17th second, whereas there was nothing happening in Figure 3(d). The above phenomenon shows that a small jitter occurred in the intervention oscillator at the moment of 17th second.

3. **Experiment Results.** Generally, the background noise has a direct influence on the measuring ability of the system. The test results show that the background noise value of the basic measurement system is 6.76E-13/s, just as shown in Figure 4 which could meet the demands of measurement of the reference frequency onboard the navigation satellite.

In order to test the function and validity of the monitoring method proposed in this paper, a lab setup is built. A view of this setup is shown in Figure 5. On the premise

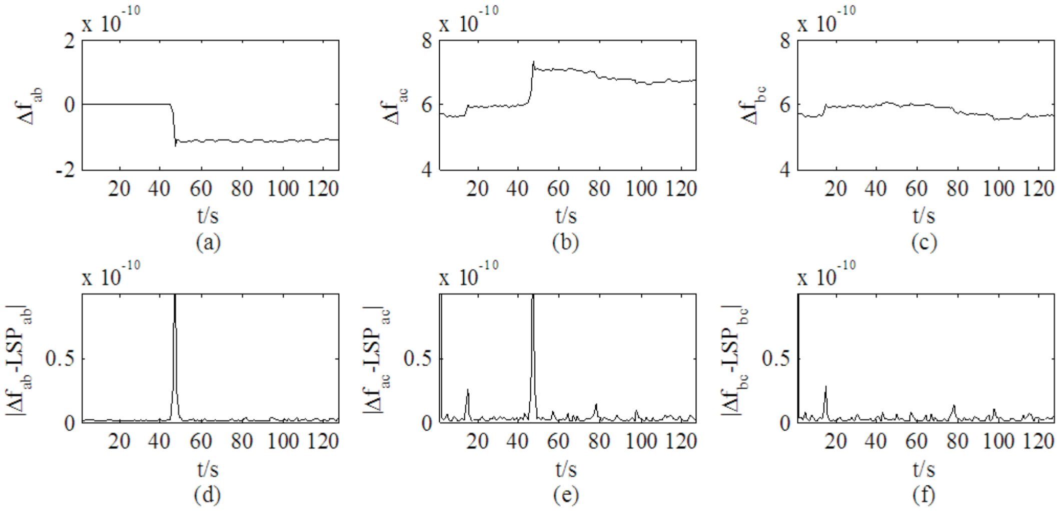

FIGURE 3. Identification of frequency anomaly

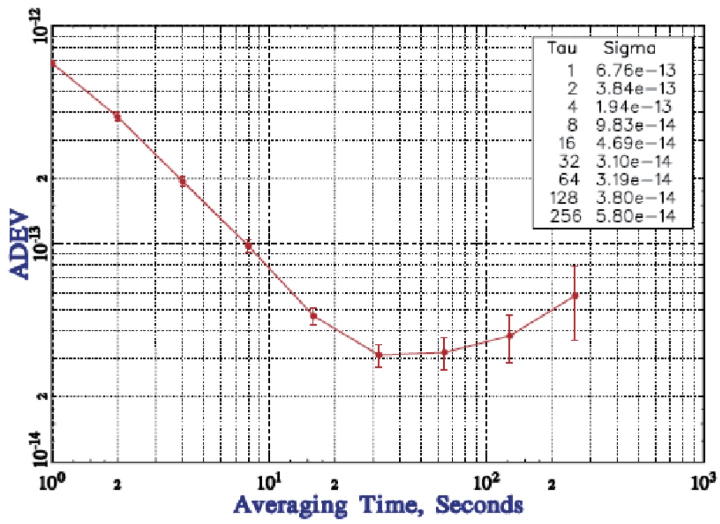

FIGURE 4. Background noise of the system

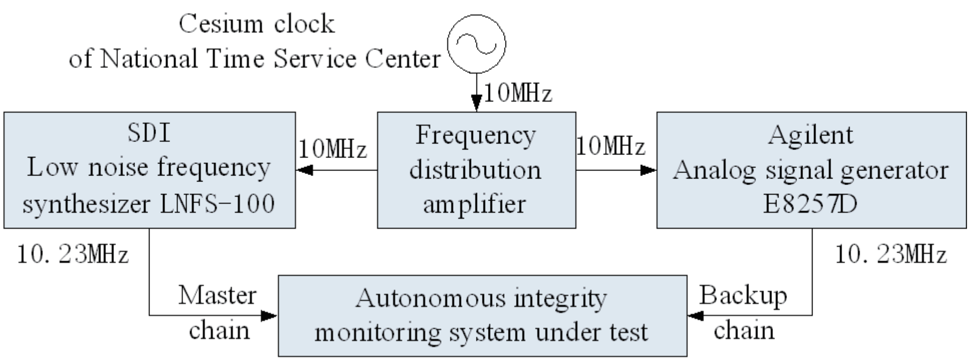

FIGURE 5. A block diagram of the lab setup for testing the characteristics of the system

of 10MHz reference locked, both stabilities of the low noise frequency synthesizer LNFS-100 and the analog signal generator E8257D are about 5E-12/s, so that the 10.23MHz outputs of them can be used to simulate the master and backup frequency chains of the

TKS onboard navigation satellite. In this experiment, the frequency jump or jitter of frequency chain can be made by minor adjusting LNFS-100 or E8257D.

If the detection threshold g = 2.9600E-11 (corresponding the absolute frequency of 0.3028mHz), the different detection rates for different frequency jump between the master chain and backup chain are shown in Table 1. As can be seen from Table 1, a frequency jump greater than 0.8000mHz (corresponding the relative frequency jump of 7.8201E-11) can be detected and isolated accurately. With this method, all the tasks of simultaneous data acquisition and processing are carried out by the DSP TMS320C3713, and can be finished in every one second.

Table 1. Detection rate and isolation rate of frequency jump

Frequency jump of master or backup chain		Detection rate	Isolation rate	
Absolute frequency (unit: mHz)	Relative frequency jump (unit: non)	(%)	Jump derived from master chain (%)	Jump derived from backup chain (%)
0.0000	0.0000	0.0093	0.0066	0.0506
0.1000	9.7752E-12	0.6095	0.6172	1.5559
0.2000	1.9550E-11	10.0779	11.8716	15.2884
0.3000	2.9326E-11	48.1001	55.5398	54.2715
0.4000	3.9101E-11	88.1365	92.7862	89.2270
0.5000	4.8876E-11	99.2053	99.7289	99.1109
0.6000	5.8651E-11	99.9864	99.9979	99.9769
0.7000	6.8426E-11	99.9999	100.0000	99.9998
0.8000	7.8201E-11	100.0000	100.0000	100.0000
0.9000	8.7977E-11	100.0000	100.0000	100.0000
1.0000	9.7752E-11	100.0000	100.0000	100.0000

4. **Conclusion.** In order to meet the needs of high precision measurement and anomaly detection towards reference frequency onboard the navigation satellite, a sine-beat digital measurement method is proposed in this paper as an improvement of the classic DMTD technique. Meanwhile, the oscillator intervention technique is introduced to solve the problem of anomaly isolation of the reference frequency. The experiment results show that small accidental jumps of the 10.23MHz reference frequency with stability of 5E-12/s which are greater than 8mHz can be accurately detected and isolated in one second. The results of the research have significance in the design of TKS autonomous integrity monitoring system onboard the navigation.

Further research will concentrate on the extension of this technique to the integrity monitoring of more general frequency sources. Therefore, adjustable offset frequency generator will be a necessary substitute for the specially-designed 10.2299MHz oscillator in our future design. Consequently, the method of generating offset frequency should be studied extensively in the future.

Acknowledgment. This work is partially supported by the National Natural Science Foundation of China (No. 11403018), the Open Fund of Key Laboratory of Precision Navigation and Timing Technology of National Time Service Center (No. 2014PNTT04), and the Natural Science Foundation of Northwest University (No. 12NW08). The authors also gratefully acknowledge the helpful comments and suggestions of the reviewers, which have improved the presentation.

REFERENCES

[1] A. Wu, Evaluation of GPS Block IIR time keeping system for integrity monitoring, *Proc. of the 39th Annual Precise Time and Time Interval (PTTI) Meeting*, Long Beach, CA, pp.351-362, 2007.

[2] D. Felbach, F. Soualle, L. Stopfkuchen and A. Zenzinger, Future concepts for on-board timing subsystems for navigation satellite, *Proc. of the 24th European Frequency and Time Forum*, Noordwijk, pp.20-26, 2010.

[3] M. Weiss, P. Shome and R. Beard, GPS signal integrity dependencies on atomic clocks, *Proc. of the 38th Annual Precise Time and Time Interval (PTTI) Meeting*, Washington, DC, pp.439-448, 2006.

[4] A. Cernigliaro, G. Fantino, I. Sesia, P. Tavella and L. Galleani, Nonstationarities in space clocks: Investigations on experimental data, *Proc. of the 28th European Frequency and Time Forum (EFTF)*, Neuchatel, pp.126-129, 2014.

[5] D. Felbach, F. Soualle, L. Stopfkuchen and A. Zenzinger, Clock monitoring and control units for navigation satellites, *Proc. of 2010 IEEE International Frequency Control Symposium (FCS)*, Newport Beach, CA, pp.474-479, 2010.

[6] Q. H. Wang and P. Rochat, An anomaly clock detection algorithm for a robust clock ensemble, *Proc. of the 41st Annual Precise Time and Time Interval (PTTI) Meeting*, Santa Ana Pueblo, NM, pp.121-130, 2009.

[7] Y. J. Heo, J. Cho and M. B. Heo, Detection of GPS clock jump using teager energy operator, *Proc. of 2010 Conference on Precision Electromagnetic Measurements (CPEM)*, Daejeon, pp.474-475, 2010.

[8] E. Nunzi and G. Saltanocchi, Real-time detection of anomalies for atomic clock in space by means of the GLRT, *Proc. of the 24th European Frequency and Time Forum*, Noordwijk, pp.1-6, 2010.

[9] L. Galleani and P. Tavella, An algorithm for the detection of frequency jumps in space clocks, *Proc. of the 42nd Annual Precise Time and Time Interval (PTTI) Meeting*, Reston, VA, pp.503-508, 2010.

[10] L. Galleani and P. Tavella, Detection of atomic clock frequency jumps with the Kalman filter, *IEEE Trans. Ultrasonics Ferroelectrics and Frequency Control*, vol.59, no.3, pp.504-509, 2012.

[11] X. Huang, H. Gong and G. Ou, Detection of weak frequency jumps for GNSS onboard clocks, *IEEE Trans. Ultrasonics Ferroelectrics and Frequency Control*, vol.61, no.5, pp.747-755, 2014.

[12] M. Weiss, P. Shome and R. Beard, On-board GPS clock monitoring for signal integrity, *Proc. of the 42nd Annual Precise Time and Time Interval (PTTI) Meeting*, Reston, VA, pp.465-479, 2010.