DE GRUYTER Open Physics 2021; 19: 434–438

Research Article

Xin Geng, Baoqiang Du*, Jianwei Zhang, and Erlin Tian

# Frequency synchronization detection method based on adaptive frequency standard tracking

https://doi.org/10.1515/phys-2021-0044
received March 18, 2021; accepted May 20, 2021

**Abstract:** In order to achieve wide-band high-resolution frequency measurement, a frequency synchronization detection method based on adaptive frequency standard tracking is proposed based on the quantized phase processing. First, the nominal value of the measured frequency signal was obtained from the rough frequency measurement module. Then, the field programmable gate array generated the nominal value of the measured frequency. After that, the direct comparison between the tracking frequency and the measured signal was carried out. Finally, the group quantized processing module gave the final result according to the phase full-period change time. Experimental results showed that the method has a wide frequency measurement range and high accuracy and can obtain frequency stability of the order of $10^{-13}$/s.

**Keywords:** frequency measurement, phase processing, frequency standard tracking

## 1 Introduction

The research of precision frequency sources has become a research hotspot in the field of time-frequency transmission, navigation, and positioning. Its development and application have penetrated into many fields of society, such as time-service and timekeeping, deep-space detection, time synchronization, time-frequency measurement, etc. [1–10]. Frequency stability is the main performance index of precision frequency sources; the best way to evaluate frequency stability is to measure precision frequency sources with high accuracy [11,12]. There are mainly four commonly used frequency measurement methods: pulse counting method, beat method, phase comparison method, and dual mixer time difference method [13–16]. The pulse counting method is to measure the signal frequency by filling high-frequency pulses within the gate time and counting. The advantage is that a wide frequency range can be measured by changing the clock frequency of the counter, while the disadvantage is that it is affected by a count error of ±1 word and the measurement accuracy is relatively low. The beating method is to directly enhance or multiply the measured signal and the frequency standard signal, then low-noise mixing output the beating signal, and use a counter to count the beating signal without gaps in multiple cycles to realize the measurement of the frequency and its stability. Its merits are high-precision, high-resolution, and wide-band measurement (up to 18 GHz), while the drawbacks are that in addition to the ±1 word count error, the system measurement error also has errors caused by the noise of the multiplier and mixer. In the phase comparison method, the phase difference between the comparison signals is taken out by a phase comparator and converted into a digital voltage, and the frequency measurement is realized by measuring the digital voltage. It is easy to integrate, and the measurement dynamic range is large. However, the resolution is limited by the conversion rate and the bit width of the digital signal. The double-mixing time difference method uses an intermediate frequency source to mix the measured signal and the frequency standard signal with low noise to generate two difference frequency signals. After low-pass filtering and zero-crossing detection, they are sent to the time interval counter as a gate switch signal; gate time is the time difference between the two difference frequency signals [17]. The change of the time difference directly reflects the change of the relative frequency difference, from which the frequency difference and the frequency of the measured signal are measured [18–25]. In order to improve the measurement accuracy and solve the contradiction between wide frequency measurement range and high resolution, this paper proposed a frequency synchronization detection method based on adaptive frequency standard tracking based on the quantized phase

* **Corresponding author: Baoqiang Du,** Department of Communication Engineering, College of Information Science and Engineering, Hunan Normal University, Changsha 410081, China, e-mail: duprofessor@yeah.net
**Xin Geng, Jianwei Zhang, Erlin Tian:** Department of Electronic Information Engineering, School of Computer and Communication Engineering, Zhengzhou University of Light Industry, Zhengzhou 450000, China

processing of different frequency groups [26]. This method combines direct digital synthesizer (DDS) technology and field programmable gate array (FPGA) on-chip technology to achieve a wide frequency range measurement of the measured signal through frequency standard tracking [27–30]. At the same time, it uses the scientific law of the group quantized phase change between the frequency standard signal and the measured signal to effectively overcome ±1 word count error, which improves the accuracy and stability of frequency measurement.

## 2 Measurement principle and scheme

### 2.1 Principles of quantized phase processing in different frequency groups

The principle of inter-frequency group quantized phase processing is to directly compare the two frequency signals after digital processing, and directly obtain the phase difference between the two compared signals [31,32]. The result only depends on the time difference between the characteristic edges of the two comparison signals and has nothing to do with the length of the respective periods of the comparison signals.

If the measured signal and the frequency standard signal have the same nominal value and a slight relative frequency deviation, the feasibility and effectiveness of the inter-frequency phase comparison can be guaranteed, which is conducive to the phase synchronization between the two signals and the generation of group period and group quantized phase [33].

Suppose two signals with the same nominal value and frequency offset $\Delta f \neq 0$ are the frequency standard signal $f_0$ and the measured signal $f_x$. The corresponding periods are $T_0$ and $T_x$. Take the time difference between the rising edge of each full cycle of $f_0$ and the subsequent rising edge of $f_x$, that is, the phase difference, as the result of direct phase comparison $f_{\text{out}}$, i.e., $[PD_1, PD_2, PD_3, \ldots, PD_n]^T$, as shown in equation (1) and Figure 1.

$$\begin{bmatrix} PD_1 \\ PD_2 \\ PD_3 \\ \vdots \\ PD_n \end{bmatrix} = \begin{bmatrix} 1T_x - 1T_0 \\ 2T_x - 2T_0 \\ 3T_x - 3T_0 \\ \vdots \\ nT_x - nT_0 \end{bmatrix} = \begin{bmatrix} 1T_{\max c} \\ 2T_{\max c} \\ 3T_{\max c} \\ \vdots \\ nT_{\max c} \end{bmatrix} = \begin{bmatrix} 1 \\ 2 \\ 3 \\ \vdots \\ n \end{bmatrix} T_{\max c} \tag{1}$$

where $n$ is a positive integer, that is, each phase difference is quantized by $T_{\max c}$. $T_{\max c}$ is the smallest and indivisible phase difference in inter-frequency phase processing, which is called phase quantization [34–36]. At this time, all $n$ phase differences are regarded as a whole, called the phase group, and the phase difference within the group is called the group quantized phase.

From equation (1), it can be seen that the quantized phase step value of any adjacent group in the phase group is $T_{\max c}$, that is equation (2):

$$|PD_n - PD_{n-1}| = T_{\max c} \tag{2}$$

When the step value of any group quantized phase accumulation is equal to an integer number of cycles $T_0$ of the frequency standard signal $f_0$, that is equation (3):

$$nT_{\max c} = mT_0 \tag{3}$$

The group quantized phase will undergo a full-period change, return to the initial state, and move in cycles. The time for any group quantized phase to undergo a full-period change is called group period $T_{\text{gp}}$, and at the same time, equation (4) can be obtained:

$$\Delta f = \frac{1}{T_{\text{gp}}} \tag{4}$$

### 2.2 Frequency synchronization detection scheme of adaptive frequency standard tracking

The scheme is shown in Figure 2 and is mainly composed of a rough frequency measurement module, a DDS frequency standard tracking circuit module, a different frequency phase comparison module, a group quantized processing module, and a data processing result display module. The rough frequency measurement module mainly adopts the method of pulse filling and counting to obtain the nominal value of the measured frequency signal and then generates the control signal of the DDS frequency standard tracking circuit module through FPGA to output the same signal as the nominal value of the measured frequency [37]. Because the DDS frequency standard tracking circuit module uses the frequency standard signal as an external clock, the signal output by the module maintains the accuracy and stability of the frequency standard signal, and there is a slight relative frequency deviation from the actual value of the measured signal.

The output signal of the DDS frequency standard tracking circuit module and the measured signal are sent to the inter-frequency phase comparison module at the same time, and the phase difference that changes

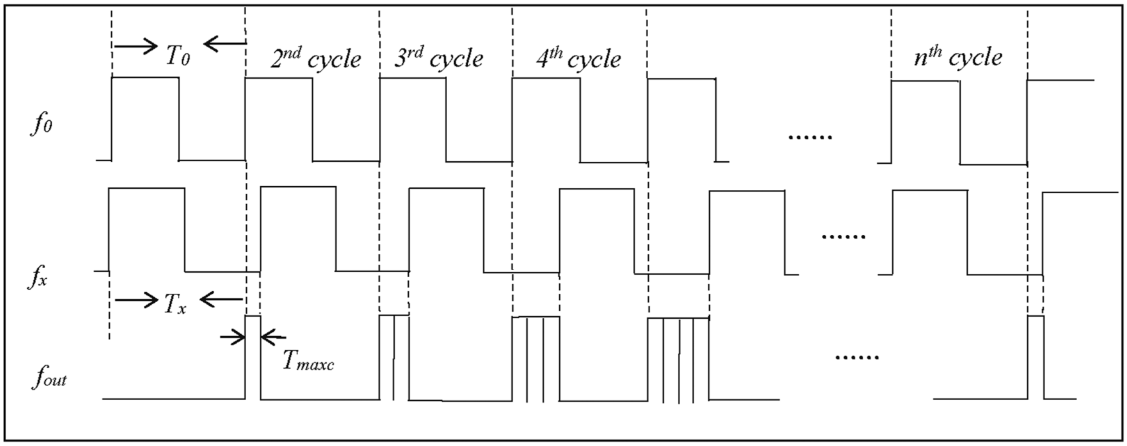


**Figure 1:** Two frequency signals with the same nominal value and slight relative frequency deviation.

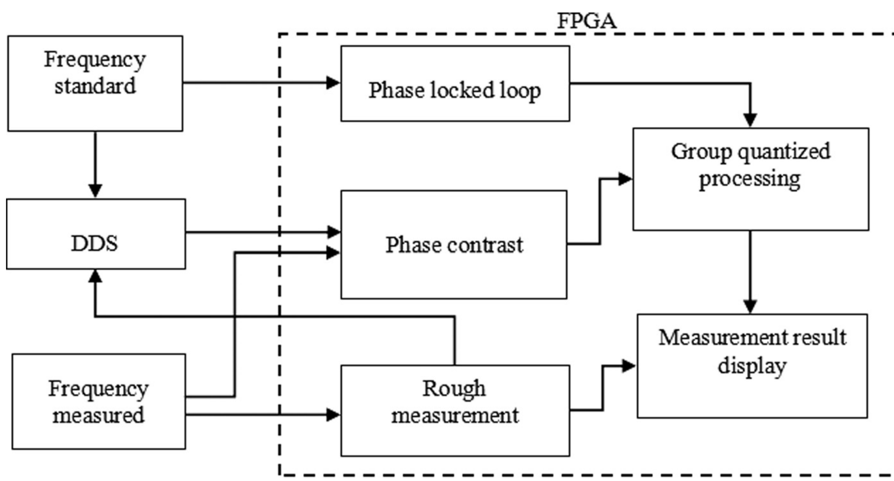


**Figure 2:** Frequency synchronization detection scheme of adaptive frequency standard tracking.

with time is obtained after direct phase discrimination and comparison [38]. The group quantized processing module measures each phase difference value in real time and saves the result. The data processing result display module determines the time interval at which two identical phase difference values occur successively, that is, the group period $T_{gp}$, the frequency offset $\Delta f$ is calculated by equation (4), and the final result is displayed in combination with the rough measurement nominal value.

## 3 Frequency measurement experiment

The experiment is shown in Figure 3. The BVA OCXO8607-B 10 MHz high-stable crystal oscillator was used as the frequency standard signal and the clock source of the DDS frequency synthesizer. The KEYSIGHT E8663D frequency synthesizer produced a series of frequency signals as the measured signal; the measurement results are shown in Table 1.

According to the data in Table 1, the frequency stability of the frequency synchronization detection scheme of adaptive frequency standard tracking in the radio frequency range can easily reach the order of $10^{-13}$/s and the highest theoretical accuracy of the double-mixing time difference method is consistent. The theoretical values of the other three commonly used frequency measurement methods are all below $10^{-12}$/s.

The measurement range of the dual mixer time difference method is generally 1–30 MHz. If the frequency measurement range is widened, a certain number of mixers must be added, which in turn introduces the superposition of additional noise, and the system frequency stability decreases. The frequency synchronization detection

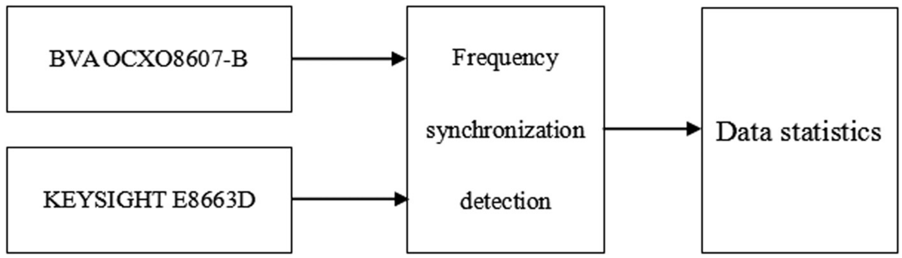


**Figure 3:** A simplified block diagram of the experiment.

**Table 1:** Experimental results of frequency measurement

| Measured signal (MHz) | Frequency standard signal (MHz) | Actual measured signal (MHz) | Frequency stability $\sigma$ (s) |
|---|---|---|---|
| 47.0000100 | 10 | 47.00000971 | $8.74403 \times 10^{-13}$ |
| 44.0000100 | 10 | 44.00000894 | $8.62075 \times 10^{-13}$ |
| 38.0000100 | 10 | 38.00000868 | $7.85734 \times 10^{-13}$ |
| 33.0000100 | 10 | 33.00000981 | $7.56542 \times 10^{-13}$ |
| 26.0000100 | 10 | 26.00000874 | $7.38754 \times 10^{-13}$ |
| 22.0000100 | 10 | 22.00000861 | $6.15675 \times 10^{-13}$ |
| 18.0000100 | 10 | 18.00000953 | $5.06854 \times 10^{-13}$ |
| 11.0000100 | 10 | 11.00000883 | $3.46806 \times 10^{-13}$ |
| 8.0000010 | 10 | 8.00000087 | $2.94948 \times 10^{-13}$ |
| 5.0000010 | 10 | 5.00000084 | $2.73543 \times 10^{-13}$ |
| 1.0000010 | 10 | 1.00000090 | $2.35785 \times 10^{-13}$ |

method of adaptive frequency standard tracking can realize frequency measurement in a wide range and high precision without reducing the stability and accuracy.

## 4 Conclusion

Based on the research on the principle of quantized phase processing of different frequency groups, a frequency synchronization detection method of adaptive frequency standard tracking is proposed. The paper mainly has following three innovation points: (1) based on the adaptive frequency standard tracking technology, the frequency measurement range is greatly expanded. This scheme can realize the direct measurement, comparison, and processing of the phase of any frequency signal in the radio frequency range. (2) On the basis of the characteristic law of the full-period change of the group quantized phase, the small frequency deviation of the tracking frequency signal is calculated, which effectively overcomes the ±1 word count error. This method can obtain frequency stability of the order of $10^{-13}$/s. (3) Compared with the four commonly used measurement methods, it has simple structure, low cost, low additional noise, and high measurement resolution.

**Acknowledgment:** This work was supported by National Natural Science Foundation of China (No. U1304618) and Scientific and Technological Project of Henan Province (No. 202102210145) and Hunan Province Natural Science Foundation (No. S2021JJMSXMO268).

**Conflict of interest:** Authors state no conflict of interest.

**Data availability statement:** The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

## References

[1] Geng X, Li S, Huang G, Du B, Chen J. Different frequency synchronization theory and its frequency measurement practice teaching innovation based on Lissajous figure method. J Beijing Inst Technol. 2018;27(2):198–205.
[2] Baoqiang D, Dongyao Z, Dazheng F, Xin G, Guangyong X, Zhigang Y. Precise frequency linking method based on phase group synchronization. Measurememt. 2015;62(2):222–9.
[3] Sheikholeslami M, Jalili P, Ganji DD. Magnetic field effect on nanofluid flow between two circular cylinders using AGM. Alex Eng J. 2018;57(2):587–94.

[4] Sheikholeslami M, Nimafar M, Ganji DD. Nanofluid heat transfer between two pipes considering Brownian motion using AGM. Alex Eng J. 2017;56(2):277–83.
[5] Ganji DD, Jannatabadi M, Mohseni E. Application of He's variational iteration method to nonlinear Jaulent-Miodek equations and comparing it with ADM. J Comput Appl Math. 2007;207(1):35–45.
[6] Peiravi M. Evaluation of the heat transfer rate increases in retention pools nuclear waste. Int J Nano Dimens. 2015;6(4):385–9.
[7] Peiravi M. Numerical study of fins arrangement and nanofluids effects on three-dimensional natural convection in the cubical enclosure. Trans Phenom Nano Micro Scales. 2019;7(2):97–112.
[8] Peiravi MM, Alinejad J. Hybrid conduction, convection and radiation heat transfer simulation in a channel with rectangular cylinder. J Therm Anal Calorim. 2020;140(6):2733–47.
[9] Peiravi MM, Alinejad J. Numerical analysis of secondary droplets characteristics due to drop impacting on 3D cylinders considering dynamic contact angle. Meccanica. 2020;55:101975–2002.
[10] Peiravi MM, Alinejad J, Ganji DD, Maddah S. 3D optimization of baffle arrangement in a multi-phase nanofluid natural convection based on numerical simulation. Int J Numer Methods Heat Fluid Flow. 2019;30:2583–605 (ahead-of-print).
[11] Du B, Feng D, Tang Y, Geng X, Zhang D, Cai C, et al. High-resolution group quantization phase processing method in radio frequency measurement range. Sci Rep. 2016;6(29285):1–14.
[12] Du BQ, Li SL, Huang GM, Geng X. High-precision frequency measurement system based on different frequency quantization phase comparison. Measurement. 2018;122:220–3.
[13] Georgakopoulos D, Quigg S. Precision measurement system for the calibration of phasor measurement units. IEEE Trans Instrum Meas. 2017;66(6):1441–5.
[14] Wang H, Zeng HY, Wang P. Linear estimation of clock frequency offset for time synchronization based on overhearing in wireless sensor networks. IEEE Commun Lett. 2016;20(2):288–91.
[15] Guo Y, Liu G, Lu IT, Ge J, Ding H:. A new time and frequency synchronization scheme for OFDM-based cooperative systems. IEEE Long Island Systems, Applications and Technology Conference. Farmingdale; 2014. p. 1–5.
[16] Xu K, Xu Y, Ma W, Xie W, Zhang D. Time and frequency synchronization for multicarrier transmission on hexagonal time-frequency lattice. IEEE Trans Signal Process. 2013;61(24):6204–19.
[17] Zuo C, Chen Q, Gu G, Feng S, Feng F, Li R, Shen G. High-speed three-dimensional shape measurement for dynamic scenes using bi-frequency tripolar pulse-width-modulation fringe projection. Opt Lasers Eng. 2013;51(8):953–60.
[18] Lukin KA, Vyplavin PL, Palamarchuk VP, Kudriashov VV, Kulpa K, Gajo ZK, et al. Phase measurement accuracy in noise waveform synthetic aperture radar. IEEE Trans Aerosp Electron Syst. 2015;51(4):3364–73.
[19] Bruno JS, Almenar V, Valls J, Corral JL. Low-complexity time synchronization algorithm for optical OFDM PON system using directly modulated DFB laser. IEEE Opt Commun Netw. 2015;7(11):1025–33.
[20] Wang WQ. Carrier frequency synchronization in distributed wireless sensor networks. IEEE Syst J. 2015;9(3):703–13.
[21] He Z, He F, Chen J, Huang H, Liang D. Phase synchronization processing method for alternating bistatic mode in distributed SAR. J Syst Eng Electron. 2013;24(3):410–6.
[22] Klepacki K, Szplet R, Pelka R. A 7.5ps single-shot precision integrated time counter with segmented delay line. Rev Sci Instrum. 2014;85(3):0347031–9.
[23] Yang JR. Measurement of amplitude and phase differences between two RF signals by using signal power detection. IEEE Microw Wirel Compon Lett. 2014;24(3):206–8.
[24] Perez MS, Carrera E. Time synchronization in Arduino-based wireless sensor networks. IEEE Lat Am Trans. 2015;23(2):455–61.
[25] Wang H, Zeng HY. Linear estimation of clock frequency offset for time synchronization based on overhearing in wireless sensor networks. IEEE Commun Lett. 2016;20(2):288–91.
[26] Kordestani H, Zhang C. Direct use of the savitzky-golay filter to develop an output-only trend line-based damage detection method. Sensors (Basel, Switzerland). 2020;20(7):1983.
[27] Zhu JX, Wu P, Chen MC, Kim MJ, Wang XY, Fang TC. Automatically processing IFC clipping representation for BIM and GIS integration at the process level. Appl Sci. 2020;10(6):2009.
[28] Pandian B, Sireesha P, Ng Y, Raj S, Law C, Patrick CEM. Assessing the knowledge of private university students on self-medication practices. Malays Matrix Sci Pharma (MSP). 2019;3(2):27–31.
[29] Zhang Y, Sun L. Study on the difference of weight reduction effect between high-intensity interval training and persistent aerobic exercise for female college students. Matrix Sci Pharma (MSP). 2019;3(2):38–40.
[30] Qin R. Study on the effect of music therapy on psychological intervention of patients after operation. Matrix Sci Pharma (MSP). 2019;3(2):41–3.
[31] Pang L. The diagnostic efficacy of urinary vascular endothelial growth factor in early stage 2 diabetic nephropathy. Matrix Sci Pharma (MSP). 2019;3(3):19–22.
[32] Zhang X. Effects of yoga exercise on body shape and cardiovascular function of female college students. Matrix Sci Pharma (MSP). 2019;3(3):1–4.
[33] Gao N, Lu K. An underwater metamaterial for broadband acoustic absorption at low frequency. Appl Acoust. 2020;169:107500.
[34] Li L, Qi M. Medical image segmentation method based on the improved artificial bee colony algorithm. Matrix Sci Pharma (MSP). 2019;3(3):5–8.
[35] Dong K, Xue X. Study on the effect of single exercise intervention on students with impaired glucose tolerance. Matrix Sci Pharma (MSP). 2019;3(3):16–8.
[36] Wang F, Li S. Research on the influence mechanism of winter swimming exercise on the cardiovascular system in the middle-aged and elderly. Matrix Sci Pharma (MSP). 2019;3(3):12–5.
[37] Li J, Ning Y, Yuan Z, Yang C. Research on medical image segmentation based on fuzzy clustering algorithm. Matrix Sci Pharma (MSP). 2019;3(3):9–11.
[38] Zhou Y, Dong Z, Deng Y, Meng Q. The study of differentially expressed serum protein in patients with different traditional Chinese medicine syndromes of knee osteoarthritis. Matrix Sci Pharma (MSP). 2019;3(3):23–5.