A Method of High Resolution Digital Linear Phase Comparison

Zhe Tan [1], Zhiqi Li [1], Xiangyang Wei[1], Ruilin Zhang[1], Min Fan [1], Wei Zhou [1]
[1]School of Mechano-Electronic Engineering, Xidian University,
Xi'an, China
zhiqili_9@126.com

***Summary*—High resolution measurement of frequency and frequency stability is crucial to the development of many modern technologies such as frequency sources, timing and punctuality. According to the law of phase difference change between periodic signals, a digital linear phase comparison method is presented. By using digital technology, measurement dead zone can be avoided. The phase value of sine signal linear area is selected by controlling the phase discrimination area to estimate the frequency stability, which improves the resolution and accuracy of sampling phase information of analog-to-digital converter. The sampling efficiency is improved by using the method of frequency doubling or frequency dividing of the reference signal. By controlling the sampling time interval with the method of counting the reference clock, the frequency stability of the measured signal can be measured from transient to long-term, realizing the frequency stability measurement in the whole frequency domain. In the digital linear phase comparison system, a 14-bit high-speed analogue-to-digital converter is used as the phase detection device. Experiment results show that the background noise of the system of the prototype at the nominal frequency of 10MHz is 2.12×10−5/100ns,1.93×10−12/s,2.41×10−16/10000s.**

Keywords—Frequency Standard Comparison, Phase Detection, Digitizing, Linear Zone, Frequency Stability

I. INTRODUCTION

High resolution frequency standard comparison method is widely used in communication network synchronization, time and frequency standard, geodetic survey, precision navigation and other fields [1][2]. With the development of high precision frequency source, high precision frequency standard comparison method and frequency measurement device need to be improved constantly. At present, the main frequency standard comparison technologies include pulse average phase comparison method and dual mixer time difference method [3].

Microsemi 's 3120A and other time-frequency measurement products use digital double mixer time difference method, the second-order frequency stability can reach 10^{-14}. However, the dual mixer time difference method requires the devices with high symmetry and high parameters to offset system errors. The complexity of the system is high and more noise is introduced. In addition, the minimum average time of frequency stability measured by 3120A is in millisecond level, which the ultra-short-term frequency stability measurement cannot be realized.

Here we show a digital linear phase comparison method. The phase information of the linear region of the measured signal is sampled by a high-speed ADC (analog-to-digital converter) to achieve high-resolution phase comparison. This method avoids dead zone and non-linear phenomenon by digitization, and the resolution is improved by collecting data in linear region [4]. The average time of the system can be from the period of the measured signal to thousands of seconds or even higher, and can obtain a wide average time range of phase information to achieve full frequency domain frequency stability measurement. In addition, it has the advantages of wide range of applications, simple hardware structure, low drift, flexible and high resolution. It is of great significance to the measurement, comparison and control of frequency standard.

II. METHODS/RESULTS

The sinusoidal signal has good linearity in the ±5% region near 0 degrees, that is, the linear region is [-18°,18°]. When the ADC samples sinusoidal signals, only the sampling points in the linear region are selected to obtain the highest resolution.

The principle of digital linear phase sampling between two signals with the same nominal frequency is shown in Figure 1, where f_x is the measured signal, f_0 is the reference signal, ΔT is the phase difference, ΔT_L is the phase difference in the linear region, $T_{min\ c}$ is the phase coincidence period [5].

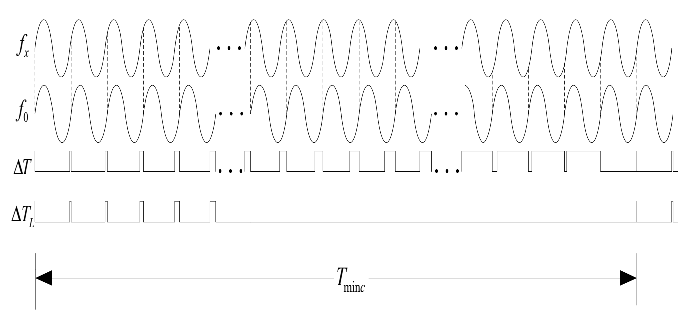

Fig.1.Digital phase sampling of signals with the same nominal frequency value

It can be seen from Fig.1 that the change between adjacent phase differences is a fixed value, that is, the quantized phase shift resolution [6]. When the sampling point enters about 90 degrees, it will enter the fuzzy area. Only in the next phase

Supported by National Natural Science Foundation of China [Supported by NSFC: 11873039], Supported by the Industry-University-Research Project of ZTE.

coincidence period does the comparison re-enter the linear region. This may increase the time to collect the phase difference in the linear region.

In order to improve the sampling efficiency to achieve continuous sampling in the linear region, this paper proposes to use the comparison of two periodic signals with multiple multiples of frequency to control the phase discrimination region.

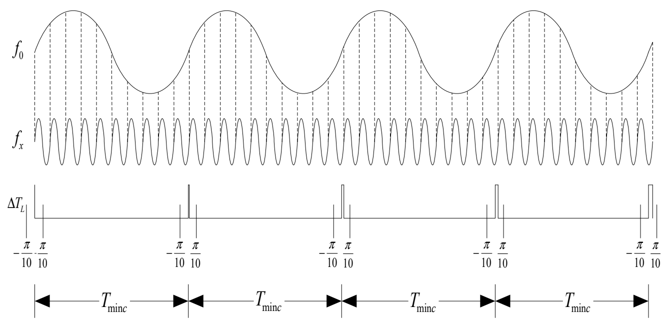

Fig.2.The principle of digital linear phase sampling

The principle of digital linear phase sampling is shown in Fig.2. When the clock frequency reaches ten times or more of the measured frequency, once the clock signal moves out of the linear region with the phase change between the two signals, the adjacent clock signal will enter the linear region. This relationship between the reference and the measured multiple and the range of the linear region ensures that at least one sampling point must be in the linear region in a cycle.

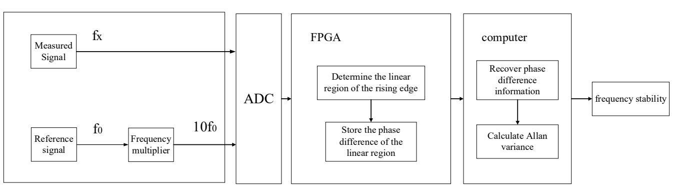

Fig.3.The structure diagram of the digital linear phase comparison system

The above diagram is the structure diagram of the digital linear phase comparison system. The system includes frequency doubling circuit module, ADC module, FPGA module for controlling acquisition and storage, and computer data processing module. The noise introduced by the frequency doubling circuit should be small enough. The RF signal generator SMB100A is selected to fulfil the frequency doubling function. The AD9255 produced by ANALOG DEVICES (ADI) is used as the phase detector. The ADC uses a differential pipelined core combined with error correction logic to provide 14-bit resolution and 125M maximum sampling rate. It has a wide range of analog differential input, and has a signal-to-noise ratio performance better than 70dBFS at 300MHz analog input. The control, storage and transmission algorithms are realized by field programmable gate array (FPGA). The storage capacity of FPGA should be large enough.

In the self-calibration experiment, the ultra-stable OCXO 8607 produced by OSA, Switzerland, is selected to generate two 10MHz signals, one as the signal under test, the other as the external reference of SMB100A, and the frequency doubling generates a 100MHz signal as the clock signal of ADC and FPGA. FPGA controls ADC sampling and transmits the sampled data to the host computer through the serial port. Then the data is processed by the upper computer, and the frequency stability of 8607 self-calibration experiment is obtained. The results of the self-calibration experiments are shown in Fig.4, transient frequency stability can reach 2.12×10^{-5}/100ns, short-term frequency stability can reach 1.93×10^{-12}/1s, and long-term frequency stability can reach 2.41×10^{-16}/10000s.

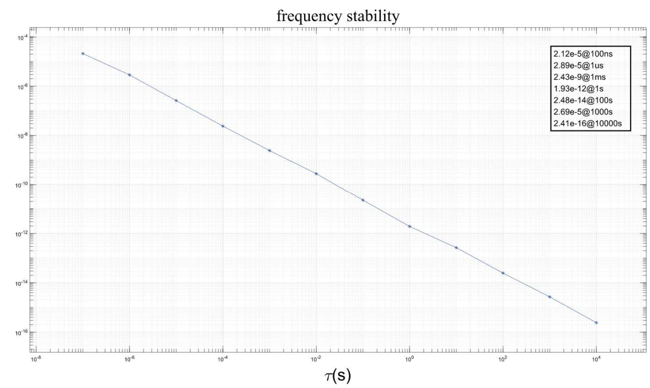

Fig.4. The result of the self-calibration experiment

III. DISCUSSION/INTERPRETATION

The experimental results of the digital linear phase comparison system show that the digital linear phase comparison method can use a 14-bit ADC as the phase discriminator, and realize the phase comparison with high resolution and wide average time range by collecting the linear phase region and doubling the reference frequency. It can meet the frequency stability measurement requirements of many applications at a small cost. Due to the introduction of noise, ADC error and circuit design deficiencies in frequency doubling, this method still has many possibilities to further improve the resolution, which provides a new idea in the field of time-frequency measurement and control.

IV. CONCLUSIONS

This paper discusses the high resolution digital linear phase comparison method. According to the change rule of phase difference between periodic signals, the phase information is directly processed to ensure high resolution. It is suitable for phase comparison with a wide average time range. In particular, it can be used to measure ultra-short-term frequency stability. This method can be applied to new digital direct phase locked loop with different frequencies. In addition, this method is simple in structure and more suitable for portable devices. In the following work, the background noise of the system will be reduced from the aspects of circuit design and ADC error processing, so as to further improve the measurement resolution. The digital linear phase comparison method provides a new idea for the field of time-frequency measurement and control.

REFERENCES

[1] Elizabeth Gibney, Hyper-precise atomic clocks face off to redefine time, Nature News, 522 pp.16-17, 2015.

[2] C. Peter, Bouhnik Dan, G. Ramesh, Marcelo David. Low Noise Chip Scale Atomic Clock (LNCSAC), IEEE International,2014, pp1-4.

[3] Yue Z, Yuzhuo W, Aimin Z, Kun D and Weibo W, Research on System of New Frequency Measurement Based on Muli-channel Dual Mixer Time Difference Measurement Instrument, Acta Metrologica Sinica. 39 pp. 568-571, 2018, DOI: 103969/j.issn.1000-1158.2018.04.25.

[4] Wei Z, A Method of High Linear Phase Discremination for High Frequency-The Phase Discremination Controlled by Dividing Frequency into Single Channel, Acta Metrologica Sinica. 2 pp. 75-79, 1981.

[5] Qinma K, Haining Jiang, Wei Z, Design of Virtual Frequency Meter Based on “Phase Coincidence” Detection Technique, Journal of Electronic Measurement and Instrument, 19(2) pp. 45-48, 2005, DOI:10.13382/j. jemi.2005.02.007.

[6] Zhiqi L, Wei Z, Wei Z, Huimin S and Weihao L, Equivalent comparison and analysis between different nominal frequencies, Chin. Phys. B 23 110602, 2014.