An Ultra-high Resolution Phase Difference Measurement meter

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***Abstract*—Conventional linear phase comparison meters are used widely in the measurement of the frequency and stability. It can also be used in the measurement of length or distance in the navigation and orientation.**

Phase comparison methods not only reduce the cost of system, but also enhance precision, which can reach the measurement resolution of $10^{-13}/\tau$ in time domain. By the research on the major factors of precision effect of in the measurement of the length with phase comparison method, such as the linearity and trigger error, a solution to the improvement of the high precision is proposed in this paper. The avoidance of the dead region and the improvement of the linearity can be realized in small scope by sampling and phasing the geminated signals, controlling the region of the discriminator and phase displacing of the fixed region. In order to improve precision, this measuring technique must reduce trigger error as much as possible. The trigger error can be decreased by small signal reshaping, frequency transformation and wave filtering. In addition, the temperature shift of the whole circuit can be improved by the supply power of the low noise, the low shift & the high stability, the simple self-adjustment technique for the shift and the filtering treatment. Besides, by the choices of circuit components and the improvement of circuit design, output saturation voltage shift can be conquered and higher precision can be obtained. In this paper, the measurement precision of length or distance can be reached 0.1ps·C.

The change on the delay in the method of the linear can reflect the subtle change on the object distance. By collecting the data of the stimulated time of the phase change, the data can be transferred into the measurement of the distance or the length so as to realize the measurement of the subtle change on the distance.

I. INTRODUCTION

Linear phase comparison method now is mainly used in the high-resolution long-term stability measurement of the frequency and frequency standard. This method can also be applied to the short-term stability measurement combining with high-speed voltage measurement.

The phase relation of the two frequencies could be converted by phase comparator into voltage signal which has linear relation to the phase. Then the converted voltage can be sampled and measured in high-resolution way. According to the relation between time and space, the corresponding space quantum value such as length or distance could be obtained.

When devising this meter, many factors which may affect the precision ought to be considered in detail. Based on the phase comparison method the space quantum measurement requires a fairly high linearity. The temperature shift and the self-adjustment technique are the key to design [1]. In order to increase precision, it is important to decrease the trigger error, output saturation voltage shift and so on.

II. THE MEASUREMENT OF LENGTH ON THE BASIS OF LINEAR PHASE COMPARISON

The two determinate signals have stable and regular phase relation. The phase relation of the two signals represents not only the frequency relationship but also the stability of the two signal sources [2]. The relation between phase and time is as follows:

$$t = \frac{\Phi}{2\pi f_0}$$

In vacuum where velocity of light is 3×10^8m/s the transfer delay is 0.3mm per ps. The measurement of the length can be converted into sampling and measuring the phase change. A subtle change of length or distance can be reflected by processing the phase relation.

$$L = (nT_0 + t)\times C$$

Here, L is length or distance, n is full periodicity, t is phase change, T0 is the frequency standard period, and C is light speed. According to the above discussion the space quantum could be measured in space by the phase relation. Thus, the measurement of length or distance can be converted into phase relation measurement by processing of phase-voltage.

Some factors which affect ultra-high precision measurement must be taken into account when phase comparison technique is used. Electronic circuitry has some delay of the input signal. It is inevitable to have dead region and nonlinearity owing to s limited speed of the phase

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discriminator. Those phenomena will affect the precision and normal work of the meter, even result in big measurement error, especially when there is a very minute phase difference between the two compared phase signals.

In order to avoid dead region and improvement of the linearity phase-shifting is used, which means to replace the nonlinear segments by linear ones. This meter makes use of good linearity of the switch phase discriminator to finish linear phase comparison by controlling the region of the phase discriminator and phase displacing of the fixed region. The two stable frequency signals with one of them being divided are magnified, shaped to trigger the phase discriminator switch.

In the length measurement it is favorable to begin linear phase comparison from 0 degree. Thus in this case, self-correction technique should be adopted to detect the two 0 phase point which is coincident phase point of the two signals. The technique of the phase coincidence detection is used to make phase comparison from 0 degree to 360 degrees.

In the ultra-high precision measurement, the effect of trigger error should not be neglected. Trigger error can partly be decreased by pulse average method. Simultaneously it can be reduced by small signal reshaping, frequency transformation, wave filtering, and the optimal design of the circuit. The ECL circuit is selected to improve the gradient of the signal [3]. Output saturation voltage shift should also be considered. The dc static work point should be stable. In order to decrease the current Leakage of the conversion part, threshold voltages should be properly reduced, for low beyond the certain threshold may lead to a failure of the transistor switch [4].

The scheme avoids regions adjacent to 0 or 360 degrees, where dead region and nonlinearity appeared. Base on the result we got from the experiment at earlier stage, the precision about 3×10^{-13}/s can be obtained [5]. The source noise must be taken into account, if linear phase comparison method is used to measure the frequencies and frequency stability. But based on the time-space relationship, the space quantum measurement which is different from frequency stability measurement requires phase difference measurement to embody corresponding length relation. Integration time has corresponding relations with the length variety. In this circumstances compared oscillator noise should be filtered out.

Relatively long integration time is of advantage to filter out oscillator noise. So stability index can approach to 10^{-14}/s in the experiment. It doesn't need to ensure short-term stability in the measurement if the phase comparison method is contacted with space quantum measuring, and integration time is completely relaxed. It is a fact that the longer integration time is the more advantages it has. The frequency source noise can be filtered out with the increase of integration time. Ultra-high precision measurement of length can be realized by linear phase comparison methods and high-precision conversion technique. Simultaneously, self-correction, hardware and software compensation and so on, are adopted. Phase compared is commencing with zero degree, improvement of the linearity is avoided by the controlling phase discriminated region, so measurement precision can be enhanced at least one degree. An ultra-high resolution and high precision can be attained by this meter with simple structure, especially in space quantum measurement.

III. TESTING RESULTS

A phase difference measurement meter is designed to improve its noise influence by experiments time after time and its working theory is shown in figure1.

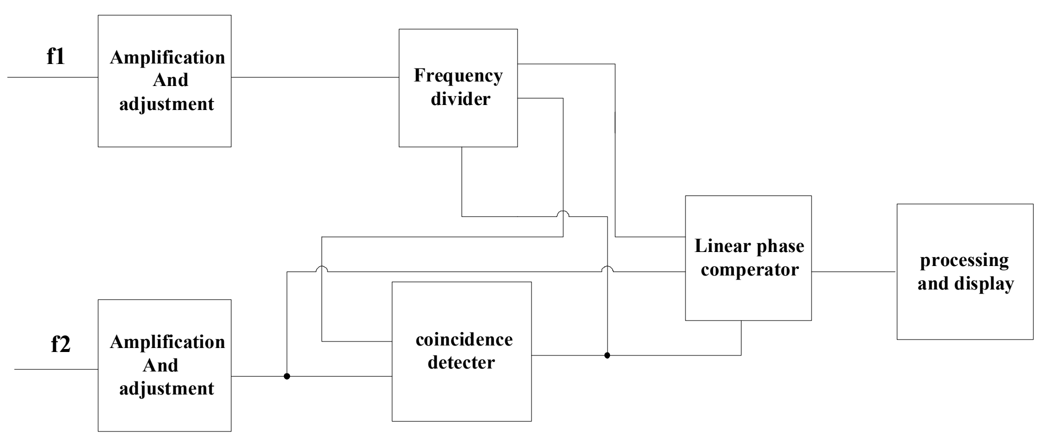

Figure 1 A high-linearity space quantum by phase comparator

This phase difference measurement meter whose integration time is changeable is used to measure the output signals. When the integration time of the meter is decided, the noise of oscillator can be improved more or less accordingly. The integration time of the meter can range from 1ms to 1s, so the measurement results from two crystal oscillators are shown in table1.

TABLE I. THE MEASUREMENT RESULTS FROMTWO STABLE CRYSTAL OSCILLATORS WITHDIFFERENTINTEGRATION TIMES

oscillator	Oscillator1 2.3~3.1$\times10^{-12}$/s	Oscillator2 3.1~3.8$\times10^{-13}$/s
integral time	length	
1s	1.3ps	0.097~0.12ps
100 ms	2.0ps	0.10~1.5ps
20 ms	2.4ps	0.16ps
1 ms	4.4ps	0.41ps

In most cases like frequency scale self-calibration measurement length measurement is carried out within the same source. One of the signals is delay signal which is correlative with length. So the measurement resolution may be higher.

Different frequency sources have different noise characteristics. In the space quantum measurement the noise influence of signals measured may be improved by suitable long integration time. Longer integration time can filter out the noise of frequency sources; accordingly, its precision can be enhanced in the space quantum measurement.

IV. CONCLUTION

Space quantum such as length or distance can be measured by the phase comparison method. Sometimes after frequency is transformed length variety is analyzed by linear comparison. In the device of this meter it is important to do some research on factors such as nonlinearity, trigger error, output saturation voltage shift, high precision sampling and conversion and so on. The measurement precision can be improved by making full use of the two frequencies' characteristic available. The measurement precision of the space quantum can reach 0.1ps.C(C is light speed) at least.

REFERENCES

[1] Byungjin Chun and Seung Hee Choi ,"A Digital Phase_locked Loop with Variable Loop Gains Derived from RLS Method, "1997-8 IEEE pp11~15

[2] Wei Zhou, et al., A Novel Frequency Measurement Method Suitable for a Large Frequency Ratio Condition, Chinese Physics Letters, May, 2004, Vol. 21, No. 5, pp. 786 – 788

[3] E.Raisanen-Ruotsalainen, T. Rahkonen and J. Kostamovaara, "A low-power CMOS time-to-digital converter," IEEE J. Solid-State Circuit, vol. 30, pp 984-990, Sept, 1993

[4] T. Rahkonen and J. Kostamovaara, "The use of stabilized CMOS delay lines for the digitization of short time intervals," IEEE J. Solid-State Circuit, vol. 28, pp 887-894, 1993

[5] Wei Zhou, et al, "A Precision Frequency Standard Comparison Comparison Method and Instrument", Proceedings of 2000 IEEE International Frequency Control Symposium, pp. 557 – 560, 2000