A New Technique for Ultrahigh Resolution Comparison between Frequency Standards

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1.Introduction

With the development of aerospace, precise positioning, communication, measurement, astronomy and other high-techs, the requirement for precision of frequency standards is becoming higher and higher, which demands techniques for high precision frequency measurement.

It is quite costly for the conventional techniques to realize high precision measurement, especially ultrahigh resolution comparison, and it is often complex in structure and big in size. To make some changes, this paper presents a novel comparison principle between frequency standards based on group phase correlation, which can meet the high precision requirement for frequency measurement with simple structure and low cost.

2.The principle of frequency measurement system with ultrahigh resolution

Now that the phase difference changes between any two periodical signals have obvious patterns [1], they can be related with each other by some new concepts, such as least common multiple period, equivalent phase comparison frequency, quantized phase variation resolution and so on. According to these concepts, the technique for frequency measurement will be simplified greatly.

In the case of two frequency signals: $f_0=Af_{maxc}$ and $f_x=Bf_{maxc}$, where f_{maxc} is their greatest common factor frequency, A and B are two positive integers prime with each other. When their phases coincide equivalently, the time interval of the two phase coincidences is called the least common multiple period, which is short for T_{minc}, and $T_{minc}=1/f_{maxc}$. From [1],$f_{equ}=ABf_{maxc}$, $\triangle T=1/f_{equ}$. In the equation above: f_{equ} is called equivalent phase comparison frequency, $\triangle T$ is called quantized phase variation resolution.

In this measurement system, integer multiples of the Tminc is taken as count gate to

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make this gate synchronous with f_0 and f_x, so ±1 count error can be eliminated [2], and then the measurement precision is improved greatly. In real measurement, when the frequency differences between f_r and f_x is too small, or the f_r and f_x are directly proportional to each other, theoretically, there is only one phase coincidence in every T_{minc}. But because the quantized phase variation resolution of f_0 and f_x is very small, generally several tens of femtosecond, no device available can detect so small a time interval, so no matter what method one uses, the phase coincidences detected are not one but a tuft[3].

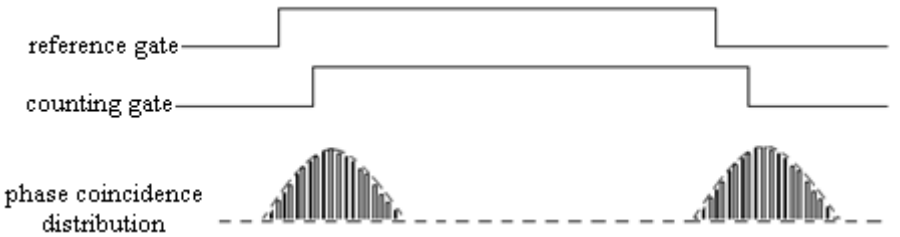

Fig.1 phase coincidence distribution and count gate generated

As shown in Fig.1, there are thousands of other phase coincidences around the absolute phase coincidence, which distribute in so wide a range that it is very difficult to detect the best phase coincidence, thus the uncertainty of count gate would cause measurement errors. In view of this situation, in order to achieve high resolution comparison, one can use a DDS to synthesize a suitable intermediary frequency f_0, with f_r as reference frequency, to make sure that the correlation between f_0 and f_x is simple, which can meet the requirements of high resolution frequency comparison.

3.The realization of the frequency standards comparison system

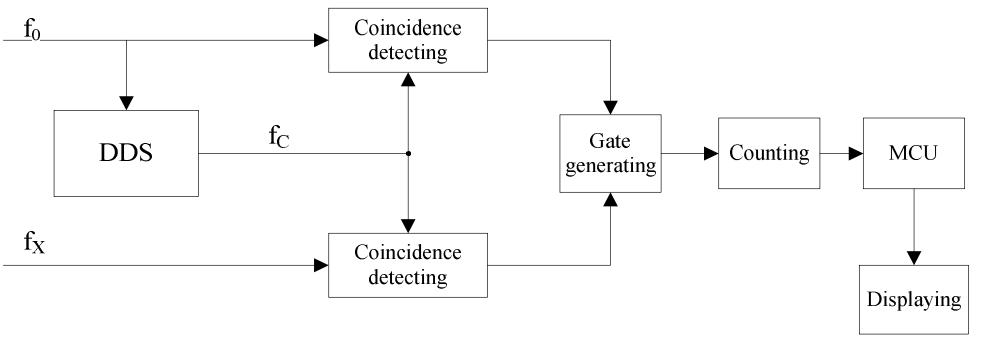

Fig. 2 the block diagram of frequency comparison system

As shown in Fig.2, f_x and f_0 are the measured and reference frequency signals respectively. f_c is the frequency signal derived from f_0 by DDS(Direct Digital Synthesizer). The phase coincidence between f_x and f_c , f_0 and f_c, are used as the start and stop signals of the count gate respectively. During the time interval represented by the gate, f_c , which is the intermediary frequency, is counted, and supposed that the counted number is Nc . Because f_c is synchronous with the start and stop signals of count gate seriously, ±1 count error wouldn't exist in Nc. The length of gate signal generated by two groups of phase coincidences includes the phase difference information between f_x and f_0, which is reflected by Nc. From reference [1], the phase difference between f_x and f_0 can be expressed by equation (1).

$$P = N_C * \Delta T \tag{1}$$

△T is the quantized phase variation resolution between the standard frequency signal f_0 and f_c. The measurement results will be calculated by MCU, and displayed with LCD. In this system, one should select suitable frequency difference between f_x and f_c , f_0 and f_c , and reduce the phase noise of the DDS frequency synthesizer to ensure its high frequency resolution and stability. At the same time, the design of the phase coincidence detecting circuit is also very important.

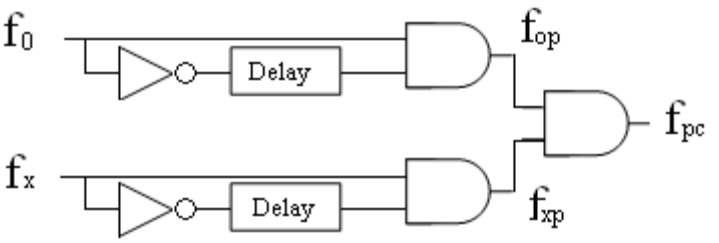

Fig. 3 principle of phase coincidence detecting circuit

The scheme shown in Fig.3 is a simple phase coincidence detecting circuit with high efficiency, where f_{op} and f_{xp} are the narrow pulses generated by f_0 and f_x respectively, their width is just the time delay of the delay unit in Fig.3.Only when the electric level of the f_{pc} is higher than the trigger level of logic device, the counter works. For present FPGA and CPLD, the time delay of delay unit in chip is as large as several hundreds ps[4], it can not meet the requirement of high resolution detecting. So an external adjustable delay unit is added for the fine adjustment of the time delay besides the internal ones.

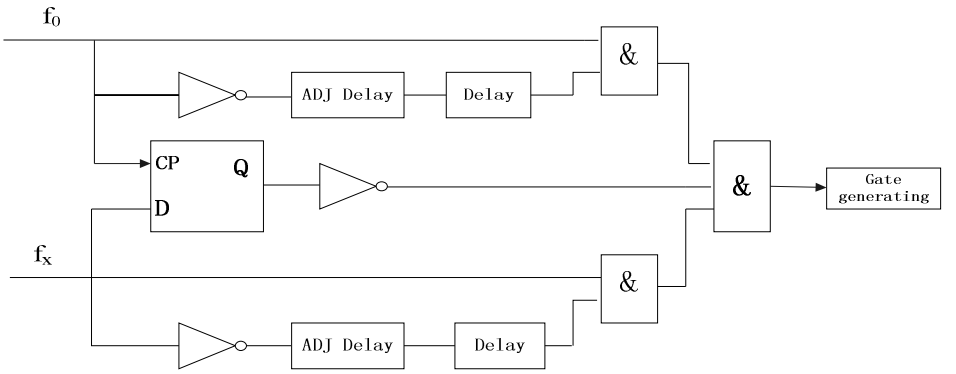

Fig.4 the block diagram of phase coincidence detection

As shown in Fig.4, because group phase coincidences are of symmetrical distribution, an edge-triggered D flip-flop is added as last phase coincidence control circuit in this phase coincidence circuits of the system. So the number of efficient pulse is reduced by half on the basis of the original ones, and the trigger uncertainty of count gate is lowed. One can achieve the optimal phase coincidence in this efficient way.

4. Experiment results of the prototype

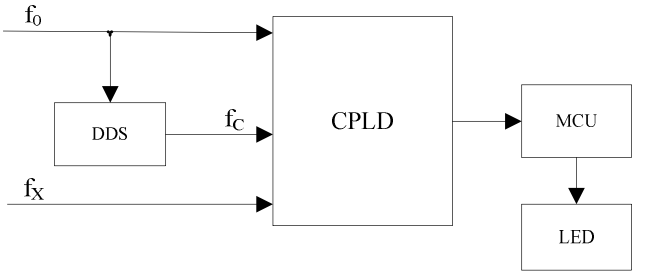

Fig 5 the implementation scheme of frequency stands comparison

Fig.5 shows the implementation scheme of frequency standards comparison. Some digital circuits are realized in CPLD, such as phase coincidence detecting, the gate generating and counters. One 10MHz frequency signal from cesium atomic frequency standard OSA5585B is compared with another 10MHz signal from rubidium atomic frequency standard X72, and the frequency f_c generated by DDS is 10000010Hz, so □T=0.1ps.

Tab1 Experiment results of frequency standards comparison

f_0	f_x	frequency stability σ(/s)
OSA5585B	X72	$1.2*10^{-11}$
OSA5585B	1250OCXO	$4.3*10^{-12}$

As showed in Tab 1, the measurement resolution can be 10^{-12}/s.And then the comparison precision calculated can be 10^{-12}/s.In a long time, the comparison precision can be 10^{-15}.

5. conclusion

The novel frequency standards comparison system, based on the phase variation principle between any two different periodical signals, is presented in this paper. Using intermediary frequency generated by DDS and high resolution phase coincidence detecting circuits, the measurement precision achieves 10^{-12}/s. If higher speed devices are used and the noise of circuit is reduced further, the measurement precision can be better.

6. references

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