A short time signal generating method based on time comb principle

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***Abstract*—The status of phase differences in the least common multiple period between two signals with various frequencies has obvious regularity. As phase differences are arrayed in accordance with the order from small to large, differences of adjacent phase differences are fixed to the quantified phase shift resolution (QPSR) which can be calculated by frequencies of two signals. When frequencies of two signals are $f_A = Af_{\max c}$ and $f_B = Bf_{\max c}$, respectively, where two positive integers A and B are prime with each other and $f_{\max c}$ is the greatest common factor frequency between f_A and f_B. QPSR of them is determined by $f_{\max c}/(f_A \cdot f_B)$. In the specific frequency relation, phase differences of two signals increase or decrease gradually with QPSR as stepping value. These phase differences with regular time widths form a time comb which's total time length is a least common multiple period of two signals. In this time comb there are various pulses which have different pulse widths from zero to a period of the lower frequency signal. Therefore time comb can be used to generate pulse signals with various time widths. QPSR is the inherent characteristics of two frequency signals and it is very accuracy and small. For example, QPSR of 1MHz and 1.0001MHz signals is 0.1ns. So a time comb formed by the signals with specific frequency relation combining with pulse selection circuit can generate different high-accuracy short time pulse signals. Based on this method, not only the non-periodic short time signal can be generated, but also the periodic short time signal and the period depends on the least common multiple period of these two signal.**

I. INTRODUCTION

With the technical improvement of atomic frequency standards, optical frequency standards and navigation and positioning [1], the request of the high-resolution measurement and processing technique of time and frequency is more and more urgent [2]. Precise short time interval generator is the important guarantee for measuring accuracy. Many physics experiments which are related to generating and controlling short time interval require especial short time interval signals. For examples, it is difficult to meet the requirement by using traditional methods for generating gradually variational time interval signals. Thus, the method which is simple to design, high-accurate for measurement and controllable in the width of time interval signal, is of great meaning.

This paper puts forward a concept of time comb which is based on phase relation and equivalent phase comparison frequency of two periodic signals and a novel method for generating time interval signal based on time comb technology. This method can flexibely get samples from the time comb's comb teeth signal, and generate short time interval signals with different widths. So the precise time interval signals can be obtained from low frequency signals. The resolution of generated time intervals can be a few hundred ps order of magnitude. The research also provides good method to mearsure short time interval.

II. TRADITIONAL TIME INTERVAL GENERATING METHOD

Traditional time interval generator uses the method of frequency synthesizer. The method gets the output signal's half period or one period of the frequency synthesizer as the time interval signal. The schematic diagram is shown in figure 1.

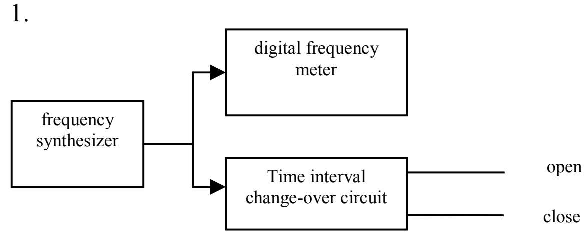

Figure 1. Schematic diagram of traditional time interval generator

Very high frequency signals are needed to produce short-time interval. For instances, signals at GHz can be uesd to produce time interval signal with ns-magnitude width. It is difficult to design the circuit. So its applications are limited. Signal waveforms of traditional time interval generator is shown in figure 2.

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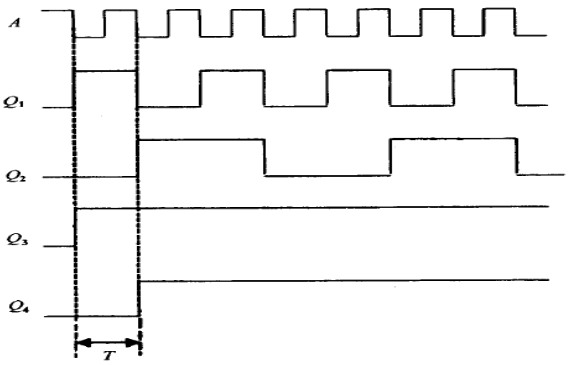

Figure 2. Waveform of traditional time interval generator

III. THE PRINCIPLE OF SHORT-TIME INTERVAL GENERATOR BASED ON TIME COMB

A. The principle of time comb

It is discovered that many regularity are very helpful to high precision detection in research of periodic signal. The concepts of the greatest common factor frequency and the least common multiple period which can reflect phase relation of two frequncy signals should be paid more attention to [3-5]. The greatest common frequency between f_1 and f_2 is defined as f_0 when $f_1 = Af_0, f_2 = Bf_0$, A and B are prime with each other. The reciprocal of the greatest common factor frequency is the least common multiple period T_{minc} ..The relation graph of phase difference of two frequency signals is shown in figure 3.

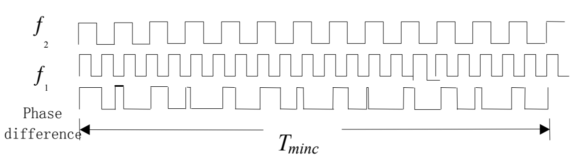

Figure 3. Phase relation of two frequency signals

It can be seen that there have A T_1 and B T_2 in one T_{minc} in figure 3. Phase relation of two frequency signals in one T_{minc}, expressed by the rising edge of f_1 as rising edge of phase difference signal and that fall edge of f_2 as the fall edge of phase differnece is as follows:

$$T_1' = n_1 T_1 - T_2$$

$$T_2' = n_2 T_1 - 2T_2$$

$$\cdots\cdots\cdots\cdots$$

$$T_X' = n_X T_1 - XT_2$$

$$\cdots\cdots\cdots\cdots$$

$$T_B' = AT_1 - BT_2 = 0$$

T_1' 、 T_2' 、 …… T_B' denote phase difference between f_2 and f_2, The phase difference characteristics for each phase point with f_2 signal as a reference. The corresponding waveforms for the phase difference are signal pulse width.

They are ≥ 0, and $(n_X - 1)T_1 < XT_2$. Here, n_1, n_2 ... ... A and X are positive integers. So $B \cdot n_x - A \cdot X$ will be a positive integer or zero. So we have the following equations:

$$[T_1, T_2, \ldots\ldots T_B] = [Y_1, Y_2, \ldots\ldots Y_B] \frac{T_1}{B}$$

$Y_1, Y_2, \ldots\ldots Y_B$ Can only be a positive integer

T_1' 、 T_2' 、 …… T_B', In the T_{minc} period, they must not be the same.

For the relations of phase difference between two arbitrary frequencies signal, if we realign the pulses by width size, then between the two signals, the value of difference between two adjacent phase difference is as follows:

$$\Delta T = \frac{1}{B} T_1 = \frac{f_{max}}{f_1 \cdot f_2}$$

We call ΔT the quantified phase shift resolution.

When phase differences are realign by width, the state of all adjacent difference is fixed to the value of the quantified phase shift resolution, which is based on the relationship between the frequency-signal. By this way, phase differences in a least common multiple period constitute a comb of time. Within the particular frequency relationship, the phase difference--time interval signal width of the time comb will increase or decrease with the quantified phase shift resolution as the step. Then we can obtain all kinds of different time interval signals which orderly decrease from the smallest period of the two signals to 0 step by step. This is favorable for the generation of different short time interval signals, and gives an advantageous method for further measurement of precise time interval. Furthermore, the time comb is also good for the measurement of ultra high frequency with high resolution. Because of the quantified phase shift resolution or equivalent phase comparison period, a time comb is made according to the phase relationship between two certain frequency signals. The total length of a time comb is equivalent to the lease common mutiple period between two signals. According to different frequency relationship, the size relationship of pulse width(comb teeth) between combs is from big to small, or from small to big, or in complex ordering relation. Regardless of complexity of relation, the width of a time comb is from the value close to 0 to the period of higher frequency signals with the quantified phase shift resolution as the step. The interval between comb's teech is equivalent to the period of low frequency(long period) signals. It should be noted that the methods of time processing and frequency processing are often complementary to each other. They often can resolve same measuring and controlling problems. And the obtained precision may be different because of objects having different difficulty or facility.

B. The method of generating short time-interval based on time comb theory

The time resolution which uses phase relation of two frequency signals to generate the time comb do not depends on the frequency of one of the two signals , but the equivalent phase comparison frequency of the two signals [6-7]. the resolution is

$$\Delta T = \frac{f_{max}}{f_1 \cdot f_2}.$$

The time interval generator must use two close frequency signals and make time interval signals expand on time axis only in a regular way which can resolve sampling problem of time intervel signals. Schematic diagram of the time interval generator based on time comb is shown in figure 4 and waveform shown in figure 5.

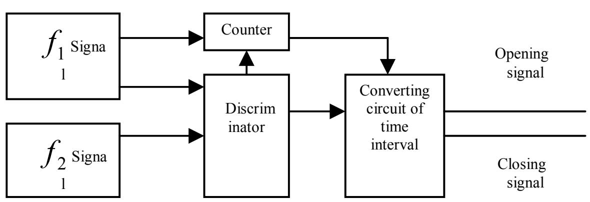

Figure 4. Schematic diagram of the time interval generator based on time comb

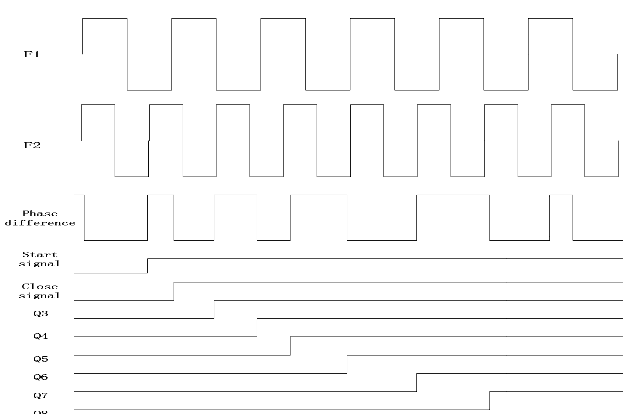

Figure 5. Waveform of the time interval generator based on time comb

If f_1=1MHz, f_2=1.0001MHz,

$$\Delta T = \frac{f_{max}}{f_1 \cdot f_2} = 0.1\text{ns} = 100\,\text{ps}$$

The resolution can be a few hundred ps order of magnitude. The traditional method must use signal generator of which frequency may be more than 10GHz. So it must utilize high speed devices. The time interval generator based on time comb has some obvious advantages compared with the traditional way. By using two low frequency signals to generate very precision time interval, this method's resolution is higher than that of traditional way. It is especially good for generating and controlling regular time interval signal and providing better means for measuring short time interval".

IV. CONCLUSION

This paper puts forward the concept of time comb and researchs a new short time interval signal generating method. By using phase relation of two period signals to construct a time comb and sampling comb teeth signals of time comb, short time intervals of any periodic or non-periodic signals will be obtained. With very precise time intervals generated by two low frequency signals, this way is not only a guarantee but also a new thought for short time interval measuring.

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