Wide Range and High-Precision 1PPS Time Interval Measurement Method

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***Abstract*—High precision time interval measurement between two 1PPS signals is important in timekeeping. In time interval measurement between two 1PPS, the method of using the surface acoustic wave filter (SWAF) as the time-interpolator and calculating the time interval through the cross-correlation algorithm has high resolution and accuracy. However, the narrow pulses generated by the event start and end edges excite the SAWF. The response of SAWF has a duration of 200ns. Time intervals smaller than the response duration cannot be measured. The cross-correlation method also limits the measurement speed. In this paper, FPGA is used as the delay module to delay two 1PPS signals respectively. By measuring the time interval between each 1PPS signal and their delay signals respectively, the measurement dead zone is avoided. The calculation time is saved by gradually reducing the number of interpolation steps. Two 1PPS from the hydrogen maser were measured at room temperature and the results showed that the RMS error of this work is higher than 4.5ps and the resolution is higher than 2ps for the time interval of two 1PPS signals when the ADC is 14bit.**

Keywords*— *time interval measurement, time interpolation, sample reconstruction, cross-correlation algorithm

I. INTRODUCTION

High precision time interval measurement, picosecond (1ps=10^{-12}s) scale measurement technology is very important [1]. It is the key technology of modern time keeping. Petr Panek first proposed the use of surface acoustic wave technology to measure the time interval and analyzed the error [2,3]. In the same year, Petr Panek used SAWF with bandwidth of 18MHz and center frequency of 525MHz combined with ADC sampling of 12bit to obtain measurement accuracy of 1.3ps [4]. The measurement system constructed by Bu Zhaohui based on SAWF used oscilloscope sampling with sample frequency of 40G and resolution of 12 bits to obtain measurement accuracy of 1.6ps and 0.8ps [5]. Using a digital oscilloscope for sampling, such implementation of the measurement module cannot be used alone without external instruments.

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The measurement range of time interval between 1PPS signals used for time transmission generally starts from 0 second, and the measurement technology of picosecond resolution within the nanosecond range of 1PPS signals is a difficulty in time interval measurement at present. For example, the 53230A frequency counter can measure resolution up to 20ps, but the minimum frequency of the measured signal starts at 10Hz. Petr Panek's measurement system is limited to the envelope width of the response of SAWF unable to measure time intervals smaller than 160ns. This paper designs a high-precision time interval measurement method for 1PPS signal. This method uses 14-bit ADC, chooses SAWF with a center frequency of 70MHz and a bandwidth of 6MHz as the time interpolator, and designs a dual-channel symmetrical delay structure by taking advantage of the good delay stability of FPGA logic unit. The picosecond time interval measurement between any 1PPS signal is realized by converting the very short interval into the longer time interval after the two-way delay.

II. METHODS

The time interval between 1PPS with no dead zone and high precision is measured in Figure 1.

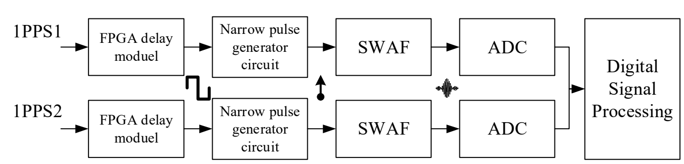

Fig. 1. 1PPS time interval measurement system

The center frequency of the SAW band-pass filter is 70MHz, and the bandwidth is 6MHz. ADC: 14 bits with a sampling rate of 120MS/s. After two 1PPS signals are input into the system, they pass through the FPGA delay module as shown in Figure 2. The delay model generates a pulse which the rising edge synchronize with the original 1PPS signal and the falling edge synchronize with delay clock signal on a single path. An *RC* circuit is used to realize the conversion from contact edge to narrow pulse. After passing SAWF, the narrow pulse signal is extended to the Sinc envelope with width of about 250ns. After sampling by ADC, the time interval between each route delay edge and the original 1PPS edge is obtained by cross-correlation, and the delay results $\check{\tau}_d$ of two 1PPS signals are obtained by subtraction.

If the time interval $\check{\tau}_d$ between the rising edge of two signals to be tested is less than the duration of SAWF response signals, then the two signals will be indistinguishable. In this paper, the reference clock base is added to establish the time delay to achieve the ultra short time interval measurement.

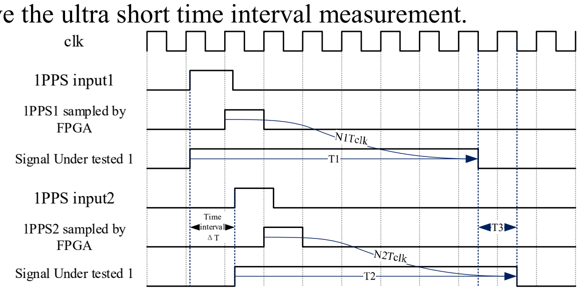

Fig. 2. Delay Module time diagram

As shown in Figure 2, after the two 1PPS signals are sampled by the reference clock *clk* in the FPGA, they are delayed for n_1 clock cycles and output a synchronization signal *out1* with the falling edge of the clock. After the signal edge passes through SAWF with sufficient delay, its response signal will not be aliasing [6]. The time interval can be obtained by counting the period of *clk*.

$$T_3 = nT_{clk} \qquad (9)$$

The time interval T1 of edge b and c and the time interval T2 are measured, then the time interval can be expressed as:

$$\text{timeinterval} = T_1 + nT_{clk} - T_2 \qquad (10)$$

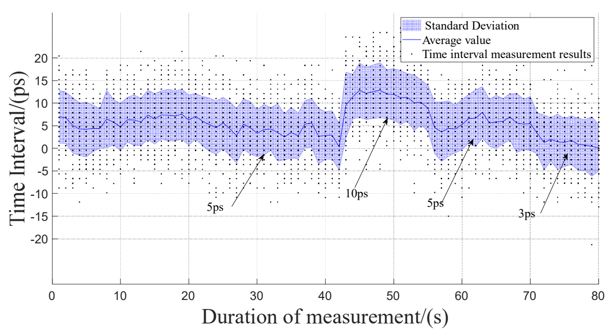

Fig. 3. The measurement was continuous for 80 minutes, and the mean and standard deviation of the measurement results were calculated according to the group interval of 60 seconds.

At room temperature, the 1PPS signal from the Hydrogen maser passes through the power divider to generate two signals to be measured, one of which is connected to the PDL-100A-100NS adjustable delay device of Golby company, and the other is directly connected to the measuring system. The 10MHz signal of hydrogen maser homologous with 1PPS signal is used as the reference clock of FPGA delay module, and the 120MHz signal generated by Agilent E8257D signal generator synchronized with the hydrogen clock is used as the ADC sampling clock.

Set the delay device to generate +10ps, +5ps, and +3ps delay successively on the basis of the delay of +5ps for measurement and record the modification time of the adjustable delay device. Data is divided into groups according to 60s, and the mean value and standard deviation of each group are calculated as shown in Figure 3.

III. DISCUSSION

Using FPGA as delay module, the uncertainty of delay clock is introduced into the measurement result. When the interval to be measured is less than one delay period, the uncertainty of the delay clock can cancel each other when the two results are subtracted. In this paper, the system is proposed to convert 1PPS signal edge through an *RC* circuit. In future work, if extremely narrow pulses are generated, they can be converted using a high center frequency surface acoustic wave filter to achieve even better resolution.

IV. CONCLUSIONS

The high resolution time interval measurement method proposed in this paper uses a surface acoustic wave filter with a center frequency of 70MHz as a time interpolator and a 14-bit ADC, utilizes the delay stability of the logic unit in FPGA, and combines the high stability reference clock as a delay processing to realize the time interval measurement from 0 second. As shown in Figure 3, the measurement accuracy of the system for two channels of 1PPS signal is higher than 4.12ps, and the measurement resolution is higher than 2ps. It can be used for high precision time service and time synchronization in modern communication.

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