A New Method for the Design of Digital Disciplined

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***Abstract*—Disciplined Clock has been widely used as a result of many fine features such as high precision, low cost and so on. In this paper, we designed a scheme implementing the Digital phase-locked loop based on the primary principles of the Disciplined Clock system. This scheme constructs a high-resolution phase detector using the good autocorrelation characteristics of Pseudo-random code, and measures phase difference. And using this scheme a GPS Disciplined Clock test system is designed. The actual measurement results show that this method can improve local 1PPS output long-term stability.**

I. INTRODUCTION

With the development of Measurement and Control, Communication technology, the demand of high–precision time source is higher and higher. High–precision time source such as Atomic clock is so expensive that is difficult to be widely used. With the development of the satellite navigation system, high–precision time source is got by the combination with satellite time services receiver and local crystal. This method has many characteristics such as high–precision and low cost and so on, therefore it is be widely used.

Conventional Disciplined Clock system use analogy or semi-digital method, and have many shortcomings such as high cost, serious environmental impact, difficulty of debugging, hardly establishment model and so on. This paper advances a digital Disciplined Clock technology based on the primary time-frequency principle of the Disciplined Clock technology, and against traditional Disciplined Clock technical shortcomings. In this new technology, autocorrelation characteristics of pseudo-random code is used to build a high-resolution phase detector, and Kalman filtering technology is integrated in the crystal noise model into the Phase-locked loop structure to improve the capacity of local time maintenance and frequency stability.

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II. PRINCIPLE AND METHOD

Oscillator output voltage[1][2] (instantaneous output voltage) is:

$$V(t) = [U_0 + \varepsilon(t)]\sin[2\pi\nu_0 t + \rho(t)] \tag{1}$$

Instantaneous phase deviation is:

$$x(t) = \frac{\rho(t)}{2\pi\nu_0} \tag{2}$$

Instantaneous frequency deviation is:

$$y(t) = \frac{dx(t)}{dt} = \frac{1}{2\pi\nu_0}\frac{d\rho(t)}{dt} \tag{3}$$

From above we can derive out:

$$V(t) = [U_0 + \varepsilon(t)]\sin[2\pi\nu_0(t + x(t))] \tag{4}$$

x (t) is the time difference in physical performance, it is also known as the phase time.

y (t) can be understood as the rate of change of time difference.

There is:

$$x(t) = x_0 + \frac{\Delta\nu}{\nu_0}t + \frac{1}{2}Dt^2 + x'(t) \tag{5}$$

Thus, the model of the oscillator clock difference is:

$$x(t) = a + bt + 1/2ct^2 + \varepsilon(t) \tag{6}$$

This model is applicable to most of the oscillator. Which the a is the initial time difference, the b is relative frequency deviation, the c is frequency drift rate also named frequency

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aging rate because of its own frequency source parameters aging, manifesting linear deviation in the frequency from the nominal frequency and quadratic deviation trend from the standard time in time. And the last one $\varepsilon(t)$ is the noise[1].

From above we can see that the main reason of frequency changes caused by the source of frequency is the initial frequency offset, aging, random noise and so on. Therefore, the essential process of Disciplined Clock is constant to overcome the above-mentioned factors that were taming the effect of frequency standard so that it will have better performance.

The basic principle of Disciplined Clock is that frequency difference is acquired by comparing the fixed frequency signals from the satellite time service receiver with the frequency signals generated by local oscillator, and then make the local oscillation frequency and the satellite time service receiver output frequency maintain synchronization. Its time-frequency model is as follows[3][4]:

The disciplined clock can be divided into two processes of frequency difference or phase difference measurement and frequency calibration.

Phase difference measurement is used to achieve the frequency difference measurement, by measuring phase difference to obtain cycle difference and then get interpolation between frequencies. To achieve this we measure the phase difference of the 1pps of satellite time service receiver and the sub- frequency seconds of the local oscillator. We use the pulse interval counter to measure the phase difference; it also means that we use a certain frequency pulse to count between two seconds. Its accuracy depends on the pulse frequency. The crystal of 10MHz, the measurement accuracy is 100ns. If we use the frequency multiplication phase-locked circuit, the measurement accuracy is about 10ns. To further improve measurement accuracy, it is necessary to measure the quantify errors. A method is converting the quantify errors to voltage range, this method is also known as T-V method, through the high-resolution AD sampling to obtain the precise value of quantify errors[3][5].

In addition, we can use the quantify delay and cursor method to measure, but these methods have some shortcomings, such as: need high frequency stability, the circuit structure is complicated, costly and difficult to achieve and so on.

Against shortage of traditional local frequencies implement methods which lacks analogy control, local digital frequency control is achieved by the use of DDS technology-based all-digital phase-locked loop. Its schematic diagram is as follows:

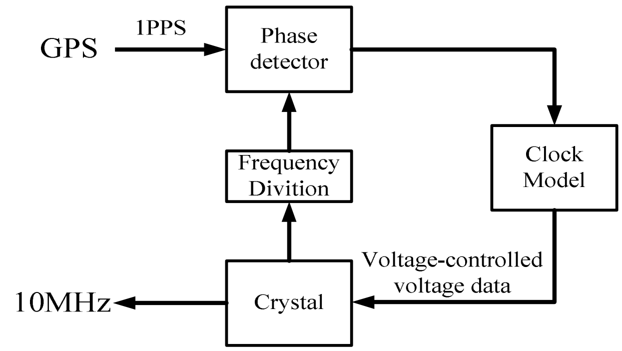

Figure 1 Schematic Diagram

DDS has many excellent performances, such as: wide relatively bandwidth, short frequency conversion time, high frequency resolution, continuous phase, quadrate output and integrated, provided for the system the performance better than analog signal sources. System can change its local output frequency by changing the frequency control word in order to achieve digital control of local output frequency. At the same time, the frequency resolution is determined by the length of the internal phase-accumulator, the longer length of phase accumulator result in the higher the frequency resolution[6].

We use pseudo-code measure method to measure local 1PPS signal, the method is using external reference 1PPS generated synchronously Pseudo-code as Quasi-code. Using two-way Pseudo-code generated by local frequency control whose phase separated from one chip as early code and late code. Through the related value of the early and late code and Quasi-code measure the phase difference of local and external reference frequency, then obtain frequency difference. The principle is as follows:

Auto-correlation characteristics of pseudo-random code[7]:

Pseudo-random code is called as Pseudo-code or PRN code for short, it is a binary code which can be pre-determined and duplicated. It also has similar statistical properties of random white noise. It has been widely used in fields of communication and radio range measurement. It has good auto-correlation characteristics.

Its auto-correlation function can be expressed as follows:

$$R(\tau)=\begin{cases}1-\dfrac{m+1}{T_0}\left|\tau-iT_0\right|, & 0\le\left|\tau-iT_0\right|\le\dfrac{T_0}{m}, \quad i=0,1,2,\cdots \\ -1/m & others\end{cases} \tag{7}$$

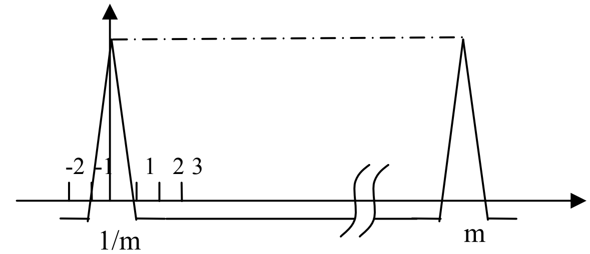

Figure 2 Auto-correlation Characteristics Chart

In the design, phase detector uses (E-L), also means that early code correlation value minus late code correlation value.

The symbol of the value stands for the direction of phase change, and the size of the value stands for the phase error. The phase resolution is related to the cycle and the width of the code. This simulation of phase features is showed in follow figure:

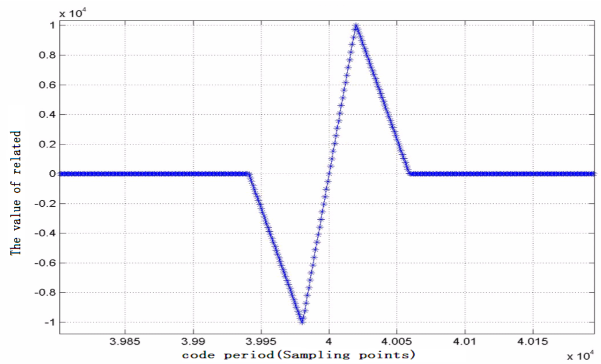

Figure3 The simulation of phase features

The advantages of using digital pseudo-code to spread spectrum phase detector is improving the phase resolution and phase range. Typical phase accuracy of the digital flip-flop is inversely proportional to the digital clock frequency. For example, using 40MHz clock can only achieve phase resolution of 25ns, phase range of 50ns.

After using pseudo-code to spread spectrum and value (E-L), phase resolution will be greatly improved and the scope of phase is widely broadened. For example, using 1.023MHz spread spectrum code, 40MHz digital sampling, the scope of the Phase is 1 chip (about 1us), phase resolution of about 50ps.

Considering loop filter with oscillator model, on the one hand, to complete smooth function of measurement noise, and it would be best to inhibited the random noise of the oscillator to some extent; at the same time, it also needs to estimate the model parameters, specifically referring to the estimation of the oscillator frequency offset coefficient b and the coefficient of frequency aging c. in this paper we use the methods in literature [8], build a Kalman filter to achieve the function of loop filtering.

The flow chart of the Kalman filters is as follows:

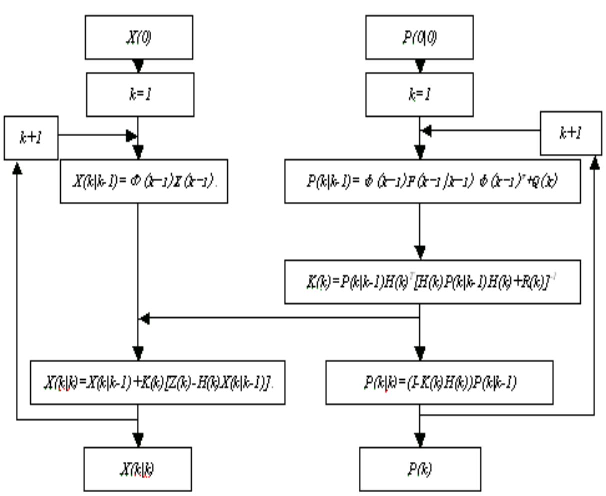

Figure 4 The flow chart of using Kalman filter do state estimation

The state parameter X (k) in the time K contains: clock difference (x(k)), frequency offset (b(k)) and aging coefficient (c(k)), X (k) can be written as follows:

$$X(k) = [x(k) \quad b(k) \quad c(k)]^T \tag{8}$$

The value of the measurement is the clock difference, that is :

$$Z(k) = x(k) \tag{9}$$

State transition matrix Φ and measurement matrix H as follows:

$$\Phi = \begin{bmatrix} 1 & 1 & 1/2 \\ 0 & 1 & 1 \\ 0 & 0 & 1 \end{bmatrix} \qquad H = [1 \quad 0 \quad 0] \tag{10}$$

We use estimation experience method to estimate Q and R, the recursive estimates of the Q value as follows:

$$Q(k) = \frac{Q(k-1) + [S(k-1)S(k-1)^T]}{2} \tag{11}$$

We use the Kalman filter to estimate model parameters with 6 hours' measured data, estimated the b is about 1.69e-7, c is about -1.456e-13, as shown in figure 5 and 6:

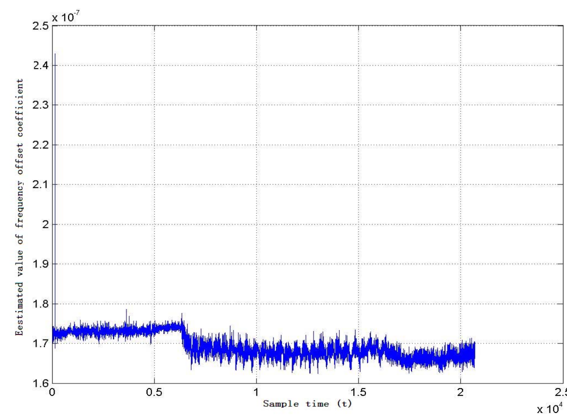

Figure 5 Frequency drift Coefficient b estimated result

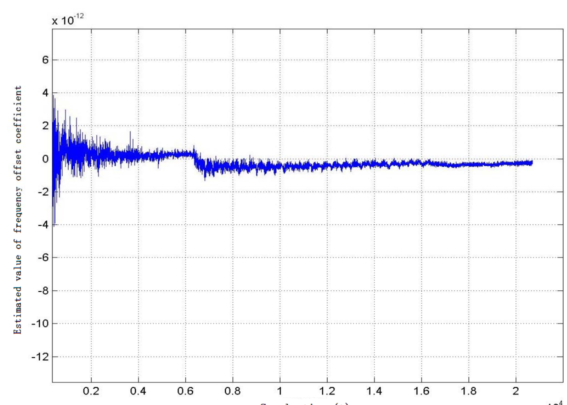

Figure 6 Aging Coefficient c estimated result

III. CONCLUSION

The scope of the phase is wide and phase resolution of high frequency is high based on a new digital detector using pseudo-code, especially fixable field of some time-frequency application. This detector improves local time-frequency precision and track stabilization according to exterior frequency source. How to optimize the filter in the loop to improve track stability and how to estimate parameter of local oscillator with measurement are the main work in the next step.

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