# Research on High Precision Master-slave Clock Synchronization Based on 1588 Protocol

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*Abstract*—**With continuous development of industrial automation, precision measurement and control, it is more and more important to conduct research on the technology of high precision time synchronization. The 1588 protocol, which provides sub microsecond network time synchronization, has received special attention from all walks of life. This research is to achieve the 1588 protocol high precision master slave time synchronization based on the low pass filter and sliding mode control. In this study, the influence of the frequency jitter of the master and slave clock and the stochastic error of the measurement process is reduced by low-pass filter; Then the sliding mode filter is used to suppress and optimize the crystal frequency drift caused by the temperature and other factors of the clock; Finally, the simulation results show that the research method in this paper is able to effectively improve the synchronization accuracy of the master and slave clocks, and realize the sub microsecond requirement of the 1588 protocol.**

***Keywords-IEEE1588; synchronization; sliding mode controller; low pass filter; master-slave clock;***

## I. INTRODUCTION

In order to make all the base stations in the mobile communication network achieve good time synchronization, the simplest and the most effective way is to install a device on all base stations to receive the time signals from GPS that most of the domestic operators of the network are using [1,2].However, if GPS is installed to all the base stations in mountainous areas, highlands, hills, wetlands, plains, obviously the operation is very difficult. Moreover, the construction cost and maintenance cost will also increase geometrically. The most important point is that the security risks are high. This method depends on the United States GPS system, and the United States has the ability to severely reduce the quality of GPS signals in specific areas, so serious security risks might exist for the country.

In this context, the IEEE1588 protocol high precision clock synchronization protocol emerged. This protocol is also commonly referred to PTP protocol [3].The PTP protocol mainly aims at the precise clock synchronization problem in distributed network system, which can synchronize each independent clock inside the system to a unified clock standard with limited network and local resources, and bring high clock synchronization accuracy. If the hardware clock provides a hardware-level timestamp tagging function, the synchronization accuracy can reach the sub-microsecond level. Meanwhile, the PTP protocol is cheap and convenient for later maintenance work.

This study is based on the IEEE1588 protocol. As the master and slave clock synchronization in the actual environment is vulnerable to external noise, temperature, device crystal aging and other factors, it is necessary to take appropriate measures to suppress and optimize the interference of the above factors. In order to solve the problem of frequency drift caused by the temperature on the clock frequency of master-slave clock, sliding mode filter is applied to control the influence of temperature in this study; Aiming at the problem of clock frequency jitter and random error in measurement and experiment, this study adopts low pass filter to filter out; Finally, the simulation results show that the sliding mode controller and low-pass filter can significantly reduce the influence of frequency drift and frequency jitter, which meets the nanosecond requirement of 1588 protocol.

## II. Introduction to the principle of IEEE1588 protocol

### *A. Master and Slave clock synchronization*

PTP's principle of precise clock synchronization proposes the delay response mechanism that is mainly divided into six steps, as shown in Fig 1:

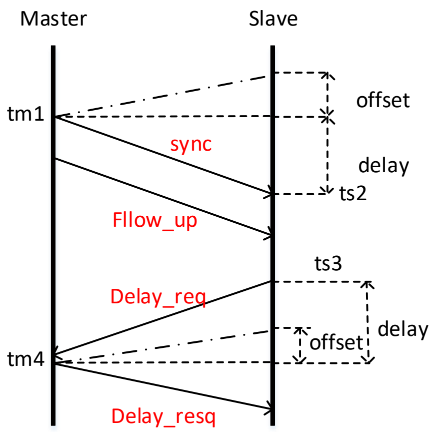


Fig1. PTP protocol delay Response mechanism

In the figure above, the 1588 protocol mainly achieves master-slave clock synchronization through sync, Follow-up, Delay_req and Delay_resq. The process of sending and receiving messages based on delay response



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synchronization mechanism is as follows:

The master clock periodically sends sync packets and records the sync packet which leaves the precise transmission time tm1 master clock. The master clock encapsulates the exact transmission time tm1 to the Follow_up message and sends the time to the slave clock. The sync message is recorded from the slave clock to the exact time of arrival from the slave clock ts2. The delay_req message is sent from the slave clock and the precise transmission time ts3 is recorded. The master clock records the precise arrival time tm4 of the delay_req message to the master clock. The master clock emits the delay_resq message carrying the accurate timestamp information tm4 to the slave clock. The time deviation between the master and slave clocks of the mechanism is offset, and the average delay of the transmission of the message in the network is delay, assuming that the delay of the transmission link of the synchronous message is symmetrical can be obtained:

$$offset = \frac{1}{2}[(t\mathrm{m}4 - ts3) - (ts2 - tm1)]. \quad (1)$$

$$\mathrm{delay} = \frac{1}{2}[(t\mathrm{m}4 - ts3) + (ts2 - tm1)]. \quad (2)$$

According to the two expressions above, the time offset and the average delay can be obtained respectively. In this paper, the low pass filter and sliding mode controller are used to realize clock control and optimization, so as to achieve high precision synchronization between master and slave time.

*B. Establishing the master and slave clock model*

In this study, the main clock is set to a standard clock source, and the slave clock is the time accumulation of the oscillation frequency of the local crystal vibration. The oscillation frequency of crystal vibration depends not only on the material, cutting angle, shape, aging and other inherent characteristics of crystal vibration, but also on the external environment including temperature, humidity, pressure, etc. Due to the influence of environmental temperature, crystal vibration itself and other factors, crystal vibration will produce a certain error, thereby resulting in error offset between the slave clock and the master clock and seriously affecting the synchronization accuracy as the time passes[5].The effect of the aging of the crystal vibration on the frequency drift of the crystal vibration is relatively slow, while the ambient temperature exerts a real-time effect on the crystal vibration[6].

There is a frequency drift between the actual application of clock crystal vibration and its nominal value. Meanwhile, the aging of the crystal vibration and the high temperature environment will further increase the frequency drift. Over time, the frequency drift of local clock crystal vibration generates more and more errors, which lead to a decrease in synchronization accuracy. The effect of crystal aging on frequency drift is much smaller than that of high temperature on the crystal vibration frequency drift [7]. At high temperatures, the effect of temperature on the watch crystal is very important. The following figure is a graph of the crystal drift characteristics ( $\varphi(t) = 35^{\circ}5^{`}$ ) , and the relationship between AT crystal vibration and temperature is three curves：

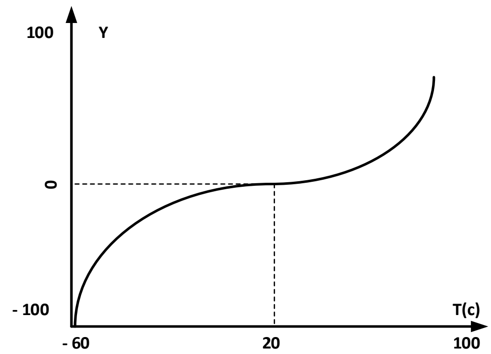


Fig2. Frequency Drift Characteristic Curve of Crystal Oscillator

In the above figure, the abscissa is the temperature T(c) and the ordinate is the drift rate ( $\mathrm{Y} = (\Delta\mathrm{f}/f) \times 10^{-6}$ ).

This paper assumes that the master clock is the standard clock source and can be set to that:

$$Mas(t) = t. \quad (3)$$

Due to the fact that the slave clock in the actual network system is affected by outside world and its own temperature and that the crystal oscillation process produces a random error that can be approximate to a Gaussian white noise, so the slave clock mathematical expression is obtained:

$$\mathrm{S}la(t) = (1 + \varphi(t))t + u(t). \quad (4)$$

In the above formula, $\varphi(t)$ is the frequency offset rate from the clock signal affected by temperature, and $u(t)$ is the random error. Master slave time warp are achieved from formulas (3) and (4):

$$\mathrm{offset} = \mathrm{Mas}(t) - Sla(t) = \varphi(t) * t + u(t). \quad (5)$$

## III. IEEE1588 protocol time synchronization system based on sliding mode control and low pass filter.

Based on low-pass filter, the sliding mode control method puts the filter into the middle of the controller and the control object, and the low-pass filter filters the controller output. Therefore, the chattering caused by the sliding mode control structure itself is suppressed and the control moment of the actual output is smoother, which has important value in practical engineering application[8].The structure diagram of sliding mode control system based on low pass filter is shown in the following figure:

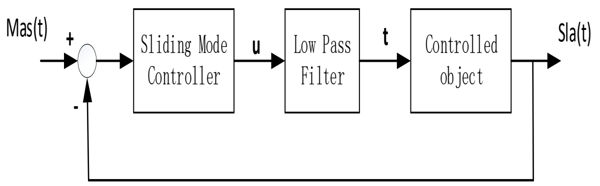


Fig3. Sliding mode control system based on low pass filter

In the above figure, u(t) is the virtual control input, $\tau(t)$ is the actual control input. In order to reduce the frequency jitter produced by sliding mode controller, the following low-pass filter is designed [9]:

$$Q(s) = \frac{\lambda}{s+\lambda}. \tag{6}$$

In the above formula, $\lambda > 0$ it can be obtained from Fig 3:

$$\dot{\tau} + \lambda\tau = \lambda u . \tag{7}$$

By the uncertain system $\mathrm{J}\ddot{\theta} = \tau - d(t)$, where J is the moment of inertia, $\tau$ is the control input, d(t) is the interference, the formula will be added to the formula (7), we can obtain:

$$\mathrm{J}\dddot{\theta} = \lambda u - \dot{d} - \lambda(J\dot{\theta} + d). \tag{8}$$

It is Assumed that the ideal position instruction is $\theta_{\mathrm{d}}(t)$ and the position trace is e(t) :

$$\mathrm{e}(t) = \theta(t) - \theta_d(t)$$

The function of designing sliding mode controller is designed as:

$$\mathrm{s}(t) = \ddot{e} + \lambda_1\dot{\mathrm{e}} + \lambda_2\mathrm{e}. \tag{9}$$

In the above formula, two values need to meet the Hurwitz condition, then:

$$\mathrm{J}\dot{s}(t) = \lambda u - \dot{d} - \lambda(J\ddot{\theta} + d) + J(-\dddot{\theta}_d + \lambda_1\ddot{e} + \lambda_2\dot{e}). \tag{10}$$

Defining Lyapunov Functions $\mathrm{V} = \mathrm{J}s^2/2$ , we can obtain:

$$\dot{V} = Js\dot{s} = s(\lambda u - \dot{d} - \lambda d - \lambda J\ddot{\theta} + J(-\dddot{\theta}_d + \lambda_1\ddot{e} + \lambda_2\dot{e})). \tag{11}$$

The sliding mode control law is designed as:

$$\mathrm{u} = -\frac{1}{\lambda}(-\lambda J\ddot{\theta} + J(-\dddot{\theta}_d + \lambda_1\ddot{e} + \lambda_2\dot{e}) + \eta\,\mathrm{sgn}(s)). \tag{12}$$

In the above formula, $\eta > \left|\dot{d} + \lambda d\right|$ .The shortcoming of this control rate is the need to accelerate the signal [10].

In this study, the master clock, being the standard clock source, is set as the input of the system, and the output is set to slave clock. The time deviation of the master and slave time offset is set as the input of the sliding mode controller [11].The purpose of this system is to control and optimize the influence of slave clock's crystal drift, jitter and stochastic error on offset, so as to achieve a more stable master and slave time follow, improve the accuracy of time synchronization, and better meet the requirements of high precision time synchronization of 1588 protocol.

## IV. The simulation results analysis

In this paper, the transfer function of the controlled object in the sliding mode controller system can be obtained by the above formula (4) for Laplace transform:

$$\mathrm{L}(s) = \frac{1+\varphi(t)}{s^2} + \frac{u(t)}{s}. \tag{13}$$

In the above formula, L(s) is the transfer function of the controlled object in the system. With a sampling time Ts of 0.001s, the controlled object can be converted to a discrete form:

$$\mathrm{M}as(k) = AMas(k-1) + B(u(k) + \omega(k)). \tag{14}$$

$$\mathrm{Sla}(k) = C\mathrm{Mas}(k) + \nu(k). \tag{15}$$

In the model of sliding mode control system based on low pass filter, firstly, the ideal position instruction is $\theta_{\mathrm{d}}$ ( $\theta_{\mathrm{d}} = 0$ ) ,J=1/121;Then the initial time offset of master and slave clock is set to 10us, and the drift rate of the master slave clock is set to 0.000001; Finally, select $\lambda = 20$ , $\lambda_1 = 30$ , $\lambda_2 = 45$ , The sliding mode control law (11) is adopted and simulated by Simulink.

The simulation results are as follows: when taking the signal of three different synchronization periods (T1 =

0.1s, T2 = 0.5s, T3 = 1.0s) , through the study of this Fig.3 of the system, the comparison result is as follows:

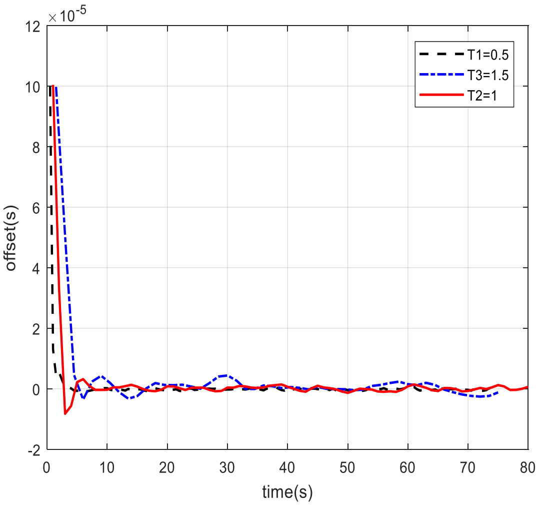


Fig4. T1=0.5s，T2=1s，T3=1.5s Comparison of simulation results

According to the simulation results, three kinds of different time synchronization period signals are based on the sliding mode control system of low-pass filter, and the time synchronization of the master and slave clock is realized by 4s,5s,6s convergence to zero respectively.

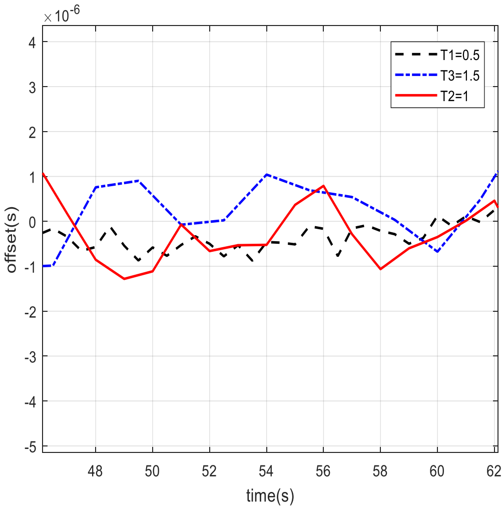


Fig5. Amplification of simulation results

Based on the simulation results of the above three different synchronization cycles: having been filtered by low-pass filter, the study can suppress the frequency jitter and stochastic error of clock, but can't solve the problem of crystal jitter and stochastic error fundamentally; the offset of master and slave clock caused by three different synchronization periods are 1us, 1.5us, 2us, respectively. The accuracy of time synchronization reaches microsecond level; via the comparison of the three results, it can be seen that when the time synchronization period is smaller, the curve is smoother and jitter is smaller, which indicates that the jitter of the master-slave clock is smaller and the synchronization accuracy is higher.

Then, in order to study that the smaller the time synchronization period is, the smaller the crystal jitter of master-slave clock and the higher the synchronization accuracy is, a group of signals with smaller time synchronization period are used to simulate the experiment. The periods are T1 = 0.1s, T2 = 0.03s, T3 = 0.01s, respectively.

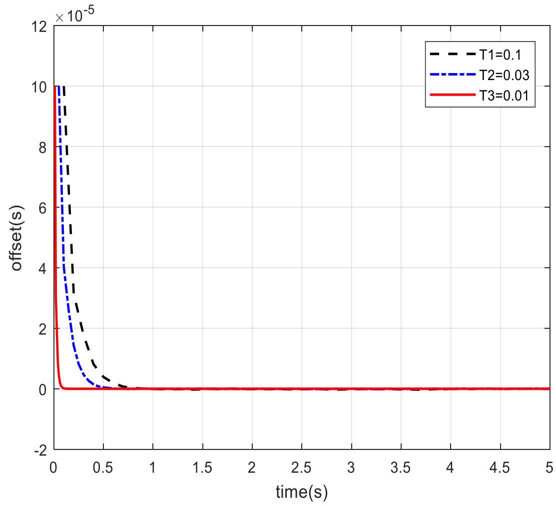


Fig6. T1=0.1s，T2=0.03s，T3=0.01s Comparison of simulation results

Through the simulation results above, it is further verified that when the time synchronization period is smaller, the curve is smoother and jitter is smaller, which indicates that the jitter of the master slave clock is smaller and the synchronization accuracy is higher; Then it can be seen that at this time three different synchronous cycle signals through 0.2s, 0.5s, 0.7s quickly converge to zero near, so as to achieve more quickly the synchronization of the master and slave clocks.

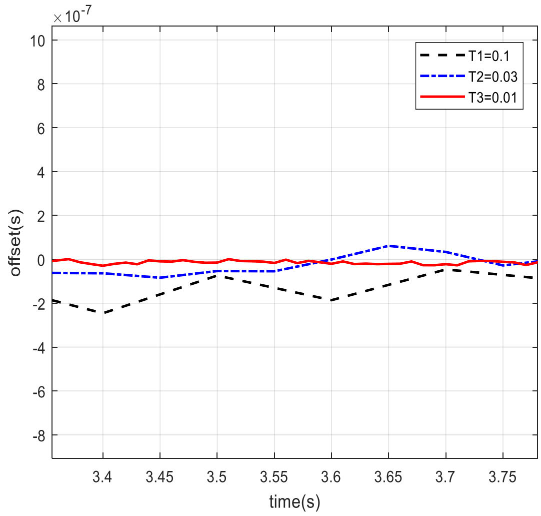


Fig6. Amplification of simulation results

It can be concluded from the above diagram that when the time synchronization period is 0.1s, 0.03s and 0.01s, the offset of the master-slave clock is 0.2us, 0.1us and 0.05us respectively, so that the accuracy of the master-slave time synchronization of the 1588 protocol reaches sub microsecond level. In this study, the sliding mode control system based on low-pass filter is able to effectively control the signals of different synchronization periods from the slave clock rate to make it follow the main clock quickly and achieve better time synchronization accuracy. Meanwhile, the optimization of 1588 protocol different master and slave clock synchronization period is achieved, which improves the accuracy of time synchronization, and meets the 5G requirement for time synchronization nanosecond level.

## V. CONCLUTION

Based on sliding mode control and low pass filter, the scheme of 1588 protocol high precision time synchronization system is proposed in this study. When the message time period is 0.01s, the system can reach the offset of 0.05us, so as to realize the time synchronization of 1588 protocol with higher precision. In this paper, low-pass filter is used to filter out the influence of frequency jitter and noise of clock crystal vibration, and the sliding mode controller is adopted to suppress the frequency drift of clock crystal vibration. Through the analysis of simulation results, the scheme of this study has certain practicability and feasibility to improve the time synchronization accuracy of 1588 protocol. In view of the problems that the low-pass filter in this study can't achieve the maximum filtering of crystal oscillation frequency jitter or noise, and the assumption that the 1588 protocol in this study is based on symmetry of transmission links, the first problem can be improved by combining better filters and algorithms, and the elapsed time of devices in the link can be corrected by using transparent clock and physical proportional method.

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