A Digital Servo with Single Frequency Modulation for Passive Hydrogen Maser

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Abstract: This paper introduces a digital servo using single frequency modulation for passive hydrogen maser. The main parts of this system include ADC, FPGA and DAC which sample error signal, process the signal and output two channels controlling voltage.

The algorithm is used to separate two errors by single frequency modulation principle. Then response curves of two channels are gotten to calculate proper PID controller parameters. In the end, two incremental PID controllers are used to get two channels control voltage to control the resonant cavity and OCXO respectively. The influence caused by the speed and precision of DAC to frequency stability has been analyzed. The experiments prove that the precision of DAC had a little influence on the short and medium term frequency stability at high control speed

The frequency stability of passive hydrogen maser with this system has been tested. It has achieved at $\sigma_y(1000)<3\times10^{-14}$.

I. INTRODUCTION

Shanghai Astronomical Observatory has devoted to development of hydrogen maser for a long period, since 2002 study on passive hydrogen maser had been carried out [1]. Since 2008, the electrical system digitization of signal-frequency passive hydrogen maser has been studying. The research of digital servo is a part of it, which Simplifies parameter regulation. And it has been achieved at $\sigma_y(1000)<3\times10^{-14}$.

II. DESIGN

In the physics package, magnetron cavity is used. The bulb is located in the center of cylindrical radiofrequency cavity. The magnetic shielding of the physics package has 4 layers and its shielding factor is about 50000.The passive Hydrogen maser is subdivided into two principal functional packages, the physics package which provides the actual atomic oscillator, and the electronic package which provides the atomic signal processing circuits and parameter control functions. The gain of physics package maser is about 3.2dB at -80dBm microwave signal input, and the H line-width is about 5Hz, as shown in fig1.

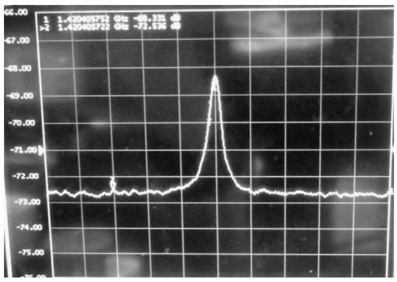

Figure 1. The parameters of the passive maser.

The main units of electronic package are detailed in fig2.These units are in charge of frequency locking of an OCXO (Oven Controlled Crystal Oscillator) and ACT (Automatic Cavity Turning) varactor diodes which compensates the frequency variation of the cavity.

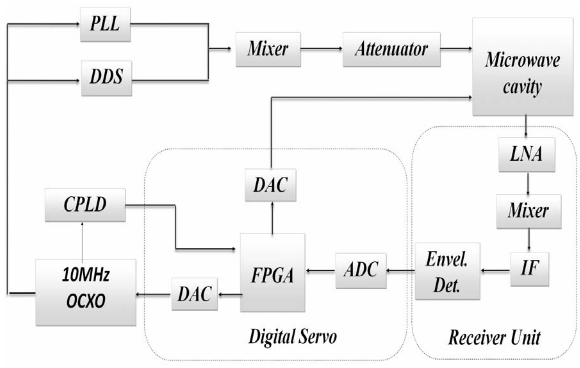

Figure 2. The functional block diagram of the passive H maser

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The 10MHz of the OCXO is directly multiplied by 140 to 1.4GHz, at the same time, it is multiplied to provide the clock of DDS to generate 20.405157Hz FSK modulated signal. The modulating signal is square wave frequency at 12.5 KHz provided by CPLD. The 1.4GHz and the modulated signal are mixed to allow double servo system for both the OCXO and ACT. After the interaction with the hydrogen atoms in microwave cavity, the output signal are first amplified by Low Noise Amplifier (LNA), then frequency mix with a free running oscillator to 20 MHz, and AM converted by envelope detector after Intermediate Frequency (IF) amplifier to generate the error signal at 12.5KHz. Finally the error signal is processed by the servo system together with Phase shifter signal from CPLD to get proper control voltage for OCXO and ACT varactor diodes.

FPGA maximizes the flexibility of the controller because it can be varied through programming means, without modification of the controller hardware. This paper introduces a digital servo system based on FPGA.

The main hardware structures of this system include ADC, FPGA and DAC. The block diagram of the digital servo system is shown in Fig. 3.

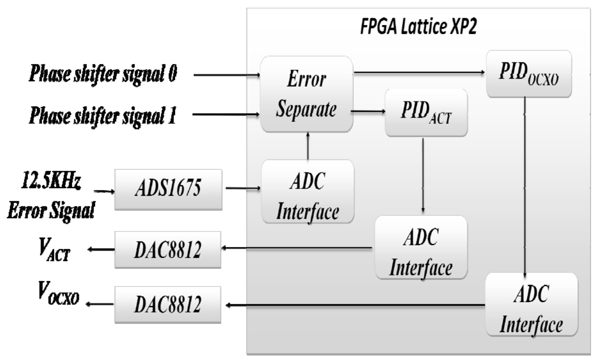

Figure 3. Block diagram of digital servo system

The ADS1675 samples the error signal form receiver unit at high sampling rate 1.28MHz. The ADC interface generates control signals in the FPGA that control the ADS1675 and transfer the 24 bit data to error separate module.

The error separate module separates two errors by single frequency modulation principle [2].

The two increment PID control systems take the errors and computes the correct signal based on the equation respectively [3].

$$
\begin{aligned}
\Delta u(k) &= u(k) - u(k-1) \\
&= P(\mathrm{e}(k) - \mathrm{e}(k-1)) \\
&\quad + I\mathrm{e}(k) + D(e(k) - 2e(k-1) + e(k-2))
\end{aligned}
\tag{1}
$$

Δ u is correction signal for OCXO and ACT varactor diodes; e is error; P, I and D are the proportional, derivative and integral parameters. PID parameters can be gotten from the response curves of two channels scanning process, which calculate proper PID controller parameters.

The two ADC interfaces generate necessary control signal in FPGA that control the DAC8812s and transfer the 16 bit data from the PIDs to DACs respectively. DAC8812s output DC voltage to control OCXO and ACT varactor diodes.

The state machine of the FPGA coding has 6 states, as shown in fig.4.

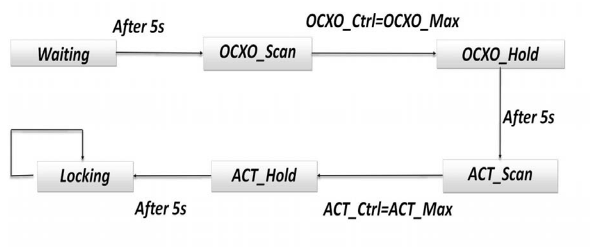

Figure 4. The state machine of the FPGA coding

At first waiting for 5s, In this state, the OCXO_Ctrl (The control variable of OCXO) set as the minimum, the ACT_Ctrl (The control variable of ACT varactor diodes) set as initial value. After 5s, get into OCXO_Scan state, in this state the OCXO_Ctrl increases to maximum.by degrees At the same time the maximum, minimum and square minimum error of the OCXO is ongoing record (fig. 5). In the COXO_Hold state, The Kp, Kd and Ki of PIDOCXO is calculated by response curve of OCXO_Scan , and set the OCXO_Ctrl at error square minimum point. The ACT_Ctrl has been also set as minimum. After 5s, get into ACT_Scan state, in this state, similar with OCXO_Scan to get response curve of ACT varactor diodes (fig. 6). In ACT_Hold state, The Kp, Kd and Ki of PIDACT is calculated by the results of ACT_Scan, and set the ACT_Ctrl at error square minimum point. The system will be in locking state after 5s. In Locking state, two channel of PID control the OCXO and ACT varactor diodes at its own speed.

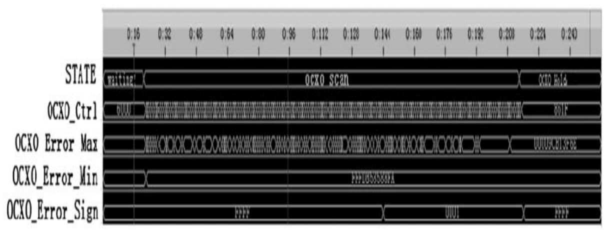

Figure 5. The OCXO_Scan state

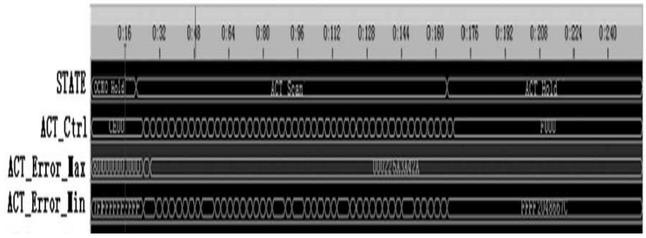

Figure 6. The ACT_Scan state

Form these two figure, we can see that the response curve of OCXO and ACT are linear within the scope of the scanning. The scope of the scanning is gotten from the experiment, and they will lock in this liner scope too.

III. VERIFICATION

Based on the above software and hardware, digital servo circuit is completed. In order to validate digital servo circuit, the frequency stability of the passive H maser with this digital servo is tested by PicoTime (from SpectraTime of Switzerland). The active H maser VCH-1003 provides the reference frequency. Tested results shown that frequency stability of the passive H-maser has been achieved at $\sigma_y(1000)<3\times10^{-14}$.

The experiments in the influence caused by the speed and precision of DA on frequency stability have been done for component selection.

The FPGA controls the DAC to imitate 14 bit, 13bit, 12bit DAC. The frequency stability has been tested with these different DAC at 7ms control speed. The experiments prove that DA had a little influence on the Short and medium term frequency stability at high control speed.

IV. CONCLUSION

This paper details the software and hardware design of a digital servo using single frequency modulation for passive hydrogen maser. Based on this servo system, good short-term stability is achieved. In order to further validate the effectiveness of the designed system, long-term stability will be tested with parameter regulation in future.

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