A Rubidium Frequency Standard Based on Unreal Time Control Approach

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Abstract

In conventional rubidium frequency standard and some passive atomic frequency standards the voltage control crystal oscillator VCOCXO exporting the frequency signal of the standards is real time controlled. Because in the locking loop there are frequency transformation circuits, servo amplifier, testing circuits, and physics package, although the output signal of the standards is very accurate and with a good long-term performance, its short-term stability and phase noise performance are poorer than those of VCOCXO. There have been some techniques to filter or control the servo noise, but it is difficult to obtain both good long-term and short-term specifications at the same time. Because a highly stable crystal oscillator not only has a good short-term stability, but also can keep the high accuracy in certain period. Therefore, as an accurate assistant frequency source, the frequency of VCOCXO does not have to be controlled in real time. The unreal time control approach means the servo voltage from the servo amplifier following physics package does not control the frequency of VCOCXO directly. Based on the ability of VCOCXO to keep the accuracy in certain period the control signal can keep unchanged. The good short-term performance of VCOCXO in the standard is taken advantage. In the new rubidium frequency standard, we use microprocessor and I/O units (A/D and D/A converters). This microprocessor can provide the capability of both processing and isolating. It can compare the mean value of output voltage signals of servo amplifier with former voltage signals that control the VCOCXO. The noise of output voltage of servo amplifier can be eliminated through the software processing. The difference between the output voltage signals and the current control voltage signals is related to the regulation value to VCOCXO. The regulation is completed evenly in step according to the least voltage stepping adjusting value in a given adjusting period. This method can guarantee the original stability of VCOCXO and even frequency locking.

The new rubidium frequency standard can show 1~2$\times 10^{-12}$/s stability and better than 5$\times 10^{-11}$/month drift. It is possible to improve its performances further.

1. Introduction

In conventional rubidium frequency standards and some passive atomic frequency standards the voltage control crystal oscillator VCOCXO exporting the frequency signal is real time controlled. Because of the function of the physics package the output signal is very accurate and with a good long-term performance. However, in the locking loop there are a lot of frequency transformation circuits and physics package, the short-term stability and phase noise performance of VCOCXO are influenced and lowered. If the good short-term stability of VCOCXO can be kept in the rubidium frequency standard its all performances will be better.

2. Conventional rubidium frequency standard based on real time control approach

In conventional rubidium frequency standards the short term stability and phase noise performance are influenced and lowered. For example, the photo – electricity transformation signal following physics package is very weak, and should be amplified often by several thousand multiples. The amplification is easy to be

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influenced by many factors. Compared with many precision OCXOs the short-term stability of rubidium frequency standards is often poorer [1]. There have been some techniques to filter or control the servo noise, but it is difficult to obtain both good long-term and short-term specifications at the same time. However, excellent rubidium frequency standards are needed which must have good long-term and short-term specifications. For example, space clocks and some frequency standards used in laboratory should have 10^{-13}/day drift and better than 1~2 × 10^{-12}/second short-term stability. The rubidium frequency standard will also be used in environment condition of vibration, acceleration and radiation. With the conventional design method it is difficult to make the frequency standard to suit the all specifications, or the cost is very high. Therefore to utilize both advantages of physics package and OCXO to design the rubidium frequency standard the problems can be solved satisfactorily.

3. Rubidium frequency standard based on unreal time control approach

Many experiments have been done to improve the performances of rubidium frequency standard. In the frequency standard design both of excellent long-term performance of conventional rubidium frequency standard and good short-term and low phase noise performance of highly-stability crystal oscillator should be kept [2]. To do so the conventional rubidium frequency standard based on real time control approach is changed into that based on unreal time control approach. Figure 1 shows the block diagram of the rubidium frequency standard based on the approach.

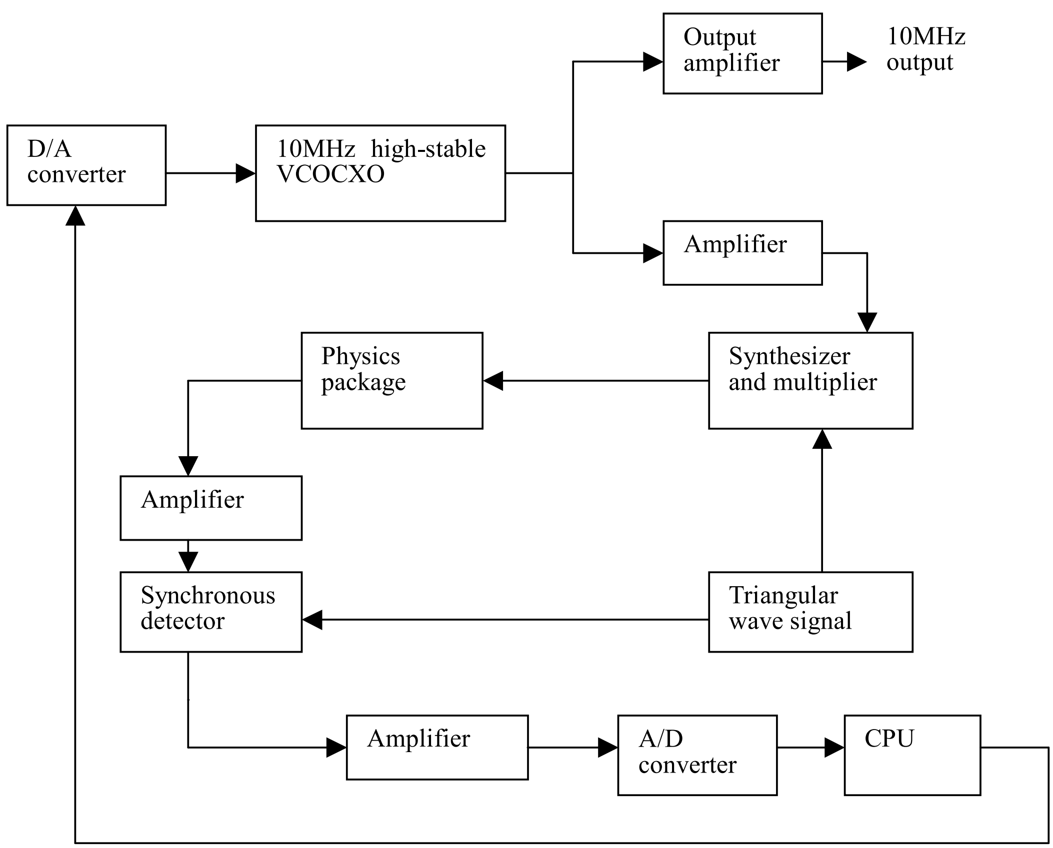


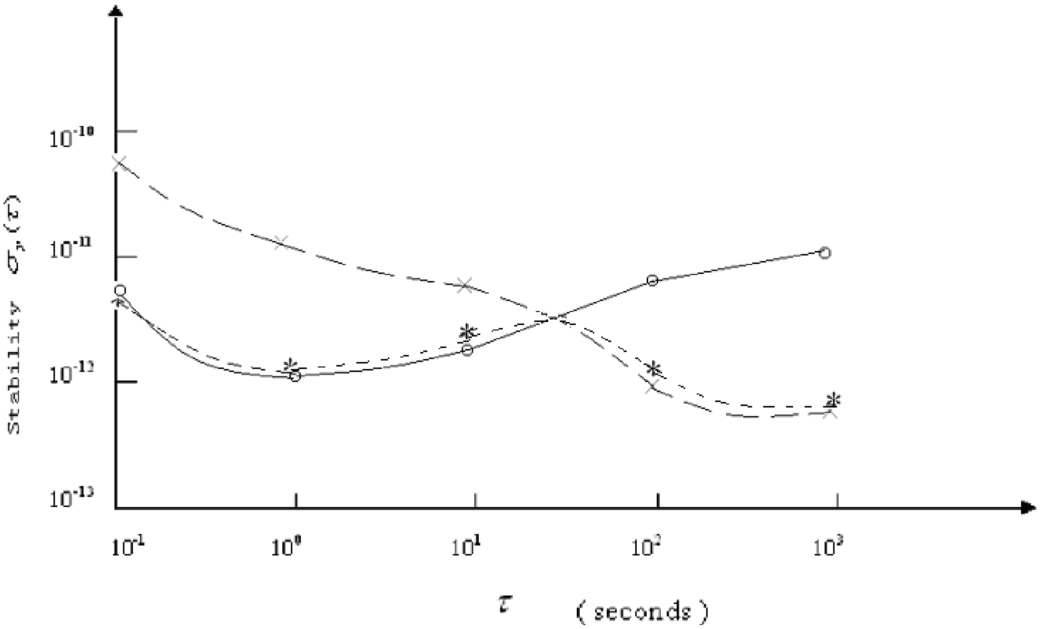
Figure 1. The block diagram of the rubidium frequency standard based on unreal time control

In the improved rubidium frequency standard, a high-stability VCOCXO with $1\sim2\times10^{-12}$/s stability and 2×10^{-11}/day aging is used as the controlled oscillator by the physics package. The highly stable crystal oscillator not only has a good short-term stability, but also can keep the high accuracy in a certain period. Since its good aging performance, its frequency does not have to be locked in time. Therefore, as an accurate assistant frequency source of the rubidium frequency standard, the frequency of VCOCXO does not have to be controlled in real time. The unreal time control approach means the servo voltage from the servo amplifier following physics package does not control the frequency of VCOCXO directly. Based on the ability of VCOCXO to keep the accuracy in certain period the control signal can keep unchanged. In the new rubidium frequency standard, we utilize a microprocessor and I/O units (12-bit A/D and 22 bit D/A converters). This microprocessor can provide the capability of both processing signal and isolating noise. It compares the mean value of output voltage signals of servo amplifier with former voltage signals that control the VCOCXO. The noise of output voltage of servo amplifier can be eliminated through the software processing. The difference between the output voltage signals and the current control voltage signals is related to the regulation value to VCOCXO. In the microprocessor the average frequency difference is calculated first then based on the voltage control of VCOCXO the control voltage is obtained. The calculation is based on the voltage difference and the voltage control sensitivity of VCOCXO. To obtain a smooth control effect and better stability a minimum regulation step voltage is set in the microprocessor. Based on the frequency difference data of VCOCXO from the physics package and after processed by the microprocessor the control voltage to VCOCXO will be fed into it according to the minimum step within the average period. With this way frequency jump can be avoided. The regulation is completed evenly in step according to the least voltage stepping adjusting value in a given adjusting period. This method can guarantee the original stability of VCOCXO and even frequency locking. Because the conventional rubidium frequency standard can show a better stability than quartz crystal oscillator at longer than several tens seconds period, the longer than 10 seconds average voltage which is from physics package is chosen and after A/D transforming fed into the microprocessor.

This rubidium frequency standard is more like a voltage-controlled stable crystal oscillator. In it the performance of the voltage controlled crystal oscillator with the good stability and low phase noise is considered more. When its frequency is accurate enough it does not have to be regulated. When its frequency is close to the frequency tolerance limitation it is regulated according to the reference from the physics package. With this way, the good short-term performance of VCOCXO can be kept well. Now some rubidium frequency standards can also show almost the same block diagram as Figure 1 [3]. However, their signal processing method is different from the unreal time control method. For a longer than 10 second period the control to VCOCXO is loop-locked. However, for a shorter period the control is loop-opened.

4. Experiment result

Figure 2 shows to the certain sample periods the different frequency stabilities of the high-stable VCOCXO itself, the unreal controlled rubidium frequency standard and the same standard with the real controlled condition. The new rubidium frequency standard system can show 1×10-12/s frequency stability and the same phase noise specification as the crystal oscillator (<-145dBc/Hz at 100 Hz and <-155dBc/Hz at 1kHz), and 5×10-11/month drift rate.



o VCOCXO

× real time controlled rubidium frequency standard

* unreal time controlled rubidium frequency standard

Figure 2. The different frequency stability situations

5. Conclusion

Unreal controlled rubidium frequency standard can show not only the accuracy and good long-term performance of a conventional rubidium frequency standard, but also the good short-term stability of the highly stable VCOCXO. Some rubidium frequency standards always work at complicated vibration, radiation or other rigid environment. In this case, some sensors can be used to sensing the environment signals and feed to the processor. Based on the different sensitivities of the VCOCXO and physics package to the different environment influences and processing of processor, the stability of the rubidium frequency standard to environment influences will be enhanced.

References

[1] Wei Zhou, et. al., "Fundamentals of Measurement and Metrology Technology", Xidian University Publishing House, 2004, pp.137 – 142

[2] Lei Hai-dong et. al., "A study of the merit integration in a passive rubidium frequency standard", Journal of Time and Frequency, Vol.26, No.1, 2003, pp. 7-11

[3] Stanford Research Systems, Model PRS10 Rubidium Frequency Standard, Preliminary Operation and Service Manual