Comparison Among Precision Temperature Compensated Crystal Oscillators

Wei Zhou, Hui Zhou, Zongqiang Xuan, Wenqing Zhang
Dept. of Measurement and Instrument, Xidian University, Xi'an, 710071, P. R. China

Abstract

There are different precision temperature compensated crystal oscillators showing the frequency – temperature stability better than 1×10^{-6} in a very wide temperature range. To choose the suitable oscillator one should consider its frequency - temperature stability, power consumption, size, cost, phase noise and other specifications. According to a lot of experiments and comparisons, as the precision TCXO, double compensated TCXO which combines analog and digital compensation approaches together is more competitive in cost, size, stability and mass production compared with ordinary precision TCXO, DTCXO and MCXO based on AT cut crystals. It is difficult to use ordinary TCXO to get a very good frequency – temperature stability, but its repeatability can be good with suitable components and circuits, and quantization error does not exist in it. Therefore it is possible to be compensated further. TCXO production technology is very mature and it is easy to obtain VCTCXO with low phase noise, simple structure and good frequency – temperature repeatability. Double temperature compensated crystal oscillator divides the request to compensation accuracy into two parts, and every part is not very high. To the first compensation, analog one, only good repeatability and low phase noise are necessary. To the second compensation, digital one, only simple structure is necessary. Therefore the double compensated TCXO can combines two low compensation accuracies to a high accuracy up to $\pm2\times10^{-7}$. In this way the high precision is easy to be obtained and mass production too.

1. Introduction

Precision temperature compensated crystals oscillators including TCXO, DTCXO, MCXO and other special temperature compensated oscillators are used widely. Although SC cut crystals are used in some precision MCXO, the most precision temperature compensated crystal oscillators still use AT cut crystals. Recent years because the different precision temperature compensated crystal oscillators are used more and more, higher performance requests to them including higher frequency – temperature stability, smaller size, lower power consumption, lower cost, wider temperature range are needed. Generally, in the all temperature compensated crystals oscillators the compensated accuracy of TCXO is not high. The ordinary DTCXO and MCXO can show a better compensation performance, but the demand to components and control accuracy is very high or its phase noise is big. TCXOs based on analog compensated approach cannot show a very good frequency – temperature stability, but the repeatability of some of them is good and without quantized error problem. Therefore it is possible to be compensated further. Recent years many different integrated TCXOs are produced therefore it is easy to obtain the very simple first-stage compensated crystal oscillators. When combined with high-quality crystals their performance repeatability is better than their temperature stability by one order. With the improved thermister compensation network to build TCXO the same performance repeatability can also be obtained.

2. Double Temperature Compensated Crystal Oscillator and Comparison among the Different TCXOs

Double compensated TCXO combines analogue and digital compensation approaches together to build the new TCXO [1]. The crystal oscillator is compensated with analog approach firstly, then compensated secondly with digital approach based on an improved frequency – temperature performance. After the first compensation the frequency – temperature performance of VCTCXO has been improved, and the characteristic is different from the cubic curve of AT cut crystal resonator but more complicated or irregular. If one wants to improve its performance, the digital or microprocessor approach is a better way. Because the demand on compensation accuracy to the second compensation is lowered obviously, the hardware and software used here can be simpler. Only around 10 times improvement or less is enough.

The principle block diagram of the temperature compensated crystal oscillator based on the double compensation approach is shown in Figure 1 [2].

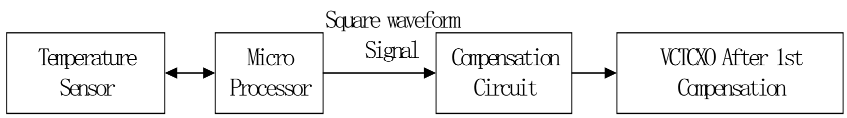


Figure 1. The principle block diagram of the double temperature compensated crystal oscillator

Double temperature compensated crystal oscillator divides the compensation accuracy request into two parts, and the accuracy of every part is not high. Only based on stable frequency – temperature performance and the limited compensation accuracies of TCXO and the simple processor, the final accuracy is higher. In the oscillator the most important is the good repeatability of the first analog compensation circuit. Some integrated VCTCXOs and thermisters compensation networks can show a good repeatability because of their low aging, small phase noise and good stability of components. The frequency – temperature stability of some analog compensated TCXO is only $\pm 2\times 10^{-6}$, but at the same temperature their biggest frequency variation is less than 0.3ppm ($\pm 0.15\,ppm$). It is possible to improve the frequency – temperature stability further. In the double temperature compensated crystal oscillator the demand to the components, especially to the components for secondly digital compensation is lowered. To obtain the highly compensated accuracy the stable temperature performance of crystals and the first analog TCXO in the wide temperature range is necessary.

Figure 2 shows the frequency – temperature curves of a good compensated TCXO in the different temperature experiments with the different time and temperature variation directions.

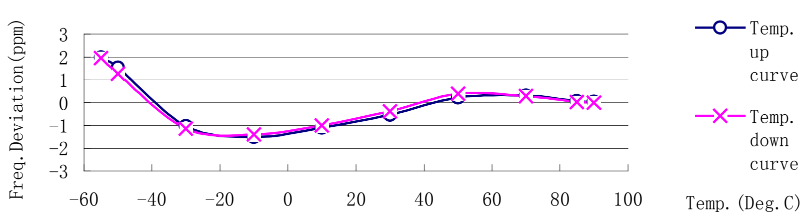


Figure 2. Frequency – temperature curves of a VCTCXO

Through the different experiments the frequency – temperature stability of the double temperature compensated crystal oscillators can be compensated into $\pm 2 \sim 3 \times 10^{-7}$ within –55 ℃to +85℃ temperature range [2].

In the all temperature compensated crystal oscillators, the compensated accuracy of TCXO is not high, for example ± 1 ppm. The microcomputer compensated crystal oscillator based on AT cut crystal can show a better compensation performance (±0.5 to ±0.2 ppm), but the demand to components and control accuracy is also very high.

According to long term experiments and comparisons, it is proved that to high precision TCXO double temperature compensated TCXO is more competitive in cost, volume, performance and production compared with ordinary TCXO, DTCXO and MCXO based on AT cut crystals. However, analog compensated TCXO has the lower phase noise.

A simple analysis equation about the frequency – temperature performance of the temperature compensated crystal oscillator can be used to express the frequency – temperature stability of the oscillator effectively. Equation 1 shows that how the frequency – temperature stability of TCXO is decided by the characteristics of crystal and improvement factor of compensation circuit.

$$\Delta F_T = \frac{\Delta F_{1T}}{Q} \qquad (1)$$

where ΔF_T is the frequency – temperature stability of TCXO,

ΔF_{1T} is the frequency – temperature stability of the uncompensated crystal oscillator,

Q is improvement factor of compensation circuit, and it is nonlinear.

Therefore, the crystal with stable and smaller frequency – temperature variation is more favorable for the excellent TCXO performance. At the same time stable and suitable Q is necessary. When ΔF_{1T} is smaller to the same ΔF_T Q can be small too. It is easy to compensate the crystal, or it is possible to obtain better frequency temperature stability.

If TCXO is based on double compensated approach, then

$$\Delta F_T = \frac{\Delta F_{1T}}{Q_1 Q_2} \qquad (2)$$

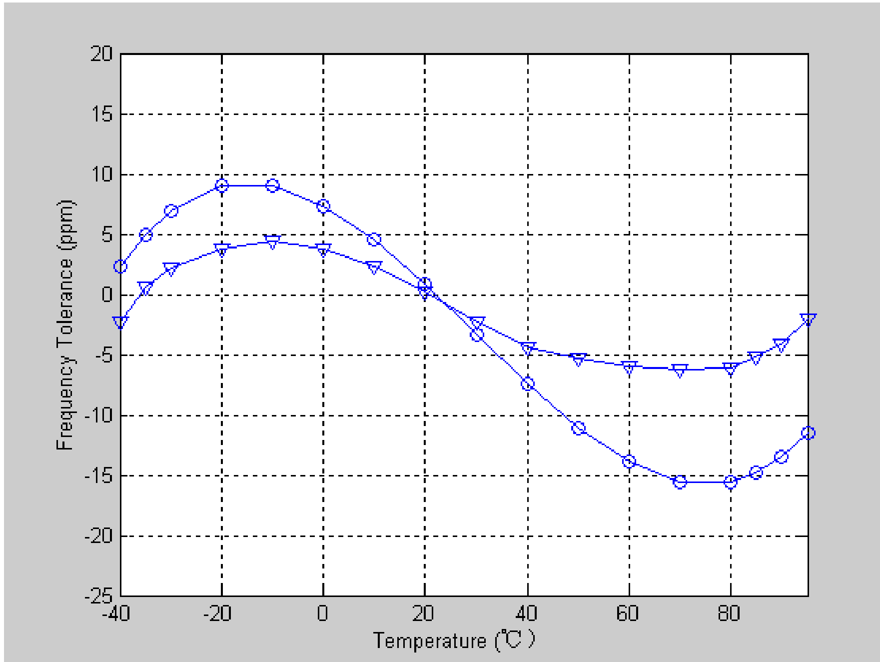
where Q1 is improvement factor of the first analog compensation,

Q2 is improvement factor of the second digital compensation.

Equation (2) expresses the contribution of Q1 and Q2 to ΔF_T. Q1 and Q2 share the function of Q and its fluctuation.

3. A potential technique for precision TCXO

A lot of principle experiments have been done for new crystals with smaller frequency variation in a wide temperature range. Besides the precise angle control of the crystal blank, compound electrode materials can also improve the frequency – temperature performance of the crystals [3]. The application of the new crystals will change the choices of temperature compensation techniques. Figure 3 shows the comparison of frequency temperature characteristics between the conventional and the new crystals.



—o conventional crystal

—▽ crystal with compound electrode

Figure 3. Comparison of frequency temperature characteristics between crystals

High stable analog compensation circuit and technique will show an important function in the development of precision temperature compensated crystal oscillators, because new-principle crystals with smaller frequency temperature variation will be manufactured. The crystals show typical cubic curve frequency – temperature characteristics at a wide temperature range, but with much smaller variation. For example from –35 ℃ to 80℃, their frequency variation is around ± 5 ppm. With analog compensation approach and based on excellent frequency – temperature performance of crystal, it is possible and easy to build new precision TCXO. Because of smaller frequency variation of the crystal in a wider temperature range the overtone crystals will also be used in the precision TCXO, and it is possible to obtain better stability and phase noise specifications with the TCXO. However, to compromise the aging and temperature performance is also important to use the crystal.

Compared with conventional digital and microprocessor compensation techniques, ± 0.5 ppm frequency temperature stability and better short term stability and phase noise specifications are easy to be completed with the crystals and analog compensated TCXOs.

4. Conclusion

There are the different precision temperature compensated crystal oscillators. The double temperature compensated crystal oscillator combines the analogue and digital compensation approaches together. Compared with the ordinary TCXO, DTCXO and MCXO, double temperature compensated TCXO is more competitive in cost, volume, frequency – temperature stability, power supply, other performances and convenient to be produced. Now it is possible for new-principle smaller frequency temperature variation crystals to be developed. In this case, analog compensated precision TCXOs will show better performance.

Reference

[1] The temperature compensated crystals oscillator based on combined analog with digital compensations, Chinese patent, patent number ZL 200420041513.9

[2] Wei Zhou, et. al., "Double Temperature Compensated Crystal Oscillator", Proceeding of 2004 IEEE International Ultrasonics, Ferroelectrics, and Frequency Control Joint 50th Anniversary Conference

[3] The method to compensate frequency temperature performance of crystal and oscillator based on stress processing of temperature sensing material, Chinese patent, patent application number 200510041941.0