Design For A Low Phase Noise Overtone TCXO

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***Abstract*—This paper relates to a novel 121.4MHz overtone TCXO with low phase noise. It differs from conventional approaches, and adding series inductances and frequency multiplication are not applied in it. It makes the frequency of a 100MHz 5th overtone crystal oscillator mixed with that of a 21.4MHz fundamental mode voltage controlled crystal oscillator(VCXO). The product is filtered and amplified to produce a 121.4MHz signal. In this design, the microprocessor AT89S52 is used to control frequency of 21.4MHz VCXO to implement the compensation. Experimental results are presented in this paper. The frequency-temperature stability of the prototype 121.4MHz TCXO has achieved ±3×10^{-7} within the temperature range from -40 to 85℃. A phase noise level of -140dBc/Hz at 1kHz offset has been realized. The approach presented in this paper can provide a high stability and low phase noise level requirement of overtone TCXO. In fact, it is also available for a higher frequency.**

I. Introduction

With the development of modern communication technology, the requirement of high stability and low phase noise TCXO has strongly increased. Because of the series-parallel resonance frequency interval of overtone crystal is inversely proportional to the square of the order of overtone, the compensation is difficult, the higher overtone order, the more difficult compensation of crystal oscillator. Many solutions have been completed to make compensation easy in past ten years[1]-[3]. The early engineering solutions for overtone TCXO are two as follows: one method is adding series inductances to resonator to expand the series-parellel resonance frequency interval; the other one is multipling the compensated fundamental frequency to the target frequency. There are sereval limitations in the first method. Firstly, it makes the loaded Q factor of crystal lower and degrades the phase noise. Secondly, the temperature stability of crystal could be degraded because of the poor temperature performance of the inductance. Besides, the latter way would deteriorate phase noise on 20lgN slope as well, where N is the multiplication times.

In recent years, a novel method by using DDS +PLL is developed to overcome the problem in temperature compensation of overtone oscillator. DDS is used to generate a correction frequency equal to the difference between the Nth overtone frequency of resonator and the desired output frequency, and then PLL is used to sum the two frequency and produce a stable output frequency. This method may achieve a good temperature stability. But the application of PLL technique has well known shortcomings[4][5]:

(1) PLL contributes “technical noise” and a spur on comparison frequency;

(2) The value of output frequency should belong to a frequency grid.

From the discussion above,we can see the system of DDS+PLL is too complicated and its phase noise is limited by noise floor of DDS and that of PLL.

In this work, we present a way of investigation which can improve the temperature stability of overtone TCXO, and provide a potential way of achieving high level of phase noise performance [6][7].

II. Basic Structure Of 121.4MHz Overtone TCXO

A block diagram of the 121.4MHz low phase noise overtone TCXO is shown in Fig. 1. The system is composed of a temperature sensor, a 100MHz low-phase noise crystal oscillator, a 21.4MHz VCXO, a mixer, a passive low-pass filter, a band-pass filter, a microcontroller and a low noise amplifier.

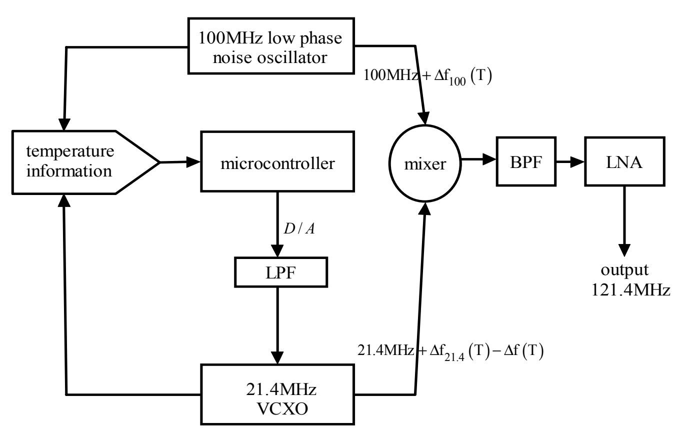


Figure 1. 121.4MHz TCXO block diagram

The 100MHz low phase noise oscillator is a Butler circuit, and the 21.4MHz VCXO is based on Colpitts circuit with fundamental-frequency resonator. This system utilizes a 100MHz AT-cut 5th overtone crystal oscillator mixed with a 21.4MHz AT-cut voltage controlled crystal oscillator(VCXO). The desired 121.4MHz signal is obtained through a mixer, a band-pass filter and a low noise amplifier. The microcontroller controls the compensating voltage of the 21.4MHz VCXO to generate a compensation frequency and implement the compensation. The passive low-pass filter is used to strongly decrease the fast frequency variations resulting from the digital compensation to improve the noise in TCXO.

III. Some Practical Considerations

In the study, it is found that the phase noise of TCXO is mainly determined by that of 100MHz low phase noise oscillator, the 21.4MHz VCXO, the mixer and the digital system. The main means to decreasing these influences on a spectrum of the output signal as follows:

(1) Design a 100MHz low phase noise crystal oscillator, it is based on a Butler circuit. The phase noise level of 100MHz oscillator is about -150dBc/Hz at 1KHz offset measured with Agilent E5500.

(2) Design a significant 21.4MHz VCXO with wide tuning frequency range. This oscillator is based on Colpitts circuit. Because the frequency range to be compensated is too wide, it makes the loaded Q-factor of oscillator lower. Therefore, it degrades the phase noise in VCXO. In this paper, it seems that it is difficult to get an excellent phase noise performance in VCXO with wide tuning frequency range.

(3) Design an excellent mixer. Mixers in the market can work at a wide frequency range, but its impedance is difficultly matched. It also deteriorates the phase noise in sytem. In this study, a simple diode mixer is designed, we compress the working frequency range and improve impedance match to improve its phase noise.

(4) Design a passive low pass filter with a time constant of about 0.4 second to produce a smooth function of compensation voltage without discrete voltage steps of D/A. As we have known, there are fast frequency variations caused by the fast digital variations[8][9]. The passive low-pass filter is used to strongly decrease the fast frequency variations due to the digital compensation and improve the noise in TCXO.

IV. Compensating Process

From -40℃ to +85℃, the output frequency of 100MHz and 21.4MHz would change with the temperature. Let's suppose the frequency deviations of the 100MHz and 21.4MHz oscillators are $\Delta f_{100}(T)$ and $\Delta f_{21.4}(T)$ respectively at a certain temperature T. After mixing and filtering, We define the total deviation as $\Delta f(T)$, and $\Delta f(T)=\Delta f_{100}(T)+\Delta f_{21.4}(T)$. Δf_{100} and $\Delta f_{21.4}$ are respectively defined as the deviation of 100MHz and 21.4MHz oscillator at a certain temperature T.

In this system, the microcontroller gets the information from the temperature sensor and converts it to a voltage. After filtering by low pass filter, the compensation voltage $\Delta V(T)$ is gained. Then adding the $\Delta V(T)$ to 21.4MHz VCXO which generates a compensation frequency $-\Delta f(T)$ to compensate the $\Delta f(T)$. The stable 121.4MHz signal is gained and the compensation is accomplished. $-\Delta f(T)$ is defined as the change of 21.4MHz VCXO output frequency, which is brought about by changing the capacitance of the varactor. It compensates the total(121.4MHz) frequency deviation of both the two oscillators, and it is a function depending on the temperature T. Here $-\Delta f(T)$ is obtained by the experiment.

V. Experiment Results

The sample is designed to verify the feasibility of low phase noise and high temperature-frequency stability with this compensation approach. The temperature measurement results are shown in TABLE I, where uncompensated frequencies are measured under a fixed voltage 1.1V.

In TABLE I, f_{uc} refers to the differences between the uncompensated frequency and f_0, and f_c refers to the differences between the compensated frequency and f_0. Then the diagram of TCXO frequency-temperature stability over -40℃ to +85℃ is shown in Fig. 2.

As it is limited by conditions of the sample, the frequency of the two crystals are higher than that we required. We choose the 121,402,700Hz as the central frequency f_0. The phase noise curve of the prototype TCXO is measured with Agilent E5052 and shown in Fig.3.

TABLE I. Compensation Results Of 121.4 MHz Overtone TCXO (the central frequency f_0=121,402,700 Hz)

T (℃)	f_{uc} (Hz)	f_c (Hz)	T (℃)	f_{uc} (Hz)	f_c (Hz)
-40	-587	-19	30	-1664	+6
-30	-123	-5	40	-2068	-10
-20	-58	+28	50	-2332	0
-10	-33	+49	60	-2406	+11
0	-417	+23	70	-2161	+31
10	-800	+24	80	-1507	+18
20	-1178	-21	85	-968	+42

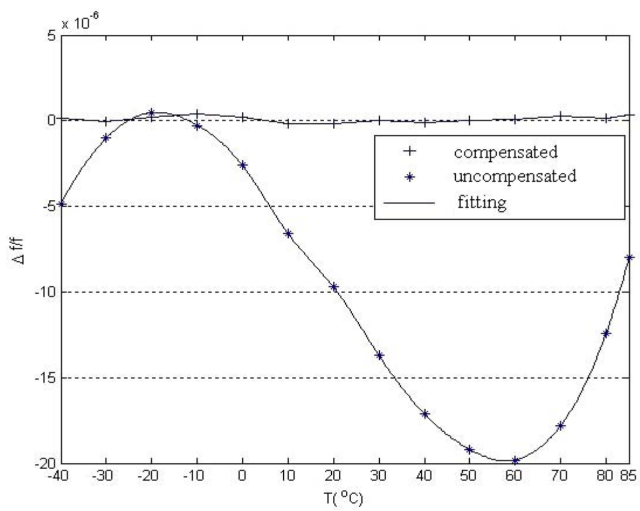
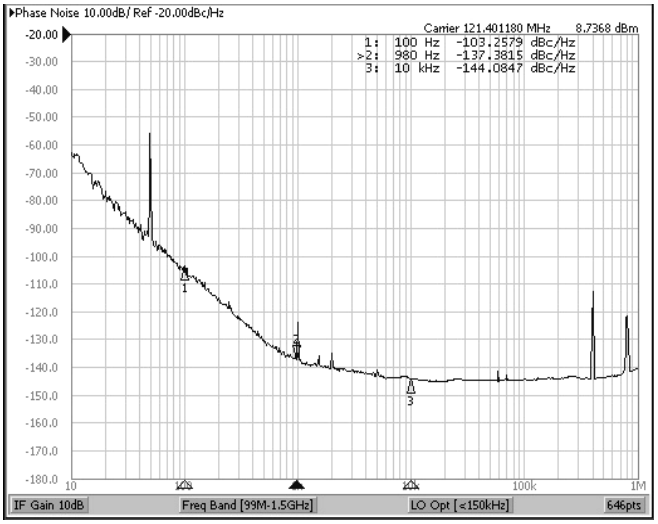
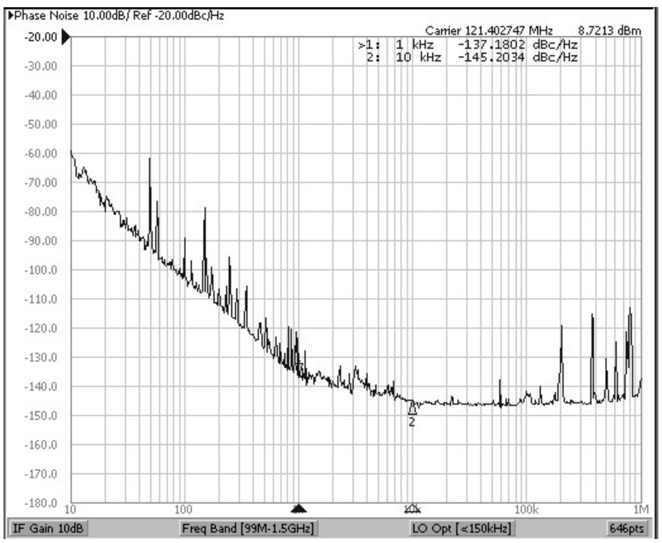


Figure 2. Temperature compensation results for TCXO



(a) Phase noise plot of the prototype TCXO without microcontroller



(b) Phase noise plot of the prototype TCXO with microcontroller

Figure 3. Phase noise plot of 121.4MHz TCXO

From Fig.3, it is indicated that the 121.4MHz TCXO achieves the phase noise level of -137dBc/Hz at 1kHz offset whether the microcontroller is connected or not, i.e. the digital system does not deteriorate the phase noise, but contributes more spurs.

In the design, we found that the phase noise of 21.4MHz VCXO is the most important for the overtone TCXO. For making the prototype TCXO implement lower phase noise, it is improved through improving the phase noise of 21.4MHz VCXO by debugging the circuit. Then the phase noise of the improved TCXO is measured as Fig.4. From this curve, the phase noise of the sample approximately achieves -140dBc/Hz at 1kHz offset.

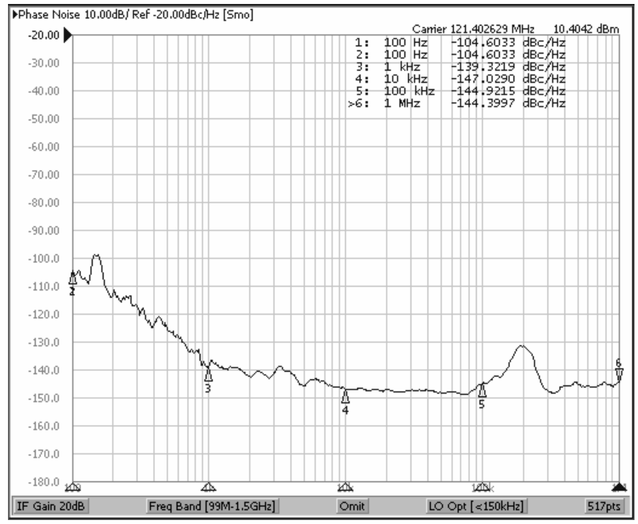


Figure 4. Phase noise plot of improved overtone TCXO

VI. CONCLUSION

A sample was successfully accomplished with the presented compensation approach. It is proved by experiments that the passive low-pass filter can produce a smooth function of compensation voltages, and improve the noise of TCXO effectively. From Fig.3 and Fig.4, we can see the phase noise of the TCXO after improved is better than before, but there is a bulge at 200kHz offset from the carrier in the improved TCXO because of the impedance mismatch existing in the circuit. Besides, additional phase noise and other spurious responses are unexpected results when connecting a digital system to TCXO. Many people use standard method of physical and electrical isolation, shielding, and electrical decoupling to minimize the induced phase noise and spurious response effects[10]. As a matter of fact, how to eliminate the spurious is still a problem, we are considering a further study.

From the above, this compensation method is able to overcome the disadvantages of frequency stability fall and phase noise deterioration that are provoked by adding inductance or frequency multiplication in traditional compensation approaches or high fundamental frequency compensation, besides, the design is much easier than that of DDS+PLL. This is a progress in technology. Compared with existing methods, this approach has some prominent advantages as follows:

(1) It is helpful for conveniently implementing the high-frequency overtone TCXO with the high stability.

(2) It is helpful for improving the phase noise in overtone TCXO.

(3) It is also available for a higher frequency.

It is indicated from experiment results that the compensation approach is helpful for implementing the high-frequency overtone temperature compensation over a wider frequency range with high stability and low phase noise. In the further study, an excellent mixer is considered, and we expect to get a lower phase noise level. So it has the vital significance to the high-frequency overtone TCXO.

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