Temperature Coefficients Improvements of VHF Oscillator Circuit for OCXO

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Abstract— **This paper presents the improvements of the temperature coefficient of the VHF oscillator circuit for OCXO. The solution for this discrepancy, not only to regulate the temperature precisely, but also the temperature coefficients of oscillator loop itself should be considered and reduced for better frequency-temperature performance to get higher frequency stability for the OCXO.**

I. INTRODUCTION

The low noise high frequency reference sources have been used for the precision time and frequency measurement equipments and Doppler systems. And additionally, point to point microwave telecom network system have been becoming important more and more, the higher frequency low noise reference source of PLL systems is preferred by the reason of the dividing ratio's reduction in it. For a typical application, the VHF OCXO is phase locked to the 10MHz external reference signal. However, when the external signal lacks, stability of the VHF OCXO may be demanded.

Generally, there will be not so big problem of the temperature coefficient of the oscillator circuit of the OCXO, since the whole of oscillator assembly including quarts crystal has been placed inside of the oven or oven mass where the oven temperature has been regulated particularly [1]. But in the case of the influence of the temperature coefficient of the oscillator loop is too large, the zero temperature coefficients is going down, and it will be lower temperature than maximum operating temperature in some cases. On the other hand, the needs for reducing the power consumption and space saving have been increasing in these days. The solution for this discrepancy, not only to regulate the temperature precisely, but also the temperature coefficients of oscillator loop itself should be considered and reduced for better frequency-temperature performance to get higher frequency stability for the OCXO.

II. OCXO DESIGN

The temperature coefficient of the oscillator circuit without quarts resonator in the OCXO package should be also considered carefully as to be the stable reference oscillator.

Each component has its own temperature coefficient and placed position at some places on the printed circuit board where the temperature changes by the ambient temperature variation. The comprehensive temperature coefficient of the oscillator circuit is depended upon such physical condition by its construction. Figure 1 shows the simplified functional block diagram for the experiments. Both of the power and the thermal regulators are also designed to avoid the noise effects to the oscillator circuit. The thermal sources are set closer to the quarts crystal, and thermal sensor is set between the thermal sources and the quarts resonator. The setting oven temperature is to keep the crystal at a stable temperature higher than the highest ambient temperature to which the OCXO will be exposed. The 50ohms pad is placed before output to reduce the effect of the reflected signal from the load to the oscillator.

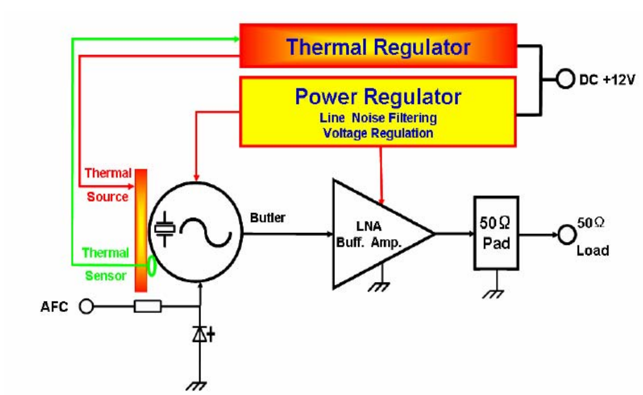

Figure 1. Simplified functional block diagram of the OCXO

Figure 2 shows the functional schematic diagram of the Butler type 5th overtone SC-cut crystal controlled oscillator. The SC-cut crystal resonator offers the best overall performance, while the AT-cut offers lower cost. The base of both of the BJT's of the oscillator loop and the buffer amplifier are connected to the ground, it can be expected the low noise as a low noise oscillator.

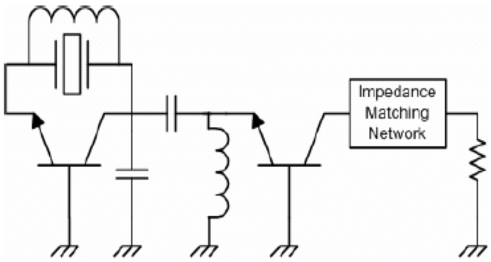

Figure 2. Functional schematic diagram of the Butler type oscillator

Figure 3 shows a simplified schematic of the Butler type oscillator circuit. The resonance frequency of the LC resonator in the oscillator loop, can keep stable excitation of the C-mode of the SC-cut crystal to avoid the B-mode excitation. Various kinds of physical designs of the oven mass and the temperature coefficient devices in the oscillator loop have been considered and experimented. Usually, the oven temperature is set to the resonator's lower turnover temperature in the range of ambient temperature from -20 to +70deg.C. Since the lower turnover temperature of the SC-cut quarts resonator is around from +80 to +90deg.C, the temperature coefficients of the oscillator loop are also considered to decrease to keep as close as this. The oscillator temperature coefficient is -10ppb/deg.C by using thermal analytic result. We have achieved very high temperature stability VHF OCXO using SC-cut crystal which is designed by using new design concept with a simple method of the temperature compensated oscillator loop and the package of the quarts crystal itself actively used as the oven mass. The new method can be expected to eliminate the process of tuning the oven temperature without any careful attention. To make it to the high temperature stability, we connected the temperature compensating type capacitor with the trimmer capacitor of the oscillation loop in parallel. Table 1 shows the equivalent constant value of the C-mode of the 5th overtone 100MHz SC-cut crystal witch is used for the predictions experiments.

Table 1. Equivalent circuit constant of the SC-cut crystal

		Unit
Q	135,517	
R_1	109.48	ohms
C_0	3.750	pF
C_1	0.107	fF
Lower turnover temperature	85.8	deg.C

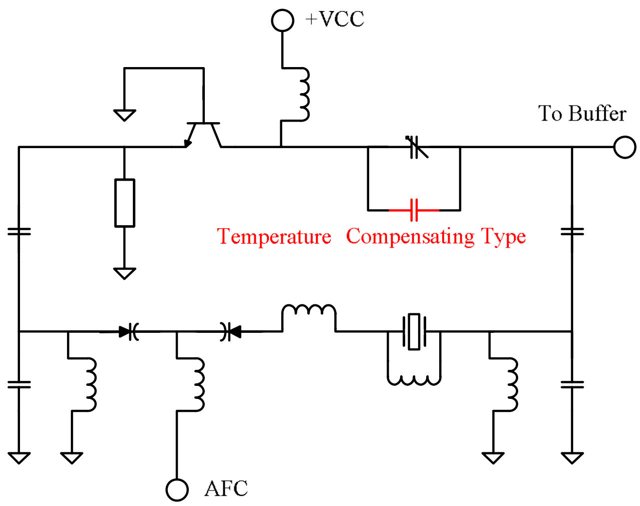

Figure 3. Simplified schematic of the Butler type oscillator circuit

Generally, frequency-temperature behavior of the OCXO using SC-cut resonator is approximately of cubic function with respect to ambient temperature as follows [2].

$$\Delta f / f = \frac{1}{G}\{\alpha(T-T_0)^3 + (\beta+\zeta+\eta)(T-T_0)+\gamma\} \qquad (1)$$

where parameter **α** is a constant which is intrinsic to SC-cut resonator. Parameter **β** depends on cutting angle of resonator. Parameter $\mathbf{T_0}$ corresponds to inflection point of cubic function. Parameter **γ** is frequency deviation. Parameter **ζ** is oscillator circuit temperature coefficient. Parameter **η** is temperature coefficient of temperature compensating type capacitor. Parameter **G** is a thermal gain of the oven. Thermal gain is defined as the external to internal temperature excursion ratio. Temperature coefficient of the temperature compensating type capacitor is -750ppm/deg.C. Table 2 is the parameter of the OCXO using 100MHz SC-cut quarts.

Table 2. Parameter of the OCXO

Symbol		Unit
α	0.0608	ppb/ deg.C^3
β	-15	ppb/ deg.C
T_0	95.3	deg.C
γ	-94	ppb
ζ	-10	ppb/ deg.C
η	6.13	ppb/ deg.C
G	1000	

We substituted the parameter of the Table 1 for equation (1). Figure 4 is Frequency deviation vs. temperature of SC-cut quarts (ζ=0, η=0, G=1), and SC-cut quarts with oscillator circuit temperature coefficient (ζ=-10, η=0, G=1).

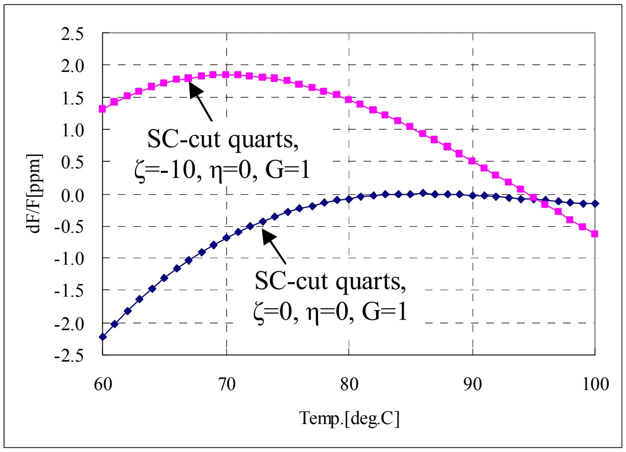

Figure 4. Frequency vs. temperature of SC-cut quarts and SC-cut quarts with oscillator circuit temperature coefficient

Figure 5 is Frequency deviation vs. temperature of SC-cut quarts with oscillator circuit temperature coefficient and oven control (ζ=-10, η=0, G=1000), and SC-cut quarts with oscillator circuit temperature coefficient, oven control and the temperature compensating type capacitor (ζ=-10, η=6.13, G=1000). By using the temperature compensating type capacitor we have achieved very high temperature stability.

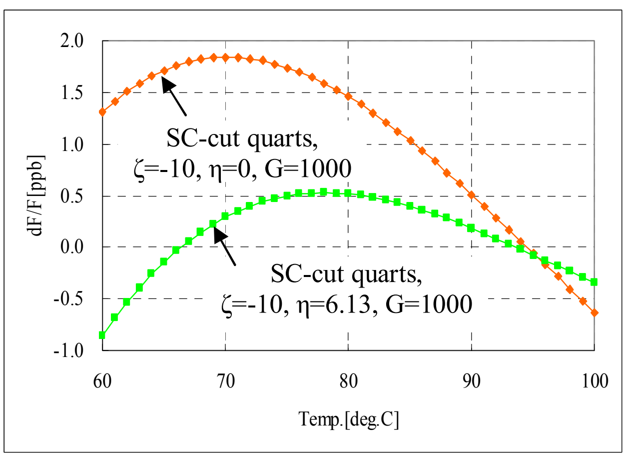

Figure 5. Frequency vs. temperature of SC-cut quarts with oscillator circuit temperature coefficient

III. PERFORMANCE RESULTS

We measured the frequency-temperature behavior of the 100MHz SC-cut quarts units. Figure 6 is frequency deviation vs. temperature of SC-cut quarts units. The lower turnover temperatures are from +83.5 to +87.1deg.C. This plot is corresponding to SC-cut quarts of Figure 4.

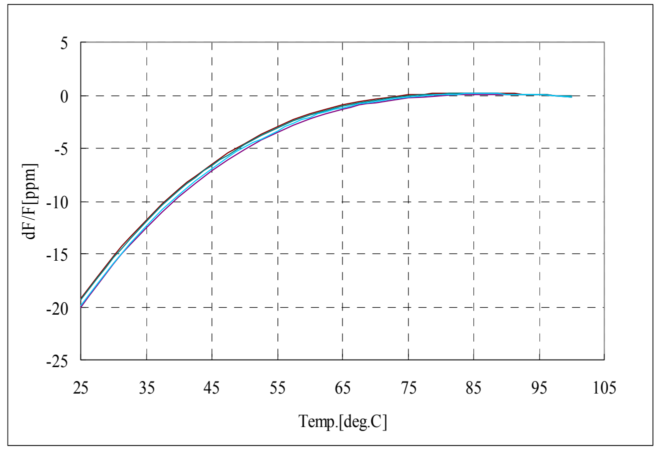

Figure 6. Frequency vs. temperature of SC-cut quarts units

Figure 7 is frequency deviation vs. temperature of the OCXO without oven control and temperature compensate. The turnover frequency changed from +85deg.C to +70deg.C. This result is corresponding to SC-cut quarts with oscillator circuit temperature coefficient of Figure 4.

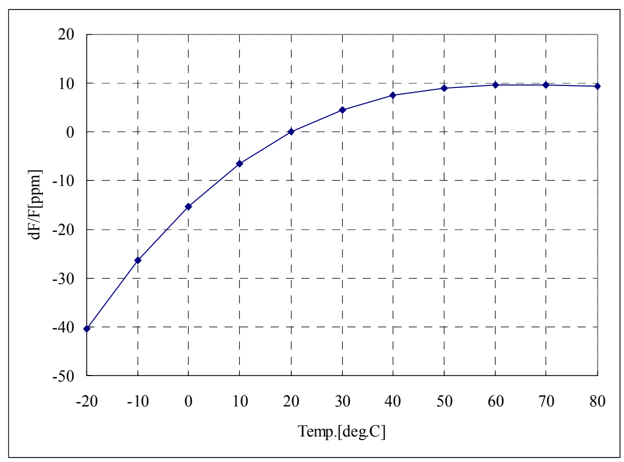

Figure 7. Frequency vs. temperature of the OCXO without oven control and temperature compensation

Figure 8 shows some sample graphs of the frequency temperature stability performance which are after compensation. These results show the temperature performance within +/-4ppb in the range of from -20 to +70deg.C.

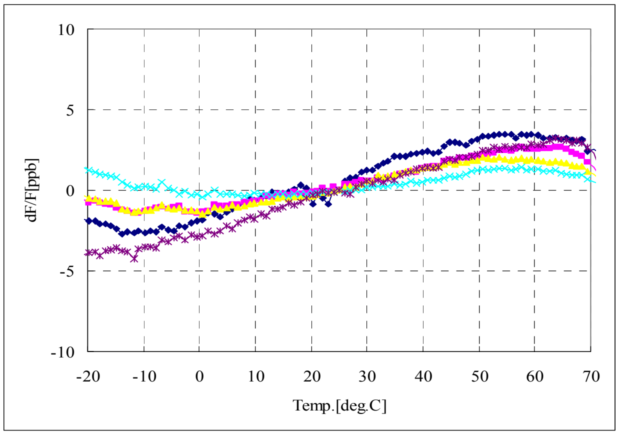

Figure 8. Frequency temperature performances of the OCXO

This OCXO requires a single +12Vdc input. Figure 9 show 1.06W power consumption as the steady state at +25deg.C in still air.

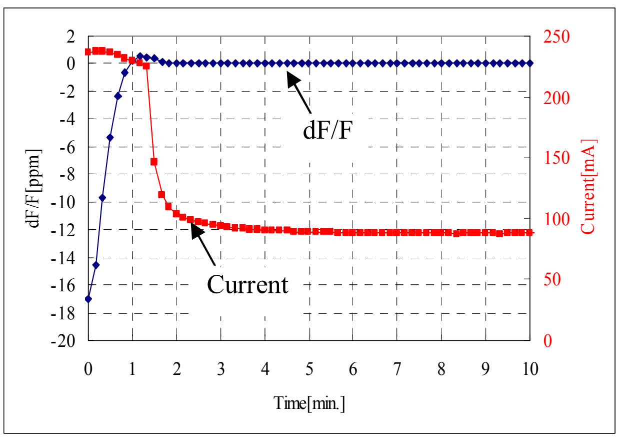

Figure 9. Start up performance of the OCXO

Aging is expressed a normalized frequency change per a day after 30 days [3]. Figure 10 shows the aging behavior of the OCXO. The aging estimated value after one year is 65.8ppb, and it is small. Therefore, the capacitance change of the temperature compensating type capacitor is a little.

Figure 11 shows the inside of the OCXO. The HC-43/U crystal unit is set under the PCB without the oven mass to reduce the total power consumption. The thermal sources are set closer to the quarts crystal, and thermal sensor is set between the thermal sources and the quarts resonator.

Figure 12 shows the resistance welded hermetic sealed package which size is 25.4x25.4x12.7mm, and lead-free designed.

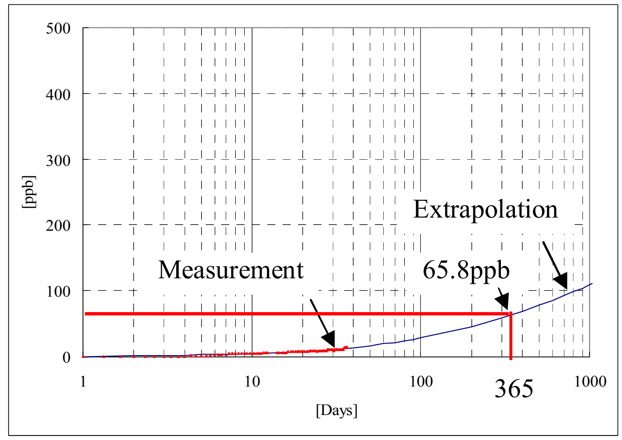

Figure 10. Aging Behavior

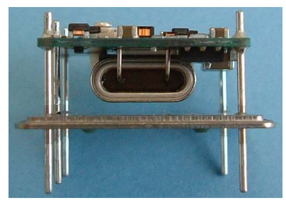

Figure 11. Inside of the OCXO

Figure 12. Finished package

IV. CONCLUSIONS

We have achieved very high temperature stability VHF OCXO using SC-Cut crystal which is designed by using new design concept with a simple method of the temperature compensated oscillator loop and the package of the quarts crystal itself actively used as the oven mass. This OCXO has been announced already as the 9325D type which output frequency covers from 80 MHz to 135 MHz. The 9325D is a low phase noise oscillator (not shown in this paper) which is suitable as VHF frequency reference source for the microwave and higher frequency synthesis and some application.

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