2000 IEEE/EIA International Frequency Control Symposium and Exhibition

ULTRA-STABLE OCXO USING DUAL-MODE CRYSTAL OSCILLATOR

Yasuaki Watanabe, Kiyoharu Ozaki, Shigeyoshi Goka and Hitoshi Sekimoto
Tokyo Metropolitan University, Hachioji, Tokyo, JAPAN

Abstract

A high-stability oven controlled crystal oscillator (OCXO) (frequency stability; ± 0.5 ppb from -10 to +50 °C) has been developed using a dual-mode SC-cut quartz crystal oscillator. The OCXO described here uses a conventional oven control system for coarse compensation and a digital correction system, which uses B-mode signals as a temperature sensor, for fine compensation. These compensations combine to greatly improve the C-mode frequency stability when the ambient temperature changes. The experimental results indicated that the proposed OCXO had a frequency-temperature stability 60 times better than that of a free-running mode oscillator.

Introduction

Oven controlled crystal oscillators (OCXOs) have been used in communication systems as highly stable frequency sources. The development of synchronous network systems has made high-performance OCXOs necessary [1]. OCXOs using SC-cut resonators have been used for such applications because they have good short-term frequency stability and low noise characteristics. However, the frequency stability when the ambient temperature changes is not very good: to prevent thermal deterioration of electronic parts, the oven temperature is generally kept at 70 °C about ten degrees lower than the turnover temperature of SC-cut resonators.

We reported a low-noise dual-mode SC-cut oscillator that simultaneously excited C and B modes in 3rd overtone resonator [2]. We showed the phase noise level in this dual-mode oscillator was only 3-6 dB higher than in a single-mode oscillation [4].

In this paper, we describe a structure and measurements of an OCXO using a dual-mode oscillator that excites the C and B-modes of a 10 MHz third overtone SC-cut crystal resonator.

The configuration of the dual-mode oscillator is described in Section II, and the temperature compensation method is described in Section III. The results demonstrate that the temperature frequency stability of the proposed OCXO is 60 times better than that of a free running OCXO.

Temperature Characteristics of SC-cut Resonators and Oscillation circuit

Figure 1 shows the frequency spectrum of the 10-MHz third overtone SC-cut resonator for dual-mode oscillator. The C mode has parabolic temperature characteristics and a peak temperature of about 80 °C. However, the oven temperature is generally set at 70-75 °C to prevent thermal deterioration of the electronic parts. This temperature difference is one for the reasons of frequency instability for the ambient temperature change.

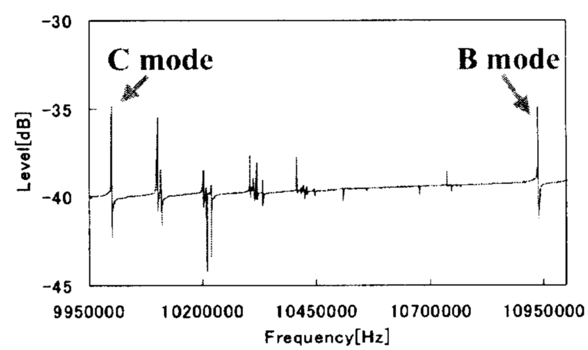

Fig. 1. Frequency spectrum of SC-cut crystal resonator.

B mode has large first-order temperature coefficient. If the other spurious modes are not located at around the B mode, the resonant frequency of the B mode changes linearly.

The proposed OCXO detects the temperature change in the oven using the B-mode frequency and controls inverse bias voltage of a varactor diode so as to keep the C-mode oscillation frequency constant.

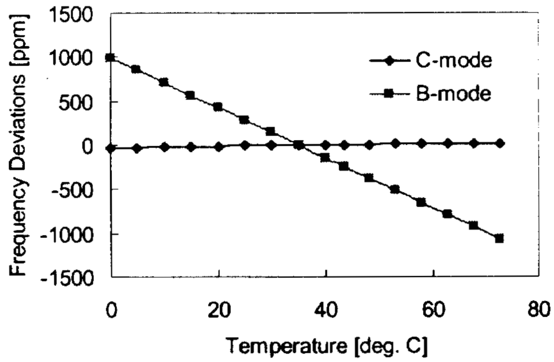

Fig. 2. Frequency - temperature characteristics of C and B modes in SC-cut resonator.

Figure 2 shows an example of the frequency-temperature characteristics of B and C modes.

Figure 3 illustrates the dual-mode oscillator we presented at the 1997 Frequency Control Symposium [4]. This oscillator uses two narrow-band active circuits with different negative-resistance bands; the circuits are connected in parallel at a common resonator terminal. This oscillator can excite any mode in the common resonator even if the resonant frequencies are close to each other. The center frequencies of the gain-band width in each oscillation circuit are determined by the series resonant frequencies of the resonator filter branches. Under the experimental conditions, the frequency change of the B mode was ± 40 ppm even with the resonator placed in the oven. We therefore used a ceramic resonator filter that produced a wide gain-band in a B-mode driving circuit.

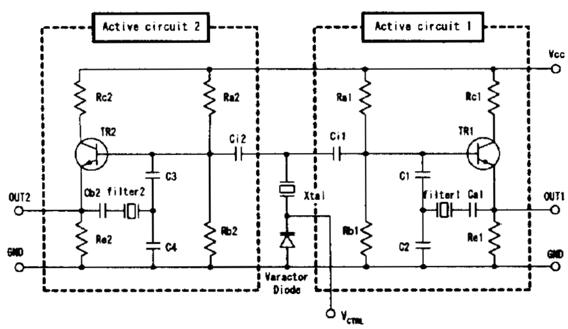

Fig. 3. Dual-mode transistor Colpitts oscillator.

Figure 4 shows the frequency spectrum of the input impedance (real part) of the dual-mode oscillator. Two negative resistance regions were obtained at around the B- and C-mode frequencies and a wide gain-band was obtained around the B-mode frequency.

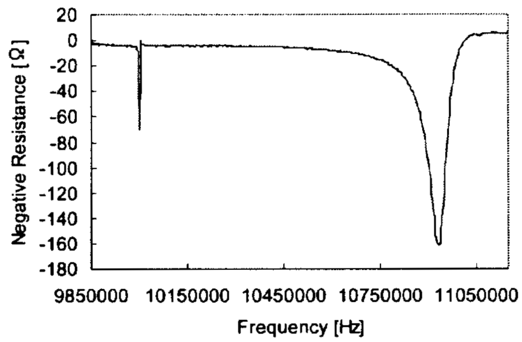

Fig. 4. Frequency characteristics of negative-resistance in dual-mode oscillator.

Temperature Detection and Frequency Compensation

In this OCXO, a B-mode signal is used as temperature sensor and a C-mode signal is the frequency reference of the B-mode counting. Figure 5 shows a block diagram of the proposed OCXO. The B-mode frequency was measured with a frequency counter and the output of the counter is inputted to a D/A converter via a control circuit. The D/A converter output controls inverse bias voltage of the varactor diode connected in series to the SC-cut resonator. The SC-cut resonator is placed in an oven typically used for OCXOs. The temperature in the oven is kept at 70 ± 1 °C.

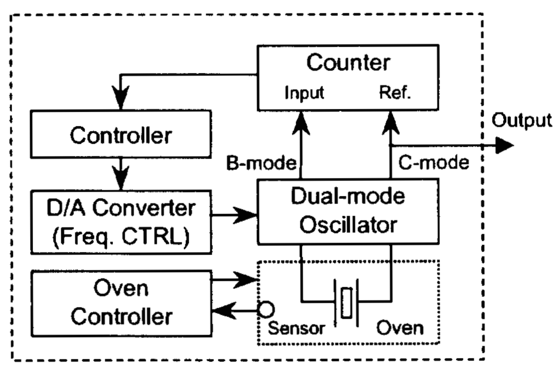

Fig. 5. Block diagram of dual-mode OCXO.

The temperature compensation data are determined using the following procedure;

1) Change ambient temperature.

2) Measure C-mode frequency with an external frequency counter using the Cesium frequency standard.

3) Generate voltage data that matches the C-mode frequency with the nominal frequency.

4) Measure B-mode frequency with an internal counter governed by C-mode frequency.

5) Record the voltage value and the B-mode frequency.

6) *Repeat 1) to 5) at ten-degree intervals.*

In this procedure, the measured B-mode frequency contains errors because the C-mode frequency is slightly changed by the control voltage. However, the temperature sensitivity of the B-mode frequency is over 100 times larger than that of C-mode, making the errors negligible.

Because of the B-mode frequency and control voltage were measured at ten-degree intervals, we used the Lagrangian form to interpolate the frequency-voltage relation.

Results

A Cesium frequency standard that has stability of 1E-13/day was used as the reference frequency when the compensation data and the frequency stability were measured. The compensation data was taken at ten-degree intervals from -10 to 50 °C, and the frequency stability of the OCXO was measured for the same temperature range at five-degree intervals. We used a six-degree Lagrangian function to interpolate the data for the compensation table.

The electrical equivalent parameters of the SC-cut resonator are shown Table 1.

Figure 6 shows a comparison of the experimental results between the free running mode (without compensation) and the compensated mode. The ordinate was normalized by the measured frequency at 20 °C. The stability of the OCXO in the free-running mode was ± 30 ppm, and very flat characteristics were obtained for the frequency compensation mode.

Figure 7 expands Fig. 6 around the intersection. The frequency stability of the compensation mode was within ± 0.5 ppb.

Table 1. Equivalent parameters of the SC-cut resonator.

Mode	R_1(Ω)	L_1(mH)	C_1(fF)	f_s(Hz)	Q
C	56.4	1170	0.22	9999741	1.35E6
B	36.8	1240	0.17	10937669	2.32E6
C_0(pF) = 5.8					

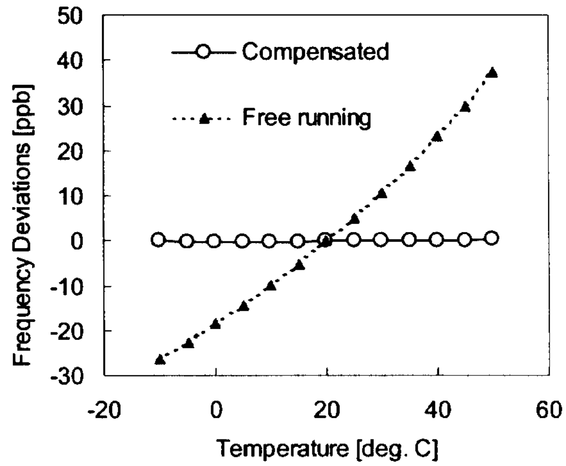

Fig. 6. Frequency-temperature characteristics of dual-mode OCXO.

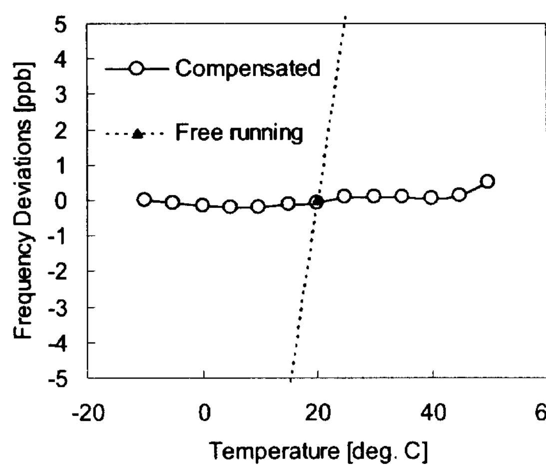

Fig. 7. Frequency-temperature characteristics of dual-mode OCXO (expanded).

Conclusion

The proposed dual-mode digital OCXO's frequency stability is 60 times better than that of free-running mode. Integration of the compensation circuit, hysteresis measurement and expansion of the operation temperature range are future areas to be explored

Acknowledgement

The authors would like to thank for Takeshi Uchida, NDK co. ltd. for supplying OCXO units.

References

[1] H. Ujiie, K. Maruo, Y. Watanabe, S. Goka and H. Sekimoto, "The Application of Wavelet Transformation to the Study of Time Prediction Errors of Clocks for Use in the CDMA Digital Communication Systems",*Proceedings of Joint Meeting of The 13th European Frequency and Time Forum and 1999 IEEE International Frequency Control Symposium.*

[2] I. Niimi, Y. Watanabe, H. Sekimoto and S. Goka, "Active-Impedance Analysis of Narrow-Band Oscillators with Resonator Filters and Its Application to Dual-Mode Crystal Oscillators", *IEICE Transactions on Electronics*, Vol.E81-C, No.2 ,pp.284-289 (Feb., 1998)

[3] Y. Watanabe, T. Okabayashi, S. Goka, and H. Sekimoto, "Phase Noise Measurements in Dual-Mode SC-Cut Crystal Oscillators", *Trans. UFFC*, Vol. 47 Number 2, pp.374

[4] Y. Watanabe, H. Sekimoto, S. Goka, and I. Niini, "A Dual Mode Oscillator Based On Narrow-Band Crystal Oscillators With Resonator Filters", *Proceedings of 1997 IEEE International Frequency Control Symposium*, pp.932-937.