A Miniature Oven-Controlled Crystal Oscillator (OCXO) with ppt Stability over Temperature Using High-Order Polynomial Temperature Control

Shuenn-Jyh Chang, Wen-Cheng Wang, Sheng-Hsiang Kao, and *Wan-Lin Hsieh
TXC Corporation
Tao Yuan City, Taiwan
*wilhsieh@txc.com.tw

***Abstract*—This work presents an ASIC-based miniature oven-controlled crystal oscillator (OCXO) with ppt (part-per-trillion) stability over ambient temperature from -40 to 85˚C using high-order polynomial temperature control. The proposed OCXO integrates the high-order polynomial temperature control circuit in an IC, thus realizing ppt stability in a miniature 9mm x 7mm footprint. The high-order polynomial temperature control is applied to compensate the complicated non-linear frequency stability error over ambient temperature contributed from higher thermal loss due to miniaturized package and more sensitive thermal effect of integrated circuit. As a result, the proposed OCXO with ppt stability in a miniature footprint provides highly accurate synchronization reference for base station, distributed unit (DUs), and centralized units (CUs) that need longer holdover capability.**

Keywords—ASIC-based miniature OCXO; high-order polynomial temperature control; ppt stability; holdover

I. Introduction

The fifth generation of mobile networks (5G) provides various options to split the baseband processing function into distributed unit (DUs) and centralized units (CUs) that requires a highly accurate synchronization reference clock, because DUs and CUs deploy variety synchronization sources and play a critical role to avoid to synchronization failure. Typically deployments need few hours of holdover capability and high stability OCXOs are commonly used as reference clock during holdover state in such practical scenario. High stability OCXOs with ppt level over ambient temperature have been demonstrated in previous works [1-2]. However, these conventional OCXOs using discrete circuit housing in a hermetically metal package with large footprint. In addition, discrete circuit needs frequency adjustment and target temperature setting during production by manually replacing discrete capacitors and resistors, respectively.

Achieving high stability over ambient temperature in an ASIC-based miniature OCXO is a challenge because of higher thermal loss due to miniaturized package [3-8] and more sensitive thermal effect of integrated circuit, contributing to a non-linear frequency stability characteristic over ambient temperature as seem the actual frequency output in Fig. 1. In this work, we proposes a high-order polynomial temperature control to compensate the complicated non-linear frequency stability error over ambient temperature in a miniature 9mm x 7mm package.

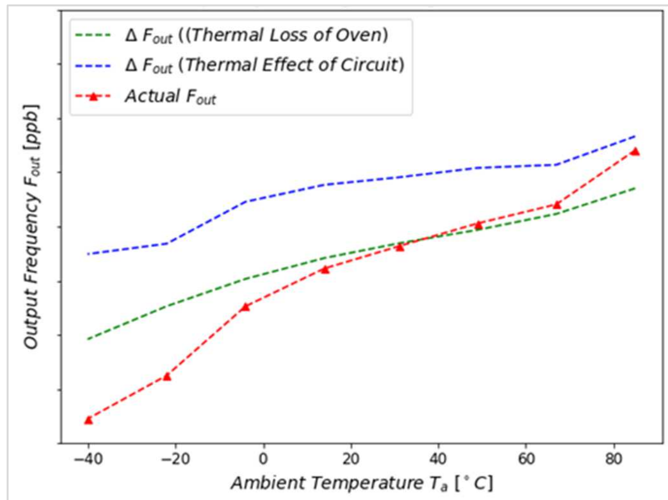

Fig. 1. Non-liniear frequency stability characterestic over ambient temperature contribured from thermal loss of oven and thermal effect of circuit.

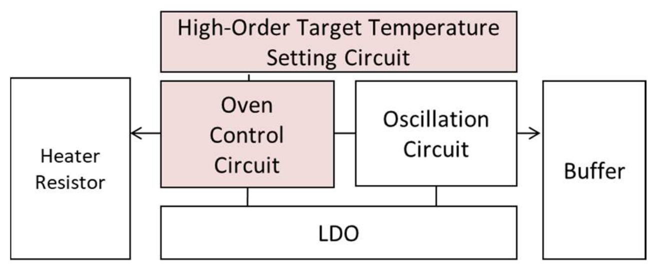

Fig. 2. A simple block diagram of the high-order polynomial temperature control of the proposed OCXO, including high-order target temperature setting circuit and oven control circuit.

II. Methods

A simple block diagram of the high-order polynomial temperature control of the proposed OCXO can be found in Fig. 2, including high-order target temperature setting circuit and oven control circuit.

The proposed high-order polynomial temperature control can be mathematically expressed as a composition of fourth-order polynomial basis functions of target temperature over ambient temperature as shown in below:

$$T_g(T_a) = \sum_{i=0}^{4} G_i(T_a - 30)^i, \quad (1)$$

where T_g [$^{\circ}$C] represents the target temperature of oven control, G_i denotes the coefficients of the fourth-order polynomial temperature control basis functions, and T_a is the ambient temperature. To optimally compensate the non-linear frequency stability error, it is crucial to get the corresponding coefficients of G_0, G_1, G_2, G_3, and G_4 of (1) of each OCXO device. First, as shown in Fig. 3, the zero-order, first-order, second-order, third-order, and fourth-order polynomial temperature control basis functions of each OCXO device can be obtained by measuring the temperature data over ambient temperature from a temperature sensor on the IC, and can be expressed as below:

$$\Delta T_{g,i} = \Delta G_i(T_a - 30)^i. \quad (2)$$

Next, considering the composition fourth-order polynomial temperature control basis functions of (2) give an optimized target temperature over ambient temperature of each OCXO device.

III. Result

Applying the optimized target temperature values obtained from (2) into the IC setting, the frequency stability measurements of the proposed OCXO subjected to a temperature change ranging from -40 to 85°C achieves ppt level. This result indicates that the proposed ASIC-based miniature OCXO provides more robust alternative for 5G base station, DUs, CUs, edge servers, small cells that need few hours of holdover capability and miniaturization requirement. Fig. 5 shows the warm-up characteristic of the proposed OCXO by monitoring the frequency with elapsed time. The result indicates a fast warm-up performance with 20 seconds after power is turned on for the frequency to be within $\pm$20 ppb referred to the measured frequency after one hour continue operation. In addition, Fig. 6 shows that the frequency stability is achieve $\pm$ 1ppb over $\pm$5% supply voltage variation referred to 3.3V.

IV. Conclusions

In this paper, we successfully demonstrated an ASIC-based miniature OCXO in a 9mm x 7mm footprint with ppt stability over ambient temperature from -40 to 85°C using high-order polynomial temperature control. With better temperature stability, the proposed miniature OCXO provides better holdover performance for base station, distributed unit, centralized units, edge servers. In addition, the proposed OCXO takes the advantages of the miniature and highly integrated features comparing conventional discrete type OCXO that needs manually manufacture in a large package.

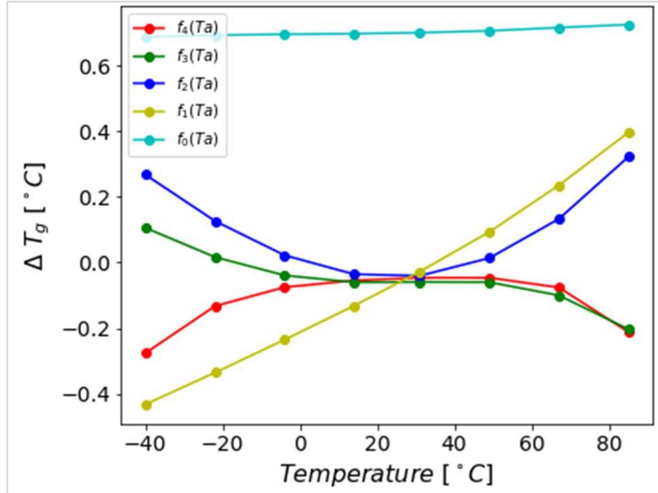

Fig. 3. Fourth-order polynomial basis functions of target temperature over ambient temperature.

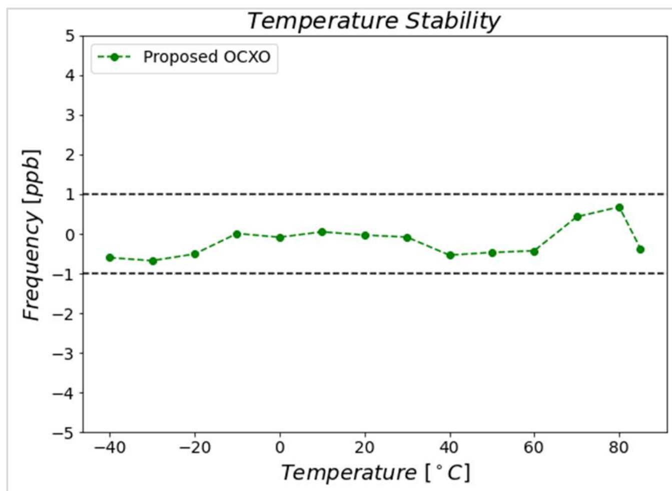

Fig. 4. Frequency stability measurements of the proposed OCXO subjected to a temperature change ranging from -40 to 85°C. The output frequency stability achieves ppt level.

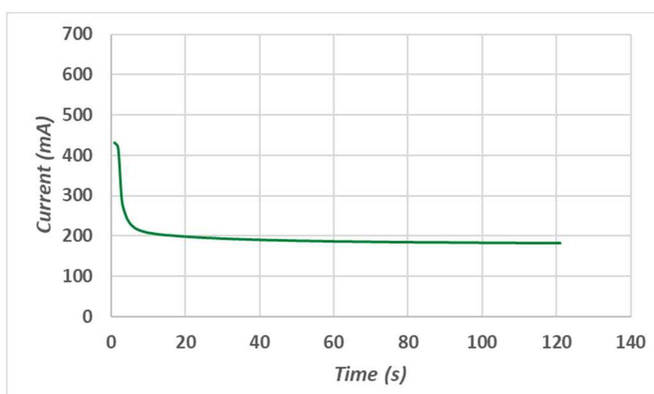

Fig. 5. Frequency characterestic at warm-up state of the proposed OCXO.

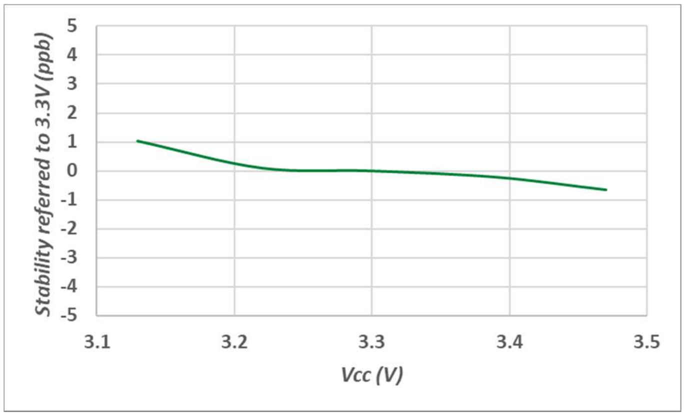

Fig. 6. Frequency stability over supply voltage variation of the proposed OCXO.

REFERENCES

[1] Ito, Manabu, Hiroyuki Mitome, and Takeo Oita. "10-10-Level Simple Single-Oven OCXO." Proceedings of the 42nd Annual Precise Time and Time Interval Systems and Applications Meeting. 2010.

[2] Frederic, Lefebvre, Weber Patrick, and Aubry Jean Pierre. "A new kind of view for a Double oven Crystal Oscillator." 2007 IEEE International Frequency Control Symposium Joint with the 21st European Frequency and Time Forum. IEEE, 2007.

[3] W.L. Hsieh, E.S. Hsu, Y.S Yen, S.H. Kao, Y.C. Huang, and M.H. Wang, “A Novel Miniature OCXO Using Hermetically Sealed Ceramic Package,” IEEE International Frequency Control Symposium and International Symposium on Applications of Ferroelectrics (IFCS-ISAF), pp. 1-4, October 2020.

[4] W.L. Hsieh, C.W. Chen, C.Y Weng, C.L. Hsu, S.H. Kao, and C.W. Chiang, “Development of High-Stability Miniaturized Oven Controlled Crystal Oscillator,” IEEE International Frequency Control Symposium (IFCS), pp. 1-4, September 2016.

[5] W.L. Hsieh, C.L. Hsu, C.W. Chen, C.Y Weng, and S.H. Kao, “Highly Stable Miniaturized OCXO with Heater-Embedded Ceramic Package,” IEEE International Frequency Control Symposium (IFCS), pp. 1-4, January 2018.

[6] W.L. Hsieh, W.C. Wang, E.S. Hsu, S.H. Kao, and M.H. Wang, “The World’s Smallest Quartz-Based OCXO for 5G Synchronization Applications,” European Frequency and Time Forum and IEEE International Frequency Control Symposium (EFTF/IFCS), pp. 1-4, November 2021.

[7] M. Ogawa, et al. “High stability miniature size OCXO using a SC-cut crystal resonator and simultaneous oscillations,” Joint Conference of the European Frequency and Time Forum and IEEE International Frequency Control Symposium (EFTF/IFCS), 2017.

[8] K. Irie, J. -I. Arai, M. Ito, T. Shinotsuka, M. Ishikawa and S. -I. Wakamatsu, "High Stability Ultra-Miniature Size OCXO Operating within W Joint Conference of the IEEE International Frequency Control Symposium and International Symposium on Applications of Ferroelectrics (IFCS-ISAF), pp. 1-4, 2020.