# The World's Smallest Quartz-Based OCXO for 5G Synchronization Applications

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***Abstract*—In this work we successfully developed an ultra-miniature Oven Controlled Crystal Oscillator (OCXO) with the size of 5.0 mm × 3.2 mm. A heater-embedded crystal package is demonstrated to establish a thermally symmetry oven structure, thus improving the oven stability and reliability. By using a three layer in series heater resistor design, an ultra-miniature size of 2.5 mm × 2.0 mm crystal can be realized. In addition, a SC minus cut is considered to further improve the temperature stability, phase noise, drive level sensitivity, gravity sensitivity, aging, and longer holdover performance. Moreover, the SC minus cut has a lower inflection temperature at 83 ℃ comparing to the traditional SC-cut crystal with higher inflection temperature at 89 ℃, thus a better aging and lower power consumption is achieved by setting a lower oven controlled temperature. As a result, the temperature stability has achieved ±20 ppb across the ambient temperature from -40 to 95 ℃, indicating that the result satisfies the requirement for 5G synchronization applications, such as IEEE1588 V2 and enhanced synchronous Ethernet equipment clock (eEEC).**

***Keywords—ultra-miniature oven controlled crystal oscillator; heater-embedded crystal package; thermally symmetry oven structure; SC minus cut;***

## I. Introduction

The related 5G equipment such as Active Antenna Unit (AAU) and Small Cell now consider downsizing to save more design spacing to meet the complicated application scenarios [1]. Temperature Compensated Crystal Oscillators (TCXOs) and OCXOs are commonly used for these versatile precise timing applications and are also expected to reduce the package size for those requirements [2-6]. In Fig. 1, the quartz-based TCXO and Micro Electro Mechanical Systems (MEMS) TCXO with the size of 5.0 mm × 3.2 mm support high stability with ±100 ppb that can meet traditional synchronous Ethernet (SyncE). However, the updated eEEC requires higher stability up to ±50 ppb, especially considering a variable temperature condition. In addition, most of 5G equipment requires local oscillator to provide holdover performance with respect to network limits when other synchronization references lost. However, longer holdover performance is a challenge for the high-end TCXOs due to the limitation to the temperature compensation algorism of both digital or analog type and the use of crystal cuts that is more sensitive to ambient temperature comparing to a SC-cut crystal [7].

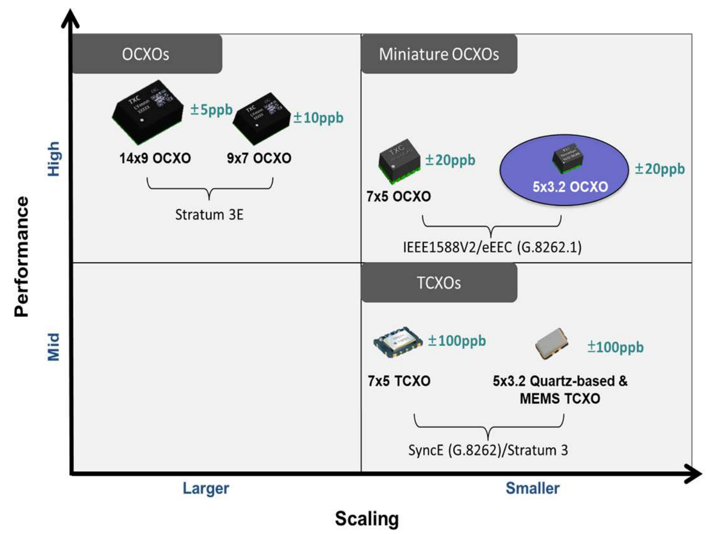


Fig. 1. SMD oscillators comparison between quartz-based OCXO, quartz-based TCXO, and MEMS TCXO in terms of scaling and performance.

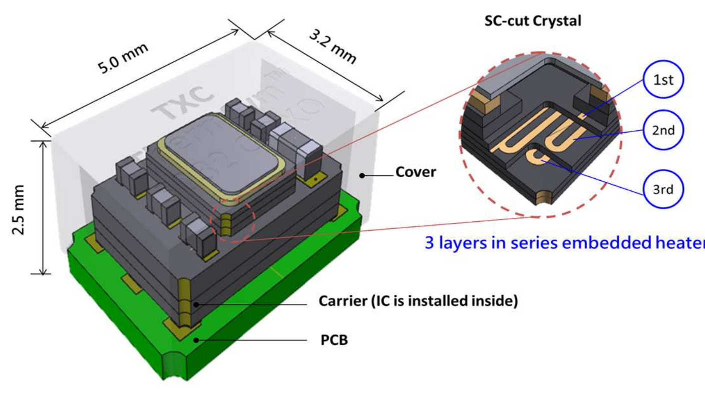


Fig. 2. The appearance of the proposed 5.0x3.2 OCXO and a sectional view of the 2.5x2.0mm SC minus crystal with the three layer in series heater resistor.

To this end, we proposed in this paper an ultra-miniature OCXO with the same size of 5.0 mm × 3.2 mm as the high-end TCXOs. The rest of this paper is organized as follows. Second section introduces the thermal structure and the use of SC minus crystal. Third section presents the performance of

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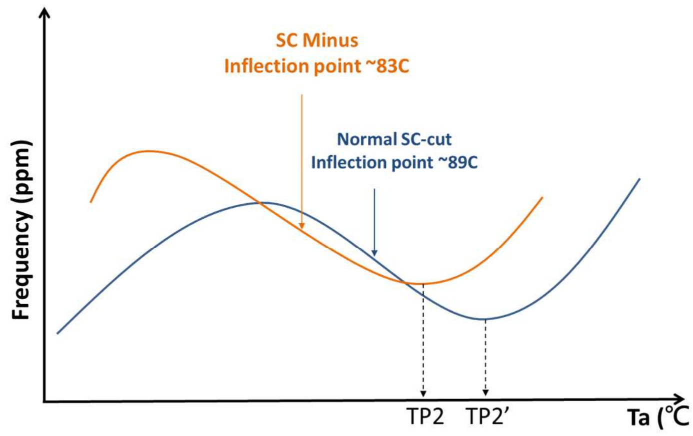


Fig. 3. Temperature curve comparison between a SC minus crystal and a normal SC-cut crystal. It shows that TP2 of SC minus crystal is smaller than that TP2' of normal SC-cut crystal.

the proposed OCXO and compares the performance of the proposed OCXO to the MEMS TCXO in terms of temperature stability and phase noise. Last section concludes the paper.

## II. Thermal structure

In Fig. 2, the appearance of the proposed 5.0 mm × 3.2 mm OCXO is illustrated, including a printed circuit board (PCB), a carrier within an installed IC, a 2.5 mm × 2.0 mm SC-cut crystal, related passive components, and a plastic cover housing with the PCB. A three-layer in series embedded heater is utilized in the 2.5 mm × 2.0 mm SC crystal as seen in the sectional view in Fig. 2. This embedded heater installed between the crystal and IC establishes a thermally symmetry field, achieving better oven stability due to the fact that the thermal resistance difference between the heater-to-junction and heater-to-crystal is minimized [2-3].

## III. SC Minus crystal

A SC minus crystal is utilized to reduce the oven controlled temperature. Fig. 3 shows that the SC minus crystal has a lower inflection temperature at 83 ℃ comparing to the traditional SC-cut crystal with higher inflection temperature at 89℃, thus a lower oven controlled temperature is achievable to reduce the aging effect and power consumption of the OCXO. Fig. 4 presents the measured frequency based on the ambient temperature from 65 to 101 ℃ of the proposed SC minus crystals. The frequency data is referred to the inflection temperature at 83 ℃, and the corresponding turnover temperature is at 97 ℃. The oven controlled temperature is therefore maintained at 97 ℃, which is designed higher than the highest operating temperature, to achieve the most insensitive portion to frequency.

## IV. Results

Fig. 5 shows the warm-up characteristic of the proposed OCXO by monitoring the frequency versus time. The result shows a fast warm-up performance with 27.5 seconds after

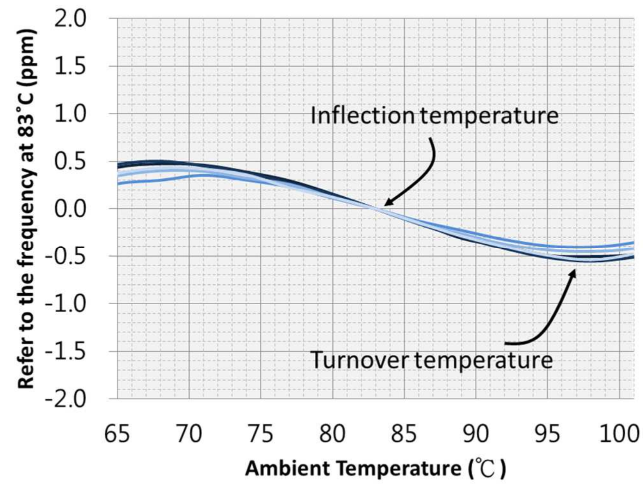


Fig. 4. Frequency characterestic versus ambient temperature of the SC minus crystals. The freqrency data is referred to the data when the ambient temperature at 83 °C.

power is turned on for the frequency to be within ±20 ppb referred to the measured frequency point after one hour operation. In addition, Fig. 6 shows that the temperature stability is achieved within ±20 ppb across over -40 to 95 ˚C of the ambient temperature as plotted in bold solid line. Moreover, the corresponding measured phase noise of -80, -108, -132, -151, -160, -162, and -162 dBc/Hz at 1, 10, 100, 1 k, 10 k, 100 k, and 1 MHz offsets with superior performance as plotted in blue bold line is shown in Fig. 7, enabling to meet the synchronization clocking needs of both jitter and wander. In addition, the proposed OCXO takes the advantages of the low jitter and exceptionally high Q comparing to the high-end TCXOs for the applications that require high speed communication, more complex modulation schemes, or excellent signal-to-noise performance.

Fig. 8 shows the bias aging performance of the proposed OCXO operating at room temperature. First, we measured the first 14 days data plotted as bold solid line in Fig. 8. Next, we adopted the aging model [8] using the measured data to

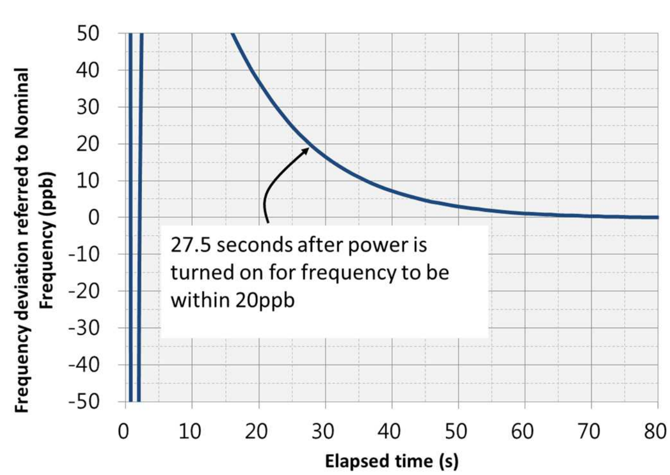


Fig. 5. Frequency characterestic at warm-up state for the proposed OCXO.

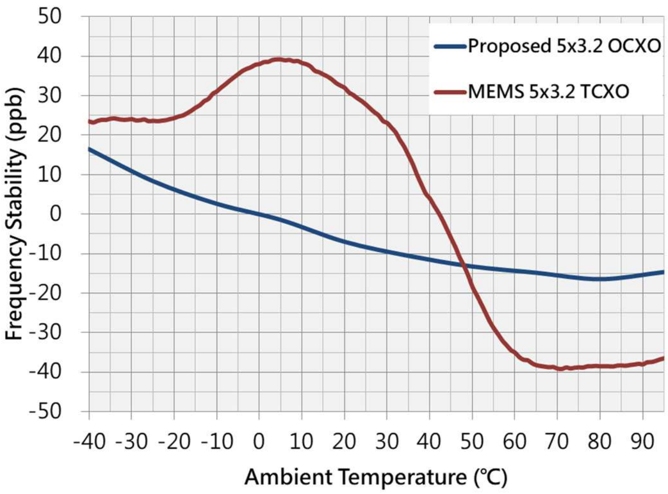


Fig. 6. Temperature stability comparison between the proposed OCXO and MEMS TCXO.

predict the aging behaviors in long-term perspective which is plotted as thin line shown in Fig. 8. The result shows the daily aging rate is less than 1 ppb/day, leading to a -300 ppb/year yearly aging performance. Fig. 9 shows the holdover capability of the proposed OCXO based on the end-to-end phase error requirement for LTE-TDD small cell mobile networks of ±1.5 µs. The measured data is recorded after 24 hours warm-up time at the ambient temperature of 25 ± 1°C envrionment. The holdover phase movement ability is better than 1.5 µs for 1.5 hours as seen in Fig. 9.

## V. Conclusions

In this paper, we successfully demonstrated an ultra-miniature OCXO with the same size of 5.0 mm × 3.2 mm as the high-end TCXOs. The oven structure combined within a heater-embedded crystal package provides excellent thermal performance. A 2.5 mm × 2.0 mm SC minus crystal is

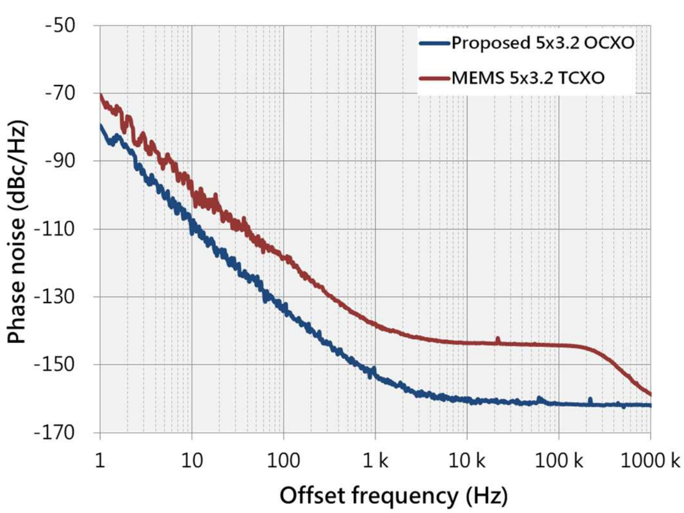


Fig. 7. Phase Noise comparison between the proposed OCXO and MEMS TCXO using 30.72 MHz carrier.

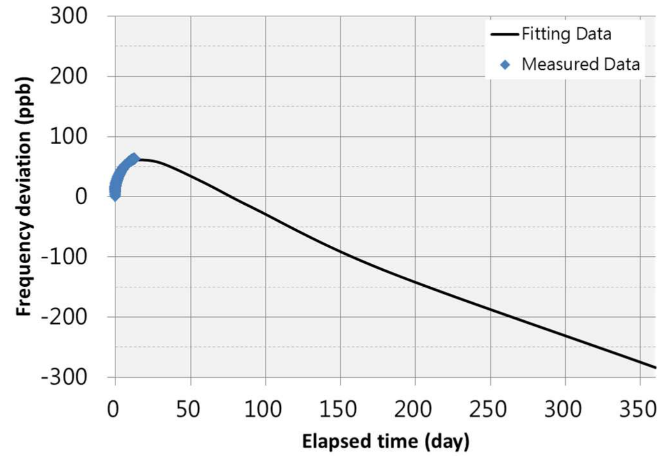


Fig. 8. Aging performance of the proposed ultra-miniature OCXO.

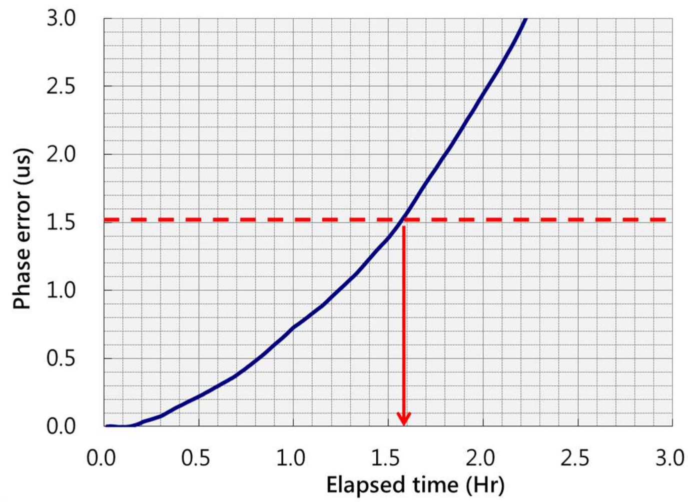


Fig. 9. The holdover capability of the proposed OCXO over 1.5 hours for 1.5 µs (5G end-to-end requirement).

adopted to further improve the temperature stability, phase noise, drive level sensitivity, gravity sensitivity, aging, and longer holdover performance. As a result, the proposed OCXO has achieved temperature stability within ±20 ppb across the ambient temperature from -40 to 95 ˚C. In addition, the proposed OCXO takes the advantages of the low jitter and exceptionally high Q comparing to the high-end TCXOs. With better temperature stability, phase noise, and aging, the proposed ultra-miniature OCXO provides more robust alternative for 5G synchronization applications and holdover requirement scenarios.

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