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A Novel Miniature OCXO Using Hermetically Sealed Ceramic Package

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***Abstract*—This work presents an ultra-miniature oven controlled crystal oscillator (OCXO) using a hermetically sealed ceramic package with the size of 7.0 mm × 5.0 mm. The oven structure combined within a heater-embedded ceramic package and a low thermal conductivity bonding adhesive provides excellent thermal performance, achieving temperature stability within ±10 ppb across -40 to 95 ˚C. Hermeticity is accomplished with a seam-welded lid to a kovar ring on the ceramic substrate. In addition, a 2.5 mm × 2.0 mm SC-cut crystal is utilized to further improve the temperature stability, aging, gravity sensitivity, and phase noise performance that can be compliance with Stratum 3E specifications. The proposed ultra-miniature OCXO provides more robust and smaller package alternative for 5G outdoor applications, such as remote radio heads (RRHs), active antenna unit (AAU), and small cells.**

Keywords—ultra-miniature oven controlled crystal oscillator; heater-embedded ceramic package; SC-cut crystal

I. Introduction

5G radio access networks (RANs) are being discussed actively and will be characterized by a wide variety of use scenarios. Typical scenarios are expected to require high data rates, low latency, cost-efficient power consumption, and improved connectivity in both indoor and outdoor environments [1]. OCXOs are commonly used for these versatile precise timing applications. To overcome abovementioned challenges, especially in harsh environmental performances demanded by the outdoor radios, the requirements for OCXO include higher operating temperature, better acceleration sensitivity, better reliability, and smaller package that provides cost-efficient energy consumption alternative for the system designers.

Numerous miniaturize OCXOs have been proposed previously to meet the small-sized demand for 5G equipment [2-4]; while these miniaturize OCXOs are non-hermetic packaging limited by the use of organic PCB as the substrate housing with a plastic or metal cover. To implement hermetic sealed level, conventional OCXOs use standard through-hole metal welded package. To further achieve surface-mount type, the dip welded metal package is usually mounted onto an organic PCB using soldering technique. However, the disadvantages of organic PCBs are the relative high coefficients of thermal expansion (CTE) which leads to thermo-mechanical defects under long life outdoor applications [5].

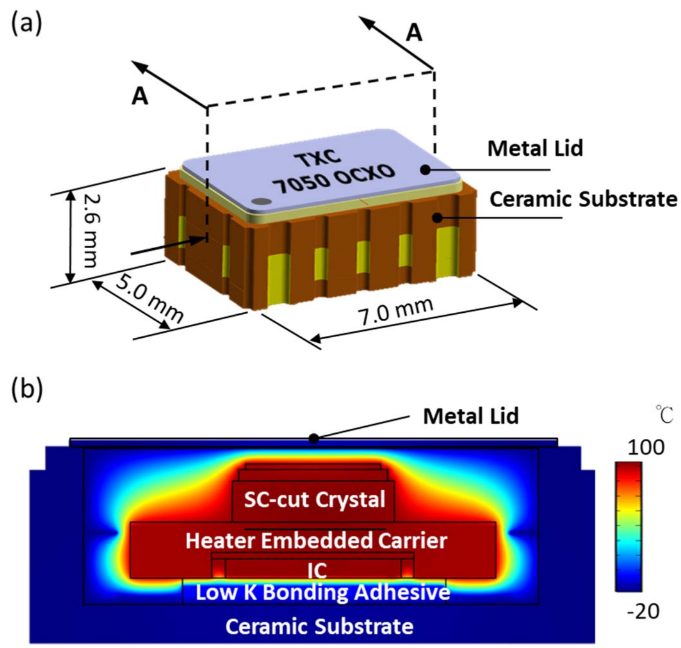

Fig. 1 (a) Simulation model of the proposed 7.0 mm × 5.0 mm OCXO hermetically sealed with a metal lid to a ceramic package. (b) Simulated temperature distribution at the cutting plane A-A, showing the thermally symmetry between crystal and IC with respect to the embedded heater and the thermally isolation by using the thin film bonding adhesive with low thermal conductivity.

Ceramic packaging solutions have shown the superior reliability performance compared to the organic technologies and are widely used for hermetical sealing application [5]. However, the feature with high thermal conductivity of ceramics becomes ineffective for the OCXO packaging design. For an ideal implementation of using the ceramic as the packaging material, an appropriate ovenized design is crucial. Here, we demonstrate an OCXO in a hermetically sealed ceramic package with the ultra-miniature size of 7.0 mm × 5.0 mm, combining within a heater-embedded ceramic package and a low thermal conductivity bonding adhesive in the oven structure, achieving excellent thermal performance with a temperature stability of ±10 ppb across -40 to 95 ˚C. In addition, hermetic seal is accomplished with a seam-welded lid to a kovar ring on the ceramic substrate, providing better reliability for outdoor applications in harsh environment.

I. Methods/Results

A. Thermal Modeling

The thermal modeling is introduced here to optimize the thermal structure. The general heat conduction equation derived from the first law of thermodynamics and the corresponding convective heat flux boundary condition is considered in the thermal modeling [4]. Fig. 1(a) illustrates the numerical model for the proposed OCXO structure. As seen in Fig. 1(b), the simulated thermal distribution at the cutting plane A-A is presented, where the operating temperature considered in the simulation is -40 °C. From the cross-section view at A-A, a SC-cut crystal, a heater-embedded ceramic carrier, an IC, a low thermal conductivity bonding adhesive are housed in the sealing packaging using a metal lid and a ceramic substrate. The embedded heater installed between the SC-cut crystal and IC establishes a symmetric thermal 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 [4]. By considering the adhesive with low thermal conductivity of 0.2 W/m˚C bonding below the IC, the thermal resistance of heater-to-crystal is increased, thus reducing the heat loss of the proposed OCXO.

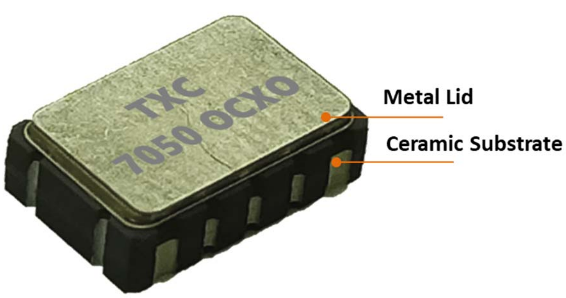

Fig. 2 Appearance of the proposed 7.0 mm × 5.0 mm OCXO.

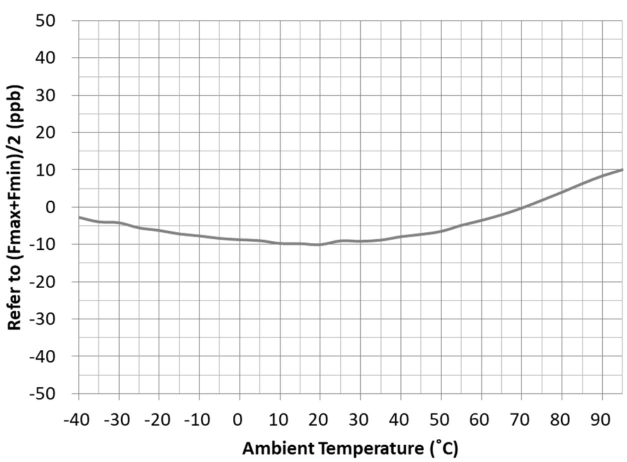

Fig. 3 Frequency stability measurements of the proposed OCXO subjected to a temperature change ranging from -40 to 95˚C. The output frequency stability achieves within ±10 ppb level.

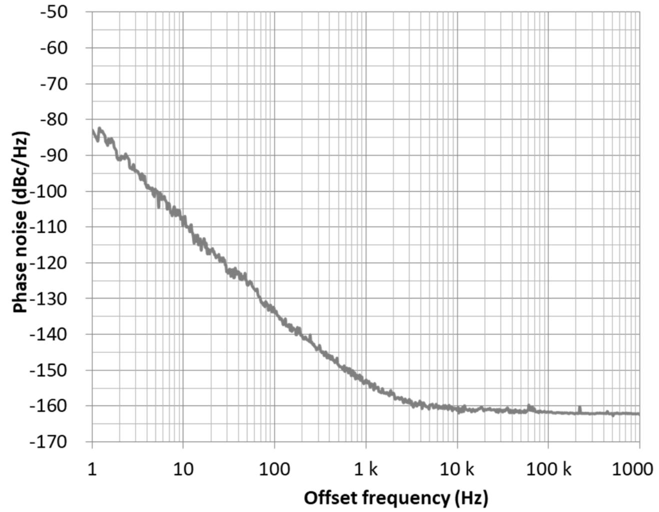

Fig. 4 Phase noise measurements of the proposed OCXO using 30.72 MHz SC-cut crystal.

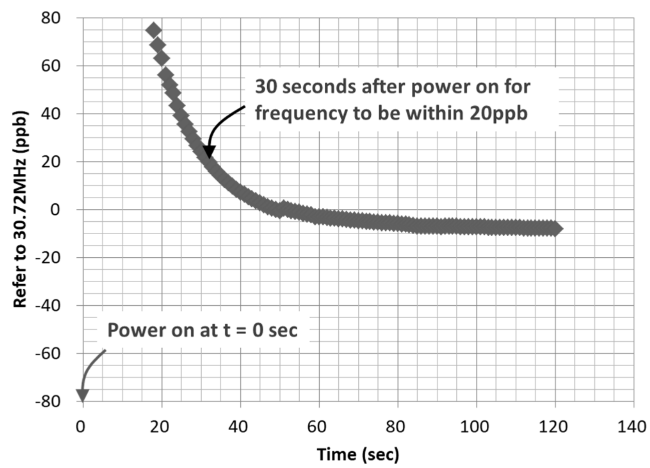

Fig. 5 Frequency characteristic from warm-up state to steady state of the proposed OCXO.

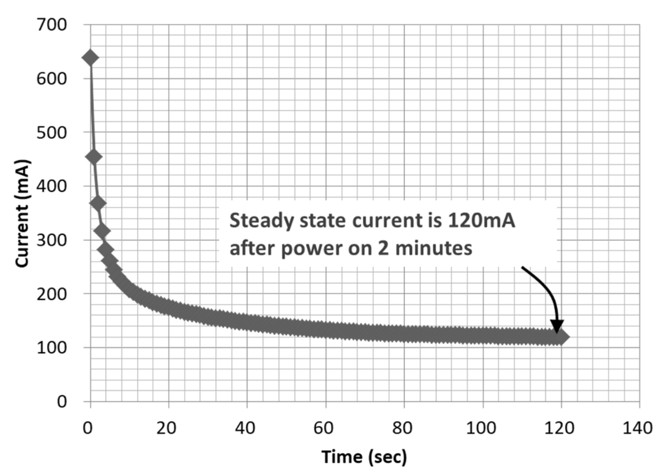

Fig. 6 Current characteristic from warm-up state to steady state of the proposed OCXO.

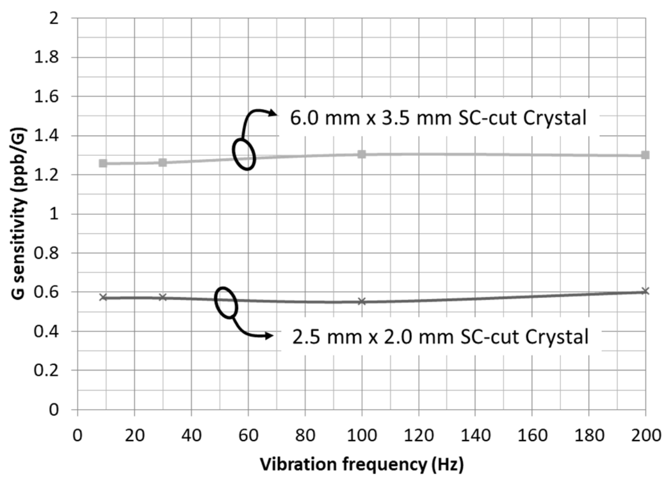

Fig. 7 Gravity sensitivity comparisons between the proposed ultra-miniature OCXO and our prior work [2] based on the 3-axis gamma factor calculation.

B. Practical Structure

Based on the numerical result, the practical structure is implemented as seen the appearance of the proposed 7.0 mm × 5.0 mm OCXO in Fig. 2, where the hermeticity is accomplished with a seam-welded lid to a kovar ring on the ceramic substrate. Inside of the package, a 30.72 MHz SC-cut crystal is utilized to further improve the temperature stability, aging, and phase noise performance [6,7]. In addition, a heater-embedded ceramic carrier for housing the OCXO IC and a thin film of non-conductive adhesive with low thermal conductivity of 0.2 W/m˚C are considered in the structure. The electrical connection between the heater-embedded ceramic carrier and the ceramic substrate is accomplished using gold bonding wires. Moreover, we consider a miniature SC-cut crystal with 2.5 mm × 2.0 mm to further improve the gravity sensitivity in this study.

C. Practical Measurement

First, the temperature stability is achieved within ±10 ppb over -40 to 95˚C as shown in Fig. 3. The corresponding measured phase noise of -84, -108, -134, -153, -160, -162, and -162 dBc/Hz at 1, 10, 100, 1 k, 10 k, 100 k, and 1 MHz offsets with superior performance is shown in Fig. 4, enabling to meet the synchronization clocking needs of both jitter and wander. In addition, the warm-up characteristic including initial frequency and current consumption is demonstrated in Fig. 5 and Fig. 6, respectively. The result shows a fast warm-up performance with 30 seconds after power is turned on for the frequency to be within 20 ppb and low power consumption at steady state less 400 mW. Moreover, the gravity sensitivity of 0.6 ppb/g level based on the 3-axis gamma factor calculation is presented as shown in Fig. 7. This result exceeds our prior work [2] that uses a 6.0 mm × 3.5 mm SC-cut crystal in a non-hermetic packaging size with 9.7 mm × 7.5 mm.

D. Analysis of Quartz Blank Size on Gravity Sensitivity

The mechanical structure modeling based on finite element method is adopted here to analyze the effect of quartz blank

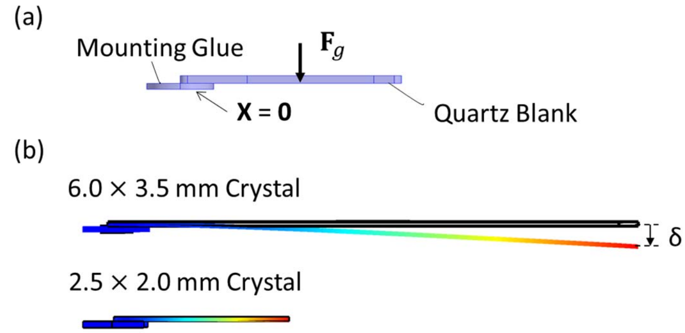

Fig. 8 (a) A Simulated model for the mechanical structure simulation, where the domain is simplified to include only quartz blank and mounting glue. (b) Simulated displacement field for the two different size crystal, showing the smaller blank size results in smaller deflection.

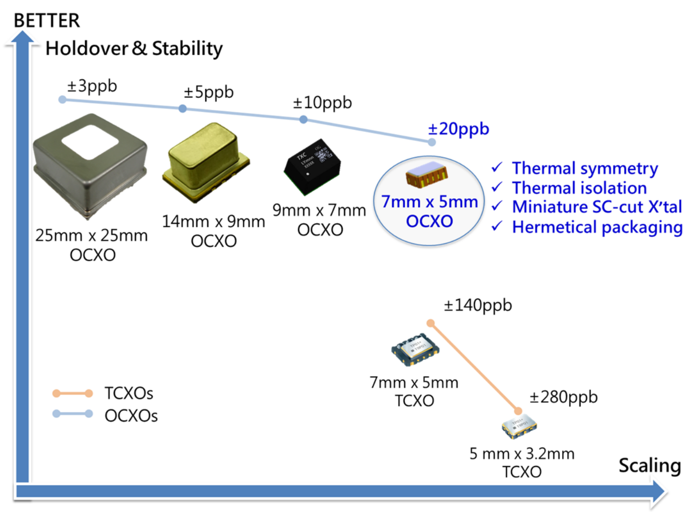

Fig. 9 Stability versus package size of OCXOs and TCXOs. The proposed 7.0 mm × 5.0 mm OCXO achieves better holdover and stability compared to the traditional high-end TCXO with same packaging size.

size on the gravity sensitivity. The simulated domain is simplified to include only quartz blank and mounting glue as seen in Fig. 8(a). A fixed condition at the bottom of the mounting glue is considered. In addition, a gravity force is applied to the quartz blank. Fig. 8(b) shows the displacement result of two different blank sizes with same size of mounting glue, where a large factor is scaled by 100 times in order to make micro-scale changes and deflections visible. It shows that the smaller size of quartz blank results in smaller deflection because the length of force arm is relative small. This indicates the structure is more insensitive to the gravity.

II. CONCLUSIONS

In this work, we demonstrated an ultra-miniature OCXO using a hermetically sealed ceramic package with the size of 7.0 mm × 5.0 mm. The oven structure combined within a heater-embedded ceramic package and a low thermal conductivity bonding adhesive provides excellent thermal performance, achieving temperature stability within ±10 ppb across -40 to 95 ˚C. Fig. 9 shows the holdover and stability versus package size for OCXOs and high-end temperature compensated crystal oscillators (TCXOs). This indicates that the proposed OCXO achieves much better holdover and stability performance compared to the traditional high-end TCXO with same packaging size. In addition, a 2.5 mm × 2.0 mm SC-cut crystal is utilized to further improve the temperature stability, aging, and phase noise performance that can be compliance with Stratum 3E specifications. Moreover, the gravity stability of 0.6 ppb/g level is achieved using the miniature SC-cut crystal with the size of 2.5 mm × 2.0 mm. With better temperature stability, fast warm-up characteristic, lower gravity sensitivity, and higher hermeticity, the proposed ultra-miniature OCXO provides more robust alternative for 5G outdoor applications, such as remote radio heads, active antenna unit, and small cells.

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