Utilization of Miniature Multilayer Ceramic Inductors in the Dual-Mode Crystal Oscillator

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Abstract. *This paper deals with dual-mode crystal oscillator (DMXO) based on two bridge-type oscillators using a quartz resonator as frequency stabilization element and sensor element of its own temperature as well. We have investigated a possibility of miniature multilayer ceramic inductors employment in the DMXO. Employment of such miniature inductors instead of air-core wire-wound ones enables further reduction of the oscillator dimensions, as well as a reduction of temperature gradients among the DMXO elements.*

Keywords: Dual-Mode Crystal Oscillator, SC-cut resonator, multilayer ceramic inductors

1. Introduction

The conventional method for sensing resonator's temperature in Temperature Compensated Crystal Oscillators (TCXO), for example, utilizes a thermistor, placed in close proximity to the resonator. This method suffers from inaccuracies due to thermal lag stemming from differences in time constants and thermal gradients between the resonator and the thermistor, as well as thermistor aging. Simultaneous excitation of two modes of vibration in a piezoelectric resonator enables to realize self-temperature-sensing of the resonator. The self-temperature-sensing method eliminates temperature offset and lag effects, since no external temperature sensor is used. The history and different applications related to the dual-mode excitation have been reviewed in [1], [2].

Self-temperature-sensing of Stress Compensated (SC) quartz resonator (or SC-cut) utilizing simultaneous excitation of the fundamental c-mode (the slow thickness-shear mode) together with the 3rd overtone c-mode in the resonator has been introduced in [3]. This method has been employed in the Microcomputer Compensated Crystal Oscillator (MCXO). Since the MCXO was primary intended for military applications, it have to operate reliably in the wide temperature range between -55°C and +85°C [4]. Optimal quartz resonators (not standard SC-cut) with the lower turnover temperature of the 3rd overtone frequency close to +20°C have been designed especially for the MCXO [5]. However later, author in [6] has presented that the differences between the aging of the two exited mode frequencies in the resonator cause an offset with a tilt in the MCXO output frequency over the operating temperature range; it limits the accuracy of the correction process implemented in the MCXO.

We have designed and investigated novel DMXO that employs a standard 10-MHz 3rd overtone SC-cut resonator with lower turnover temperature of the 3rd overtone between +80°C and +85°C [7], [8]. Such quartz resonators are utilized in the highest-stability Oven Controlled Crystal Oscillators (OCXO). Possible applications of the DMXO with excitation of the two overtones include stabilization of the SC-cut resonator's temperature as well as compensation for frequency shifts due to the variations of the temperature in the resonator surrounding.

In this paper we illustrate a possibility of employment of nowadays miniature multilayer ceramic inductors in the DMXO we have developed.

2. Implementation of the SC-cut Resonator Self-Temperature-Sensing

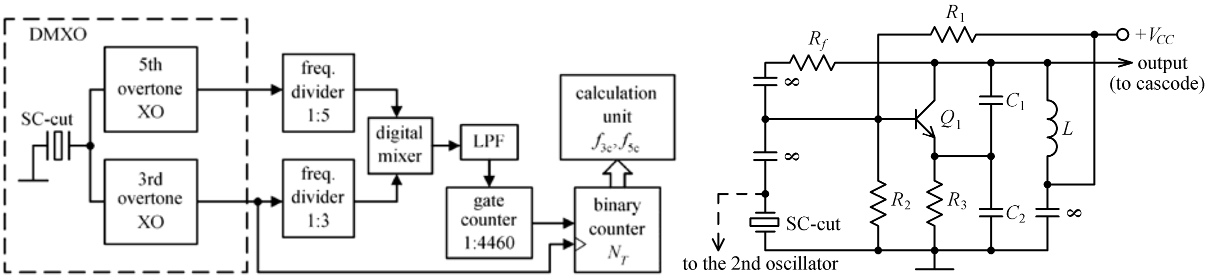

Fig. 1. Block diagram of the SC-cut self-temperature-sensing implementation (left) and simplified schematic diagram of the bridge-type crystal oscillator (right); two similar structures form the DMXO.

Block diagram of our SC-cut self-temperature-sensing implementation is shown in Fig. 1 (left). The 5th overtone oscillator's frequency divided by five is subtracted from the 3rd overtone oscillator's frequency divided by three, with assistance of the digital mixer and low pass filter (LPF). The difference frequency f_d at the output of the LPF can be expressed as follows

$$f_d(\vartheta) = \frac{f_3(\vartheta)}{3} - \frac{f_5(\vartheta)}{5} \tag{1}$$

where ϑ is the temperature of the SC-cut resonator.

The gate counter, shown in Fig. 1, produces approximately one-second time interval, during which the binary counter accumulates clock pulses with frequency f_3 (i.e. frequency of the 3rd overtone XO). After the clock pulses accumulation, the content of the binary counter can be expressed by following formula

$$N_T(\vartheta) = \mathrm{int}\left(\frac{f_3(\vartheta)}{f_d(\vartheta)} \cdot 4460 \right). \tag{2}$$

The content of the binary counter (2) is used to form an independent variable $N=N_T-N_o$ that represents actual temperature of the SC-cut resonator. The integer N_o is the constant, which represents content of the binary counter at selected temperature of the SC-cut resonator, e.g. at the lower turnover temperature of the 3rd overtone frequency (Fig. 3).

The data representing the f_3 vs. N dependency (or f_5 vs. N dependency) are collected during the calibration run (with assistance of temperature chamber, precise counters and computer). The dependency usually can be approximated by simple polynomial. The calculation unit (shown in Fig. 1) then can determine an actual value of the frequency f_3 (or f_5) according to actual value of the independent variable N by computing of appropriate polynomial.

3. Employment of Multilayer Ceramic Inductors in the DMXO

We have investigated an impact of instabilities of the miniature (L×W×T=1.6×0.8×0.8mm) multilayer ceramic inductors (HK1608 series from Taiyo Yuden Co. Ltd.) due to temperature variations on the DMXO's frequencies. To be the influence more obvious, we replaced the SC-cut resonator in the particular bridge-type oscillator (Fig. 1) by the resistor with the resistance approximately equal to motional resistance of the appropriate mode, normally excited in the SC-cut resonator. Corresponding frequency vs. temperature characteristics of the particular oscillators are shown in Fig. 2 (left). The temperature was measured with assistance of miniature platinum resistance temperature detector (PT100) placed in the vicinity of the oscillator elements.

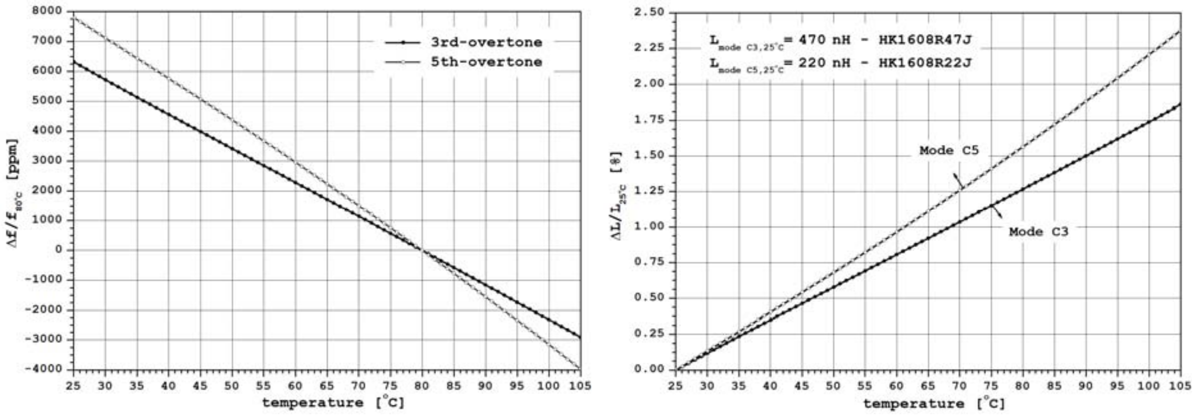

Fig. 2. Measured frequency vs. temperature of the particular oscillators forming the DMXO without the SC-cut (left) and estimated values of the inductance vs. temperature of the used multilayer ceramic inductors (right); the SC-cut resonator was replaced in the DMXO by the two appropriate resistors.

If we consider that the temperature dependency of the used inductor in the bridge oscillator is dominant, then we can estimate its inductance at the temperature ϑ using following formula

$$L(\vartheta) = L_{25^\circ \mathrm{C}} \cdot \left(\frac{f(25^\circ \mathrm{C})}{f(\vartheta)} \right)^2 = L_{25^\circ \mathrm{C}} \cdot \left[1 + \alpha_L \cdot (\vartheta - 25) \right] \qquad (3)$$

where α_L represents a temperature coefficient of the inductor inductance; $f(25^\circ\mathrm{C})$ and $f(\vartheta)$ are the measured frequencies of the appropriate oscillator at room temperature (25°C) and at given temperature ϑ, respectively; and $L_{25^\circ\mathrm{C}}$ represents value of the inductor L inductance at room temperature (i.e. its nominal value).

Estimated values of inductance of the particular multilayer ceramic inductors vs. temperature are shown in Fig. 2 (right).

4. Results and Conclusions

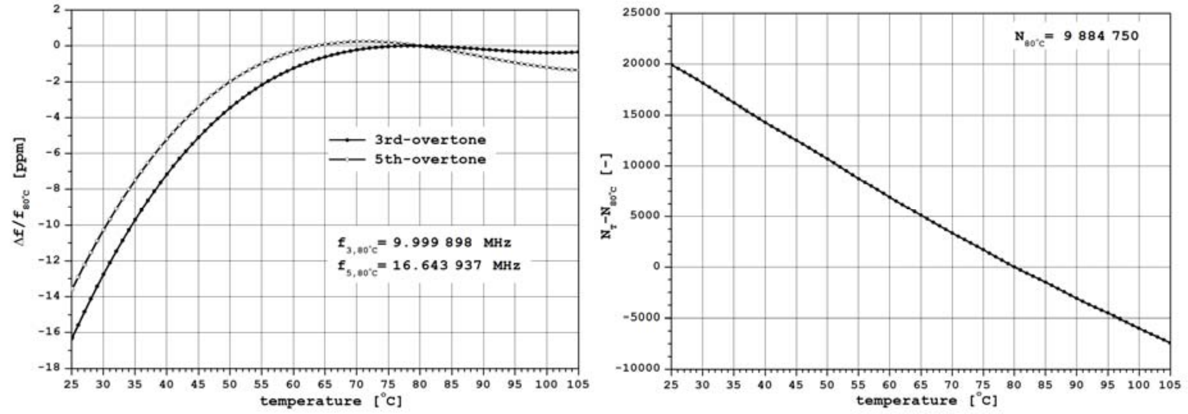

Fig. 3. Measured resonant frequency of the two investigated overtones (c-modes) of the SC-cut vs. temperature (left). Number of clock pulses accumulated in the binary counter during the time interval 4460 / f_d vs. temperature (right).

We have evaluated possibility of employment of nowadays miniature multilayer ceramic inductors in the DMXO with simultaneous excitation of two overtones in the SC-cut resonator. Inductance of investigated multilayer ceramic inductors is more temperature dependent in comparison with the wire-wound air-core inductors. However, our experimental results (Fig. 3 and Fig. 4) illustrate that the nowadays miniature ceramic inductors can be reliably employed in the DMXO circuit.

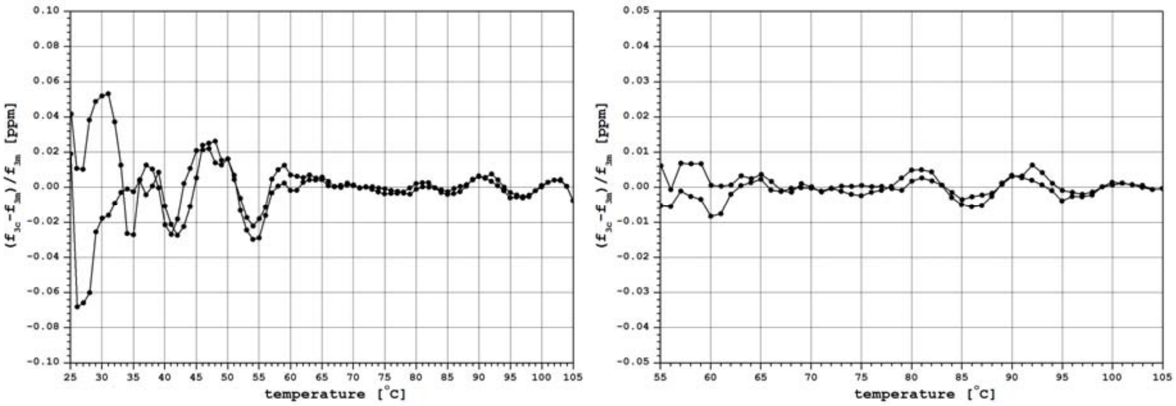

Fig. 4. Residuals vs. temperature in the case of 3rd overtone XO; data from calibration-run were fit to a single-segment 9th order polynomial over the temperature range between +25°C and +105°C (left), and over the reduced temperature range between +55°C and +105°C (right).

Consequently, the DMXO dimensions, as well as temperature gradients among the circuit elements may be reduced. Investigation of a long-term frequency stability of both excited overtones in the developed DMXO is our aim also; however, it requires a long-time evaluation of the realized prototypes.

Acknowledgements

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