Dual-Mode Crystal Oscillator with Simultaneous Excitation of Two Overtones in a Stress Compensated Quartz Resonator

Vladimír Štofanik
Department of Thermophysics
Institute of Physics, Slovak Academy of Sciences
Bratislava, Slovak Republic
fyzistof@savba.sk

Igor Baláž, Marián Minárik
Department of Radio and Electronics
Faculty of Electrical Engineering and Information Technology, Slovak University of Technology
Bratislava, Slovak Republic

***Abstract*—The paper introduces novel dual-mode crystal oscillator (DMXO) that employs a standard 10-MHz 3rd overtone stress compensated (SC) quartz resonator. In the DMXO, the two overtones (c-modes) of the SC-cut resonator are simultaneously excited: the 3rd overtone and the 5th overtone. The ability of utilization of the two excited overtones to implement the resonator self-thermometry we have evaluated. The resonator self-temperature-sensing method eliminates temperature offset and lag effects, since no external temperature sensor is used [1], [2], [3]. Eventual applications of the DMXO with excitation of the two overtones include the stabilization of the SC-cut resonator's temperature as well as compensation for frequency shifts due to the variations of the ambient temperature.**

I. INTRODUCTION

Stress compensated (SC) quartz resonator self-temperature-sensing utilizing simultaneous excitation of two slow thickness-shear modes (i.e. c-modes) has been introduced by Schodowski in 1989 [1]. Processing of both c-mode actual frequencies enables prediction of their frequency shifts due to ambient temperature variations in a wide range. Temperature offset and lag effects are eliminated, since no external temperature sensor is used. For example, in microcomputer compensated crystal oscillator (MCXO) that operates in temperature range between -55°C and +85°C, a dual-mode crystal oscillator (DMXO) utilizes simultaneous excitation of fundamental c-mode and 3rd overtone c-mode of special SC-cut resonator. In the case of the optimum MCXO SC-cut resonator, the lower turnover temperature of the 3rd overtone is close to +20°C [2], [3]. The minimization of the differences between aging rates of the two excited c-mode's frequencies is very important for MCXO, since the different aging rates cause an offset with a tilt in the MCXO frequency output over the operating temperature range [4].

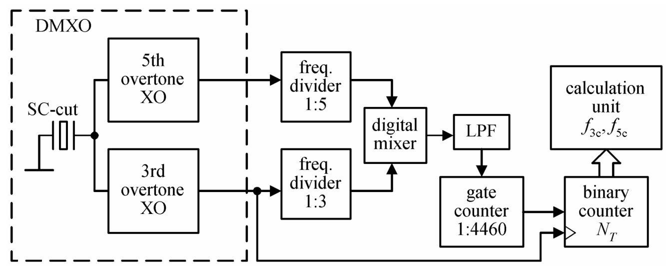

Figure 1. Block diagram of the resonator self-thermometry implementation.

We have designed and investigated dual-mode crystal oscillator (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. In the DMXO, the two overtones (c-modes) of the SC-cut resonator are simultaneously excited: the 3rd overtone and the 5th overtone.

The ability of utilization of the two excited overtones to implement the resonator self-thermometry, shown in Fig. 1, we have evaluated in temperature range between +55°C and +105°C. Eventual applications of the DMXO with excitation of the two overtones include the stabilization of the SC-cut resonator's temperature as well as compensation for frequency shifts due to the variations of the ambient temperature.

II. DESCRIPTION OF THE DESIGNED DMXO STRUCTURE

The DMXO we have designed consists of two similar crystal oscillators (XOs), as it is shown in Fig. 1: the 3rd overtone XO and the 5th overtone XO. The two XOs share the common SC-cut resonator. Figure 2 shows the schematic diagram of the XOs. Each of the XOs comprises of: the sustaining amplifier to provide regeneration for the respective mode of the SC-cut; automatic level control (ALC) circuit to control and to stabilize the amplitude of the oscillations; and cascode amplifier to provide sufficient isolation and to minimize the effect of a loading impedance.

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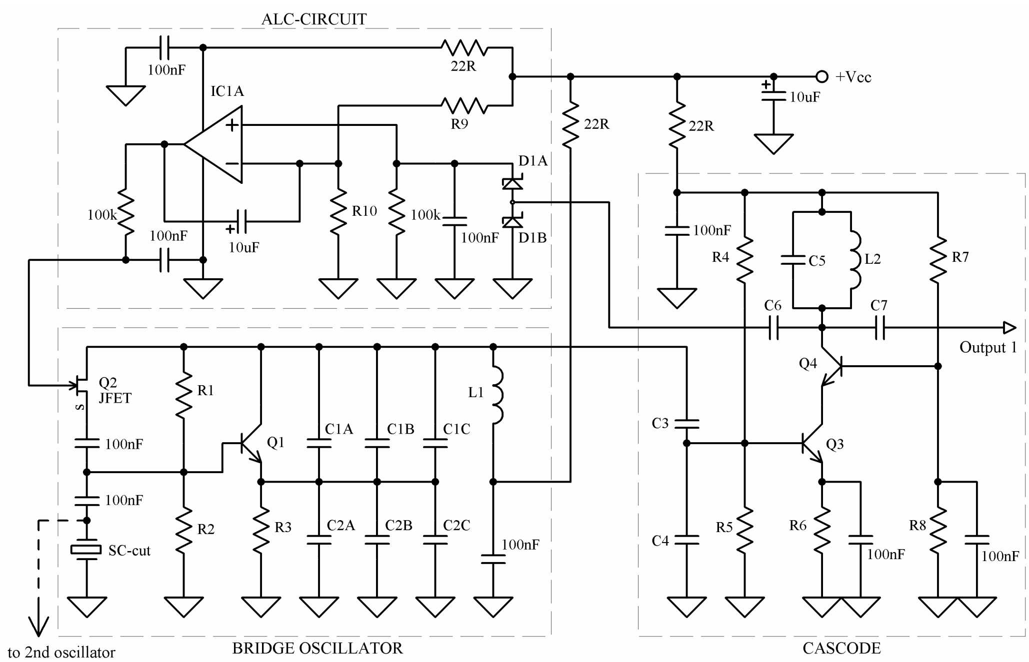

Figure 2. Schematic diagram of the crystal oscillator (two XOs with the similar structure forms the DMXO).

The amplitude of oscillations is derived from ac voltage at the cascode output (i.e. from the XO output). Analog voltage-comparator with an operational amplifier compares the rectified voltage, which is obtained from a simple voltage-doubler circuit using two Schottky diodes, with the predefined level (dc voltage).

ALC provides significant collateral benefits: it controls the crystal current, and it also reduces the starting time of the oscillator. The use of ALC may also mitigate the effects of radiations on crystal resistance [3].

The comparator output voltage controls the resistance of N-channel junction field-effect transistor (JFET). The JFET forms the negative feedback in the bridge oscillator sustaining amplifier. Since the DMXO comprises of the two XOs that have two separated ALC circuits, the drive levels (i.e. currents through the resonator) of the two excited modes are controlled independently. It is advantageous, since the drive levels affect both short-term as well as long-term frequency stability (i.e. an aging rate) of the both excited modes.

III. Evaluation of the Resonator Self-Thermometry Utilizing the Designed DMXO Prototype

Block diagram of the resonator self-thermometry implementation is shown in Fig. 1. Figure 3 captures the measured frequency of the 3rd overtone XO versus temperature. The measured frequency of the 5th overtone XO versus temperature is shown in Fig. 4.

Subtracting the 5th overtone frequency divided by 5 from the 3rd overtone frequency divided by 3 using digital mixing method gives the difference frequency f_d.

$$f_d = f_3/3 - f_5/5 \tag{1}$$

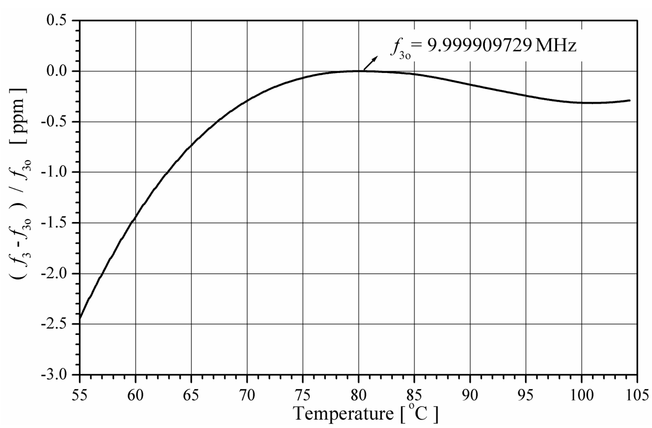

Figure 3. Measured 3rd overtone XO frequency vs. temperature.

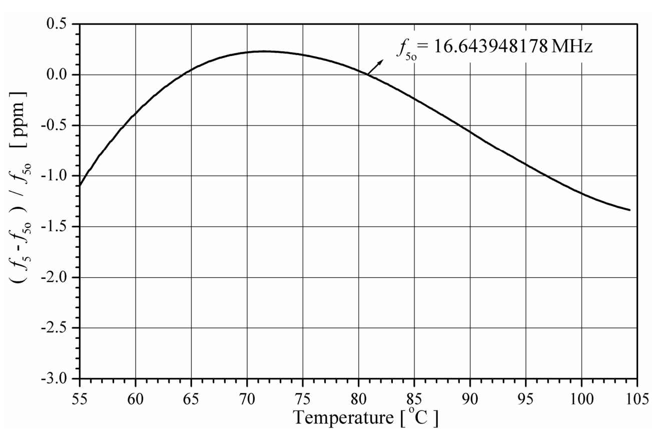

Figure 4. Measured 5th overtone XO frequency vs. temperature.

Figure 5 illustrates that the difference frequency is almost linear function of the resonator's temperature with the positive slope of approximately 37ppm / ^{o}C.

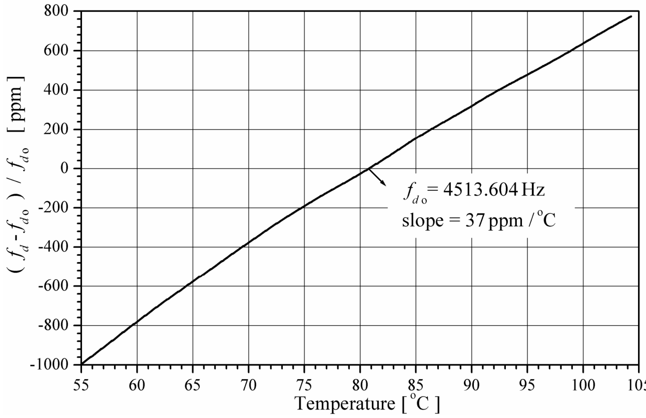

Figure 5. Measured difference frequency vs. temperature.

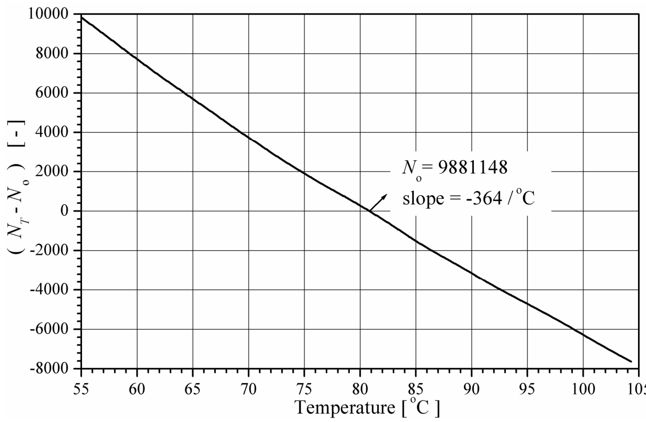

Figure 6. Number of clock pulses accumulated in the binary counter during the time interval 4460 / f_d vs. temperature.

Simple gate counter produces the time interval $4460/f_d$ (the time interval is approximately one second) during which the binary counter accumulates clock pulses with frequency f_3. After the clock pulses accumulation, the content of the binary counter can be expressed by following formula:

$$N_T = \mathrm{int}\left(\frac{f_3}{f_3/3 - f_5/5} 4460 \right) \qquad (2)$$

The content of the binary counter is used to form an independent variable $N=N_T-N_o$ that represents the actual temperature of the SC-cut resonator in the DMXO. The N is again almost linear function of temperature with the negative slope of -364 / °C as it is illustrated in Fig. 6.

IV. Results and Conclusions

The single-segment 9th order polynomial was utilized to calculate the frequencies of the 3rd overtone XO and of the 5th overtone XO according to N. Figure 7 shows the relative shift between calculated frequency and measured frequency of the signal generated at the 3rd overtone XO output. Similar result, in the case of 5th overtone XO, is shown in Fig. 8. The frequency residuals less than 0.015 ppm, including hysteresis, we have achieved in the temperature range between +55°C and +105°C during the experiments.

Since all necessary temperature information is obtained directly from the resonator itself, rather than from an external sensor, temperature offset and lag effects are eliminated.

Investigation of a long-term frequency stability of both excited overtones in the developed DMXO is also our aim; however, it will require a long-time evaluation of the realized prototypes.

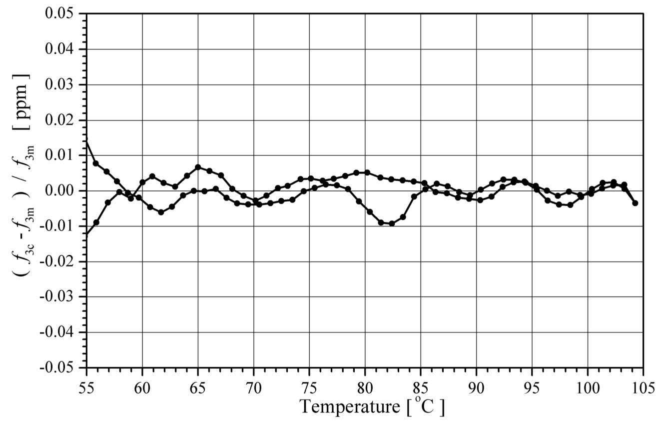

Figure 7. Residuals vs. temperature in the case of 3rd overtone XO; data from calibration-run were fit to a single-segment 9th order polynomial.

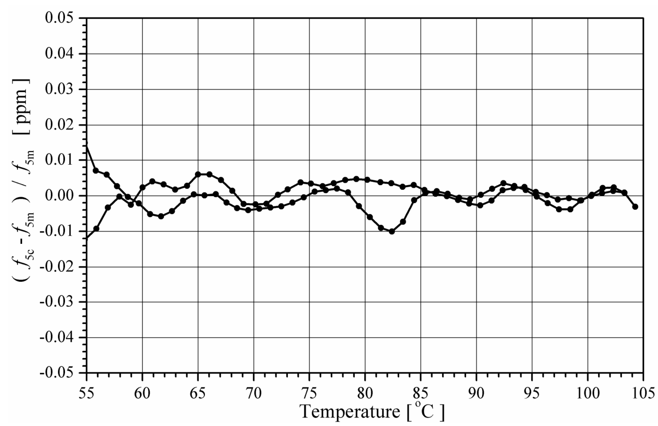

Figure 8. Residuals vs. temperature in the case of 5th overtone XO; data from calibration-run were fit to a single-segment 9th order polynomial.

References

[1] S. S. Schodowski, “Resonator Self-Temperature-Sensing using a Dual-Harmonic-Mode Oscillator,” Proc. of the 43rd Annual Symposium on Frequency Control, 1989, pp. 2-7.

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