SINGLE TRANSISTOR DUAL-MODE CRYSTAL OSCILLATOR

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Abstract

This paper deals with a single transistor dual-mode crystal oscillator using a quartz resonator as frequency stabilization element and sensor element of its own temperature as well. The attention is devoted to computer simulations of the oscillator as well.

1. **Introduction**

Approaches to solution of the problem of temperature-frequency stabilization of crystal oscillators based on dual-mode oscillator belong to advanced ones. Intrinsic to all high-performance quartz frequency (time) sources is a precision temperature-sensing, i.e., a thermometer, which detects crystal temperature to effect either temperature compensation or temperature control. The conventional method for sensing crystal temperature in Temperature Compensated Crystal Oscillators (TCXO), for example, makes use of thermistor or thermistors, placed in close proximity to the resonator. This method suffers from inaccuracies due thermal lag stemming from a difference in crystal and thermistor effective time constant, thermal gradients and thermistor aging. To overcome these limitations Kusters at the 1978 Frequency Control Symposium proposed the use of B-mode of an SC-cut for temperature sensing in dual B and C-mode oscillator. However, excessive activity dips associated with B-mode have eliminated this method from current consideration in wide temperature range TCXO. The problem referring B-mode has been successfully solved by a resonator self-temperature-sensing method using a pair of harmonically related C-modes in a dual C-mode oscillator. By employing an SC-cut, the C-modes are almost quarantined to be free of activity dips over the full operating temperature range. The stress and thermal-transient-compensated characteristics of the SC-cut can then be exploited to their fullest extent.

The dual c-mode method overcomes the limitations of existing temperature sensing methods and makes possible a new generation of higher accuracy crystal oscillators. It is particularly suited for application in MCXO (Microcomputer Compensated XO) to provide 10 to 100 times improvement in frequency-temperature stability when compared to conventional TCXO.

Because of better characteristics than AT-cut crystal and self-temperature sensing, the most high-stability MCXOs are based on SC-cut dual-mode crystal oscillators [5].

2. Principle of a resonator-self-temperature method

By simultaneously exciting a pair of harmonically related C-mode of a temperature stable oscillator in dual-mode crystal oscillator and combining their signals (Fig.1), a beat frequency (f_β) is obtained which can be used to compensate either one of the generated C-mode signals. Several means for combining the signals are possible.

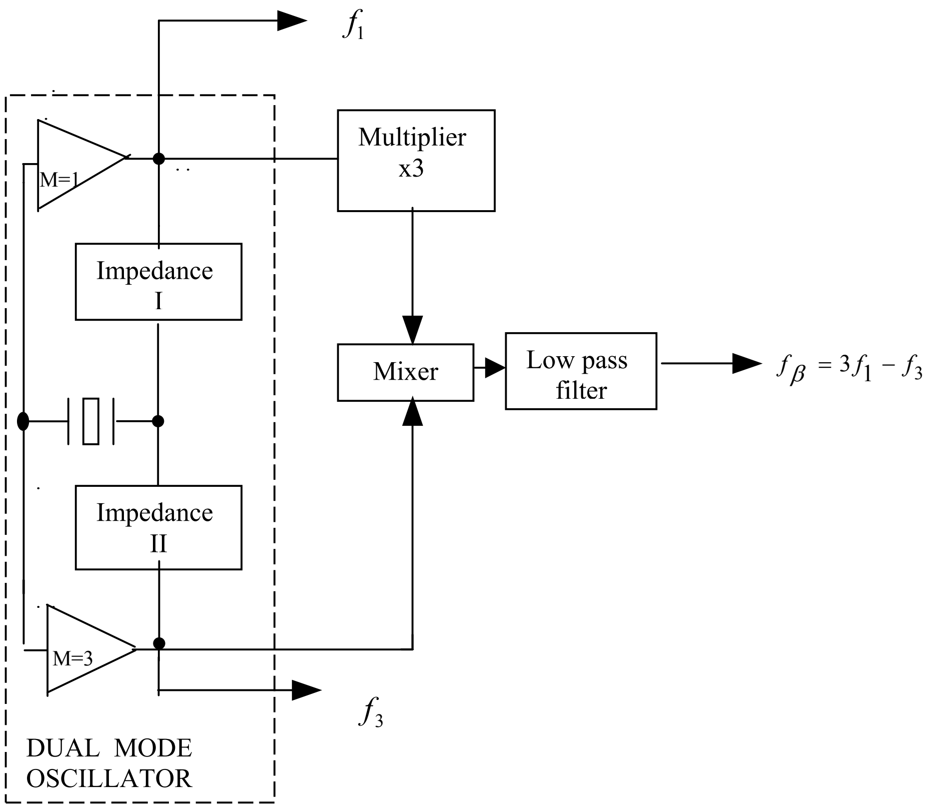

Fig.1 Illustration of the dual C-mode thermometry method.

In this illustration the lower harmonic C-mode (M=1), i.e., the fundamental frequency f_1, is multiplied by three and then mixed with the higher harmonic C-mode (M=3), i.e., the third overtone frequency f_3 to obtain different product, or beat frequency f_β, which is

$$f_\beta = 3f_1 - f_3 \tag{1}$$

The beat frequency can also be obtained by dividing the dual-mode oscillator's the third-overtone output frequency by three and then mixing the divided signal with the fundamental output frequency. Although f_β is now one-third of the value it have had in the initial example, it retains the same temperature coefficient as previously.

According to (1) the beat frequency can be described in normalized form as

$$\frac{\Delta f_\beta(\upsilon)}{f_\beta} = \frac{3}{3-n}\frac{\Delta f_1(\upsilon)}{f_1} - \frac{n}{3-n}\frac{\Delta f_3(\upsilon)}{f_3} \tag{2}$$

where n is the noninteger ratio of the frequencies for the harmonic pair at the reference temperature, i.e., n= f_3/f_1; values of n ranging from 2.94 to 2.98 were found to be typical for a variety of SC cut designs inspected, and where υ is any variable, etc. supply voltage, load, temperature, etc. Using f-T dependence of the two modes as follows

$$\frac{\Delta f_M}{f_M} = a_M \Delta T + b_M \Delta T^2 + c_M \Delta T^3 \tag{3}$$

where the normalized frequency $\Delta f_M / f_M$ and the difference temperature ΔT are referred at the inflection temperature and a_M, b_M, and c_M are the first, second and third order temperature coefficients of frequency at harmonic number M. Eg.(2) can be rewritten as a function of temperature

$$\frac{\Delta f_\beta(T)}{f_\beta} = \frac{3a_1 - na_3}{3-n}\Delta T + \frac{3b_1 - nb_3}{3-n}\Delta T^2 + \frac{3c_1 - nc_3}{3-n}\Delta T^3 \tag{4}$$

where a_1, b_1, c_1 and a_3, b_3, c_3 are the temperature coefficients of frequency for the fundamental and third overtone, respectively. Equation (4) then yields the temperature coefficients for the beat frequency.

3. Computer simulations of the dual mode oscillator

Figure 2 shows the single-gain-loop dual-mode crystal oscillator (DMXO) capable of generating of the two C-modes (simultaneous excitation of the C-modes). Suppression of undesired SC-cut B-mode frequencies is accomplished by the network C_2, L_2,C'_2, L'_2, which is designed to appear capacitate and provides the correct phase shift for oscillation at only the two C-mode frequencies. Inherent nonlinearities in he transistor provide for multiplication and mixing such that the beat frequency is available at the collector output, following filtering of the higher frequency components. Either the fundamental or third overtone frequencies can be extracted at the emitter using a frequency selective amplifier. The single gain loop DMXO basically offers lower parts count and lower input power than the double gain loop circuit. However, it does trade off the flexibility for separate control over crystal-mode-current-adjustment and stability coefficient optimization. This limited capability can prevent the single gain loop DMXO from achieving the same high level of performance as the double gain loop design. However, its use may be warranted in applications permitting somewhat less temperature sensing accuracy.

The dual mode oscillator shown in Figure 2 was analyzed by means of computer simulation using program MicroCap. For the purpose of the simulation we have used the elements of the oscillator as follows.

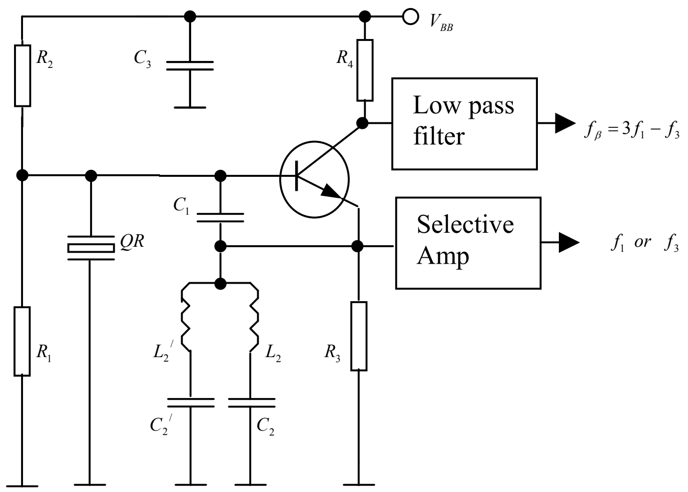

Fig.2 Single transistor dual-mode crystal oscillator

Quartz resonator(QR): fundamental $(\approx 10MHz): L_1 = 9.79mH; C_1 = 2.59.10^{-14}F; R_1 = 3.6\Omega$ third overtone $(\approx 30MHz)$: $L_3 = 27.048mH; C_3 = 1{,}0442.10^{-15}F; R_1 = 13\Omega$. The other elements: transistor 2N3478; R_1=R_2=39k, R_3=3.9k, R_4=0(omited), C_1=180pF, C_2= 10,4pF, C'_2= 2.6pF , L_2= 20.1μH , L'_2=10μH.

The results of the computer simulations obtained at the outputs of the selective amplifiers (U_{f1} for fundamental; U_{f3} for third overtone) are in Figure 3.

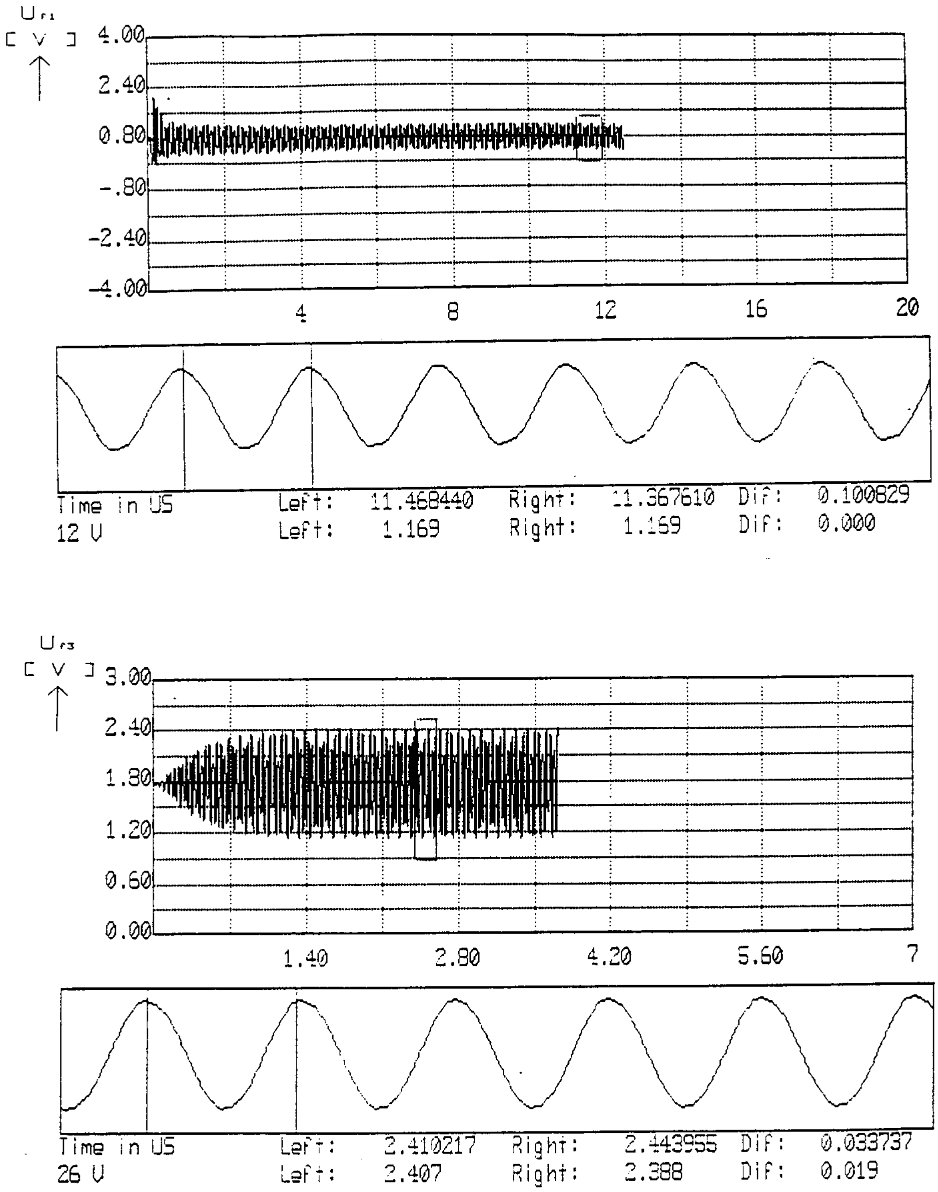

Fig.3. The results of the computer simulation (U_{f1} for fundamental- the upper part of the Figure ; U_{f3} for third overtone- the lower part of the Figure)

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