Design, Simulation and Realization of a Dual-Mode Oscillator with Distributed RC Structure

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Abstract

This submission dealt with the design, simulation and realisation of a dual mode oscillator with distributed RC structures that use AT-cut quartz resonator as stabilisation element and sensor element of its own temperature. Simulations, experimental results and evaluation of the short-term stability are also included.

Keywords

Oscillators, dual-mode oscillators, RC structures.

1. introduction

Not only since the discovery of the piezoelectric resonators, but also in its future development they have been coupled with the establishment and development of the radio and electronics devices. They were designed, first of all, to fit the needs of increasing the frequency stability of radio and telecommunication systems, which play a great role nowadays [1]. The dual-mode oscillator presents a very important part of the progressive Microprocessor Compensated quartz oscillators (MCXO). Inductors used in dual-mode oscillators belong to the most important parts of the oscillators, but because of its relative unwieldiness, we search after alternatives. To avoid using inductors there is a very attractive idea to utilise RC structures with distributed parameters in a dual-mode quartz oscillator [2]. The idea of design a dual-mode oscillator with distributed parameters was originally published for the first time in the "1997 IEEE frequency control symposium" [3]. The dual-mode oscillator presented in such a way can not be only fully inductorless, but also the RC structures and the most passive elements can be implemented into one integrated circuit (IC). Consequently, the dimensions of the mentioned oscillator can be essentially determined by the used IC and the quartz resonator [4].

2. The design of a dual-mode oscillator

The main idea resides in using two RC structures with distributed parameters (Fig.1) separated by the infinity gain buffer stage. The second RC structure given by nR and nC is connected with lumped resistor R_T.

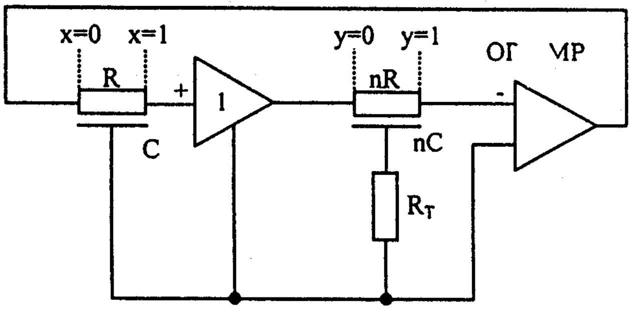

Fig. 1 Oscillator with two separated distributed RC structures

The transfer function of the above open loop connection network can be expressed as:

$$P(\Theta) = \frac{1}{\cosh(\Theta)} \cdot \frac{1 + kn\Theta \sinh(n\Theta)}{\cosh(n\Theta) + kn\Theta \sinh(n\Theta)}$$

$$= \frac{1 + kn\Theta \sinh(n\Theta)}{\cosh(\Theta)(\cosh(n\Theta) + kn\Theta \sinh(n\Theta))} \quad (1)$$

where $\Theta = \sqrt{j\omega RC}$ is the normalised frequency.

By using an appropriate ratio $k = R_T/nR$ and n=3 it is possible to obtain the form of the curves given in Fig. 2 and Fig. 3. For the first homogenous RC structure with distributed parameters considering the one-dimensional model, the following can be written:

$$\partial^2 u(x,\tau)/\partial x^2 = \partial u(x,\tau)/\partial \tau \quad (2)$$

where $x \in <0;1>$, $\tau = t / RC$ are normalised values.

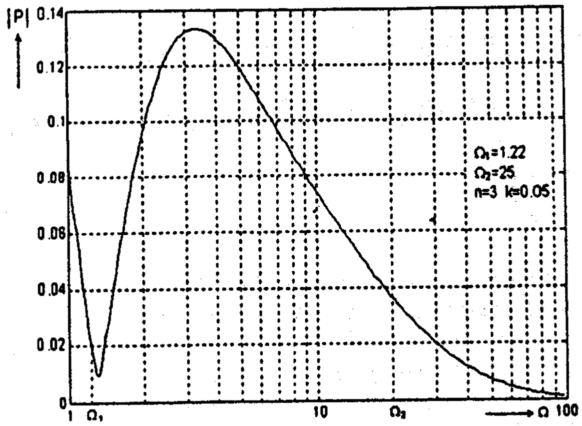

Fig. 2 The magnitude vs. normalised frequency characteristic

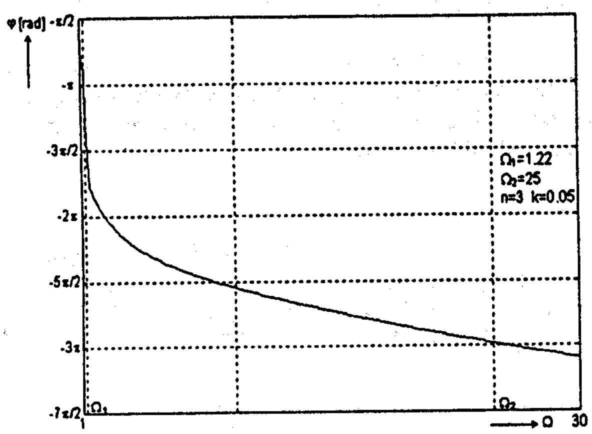

Fig. 3 The phase vs. frequency characteristic

Also, for the second RC structure with the lumped resistor R_T shown in Fig. 4 the following will hold true:

$$\partial^2 v(y,\tau)/\partial y^2 = n^2\, \partial v(y,\tau)/\partial\tau \qquad (3)$$

Also here y and τ are normalised values.

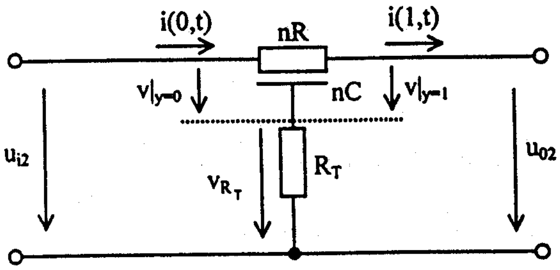

Fig. 4 RC structure with lumped resistor

Assuming that the unity buffer stage and the operational amplifier have a very high input and very low output impedance for Fig. 4 and Fig. 5 we can write:

$$u\big|_{x=1} = u_{i2},\ \ u_{i2} = v(y,\tau)\big|_{y=0} + v_{R_T},$$

$$v_{R_T} = R_T\, i(y,\tau)\big|_{y=0} \qquad (4)$$

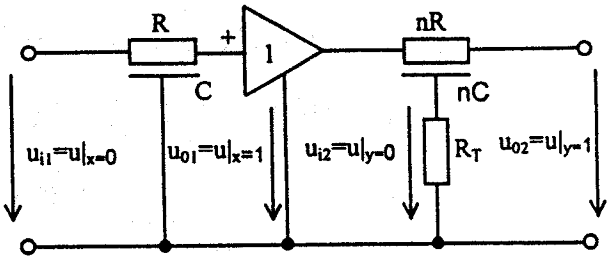

Fig. 5 The two RC structures separated by the unity buffer stage

For the second RC structure the following can be also obtained:

$$i(y,\tau) = -\frac{1}{nR}\frac{\partial v(y,\tau)}{\partial y} \qquad (5)$$

Substituting (5) into (4) gives:

$$u_{i2} = u(x.\tau)\big|_{x=1} = v(y,\tau)\big|_{y=0} - \frac{1}{k}\frac{\partial v(y,\tau)}{\partial y}\bigg|_{y=0} \qquad (6)$$

Expression (6) specifies the first boundary condition.

The next two boundary conditions can be obtained from the unload RC networks:

$$\frac{\partial u(x,\tau)}{\partial x}\bigg|_{x=1} = 0 \qquad (7)$$

$$\frac{\partial v(y,\tau)}{\partial y}\bigg|_{y=1} = 0 \qquad (8)$$

Considering the third power symmetric polynomial approximation of the operational amplifier non-linear characteristic i.e. the linear and cubic terms $u\big|_{x=0} = -K_0 u_{o2} + K_2 u_{o2}^3$ the fourth boundary condition can be derived:

$$u\big|_{x=0} = -K_0\left(v(y,\tau)\big|_{y=1} - \frac{1}{k}v(y,\tau)\big|_{y=0}\right) + \\ + K_2\left(v(y,\tau)\big|_{y=1} - \frac{1}{k}v(y,\tau)\big|_{y=0}\right)^3 \qquad (9)$$

where it is supposed that $K_0>0$ and $K_2>0$.

Author in [5], outgoing from the Hopf bifurcation theorem, solved the two parabolic partial equations (2) and (3) with the four boundary conditions (6)-(9) by using the separation of the slow and fast motions of the characteristic equations roots and by defining the small parameter for two asynchronous oscillations.

For the angular frequencies Ω_1, Ω_2 the values of magnitude vs. frequency characteristics can be approximately equal (Fig. 2), where the phase shifts are $\varphi_1(\Omega_1)=-\pi$ and $\varphi_2(\Omega_2)=-3\pi$ (Fig. 3). By changing the operational amplifier gain the conditions for originating of oscillation can be satisfied simultaneously or gradually. The negative character of the slope of the phase characteristic, which is a necessary condition for existence of the stable periodical oscillations, in both cases will be sustained.

Against the above background a dual-mode oscillator with two distributed RC structures using one quartz and one COMS (IC) represented by six inverters (two of them were used) has been designed. The block diagram of the designed oscillator is shown in Fig. 6.

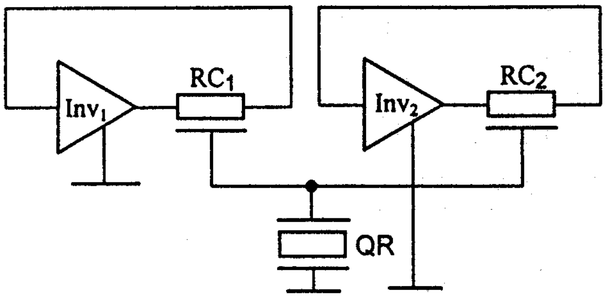

Fig. 6 The block diagram of the designed oscillator

The RC_1 structure with the quartz equivalent electrical branch of R_1, L_1, and C_1 give the positive feedback loop of the oscillator for the fundamental frequency and the RC_2 structure with the branch R_3, L_3, and C_3 give the third overtone frequency of the oscillator Fig. 7

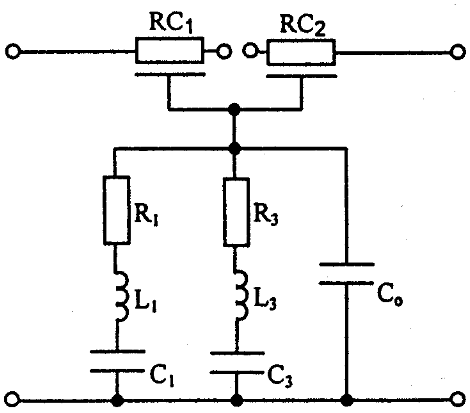

Fig. 7 The positive feedback loop of the oscillator

3. Simulations and results

The network connection in Fig. 5 was simulated by means of program Micro-Cap III, where the RC structures RC_1 and RC_2 have been modelled by a cascade configuration of three identical RC lumped low-pass filters (Fig. 8).

The used values of RC elements in simulations are R_1=680Ω, C_1=96.7pF and R_2=2040Ω, C_2=290.1pF. The used value of the transversal resistor R_T=102Ω. The simulation result is presented in Fig. 9.

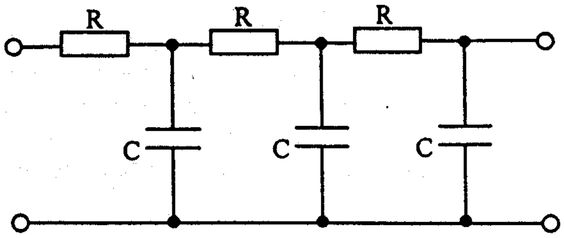

Fig.8 The used circuit in simulation as the RC structure equivalent

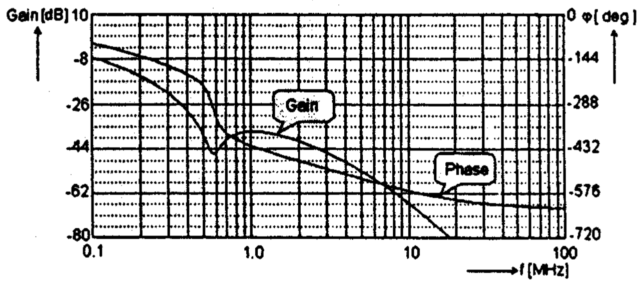

Fig.9 The simulation result of the circuit given in Fig. 5

Also, the positive feedback loops of the oscillator for the fundamental and third overtone frequency has been simulated, where the amplitude and phase vs. frequency characteristics were the subject of interest. The quartz resonator electrical equivalent parameters have been measured and used in simulations. The equivalent parameters are L_1=93.31mH, C_1=15.44fF, R_1=32.625Ω, L_3=76.57mH, C_3=2.12144431fF, R_3=50Ω and C_o=14.88pF. The obtained simulation results are presented in Fig. 10 and Fig. 11.

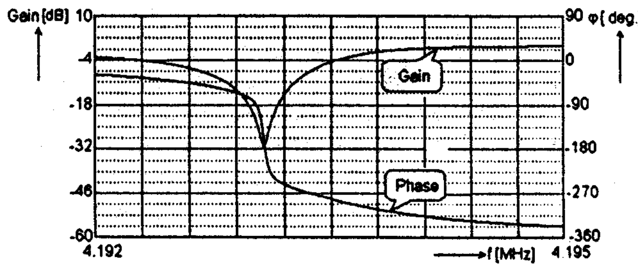

Fig.10 The amplitude and phase vs. frequency characteristic for the fundamental frequency

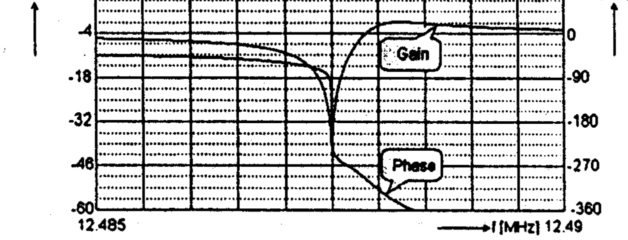

Fig. 11 The amplitude and phase vs. frequency characteristic for the third overtone frequency

4. Experimental results

The circuit layout of the designed and realised dual mode quartz oscillator with distributed RC structures is shown in Fig. 12. In this diagram U_{1har} specifies the output signal that corresponds to the oscillator with the fundamental frequency of the resonator "QR" and U_{2har} is the output signal corresponding to the oscillator with the third overtone frequency of the "QR".

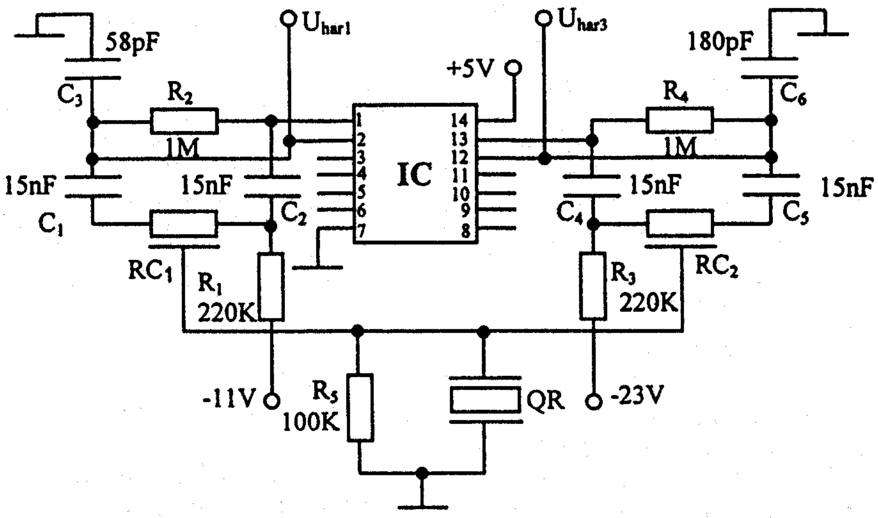

Fig. 12 The circuit layout of the designed and realised dual-mode quartz oscillator with two distributed RC structures

In this design The CMOS-IC SN54HCT04 device manufactured by Texas Instrument has been used as inverter. This device contains six independent inverters performing the Boolean function $Y = \overline{A}$ in positive logic and it is characterised for operation over full military temperature rang of -55 °C to 125 °C. The capacities of RC structures are adjusted by means of voltages -11V and -23V. The amplitude and phase vs. frequency characteristic of the above-mentioned oscillator for the fundamental frequency have been measured and carried out into diagrams (Fig.13-14). The voltage applied to RC structures was -11V.

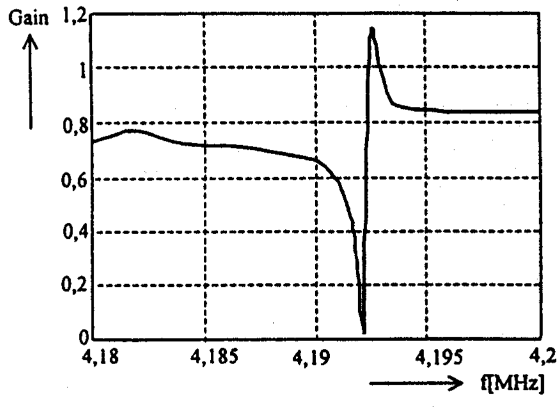

Fig. 13 The measured amplitude characteristic of the oscillator

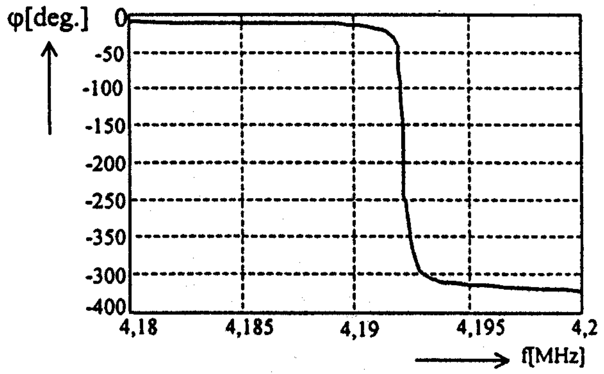

Fig. 14 The measured phase characteristic of the oscillator

The short-term stability of the oscillator was also a subject of investigated, therefore the realised oscillator was undergone a measurement, where the short-term stability (one and ten seconds) of the fundamental and third overtone frequency was evaluated by Alliance variance.

The short-term stability for signal U_{1har} has been:

δ(1s)= 8,32525E-10.

δ(10s)= 11,4565E-10.

The short-term stability for signal U_{3har} has been:

δ(1s)= 1,77671E-09.

δ(10s)=4,24526E-9.

5. Conclusion

In this contribution a concept, how to design and realise a dual-mode oscillator with distributed RC structures, which essentially minimise the dimensions of the oscillator circuitry. Simulation and experimental results are also included. These results will be degraded by the non-ideal amplifier input and output impedance and by the incorrect selected ratio of R_T/R, where R is the value of the distributed RC structure. The short-term stability has been evaluated by Allan variance.

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Marian MINÁRIK was born in 1952, Detva, Slovak republic. In 1976 he received the MS degree and in 1996 the Ph.D. degree both from the Slovak Technical University of Technology in Bratislava. Since 1992 he has worked as a lecturer at the Department of Radioelectronics of the Faculty of Electrical Engineering and Information Technology.