DESIGN, SIMULATION AND REALIZATION OF A DUAL-MODE OSCILLATOR WITH DISTRIBUTED RC STRUCTURE

Rami OWEIS
Marian MINÁRIK
Slovak University of Technology
Faculty of Electrical Engineering and Information Technology
Department of Radioelectronics
Ilkovičova 3, 812 19 Bratislava
Slovak Republic
E-mail: oweis@elf.stuba.sk

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, experimetal 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](image)

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

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

\[= \frac{1 + kn \Theta \sinh(n\Theta)}{\cosh(\Theta)(\cosh(n\Theta) + kn \Theta \sinh(n\Theta))}
\]

where \( \Theta = \sqrt{\frac{1}{2}RC} \) 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:

\[
\frac{\partial^2 u(x,\tau)}{\partial x^2} = \frac{\partial u(x,\tau)}{\partial \tau}
\]

where \( x \in (0;1) \), \( \tau = t/RC \) are normalised values.
Design, realisation and simulation of a dual-mode oscillator with distributed parameters

R. OWEIS, M. MINÁŘIK

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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:

$$\partial^2 v(y, \tau)/\partial y^2 = n^2 \partial v(y, \tau)/\partial \tau$$  \hspace{1cm} (3)

Also here $y$ and $\tau$ are normalised values.

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:

$$u_{i,x=0} = u_{i,2} = v(y, \tau)|_{y=0} + v_{R_T}$$

$$v_{R_T} = R_T i(y, \tau)|_{y=0}$$  \hspace{1cm} (4)

Fig. 4 RC structure with lumped resistor

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

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

Substituting (5) into (4) gives:

$$u_{i,2} = u(x, \tau)|_{x=1} = v(y, \tau)|_{y=0} \frac{1}{k} \frac{\partial v(y, \tau)}{\partial y}|_{y=0}$$  \hspace{1cm} (6)

Expression (6) specifies the first boundary condition.

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

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

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

Considering the third power symmetric polynomial approximation of the operational amplifier non-linear characteristic i.e. the linear and cubic terms $u_{i,x=0} = -K_0 u_{o,2} + K_2 u_{o,2}^3$ the fourth boundary condition can be derived:

$$u_{i,1} = -K_0 \left(v(y, \tau)|_{y=0} - \frac{1}{k} v(y, \tau)|_{y=0} \right) + K_2 \left(v(y, \tau)|_{y=1} - \frac{1}{k} v(y, \tau)|_{y=0} \right)^3$$  \hspace{1cm} (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 $\Omega_1$, $\Omega_2$ the values of magnitude vs. frequency characteristics can be approximately equal (Fig. 2), where the phase shifts are $\varphi(\Omega_1) = -\pi$ and $\varphi(\Omega_2) = 3\pi$ (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.

![Block Diagram of the Designed Oscillator](image)

Fig. 6 The block diagram of the designed oscillator

The RC₁ structure with the quartz equivalent electrical branch of \( R₁, L₁, \) and \( C₁ \) give the positive feedback loop of the oscillator for the fundamental frequency and the RC₂ structure with the branch \( R₃, L₃, \) and \( C₃ \) give the third overtone frequency of the oscillator Fig. 7

![Positive Feedback Loop of the Oscillator](image)

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 RC₁ and RC₂ 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 \( R₁=680\, \Omega, \) \( C₁=96.7\, \text{pF} \) and \( R₃=2040\, \Omega, \) \( C₃=290.1\, \text{pF} \). The used value of the transversal resistor \( R₄=102\, \Omega \). The simulation result is presented in Fig. 9.

![Simulation Results](image)

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

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 \( L₁=93.31\, \text{mH}, \) \( C₁=15.44\, \text{pF}, \) \( R₁=32.62\, \text{kΩ}, \) \( L₃=76.57\, \text{mH}, \) \( C₃=2.12\, \text{pF} \), \( R₃=50\, \text{kΩ} \) and \( C₄=14.88\, \text{pF} \). The obtained simulation results are presented in Fig. 10 and Fig. 11.

![Amplitude and Phase for Fundamental Frequency](image)

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

![Amplitude and Phase for Third Overtone Frequency](image)

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 \( U_{\text{out}} \) specifies the output signal that corresponds to the oscillator with the fundamental frequency of the resonator "QR" and \( U_{\text{out}} \) is the output signal corresponding to the oscillator with the third overtone frequency of the "QR".

![Circuit diagram](image)

**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 \( Y = A \) in positive logic and it is characterised for operation over full military temperature range 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.

![Amplitude characteristic](image)

**Fig. 13** The measured amplitude characteristic of the oscillator

![Phase characteristic](image)

**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 \( U_{\text{out}} \) has been:

\[ \delta(1s) = 8,32525E-10. \]

\[ \delta(10s) = 11,4565E-10. \]

The short-term stability for signal \( U_{\text{out}} \) has been:

\[ \delta(1s) = 1,77671E-09. \]

\[ \delta(10s) = 4,24526E-9. \]
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 $R_f/R$, where $R$ is the value of the distributed RC structure. The short-term stability has been evaluated by Allan variance.

References


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About authors...

Rami OWEIS was born in 1970 Zarqa, Jordan. He received Ing. (MS) in Electronics with the option specialisation Biomedical Electronics in 1994 at the Slovak Technical University of Technology in Bratislava. Since February 1995 he has started His doctoral studies at the Department of Radioelectronics of the Faculty of Electrical Engineering and Information Technology. His topic of Ph.D. thesis is Inductorless Dual-mode Oscillator realised by means of RC structures with distributed parameters.

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