International Journal of Engineering and Advanced Technology Studies
Vol.10, No.3, pp.1-10, 2022
Print ISSN: 20535783(Print)
Online ISSN: 20535791(online)

Sine Oscillator in Quadrature with Double Simulation: Electronic Quartz

Ciugudean Mircea

Citation: Mircea C. (2022) Sine Oscillator in Quadrature with Double Simulation: Electronic Quartz, *International Journal of Engineering and Advanced Technology Studies*, Vol.10, No.3, pp.1-10

ABSTRACT: *This article presents a new type of sine oscillator, discovered and studied at the Faculty of Electronics and Telecommunications in Timisoara. It analyzes the numerous theoretical and practical aspects that appear and signals its spectacular performances. The scheme of the new oscillator was introduced for the first time in Electronic Engineering, London, Febr. 1993. But here is presented the complete theory of the oscillator established after several years of research. The new sine oscillator is sure to have the best performancse of all known quartz-free oscillators.*

KEYWORDS*:* sine oscillator, quadrature, double simulation, electronic quartz

In the following is presented a new type of sine oscillator, discovered and studied at the Faculty of Electronics and Telecommunications in Timisoara [1, 2, 5, 6], analyzing the numerous theoretical and practical aspects that appear and signaling its spectacular performances. The scheme of the new oscillator is one of the most interesting applications of operational amplifiers. It is made using a parallel LC oscillating circuit, including both simulated components using operational amplifiers. Due to the variable resistance of the amplitude limitation device, the oscillating circuit is automatically established in an unamortized regime, characterized by a quality factor $Q = \infty$. Here will be presented the main equations that give the condition and frequency of oscillation, the phase and the amplitude of the output voltages [3]..

The new type of oscillator, proposed in [1], is based on a parallel circuit, consisting of an inductance and capacity, L_{eq} and C_{eq}, as shown in fig.1.

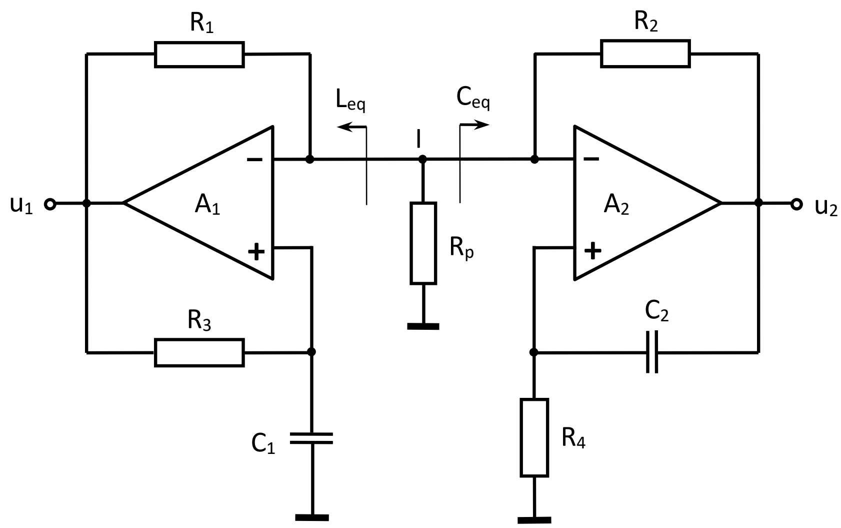


Fig. 1. Departure scheme of the oscillator

Here, the circuit that includes the A_1 represents an NIC ("negative impedance converter") whose inverting input simulates, under ideal conditions, a purely inductive impedance, given by:

$$z_{i1} = -\frac{1}{j\omega C_1}\frac{R_1}{R_3} = j\omega L_{eq}$$

It follows from this:

$$L_{eq} = \frac{R_1}{\omega^2 C_1 R_3}$$

The circuit with A_2 represents a NAIC ("negative admittance / impedance converter") whose inverting input simulates, under ideal conditions, a purely capacitive impedance, given by:

$$z_{i2} = -j\omega C_2 R_2 R_4 = \frac{1}{j\omega C_{eq}}$$

It follows from this:

$$C_{eq} = \frac{1}{\omega^2 C_2 R_2 R_4}$$

Having in reality in the scheme two capacitors with losses (we note with R_c the parallel loss resistance of the capacitor) they both transfer a negative resistance in node I (fig.2). Thus, a certain (positive) value of the resistor R_p can compensate the negative resistance and cause the oscillating circuit to be unamortized (i.e., to have a factor $Q = \infty$). The optimal value of the R_p resistor will be discussed later.

Because of the positive reaction from the A_1 amplifier, closed by R_3, the output of A_1 reaches saturation, so that the oscillations produced in the diagram in fig.1 are not sinusoidal and cannot be used. To achieve a negative reaction to keep both output voltages at zero, considering that the inputs of the amplifiers have, in the ideal case, the same voltage, the connections to the inputs of the two OA are reversed between them (fig.2). Thus, the reaction from the A_2 amplifier is negative.

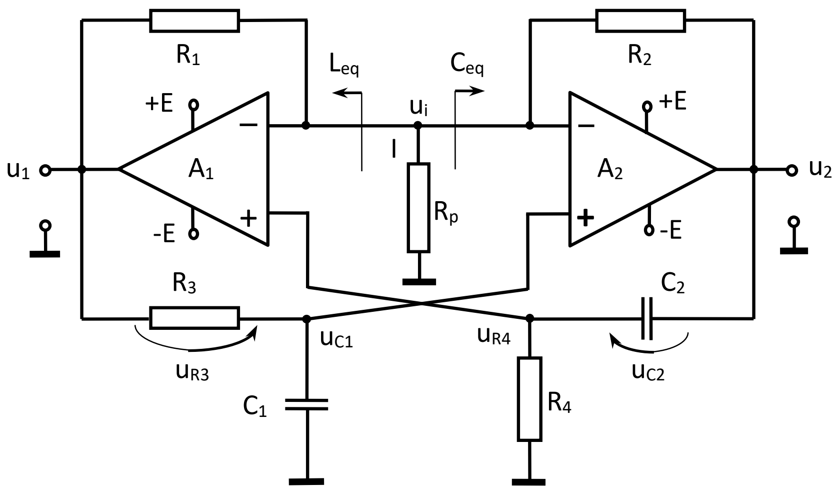


Fig. 2. Principle scheme of the oscillator

The two tensions are now sinusoidal and theoretically without the continuous component. The oscillator frequency [1] is given by the equation:

$$f_0 = \frac{1}{2\pi\sqrt{L_{eq}C_{eq}}} = \frac{1}{2\pi}\sqrt{\frac{R_1}{R_2R_3R_4C_1C_2}}$$

and, in the case of the fully symmetrical scheme (i.e. for the $R_1 = R_2$, $R_3 = R_4 = R$, $C_1 = C_2 = C$)

$$f_0 = \frac{1}{2\pi\ RC}$$

If the resistors R_1 and R_2 are made unequal (by a potentiometer) the frequency follows:

$$f_0 = \frac{1}{2\pi\ RC}\sqrt{\frac{R_1}{R_2}}$$

noting the possibility of adjusting the frequency by the ratio R_1/R_2

By omitting the resistor R_p from the oscillator scheme in fig.2, one can find an oscillating circuit including the capacity C_1 in parallel with a simulated inductance (in the node at the non-inverting input of A_2), discovered by A. Antoniou [1, 7] and proposed as a filter passes band. If this filter circuit is powered by a sinus source

@ECRTD-UK: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

with low internal resistance it does not oscillate. It is the merit of the author of the article [1] to have signaled that this circuit can generate sine oscillations by itself.

Amplitudes and phase shifts of voltages

In the fully symmetrical diagram of fig.3, the amplitudes of the two output voltages are limited by the supply voltages (i.e. ±E), in the vicinity of the E-1 V value.

On the divider R_3 - C_1, considering $u_{C1}= u_i$, we have:

$$u_1 = u_i + u_{R3} = u_i + j\omega C_1 R_3 u_i = u_i(1 + j\omega C_1 R_3)$$

and, with the above frequency equation:

$$u_1 = u_i\left(1 + j\sqrt{\frac{C_1 R_2 R_3}{C_2 R_1 R_4}}\right)$$

On the $C_2 - R_4$ divider, considering $u_{R4}= u_i$, the following are obtained:

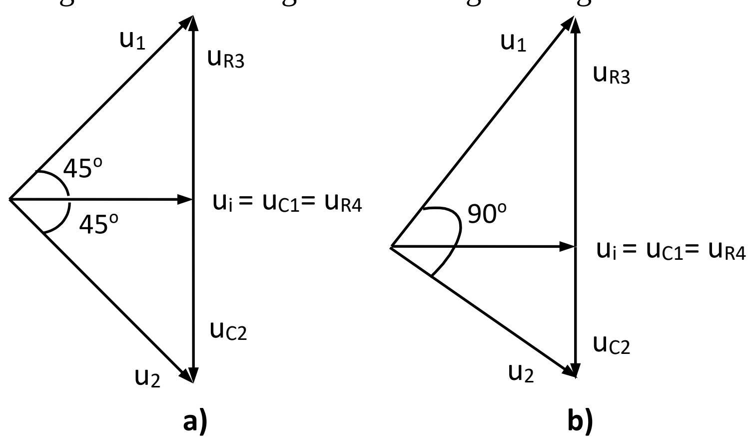
$$u_2 = u_i + u_{C2} = u_i + \frac{u_i}{j\omega C_2 R_4} = u_i\left(1 + \frac{1}{j\omega C_2 R_4}\right)$$

and, with the above frequency equation:

$$u_2 = u_i\left(1 - j\sqrt{\frac{C_1 R_1 R_3}{C_2 R_2 R_4}}\right)$$

Based on these relationships, one can construct the phasorial diagram of the two output voltages.

Fig.3 Phasorial diagrams of voltages in Fig.2 in two cases.



Thus, in the case of the fully symmetrical diagram, the phasorial diagram has the shape from fig.3a. It can be seen that the two output voltages are in quadrature and have amplitude:

$$u_{1m} = u_{2m} = \sqrt{2}u_{im}$$

Print ISSN: 20535783(Print)
Online ISSN: 20535791(online)

For a non-symmetrical scheme, the voltages u_1 and u_2 may also be in quadrature if (Pythagorean theorem):

$$u_{1m}^2 + u_{2m}^2 = (u_{R3m} + u_{C2m})^2$$

cu $$u_{1m} = u_{im}\sqrt{1+\frac{C_1R_2R_3}{C_2R_1R_4}} \qquad u_{2m} = u_{im}\sqrt{1+\frac{C_1R_1R_3}{C_2R_2R_4}}$$

$$u_{R3m} = u_{im}\sqrt{\frac{C_1R_2R_3}{C_2R_1R_4}} \qquad u_{C2m} = u_{im}\sqrt{\frac{C_1R_1R_3}{C_2R_2R_4}}$$

This leads to the condition: $C_1R_3 = C_2R_4$

Thus, for partially symmetrical scheme (C_1=C_2=C, R_3=R_4=R) the two voltages are in quadrature regardless of the ratio R_1/R_2 (fig.3b) and have amplitudes [3]:

$$u_{1m} = u_{im}\sqrt{1+\frac{R_2}{R_1}} \quad , \quad u_{2m} = u_{im}\sqrt{1+\frac{R_1}{R_2}}$$

Consequently, if the frequency is changed by the ratio R_1/R_2, the two amplitudes become uneven but the respective voltages remain in quadrature [1].

We use the notation L_{eq}^* for the Antoniou cell (with R_{pp}) [7]. The presence of a second parallel oscillating circuit, namely C_1 (fig.4), having the same resonance frequency, this time connected to the non-inverting input of the amplifier A_2, can be exploited in order to achieve a simple amplitude limitation to the desired value (fig.5).

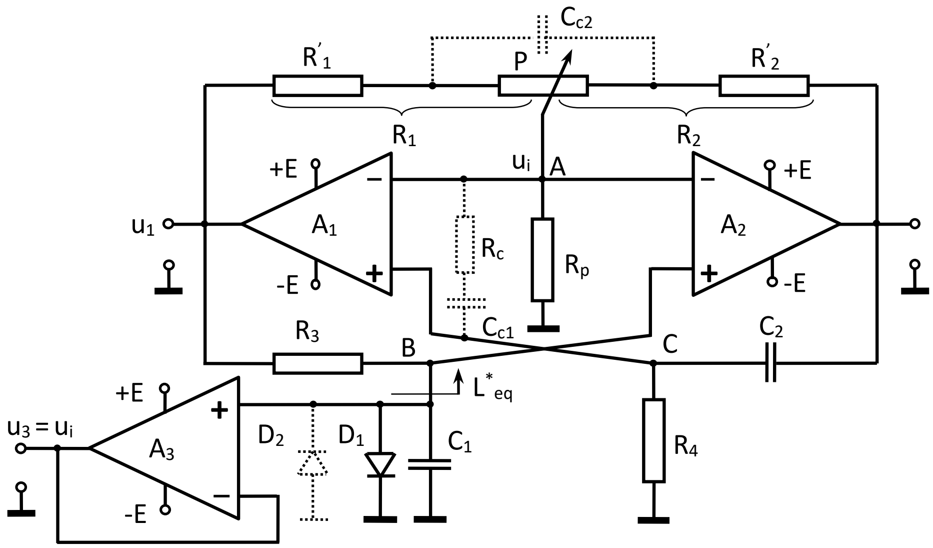


Fig. 4. Oscillator application scheme

The simplest amplitude limitation can be obtained using a single diode (or two connected in the antiparalel) as shown in fig.4. Symmetrical limitation with two devices ensures better spectral purity. According to a previous discovery of the author of the scheme [6], diodes connected in parallel on an oscillating circuit have an equivalent dynamic resistance:

$$r_{deq} \approx kQ^* r_{dp}$$

where:

- k is a coefficient that depends on the type and number of limiting diodes; for a single diode k=2,2 and for two diodes in antiparalel k=0,5; for a limiting branch with Zener diode and an ordinary diode in series, back to back, k=1 and for two such branches in antiparalel k=0,25;

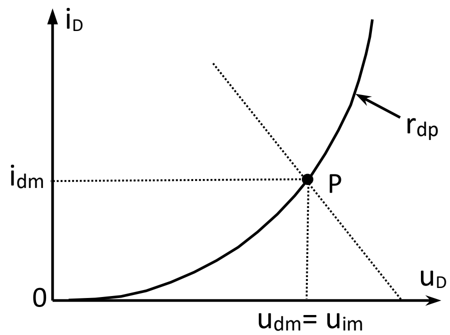


Fig.5. Definition of the diode "peak" resistance

- Q* is the quality factor of the $C_1 \| L^*_{eq}$ oscillating circuit and it has a high value;

- rdp is the dynamic "peak" resistance of a diode, defined as the slope of the u-i characteristic at the working point at the amplitude of the sinusoidal voltage u_i (fig.5).

A value of 1kΩ is required for the resistance of r_{dp} if a single diode is to be used, 2kΩ for two diodes and 3kΩ for a Zener diode. This value provides a compromise between the efficiency of limiting the amplitude of the output voltage and, respectively, the spectral purity. Due to the high value of the quality factor Q* (as will beeseen further) r_{deq} is large also and the limiting diode influences the distortion factor of the output voltages a little bit. It was obtained for it a value of 0,01% [3, 6]. Consequently, the shape of the output voltages is extremely close to a sinusoidal one.

If a limitation branch with a Zener diode and a simple diode in series are used, the amplitude of the u_{im} voltage will be close to the U_z voltage. Thus, the desired value of the output voltage can be obtained. It is also possible to use as a limiting device one or two LEDs, when the amplitude of the u_i voltage will be $u_{im} \approx 1.3$V. The use of LEDs brings the advantage of a better thermal stability of the u_{im} voltage.

The best limiting solution is to use one or two collector junctions of thermostated transistors from the µA726 integrated circuit. In this case the influence of temperature on the output voltages amplitude and on the frequency is minimized.

@ECRTD-UK: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

A third voltage output, through the repeater with OA A_3, as seen in fig.4, is made to obtain an amplitude of voltage $u_{3m}=u_{im}$, almost invariably at adjusting the frequency (when adjusting the potentiometer).

Some types of OA used in the oscillator require a modified phase advance-delay compensation to remove the parasitic oscillation. This frequency compensation is required only for the A_1 amplifier and is provided by the C_{c1} and R_c components (of several tens of pF and a few kΩ, respectively). Typically, OA with input on TECJ does not require this operation.

When a wide frequency adjustment range is provided (the value of the potentiometer P is greater than $R_{1'} = R_{2'}$) a second compensation capacitor C_{c2} must be used. It will have such a value as to ensure the shunting of the potentiometer at the parasitic oscillation frequency (several MHz). This oscillation would occur when the potentiometer is operated towards one end. With the help of C_{c2}, the symmetry of the scheme at high frequency is ensured and the parasitic oscillation disappears.

Oscillation condition and quality factors

Fig.4 (without A repeater A_3 and compensation components in frequency) can be redrawn in the form given in fig.6 [3]. This highlights the Antoniou cell that has a purely L_{eq}* inductive input impedance (if you ignore the losses of the capacitors). The introduction of the resistor R_p and r_{deq} allow the Antoniou cell to oscillate by compensating for the negative resistance in node A.

In the following calculation it is assumed that the operational amplifiers are ideal. Thus, the sinusoidal voltage u_i, indicated in fig.4, appears in three nodes of the circuit: A, B and C. Then, the sums of the currents in the nodes can be caught in equations of matrix form as follows [3]:

$$\begin{vmatrix} \frac{1}{R_1}+\frac{1}{R_2}+\frac{1}{R_p} & -\frac{1}{R_1} & -\frac{1}{R_2} \\ \frac{1}{r_{deq}}+\frac{1}{R_3}+j\omega C_1 & -\frac{1}{R_3} & 0 \\ \frac{1}{R_4}+j\omega C_2 & 0 & -j\omega C_2 \end{vmatrix} \times \begin{vmatrix} u_i \\ u_1 \\ u_2 \end{vmatrix} = \begin{vmatrix} 0 \\ 0 \\ 0 \end{vmatrix}$$

The condition of oscillation is obtained by equaling with zero the determinant of the first matrix. This leads to the equation:

$$(j\omega)^2 \frac{C_1C_2}{R_1} + (j\omega)C_2\left(\frac{1}{r_{deq}R_1} - \frac{1}{R_3R_p}\right) + \frac{1}{R_2R_3R_4} = 0$$

Thus, the condition of maintaining the oscillations is:

$$\frac{R_p}{r_{deq}} = \frac{R_1}{R_3} \qquad \text{sau} \qquad R_p = r_{deq}\frac{R_1}{R_3}$$

@ECRTD-UK: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

and the formula of the oscillation frequency results in the same way as the one given at the beginning.

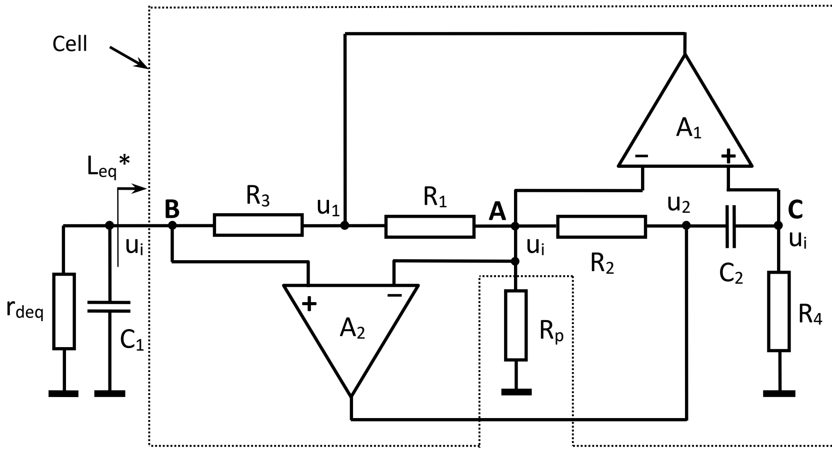


Fig. 6. Antoniou cell in the proposed oscillator

In [3] the quality factor of the parallel oscillating circuit $L_{eq} \| C_{eq}$ was deduced in node A (for the fully symmetrical scheme):

$$Q^{-1} = R\left(\frac{1}{R_p} - \frac{1}{r_{deq}}\right)$$

For the case when $R_1=R_2$, $R_3=R_4$, $C_1=C_2$ and take into account the loss resistance of the capacitors, R_C, (in parallel with C and equal to all capacitors for simplicity) and the input resistance of OA, R_i (equal to all OA for simplicity), it can be shown that:

$$Q^{-1} \cong \left(\frac{R_1}{R_p \| 0{,}5R_i} - \frac{R_3}{r_{deq} \| 0{,}5R_C}\right)$$

It can be seen that Q is independent of frequency. This allows to reduce the oscillation frequency towards 1Hz, keeping the quality factor very high!

The quality factor can reach an ideal value $Q = \infty$ if:

$$\frac{R_1}{R_p \| 0{,}5R_i} - \frac{R_3}{r_{deq} \| 0{,}5R_C} \Rightarrow 0$$

or :

$$R_p \cong \frac{0{,}5R_i (R_1/R_3)(r_{deq} \| 0{,}5R_C)}{0{,}5R_i - (R_1/R_3)(r_{deq} \| 0{,}5R_C)}$$

which must be positive. Using OA with very high input resistance (with TECJ's or MOS's at inputs) the formula is simplified:

$$R_p \cong (R_1/R_3)(r_{deq} \| 0{,}5R_C)$$

Apparently this condition seems to be difficult to meet due to the lack of precision and instability of the included resistances. But article [3], which analyzed the condition of oscillation (for $R_i = \infty$), demonstrated that the above equation represents exactly the condition of oscillation. This being fulfilled when the oscillator is working, we can draw an important conclusion: **the Leq‖Ceq oscillating circuit works with $Q = \infty$.** For an imprecise value R_p this situation is automatically realized and maintained due to the fact that the r_{deq} resistance adapts its value (i.e. the voltages u_i, u_1, u_2 change with something) to meet the condition of oscillation. Consequently, the value of R_p is not at all critical.On the contrary, it can be modified in a fairly wide range. It should be noted that this oscillation condition can be met (with a suitable R_1/R_3 ratio) even if OA have a low input resistance (i.e. for usual OA) and when the capacitors have higher losses (lower R_C). But, the frequency stability is higher when using higher R_C.

It can be shown that the formula of the quality factor Q*, encountered above, is similar to that of Q after the rdeq is deleted, i.e.:

$$Q^{*-1} = \frac{R_1}{R_p \| 0{,}5R_i} - \frac{R_3}{0{,}5R_C}$$

It means that the Q* factor has a finite value that is very high (in the thousands or higher) if R_1 and R_3 are small enough because r_{deq} has a high value comparable to $0.5R_C$.

There were performed simulations for fully symmetric oscillators, [1], [3] in the filter band pass mode (without amplitude limitation), having the R_p resistance precisely established from the oscillation condition. The frequency characteristic cannot be raised for the situation with amplitude limitation in operation because then the amplitudes of the voltages cannot vary with the frequency. Considering a finite number of points in the frequency characteristic, an intermediate value of Q of the order nx10,000 was obtained, but the test, gradually increasing the number of points, is endless. In fact, this result confirmed the theoretical conclusion that the oscillating circuit has, under ideal conditions, a quality factor $Q = \infty$. If a R_p value slightly different from that given by the oscillation condition was used, the result is a finite value for Q.

By simulating some concrete oscillators, the phase shifts between the output voltages and at the OA input were verified, which resulted according to the phasorria diagram given in fig.2. An important test was also done, changing the value of R_p to the oscillator .It was possible to establish the existence of the mechanism of self-adaptation of the r_{deq} value for the observance of the oscillation condition, highlighted by the corresponding modification of the amplitude of the u_i voltage (of the peak voltage on the diode) without the harmonic distortion factor to decrease. It means that the huge value of the quality factor Q is maintained.

Experiments and measurements made on several concrete schemes of oscillators, with amplitude limitation with diodes or junctions of thermostated transistors, and with reduced values for resistors R_1... R_4 , confirmed the conclusions of the theoretical study [5, 6]..

@ECRTD-UK: https://www.eajournals.org/
Publication of the European Centre for Research Training and Development -UK

The best results were obtained using OA with input on TECJ, resistances with metal film, polystyrene capacitors and junctions of thermostated transistors from the integrated μA726. The R and C components had temperature coefficients of opposite signs that compensated each other to a large extent. The instability of the frequency with the temperature was:

$$\Delta f / f_o \Delta T \approx 2 \cdot 10^{-6} /^oC$$

which is close to the performance of quartz oscillators. This explains the name "electronic quartz" given to the circuit by the inventor.

It was also obtained a small instability of the amplitudes of the output voltages with the temperature:

$$\Delta u_1 / u_1 \Delta T \approx 2 \cdot 10^{-4} /^oC$$

as well as an excellent spectral purity of tensions. Thus, the third harmonic component reached a level 80 dB (10,000 times) lower than the fundamental [3].

An interesting application of the new quadrature oscillator was the realization, with the help of two more OA, of a performance three-phase oscillator [4].The new sinusoidal oscillator is sure to have the best performance of all known quartz-free oscillators. Carefully realized it achieves a frequency stability close to that of ordinary quartz oscillators.

The new sine oscillator is sure to have the best performances of all known quartz-free oscillators. Carefully realized it achieves a frequency stability close to that of ordinary quartz oscillators. It is also distinguished by the fact that it is in quadrature, can provide very low frequencies and has a very low harmonic distortion factor.

REFERENCES

1, M.Ciugudean, A Sine Oscillator with Simulated LC, Electronic Engineering, London, Febr. 1993
2. M.Ciugudean, Oscilator sinusoidal de foarte mare stabilitate, Brevet de invenţie Nr. 109262/1994, OSIM Bucureşti
3. E. Garnier, Ph. Marchegay, M. Ciugudean, An Impedance Conversion Sine Oscillator, Acta Technica Napocensis, Electronics and Telecommunications, Cluj-Napoca, No.1, 1998
4. M. Ciugudean, L. Jurca, I. Lie, Tree Phase Sine Generators, Electronic and Telecommunications Symposium, September 1996, Vol.I, pp.68-73
5. M. Ciugudean, Circuite integrate analogice, U. P. Timişoara, 1995
6. L. Jurca, M. Ciugudean, Circuite integrate analogice, Editura Politehnica Timişoara, 2007, pp. 119-127
7. A. Antoniou, Realisation of Gyrators Using OA and their Use in Active Network Synthesis, Proceedings of the IEEE, Vol.116, Nov.1969