A NEW RC CURRENT MODE OSCILLATOR

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Abstract: This paper refer to a group of constructive elements with which, (through adequate combinations) one can generate current mode RC oscillator transfer functions. Obviously this elements set is not unique. From the multitude of possible solutions only the solutions that accommodate the below conditions stand out: the active elements can be easily produced in monolithic technology; each oscillator must have two resistors or two capacitors connected to the mass. The latter requirement is very important for the oscillators with variable frequency. It was made a RC oscillator and its transfer function, and it was made a study of errors which affects maintaining gain of oscillations and frequency of oscillation. The paper point out the experimental results obtained through RC oscillator implementation with PA 630 current conveyors showing that the current mode oscillators appears to be an interesting approach from the perspective of the simplicity/performance compromise.

Keywords: RC oscillator, transfer functions, oscillation frequency

1. INTRODUCTION

In this paper we present an intuitive method for the creation of a new current mode oscillator structure, based on the understanding of the way the oscillation frequency is being determined and the loop transfer ratio is being adjusted. This method results in a new and elegant structure.
Here are some of the features such a structure is indented to achieve.

- The frequency tuning is to be done through the modification of a single passive component, preferably a resistor. For high frequency usage the use of a varicap diode is accepted. For frequency tuning that is achieved through multiple components, no precise pairing of those is required.
- The loop transfer control is done independently from the oscillation frequency. Although there are multiple structures that comply with this requirement (at least within the boundaries of an initial approximation that ignores the side effects), most of such oscillators have a certain dependency of the loop transfer tuning to the oscillation frequency.
- A wide range of frequency variation must be supported, which usually means more complicated circuitry needs to be put in place.
- It is desirable that all capacitors have one end connected to the ground so that these oscillators can be implemented within an integrated circuit.
- There should also be available a simple means of control for the oscillation amplitude. This is vital for an oscillator because a slight variation of the oscillation amplitude can lead to the oscillation being distorted or even interrupted.
- For RC oscillators it may seem absurd to talk about obtaining a high degree of thermal stability of the oscillation frequency as long as none of them are very stable. We should on the other hand make sure

that the oscillation frequency is not dependant on any of the parameters of the active components, since these elements usually have a significant dependency to the environmental temperature.

2. DETERMINING THE FUNCTIONING CONDITIONS OF THE OSCILLATOR

The oscillator in figure 1 is built using a CR net with two sections that are differentially coupled to the SIDO amplifier ($\pm$ A) and to the simple amplifier $+A_1$ The transfer ratio for the loop is obtained by multiplying the transfer loop of the double section CR net with the gains of the two current amplifiers (A and A_1). Thus the expression is:

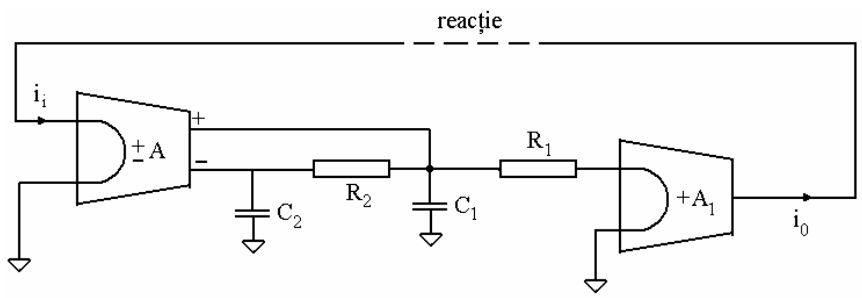

Fig. 1 RC oscillator

$$\frac{i_0}{i_i} = AA_1 \frac{sR_2C_2}{s^2 R_1R_2C_1C_2 + s\left(R_1C_1 + R_2C_2 + R_1C_2\right) + 1} \tag{1}$$

The sustaining gain expression is (2) while the oscillation frequency is (3)

$$G_0 = 1 + \frac{R_1}{R_2} + \frac{R_1}{R_2} \cdot \frac{C_1}{C_2} \tag{2}$$

$$\omega_0 = \frac{1}{\sqrt{R_1R_2C_1C_2}} \tag{3}$$

Expression (2) shows that the value of the sustaining gain is constant if the ratios between the resistors and capacitors remain constant, even if their particular values may be changed.

The schematic in figure 1 can be utilized to build variable frequency oscillators that can be brutally tuned by switching two equal resistors of fine tuned by the use of a variable capacitor with two identical sections.

In this case for oscillations to be maintained we need the following condition to be true:

$$A \cdot A_1 = 3 \tag{4}$$

One can note that the transfer ratio in expression (1) is identical to that of a current mode Wien net. On the other hand the edge this circuit has compared to a Wien net is that of having both capacitors connected to the ground.

Theoretically speaking the A_1 amplifier in figure 1 could be eliminated should the SIDO amplifier offer sufficient gain so that the required sustaining gain be obtained.

One can also note that theoretically speaking the oscillator in figure 1 works similarly should the resistors and capacitors be interchanged. Thus if R_1 and C_1 are interchanged, as well as R_2 si C_2, the transfer ratio becomes:

$$\frac{i_0}{i_1} = A \cdot A_1 \cdot \frac{sR_2C_2}{s^2 R_1 R_2 C_1 C_2 + s\left(R_1C_1 + R_2C_2 + R_2C_1\right) + 1} \tag{5}$$

The oscillation frequency is then given by (3), and the sustaining gain is:

$$G_0 = 1 + \frac{C_1}{C_2} + \frac{C_1}{C_2} \cdot \frac{R_1}{R_2} \tag{6}$$

The oscillator's behavior is again equivalent to that of a Wien net oscillator , but in this second case it has the advantage of having two resistor connected to the ground. In fact the above change is equivalent to the use of a double section RC net.

3. ERROR STUDY

We will compute the errors induced by those parameters that can be estimated and that impact the expressions for the sustaining gain and the oscillation frequency.

When estimating the impact a parameter has on the above mentioned values all other parameters will be considered constant and the overall relative error is determined by cumulating the errors induced by the given parameters, through each of their values.

3a. Errors due to the actual conveyor impedances

The actual values are now being taken into account for the in/out resistors and capacitors of the PA630 integrated conveyors compared to the initially considered ideal values (R_X=0,R_Z=0,C_Z=0). According to the existing catalogue data the input resistor value on the X terminal of the inverting repeater connection is typically R_X=2Ω, the output capacitance is C_Z=11pF and the output resistance is R_Z=3MΩ.

For the circuit in figure 1, the output capacitances of the SIDO (made out of two CCII) are put in parallel to the C_1 and C_2 capacitors, the (R_Z) output resistor of the non-inverting terminal of the SIDO is in parallel with C_1, R_1 and the output (R_Z) output resistor of the inverting terminal of the SIDO is in parallel with C_2. If R_1, $R_2 << R_Z$ their effect is negligible.

The input resistance of the A_1 amplifier (R_X) is in series with R_1. In this case the loop transfer ratio becomes:

$$\left(\frac{i_0}{i_i}\right)^* = \frac{AA_1 sR_2(C_2+C_Z)}{s^2(R_1+R_X)R_2(C_1+C_Z)(C_2+C_Z)+s\left[(R_1+R_X)(C_1+C_Z)+R_2(C_2+C_Z)+(R_1+R_X)(C_2+C_Z)\right]+1} \tag{7}$$

The sustaining gain is:

$$G_0^* = 1 + \frac{R_1 + R_X}{R_2} + \frac{R_1 + R_X}{R_2} \cdot \frac{C_1 + C_Z}{C_2 + C_Z} \tag{8}$$

While the oscillation frequency is:

$$\omega_0^* = \frac{1}{\sqrt{(R_1 + R_X) R_2 (C_1 + C_Z)(C_2 + C_Z)}} \tag{9}$$

By (*) we mark here the parameters that are prone to errors.

$$\varepsilon_A^M = \left|\frac{M_A - M_0}{M_0}\right| 100[\%] \tag{10}$$

Where by ε_A^M we mean the relative error in percentages, M_0 stands for the errorless value of M and M_A stands for the value of M affected by error A.
For the estimation of the inserted errors we will take into consideration the worst case scenario, meaning $R_1=R_2=10\,\Omega$, respectively $C_1=C_2=68pF$ (corresponding to the minimal values of R and C used in the practical implementation).

We therefore obtain the numerical values of: $\varepsilon_{imp}^{G_0} = 13,3\%$ and $\varepsilon_{imp}^{\omega_0} = 27,6\%$. For the usual values $R_1=R_2=100\,\Omega$ respectively $C_1=C_2=1nF$ one obtains $\varepsilon_{imp}^{G_0} = 1,3\%$ and $\varepsilon_{imp}^{\omega_0} = 1,19\%$.

3b. Errors due to the inaccuracy of the conveyor current transfer

To estimate these errors we will consider the below expression of the conveyor current transfer

$$\frac{i_0}{i_i} = 1 \pm \delta \tag{11}$$

Where $\delta = 0,5\%$ is according to the catalogue data.

We must take into account the fact that a differential stage is made of two current conveyors. Considering $i_+ = (1+\delta_2)\, i_i$ respectively $i_- = (1+\delta_1)\, i_i$, the expression of the transfer ratio becomes:

$$\left(\frac{i_0}{i_i}\right)^* = AA_1 \frac{sC_2R_2(1+\delta_2) + \delta_2 - \delta_1}{s^2C_1C_2R_1R_2 + s(R_1C_1 + R_2C_2 + C_2R_1) + 1} \tag{12}$$

The oscillation frequency:

$$\omega_0^* = \sqrt{\frac{1}{C_1C_2R_1R_2}} \sqrt{1 - \frac{(\delta_2+\delta_1)}{1+\delta_2}\left(1 + R_1/R_2 + C_1R_1/C_2R_2\right)} \tag{13}$$

The sustaining gain is

$$G_0^* = \frac{1}{1+\delta_2}\left(1 + R_1/R_2 + C_1R_1/C_2R_2\right) \tag{14}$$

With expressions 13 and 14 we can now calculate the relative errors of the oscillation frequency and the sustaining gain:

$$\varepsilon_\delta^{\omega_0} = \left|1 - \sqrt{\frac{1 - 2\delta_2 + 3\delta_1}{1+\delta_2}}\right| \tag{15}$$

$$\varepsilon_\delta^{G_0} = \left|1 - \frac{1}{1+\delta_2}\right| \tag{16}$$

In the worst case scenario ($\delta_1 = +0,5\%$ respectively $\delta_2 = -0,5\%$) one gets $\varepsilon_\delta^{G_0} = 0,5\%$ respectively $\varepsilon_\delta^{\omega_0} = 1,49\%$.

3c. Errors due to the miss-pairing of the passive components

We only consider the tolerance of the manufacturing process of the components and neglect the temperature dependency of the components values. Thus

$$\begin{gathered} R_1 = R_{1n}\left(1 \pm \lambda_1\right); R_2 = R_{2n}\left(1 \pm \lambda_2\right); \\ C_1 = C_{1n}\left(1 \pm \lambda_3\right); C_2 = C_{2n}\left(1 \pm \lambda_4\right) \end{gathered},$$

where λ_{1-4} is the components tolerance (in percentages).

We can say that the components tolerance has a small impact on the sustaining gain expression, because they only come in the shape of ratios R_1 / R_2 , while these ratios have small values (2%) for integrated implementations.

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he oscillation frequency is

$$\omega_0^* = \frac{1}{\sqrt{R_{1n} R_{2n} C_{1n} C_{2n}\left(1 \pm \lambda_1\right)\left(1 \pm \lambda_2\right)\left(1 \pm \lambda_3\right)\left(1 \pm \lambda_4\right)}} \tag{17}$$

And the relative error of the oscillation frequency is:

$$\varepsilon_\lambda^{\omega_0} = \left| 1 - \frac{1}{\sqrt{\left(1 \pm \lambda_1\right)\left(1 \pm \lambda_2\right)\left(1 \pm \lambda_3\right)\left(1 \pm \lambda_4\right)}} \right| \tag{18}$$

Should we consider equal tolerances for all four components, the worst case scenario is when they all are positive:

For $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4$ =1% we get $\varepsilon_\lambda^{\omega_0}$ =1,9%, for $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4$ =5%, $\varepsilon_\lambda^{\omega_0}$ =9,2% and for $\lambda_1 = \lambda_2 = \lambda_3 = \lambda_4$ =10% we get $\varepsilon_\lambda^{\omega_0}$ =17,35%.

3d. Errors due to the oscillation amplitude limitation circuit

For a minimal implementation the oscillation amplitude limitation circuit is made of a resistance divisor bridged by two anti-parallel coupled diodes (figure 2a). Since the limitation is done by a non-linear circuit, important errors may appear both related to variations from the nominal oscillation frequency, and the frequency specter of the resulting signal (we may get typical harmonic distortions of 3-5 %).

The evaluation of such errors is very complex and can only be approached by the use of a computer. One should also take into account the fact that these latter errors can be used to compensate for the previous ones.

4. PRACTICAL IMPLEMENTATIONS

An oscillator as shown in figure 1 has been implemented in practice. On the printed circuit we created, there was a ground plane created on the components side, with the purpose of protecting the assembly from external interference. With the same purpose the entire circuit has also been inserted in a metal case. The circuit power source is a V_{CC}=V_{SS}=±10V (E4109), and the oscillations visualization was done by an E0103-A oscilloscope, while the oscillation frequency was done with a BM526 (TESLA) frequency meter. For the created oscillator, the required gain for the sustaining of a unary transfer ration in the loop was ensured by the first differential stage, all the other active stages, having a unary gain. One can't discard the use of the current repeating stage because we require the RC de-phasing networks to be evaluated against their current behavior.

For the implementation of a SIDO stage we require two PA630 current conveyors, while for the implementation of a current repeater there was only one PA630 current conveyor required.

Figure 2a schematically displays the configuration of a SIDO, while figure 2b is showing the configuration of a simple current repeater.

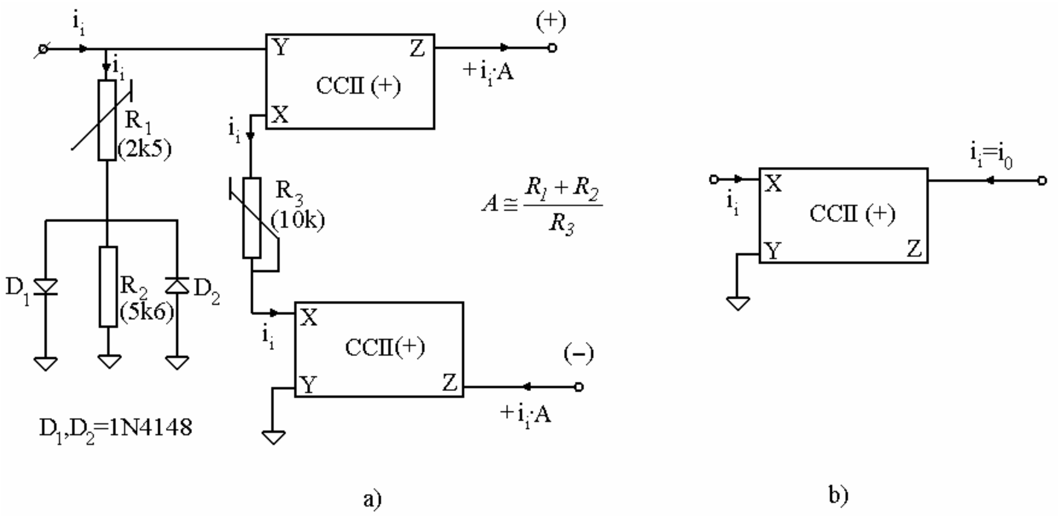

Fig. 2 a) SIDO amplifier
b) The configuration of a simple current repeater

Note: The collectors of the Y input transistors we're connected to –Vss for all CCII.

From figure 2a stands out the oscillation limitation circuit, formed of the D_1 and D2 diodes, which are bridging the R_1, R_2 input resistive divisor. With an initial approximation the SIDO gain is given by $\left(R_1+R_2\right)/R_3$. We should take notice that if for any given reason the oscillation amplitude may tend to grow, the D_1 and D_2 diodes will tend to further open, thus decreasing the initial value of R_1+R_2 and so the entire transfer ratio of the loop will decrease.

To avoid the latch-up phenomenon specific to the PA630 current conveyor, we will use (if required) on the Z outputs of the conveyor, some 3.6V Zenner diodes (DZ3V6), in series with 1N4148 fast diodes, as shown in the PA630 catalogue. Obviously the use of such diodes will lead to a change in the loop transfer ratio and also of the oscillation amplitude.

The conveyors polarization was done according to the catalogue schemas, by ensuring a polarization current of 1.26mA. In order to implement the RC de-phasing circuits, we used 1% tolerance metal foil resistors, high precision capacitors (1-2% precision) and high tolerance electrolytic capacitors (20-50% tolerance).

The following measurements have been performed:

The oscillation amplitude has been fixed to 280mV.
a) We fixated $R_1=R_2=1K\Omega$ and tuned $C_1=C_2$ between 136pF and 100µF. For capacitor values under 1nF the loop gain needed to be diminished.
For values of $C_1=C_2$ between 5,651nF and 10µF (1785:1) we went through a frequency domain between 16Hz and 28,164 KHz (1760:1) with a precision of approximately 5%.

We can demonstrate that for capacitors values below 1nF, the errors rise up to about 67%. Also for large values of the capacitors, the errors also reach to 50%, but in this case these errors can be blamed on the high tolerance of the electrolytic capacitors being used.
b) We fixated $C_1=C_2=47nF$ and $R_1=R_2$ have been modified between 10Ω and 61,9KΩ. The oscillation amplitude has been fixed at 280mV. For values of $R_1=R_2>50K\Omega$ the loop gain also needed to be changed and same for $R_1=R_2<100\Omega$. For values of $R_1=R_2$ ranging from 215Ω to 61,9K Ω(283:1) the obtained frequencies ranged from 55Hz to 15KHz (272: 1) with a 5% precision. When $R_1=R_2 \leq 200\Omega$ the errors grow up to 100%.

5. CONCLUSIONS

From the experimental measurements we can conclude the following related to the design of current mode oscillators by current conveyors:

- Circuits may work in a wide range of frequencies, should the components pairing be better than 2-5 %, in order to have a reasonable precision.
- We also experience a higher precision of the oscillation frequency with the change of the resistors when the capacitances are constant than with the change of the capacitances with constant resistances. This is a consequence of the low tolerance of the resistors used (1%) compared with the one of the capacitors (2-10%)
- For low values of the capacitances (<1nF) even at tens of KHz frequency values errors can be quite large and this can be explained by the inductive behavior of the conveyors input impedance.
- Also for small values of resistances (smaller than several hundreds ohms) errors can be quite significant and can be explained by the growth with the frequency of the conveyor input impedance value.
- From a practical perspective the solution has the disadvantage of not ensuring the polarization stability through negative continuous current reaction on the loop.

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