Theoretical And Experimental Research On The Current-Mode RC Oscillators

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Abstract - This paper proposes an application of the current using its advantages in harmonic signals generation. Using current-conveyors in harmonic oscillators building, the frequency band of active device is well valorised, comparing with the situation of operational amplifiers using. The author chooses from all RC oscillators the oscillator with Wien network, as one of the most used net for RC oscillators with voltage operating mode. Both variable elements haven’t any ground contact so, in working conditions, some issues regarding the screening and driving of these elements will emerge. To solve this problem we propose a RC sinusoidal oscillator circuit, made with current conveyors of second generation (CCII), of which selective network is characterised by a transfer function Wien type. This net is different of standard one, having the both capacitors for frequency adjustment ground connected. It was used current-conveyors of second generation PA 630 Phototronix, where with a structure of current amplifier with differential out comes and a selective network were made.

Keywords - RC oscillator, current-conveyors maximum frequency, frequency stability, distortion level.

I. INTRODUCTION

To meet the increasingly high performance requirements, especially in terms of work speed, a number of new solutions are resorted to in this field.

These solutions are related to the complementary bipolar process of analog integrated circuits manufacturing. PNP transistor performance has grown up to the level of NPN, which caused the disappearance of a whole series of limitations to the analog circuit design technique. Circuits in current mode take advantage of the extra speed occuring when working with low impedances. Representative for the current processing technique are the current conveyor and the operational amplifier with current-feedback [1], [2]. One of the applications where the benefits of current processing are well represented is the generation of harmonic signals. By using current conveyors in the manufacture of harmonic oscillators the frequency band of the active device is better used compared to the use of operational amplifiers.

II. RC OSCILLATOR WITH ACTIVE CUASI-WIEN NETWORK ACHIEVED WITH CCII

The Wien network remains one of the most used RC oscillators in voltage mode. However, because the two variables elements have no grounded end, in practice there are problems of screening and driving these elements.

Figure 1 illustrates an RC sinusoidal oscillator circuit manufactured with second generation current conveyors (CCII), whose selective network is characterized by a transfer function of Wien type [1], [4]. This network differs from the standard network with both frequency control capacitors grounded. Widely used are current-conveyors of second generation, PA 630 from Phototronix company. Its simplified circuit is shown in Figure 2. The conveyor function is achieved by the \( Q_1, Q_2 \) transistors structure. This would work but only for unipolar currents. To be able to work with bipolar signals it has been introduced the current mirror consisting of \( Q_3 \) and \( Q_7 \).

PA 630 circuit is programmable, meaning that the user can prescribe the polarization current \( I_B \) of the circuit as required. In the static point Y entry is grounded while X terminal is offine \( (i_c=0) \). According to the functional relation \( (v_x=v_y) \), it results \( v_i=0 \) [1].

Basic current is calculated by the expression

\[
I_B = \frac{V_{EE} \pm V_{BE}}{R_B} \approx \frac{V_{EE}}{R_B}
\]  

(1)

This current flows through \( Q_5 \), \( Q_6 \) and \( Q_7 \) and, due to the mirror action, through \( Q_1 \), \( Q_2 \), \( Q_3 \) and \( Q_7 \) it will flow the same current which subsequently reduces the static errors.

The simple solution provided in Figure 2 is characterized by an important gap voltage between nodes X and Y because of the un-matching between voltages \( V_{BE} \) of NPN and PNP transistors [1]. The expression of this voltage is given by 2:

\[
V_y - V_x \approx V_{BE} - V_{BE} = V \ln \frac{I_{SP}}{I_{SN}}
\]  

(2)

where \( I_{SP} \) and \( I_{SN} \) are saturation currents of transistors PNP and NPN.

For the process of PA 630 circuit, the typical values of the two currents are \( I_{SP} = 125 \times 10^{-15} \) A and \( I_{SN} = 200 \times 10^{-15} \) A, currents resulting in a voltage gap of 11 mV. This error, depending on the process, can be reduced by introducing into the conveyor two balancing diodes \( D_1 \) and \( D_2 \) as shown in Figure 3.
The gap voltage is now
\[ V_V = \left| V_{BE} \right| + V_{z} - \left( V_{BE} + V_{z} \right) = \]
\[ \left( \left| V_{BE} \right| - V_{r} \right) + \left( V_{r} - V_{BE} \right) \] \hspace{1cm} (3)

If \( D_1 \) is of type PNP and \( D_2 \) of type NPN, under ideal conditions the above voltage is cancelled.

In practical circuits, the un-matching between transistors of the same type makes the gap value be different from zero, being lower, compared to where there are two diodes, at least by one order of magnitude.

The introduction of the two balancing diodes has two disadvantages: it reduces the input dynamic range by an opening voltage and doubles the small signal resistance across the terminal \( X \).

Back to Figure 2, it can be seen that the circuit basically fulfills the functions required by the functional relationships

\[ v_x = v_y \] \hspace{1cm} (4)

\[ i_z = \pm i_x \] \hspace{1cm} (5)

A voltage signal \( v_y \) applied to the base of \( Q_2 \) is repeated in its emitter applied under \( Q_1 \), and repeated by this to the output \( X \). A current \( i_x \) injected into the output \( X \) will run through \( Q_1 \) in common-base connection, then through \( Q_2 \), and will be transported by \( Q_3 \) to the output in the sense illustrated in Figure 2 [2].

This is the reversing conveyor. The current \( i_z \) runs entirely through \( Q_1 \) because through \( R_B \) there is no signal current, its ends being connected to fixed potentials, therefore the signal current flowing through \( Q_2 \) will be null.

Figure 1 shows an RC sinusoidal oscillator scheme made with current conveyor of second generation, whose selective network is characterized by a transfer function of Wien type [5]. Unlike standard achievements of this network, with the solution of Figure 4 both frequency tuning capacitors are grounded. The selective network is made with CC II+ \( R_1 \), \( R_3 \) and \( C_1 \), \( C_2 \).

Current conveyors CC II+, CC II+ \( R_1 \), \( R_3 \), together with \( R_2 \) and \( R_4 \) form a current amplifier structure with differential outputs [3].

Supposing, in Figure 1[4], that the response loop is interrupted and an excitation current \( i_{in} \) is applied on its input, we could write the output currents in the differential amplifier \( i_{x1} \) and \( i_{x2} \) as follows:

\[ i_{x1} = \frac{R_1}{R_3} \cdot i_{in} \] \hspace{1cm} (6)

\[ i_{x2} = \frac{R_4}{R_3} \cdot i_{in} \] \hspace{1cm} (7)

where \( R_3 \) denotes the equivalent resistance of the group \( R_{ds}, R_{db}, D_1, D_2 \). By simplified calculations we can determine the the output current of the selective network, denoted \( i_w \).
It should be noted that up to a constant, this network is identical to the transfer function of a standard Wien network. The conveyor $CCII+\beta$ receives current $i_o$ and transports it to $Z$ output, the current loop gain is given by (11) relation.

\[
\frac{i_o}{i_i} = \frac{R_3}{R_1}, \quad \frac{1}{sR_1C_1 + \frac{R_1}{R_2}(\frac{C_2}{C_1} + 1)} + 1
\]  

(9)

\[
\frac{i_o}{i_i} = \frac{R_3}{R_1}, \quad \frac{1}{sR_2C_2 + s(R_1C_1 + R_2C_2 + R_3C_3)}
\]  

(10)

\[
\frac{i_o}{i_i} = \frac{R_3}{R_1}, \quad \frac{sR_2C_2}{s^2R_2C_2C_3 + s(R_1C_1 + R_2C_2 + R_3C_3)}
\]  

(11)

We know that the network Wien has a special behavior and if $R_2=R_3=R_0$ and $C_1=C_2=C_0$ the oscillation frequency is (12) and the loop phase shift is zero.

\[
f_0 = \frac{1}{2\pi R_1C_0}
\]  

(12)

To maintain the sinusoidal oscillations, the following relationship should exist between the two resistors:

\[
R_1 = 3R_3
\]  

(13)

$R_{ab}$, $R_{ab}$ are so dimensioned that their sum is greater than the value determined using a relationship (13). Thus on the initial moment it is ensured a current gain on the loop higher than one and the sinusoidal oscillations are started.

After priming the oscillation by action of diodes, the oscillations level will be set at such a value that the relation (13) is fully met. The output voltage is obtained after the voltage repeater made with $CCII+\beta$.

III. PRACTICAL IMPLEMENTATION

The oscillator has a frequency range between $f_{\text{omin}}=0.5\text{MHz}$ and $f_{\text{omax}}=40\text{MHz}$, the amplitude of the output sinusoidal signal $U_{\text{omin}}=1.22\text{V}$.

Since the maintenance gain formula $A_0$, there is the $\frac{C_2}{C_1}$ ratio, this must be constant to variations of the frequency and capacity. This is necessary for the amplitude of the sinusoidal signal generated to be independent from the oscillation frequency variation. For this reason we chose a variable air capacitor with two identical sections with a capacity between $C_{\text{Vin}}=5\text{pF}$ and $C_{\text{Vmax}}=300\text{pF}$, and a rotation angle $\alpha=180^\circ$ therefore with the proposed oscillator $C_1 = C_2 = C_0$ and $R_1 = R_2 = 1\text{K}\Omega$.

We calculate again the values of the frequency at the ends of the range by considering $R_1=R_2=R=1\text{K}\Omega$.

\[
f_{\text{omin}} = \frac{1}{2\pi R_C V_{\text{max}}} = 0.52\text{MHz}
\]

\[
f_{\text{omax}} = \frac{1}{2\pi R_C V_{\text{min}}} = 38\text{MHz}
\]

The center of frequency oscillation is:

\[
f_0 = \frac{f_{\text{omax}} + f_{\text{omin}}}{2} = 19.2\text{MHz}
\]

Therefore the frequencies generated satisfy the requirements. The maintenance gain for the center oscillation frequency is:

\[
A_0 = \frac{b_i}{a_i}
\]

\[
A_0 = \frac{R_1C_1 + R_2C_2 + 1}{R_1C_2} = \frac{R_1C_1 + R_2C_2 + 1}{R_1C_2} + 1 = 3
\]

We adopt a gain allowance $A_0 = 3.2$.

\[
A_0 = \frac{R_1 + R_2}{R_{ab}} = 3.2
\]

\[
U_0 = (R_1 + R_2)I_2 = 1.22\text{V}
\]

\[
U_{\text{omin}} = R_1I_2 = 0.6\text{V}
\]

therefore:

\[
\frac{U_0}{U_{\text{omin}}} = \frac{R_1 + R_2}{R_1} = \frac{1.2}{0.6} = 2
\]

or

\[
\frac{R_2}{R_3} + 1 = 2 \Rightarrow \frac{R_2}{R_3} = 1
\]

We adopt $R_2 = 10\text{K}\Omega\pm1\%$ and $R_3 = 10\text{K}\Omega\pm1\%$ chemical resistors with metallic film of the type RPM 3012.

So

\[
R_{ab} + R_{ab} = \frac{R_2 + R_3}{3.2} \Rightarrow R_{ab} + R_{ab} = \frac{20}{3.2} = 6.25\text{K}\Omega
\]
We choose the semi-adjustable resistor $R_{ub} = 1\, \Omega \pm 20\%$ with carbon film from which the amplitude of the signal is varied and $R_{wb} = 5\, \Omega \pm 1\%$ metal film chemical resistant is varied.

The correctness of the circuit running has been verified using specialized Orcad PSpice 10.5 software. The current conveyors were designed by NS 3905 and NS3904 transistors (see Figure 4), and the obtained shapes of waves are in figure 5.

CONCLUSION

This paper showed that using of current mode circuits has some practical advantages confronted by conventional devices with voltage operating mode, such as higher working speed and a better working linearity.

Speaking about this aspect, one of this paper goal is, first of all, to show that the current mode circuits can be used to produce high frequency oscillations and to show in what conditions this could be happened.

It is usual that the electronic device performances used in oscillators to be expressed by some feature of output signal, such as: maximum frequency, frequency stability, distortion level.

Speaking about the highest limitation of working frequency, this depends of many intrinsic parameters of the semiconductor or of the electronic device design. Frequency stability depends, first of all, by stability of passive elements values with environment factors, of which the most important is the temperature the others such as humidity and pressure have low influences.

The electronic device temperature produced by the environment or by dissipate energy on device can affect the frequency stability frequency less than passive elements. The temperature influence can be reduced through a judicious semiconductor microchip design so that dissipative high power junctions to carry out an intensive heat transfer towards external surface.

One observes the stability of the amplitude and the oscillation frequency obtained with the current mode oscillator is superior the ones obtainable by means of voltage mode circuits.

REFERENCES