Abstract – This paper presents two new applications of modified version of the voltage differencing current conveyor (VDCC) active device in electronically linearly controllable quadrature oscillators. In this particular case, VDCC element is modified in such a way that it uses electronically adjustable current gain controlled independently in each of output current branches of this device. Brief Spice simulation tests based on emulators of VDCC employing commercially available subparts and including system for amplitude stabilization are also presented. Results confirmed expected behavior.

Keywords - electronic control; transconductance; current gain; input resistance; quadrature oscillator; linear tuning; voltage differencing current conveyor

I. INTRODUCTION

This study is focused on special modification of voltage differencing current conveyor (VDCC) – so-called controlled gain VDCC (CG-VDCC), where electronic control of current gain of the second internal subpart (electronically controllable current conveyor of second generation – ECCII [2]-[4]) is divided to two independent output branches. Except control of current gain, CG-VDCC offers also two other controllable features – transconductance [5] and resistance of current input terminal [6]. In comparison to all recent works, external utilization (interconnection) of X input terminal is not supposed in this work. More information about current conveyor-based derivations of active devices can be found in [7]. Dual independent control of gains of output currents allows special features for example in applications as linearly controllable oscillators.

Not many oscillators based on VDCC device with its controllable parameter has been reported in the past. Work [8] deals with single ZC-CG-VDCC (Z-copy feature [1]) element-based oscillator producing output signals with π/4 phase distance. Parameters $R_X$ and $g_m$ are used for linear control of frequency of oscillations (FO) and single current gain ($B$) is used for control of condition of oscillations (CO). Circuity presented in [8] has similar complexity as solutions discussed in this paper. However, it is not suitable for production of quadrature signals. Similarly complex single active element-based quadrature oscillator solution was presented in [9]. However, oscillator in [9] utilizes only one electronically controllable parameter ($g_m$) and does not offer such variability (CO and FO are adjustable only by variation of values of external grounded passive components) and FO is not tunable linearly. The work, dealing with VDCC used in oscillators, was published also by Rawat et al. [10]. Similarly as in [9], VDCC concept employs only $g_m$ as adjustable parameter (but not used in application) and resulting structures of oscillators are very complex (two and more active devices). It is however not necessary in many cases.

II. CG-VDCC BASED OSCILLATORS

We designed two solutions of quadrature oscillators based on single CG-VDCC active device. Their specifications focus on simple electronic linear controllability of FO, unchangeable output amplitudes during the process of tuning of FO and implementation of precise system for amplitude stabilization (automatic gain control circuit - AGC). Speciality that was not used in previous designs and is typical in both presented solutions in this paper consists in VDCC concept enhanced by two independently controllable output branches of $Z$ terminal (2x $Z_n$, or $Z_n$ and $Z_p$ terminals).

A. Brief CG-VDCC description

The CG-VDCC device has been introduced in [11]-[13] (see for more details). Brief principle is indicated in Fig. 1. There are four controllable parameters available (transconductance – $g_m$, resistance of current input terminal – $R_X$, X terminal not used in this particular case (grounded); current gains of two output terminals – $B_1$, $B_2$). We suppose $R_X$ as an “internal” electronically adjustable component. Due to the used concept (as explained later in Fig. 3 and Fig. 5 - division of current to two branches) of the controlled gains in both output branches ($Z_p$, $Z_n$), transfers are defined as $I_m = -0.5B_1I_X$, $I_m = 0.5B_2I_X$.

B. The first type of the oscillator

The first designed circuit is shown in Fig. 2. We can see that all controllable features of the CG-VDCC are engaged in order to control specific features of the oscillator.

When comparing (2) and (3), we can see that CO and FO can be expressed as:

\[
B_1 \geq 2g_mR_x, \quad \omega_0 = \frac{g_mB_1}{2R_xC_1C_2}. \tag{2}, \tag{3}
\]

where CO and FO can be expressed (supposing \(g_m = 1/R_x\)) for verification. Utilization of electronically controllable current conveyors of second generation (ECCII) available under designation EL2082 and subparts of so-called “diamond transistor and diamond voltage buffer in one package” were utilized to provide four electronically controllable parameters used for control of the device and therefore also its applications. These parameters are formed as follows: \(g_m = B_{gm}/R_{gm} \equiv V_{SET_{gm}}/R_{gm};\) \(R_x = R_{xint};\) \(V_{SET_{rset}} \equiv V_{SET_{b1}};\) \(B_1 \equiv V_{SET_{b2}}.\) Taking previously discussed simplifications of the oscillator design into account, we can directly specify equation for FO, where DC control voltages \(V_{SET}\) are included:

\[
\omega_0 = \frac{g_mB_2}{2R_xC_1C_2} = \frac{V_{SET_{rset}}^2V_{SET_{b1}}^2}{2R_xR_{xint}C_1C_2}. \tag{6}
\]

Condition of oscillation \((g_m = 1/R_x = R)\) is fulfilled) has now form: \(V_{SET_{b1}} \geq 2.\) In case of \(V_{SET_{b2}} = 2\) \(V,\) (6) simplifies to:

\[
\omega_0 = \frac{V_{SET_{rset}}^2V_{SET_{b1}}^2}{2R_xR_{xint}C_1C_2}. \tag{7}
\]

and linear control of FO is possible \((V_{SET_{gm}} = V_{SET_{b2}} = V_{SET_{fo}}).\)

C. The second type of the oscillator

Despite influence of term \(g_mR_x\) in CO (2) can be removed by utilization of \(g_m\) and \(R_x\) \((g_m = 1/R_x)\) for
linear tuning of FO, the CG-VDCC device can be used also for design of the quadrature oscillator without this term ($g_{m}R_{x}$) present in CO. The circuit solution fulfilling these requirement is shown in Fig. 4. It contains additional grounded resistor in comparison to Fig. 2. CG-VDCC with two current outputs having the same polarity but independently controllable current gains was used in this case. Figure 5 shows the behavioral model of the second type of the oscillator and it is much simpler than model in Fig. 3.

\[ s^3 + \frac{(2R_x - RB)}{2RC_{1}}s + \frac{g_mB_s}{2RC_{1}C_{2}} = 0, \]  

where FO has the same form as (3) and CO is expressed as: $B_1 \geq 2R_s/R$. For equality $R_X = R$, we obtain $B_1 \geq 2$.

Taking real DC control voltages into account, FO can be transformed to:

\[ \omega = \sqrt{\frac{g_mB_s}{2RC_{1}C_{2}}} \]  

\[ \frac{V_{SET_{gm}}}{V_{SET_{b2}}} = \frac{V_{SET_{fo}}}{\sqrt{2}RC_{2}}. \]  

Supposing $R_X = R$, $V_{SET_{gm}} = V_{SET_{b2}} = V_{SET_{fo}}$ — used for linear control of FO, $C_1 = C_2 = C$, resulting relation of produced output signals has form:

\[ V_2 = -\frac{1}{2sC_{1}R_{x}} V_1 \Rightarrow V_2 = R \frac{V_1}{C_1} \Rightarrow V_2 = \frac{\sqrt{2}}{2} V_1. \]

\[ \omega = \sqrt{\frac{g_mB_s}{2RC_{1}C_{2}}}. \]  

\[ \frac{V_{SET_{gm}}}{V_{SET_{b2}}} = \frac{V_{SET_{fo}}}{\sqrt{2}RC_{2}}. \]  

\[ V_2 = -\frac{1}{2sC_{1}R_{x}} V_1 \Rightarrow V_2 = R \frac{V_1}{C_1} \Rightarrow V_2 = \frac{\sqrt{2}}{2} V_1. \]

\[ D. \text{ Amplitude stabilization} \]

Stabilization of amplitude of produced signals ensures constant output level without fluctuations and decreases THD. Inertial system for automatic gain control (AGC) in loop can be established as shown in Fig. 6.

\[ \text{Fig. 6. AGC system for amplitude stabilization} \]

\[ \text{III. RESULT OF VERIFICATION} \]

Both oscillators shown in Fig. 3 and Fig. 5 together with AGC from Fig. 6 were analyzed using PSpice software. Initial design of both solutions supposes values $R_X = R_{gm} = R = 1 \, k\Omega$, $C_1 = C_2 = C = 100 \, pF$.

\[ \text{A. The first type of the oscillator} \]

The first type of the circuit (Fig. 3) supposes $B_2 = 2$ ($V_{SET_{b2}} = 2 \, V$). All necessary constants are included directly in figures. Tuning of the oscillator in frequency domain is shown in Fig. 7. Results indicate the THD below 1% (suppression of levels of higher harmonic components from fundamental tone is more than 45 dBC). Dependence of FO on $V_{SET_{gm}}$ and dependence of produced levels ($V_{pp}$) on FO are shown in Fig. 8 and Fig. 9. Oscillator is tunable approximately from 0.3 MHz to 2.6 MHz ($V_{SET_{gm}} = V_{SET_{b2}}$ from 0.2 to 2 V) while levels of output voltages are between 1.8 and 2 $V_{pp}$.

\[ \text{Fig. 7. Spectral analysis of produced signals for five discrete frequencies (first oscillator)} \]

\[ \text{B. The second type of the oscillator} \]

The same evaluation as in previous case was provided for the second oscillator. Spectral purity (Fig. 10) of produced signals is slightly worse in direction to the lowest frequencies (separation about 40 dBC – THD about 1%). Tunability range is slightly moved to lower frequencies (from 0.2 MHz to 1.9 MHz for the same range of DC control voltage as in previous case) in comparison to previous results, due to difference of (7) and (9), see Fig. 8. Small variations of the output levels are indicated in Fig. 9. Setting of AGC influences obtained results and in case
of real experiments we can expect better results because of simpler setting of AGC in case of real implementation.

![Figure 8. Dependence of FO on DC control voltage (both oscillators)](image)

![Figure 9. Dependence of output levels on FO (both oscillators)](image)

![Figure 10. Spectral analysis of produced signals for five discrete frequencies (second oscillator)](image)

IV. CONCLUSION

We prepared two solutions of oscillators based on CG-VDCC device. Both solutions are suitable for linear control of FO and independent control of CO. Tuning ranges are different because of difference of equations for FO (the second variant has slightly decreased band due to constant 2 in denominator of theoretical FO). No that this disadvantage can be minimized if $V_{\text{SET, gm}} = 2 V_{\text{SET, B2}}$ (or vice versa).

REFERENCES


