New Single VDCC-based Explicit Current-Mode SRCO Employing All Grounded Passive Components

Dinesh Prasad, D. R. Bhaskar and Mayank Srivastava

Abstract—This paper proposes a new single resistance controlled sinusoidal oscillator (SRCO) which employs only one voltage differencing current conveyor (VDCC), two grounded resistors and two grounded capacitors. The presented circuit configuration offers the following advantageous features (i) explicit current-mode output with independent control of condition of oscillation (CO) and frequency of oscillation (FO) (ii) low active and passive sensitivities and (iii) a very good frequency stability. The proposed structure can also be configured as (a) trans-admittance low pass filter and band pass filter and (b) quadrature oscillator. The validity of the proposed SRCO, quadrature oscillator and trans-admittance low pass filter and band pass filter has been verified by PSPICE simulations using TSMC CMOS 0.18μm process model parameters.

Index Terms—VDCC, SRCO, current mode, filter.

Original Research Paper
DOI: 10.7251/ELS1418081P

I. INTRODUCTION

Recently, attention is being given to single active element-active building block (ABB) based SRCOs [1]-[12] and in particular explicit current-mode (CM) SRCOs [13]-[18] and the references cited therein. The use of single ABB has the advantageous features like small chip area, low power dissipation and manufacturing cost as compared to two or more ABBs. The CM operation has received much attention over voltage-mode (VM) operation due to its wider bandwidth and high linearity [19]. The usefulness of explicit CM SRCO is well defined in [20]. The VDCC provides electronically tunable transconductance gain in addition to transferring both current and voltage in its relevant terminals [21]. The application of VDCC as positive/ negative lossy/ lossless grounded inductance simulation circuits and a floating inductance simulation circuit using single VDCC have been described in [22]-[23]. Therefore, the purpose of this article is to present a new explicit CM SRCO, quadrature oscillator and trans-admittance low pass filter and band pass filter using single VDCC and with bare minimum passive components. The performance of the various modes both in time-domain and frequency-domain has been verified by PSPICE simulation.

The paper is organized as follows: Proposed circuit is described in section 2. Section 3 includes non ideal analysis and sensitivity performance of the circuit. Frequency stability of the proposed circuit is presented in section 4. Sections 5 and 6 represent the simulation results and conclusion of the paper.

II. PROPOSED CIRCUIT CONFIGURATION

The symbolic notation of recently proposed six-terminals active building block namely, VDCC is shown in Fig. 1, where P and N are input terminals and Z, X, W_P and W_N are output terminals. All terminals of VDCC exhibit high impedance, except the X terminal [22]. The ideal terminal characteristics of VDCC can be defined by the hybrid matrix as given by equation (1). The proposed configuration is shown in Fig. 2.

![Fig. 1. The symbolic notation of VDCC.](image)

\[
\begin{bmatrix}
I_N \\
I_P \\
I_Z \\
V_X \\
I_{W_P} \\
I_{W_N}
\end{bmatrix} = 
\begin{bmatrix}
0 & 0 & 0 & 0 & V_P \\
0 & 0 & 0 & 0 & V_N \\
-\sum g_m & 0 & 0 & 0 & V_Z \\
0 & 0 & 1 & 0 & I_X \\
0 & 0 & 0 & 1 & I_{W_P} \\
0 & 0 & 0 & -1 & I_{W_N}
\end{bmatrix}
\]
The characteristic equation of the proposed SRCO as shown in Fig. 2, can be derived using routine circuit analysis as:

\[ s^2 + \frac{1}{C_1} \left( \frac{1}{R_1} - g_m \right) + \frac{g_m}{R_2 C_1 C_2} = 0 \]  \hspace{1cm} (2)

Thus, from equation (2), it is clear that the CO and FO are obtained as:

\[ \left( \frac{1}{R_1} - g_m \right) \leq 0 \]  \hspace{1cm} (3)

and

\[ \omega_0 = \frac{g_m}{\sqrt{R_2 C_1 C_2}} \]  \hspace{1cm} (4)

From equations (3) and (4), CO can be established by \( R_1 \) and FO is controlled by \( R_2 \). Hence, both CO and FO are independently controllable.

With the feedback link broken at node ‘1’ and considering the ‘P’ terminal of VDCC as the input, the two open loop transfer functions realized by the proposed circuit are given by:

\[ \frac{I_{i_1}}{I_{o_1}} = \frac{s \left( \frac{C_2 g_m}{R_2} \right)}{s^2 + \frac{1}{R_1 C_1} + \frac{g_m}{R_2 C_1 C_2}} \]  \hspace{1cm} (5)

\[ \frac{I_{i_4}}{I_{o_4}} = \frac{s^2 g_m}{s^2 + \frac{1}{R_1 C_1} + \frac{g_m}{R_2 C_1 C_2}} \]  \hspace{1cm} (6)

Thus, in this mode, the same configuration can also be used to realize trans-admittance band pass and high pass filters simultaneously. From equations (5) and (6), the natural frequency \( (\omega_0) \) and bandwidth (BW) are given by

\[ \omega_0 = \frac{g_m}{\sqrt{R_2 C_1 C_2}} \]  \hspace{1cm} (7)

\[ BW = \frac{1}{R_1 C_1} \]  \hspace{1cm} (8)

Thus, it is seen that and BW are independently tunable.

In the third mode of operation, the various current transfer functions obtained from Fig. 2 are

\[ \frac{I_{i_0}}{I_{o_1}} = -\frac{1}{s R_2 C_1} \]  \hspace{1cm} (9)

\[ \frac{I_{i_0}}{I_{o_2}} = \frac{1}{s R_2 C_1} \]  \hspace{1cm} (10)

\[ \frac{I_{i_0}}{I_{o_3}} = \frac{1}{s R_2 C_1} \]  \hspace{1cm} (11)

\[ \frac{I_{i_0}}{I_{o_4}} = \frac{1}{s R_2 C_1} \]  \hspace{1cm} (12)

For sinusoidal steady state, Equations (9), (10), (11) and (12) become

\[ \frac{I_{i_0}}{I_{o_1}} = \frac{1}{\omega_2 R_2 C_1} e^{-j90^\circ} \]  \hspace{1cm} (13)

\[ \frac{I_{i_0}}{I_{o_2}} = \frac{1}{\omega_2 R_2 C_1} e^{j90^\circ} \]  \hspace{1cm} (14)

\[ \frac{I_{i_0}}{I_{o_3}} = \frac{1}{\omega_2 R_2 C_1} e^{-j90^\circ} \]  \hspace{1cm} (15)

\[ \frac{I_{i_0}}{I_{o_4}} = \frac{1}{\omega_2 R_2 C_1} e^{j90^\circ} \]  \hspace{1cm} (16)

Thus, the phase difference between \((I_{o_1} \text{ and } I_{o_2})\) is \(90^\circ\) and between \((I_{o_3} \text{ and } I_{o_4})\), \((I_{o_3} \text{ and } I_{o_4})\) and \((I_{o_5} \text{ and } I_{o_6})\) is \(-90^\circ\)

Hence, the currents \((I_{o_1} \text{ and } I_{o_2}), (I_{o_3} \text{ and } I_{o_4}), (I_{o_3} \text{ and } I_{o_4})\) and \((I_{o_5} \text{ and } I_{o_6})\) are in the quadrature form. Thus, in this mode of operation, the circuit works as quadrature oscillator.

III. NON–IDEAL PERFORMANCE AND SENSITIVITY ANALYSIS

Considering the various parasitics of VDCC i.e. the X-terminal impedance consisting of a resistance \( R_x \) in series with inductance \( L_x \), the impedance at the Wp-terminal consisting of a resistance \( R_p \) in parallel with capacitance \( C_p \), the impedance at the Wn-terminal consisting of a resistance \( R_n \) in parallel with capacitance \( C_n \) and the impedance at the Z-terminal consisting of a resistance \( R_z \), the FO and CO for the circuit shown in Fig. 2 are given as:
\[ \omega_n = \frac{R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7 + R_8 + R_9 + R_{g_n}}{R_1 + R_2 + R_3 + R_4 + R_5 + R_6 + R_7 + R_8 + R_9 + R_{g_n}} \]

(17)

and CO:

\[ \begin{align*}
C_1 (R_1 + R_2) & - R_{g_n} \\
C_2 (R_1 + R_2) & + \left( C_3 + R_3 \right) \\
C_4 (R_1 + R_2) & - R_{g_n} \\
L (R_1 + R_2) & - R_{g_n} \\
C_5 & \left( C_3 + R_3 \right) \\
L (C_1 + C_2) & + R_1 \\
C_6 (R_1 + R_2) & - R_{g_n} \\
C_7 (R_1 + R_2) & + C_2 L (1 + \frac{R_1}{R_2} - R_{g_n}) \\
C_8 & \left( C_3 + R_3 \right) \\
S_{R_i}^{\omega_n} & = \left[ \frac{2 R_1 R_2 g_n L (C_2 + C_3) + g_n L (C_1 + C_2) \frac{C_4 L (R_1 + R_2) + C_7 (R_1 + R_2)}{R_2}}{R_1} \right] X \]

(18)

The sensitivities of \( \omega_n \) with respect to active and passive components are given as:

\[ S_{R_i}^{\omega_n} = \left[ \frac{1}{R_1} + \frac{R_1}{R_2 R_3} - \frac{R_{g_n}}{R_2} \right] X - \frac{2 C_1 C_2 R_1^2 R_2 g_n}{R_1} - \frac{2 C_1 C_2 R_1^2 R_2^2 g_n}{R_2} - C_1 C_2 R_1^2 g_n - C_1 C_2 R_2^2 g_n \]

\[ S_{R_2}^{\omega_n} = \left[ \frac{1}{R_1} + \frac{R_1}{R_2 R_3} - \frac{R_{g_n}}{R_2} \right] X - \frac{2 C_1 C_2 R_1^2 R_2 g_n}{R_1} - \frac{2 C_1 C_2 R_1^2 R_2^2 g_n}{R_2} - C_1 C_2 R_1^2 g_n - C_1 C_2 R_2^2 g_n \]

\[ S_{C_1}^{\omega_n} = \left[ \frac{1}{R_1} + \frac{R_1}{R_2 R_3} - \frac{R_{g_n}}{R_2} \right] X - \frac{2 C_1 C_2 R_1^2 R_2 g_n}{R_1} - \frac{2 C_1 C_2 R_1^2 R_2^2 g_n}{R_2} - C_1 C_2 R_1^2 g_n - C_1 C_2 R_2^2 g_n \]

\[ S_{C_2}^{\omega_n} = \left[ \frac{1}{R_1} + \frac{R_1}{R_2 R_3} - \frac{R_{g_n}}{R_2} \right] X - \frac{2 C_1 C_2 R_1^2 R_2 g_n}{R_1} - \frac{2 C_1 C_2 R_1^2 R_2^2 g_n}{R_2} - C_1 C_2 R_1^2 g_n - C_1 C_2 R_2^2 g_n \]

\[ S_{C_3}^{\omega_n} = \left[ \frac{1}{R_1} + \frac{R_1}{R_2 R_3} - \frac{R_{g_n}}{R_2} \right] X - \frac{2 C_1 C_2 R_1^2 R_2 g_n}{R_1} - \frac{2 C_1 C_2 R_1^2 R_2^2 g_n}{R_2} - C_1 C_2 R_1^2 g_n - C_1 C_2 R_2^2 g_n \]
\[
S_{C_{z}}^{0.5} = \frac{C_{z}C_{p}[R_{z} + R_{p}] + C_{z}L_{p}[\frac{R_{z}}{R_{p}}]}{C_{z}L_{p}} - C_{z}L_{p}g_{m}
\]

\[
S_{C_{z}}^{0.5} = \left[ C_{z}C_{p}[R_{z} + R_{p}] + C_{z}C_{p}[R_{z} + R_{p}] + C_{z}L_{p}\left(1 + \frac{R_{z}}{R_{p}} - R_{z}g_{m}\right)\right] + \left[ C_{z}C_{p}[R_{z} + R_{p}] + C_{z}C_{p}[R_{z} + R_{p}] + C_{z}L_{p}\left(1 + \frac{R_{z}}{R_{p}} - R_{z}g_{m}\right)\right]
\]

\[
X = 2\left[ C_{z}L_{p}\left(1 + \frac{R_{z}}{R_{p}}\right) + C_{z}\frac{L_{p}}{R_{p}} - C_{z}L_{p}g_{m}\right]
\]

\[
Y = 2\left[ C_{z}C_{p}[R_{z} + R_{p}] + C_{z}C_{p}[R_{z} + R_{p}] + C_{z}L_{p}\left(1 + \frac{R_{z}}{R_{p}} - R_{z}g_{m}\right)\right] + C_{z}L_{p}\left(1 + \frac{R_{z}}{R_{p}} + C_{z}L_{p}R_{z} - C_{z}L_{p}g_{m}\right)]
\]

\[
Z = C_{z}L_{p}\left(1 + \frac{R_{z}}{R_{p}} - R_{z}g_{m}\right) + C_{z}L_{p}\left(1 + \frac{R_{z}}{R_{p}} - C_{z}L_{p}g_{m}\right)
\]

\[
W = \frac{R_{z}}{R_{p}} + \frac{R_{z}}{R_{p}} + \frac{R_{z}}{R_{p}} + \frac{R_{z}}{R_{p}} + \frac{R_{z}g_{m}}{R_{p}} - g_{m}\left(1 + \frac{R_{z}}{R_{p}}\right)
\]

Taking \( C_{1} = C_{2} = 0.01\text{nF}, \ C_{p} = C_{n} = 0, \ R_{z} = R_{p} = R_{n} = \infty, \ R_{x} = 0, \ L_{x} = 0, \ R_{1} = 3.675\text{k}\Omega \) and \( R_{2} = 10\text{k}\Omega \), these sensitivities are found to be (0, -1/2, 0, 0, -1/2, -1/2, 0, 1/2) for equations (19). Thus, all the passive and active sensitivities of natural frequency \( (\omega_{n}) \) are low.

IV. FREQUENCY STABILITY

Using the definition of the frequency stability factor \( S^{f} \) as given in [4] \( S^{f} = \frac{d\phi(u)}{du} \mid_{u=1} \) (where \( u = \frac{\omega}{\omega_{n}} \) is the normalized frequency and \( \phi(u) \) represents the phase of the open-loop transfer function of the oscillator circuit), with \( C_{1} = C_{2} = C, \ g_{m} = \frac{1}{R_{1}} \) and \( g_{2} = \frac{1}{R_{2}} = n g_{m} \), the \( S^{f} \) of the proposed oscillator is found to be \( 2\sqrt{n} \). Therefore, very good frequency stability is obtainable by selecting larger value of \( n \).

V. SIMULATION RESULTS

To verify the theoretical analysis, the proposed circuit was simulated using CMOS VDCC [22]. The passive components were selected as \( C_{1} = C_{2} = 0.01\text{nF}, \ R_{1} = 3.675\text{k}\Omega \) and \( R_{2} = 10\text{k}\Omega \). The transconductance of the VDCC is taken as \( 277.83\mu\text{A/V} \). PSPICE generated output waveforms indicating transient and steady state responses are shown in Fig. 3(a) and 3(b) respectively. These results, thus, confirm the validity of the proposed configuration. Fig. 4 shows the output spectrum, where the frequency of the generated wave is 2.654MHz and the total harmonic distortion (THD) is found to be 1.584%.

Fig. 3. (a) Transient output waveform, (b) Steady state response of the output.
Fig. 5 shows the frequency response of Transadmittance band pass and high pass filters.

From Fig. 7 it is clear that the two currents are in quadrature and the measured value of phase shift between two waveforms is $89.59^\circ$.

Fig. 6 shows the transient response and steady state response (considering all five currents).

Fig. 7. Currents showing quadrature wave forms.
Fig. 8 shows the transient response of output waveform of Fig. 2 to achieve $S_F = 2$. The circuit of Fig 2 has been checked for robustness using Monte-Carlo simulations, the sample result has been shown in Fig. 9, which confirms that for ±10% variations in the value of $R_1$, the value of oscillation frequency remain close to its normal value of 2.654MHz and hence almost unaffected by change in $R_1$. The circuit is re-simulated for larger value of $n$ ($n = 100$) and the transient response is shown in Fig. 10. Fig. 11 shows the variation of frequency of output with respect to resistance $R_2$. Fig. 12 represents the variation of $S_F$ with $n$. A comparison with other previously known explicit CM SRCOs using single ABB has been given in Table 1. These results, thus, confirm the validity of the proposed configuration.
VI. CONCLUSION

A new SRCO has been proposed using a recently introduced VDCC. The proposed circuit employs four grounded passive components (two grounded resistors and two grounded capacitors) and yet offers independent control of FO through the resistor $R_2$ and CO through the resistance $R_1$, low active and passive sensitivities, realizes two trans-admittance filters (Band Pass and Low Pass) and a very good frequency stability. The performance of the proposed configuration in all three modes has been confirmed by PSPICE simulations.

TABLE 1

COMPARASION OF PROPOSED SRCO WITH OTHER PREVIOUSLY KNOWN SAME TYPE OF SRCOs

<table>
<thead>
<tr>
<th>Reference</th>
<th>Active Component</th>
<th>Capacitors</th>
<th>Resistors</th>
<th>Availability of Explicit current-mode output</th>
<th>Independent controllability of CO and FO through grounded resistors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Grounded</td>
<td>Floating</td>
<td></td>
<td></td>
</tr>
<tr>
<td>[14]</td>
<td>1 FTFN</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Case I</td>
<td></td>
<td>3</td>
<td>0</td>
<td>5</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>3</td>
<td>0</td>
<td>5</td>
<td>YES</td>
</tr>
<tr>
<td>Case II</td>
<td></td>
<td>1</td>
<td>1</td>
<td>3</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>0</td>
<td>2</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>1</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td>Case III</td>
<td></td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td>Case IV</td>
<td></td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1</td>
<td>2</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2</td>
<td>1</td>
<td>4</td>
<td>YES</td>
</tr>
<tr>
<td>[15]</td>
<td>1 DVCCC</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>YES</td>
</tr>
<tr>
<td>[16]</td>
<td>1 FDCCI</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>YES</td>
</tr>
<tr>
<td>[17]</td>
<td>1 CFOA</td>
<td>0</td>
<td>3</td>
<td>3</td>
<td>YES</td>
</tr>
<tr>
<td>[18]</td>
<td>1 DVCCC</td>
<td>2</td>
<td>0</td>
<td>3</td>
<td>YES</td>
</tr>
<tr>
<td>Proposed</td>
<td>1 VDCC</td>
<td>2</td>
<td>0</td>
<td>2</td>
<td>YES</td>
</tr>
</tbody>
</table>

REFERENCES


