High-performance Second-Generation Controlled Current Conveyor CCCII and High Frequency Applications

Néjib Hassen, Thouraya Ettaghzouti, Kamel Besbes

Abstract—In this paper, a modified CCCII is presented. We have used a current mirror with low supply voltage. This circuit is operated at low supply voltage of ±1V. Tspice simulations for TSMC 0.18µm CMOS Technology has shown that the current and voltage bandwidth are respectively 3.34GHz and 4.37GHz, and parasitic resistance at port X has a value of 169.32Ω for a control current of 120µA.

In order to realize this circuit, we have implemented in this first step a universal current mode filter where the frequency can reach the 134.58MHz. In the second step, we have implemented two simulated inductors: one floating and the other grounded. These two inductors are operated in high frequency and variable depending on bias current. Finally, we have used the two last inductors respectively to implement two sinuosoidal oscillators. The impedance architecture based on modern electronics allow the design of many three port networks X, Y and Z. The relation between terminal X and Y. The last pair is linked together by a grounded inductor, oscillator, universal filter. 

I. INTRODUCTION

In recent years, the current conveyor has improved especially for high operating frequencies, low power and low supply voltage. The concept of circuit current controlled conveyor CCCII was introduced in 1995 [1]. These circuits based on modern electronics allow the design of many electronic functions as well as the voltage mode instead of the current mode. These circuits represent a logical evolution of second generation current conveyor. They become used in high frequency applications filtering [2]-[5] and oscillator [6]. The second generation current controlled conveyor has three port networks X, Y and Z. The relation between terminal voltage and current is given by the following matrix equation:

\[
\begin{bmatrix}
I_y \\
V_x \\
I_z
\end{bmatrix} = \begin{bmatrix}
0 & 0 & 0 \\
1 & R_x & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
Y_y \\
I_x \\
Y_z
\end{bmatrix}
\]

(1)

The plus and minus signs in the third row specified the polarity of the current conveyor (CCCII+, CCCII-). Due to the

architecture used for the design of CCCII, the circuit will introduce parasitic elements. The characteristic equation has become:

\[
\begin{bmatrix}
I_y \\
V_x \\
I_z
\end{bmatrix} = \begin{bmatrix}
0 & 0 & 0 \\
1 & Z_x & 0 \\
0 & 0 & 1
\end{bmatrix} \begin{bmatrix}
Y_y \\
I_x \\
Y_z
\end{bmatrix}
\]

(2)

On the terminal Y and Z, two impedances are specific to a parallel resistor with a capacitor. The impedance Z_x on terminal X is a parasitic resistor R_x. Where \(\alpha\) and \(\beta\) denotes respectively current and voltage gains.

In this article, we have improved the current controlled conveyor. Subsequently, we will use it to implement a current mode universal filter. Second, we will use it to produce two inductors: floating and tied to ground. Based, on these last two experiences, we have made two oscillators functioning at high frequency.

II. NEW CCCII CONFIGURATION

The circuit current controlled conveyors CCCII classic introduced by [7]-[11] is shown in Fig.1.a. In intention to ameliorate bandwidth in current mode of this circuit, we present two current mirrors FVF (M8, M9, and M14) and (M12, M13, M16) which works in low voltage and characterized by low input impedance [12-15] (Fig.1.b). The two current mirrors can duplicate the current in the borne X on to the borne Z. The transistors M14 and M16 are used to adjust the linearity of the transfer characteristic of two mirrors of the output current and have currents in the paths equal X and Z (\(I_z = I_x = I_{G2} - I_{G1}\)).

The second property of CCCII is a voltage follower between terminal X and Y, the last pair is linked together by a mixed trans-linear loop (M1, M2, M3, M4).

\[
V_{xy} = (V_{GS1})_p - (V_{GS4})_p = (V_{GS1})_N - (V_{GS2})_N
\]

With: 

\[
(V_{GS})_N = \sqrt{\frac{(I_d)_N}{\frac{1}{2}\mu_p C_{ox} \frac{W}{L}_N}} + V_{THn}
\]

and

\[
(V_{GS})_P = -\sqrt{\frac{(I_d)_P}{\frac{1}{2}\mu_p C_{ox} \frac{W}{L}_P}} + V_{THp}
\]

The current through transistors M1 and M3 is equal to I_0. In this case, the potential difference \(V_{ex}\) is equal to: 

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By identifying the characteristic equations CCCII circuit, we have:

\[ R_x = \frac{1}{\sqrt{2I_0 C_{ox} \left( \mu_p \frac{W}{L} \right)_p + \mu_n \frac{W}{L} \left( \frac{W}{L} \right)_n}} \]  

(7)

If \( \mu_p \left( \frac{W}{L} \right)_p = \mu_n \left( \frac{W}{L} \right)_n \)

The expression of input resistance becomes:

\[ R_x = \frac{1}{\sqrt{8C_{ox} \mu I_0}} \]  

(8)

To achieve a current controlled conveyor with negative transfer (CCCII\textsuperscript{−}) we just need to reverse the current in the terminal Z. This inversion is carried out in two additional current mirrors (M1P, M2P) and (M1N, M2N) whose entries are crossed [16]-[19] (Fig.2).

### A. Simulation Results of CCCII

The results are optimized by the size of transistors summarized in Table I and II for a bias current \( I_0 \) of 120\( \mu \)A and a supply voltage of \( \pm 1 \)V. These different schemes are simulated using TSpice based BSIM3v3 transistor model for the TSMC 0.18\( \mu \)m CMOS process available from MOSIS [20].

#### Table I

<table>
<thead>
<tr>
<th>Transistors</th>
<th>W / L</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1, M2</td>
<td>60 ( \mu )m /0.18 ( \mu )m</td>
</tr>
<tr>
<td>M3, M4</td>
<td>90 ( \mu )m /0.18 ( \mu )m</td>
</tr>
<tr>
<td>M5, M6</td>
<td>20 ( \mu )m /0.18 ( \mu )m</td>
</tr>
<tr>
<td>M7</td>
<td>22 ( \mu )m /0.18 ( \mu )m</td>
</tr>
<tr>
<td>M8, M9</td>
<td>28 ( \mu )m /0.18 ( \mu )m</td>
</tr>
<tr>
<td>M10, M11</td>
<td>2 ( \mu )m /0.18 ( \mu )m</td>
</tr>
<tr>
<td>M12, M13</td>
<td>17 ( \mu )m /0.18 ( \mu )m</td>
</tr>
</tbody>
</table>
TABLE II
DIMENSIONS OF TRANSISTORS OF AMENDED CCCII

<table>
<thead>
<tr>
<th>Transistors</th>
<th>W/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1, M2</td>
<td>60 µm/0.18 µm</td>
</tr>
<tr>
<td>M3, M4</td>
<td>90 µm/0.18 µm</td>
</tr>
<tr>
<td>M5, M6</td>
<td>20 µm/0.18 µm</td>
</tr>
<tr>
<td>M7</td>
<td>22 µm/0.18 µm</td>
</tr>
<tr>
<td>M8, M9</td>
<td>10 µm/0.18 µm</td>
</tr>
<tr>
<td>M10, M11</td>
<td>2 µm/0.18 µm</td>
</tr>
<tr>
<td>M12, M13</td>
<td>8 µm/0.18 µm</td>
</tr>
<tr>
<td>M14</td>
<td>22 µm/0.18 µm</td>
</tr>
<tr>
<td>M15</td>
<td>0.55 µm/0.18 µm</td>
</tr>
<tr>
<td>M16</td>
<td>12 µm/0.18 µm</td>
</tr>
<tr>
<td>M17</td>
<td>1.52 µm/0.18 µm</td>
</tr>
</tbody>
</table>

B. Simulation Static

The Fig.3.a represents the characteristic transfer of output current I_z according to I_x in the range ±0.7mA. The linearity error is shown in Fig.3.b. It does not exceed 0.8% in the range ± 0.35mA for the improved circuit. In contrast, the reference circuit, this error is much greater approximation of 5% over the same interval. The change in input resistance as a function of bias current I_0 is shown in Fig.4.

![Fig. 4 Input resistance R_X as a function of bias current I_0](image)

Fig. 4 Input resistance R_X as a function of bias current I_0

C. Simulation AC

Dynamic simulation is for a resisting load of 1kΩ. The frequency response of the current gain is shown in Fig.6.a. The bandwidth of the current gain at -3dB is 3.34GHz instead of 1.45GHz. Dynamic simulation mode voltage (Fig.6.b) gives a bandwidth of 4.37GHz and a static gain of 0.948. In Table 3, we have synthesized all the results of circuit simulation with the modified circuit of [8], [9], [11].

![Fig. 5 Variation of output voltage Vx as a function of input voltage Vy](image)

Fig. 5 Variation of output voltage Vx as a function of input voltage Vy

![Fig. 6 (a) Current Gain as a function of frequency (b) Voltage gain as a function of frequency](image)

Fig. 6 (a) Current Gain as a function of frequency(b) Voltage gain as a function of frequency
<table>
<thead>
<tr>
<th>Technology</th>
<th>Modified circuit</th>
<th>Classic circuit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bias voltage (Vcc-Vss)</td>
<td>0.18µm TSMC</td>
<td>0.18µm TSMC</td>
</tr>
<tr>
<td>Voltage Gain</td>
<td>2V</td>
<td>2V</td>
</tr>
<tr>
<td>Current gain</td>
<td>0.948</td>
<td>0.948</td>
</tr>
<tr>
<td>Bandwidth current Fc</td>
<td>3.34GHz</td>
<td>1.45GHz</td>
</tr>
<tr>
<td>Bandwidth voltage Fv</td>
<td>4.37GHz</td>
<td>5.38GHz</td>
</tr>
<tr>
<td>Error voltage (±0.4V) (%)</td>
<td>1.5</td>
<td>2.3</td>
</tr>
<tr>
<td>Error current (±0.35mA) (%)</td>
<td>0.8</td>
<td>5.16</td>
</tr>
<tr>
<td>Input Resistor R_i</td>
<td>169.32Ω</td>
<td>196Ω</td>
</tr>
<tr>
<td>Input Impedance (R_i/C_i)</td>
<td>5.67KΩ/164fF</td>
<td>8.12KΩ/149fF</td>
</tr>
<tr>
<td>Output Impedance (R_o/C_o)</td>
<td>6.81KΩ/37.5fF</td>
<td>0.876KΩ/108.01fF</td>
</tr>
<tr>
<td>THD at 1 MHz @ 0.3mA</td>
<td>0.24%</td>
<td>0.86%</td>
</tr>
<tr>
<td>THD at 1 MHz @ 0.3V</td>
<td>0.41%</td>
<td>0.47%</td>
</tr>
</tbody>
</table>
III. APPLICATIONS

A. Universal Filter

Circuit current conveyors are widely used in filtering applications. In recent years, several studies have been made specifically to improve the universal filter [2]-[5], [21]-[31]. We will use three circuits current controlled conveyors multi-output (MOCCCII) (Fig.7) to achieve a universal filter current-mode [7].

![Diagram of universal filter based on three MOCCCII](image)

The transfer functions of the universal filter: Low-pass, High-pass, Band-pass, Notch and All-pass are given respectively by the following expressions:

\[
I_{LP} = \frac{R}{I_{in}} \left( \frac{-1}{R_2 R_3 C_1 C_2} \right)
\]

(9)

\[
I_{HP} = \frac{R}{I_{in}} \left( \frac{p^2}{R_1 R_2 C_1 C_2} \right)
\]

(10)

\[
I_{BP} = \frac{R}{I_{in}} \left( \frac{p^2}{R_1 R_2 C_1 C_2} \right)
\]

(11)

\[
I_{AP} = \frac{R}{I_{in}} \left( \frac{p^2}{R_1 R_2 C_1 C_2} \right)
\]

(12)

The proper frequency \(f_0\) and the gain \(G_0\) of the current mode universal filter are given by the following terms:

\[
f_0 = \frac{1}{2\pi R_1 R_2 C_1 C_2}
\]

(14)

\[
G_0 = \frac{R}{R_{x^f}}
\]

(15)

To confirm the theoretical results obtained, we have performed simulations based on CMOS technology Tspice with TSMC 0.18µm and with a voltage bias of ±1V. The bias currents of CCCII three circuits are equal to 120µA. The values of passive components used are \(C_1 = C_2 = 15pF\) and \(R = R_X\). Subsequently, we have obtained a center frequency of 67.45MHz (Fig.8). In the contrast with the calculated theoretical value which is about 62.7MHz.

![Result of simulation of the module universal filter](image)

The variation of \(f_0\) based bias current \(I_0\) is shown in Fig.9, with \(C_1 = C_2 = 15pF\).

Table IV shows the comparison of our results with other work on the current-mode universal filter.

<table>
<thead>
<tr>
<th>Ref</th>
<th>Information about the circuit</th>
<th>Numbers of active elements</th>
<th>Center frequency (MHz)</th>
<th>Quality factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>[2]</td>
<td>0.5µm CMOS Spice (V_{cc}=V_{ss}=1.5V)</td>
<td>4-DOICCI</td>
<td>10MHz</td>
<td>0.707</td>
</tr>
<tr>
<td>[3]</td>
<td>0.35µm TSMC H-Spice (V_{cc}=V_{ss}=1.65V)</td>
<td>3-MOCCCII</td>
<td>110KHz</td>
<td>1</td>
</tr>
<tr>
<td>[5]</td>
<td>0.18µm CMOS T-Spice (V_{cc}=V_{ss}=1V)</td>
<td>3-MOCCCII</td>
<td>134.58MHz</td>
<td>1</td>
</tr>
<tr>
<td>Our results</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Change in frequency as a function of bias current](image)
B. Implementing an inductance

This problem has drawn the attention of many researchers. They have decided to make inductors based on active elements such as current conveyors, resistors and capacity. In this section, we present the creation of types of inductors, floating and related to ground, based on CCCII circuit modified.

1. Floating inductor

Scheme of a floating active inductor using four CCCII+ [33]-[35] is shown in Fig.10.

![Fig. 10 Realization of floating inductance using four CCCII](image)

The circuits CCCII 1 and 2 are biased by an identical current I_{01}, so that the capacitance C is covered by the same current. Similarly, the conveyor CCCII 3 and 4 are biased by I_{02} to have equal currents in A and B. R_{x1} is the parasitic resistance associated with the CCCII1 and 2 for the current I_{01}. Similarly, R_{x2} is the parasitic resistance associated with the CCCII3 and 4 for the current I_{02}.

\[
V_{AB} = 2R_{x1}I_{1}
\]
\[
V_i = \frac{1}{pC}I_1 = 2R_{x2}I_{in}
\]
\[
V_{AB} = p(2R_{x1})(2R_{x2})C I_{in}
\]
\[
L = (2R_{x1})(2R_{x2})C
\]

2. Inductor connected to ground

Subsequently, based on [33]-[37], we have introduced another inductor based on current conveyor, one with positive transfer and the other with negative transfer and capacity.

![Fig. 11 Realization of an inductor connected to ground](image)

The implementation of this inductance is illustrated in Fig.11. Taking into account the presence of parasitic resistors R_{x1} and R_{x2}:

\[
V'_{in} = V_{x1} = -R_{x1}I_{x1}
\]
\[
V_{y2} = V'_{x2} = -\frac{1}{j\omega}I_{x1} = R_{x2}I_{in}
\]

According to equation (21), we have:

\[
I_{x1} = -jR_{x2}C\omega I_{in}
\]

The confusion of two expressions (20) and (22) gives:

\[
V_{in} = jR_{x1}R_{x2}C\omega I_{in}
\]

The input impedance is given by the following expression:

\[
Z_{in} = \frac{V_{in}}{I_{in}} = jR_{x1}R_{x2}C\omega
\]

It is equivalent to an inductance L for:

\[
L_{eq} = R_{x1}R_{x2}C
\]

3. Simulation results

In both structures, we have minimized the number of circuits used. We have used only the conveyors current to single output and only one capacity. Both inductors have an operating frequency zone and L values vary with bias current I_{in}. At each change in bias current I_{in}, we have found the area of operation frequency with an accuracy of ± 5 degrees of phase (table 5).
TABLE V
THE VALUES OF INDUCTORS ACCORDING TO THE BIAS CURRENT $I_0$

<table>
<thead>
<tr>
<th>$I_0$ (µA)</th>
<th>Frequency (MHz)</th>
<th>$L$ (µH)</th>
<th>Frequency max (MHz)</th>
<th>$L$ (µH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10</td>
<td>98.56-120.46</td>
<td>0.2830</td>
<td>24.07</td>
<td>0.0705</td>
</tr>
<tr>
<td>20</td>
<td>120.36-152.11</td>
<td>0.1410</td>
<td>45.66</td>
<td>0.0804</td>
</tr>
<tr>
<td>30</td>
<td>135.31-181.31</td>
<td>0.0844</td>
<td>66.99</td>
<td>0.0882</td>
</tr>
<tr>
<td>60</td>
<td>177.8-238.25</td>
<td>0.0270</td>
<td>170.42</td>
<td>0.102</td>
</tr>
<tr>
<td>80</td>
<td>216.1-295.27</td>
<td>0.0155</td>
<td>172</td>
<td>0.1025</td>
</tr>
<tr>
<td>90</td>
<td>220.36-301.1</td>
<td>0.0161</td>
<td>184.93</td>
<td>0.104</td>
</tr>
<tr>
<td>100</td>
<td>242.9-301.1</td>
<td>0.0158</td>
<td>212.32</td>
<td>0.1035</td>
</tr>
<tr>
<td>120</td>
<td>252.6-325.5</td>
<td>0.0092</td>
<td>252.93</td>
<td>0.107</td>
</tr>
<tr>
<td>130</td>
<td>266.77-334.07</td>
<td>0.00924</td>
<td>300.61</td>
<td>0.109</td>
</tr>
<tr>
<td>200</td>
<td>273.18-338.32</td>
<td>0.00775</td>
<td>305.14</td>
<td>0.11</td>
</tr>
<tr>
<td>250</td>
<td>276.03-345.92</td>
<td>0.00785</td>
<td>311.53</td>
<td>0.1090</td>
</tr>
<tr>
<td>300</td>
<td>287.35-361.94</td>
<td>0.00777</td>
<td>315.5</td>
<td>0.1086</td>
</tr>
<tr>
<td>180</td>
<td>301.33-373.58</td>
<td>0.00629</td>
<td>316.96</td>
<td>0.1082</td>
</tr>
<tr>
<td>200</td>
<td>324.22-401.35</td>
<td>0.00504</td>
<td>728.62</td>
<td>0.117</td>
</tr>
<tr>
<td>220</td>
<td>329.39-409.4</td>
<td>0.005</td>
<td>701.46</td>
<td>0.1168</td>
</tr>
<tr>
<td>250</td>
<td>344.7-423</td>
<td>0.0036</td>
<td>719.46</td>
<td>0.144</td>
</tr>
<tr>
<td>280</td>
<td>354.42-436.6</td>
<td>0.00358</td>
<td>726.11</td>
<td>0.1132</td>
</tr>
<tr>
<td>300</td>
<td>361.86-439.2</td>
<td>0.00357</td>
<td>731.14</td>
<td>0.1124</td>
</tr>
<tr>
<td>320</td>
<td>363.36-440.5</td>
<td>0.0035</td>
<td>1180</td>
<td>0.116</td>
</tr>
<tr>
<td>350</td>
<td>376.2-456.78</td>
<td>0.003</td>
<td>1200</td>
<td>0.115</td>
</tr>
</tbody>
</table>

C. Sinusoidal Oscillator

We have given the importance of oscillators in the field of signal processing; many researchers have proposed many structures to improve their frequency performance, low power and low voltage. The proposed oscillator circuit based on an operational amplifier is shown in Fig.12.

![Fig.12 Implementation of an oscillator](image)

Based on the equivalent circuit, the network reaction has as input impedance:

$$Z_{in} = Z_j/(Z_2 + Z_j) = \frac{Z_3 (Z_2 + Z_j)}{Z_1 + Z_2 + Z_3} \quad (26)$$

The transfer function of the amplifier:

$$H = \frac{V_o}{V_{in}} = \frac{A \cdot V_{in}}{Z_2 + R_i} = \frac{A \cdot Z_{in}}{R_i + Z_{in}} \quad (27)$$

With $A_0$: The gain of the direct chain. ($A_0 = -\frac{R_2}{R_1}$).

$R_i$: The output resistance characteristic of the amplifier.

The transfer function of the chain reaction is given by

$$K = \frac{V_o}{V_0} = \frac{Z_1}{Z_1 + Z_2}$$

According to the Barkhausen condition $H \times K = 1$.

We have:

$$A_0 \cdot Z_2 \cdot Z_j = R_3 (Z_1 + Z_2 + Z_3) + Z_3 (Z_2 + Z_1)$$

With $Z_i = j \cdot X_i$, $i = 1, 2, 3$

The oscillation condition becomes:

$$-A_0 \cdot X_1 \cdot X_3 = j \cdot R_3 (X_1 + X_2 + X_3) - X_3 (X_2 + X_1)$$

In our case $A_0 < 0$, by identifying:

$$A_0 \cdot X_i = -X_3$$

We used the same reactors studied previously.

A basis of an inductor connected to ground, this circuit has an oscillation frequency and gain:

$$f_0 = \frac{1}{2 \pi \sqrt{(L_j + L_2) C}} \quad (28)$$
\[ A_0 = \frac{-L_2}{L_1} = -\frac{R_2}{R_1} \]  

(29)

A basis of a floating inductor, the circuit has an oscillation frequency and gain:

\[ f_0 = \frac{I}{2\pi \sqrt{C_1 C_2 L}} \]  

(30)

\[ A_0 = \frac{C_1}{C_2} = -\frac{R_2}{R_1} \]  

(31)

We performed simulations with a supply voltage of ± 1V. The choice of components is as follows: \( C = 100\text{nF} \) to the first circuit and \( C_1 = C_2 = 0.1\text{pF} \) for the second with the condition \( R_2 = 10 \times R_1 \). By the current variation of \( I_0 = 80\mu\text{A}, 350\mu\text{A} \), we obtained an oscillation frequency variable [358MHz, 572MHz] and [470MHz, 694MHz], respectively the first and second circuit (Fig.14)

For a bias current \( I_0 = 120\mu\text{A} \), the signal of the oscillator is shown in Fig.15

Fig. 13 Implementation of two oscillator circuit based on CCCII
(a). a basis of an inductor connected to ground(b). a basis of a floating inductor

(a)

(b)

Fig. 14 Frequency of the oscillator based on current \( I_0 \)
(a). A basis of an inductor connected to ground(b). A basis of a floating inductor

(a)

(b)

Fig. 15 Output signal of the oscillator(a). A basis of an inductor connected to ground(b). A basis of a floating inductor

(a)

(b)
IV. CONCLUSION

In this paper we have made several improvements to the circuit current conveyor CCCII controlled using current mirrors with low supply voltage. This circuit operates at low supply voltage of ±1V and present to a bias current of 120µA, a bandwidth of 3.34GHz and 4.37GHz respectively in current mode and voltage mode for expenses and a 1kΩ parasitic resistance Rx of 169.32 Ω. Based on this circuit, we have implemented first a universal filter, current mode. The frequency can reach the 134.58MHz. In the second, we have implemented two inductors, one floating and the other tied to ground, operating in high frequency and variable depending on bias current I0. We have used the last two, respectively, to implemented two sinusoidal oscillators frequency one [358MHz, 572MHz], second [470MHz, 692MHz] for bias currents I1 [80µA, 350µA].

REFERENCES

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