SINGLE-CURRENT-CONTROLLED SINUSOIDAL OSCILLATOR
WITH CURRENT AND VOLTAGE OUTPUTS USING SINGLE
CURRENT-CONTROLLED CONVEYOR
TRANSCONDUCTANCE AMPLIFIER AND GROUNDED
PASSIVE ELEMENTS

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Key words: Current-controlled conveyor transconductance amplifier (CCCTA),
Single-current-controlled (SCC), Sinusoidal oscillator.

This work presents a single-current-controlled (SCC) sinusoidal oscillator that
explicitly generates both current and voltage outputs, and employing only a single
current-controlled conveyor transconductance amplifier (CCCTA) as the active
building block, and three passive components. The presented circuit provides the
advantage features of independent electronic control of oscillation condition and
oscillation frequency, and use of all grounded passive components. The circuit also
exhibits low active and passive sensitivities and permits good frequency stability.
Computer simulation results obtained from PSPICE program using 0.35-μm BiCMOS
real process parameters are performed to confirm the excellent performance of the
proposed oscillator circuit.

1. INTRODUCTION

Since an introduction of the newly defined active building block namely, the
current conveyor transconductance amplifier (CCTA) in 2005 [1], this device has
been gaining an increasing attention that led to a great number of analog function
circuits. Basically, the CCTA device can be realized by cascading the second-
generation current conveyor with the multi-output transconductance amplifier in
monolithic form. By combining the advantages of both circuit topologies, the
CCTA possesses wide bandwidth, high-slew rate, high dynamic range, and low
power consumption. Considering these reasons, the CCTA is suitable for a class of

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analog signal processing which can process in both current and voltage signals. Hence, a great number of numerous analog adjustable functions is available in technical literature [1–4]. In 2008, the current-controlled conveyor transconductance amplifier (CCCTA) which is a modified version of the CCTA, was introduced [5]. The parasitic resistance looking into the x-terminal \( R_x \) of the circuit is used to advantage in current-controlled circuit parameter, because it is easily adjusted by an external biasing current. This advantage allows the implementation of numerous electronically tunable circuits without requiring external passive resistors, which is especially important for integrated circuit implementation.

The sinusoidal oscillators constitute an essential circuit blocks of a typical information system, modern electronic or communication system. A great number of schemes based on modern active function blocks have been developed to realize sinusoidal oscillator [6–13]. However, the oscillator circuits reported in [6–12] are not minimal in a number of active and passive components. The works in [6–11] also do not provide electronic controllability to their important parameters. Moreover, all of them generate either voltage signal output or current signal output only.

This work describes a novel single-current-controlled (SCC) sinusoidal oscillator with current and voltage signal outputs, constructing one CCCTA, one grounded resistor and two grounded capacitors. The circuit provides the independent current controllability of the oscillation condition and oscillation frequency \( \omega_o \), and suitability for integration due to employing only grounded passive components. Circuit analyses show that the circuit provides low component sensitivity, and good frequency stability. The presented oscillator circuit with dual-mode outputs is verified by the practical PSPICE model of the CCCTA. The simulation results using PSPICE program show an adequate agreement with the theoretical conclusions.

2. CURRENT-CONTROLLED CONVEYOR TRANCONDUCTANCE AMPLIFIER (CCCTA)

The CCCTA device is conceptually based on the combination of second generation current-controlled conveyor (CCCII) and transconductance amplifier. Its electrical symbol can be shown in Fig.1. As shown, the CCCTA device consists of two input terminals (y and x) and two output terminals (z and o). The x-terminal has a parasitic serial resistance \( R_x \), where its value usually depends on an external supplied current. The y-terminal is the high-input impedance terminal, while the z and o-terminals are two types of high-output impedance terminals. The property of the CCCTA can be described by the following matrix:
where $R_x$ and $g_m$ are the finite parasitic resistance looking into the x-terminal, and the transconductance gain of the CCCTA, respectively. In addition, an auxiliary $zc$ terminal provides a copy current of the current flowing out of the $z$-terminal, i.e., $i_{zc} = i_z$. Here, the values of $R_x$ and $g_m$ depend on the external dc bias currents $I_A$ and $I_B$, respectively.

\[
\begin{bmatrix}
    i_y \\
    v_x \\
    i_z \\
    i_o
\end{bmatrix}
= \begin{bmatrix}
    0 & 0 & 0 & 0 \\
    R_x & 1 & 0 & 0 \\
    1 & 0 & 0 & 0 \\
    0 & 0 & g_m & 0
\end{bmatrix}
\begin{bmatrix}
    i_x \\
    v_y \\
    v_z \\
    v_o
\end{bmatrix}
\]  

(1)

Figure 1 – Circuit representation of the CCCTA.

Figure 2 shows the schematic BiCMOS realization of the CCCTA [14], which mainly consists of the CCCII (Q1-Q2, M1-M4, M9-M12) and transconductance amplifiers (Q3-Q4, Q5-M8, M13-M15). Groups of transistors Q1-Q2, Q3-Q4 and Q5-Q6, which are assumed to be well matched, act as transconductance amplifiers to convert the voltage signal to the current signal. The current mirroring has been achieved by simple current mirror circuits (M1-M4), (M5-M6), (M7-M8), (M9-M12) and (M13-M15). The internal intrinsic resistance at the x-terminal ($R_x$) of the CCCTA can be derived as [14]:

\[
R_x \approx \frac{2V_T}{I_A},
\]

(2)

where $V_T \approx 26$ mV at 27 °C is the thermal voltage. It is clearly seen from eq.(2) that the resistance $R_x$ is controllable electronically by adjusting the bias current $I_A$.

Similarly, the small-signal transconductance gain ($g_m$) of the CCCTA derived from the transconductor Q3-Q4 (Q5-Q6) can be expressed as [14]:

\[
g_m = \frac{i_o}{v_z} = \frac{I_B}{2V_T}.
\]

(3)
Also note that the $g_m$-value can be controlled electronically and linearly by changing the $I_B$-value.

$$m = \frac{1}{R} + \frac{1}{R_c C_2}$$

From Eq. (4), the condition of oscillation and the frequency of oscillation ($\omega_o$) can be obtained by :

$$R_1 = R_x$$

and

$$\omega_o = \sqrt{\frac{g_m}{R_x C_1 C_2}}$$

Eq. (5) shows that the condition of oscillation can be controlled independently by a grounded resistor $R_1$. It is also clear from Eq. (6) that the $\omega_o$ is electronically controlled by the $g_m$ value without affecting the condition of oscillation. Since the the $g_m$ value is controlled by the external biasing circuit $I_B$ of
the CCCTA as given in eq. (3), the proposed circuit may be considered as a single-current-controlled variable frequency sinusoidal oscillator. The sensitivity analysis shows that the various active and passive sensitivities of the parameter $\omega_o$ are all low and obtained as:

$$S_{g_m}^\omega = -S_{R_x}^\omega = -S_{C_1,C_2}^\omega = \frac{1}{2}.$$  \hspace{1cm} (7)

4. FREQUENCY STABILITY

The classical frequency stability factor ($S_F$) can be defined as [6]:

$$S_F = \frac{d\phi(u)}{du} \bigg|_{u=1},$$  \hspace{1cm} (8)

where $u = \omega/\omega_o$ and $\phi(u)$ is the phase function of the open-loop transfer function of the oscillator in Fig. 3. With $C_1 = C_2$, $R_x = R_1 = R$ and $g_m = R/n$, the $S_F$ factor of Fig. 3 is derived as

$$S_F = \frac{2n\sqrt{n}}{n+1}.$$  \hspace{1cm} (9)

If $n >> 1$ is satisfied, the value of $S_F$ can be made quite high. It reveals that this sinusoidal oscillator has good frequency stability.
5. COMPUTER VERIFICATION AND DISCUSSION

To verify the theory, the proposed SCC dual-mode sinusoidal oscillator of Fig. 3 has been simulated with PSPICE simulation program. In simulations, the CCCTA structure depicted in Fig. 2 was performed using standard 0.35 μm BiCMOS process parameters [14]. The dc supply voltages were selected as: +V = – V = 1V. The transistor aspect ratios (W/L in μm/μm) were chosen as: 7/0.7 and 8.5/0.7 for all the PMOS and NMOS transistors respectively. The following component values were chosen as: \(I_A = 10 \mu\text{A}, I_B = 35 \mu\text{A}\) and \(C_1 = C_2 = 0.1 \text{nF}\), resulting in \(R_e \approx 5 \text{kΩ}, g_m \approx 0.67 \text{mA/V}\) and \(f_o = \omega_o/(2\pi) \approx 584 \text{kHz}\), respectively. The value of \(R_1 \approx 5.2 \text{kΩ}\) was chosen to be slightly larger than \(R_o\), in order to ensure that the oscillation will occur.

Fig. 4 – Simulated output waveforms for \(v_o\) and \(i_o\) of the proposed oscillator circuit in Fig. 3: a) during initial state; b) during steady-state.
Figure 4 illustrates the simulated time domain responses for the sinusoidal output signals $v_o$ and $i_o$ of the proposed oscillator circuit of Fig. 3. The simulated $f_o$ obtained from the results was measured as: $f_o \approx 556$ kHz. Fig. 5 shows the simulated frequency spectrums for both outputs, giving the total harmonic distortion (THD) equal to 4.28%.

![Fig. 5 – Simulated frequency spectrums for $v_o$ and $i_o$ of the proposed oscillator circuit in Fig.3.](image)

Figure 6 shows the variability of $f_o$ as a function of the bias current $I_o$.

![Fig. 6 – Variation of $f_o$ as a function of the bias current $I_o$.](image)

As can be seen, the difference between the theory and the simulated plots especially in high bias current value region is mainly attributed to the deviation of the values of $R_x$ and $g_m$ that differ from the calculation values. Since the expressions of $R_x$ and $g_m$ for the proposed oscillator configuration in Figure 3 include voltage equivalent of temperature, i.e., $V_T$ term, the circuit is prone to thermal influence, needing measures to counteract. Figure 7 displays the simulated
$f_0$ of the proposed oscillator versus ambient temperature ($T$). As calculated from the results, the relative sensitivity of $f_0$ with respect to $T$, which is defined by $S_{f_0}^{\partial} = (\partial f_0 / \partial T) / f_0$, is around 11.17$\times$10$^{-3}$.

Fig. 7 – Variation of $f_0$ as a function of the ambient temperature $T$.

Fig. 8 – Monte-Carlo analysis for $f_0$ when 10% deviation in $R_x$ and $R_1$ values.

Fig. 9 – Monte-Carlo analysis for $f_0$ when 10% deviation in $C_1$ and $C_2$ values.

In addition, the impact of the component mismatching on the oscillator’s response has been evaluated through Monte-Carlo statistical analysis. In this study, the Monte-Carlo simulations with 10% Gaussian deviation on the values of $R_x$, $R_1$, $C_1$ and $C_2$ were performed for the proposed oscillator circuit. The derived statistical
histograms of $f_o$ variation in percent are given in Figs. 8 and 9. Both graph were generated from the same 200 simulation runs. In Fig. 8, a standard deviation of $f_o$ was 2.78%, and maximum and minimum $f_o$ were 571 kHz and 515 kHz, respectively. Likewise, the plots of Fig. 9 also indicate that the standard deviation, and maximum and minimum $f_o$ were obtained as : 5.75%, 631 kHz and 474 kHz, respectively. These results reveal that the proposed oscillator has reasonable sensitivity performance. In conclusion, a comparative study of performance specifications of the proposed oscillator circuit with some of the earlier reported oscillators has been summarized in Table 1.

Table 1
Comparison of the proposed SCC dual-mode sinusoidal oscillator of Fig. 3 to the earlier reported oscillator circuits [6–13]

<table>
<thead>
<tr>
<th>Circuits [Ref]</th>
<th>No. of active components</th>
<th>No. of passive components</th>
<th>All grounded passive components</th>
<th>Electronic tunability</th>
<th>Voltage and current outputs</th>
<th>Technology Supply voltages</th>
</tr>
</thead>
<tbody>
<tr>
<td>[6] CCII = 1, buffer = 1</td>
<td>$R = 3$, $C = 2$</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>CA3096, LF356</td>
<td>±12V</td>
</tr>
<tr>
<td>[7] CCII = 1, buffer = 2</td>
<td>$R = 3$, $C = 2$</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>CA3096, OA741</td>
<td>±12V</td>
</tr>
<tr>
<td>[8] FTFN = 1</td>
<td>$R = 4$, $C = 2$</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>AD844</td>
<td>±10V</td>
</tr>
<tr>
<td>[9] OTRA = 1</td>
<td>$R = 3$, $C = 2$</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>0.8 µm AMS</td>
<td>±2.5V</td>
</tr>
<tr>
<td>[10] AD844 = 2</td>
<td>$R = 4$, $C = 2$</td>
<td>yes</td>
<td>no</td>
<td>no</td>
<td>AD844</td>
<td>±12V</td>
</tr>
<tr>
<td>[11] CCII = 2</td>
<td>$R = 2$, $C = 2$</td>
<td>no</td>
<td>no</td>
<td>no</td>
<td>AD844</td>
<td>±5V</td>
</tr>
<tr>
<td>[12] CDTA = 3</td>
<td>$R = 1$, $C = 2$</td>
<td>no</td>
<td>yes</td>
<td>no</td>
<td>0.5 µm MIETEC</td>
<td>±2.5V</td>
</tr>
<tr>
<td>[13] CCCTA = 1</td>
<td>$R = 1$, $C = 2$</td>
<td>yes</td>
<td>yes</td>
<td>no</td>
<td>0.25 µm TSMC</td>
<td>±1.25V</td>
</tr>
<tr>
<td>Proposed</td>
<td>CCCTA = 1</td>
<td>$R = 1$, $C = 2$</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
<td>0.35µm BiCMOS</td>
</tr>
</tbody>
</table>

6. CONCLUSION

This paper describes a single-current-controlled sinusoidal oscillator employing a single CCCTA along with three grounded passive elements, i.e. one resistor and two capacitors. The proposed oscillator circuit provides voltage-mode as well as current-mode outputs simultaneously from the same configuration. The circuit enjoys the non-interactive current controls for both oscillation condition and oscillation frequency, which can be used as a current-controlled variable frequency sinusoidal oscillator. The simulation results have been performed for the realized sinusoidal oscillator circuit to verify the theoretical expectation.
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