Current Controlled CCTA Based- Novel Grounded Capacitance Multiplier with Temperature Compensation

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Abstract— This article introduces a grounded capacitance multiplier employing current controlled current conveyor transconductance amplifiers (CCCCTAs). The provided capacitor is a grounded element. Its outstanding feature is that the capacitive value can be electronically adjusted by input bias currents of the CCCCTA and is temperature-insensitive. The circuit construction comprises two CCCCTAs, cooperating with a grounded capacitor. The circuit performances are depicted through PSPICE simulations, they show good agreement to theoretical anticipation. Application as a fifth-order Chebyshev low-pass filter is included.

I. INTRODUCTION

It is well accepted that a capacitor is an important element which is used in the most of circuits and systems. For example, it is used for tuning in filters, oscillators and etc. However, in the integrated circuit fabrication, it is impractical to realize large-valued capacitors because of the occupied area. In fact, in a standard CMOS polysilicon layers, a 20pF capacitor is equivalent, relatively to the silicon area, to thousands of transistors [1]. This means that the integration of capacitor as large as 100pF is not possible. In some applications, however, such as integrated lock-in amplifiers, sampled-data systems and capacitive sensor interfaces [2-5], they are necessary to have higher capacitive values.

A possible solution is the use of a capacitance multiplier, which performs the multiplication of small capacitive values, to obtain higher equivalent integrated capacitors, avoiding the need of a large silicon area [6]. From literature studies, several works which can provide a multiplied capacitor have been proposed. Although, the voltage-mode operational amplifier (op-amp) based capacitance multipliers are available in the literatures [7-9], they are not suitable from the view point of IC fabrication.

The modern active building blocks employed to synthesize the capacitance multipliers are emphasized on Operational Transconductance Amplifiers (OTAs) [9-11] and current conveyors [12-18] due to commercial availabilities. The literature surveys show that a large number of modern circuit realizations for capacitance multipliers have been reported [10-18]. Unfortunately, these reported circuits suffer from one or more of following weaknesses

a) Need for passive element matching [9-11, 15-16].
b) Lack of electronic tunability [12-15], [17], which can not be implemented in automatic control systems.
c) Excessive use of the active and/or passive elements [10-18].
d) Use of floating capacitor, which is not convenient to further fabricate in IC [9-11, 13, 17].
e) Use of a capacitor connected to inappropriate terminal, which results in an extra pole, and consequently provides lower frequency of operation [12, 18].

A major restriction of the all previous capacitance multipliers is temperature dependence of the capacitive values due to parasitic parameters of active elements used in circuits which limits the performances of the circuits, especially in the works suffered from environment variations.

Recently, the capacitance multipliers using DVCC cooperating with CCCIs [19] and OTAs [20] have been introduced. These circuits do not need any matching conditions of the elements. In addition, the capacitive values are ideally temperature-insensitive. Unfortunately, the circuit in [19] consists of many different active elements and the reported circuit in [20] comprises 4 OTAs, which is not convenient to further fabricate in IC and providing high power consumption.
In this paper, we present a novel capacitance multiplier emphasizing on use of the CCCCTA. The CCCCTA is an interesting active building block recently proposed [21], because it can be employed to synthesize and design the modern electronic circuits and systems employing only a few numbers of elements which subsequently offers low power consumption. The features of proposed circuit are that: the proposed circuit consumes a two number of active element: it employs only single grounded capacitor, which is convenient to realize in IC [22-23]: it does not need any matching conditions of the employed elements: the capacitive value is temperature-insensitive. In addition, it can be controlled via input bias currents and offers low power consumption. The performances of proposed circuit are illustrated by PSPICE simulations, they show good agreement as depicted. An application as a fifth-order Chebyshev low-pass filter is included.

![Figure 1. CCCCTA (a) Symbol (b) Equivalent circuit](image)

**II. PRINCIPLE OF OPERATION**

**A. The Current Controlled Current Conveyor Transconductance Amplifier (CCCCTA)**

CCCCTA properties are similar to the conventional CCTA [21], except that the CCCCTA has finite input resistance \( R_x \) at the \( x \) input terminal. This parasitic resistance can be controlled by the bias current \( I_{B1} \) as shown in the following equation:

\[
\begin{bmatrix}
I_y \\
V_x \\
I_z \\
V_o
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 \\
0 & 1 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 0 & \pm g_m & 0
\end{bmatrix}
\begin{bmatrix}
I_x \\
V_y \\
I_o \\
V_o
\end{bmatrix},
\]

where

\[ R_x = \frac{V_x}{2I_{B1}}, \]

and

\[ g_m = \frac{I_{B2}}{2V_T}, \]

where \( g_m \) is the transconductance gain of the CCCCTA and \( V_T \) is the thermal voltage. The symbol and equivalent circuit of the CCCCTA are illustrated in Fig. 1(a) and (b), respectively.

**B. Proposed Grounded Capacitance Multiplier**

Fig. 2 depicts the proposed grounded capacitance multiplier. Considering the circuit in Fig. 2 and using CCCCTA properties in section II. A, we will receive

\[ I_c = \frac{R_2 g_m C_s}{R_{o1} g_m} V_o, \]

and

\[ Z_m = \frac{V_o}{I_c} = \frac{R_2 g_m}{R_{o2} g_m C_s}. \]

From Eq. (6), it is clearly seen that, the proposed circuit can provide the new grounded capacitor with a value

\[ C_c = \frac{R_2 g_m C}{R_{o2} g_m}. \]

If we substitute \( R_{o1} = V_{o1} / 2I_{B1} \), \( R_{o2} = V_{r} / 2I_{B3} \), \( g_{m1} = I_{B2} / 2V_T \) \( g_{m2} = I_{B4} / 2V_T \), the grounded capacitance is modified to

\[ C_c = K_{mul} C = \frac{I_{B1} I_{B2}}{I_{B3} I_{B4}} C. \]

It is evident that, the capacitive value is multiplied with a gain as

\[ K_{mul} = \frac{I_{B1} I_{B2}}{I_{B3} I_{B4}}. \]

![Figure 2. Proposed Grounded Capacitance Simulator](image)

We can found that, if the connected capacitor is free from temperature, the obtained capacitive value is temperature-insensitive and can be adjusted by any input bias currents. Thus, \( K_{mul} \) can be multiplied as high as more than 6
decades, because $I_{B1}$ and $I_{B2}$ can be as high as milliamperes range, while $I_{B3}$ and $I_{B4}$ can be as low as nanoamperes range.

III. SIMULATION RESULTS AND DISCUSSIONS

To prove the performances of the proposed circuit, the PSPICE simulation program was used for the examination. The PNP and NPN transistors employed in the proposed circuit were simulated by respectively using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T \[24\] with ±1.5V supply voltages. Fig. 3 depicts schematic description of the CCCCTA used in the simulations. Fig. 4 shows the typical waveforms of the voltage and current through the proposed grounded capacitance multiplier of Fig. 2. It provides a current leading to a voltage of 90°, similar to an ideal capacitor. Table 1 displays capacitance deviations of obtained capacitances due to capacitance and multiplied gain variations. It can be found that the slight errors can be obtained due to effects of the internal parasitic elements.

![Figure 3. Internal construction of CCCCTA](image)

![Figure 4. Transient responses of current and voltage dropping input of capacitance multiplier](image)

To illustrate frequency response of the grounded capacitance multiplier, Fig. 5 shows the absolute magnitude of input impedance for several frequencies. It should be noted that the usable frequency range of the proposed circuit is up to approximately 1MHz.

In addition, from the result in Fig. 6, it is insisted that in the usable frequency range, the proposed circuit provides a grounded capacitance with temperature-insensitivity. At higher frequencies, the internal parasitic elements, covering capacitances and resistances, degrade the performances of the proposed circuit. Similarly, these factors effect on temperature dependence of input impedance at the higher frequencies, as shown in Fig. 6.

To show usability of the proposed circuit, an application as a fifth-order Chebyshev low-pass filter \[25\] as shown in Fig. 7 is included. The results of frequency responses of the proposed capacitance multiplier, compared to the ideal capacitance, are confirmed in Fig. 8, where $V_{in} = 1mV$.

![Figure 5. Magnitude and phase of input impedance relative to frequency variations](image)

![Figure 6. Frequency responses of magnitude of input impedance due to temperature variations](image)

![Figure 7. A fifth-order Chebyshev low-pass filter](image)

**Table 1. Capacitance deviations of obtained capacitances at several capacitors and multiplied gains**

<table>
<thead>
<tr>
<th>Multiplied Gains</th>
<th>Capacitors (nF)</th>
<th>Obtained capacitances (F)</th>
<th>Errors (%)</th>
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<tbody>
<tr>
<td>1</td>
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<td>9.50E-10</td>
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<tr>
<td>10</td>
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<td>9.75E-09</td>
<td>2.52</td>
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<tr>
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<td>10</td>
<td>1.03E-3</td>
<td>-3.07</td>
</tr>
</tbody>
</table>
capacitance-based circuits. Fabricating into an integrated circuit and implementing to capacitance multiplier is appropriate for and further voltages. Consequently, the proposed grounded consumption is approximately 0.822mW at ±1.5V supply results confirm the mentioned benefits. The power cooperating with a grounded capacitor. The PSPICE The circuit construction comprises only two CCCCTAs, currents of the CCCCTAs and is temperature-insensitive. Capactive value can be widely adjusted by any input bias CCCCTAs has been introduced in this paper. The controlled ideal C-multiplier,” Electronics letters, vol. 22, pp. 365-367, 1986.


REFERENCES


IV. CONCLUSION

A novel grounded capacitance multiplier using CCCCTAs has been introduced in this paper. The capacitive value can be widely adjusted by any input bias currents of the CCCCTAs and is temperature-insensitive. The circuit construction comprises only two CCCCTAs, cooperating with a grounded capacitor. The PSPICE results confirm the mentioned benefits. The power consumption is approximately 0.822mW at ±1.5V supply voltages. Consequently, the proposed grounded capacitance multiplier is appropriate for and further fabricating into an integrated circuit and implementing to capacitance-based circuits.