**EMPLOYING CCCII and OTA-BASED ACTIVE C-CURRENT-MODE UNIVERSAL FILTER**

Akhilesh Kumar Maurya\(^*\)

ECE, Integral University

pakhil.sam@gmail.com

Dr. N.R. Kidwai\(^2\)

ECE, Integral University

nrkidwai@iul.ac.in

Saroj Mandal\(^3\)

BME, BBD University

sarojmandal20018@gmail.com

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**Abstract**—A new active C-current mode (CM) universal filter structure employing two CCCIIIs, two OTAs and only grounded capacitors are presented. It’s compatible with VLSI technology since no resistance is used in the circuit. This versatile filter can simultaneously realize five basic transfer functions from the same configuration. It still maintains the following advantage: High-order filter structure can be easily derived from the proposed filter structure. The parameter \(a_0\) can be tuned by changing component manually without effect to the \(Q\). The simulation results have been carried out by Pspice.

Keywords—operational transconductance amplifier (OTA), current conveyor, universal filter

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**I. INTRODUCTION**

The applications and advantages in the realization of various active filter transfer functions employing current control conveyors (CCC) have received considerable awareness [1-8], second-order active-C filters are of great interests because several counterparts of this kind can be directly connected in cascade to implement higher order filters. Compared with voltage-mode (VM), current-mode (CM) filter has high performance properties such as wider signal bandwidths, greater linearity, lower power consumption, larger dynamic range, more simple circuitry and occupancy of lesser chip area. Circuits compiled of CCCII or OTA are typically more suitable for construction of current-mode filter. In the realization of active filters the second generation current control conveyors (CCCIIs) are widely used because they are functionally flexible and versatile [4-8]. Also, an active filter employing CCCII is attractive for providing some electric characteristics, such as: electronic tunable and wide range of X-terminal resistance by the bias current. Operational transconductance amplifier (OTA) [7, 10, 12] is also an attractive device that represents the ratio of output current to the input voltage. It is adjustable by a supplied bias current, which has high input and output impedances.

To design a universal filter employing CCCII or OTA, four characteristics will be taken into consideration: chip area, versatile, tunable and flexible. Some universal filters were proposed [3-13]. However, these circuits suffer from one or more of following drawbacks:

a) Passive resistances are used in circuits which will need larger chip area for integration [2, 3, 6, 11].

b) Resonance angular frequency \(a_0\) can’t be tuned [2-5].

c) The second-order filter can’t expand to high-order filter [2-8].

d) The basic five transfer functions of filter can’t be realized from a same configuration [3].

Beside, [2] and [7] proposed voltage-mode circuits which show lower linearity and poorer high frequency performances compared to current-mode circuits. This paper, a new tunable versatile and flexible filter using CCCII and OTA can easily realize all five transfer functions and expand to high-order filter without resistances. Moreover, the parameters \(a_0\) and \(Q\) can be electronically tuned through adjusting the transconductance gains of the OTAs.

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**II. CIRCUIT DESCRIPTION**

The port relationships of a CCCII can be characterized by:

\[
\begin{bmatrix}
I_x \\
V_x
\end{bmatrix} = \begin{bmatrix}
0 & 0 & 0 & 1 & 0 & 1 \\
0 & 1 & 0 & 0 & 0 & -1
\end{bmatrix}
\begin{bmatrix}
I_y \\
V_y
\end{bmatrix}
\]

Where \(R_X\) is the input resistance at \(X\) port which is given by \(R_X = V_T/2I_B\). \(V_T\) is the thermal voltage, \(I_B\) is bias current of CCCII, the positive and negative signs respectively refer to plus and minus type CCCII.

The symbol and the equivalent circuit of CCCII are illustrated in Fig.1 (a) and Fig.1 (b) respectively.

![Figure 1](image)

**Figure 1.** (a) Symbol and (b) Equivalent circuit of CCCII.

For an OTA, connect pulse output current with minus input terminal and connect pulse input terminal to the ground as show in Fig. 2, the feature of OTA can be seen as a resistance. A high resistance can be formed by tuning the transconductance \(g_m\). The electronic resistor circuit structured by OTA occupies smaller chip area.

\[
R_n = \frac{V_m}{I_m} = \frac{(V - V_m)}{I_m} = \frac{-(V - V_m)}{-I_{out}} = \frac{1}{g_m}
\]

The multiply output operational transconductance amplifier and grounded capacitors as show in Fig.3 are initiated as a current-mode lossless integrator [6, 11]. And the proposed universal filter is shown in Fig.4. In the circuit, the first OTA is used as a large resistance.
V_{\text{in}} g_{\text{m}} \gamma = I_{\text{out}}, \text{ where } \gamma = 1 - e_\gamma \text{ and } e_\gamma \text{ denotes the}
\text{transconductance-tracking error. The denominator}
\text{polynomial of the transfer functions for the proposed filter}
\text{becomes:}
\begin{align}
I_{\text{hp}} &= s^2 C_1 C_2 R_{x2} / g_{\text{m}} D_1(s) \\
I_{\text{lp}} &= s \alpha \beta \gamma_1 C_1 R_{x1} / D_1(s) \\
I_p &= \alpha \beta \gamma_1 / D_1(s)
\end{align}
\text{where}
\begin{align}
D_1(s) &= s^2 \left( \gamma g_{\text{m}} R_{x0} + 1 \right) C_1 C_2 R_{x2} / g_{\text{m}} + \alpha \beta \gamma_1 C_1 R_{x1} + \alpha \beta \gamma_1
\end{align}

\text{The resonance angular frequency } \omega_0 \text{ and quality factor } Q \text{ can be expressed as:}
\begin{align}
\omega_0 &= \frac{\alpha \beta \gamma_1}{\sqrt{(\gamma g_{\text{m}} R_{x0} + 1) C_1 C_2 R_{x2} g_{\text{m}}}} \\
Q &= \frac{\gamma g_{\text{m}} R_{x0} + 1}{\alpha \beta C_1 C_2 R_{x2} g_{\text{m}}}
\end{align}

A sensitivity study forms an important index of the performance of any active network. The formal definition of sensitivity is
\begin{align}
S_y^f = \frac{x}{F} \frac{\partial F}{\partial x} \text{ (10)}
\end{align}

Where \( F \) represents one of \( \omega_0, Q \) and \( x \) represents any of the passive elements \( (g_{\text{m}}, R_X, C_1, C_2) \) or the active parameters \( (\alpha_1, \beta_1, \gamma_0, \gamma_1) \). Using the above definition, the active and passive sensitivities of the proposed circuit shown in Fig.4 are given as:
\begin{align}
S_y^{\omega_0} &= \frac{g_{\text{m}} R_{x0}}{2(g_{\text{m}} R_X + 1)} = \frac{1}{2} - \frac{1/2}{g_{\text{m}} R_X + 1}
\text{ (11)}
\end{align}

Thus
\begin{align}
-1/2 < S_y^{\omega_0} < 0
\end{align}

In the similar way, the other sensitivities of the proposed circuit satisfy:
\begin{align}
-1/2 < S_y^{\omega_0} < 0 \\
0 < S_y^{\omega_0, S_y^{\omega_0}} < 1/2
\end{align}

\begin{align}
S_y^{\omega_0} = S_y^{\omega_0} = S_y^{\omega_0} = S_y^{\omega_0} = S_y^{\omega_0} = S_y^{\omega_0} = S_y^{\omega_0} = S_y^{\omega_0} = S_y^{\omega_0} = 1/2
\text{ (13)}
\end{align}

The values demonstrate that the filter circuit enjoys very low sensitivities. It also proves that the sensitivities don’t depend upon the active and passive component values.

IV. HIGH ORDER FILTER REALIZATION

In order to realize the high-order filter, add lossless integrators using OTAs and CCCIIs. Note the first transconductance of OTA as \( g_{\text{m}0} \), the following as \( g_{\text{m}1}, g_{\text{m}2}, \ldots, g_{\text{m}n-1} \), note the first resistance of CCCIIs as \( R_{x0} \), the following as \( R_{x1}, R_{x2}, R_{x3}, \ldots R_{xK} \), respectively. For simplicity, assume the resistance of CCCIIs \( R_{x0} = 1/g_{\text{m}0} \), then all the resistances of active components is sign as \( 1/g_{\text{m}} \). The configuration of the circuit is shown as Fig.5.

The transfer function of low-pass, band-pass and all-pass are given as follow:
Figure 5. The high-order filter configuration.

\[
I_{\text{out1}} = I_{\text{ip}} = \frac{s^m (\prod_{i=1}^{n} \left( C_i g_m \right))}{D_i(s)}
\]

\[
I_{\text{out2}} = I_{\text{ip}} = \frac{1}{D_i(s)}
\]

\[
I_{\text{out3}} = I_{\text{ip}} = \frac{s^{\mu} (\prod_{i=1}^{n} \left( C_i g_m \right))}{D_i(s)}
\]

\[
D_i(s) = g_m R_x s^{\mu} \left( \prod_{i=1}^{n} \left( \frac{C_i g_m}{g_m} \right) + \sum_{j=1}^{n} \left( s^j \left( \prod_{i=1}^{n} \left( \frac{C_i g_m}{g_m} \right) \right) \right) + 1
\]

(16)

In the similar way, let \( g_m R_x \ll 1 \) in the simulation, \( D_i(s) \) is simplified to:

\[
D_i(s) = \sum_{j=1}^{n} \left( s^j \left( \prod_{i=1}^{n} \left( \frac{C_i g_m}{g_m} \right) \right) \right) + 1
\]

(17)

Thus the high-order filter can realize three basic transfer functions: high-pass, low-pass and band-pass in a configuration derived from the second-order filter.

V. SIMULATION RESULTS

The performance of the proposed circuit is sustain using the SPICE simulation program. The MOS transistors are simulation program. The MOS transistors are simulated using TSMC CMOS 0.35µm process model parameters. The CMOS implementation of a CCCII is shown in Fig.6 [2, 6], the aspect ratios of the transistors are given in Table.1. The bias voltages \( VDD=-VSS=1.85V \). The bias current \( I_B \) controls \( R_x \). For \( R_0 \), let \( I_B=150\mu A \), and for the other CCCII, including the high-order circuit, let \( I_{R2}=14.5\mu A \). The inner structure of the OTA is given in Fig.7 [10], and the aspect ratios of the transistors are given in Table.2. The bias voltages \( VDD=-VSS=1.85V \). The bias current \( I_B \) controls the transconductance \( g_m \). For \( g_m \), let \( I_B=3\mu A \), for the other OTAs, including the high-order circuit, let \( I_{R2}=212\mu A \).

![Image](https://example.com/image1)

TABLE I. ASPECT RATIOS OF THE MOS IN CCCII

<table>
<thead>
<tr>
<th>MOS transistors</th>
<th>W/L</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1-M2,M7-M10,M14,M15,M18,M19</td>
<td>10µm/2µ</td>
</tr>
<tr>
<td>M3-M6,M11-M13,M16,M17</td>
<td>10µm/1µ</td>
</tr>
</tbody>
</table>

To verify theoretical conclusion of the proposed network, the simulated results of second-order and fourth-order filter has shown in Fig.8 and Fig.9. In two figures, solid trace represent reality simulation, dashed trace represent for ideal simulation. As can be seen, low-pass, high-pass, band-pass and notch are closely agree between theory and simulation.
Besides, the resonance angular frequency $\omega_0$ can be tuned by bias current. Keep $Q=1$, let $I_{b1}=150\mu A$, $I_{b2}=3\mu A$, change the value of $I_{b2}$ and $I_{b1}$, as Table 3. And the simulated $\omega_0$ of the proposed second-order filter has also shown in the table. According to the simulation shown in the Fig.10, the tunable range of $\omega_0$ is from 0.7MHZ to 7MHz. In the same way, keep $\omega_0$ constant, let $I_{b1}=150\mu A$, $I_{b2}=3\mu A$, change the Q by tuning the bias current shown in Table 4. The simulated notch responses with Q-tuning are also given in Fig.11.

![Image](image.png)

**Figure 8.** Amplitude-frequency response of second-order filter with $f_n=5.29$MHz and $C=C=10$pf.

![Image](image.png)

**Figure 9.** Amplitude-frequency response of fourth-order filter with $f_n=3.56$MHz and $C=C=10$pf.

![Image](image.png)

**Figure 10.** Proposed notch response with varying $\omega_0$.

![Image](image.png)

**Figure 11.** Proposed notch response with varying Q.

**TABLE III.** Resonance Angular Frequency $\omega_0$ TUNED BY BIASE CURRENT

<table>
<thead>
<tr>
<th>$I_{b2}$ (µA)</th>
<th>$I_{b1}$ (µA)</th>
<th>Simulated $\omega_0$ (MHz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>29</td>
<td>425</td>
<td>0.95</td>
</tr>
<tr>
<td>7</td>
<td>106</td>
<td>1.82</td>
</tr>
<tr>
<td>1.7</td>
<td>26</td>
<td>3.65</td>
</tr>
<tr>
<td>0.4</td>
<td>6.5</td>
<td>6.46</td>
</tr>
</tbody>
</table>

**TABLE IV.** Quality Factor Q TUNED BY BIASE CURRENT

<table>
<thead>
<tr>
<th>$I_{b2}$ (µA)</th>
<th>$I_{b1}$ (µA)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7</td>
<td>435</td>
</tr>
<tr>
<td>14.5</td>
<td>212</td>
</tr>
<tr>
<td>29</td>
<td>106</td>
</tr>
<tr>
<td>58</td>
<td>53</td>
</tr>
</tbody>
</table>

**VI. CONCLUSION**

The new structure filter employing CCCH and OTA have advantages as follow:
1. It can feasibly expand to high-order filter.
2. The parameter $\omega_0$ can be tuned by changing component manually without effect to the Q.
3. The active and passive element sensitivities of the circuit are very low.
4. The universal filter can realize five basic functions of high-pass, low-pass, band-pass, notch and all-pass in a same configuration.

The circuit is suitable with VLSI technology because of no resistances have employed in the circuit.

**Reference**


Authors Profile:

1: AKHILESH KUMAR MAURYA

He has received the B.Tech. degree in Electronics and Instrumentation Engineering from Uma Nath Singh Institute of Engineering and Technology Jaunpur, in 2007. He is currently pursuing M.Tech degree in Electronics Circuit and System from Integral University Lucknow. Currently, he is working as Asst. Prof. in the dept. of E & I Engineering at BBDNITM, Lucknow.

2: DR. N.R. KIDWAI

He has received the B.Sc. Engineering (Electronics) from A.M.U Aligarh in 1996. He has received the MBA (part time) from Jamia Millia Islamia University, New Delhi in 1999. He has received the M.Tech (Digital Communication) from UPTU, Lucknow in 2006. He has received the Ph.D. from Integral University, Lucknow in 2014. Currently he is working as Associate Professor in ECE, Faculty of Engineering at Integral University, Lucknow.

3: SAROJ MANDAL

He has received the B.Tech. Degree in Electronics and Communication Engineering from Lumbini Engineering College, Pokhara University, Nepal, in 2006. He has received the M.Tech degree in Biomedical Engineering from MNNIT, Allahabad in 2010. Currently, he is working as Asst. Prof. in the dept. of Biomedical Engineering at BBDNIIT, Lucknow.