Low-component-count current-mode Universal Filter based on active-only Lossy and Lossless Integrators

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Abstract—An universal current-mode active-only filter using the biquadratic transfer function is proposed. The proposed circuit is realized by lossy and lossless integrators with minimize active components count without external passive elements. The different kinds of filter functions as lowpass, highpass, bandpass and band-reject response can be obtained without changing circuit topology. The proposed circuit implementation is realized by using MOS transistors, CMOS MO-OTAs, and CMOS OPAMPs. The parameters \( a_0 \) can be tuned electronically through adjusting the transconductance gains of the OTA or electronic resistor power supplies. The simulation results are given by PSpice.

Keywords: Active-only, Filter, Lossy integrator, Tunable

I. INTRODUCTION

The high performance analog filter is much attractive for presently design in current-mode approach. There are many benefits larger than a voltage-mode counterpart as well as simply to summation and subtraction of their nodes, no need impedance matching. The previous works have been presented the various current-mode filters. Current follower (CF) [1], Current conveyor (CCII) [2], Operational Transcon-ductance Amplifier: OTA [3] have been constructed as the current-mode filters but they used external passive element or grounded capacitor as well.

A biquadratic function transfer function is a well known method for realization of active filter. This multi-functions filter can be also obtained using this method. The open-loop gain bandwidth product (GBW) of OpAmp (OA) is familiar factor that is an operation bandwidth as an integrator. The OTA can be co-operated with OA for high frequency and suitable for further integration forms without passive components. Many papers introduced current-mode [5-7] and voltage-mode [8-9] but some performances have been limited and also many components needed. Consider the previous active-only current-mode filters [5-6] used 2 OAs and 3 OTAs, the frequency response has been non-linearity controlled. Another paper enjoys linear controlled for frequency response but many components, 2 OAs and 5 OTAs are needed.

This paper proposes a reduce components configuration of current-mode active-only filter based on a lossy and a lossless integrators loop. The 2 OAs and 2 MO-OTAs is used for a proposed circuit therefore, overall transistors are more reduced. The good benefits of electronically controlled and multi-function filters without changing circuit topology can be obtained.

II. THEORY AND PRINCIPLE

The biquadratic functions are familiar that related for the particular filter functions. The low-pass biquadratic function as shown Eq.(1) is used for an initial function for this paper.

\[
\frac{Y(s)}{X(s)} = \frac{a_0}{s^2 + sa_1 + a_0}
\]  

(1)

Rearrangement of Eq.(1) in term of integrators.

\[
Y(s) = \left( X(s) - Y(s) \right) \left( \frac{a_0}{s + a_1} \right) \cdot \frac{1}{s}
\]  

(2)

From Eq.(2), the block diagram can be written by a lossy and a lossless integrators as shown in Fig.1.

\[ \text{Fig.1 Lossy and Lossless integrators loop block diagram} \]

A. Proportional Circuit

Proportional or voltage-gain circuit [10] which used in this paper consists of an OTA and an electronic resistor as shown in Fig. 2. The transresistance of the electronic resistor circuit can be expressed in Eq.(3)
\[ R_{eq} = \frac{V_o}{I_{in}} = \frac{L}{2\mu C_{ox} W(V_{DD} - V_t)} \]  

(3)

D. Universal Current-mode Realization

The proposed filter is realized by using an above method in Fig.1-4 as shown in Fig. 5. The various transfer functions are illustrated in Eq. (7) –(10).

\[ T_{LP} = \frac{i_{LP}}{i_{in}} = \frac{R_{eq} R_{o2} B_1 B_2 g_1 g_2}{D(s)} \]  

(7)

\[ T_{BP} = \frac{i_{BP}}{i_{in}} = \frac{s R_{eq} B_1 B_2 g_2}{D(s)} \]  

(8)

Other filter can be provided by summation of above functions as follows.

\[ T_{HP} = 1 - T_{LP} - T_{BP} = \frac{i_{HP}}{i_{in}} = \frac{s^2}{D(s)} \]  

(9)

and

\[ T_{BR} = 1 - T_{LP} - T_{BP} = \frac{i_{BR}}{i_{in}} = \frac{s^2 + R_{eq} R_{o2} B_1 B_2 g_2}{D(s)} \]  

(10)

where \( D(s) = s^2 + s R_{eq} B_2 g_2 + R_{eq} B_1 B_2 g_1 g_2 \), the parameters \( \omega_p \) and \( Q_p \) can be obtained as

\[ \omega_p = \sqrt{\frac{R_{eq} R_{o2} B_1 B_2 g_1 g_2}{R_{eq} B_2 g_2}} \]  

(11)

and

\[ Q_p = \frac{R_{eq} B_1 g_1}{\sqrt{R_{eq} B_2 g_2}} \]  

(12)

The parameters \( g_i \) represents for the transconductance of OTAs and \( R_{eq} \) represents for the electronic resistors. Generally, the electronic resistors are equalled (\( Q_p = 1 \)) and \( B_i \) is an OA open-loop gain-bandwidth. From (11), the \( \omega_p \) can be electronically controlled by setting of open-loop gain-bandwidth to be equalled. Therefore, the frequency response can be linearly tuned through the transconductance gain of OTAs by using identical of both OTAs.

III. SENSITIVITY

The other filter performances can be considered by its sensitivities. The performance with respect to active
elements according with the frequency response $S_{xy}^{op}$ and quality factor $Q_x$, while $x$ is active elements. The achieved sensitivities can be listed in Table I.

<table>
<thead>
<tr>
<th>Table I: Sensitivity of Active Components</th>
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<tr>
<td>$x$</td>
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<tr>
<td>---</td>
</tr>
<tr>
<td>$g_1$</td>
</tr>
<tr>
<td>$g_2$</td>
</tr>
<tr>
<td>$R_{eq1}$</td>
</tr>
<tr>
<td>$R_{eq2}$</td>
</tr>
<tr>
<td>$B_1$</td>
</tr>
<tr>
<td>$B_2$</td>
</tr>
</tbody>
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Low-component count can be confirmed based on the same simple structure of OTA and OA as shown in Fig.6 and Fig.7. The numbers of devices of proposed circuit compared with numerous recent works are illustrated in Table IV.

<table>
<thead>
<tr>
<th>Table IV: Numbers of Devices Comparison</th>
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<tbody>
<tr>
<td>Filter</td>
</tr>
<tr>
<td>-----</td>
</tr>
<tr>
<td>[6]</td>
</tr>
<tr>
<td>[7]</td>
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<tr>
<td>[8]</td>
</tr>
<tr>
<td>Proposed</td>
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III. Non-Ideal Analysis

In this section, the non-idealities effects of the OAs on the transfer function of the proposed multifunction filter are discussed. Considering the parasitic pole of OA, the open loop gain $A(s)$ can be assumed as

$$A(s) = \frac{B_s}{s + \omega_p}; \quad (i=1, 2)$$

Where $\omega_p$ denote the second pole of OA and $\tau = 1/\omega_p$. In the frequency range $\omega < \omega_p$ of our interest, $A(s)$ is assumed to be

$$A(s) = \frac{B_i}{s} (1 - \tau, s)$$

Using Eq. (14) and reanalysis of the proposed circuit gives the following functions:

$$D_i(s) \equiv s^2[1 - g_2 R_{eq} B_2 \tau + g_1 g_2 R_{eq} R_{eq1} B_2 \tau_2] + g_1 g_2 R_{eq} R_{eq1} B_1$$

Using Eq. (14) and reanalysis of the proposed circuit gives the following functions:

$$T_{ipm}(s) \equiv g_2 g_1 R_{eq} R_{eq1} B_2 B_1 [s^2 \tau_1 \tau_2 - s(\tau_1 + \tau_2) + 1]$$

It can be seen that due to the parasitic effects. The parasitic poles are not disturbed to the frequency response of proposed filter but the small affected of quality factor $(Q_{pm})$ can be observed. Undesirable factors are yielding in the transfer functions of the filter. From (15)-(19), it is found that such factors can be made negligible by satisfying the following conditions for the circuit.

Where $\tau = 1/\omega_p$ of the $i$th OA. From Eq. (15), the parameters of the non-ideal multifunction filters are expressed as

$$\omega_p \equiv \sqrt{g_1 g_2 R_{eq} R_{eq1} B_1 B_2}$$

$$Q_{pm} \equiv \frac{1}{g_2 R_{eq} B_2 [1 - g_1 g_2 R_{eq} B_1 \tau_2]}$$
\[
\left( g_2 R_{eq} B_2 \tau_2 + g_1 g_2 R_{eq} R_{eq} B_1 B_2 \tau_1 \tau_2 \right) << 1 \\
g_2 g_2 R_{eq} R_{eq} B_1 \left( \tau_1 + \tau_2 \right) << \left( g_2 R_{eq} B_2 \right)
\]  

(22)

IV. SIMULATION RESULTS

The proposed universal current-mode active-only filter can be confirmed its performances and characteristic by PSpice. The TSMC MOSIS 0.25μm level3 model has been employed. The implementations of CMOS OAs, CMOS MO-OTA and their aspect ratio with ±1.5 volts power supplies are illustrated in Fig.6, Fig.7 and listed in Table II, III, respectively. Electronic resistors are used the same aspect ratio (W/L=2μm/1μm).

The electronically controlled of \( \omega_p \) can be done by two methods; varied bias current \( I_b \) of both OTAs and changing power supply of electronic resistors \( V_{DDR} \). Firstly method, Fig.8 and Fig.9 show a tunable frequency response characteristic by bias current of OTA while varied \( I_b \) of 1μA and 100μA with \( V_{DDR} \) is keeping in constant at ±1V. Achieved tunable frequency response respectively about 260 kHz and 5.5 MHz can be observed.

Secondly method, Fig.10 shows a frequency response characteristic of tuning by electronic resistor while varied \( V_{DDR} \) of ±3V with \( I_b \) is keeping in constant at 100μA. The frequency response is reduced to 3MHz compared with first method in Fig.9.

For BRF phase response by setting of \( I_b = 80μA \) and \( V_{DDR} = ±3volts \) is resulting in Fig.11 with 1MHz frequency cut-off. In order to achieve all-pass characteristic, it is easily obtained by current subtraction between Eq.(10) and Eq.(8), \( T_{AP} = T_{BR} - T_{BR} \). The all-pass function can be expressed as

\[
T_{AP} = \frac{i_{AP}}{i_n} = \frac{s^2 - s R_{eq} B_2 G_2 + R_{eq} R_{eq} B_1 B_2 G_2 G_2}{D(s)}
\]

(23)

Magnitude and phase response of proposed all-pass filter can be confirmed based on biased current of OTAs.
and the voltage supplies of electronic resistors are ±3 volts. Fig.13 shows magnitude and phase response of all-pass filters. The low-power dissipation of proposed circuit at maximum frequency of 5.5MHz is 66.1mW.

V. CONCLUSION

This paper presents an low-component count active-only current-mode universal filter without external passive elements. The pole frequency is given by GBW product of OAs. The proposed circuit is based on 2 type integrators loop topology and a minimized number of component counts. It uses only 2 OAs, 2 OTAs and 4 MOS transistors. The $\omega_0$ can be electronically tuned through the transconductance gain. The high-frequency can be applied and also suitable for further ICs technology. The electronically tunable of $Q_0$ method is also proposed through the transconductance ratio of 2 OTAs without any effect to $\omega_0$. The multifunction filters can be obtained by proposed filter without any change of the topology.

REFERENCES