Realization of CMOS OTAs Current Mode Universal Filter Based on Lossless Differentiator Circuits

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Abstract—This paper presents a realization of CMOS OTAs current-mode universal filter based on lossless differentiator circuits by which the obtained result still achieves the advantages obtained by employing CMOS OTAs and two grounded capacitors. The proposed filter consists of three inputs and single output, where either one of five filtering transfer functions (LPF, HPF, BPF, BRF, APF) can be achieved by the proposed structure. In addition, parameters orthogonally with frequency response (\(Q_p\)) of quality factor (\(Q_p\)) can be also electronically tuned. Characteristics of the proposed filter are simulated using PSpice and its results are in agreement with the theory.

Keyword: CMOS OTA, Universal Filter, Differentiator

I. INTRODUCTION

In currently analog signal processing area, current mode analog filters are rapidly developed which have more advantages than voltage mode counterpart. Recent current mode filters have been reported which are preferred to use several active devices such as Current Follower (CF), Second Generation Current Conveyor (CCII) and Operational Transconductance Amplifier (OTA) [1-3].

Biquadratic transfer function is widely used in order to realize the filters. Many kinds of filter can be realized based on only integrators building blocks. [4-10]. However, integrator circuit performs as a low-pass filter. In high frequency, stage gain of integrator is decreased due to component bandwidth and integrator characteristic. In order to realize a filter, magnitude response of filter in high-frequency would be unstable according to the mention characteristic. Differentiator circuit performs as high-pass filter that compensated with component bandwidth for stabilized of magnitude response in high frequency.

This paper presents an analysis and design of biquadratic filter based on differentiator realization. Basic MO-OTAs and grounded capacitors are mainly components which pave a way to further integrated circuit production. Low-pass function is supposed and raised up to initial the filter synthesis. Current-mode five types of basic second-order filter functions are obtained by the same topology. Multiple inputs and single output is obtained with its electronically tuning of quality factor (\(Q_p\)) is independent of frequency response (\(\omega_p\)).

II. GENERAL PRINCIPLE

A) Biquadratic LPF Function

Biquadratic equation in term of low-pass filter can be expressed as

\[
\frac{B(s)}{A(s)} = \frac{xy}{s^2 + sy + xy}
\]

Rearrangement Eq.(1) differentiator forming of Eq.(1) becomes

\[
B(s) = A(s) - \frac{B(s)x^2}{xy} - \frac{s}{y}
\]

It consists of two differentiators, a proportional block and a summing function. The block diagram of Eq.(2) can generally be described in Fig.1.

Fig.1 LPF Function Based on Differentiator Block

III. BASIC CMOS MULTIPLE OUTPUTS OTA CIRCUIT

Fig.2 Basic CMOS Multiple Outputs OTA Circuit
B) CMOS Multiple Outputs OTA

A simple CMOS (Multiple Outputs OTA: MO-OTA) [10] as shown in Fig.2 is a versatile device that given multiple plus/minus output currents while applying a differential voltage input. The output current and differential input relation named the transconductance is given by

\[ \pm \frac{I_o}{V_{in}} = g_m = \sqrt\left(\mu_0 C_{ox} W/L\right) \]

From Eq.(1), where \( \mu_0, C_{ox}, W \) and \( L \) represent for surface mobility, oxide capacitance, channel width and length of MOS transistor, respectively. Consequently, \( g_m \) can be tuned electronically by current biased \( (I_b) \)

III. CIRCUIT DESCRIPTION

A) OTA-C Differentiator Circuit

Considering the principle block diagram in Fig.1 the lossless differentiator block needs to realization which preferred to use MO-OTA and grounded capacitor. The realization of OTA based lossless differentiator is depicted in Fig.3 and its equation is expressed in Eq.(4)

\[ I_o = \frac{sC}{g_m} \]

Fig.3 MO-OTA Based on Lossless Differentiator Circuit

B) Current Mode Universal Filter

From block diagram Fig. 1 and lossless differentiator Fig.3, current-mode biquadratic filter is constructed as shown in Fig.4. It can be seen that \( g_m3 \) is disappeared in Eq.(5) because it is prior cancelled from Eq.(4)

\[ I_{in} \cdot I_{in} = \frac{g_{m0} + g_{m2} S_{m0} + g_{m4} S_{m4}}{g_{m0} + g_{m2} S_{m2} + g_{m4} S_{m4}} \]

where \( D(s) = s^2 + \frac{g_{m0} g_{m2}}{g_{m2} C_2} + \frac{g_{m0} g_{m4}}{g_{m4} C_2} \)

which compared to the standard biquadratic equations in Eq.(6) then the parameters are found to be

\[ D(s) = s^2 + \frac{g_{m0} g_{m2}}{g_{m2} C_2} + \frac{g_{m0} g_{m4}}{g_{m4} C_2} \]

From Eq.(5), it can be seen that five types of filter function can be obtained by applying appropriated inputs by following conditions:

- Low-pass filter (LPF), \( I_{in1}=I_{in2}=0 \) and \( I_{in3}=I_{in} \)
- Band-pass filter (BPF), \( I_{in1}=I_{in2}=0 \) and \( I_{in3}=I_{in} \)
- High-pass filter (HPF), \( I_{in2}=I_{in1}=0 \) and \( I_{in3}=I_{in} \)
- Band-reject filter (BRF), \( I_{in3}=0 \) and \( I_{in1}=I_{in2}=I_{in} \)
- All-pass filter (APF), \( I_{in1}=I_{in2}=I_{in3}=I_{in} \)

IV. CIRCUIT SENSITIVITY

Sensitivity of filter is an important parameter for evaluate its performance. Passive and active components sensitivities with respect to frequency cut-off (\( S_{\omega P} \)) and quality factor (\( S_{Q P} \)) are considered which can be expressed in Eq.(9)-(12)

\[ S_{\omega P} = S_{Q P} = 0 \]

V. NON-IDEAL ANALYSIS

In this section we discuss the effects of non-idealities of the OTA-C on the transfer function of the proposed multifunction filter. The schematic and symbol of a basic OTA are shown in Fig.2. The characterization of the OTA plays an important role when dealing with a wide frequency range of operation. An OTA macromodel is desirable to facilitate filter performance characterization.
A simple practical small signal OTA macromodel is shown in Fig.5.

\[ D_s(s) = s^2 \left(1 - \frac{g_m}{C} s + \frac{g_m^2}{C^2} s^2 \right) + s \left(\frac{g_m}{C} - 2 r \frac{g_m}{C} \right) + \frac{g_m^2}{C^2} \tag{20} \]

\[ T_{ip}(s) = \frac{\frac{g_m}{C} \left(1 - 2 r s + s^2 r^2 \right)}{D_s(s)} \tag{21} \]

\[ T_{op}(s) = \frac{s^2 + \frac{g_m}{C} \left(s^2 r - s + 2r + 1 \right)}{D_s(s)} \tag{22} \]

From Eq.(20)-(22), it found that parameters \((\omega_{po})\) does not affected from parasitic poles but \((Q_{po})\) received small affected from parasitic poles in high frequency as described in Eq.(23) and (24).

\[ \omega_{po} = \frac{g_m}{C} \tag{23} \]

\[ Q_{po} = \left(\frac{g_m}{g_m} \frac{s^2 r - s + 2r + 1}{s^2 r + s \left(r + r_0 \right) + 1}\right) \tag{24} \]

VI. SIMULATION RESULTS

Proposed CMOS OTA universal filter is simulated by PSpice. MO-OTA uses MOSIS TSMC 0.25 \mu m model with \( \pm 1.2V \) power supplies. The transistor aspect ratios are listed in Table.1

<table>
<thead>
<tr>
<th>Transistor W(\mu m)</th>
<th>L(\mu m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1, M2, M3, M4, M5, M6, M7</td>
<td>5 1</td>
</tr>
<tr>
<td>M8, M9</td>
<td>5.5 1</td>
</tr>
<tr>
<td>M10-M12</td>
<td>3 1</td>
</tr>
</tbody>
</table>

Filter characteristics are exhibited in Fig.6 and Fig.7 for confirm the electronically tunable of natural frequency \((\omega_0)\). The capacitors \(C_1\) and \(C_2\) are supposed of 10pF while varied the biased current \((I_b)\) at 1\uA and 100\uA. Frequency response are respectively illustrated around 200kHz and 4.5MHz.
BPF and BRF results are shown in Fig.8 and Fig.9 for confirm the adjusting of quality factor \((Q_p)\) is independent with frequency cut-off \((\omega_p)\). Biased current \((I_B)\) and capacitors \((C_1=C_2)\) are respectively supposed at 100\(\mu\)A and 0.46nF. It found that the adjusting of \((Q_p)\) can be tuned by \((I_B)\) without any effects to \((\omega_p)\).

Form Fig.10 shows an all-pass response at 1MHz which is obviously seen that low-magnitude fluctuation at center frequency. Fig.11 shows the plots of frequency response against varied \((I_B)\) and \(C\). They are totally in agreement with the theoretical.

**REFERENCES**


