Abstract— An active-only devices current-mode universal filter using the biquadratic transfer function is proposed. The proposed circuit is realized focusing on the minimized active-only components count without external passive elements. The different kinds of filter function as low-pass, high-pass, band-pass and band-reject response can be obtained without changing circuit topology. The proposed circuit is realized by using 4 MOS transistors, 2 OTAs, and 2 OPAMPs. The parameters can be electronically tuned by simply adjusting the transconductance gains of the OTAs or supply voltage of electronic resistors. The Qp can be tuned in both concepts, changing of their components and the transconductance gain. The simulation results are given by PSpice.

I. INTRODUCTION

The high performance active filters have been received much attention. In filter circuit design, current-mode filters are becoming popular, since they have many advantages compared with their voltage-mode counterparts. Design of current-mode filters employing active devices such as current followers (CFs) [1], second generation current conveyors (CCIIs) [2] and operational transconductance amplifiers (OTAs) [3,4]. The transfer function biquadratic filter is a basic principle for synthesized filter circuit to obtain efficiency especially universal filter, and the principle for auxiliary create to filter with integrator based on a synthesized [13]. The open-loop gain of operational amplifier, OA is known well in term of Gain-Bandwidth, GBW. While to obtain using OTA, therefore can be implemented by filter circuit. The same with a high frequency and they have been introduced in the literatures. The current-mode operations were proposed in recent literatures [5-7]. The voltage-mode operations were proposed in recent literatures [8-9]. Although, many active elements are employed but they have very advantages in high-frequency and further integration.

This paper focuses on the synthesized of universal filter using active-only devices. The proposed circuit is realized by using MOS transistors, OAs, and OTAs. The objective on the design is current-mode of evaluation based on biquadratic function using only active elements without any external passive elements in recent literatures [5-9]. The minimization of active elements and electronically is tunable a core of this paper.

Consider in previous of current-mode active-only filter in recent literatures [5-6], which using 2 OAs and 3 OTAs. The ωp is tuned by an OTA which in term of square-root function. The linear controlled can not be achieved and complicate in the practical. Another filter [7], the ωp is tuned with linear controlled has been achieved but the many components are used, 2 OAs, 5 OTAs, that is not suitable for the compactness ICs fabrication. This paper proposed only using 2 OAs, 2 OTAs and 4 MOS transistors for circuit implementation. The achieved circuit can be electronically tuned by either transconductance gains of OTA and electronic resistor for the ωp parameter. The proposed circuit can be also physically and electronically tuned by changing of transistor aspect ratio for Qp parameter without effect to the ωp parameter.

II. THEORY AND PRINCIPLE

The 2 integrators-loop principles have been introduced in recent literatures [12]. The block diagram has been shown in Fig.1 and transfer function can be expressed in (1) as follows

$$\frac{V_2(s)}{V_1(s)} = \frac{sB_2}{s^2 + sB_2k_1 + B_1B_2k_0}$$

The comparison of (1) and characteristic equation (2)

$$D(s) = s^2 + s\frac{\omega_p}{Q_p} + \omega_p^2$$

The parameters ωp and Qp can be expressed as

$$\omega_p = \sqrt{B_1B_2k_0} \quad \text{and} \quad Q_p = \frac{1}{k_1} \sqrt{\frac{B_1B_2k_0}{B_2}}$$

A. Voltage-Gain Circuit

The voltage-gain circuit [10] which used in this paper consists of an OTA and an electronic resistor as show in Fig.2. The transresistance of the electronic resistor circuit can be expressed in (4)
The voltage gain of Fig.2 can be obtained to

\[ \frac{V_O}{V_{in}} = g_m R_{eq} \]  

(5)

**B. Opamp as a lossless integrator**

Consider the open-loop GBW of OA [6], as shown in Fig.3 can be expressed the transfer function as a lossless integrator as (6)

\[ A(s) = \frac{B_i}{s} \quad (i=1, 2) \]  

(6)

**C. Current-mode Universal Filter Realization**

The proposed filter are realized by using the above methods as shown in Fig.4

![Fig.2 The voltage-gain circuit [10]](image)

![Fig.4-1 The first implementation of proposed current-mode universal filter](image)

Fig.3 The OA and frequency response, \( \omega_P \)

![Fig.4-2 The second implementation of proposed current-mode universal filter](image)

From Fig.4-1and 4-2, the different transfer functions are illustrated in (7) – (10)

\[
\frac{I_{LP}}{I_{in}} = \frac{R_{eq} R_{eq2} B_1 B_2 g_1 g_2}{D(s)} \\
\frac{I_{HP}}{I_{in}} = \frac{s^2}{D(s)} \\
\frac{I_{RR}}{I_{in}} = \frac{s^2 + R_{eq} R_{eq2} B_1 B_2 g_1 g_2}{D(s)} \\
\frac{I_{BPa}}{I_{in}} = \frac{sR_{eq} B_2 g_2}{D(s)}; \text{ for Fig.4-1 (10a)} \\
\frac{I_{BPb}}{I_{in}} = \frac{sR_{eq} B_1 g_1}{D(s)}; \text{ for Fig.4-2 (11b)}
\]

where \( D(s) = s^2 + sR_{eq2} B_2 g_2 + R_{eq} R_{eq2} B_1 B_2 g_1 g_2 \) (11a) and \( D(s) = s^2 + sR_{eq2} B_1 g_1 + R_{eq} R_{eq2} B_1 B_2 g_1 g_2 \) (13b)

Eq.(11a) and (11b) are obtained for Fig.4-1 and 4-2, respectively. The concerning parameters \( \omega_P \) and \( Q_P \) are become

\[
\omega_P = \sqrt{R_{eq} R_{eq2} B_1 B_2 g_1 g_2} \\
Q_{Pa} = \frac{R_{eq} B_1 g_1}{\sqrt{R_{eq2} B_1 g_2}}; \text{ for Fig.4-1 (13a)}
\]

and \( Q_{Ph} = \frac{R_{eq} B_2 g_2}{\sqrt{R_{eq2} B_2 g_1}}; \text{ for Fig.4-2 (13b)} \)

The parameter \( g_i \) represents for the transconductance of OTA \((i)\) and \( R_{eq} \) represents for the electronic resistors \((i)\) Generally, \( B_i \) is OAs open-loop GBW, are identical suppose that \( B_1=B_2=B \), the quality factor is unity \((Q=1)\). From (12) and (13), the \( \omega_P \) can be electronically tuned by giving simply parameters as \( g_1 = g_2 = g \) and \( R_{eq} = R_{eq2} = R_{eq} \). From (12), The frequency response parameter can be will become is also obtained \( \omega_P = R_{eq} B g \).
Therefore, the frequency response can be linearly tuned by 2 approaches, through the transconductance gain of OTA or the electronic resistors from (4) and (13). The parameter \( Q_P \) is distinguished for flexible to adjust in electronically and physically.

For \( Q_P > 1 \), first method the physically tuned can be obtained by ratio adjusting of \((R_{eq1}, R_{eq2})\) while \((g_1 = g_2 = g)\), another method can be tuned by the transconductance gain \( g_1 \) and \( g_2 \) while \((R_{eq1} = R_{eq2} = R_q)\). However, \( Q_P \) achievement by ratio adjusting of \((R_{eq1}, R_{eq2})\) or \((g_1, g_2)\) have to perform in the properly rule otherwise that may effect to the \( \omega_P \). The properly adjusting rule of \((g_1, g_2)\) is described below

\[
g_1g_2 = A \quad \text{or} \quad g_1 = \frac{A}{g_2} \tag{14}
\]

From (13), the parameters are given as \((R_{eq1} = R_{eq2})\) and \((B_1 = B_2)\). The parameter \( Q_P \) in (13) can be obtained by setting of \( g_1 \) and \( g_2 \) as follows

\[
Q_{PA} = \frac{g_1}{\sqrt{A/g_1}} = \frac{g_1}{\sqrt{A}} \quad g_2 \tag{15a}
\]

\[
Q_{PB} = \frac{\sqrt{A/g_1}}{g_2} = \frac{\sqrt{A}}{g_2} \tag{15b}
\]

### III. Sensitivity

The other filter performances can be considered by its sensitivities. The performance with respect to active elements according to the frequency response \( S^A_{\text{op}} \) and quality factor \( S^Q_{\text{op}} \), while \( x \) is active elements. The achieved sensitivities can be as follows: \( S^A_{g_1, g_2, R_{eq1}, R_{eq2}, B_1, B_2} \) and \( S^Q_{g_1, g_2, R_{eq1}, B_1} \) are 0.5 and \( S^Q_{g_1, g_2, R_{eq1}, B_1} = -0.5 \), respectively.

![Fig.5 Proposed filter characteristic while power supply of \( R_q \) are ± 5 Volt](image)

### IV. Simulation Results

The proposed universal filter can be confirmed its performances and characteristics by PSpice. The T14Y MOSIS 0.25 \( \mu \)m CMOS model has been employed, \( V_{DD} = 0.42 \) volts and \( \mu cC_{ox} = 250.1048 \mu A/V^2 \) for the electronic resistors. The OA and OTA use the macro model [11] of LF351 and CA3080, respectively. The \( ± 5 \) volts power supply is used for the electronic resistors. The transistor aspect ratio \((W/L)\) used for electronic resistors \((R_{eq1}, R_{eq2})\) are defined for the \( Q_P \) adjustment according to (4) and (13).

The electronically controlled \( \omega_P \) can be confirmed by adjusting power supply of \( R_q \) shows in Fig.5 and Fig.6. The characteristics of universal filter as shows in Fig.4 with \( Q_P = 1 \). The following equipment parameters can be defined \((W/L) \) = \((1 \mu m/1 \mu m)\) for the electronic resistors \( R_{eq1} = R_{eq2} = 2.63 \text{ k}\Omega \), open-loop GBW of OAs are about \((4 \text{ MHz})\) or \( B_1 = B_2 = 25.37 \times 10^6 \text{ rad/s}\), power supply of \( R_q \) are \( ± 5 \) volts and \( ± 1 \) volts, respectively. The frequency response \( \omega_P \) are shown about \( 100 \text{ kHz} \) and \( 220 \text{ kHz} \). The electronically controlled \( \omega_P \) by adjusting the supply voltage of electronic resistors or transconductance gain 2 OTAs are confirmed according to the theory above.

### Table I. The Different \( Q_P \) Adjusted by \( R_{eq1}, R_{eq2} \) and \( g_1, g_2 \)

<table>
<thead>
<tr>
<th>( Q_P )</th>
<th>( R_{eq1} ) (W/L)</th>
<th>( R_{eq2} ) (W/L)</th>
<th>( g_1 = g_2 = 9.42 \mu )s/1.0 ( \mu m )</th>
<th>( R_{eq1}=R_{eq2}=(1 \mu m/1 \mu m) )</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>((1 \mu m/1 \mu m))</td>
<td>((1 \mu m/1 \mu m))</td>
<td>9.42 ( \mu )s</td>
<td>9.42 ( \mu )s</td>
</tr>
<tr>
<td>2</td>
<td>((2 \mu m/1 \mu m))</td>
<td>((5 \mu m/1 \mu m))</td>
<td>18.84 ( \mu )s</td>
<td>4.71 ( \mu )s</td>
</tr>
<tr>
<td>4</td>
<td>((4 \mu m/1 \mu m))</td>
<td>((25 \mu m/1 \mu m))</td>
<td>37.68 ( \mu )s</td>
<td>2.35 ( \mu )s</td>
</tr>
<tr>
<td>8</td>
<td>((8 \mu m/1 \mu m))</td>
<td>((12 \mu m/1 \mu m))</td>
<td>75.36 ( \mu )s</td>
<td>1.17 ( \mu )s</td>
</tr>
<tr>
<td>16</td>
<td>((16 \mu m/1 \mu m))</td>
<td>((60 \mu m/1 \mu m))</td>
<td>150.7 ( \mu )s</td>
<td>0.59 ( \mu )s</td>
</tr>
</tbody>
</table>
Consider (15), the adjusting of \( Q_\phi \) without effect to \( \omega_p \) by simulation results of universal filter. The \( \omega_p \) is defined at 100kHz while \( Q_\phi \) is varied as 1, 2, 4, 8 and 16, respectively. Firstly, The parameters \((g_1, g_2, g)\) are defined. The adjustment resistor \( R_{eq1} \) and \( R_{eq2} \) can be adjusting of by \((W/L)\) as table I. The secondly method is based on the setting of \((R_{eq1} = R_{eq2} = R_{eq})\) and transconductance gain of OTA, \( g_1, g_2 \) are adjusted electronically according to table I.

The simulation results in term of BPF and BRF with the different \( Q_\phi \) in table I, are shown in Fig.7 and 8 respectively. The adjusting parameter \( Q_\phi \) without effect to its \( \omega_p \) can be observed. The frequency response when \( Q_\phi \) increased has a few errors because the error of electronic resistor that is a channel length modulation effects: \( \lambda \) \((\lambda = 1\mu m)\). The \( \omega_p \) and its magnitude are quite stable while \( Q_\phi \) is varied according to the theory above.

\[
\begin{align*}
\text{Gain (dB)} & \quad 100kHz \quad 300kHz \\
\text{3kHz} & \quad Q_\phi = 1 \times Q_\phi = 2 \times Q_\phi = 4 \times Q_\phi = 8 \times Q_\phi = 16
\end{align*}
\]

Fig.7 Proposed BPF output with varying \( Q_\phi \) by 1-16

\[
\begin{align*}
\text{Gain (dB)} & \quad 100kHz \quad 300kHz \\
\text{3kHz} & \quad Q_\phi = 1 \times Q_\phi = 2 \times Q_\phi = 4 \times Q_\phi = 8 \times Q_\phi = 16
\end{align*}
\]

Fig.8 Proposed BRF output with varying \( Q_\phi \) by 1-16

V. Conclusion

This paper described a minimum active-only devices current-mode universal filter without external passive elements. In this paper, the high-frequency applications and further ICs technology are suitable. The proposed filter realization is operated based on 2 integrators-loop principles.

The \( \omega_p \) can be electronically tuned through the transconductance or supply of devices. The proposed circuit comprised 2 OTAs, 2 OAs, and 4 MOS transistors that met the minimum devices target. The pole frequency response is given by open-loop GBW of OA corporated with the transconductance gain. The adjustable \( Q_\phi \) can be obtained without effect to \( \omega_p \).

REFERENCES