Abstract

A novel circuit configuration for the realization of the single-input and three-output (SITO) current-mode biquadratic filters employing only three multiple-output OMAs is presented. The proposed circuit can simultaneously realize lowpass, bandpass and highpass filter functions at three high-impedance outputs without changing the circuit configuration and elements. Moreover, the resultant current-mode filter provides low passive and active sensitivities, uses of only grounded passive elements and can be orthogonal tuned of the parameters $\omega_0$ and $Q$-factor.

1. Introduction

Owing to the usefulness and advantages of operational mirrored amplifiers (OMAs) and four-terminal floatingnullors (FTFNs) over current conveyors (CCs) [1-4], there has been great emphasis in the design and implementation of analog signal processing circuits using OMAs and FTFNs as active elements. In the recent past, several techniques for realizing floating immittances and current-mode filters using OMAs and FTFNs have been described by various authors [1-2, 5-8]. One of these filters known as a current-mode single-input and three-output (SITO) type multifunction filter which offers particularly attractive features, such as, simultaneously realizes lowpass (LP), bandpass (BP) and highpass (HP) filter characteristics without changing the circuit configuration and elements, provides high-impedance current outputs [9-12]. Only SITO current-mode biquadratic filter that obtains the mentioned advantages using OMAs as active elements has been recently presented [12]. However, it requires four OMAs, floating passive elements and, more importantly it parameters $\omega_0$ and $Q$-factor are interdependent. The major goal of this paper is to present the SITO current-mode biquadratic filter employing only three multiple-output OMAs with all grounded elements. The number of active elements proposed here is less than that required by the previous SITO filter proposed in reference [12], when the filter provides three high output impedance current output. The proposed filter realizes three current transfer functions simultaneously and all passive and active sensitivities are quite low. Moreover, it offers the attractive feature of independent grounded-element control of the parameters $\omega_0$ and $Q$-factor.

2. Proposed Configuration

2.1 Operational Mirrored Amplifiers (OMAs)

Fig.1 shows the circuit implementation and representation of the operational mirrored amplifiers (OMAs). The negative OMA (OMA-), comprising an opamp and two pairs of current mirrors as
shown in Fig.1(a), is a more general and flexible device owing to it can be equivalent to an ideal nullor or FTFN [3,13]. Whereas the other type of OMA which requires only one pairs of current mirrors is named the positive OMA (OMA+) and is shown in Fig.1 (b). Therefore, it can be concluded from the Fig.1 that the port characteristics of the OMA can be characterized as:

\[
v_2 = v_1, \quad i_1 = i_2 = 0 \quad \text{and} \quad i_4 = i_3 \quad (1)
\]

2.2 Multiple-Output OMAs

For realizing the multiple-output OMA, it can easily be modified from the conventional OMA realization of the Fig.1 by adding n-output current mirror terminals as shown in Fig.2. Thus, the resulting building blocks become the multiple-output OMAs, which can be described by the following port relations:

\[
v_2 = v_1, \quad i_1 = i_2 = 0 \quad \text{and} \quad i_n = ... = i_j = i_j \quad (2)
\]
2.3 Proposed SITO Current-Mode Filter

Fig. 3 shows the proposed current-mode filter with single-input and three-output terminals using three multiple-output OMAs, four grounded-resistors and two grounded-capacitors. According to the port relations of the multiple-output OMA from equation (2), a elementary circuit analysis shows that the current transfer functions of this circuit can be expressed as:

\[
\begin{align*}
T_{HP}(s) & = \frac{I_{o1}(s)}{I_{o}(s)} = \frac{R_1}{R_{4}} \\
T_{BP}(s) & = \frac{I_{o2}(s)}{I_{o}(s)} = -\frac{R_2 R_1}{R_4} \frac{1}{D(s)} \\
T_{LP}(s) & = \frac{I_{o3}(s)}{I_{o}(s)} = -\frac{R_3}{R_1 R_2 R_4 C_1 C_2} \frac{1}{D(s)}
\end{align*}
\]

where \(D(s) = s^2 + \frac{R_1}{R_1 R_4 C_1} + \frac{R_3}{R_1 R_2 R_4 C_1 C_2}\)

The equations (3) to (5) show that this filter can realize the highpass \(THP(s)\), bandpass \(TBP(s)\), and lowpass \(TLP(s)\), current transfer functions simultaneously without changing the circuit configuration and elements. Moreover, it can also provide a high-impedance output port that is suitable for cascadable systems and it contains only grounded elements. Noting that the advantage for filters that employ grounded capacitors is the ease of the integrated circuit implementation [14]

The natural angular frequency \(\omega_0\) and the \(Q\)-factor of this configuration can be given by:

\[
\omega_0 = \frac{R_1}{\sqrt{R_1 R_2 R_4 C_1 C_2}} \quad (6)
\]

and

\[
Q = \left(\frac{R_1 R_2 C_1}{R_2 R_4 C_2}\right)^{-1/2} \quad (7)
\]

Then the passive sensitivities of \(\omega_0\) and \(Q\)-factor are

\[
S_{\omega_0}^R = S_{\omega_0}^C = -S_{\omega_0}^R - S_{\omega_0}^C - S_{\omega_0}^C = -S_{\omega_0}^C = -\frac{1}{2} \quad (8)
\]

\[
S_Q^R = -S_Q^C = S_Q^R = S_Q^C = S_Q^C = \frac{1}{2} \quad (9)
\]

It can be found that all of the sensitivities with respect to the passive elements are less than unity. Furthermore, by setting \(R_1 = R_4 = R_a, R_2 = R_3 = R_b\) and \(C_1 = C = C_2\), then the parameters \(\omega_0\) and \(Q\)-factor of this filter, from equations (6) and (7), will be rewritten as

\[
\omega_0 = \frac{1}{R_a C} \quad (10)
\]

and

\[
Q = \frac{R_a}{R_b} \quad (11)
\]

It is important to noted from equations (10) and (11) that the natural angular frequency \(\omega_0\) can be varied by tuning the value of the grounded resistor \(R_a\) and/or the grounded capacitor \(C\) without disturbing the value of \(Q\)-factor. Moreover, the \(Q\)-factor can be
independently controlled through a single grounded resistor RB. Therefore, the proposed filter provides orthogonal grounded-element control of the parameters $\omega_o$ and $Q$-factor.

3. Effects of the Non-Idealities of the Multiple-Output OMAs

By taking into consider the non-ideal performance of the multiple-output OMA, its characteristics can be modeled as $v_2 = \beta v_1$, $i_n = ... = i_2 = \alpha i_1$, where $b = 1 - \omega_0$, $(|\omega| << 1)$, denotes the input voltage tracking error and $\alpha = 1 - \delta$, $(|\delta| << 1)$, represents the output current tracking error of the multiple-output OMA. In this case, reanalysis of the configuration in Fig. 3 shows that the current transfer functions become:

$$T_{D}(s) = \frac{I_{o2}(s)}{I_o(s)} = \frac{s^2}{2} \left( \frac{\beta_1 R_1}{R_4} \right) \frac{1}{D_n(s)}$$

$$T_{D}(s) = \frac{I_{o2}(s)}{I_o(s)} = \frac{s^2}{2} \left( \frac{\beta_1 R_1}{R_4} \right) \frac{1}{D_n(s)}$$

$$T_{D}(s) = \frac{I_{o2}(s)}{I_o(s)} = \frac{s^2}{2} \left( \frac{\beta_1 R_1}{R_4} \right) \frac{1}{D_n(s)}$$

and $D_n(s) = s^2 + \frac{1}{R_2} \sum \left( \frac{1}{R_1} \right) + \sum \left( \frac{1}{R_1 R_2} \right)$

where $\beta_i$, and $\alpha_i$, $(i = 1, 2, 3)$, are the voltage- and the current-tracking errors of the $i$-th multiple-output OMA. By using the same condition mentioned above, the parameters $\omega_{on}$ and $Q_n$-factor for the non-ideal cases can be given, respectively, by

$$\omega_{on} = \frac{1}{R_4 C} \sqrt{\beta_1 \beta_2 \beta_3 \gamma_2 \gamma_3}$$

$$Q_n = \frac{R_4}{R_R} \sqrt{\frac{\beta_1 \beta_2 \beta_3 \gamma_2 \gamma_3}{\beta_1 \beta_2 \beta_3 \gamma_2 \gamma_3}}$$

Hence, its active sensitivities for this case are obtained as

$$S_{\omega_{on}}^{\omega_{on}} = S_{\omega_{on}}^{\omega_{on}} = \frac{1}{2}$$

$$S_{\omega_n}^{\omega_n} = S_{\omega_n}^{\omega_n} = -\frac{1}{2}$$

all of which are equal to 0.5 in magnitude.

4. Simulation Results

To verify the validity of the proposed configuration, the filter of Fig.3 has been simulated through the use of a PSPICE simulation program. In the simulation, possible realizations of multiple-output OMAs using power-supply current-sensing technique [15] are shown in Fig.4. The OMAs were built by employing AD704 operational amplifier
together with improved Wilson current mirrors composed of \textit{pnp} 2N2907A and \textit{npn} 2N2222A transistors. The biasing power supplies used were taken as \(+V = +15\text{V}\) and the capacitor values were \(C_1 = C_2 = 5 \text{nF}\).

Fig.5 represents the frequency responses, all the three current functions, obtained with the following values for passive components: \(R_A = R_B = 10 \text{k}\Omega\), designed for \(Q = 1\) and \(f_o = 3.18 \text{kHz}\).

As an illustration of the controllability of the natural frequency \(\omega_o\), Fig.6 shows bandpass output responses for three different values of \(R_i = R_A = R_B\); i.e., \(R_i = 5 \text{k}\Omega\), 10 k\Omega\) and 20 k\Omega\). The corresponding natural frequency obtained by simulation are 6.45 kHz, 3.23 kHz and 1.62 kHz, respectively.

\textbf{Figure 5} Frequency responses of LP, BP and HP filters obtained from the circuit of Fig.3 with \(R_i=R_A=R_B=10 \text{k}\Omega\) and \(C_1=C_2=5 \text{nF}\).

\textbf{Figure 6} Simulation results of BP response for various values of \(\omega_o\).

\textbf{Figure 7} Simulation results of BP response for various values of Q-factor which are in good agreement with theoretical values calculated from equation (10): 6.36 kHz, 3.18 kHz and 1.59 kHz, respectively.

The obtained responses of the bandpass output for variable \(Q\)-factor (i.e.; \(Q\)-factor = 1, 2, 10) are shown in Fig.7, while \(R_A\) set to constant at 10 k\Omega\). This figure shows that the various values of \(Q\)-factor can be obtained by varying \(R_B\) without disturbing the parameter \(\omega_o\). It can be concluded from above mentioned that in both cases the filter characteristics are very close to the theoretical analysis which is deduced from equations (10) and (11).

5. Conclusions

A variety of new single-input and three-output (SITO) current-mode biquadratic filters using only three multiple-output OMAs has been proposed. The proposed filter provides the following advantages:

(i) simultaneous realization of lowpass, bandpass and highpass current transfer functions without changing the circuit configuration and elements,
(ii) employment of only grounded elements,
(iii) cascadable structure,
(iv) independent control of the parameters \(\omega_o\) and \(Q\)-factor through grounded elements, and
(v) low passive and active sensitivities. The validity of the proposed filter has been confirmed by the simulation results.
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References


