Tunable Versatile High Input Impedance Voltage-Mode Universal Biquadratic Filter Based on DDCCs

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Abstract. A high input impedance voltage-mode universal biquadratic filter with three input terminals and seven output terminals is presented. The proposed circuit uses three differential difference current conveyors (DDCCs), four resistors and two grounded capacitors. The proposed circuit can realize all the standard filter functions, namely, lowpass, bandpass, highpass, notch and allpass, simultaneously. The proposed circuit offers the features of high input impedance, using only grounded capacitors, and orthogonal controllability of resonance angular frequency and quality factor.

Keywords
Current conveyor, biquadratic filter, active circuit, voltage-mode.

1. Introduction
The differential difference current conveyors (DDCC) [1] or differential voltage current conveyors (DVCC) [2], [3] have received considerable attention on realizing multifunction filters and oscillators. This is due to the fact that the addition and subtraction operations for voltage signals can be performed easily.

High input impedance voltage-mode active filters are of great interest because several cells of this kind can be directly connected in cascade to implement higher order filters [4]-[6]. Besides the use of only grounded capacitors and resistors are beneficial from the point of view of integrated circuit fabrications [7]-[9].

Several high input impedance voltage-mode universal biquads each with multi-input terminals were presented in [5], [10]-[14]. Five kinds of standard filter functions can be derived by the selections of different input voltage terminals in these circuits. However, only one standard filter function can be obtained in each realization of [5], [10]-[12]. Moreover, four kinds of standard filter functions at most can be obtained, simultaneously, in each circuit realization of [13], [14]. Moreover, the resonance angular frequencies and quality factors of these circuits cannot be orthogonally controllable. Three multi-inputs and one output universal biquads were presented in [15]-[17]. Although the resonance angular frequencies and quality factors of these circuits can be orthogonally controllable, they require passive components matching conditions in the realizations of some filter functions. Two high input impedance three-inputs and one output universal biquads were presented in [18]. However, the resonance angular frequency and quality factor of the first proposed circuit cannot be orthogonally controllable and both circuits require passive components matching conditions in the realization of allpass filter functions.

The circuits that consist of more filter functions mean more applications they can be used. Therefore, many high input impedance circuits that can realize all of the standard filter functions; namely highpass, bandpass, lowpass, notch and allpass from the same circuit configuration simultaneously were presented in the literatures [15], [19]-[25]. However, the resonance angular frequencies and quality factors of the circuits in [15], [19], [20] cannot be orthogonally controllable. The circuits in [21]-[25] have the feature of orthogonally controllable of resonance angular frequencies and quality factors but they use floating resistors.

In this paper, a new high input impedance voltage-mode universal biquadratic filter with three input terminals and seven output terminals using three DDCCs is presented. The proposed circuit uses four resistors and two grounded capacitors. The proposed circuit has the following features: (i) high input impedance, (ii) using only grounded capacitors, (iii) five kinds of standard filter functions can be obtained simultaneously from the same circuit configuration, and (iv) orthogonal controllability of resonance angular frequency and quality factor. Moreover, if one of the output terminals at the proposed circuit is not required (deleted), five kinds of filter functions still can be obtained from the circuit by appropriate selecting the input terminals. This circuit configuration needs not passive component matching condition in the realization of all filter types and using only grounded passive components. With respect to the multi-inputs universal biquads in [5], [10]-[14], the resonance angular frequency and quality factor can be orthogonally controllable in the proposed circuit. With respect to the three inputs universal biquads in [15]-[18], the proposed circuit needs no passive compo-
nents matching conditions in the realization of allpass filter functions. Comparisons of some multi-inputs biquads are given in Tab. 1. Tab. 1 shows the features of the proposed circuit in orthogonally controllable of resonance angular frequency and quality factor and using only grounded passive components. Comparisons of some multi-output biquads that can realize all of the standard filter functions simultaneously are given in Tab. 2.

2. Circuit Description

Using standard notation, the port relations of an ideal DDCC can be characterized by

\[
\begin{bmatrix}
    y_1 \\
    y_2 \\
    y_3 \\
    x \\
    z_1 \\
    z_2 \\
    \vdots \\
    u_k
\end{bmatrix}
= \begin{bmatrix}
    1 & -1 & 1 & 0 & 0 & \ldots & 0 \\
    0 & 0 & 0 & 0 & 0 & \ldots & 0 \\
    0 & 0 & 0 & 0 & 0 & \ldots & 0 \\
    0 & 0 & 0 & 0 & 0 & \ldots & 0 \\
    0 & 0 & \pm 1 & 0 & 0 & \ldots & 0 \\
    0 & 0 & \pm 1 & 0 & 0 & \ldots & 0 \\
    \vdots \\
    0 & 0 & \pm 1 & 0 & 0 & \ldots & 0
\end{bmatrix}
\begin{bmatrix}
    y_1 \\
    y_2 \\
    y_3 \\
    x \\
    z_1 \\
    z_2 \\
    \vdots \\
    u_k
\end{bmatrix}
\]

(1)

where the plus and minus signs indicate whether the conveyor is configured as a non-inverting or inverting type circuit, termed DDCC+ or DDCC-.

The proposed configuration is shown in Fig. 1. The output voltages can be expressed as:

\[
V_{\text{out}1} = \frac{(s^2C_2G_1 + G_2G_3V_{\text{in}})V_{\text{in}} - sC_1G_2G_3V_{\text{in}}^2 - s^2C_1C_2G_3V_{\text{in}}^3}{s^2C_1C_2G_1 + sC_1G_2G_1 + G_1G_2G_3}
\]

(2)

\[
V_{\text{out}2} = \frac{-sC_1G_2G_3V_{\text{in}} - sC_1G_2G_3V_{\text{in}}^2 + (sC_1G_2G_1 + G_1G_2G_3)V_{\text{in}}^3}{s^2C_1C_2G_1 + sC_1G_2G_1 + G_1G_2G_3}
\]

(3)

\[
V_{\text{out}3} = \frac{G_1G_2G_3V_{\text{in}} + G_1G_2G_3V_{\text{in}}^2 + sC_1G_2G_3V_{\text{in}}^3}{s^2C_1C_2G_1 + sC_1G_2G_1 + G_1G_2G_3}
\]

(4)

\[
V_{\text{out}4} = \frac{sC_1G_2G_3V_{\text{in}} + sC_1G_2G_3V_{\text{in}}^2 + s^2C_1C_2G_3V_{\text{in}}^3}{s^2C_1C_2G_1 + sC_1G_2G_1 + G_1G_2G_3}
\]

(5)

\[
V_{\text{out}5} = \frac{-s^2C_1C_2G_3V_{\text{in}} - s^2C_1C_2G_3V_{\text{in}}^2}{s^2C_1C_2G_1 + sC_1G_2G_1 + G_1G_2G_3}
\]

(6)

\[
V_{\text{out}6} = \frac{-sC_1G_2G_3V_{\text{in}} - sC_1G_2G_3V_{\text{in}}^2 - s^2C_1C_2G_3V_{\text{in}}^3}{s^2C_1C_2G_1 + sC_1G_2G_1 + G_1G_2G_3}
\]

(7)

From (2)-(8), we can see that six circuit types can be obtained from Fig. 1:

1. If \(V_{\text{in}2} = V_{\text{in}3} = 0\) (grounded); \(V_{\text{in}1}\) = input voltage signal, a notch filter can be obtained at \(V_{\text{out}1}\), three bandpass filters can be obtained at \(V_{\text{out}2}\), \(V_{\text{out}3}\), \(V_{\text{out}4}\), \(V_{\text{out}5}\), and \(V_{\text{out}6}\), a lowpass filter can be obtained at \(V_{\text{out}5}\), and if \(R_4 = R_1\), an allpass filter can be obtained at \(V_{\text{out}7}\).

2. If \(V_{\text{in}1} = V_{\text{in}3} = 0\) (grounded); \(V_{\text{in}2}\) = input voltage signal, five bandpass filters can be obtained at \(V_{\text{out}1}\), \(V_{\text{out}2}\), \(V_{\text{out}4}\), \(V_{\text{out}5}\), and \(V_{\text{out}6}\), a lowpass filter can be obtained at \(V_{\text{out}3}\), and a highpass filter can be obtained at \(V_{\text{out}5}\).

3. If \(V_{\text{in}1} = V_{\text{in}2} = 0\) (grounded); \(V_{\text{in}3}\) = input voltage signal, four highpass filters can be obtained at \(V_{\text{out}1}\), \(V_{\text{out}4}\), \(V_{\text{out}5}\), and \(V_{\text{out}6}\), and a bandpass filter can be obtained at \(V_{\text{out}7}\).

4. If \(V_{\text{in}3} = 0\) (grounded), then \(V_{\text{in}1} = V_{\text{in}2}\) = input voltage signal, an allpass filter can be obtained at \(V_{\text{out}1}\), three bandpass filters can be obtained at \(V_{\text{out}2}\), \(V_{\text{out}3}\), \(V_{\text{out}4}\), \(V_{\text{out}5}\), and \(V_{\text{out}6}\), a lowpass filter can be obtained at \(V_{\text{out}3}\) and a highpass filter can be obtained at \(V_{\text{out}5}\).

5. If \(V_{\text{in}2} = 0\) (grounded), then \(V_{\text{in}1} = V_{\text{in}3}\) = input voltage signal and \(R_3 = R_1\), two lowpass filters can be obtained at \(V_{\text{out}1}\) and \(V_{\text{out}2}\) and a bandpass filter can be obtained at \(V_{\text{out}5}\).

6. If \(V_{\text{in}1} = 0\) (grounded), then \(V_{\text{in}2} = V_{\text{in}3}\) = input voltage signal and \(R_3 = R_1\), a lowpass filter can be obtained at \(V_{\text{out}2}\) and a bandpass filter can be obtained at \(V_{\text{out}5}\).
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<thead>
<tr>
<th>Active device</th>
<th>Needs inverting inputs</th>
<th>Grounded passive components</th>
<th>Floating passive components</th>
<th>Matching constraints</th>
<th>High input impedance</th>
<th>$\omega_o/Q$ orthogonal controllability</th>
<th>Kinds of filter functions simultaneously</th>
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**Tab. 1.** Comparisons of some multi-inputs biquads (The resistor $R_4$ in the proposed circuit is shorted).

<table>
<thead>
<tr>
<th>Active device</th>
<th>Grounded passive components</th>
<th>Floating passive components</th>
<th>Matching constraints</th>
<th>High input impedance</th>
<th>$\omega_o/Q$ orthogonal controllability</th>
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<td>no</td>
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<td>no</td>
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<td>yes</td>
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<td>yes</td>
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<td>yes</td>
</tr>
<tr>
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<td>yes</td>
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<tr>
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<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>three DVCCs</td>
<td>4</td>
<td>2</td>
<td>yes</td>
<td>yes</td>
<td>yes</td>
</tr>
<tr>
<td>New circuit</td>
<td>three DDCCs</td>
<td>5</td>
<td>1</td>
<td>yes</td>
<td>yes</td>
</tr>
</tbody>
</table>

**Tab. 2.** Comparisons of some biquads that can realize all of the standard filter functions simultaneously.
The resonance angular frequency \( \omega_{0} \) and quality factor \( Q \) are obtained by

\[
\omega_{0} = \frac{G_{1}G_{2}}{C_{1}C_{2}}, \tag{9}
\]

\[
Q = G_{1}\frac{C_{2}}{C_{1}G_{2}G_{3}}. \tag{10}
\]

In first circuit type, all standard filter functions can be simultaneously obtained from the same circuit configuration. If the output terminal \( V_{out} \) is not required, the floating resistor \( R_{4} \) is not needed and can be shorted. Note that if the output terminal \( V_{out} \) is not needed, five kinds of filter functions still can be realized by appropriately selecting the input terminals without component matching condition and using only grounded passive components.

The proposed circuit uses grounded capacitors, which are attractive for integrated circuit implementation [7]. Due to the three input signals, \( V_{in1}, V_{in2} \) and \( V_{in3}, \) are connected to the high input impedance input nodes of the three DDCCs (the \( y \) port of the DDCC), respectively, the proposed circuit enjoys the feature of high input impedance. From (9), (10), the resonance angular frequency can be controlled by \( R_{2} \) or \( R_{3} \). The quality factor can be independently controlled by \( R_{1} \). Therefore, the resonance angular frequency and quality factor can be orthogonally controllable.

3. Sensitivities Analysis

Taking the non-idealities of the DDCC into account, the relationship of the terminal voltages and currents can be rewritten as

\[
\begin{bmatrix}
V_{x}
\end{bmatrix} = \begin{bmatrix}
\alpha_{l1}(s) & -\alpha_{l2}(s) & \alpha_{l3}(s) & 0
\end{bmatrix} \begin{bmatrix}
V_{y}
\end{bmatrix} + \begin{bmatrix}
0
\end{bmatrix} \begin{bmatrix}
0
\end{bmatrix} \begin{bmatrix}
i_{x}
\end{bmatrix}
\]

\[
\begin{bmatrix}
V_{y}
\end{bmatrix} = \begin{bmatrix}
0
\end{bmatrix} \begin{bmatrix}
0
\end{bmatrix} \begin{bmatrix}
i_{y}
\end{bmatrix} + \begin{bmatrix}
0
\end{bmatrix} \begin{bmatrix}
0
\end{bmatrix} \begin{bmatrix}
i_{x}
\end{bmatrix} + \begin{bmatrix}
\alpha_{l1}(s)
\end{bmatrix} \begin{bmatrix}
0
\end{bmatrix} \begin{bmatrix}
i_{y}
\end{bmatrix}
\]

\[
\begin{bmatrix}
V_{z}
\end{bmatrix} = \begin{bmatrix}
0
\end{bmatrix} \begin{bmatrix}
0
\end{bmatrix} \begin{bmatrix}
i_{z}
\end{bmatrix} + \begin{bmatrix}
\alpha_{l1}(s)
\end{bmatrix} \begin{bmatrix}
0
\end{bmatrix} \begin{bmatrix}
i_{z}
\end{bmatrix}
\]

where \( \alpha_{l1}(s), \alpha_{l2}(s), \) and \( \alpha_{l3}(s) \) represent the frequency transfer functions of the internal voltage followers and \( \beta_{k}(s) \) represent the frequency transfer function of the internal current follower of the \( k \)-th DDCC. They can be approximated by first order lowpass functions, which can be considered to have a unity value for frequencies much lower than their corner frequencies [2]. If the circuit is working at frequencies much lower than the corner frequencies of \( \alpha_{l1}(s), \alpha_{l2}(s), \) and \( \alpha_{l3}(s) \) and \( \beta_{k}(s), \) then \( \alpha_{l1}(s) = \alpha_{l3} = 1 - \alpha_{l3}, \) and \( \alpha_{l1}(s) = 1 - \alpha_{l3}, \) and \( \alpha_{l3} \) can be regarded as the voltage tracking error from \( y_{1} \) terminal to \( x \) terminal of the \( k \)-th DDCC, \( \alpha_{l2}(s) = 1 - \alpha_{l2}, \) and \( \alpha_{l3} \) can be regarded as the voltage tracking error from \( y_{2} \) terminal to \( x \) terminal of the \( k \)-th DDCC, \( \beta_{1}(s) = 1 - \beta_{1}, \) and \( \beta_{3} \) can be regarded as the current tracking error of the \( k \)-th DDCC. The denominator of the non-ideal output voltage transfer function for Fig. 1 becomes

\[
D(s) = s^{2}C_{1}G_{1}\alpha_{l1}\beta_{11}\beta_{12} + sC_{1}G_{1}G_{2}\alpha_{l3}\beta_{11}\beta_{12} + G_{1}G_{2}G_{3}\alpha_{l1}\alpha_{l3}\beta_{11}\beta_{12} \tag{12}
\]

The resonance angular frequency \( \omega_{0} \) and quality factor \( Q \) become

\[
\omega_{0} = \frac{G_{1}G_{2}G_{3}\alpha_{l1}\alpha_{l3}\beta_{11}\beta_{12}}{C_{1}C_{2}}, \tag{13}
\]

\[
Q = G_{1}\frac{C_{2}}{C_{1}G_{2}G_{3}G_{3}\beta_{11}\beta_{12}}. \tag{14}
\]

The active and passive sensitivities of \( \omega_{0} \) and \( Q \) are shown as

\[
S_{a_{l1},a_{l3},\beta_{11},\beta_{12}}^{a_{l1}} = -S_{\beta_{11}}^{a_{l1}} = S_{a_{l1}}^{a_{l1}} = S_{\beta_{11}}^{a_{l1}} = \frac{1}{2};
\]

\[
S_{a_{l1}}^{\beta_{11}} = S_{a_{l1}}^{\beta_{11}} = 1;
\]

\[
S_{a_{l1},\beta_{11},\beta_{12}}^{\beta_{11}} = -S_{\beta_{11},\beta_{12}}^{\beta_{11}} = \frac{1}{2};
\]

\[
S_{\beta_{11}}^{\beta_{11}} = -S_{\beta_{11}}^{\beta_{11}} = \frac{1}{2}.
\]

All the active and passive sensitivities are no larger than 1.

4. Influence of Parasitic Elements

A non-ideal DDCC model is shown in Fig. 2 [26]. It is shown that the real DDCC has parasitic resistors and capacitors from the \( y_{1}, y_{2}, y_{3} \) and \( z \) terminals to the ground, and also, a series resistor at the input terminal \( x. \) Taking into account the non-ideal DDCCs and assuming the circuits are working at frequencies much lower than the corner frequencies of the \( \alpha_{l}(s), \) and \( \beta_{k}(s), \) namely, \( \alpha_{l} \equiv \beta_{k} \equiv 1. \) Moreover, in practical DDCCs, the external resistors can be chosen to be much smaller than the parasitic resistors at the \( y \) and \( z \) terminals of DDCCs, much greater than the parasitic resistors at the \( x \) terminals of DDCCs, i.e. \( R_{p} \gg R_{v} \gg R_{e}. \) The external capacitances \( C_{1} \) and \( C_{2} \) can be chosen to be much greater than the parasitic capacitors at the \( y \) and \( z \) terminals of DDCCs, i.e. \( C_{y} \equiv C_{z}. \) Furthermore, assuming that the resistances \( R_{p} \equiv R_{v} \) and the parasitic capacitances at the \( y \) terminals and \( z \) terminals of the DDCCs are equal, i.e. \( C_{y} \equiv C_{z}. \)
Under these conditions, the denominator of Fig. 1 becomes

$$D(s) \equiv 2s^4C_1'C_2'C_2'^2 + 4s^3C_1'C_2'C_2'G_1 + s^2C_1'C_2'^2G_1G_1' + sC_1'C_2'C_2'G_1'G_1$$

$$+ s^2C_1'C_2'C_2'G_1'G_1'G_1$$

(15)

where

$$C_1' = C_1 + C_{y11} + C_{y22}, \quad C_2' = C_2 + C_{z2} + C_{y31},$$

$$R_1' = R_1 + R_{x1}, \quad R_2' = R_2 + R_{x2}, \quad R_3' = R_3 + R_{x3}.$$ 

In (15), undesirable factors are yielded by the non-idealities of the DDCCs. The capacitance $C_z$ becomes effective at very high frequency. To minimize the effects of the DDCCs' non-idealities, the operation angular frequency should be restricted to the following conditions

$$\omega < \min \left\{ \frac{1}{\sqrt{2R_1'C_z}}, \frac{1}{2R_2'C_z}, \frac{1}{2R_3'C_z} \right\}.$$  

Moreover, application of the Routh-Hurwitz test to the denominator of (15) shows that $C_z$ may cause instability. According to this test, the transfer functions is stable if

$$C_z' > \max \left\{ C_z \left( \frac{G_1'G_1'}{2G_1'^2} \right), C_z \left( \frac{8C_1'G_1'^2 + C_1'G_1'^2}{2C_1'^2G_1''} \right) \right\}.$$  

(17)

It is not difficult to satisfy this condition, since the external capacitance $C_z$ can be chosen very much greater than $C_{y3}$.

5. Simulation Results

HSPICE simulations were carried out to demonstrate the feasibility of the proposed circuit in Fig. 1. The DDCC was realized by the CMOS implementation of Elwan and Soliman [2] (by ungrounding the gate of MOSFET M2 and treating this as the third $y$-input $y_3$) and is redrawn in Fig. 3. The simulations use TSMC (Taiwan Semiconductor Manufacturing Company, Ltd.) 0.18μm level 49 CMOS technology process parameters. The supply voltages are $V^+ = +1.25$ V, $V^- = -1.25$ V, $V_{b1} = -0.45$ V and $V_{b2} = 0.3$ V. The dimensions of the NMOS transistors in the DDCC are set to be $W = 4.5$ μm and $L = 0.9$ μm. The dimensions of the PMOS transistors in the DDCC are set to be $W = 9$ μm and $L = 0.9$ μm. Fig. 4 (a)-(g) represent the simulated frequency responses for the notch ($V_{out}$), inverting bandpass ($V_{out3}$), lowpass ($V_{out5}$), bandpass ($V_{out4}$), highpass ($V_{out5}$), inverting bandpass ($V_{out6}$) and allpass ($V_{out7}$) filters of
Fig. 1, respectively, designed with $V_{in2} = V_{in3} = 0$ (grounded), $V_{in1}$ = input voltage signal, $Q = 1$ and $f_0 = 1.5915 \text{ MHz}$. $C_1 = C_2 = 10 \text{ pF}$ and $R_1 = R_2 = R_3 = R_4 = 10 \text{ k} \Omega$. Fig. 5 represents the INOISE and ONOISE simulation results of the bandpass filter at $V_{out}$. Fig. 6 shows the the total harmonic distortion (THD) of the $V_{out2}$ and $V_{out4}$ output voltages (bandpass signals). They are given at 1.5915 MHz operation frequency with $V_{in1}$ = input voltage signal, $V_{in2} = V_{in3} = 0$ (grounded) and $Q = 1$; $C_1 = C_2 = 10 \text{ pF}$ and $R_1 = R_2 = R_3 = R_4 = 10 \text{ k} \Omega$. Fig. 6 shows that the THDs of $V_{out2}$ and $V_{out4}$ are less than 3 percent at 1000 mV output voltages (peak to peak).
Fig. 4. Simulated frequency responses of Fig. 1 designed with
\( V_{in2} = V_{in3} = 0 \) (grounded), \( V_{in1} = \) input voltage signal: (a) notch filter \( (V_{out1}) \), (b) inverting bandpass filter \( (V_{out2}) \), (c) lowpass filter \( (V_{out3}) \), (d) bandpass filter \( (V_{out4}) \), (e) highpass filter \( (V_{out5}) \), (f) inverting bandpass filter \( (V_{out6}) \), (g) allpass filter \( (V_{out7}) \).

Fig. 5. INOISE and ONOISE simulation results of the proposed bandpass filter at \( V_{out4} \).

Fig. 6. THD analysis results of the proposed bandpass filters at \( V_{out2} \) and \( V_{out4} \).

Fig. 7 represents the simulated frequency responses for the allpass \( (V_{out1}) \) filter of Fig. 1, designed with \( V_{in3} = 0 \) (grounded), \( V_{in1} = V_{in2} = \) input voltage signal, \( Q = 1 \) and \( f_0 = 1.5915 \) MHz: \( C_1 = C_2 = 10 \) pF and \( R_1 = R_2 = R_3 = R_4 = 10 \) kΩ. Fig. 8 represents the simulated gain responses for the inverting highpass \( (V_{out1}) \) filter of Fig. 1, designed with \( V_{in1} = V_{in2} = 0 \) (grounded); \( V_{in3} = \) input voltage signal, \( Q = 1 \) and \( f_0 = 1.5915 \) MHz: \( C_1 = C_2 = 10 \) pF and \( R_1 = R_2 = R_3 = R_4 = 10 \) kΩ. Fig. 9 represents the simulated frequency responses for the inverting bandpass \( (V_{out2}) \) filter of Fig. 1 as the resistor \( R_1 \) in \( Q \) is varied designed with \( V_{in2} = V_{in3} = 0 \) (grounded) and \( V_{in1} = \) input voltage signal: \( C_1 = C_2 = 10 \) pF and \( R_2 = R_3 = R_4 = 10 \) kΩ. The quality factor was found to vary as 3.157, 1.988, 1.468 and 0.994 for four values of \( R_1 \) as 2 kΩ, 4 kΩ, 6 kΩ and 10 kΩ, respectively. All the simulation results are coherent and support the theoretical analyses.
The DDCC has parasitic resistor from the $z$ terminal to the ground ($R_z$) [26]. When the $z$ terminal load of the DDCC is a capacitor ($C$), it introduces a pole produced by $R_z$ and $C$ at low frequency. This can explain why Fig. 4(b), 4(d), 4(f) and Fig. 8 have non-ideal phase responses at low frequencies. This effect can be minimized by using larger loading capacitors.

6. Conclusion

In this paper, a new high input impedance voltage-mode universal biquadratic filter with three input terminals and seven output terminals is presented. The proposed circuit uses three DDCCs, four resistors and two grounded capacitors and offers the following advantages: high input impedance, the use of only grounded capacitors, the versatility to synthesize lowpass, bandpass, highpass, notch, and allpass responses, simultaneously and orthogonal controllability of resonance angular frequency and quality factor.

Finally, it should be mentioned that if the output terminal $V_{out}$ at the proposed circuit is not required, the floating resistor $R_z$ can be deleted. Note that five kinds of filter functions still can be obtained from this circuit by appropriate selecting the input terminals. This circuit configuration needs not passive component matching condition in the realizations of all filter functions and using only grounded passive components.

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References


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