LETTER TO THE EDITOR

Current-mode biquadratic filter using DO-CCCDBAs

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SUMMARY

This paper presents a current-mode universal biquadratic filter performing three functions; low pass, high pass and band pass, based on dual-output current-controlled current differencing buffered amplifiers (DO-CCCDBAs). The features of the circuit are that the quality factor and pole frequency can be tuned independently via the input bias currents; the circuit description is very simple, consisting of merely three DO-CCCDBAs and two grounded capacitors. Without any external resistors that require component matching conditions and using only grounded elements, the proposed circuit is very appropriate to further develop into an integrated circuit. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation. Copyright © 2008 John Wiley & Sons, Ltd.

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1. INTRODUCTION

In electrical engineering applications, it is well known that an analog filter is an important block that is widely used for continuous-time signal processing. It can be found in many fields for instance, communication, measurement and instrumentation, and control systems [1, 2]. One of the most popular analog filters is the universal biquadratic filter as it can provide several functions [3, 4]. Nowadays, a universal filter working in current-mode is more popular than one working in voltage-mode one. Since the last decade, there has been much effort to reduce the supply voltage of analog systems. This is due to the demand for portable and battery-powered equipment. As a low-voltage operating circuit becomes necessary, the current-mode technique is ideally suited for

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this purpose. In fact, a circuit using the current-mode technique has many other advantages for example, larger dynamic range, higher bandwidth, greater linearity, simpler circuitry and lower power consumption [5–9]. Examples of low-voltage analog current-mode signal processing circuits can be found in [10–14].

The current differencing buffered amplifier (CDBA) is a reported active component especially suitable for a class of analog signal processing [15]. The CDBA has been developed from differential current conveyor [16]. This device can operate in both current- and voltage-modes, provides flexibility and enables a variety of circuit designs. In addition, it can offer advantageous features such as high-slew rate, free from parasitic capacitance, wide bandwidth and simple implementation [17]. However, the CDBA cannot be controlled by the parasitic resistances at two current input ports, thus when it is used in a circuit, it must unavoidably require some external passive components, especially the resistors. This makes it inappropriate for IC implementation as it occupies more chip area, has high power dissipation and is electronically uncontrollable. Recently, Maheshwari and Khan have proposed the modified-version of CDBA in which the parasitic resistances at the two current input ports can be controlled by an input bias current and it is newly named as current-controlled current differencing buffered amplifier (CCCDBA) [18]. From our survey, we found that several implementations of current-mode universal filters employing the CDBA and CCCDBA as active elements have been reported [17–24]. Unfortunately, these reported circuits suffer from one or more of the following weaknesses:

(a) excessive use of the passive elements, especially the external resistors [19–22, 24];
(b) require changing circuit topologies to achieve several functions [18, 19, 24];
(c) lack of electronic adjustability [19, 20, 22, 24];
(d) some outputs of the filter responses are not in high output impedance and the cascade-ability is not directly achieved [17, 18, 20, 21, 23];
(e) use of floating capacitor, which is not convenient to further fabricate in IC [19, 22, 24].

A Current-Controlled-Conveyor II (CCCI) and Operational Transconductance Amplifier (OTA) whose x-port resistance and transconductance are electronically controllable, have been recently used to realize electronically controllable current-mode biquad filters, for instance, see [25–31] and the references cited therein. In this paper, we have focused on how DO-CCCDBAs can be used to realize electronically controlled biquad filters along with a number of advantages.

The aim of this paper is to propose a current-mode universal biquadratic filter, emphasizing the use of DO-CCCDBAs. The features of the proposed circuit are that the proposed universal filter can provide three standard functions (low pass, high pass, band pass) without changing the circuit topology; the circuit description is very simple as it uses only grounded capacitors, which are suitable for fabricating in monolithic chip and the quality factor and pole frequency can be independently adjusted. The performances of the proposed circuit are illustrated by PSPICE simulations and they show good agreement as mentioned.

2. PRINCIPLE OF OPERATION

2.1. The DO-CCCDBA

As the proposed circuit is based on DO-CCCDBAs, a brief review of it is given in this section. Basically, the DO-CCCDBA is composed of translinear elements, mixed loops and complementary current mirrors. Generally, its properties are similar to the conventional CDBA, except that input
voltages of DO-CCCDBA are not zero and that it has finite input resistances $R_p$ and $R_n$ at the $p$ and $n$ input terminals, respectively. These intrinsic resistances are equal and can be controlled by the bias current $I_B$ as shown in the following equation:

\[
\begin{bmatrix}
V_p \\
V_n \\
I_{z1,z2} \\
V_w
\end{bmatrix}
= 
\begin{bmatrix}
R_p & 0 & 0 & 0 \\
0 & R_n & 0 & 0 \\
1 & -1 & 0 & 0 \\
0 & 0 & 1 & 0
\end{bmatrix}
\begin{bmatrix}
I_p \\
I_n \\
V_{z1} \\
I_w
\end{bmatrix}
\]  

(1)

where

\[R_p = R_n = \frac{V_T}{2I_B}\]  

(2)

and $V_T$ is the thermal voltage. The symbol and the equivalent circuit of the DO-CCCDBA are illustrated in Figures 1(a) and (b), respectively.

2.2. Proposed current-mode universal filter

The proposed current-mode universal filter is shown in Figure 2, where $I_{B1}$, $I_{B2}$ and $I_{B3}$ are input bias currents of DO-CCCDBA1, DO-CCCDBA2 and DO-CCCDBA3, respectively. By routine analysis the circuit in Figure 2 and using DO-CCCDBA properties in Section 2.1, we will receive

\[I_{HP} = I_{z31} = I_{in} + I_{z11} - I_{p3}\]  

(3)

The voltage at $z_{31}$ terminal can be found as

\[V_{z31} = V_{w3} = \frac{I_{HP}}{sC_1}\]  

(4)
The current at $p_3$ terminal can be found as

$$I_{p3} = \frac{V_{w3}}{R_3} = \frac{I_{HP}}{sC_1R_3}$$

(5)

The current at $p_2$ terminal can be found as

$$I_{p2} = \frac{V_{w3}}{R_{p2}} = \frac{I_{HP}}{sC_1R_{p2}}$$

(6)

The current at $z_{21}$ terminal can be found as

$$I_{z21} = I_{BP} = -I_{p2} = -\frac{I_{HP}}{sC_1R_{p2}}$$

(7)

The voltage at $z_{21}$ terminal can be found as

$$V_{z21} = V_{w2} = \frac{I_{z21}}{sC_2} = -\frac{I_{HP}}{s^2C_1C_2R_{p2}}$$

(8)

The current at $n_1$ terminal can be found as

$$I_{n1} = \frac{V_{w2}}{R_{n1}} = -\frac{I_{HP}}{s^2C_1C_2R_{n1}R_{p2}}$$

(9)

The current at $z_{11}$ terminal can be found as

$$I_{z11} = I_{LP} = -\frac{I_{HP}}{s^2C_1C_2R_{n1}R_{p2}}$$

(10)

Substituting Equations (5) and (10) into (1), yields

$$I_{in} = I_{HP} \left( 1 + \frac{1}{sC_1R_3} + \frac{1}{s^2C_1C_2R_{n1}R_{p2}} \right)$$

(11)

So, the transfer functions at each terminal can be expressed to be

$$\frac{I_{HP}}{I_{in}} = \frac{s^2}{s^2 + s \frac{1}{C_1R_3} + \frac{1}{C_1C_2R_{n1}R_{p2}}}$$

(12)
\[
\frac{I_{LP}}{I_{in}} = \frac{-1}{s^2 + s \frac{1}{C_1 R_3} + \frac{1}{C_1 C_2 R_{n1} R_{p2}}} \tag{13}
\]

and

\[
\frac{I_{BP}}{I_{in}} = \frac{-s}{s^2 + s \frac{1}{C_1 R_3} + \frac{1}{C_1 C_2 R_{n1} R_{p2}}} \tag{14}
\]

where \(R_{n3} = R_{p3} = R_3\). From Equations (12) to (14), it is clearly seen that the proposed circuit can perform low-pass \((I_{LP})\), high-pass \((I_{HP})\) and band-pass \((I_{BP})\) functions at the same time without disturbing circuit topology. The pole frequency \((\omega_0)\) and quality factor \((Q_0)\) of the system can be shown as

\[
\omega_0 = \frac{1}{\sqrt{C_1 C_2 R_{n1} R_{p2}}} \tag{15}
\]

and

\[
Q_0 = R_3 \sqrt{\frac{C_1}{C_2 R_{n1} R_{p2}}} \tag{16}
\]

If \(R_i = V_T/2I_{Bi}\), Equations (15) and (16) are subsequently modified to

\[
\omega_0 = \frac{2}{V_T} \sqrt{\frac{I_{B1} I_{B2}}{C_1 C_2}} \tag{17}
\]

and

\[
Q_0 = \frac{1}{I_{B3}} \sqrt{\frac{C_1 I_{B1} I_{B2}}{C_2}} \tag{18}
\]

It is obviously found that, from Equations (17) and (18), the quality factor can be adjusted by \(I_{B3}\) without affecting the pole frequency. Furthermore, if \(I_{B1} = I_{B2} = I_B\) and \(I_B = k I_{B3}\), which can be easily realized by using a programmable current mirror \([32, 33]\), the pole frequency and quality factor are subsequently modified as

\[
\omega_0 = \frac{2I_B}{V_T} \sqrt{\frac{1}{C_1 C_2}} \tag{19}
\]

and

\[
Q_0 = k \sqrt{\frac{C_1}{C_2}} \tag{20}
\]

From Equations (19) and (20), it should be remarked that the pole frequency can be electronically adjusted by \(I_B\) without disturbing the quality factor. While the quality factor can be controlled...
independently from pole frequency by gain: \( k \). In addition, bandwidth (BW) of the system can be expressed by

\[
\text{BW} = \frac{\omega_0}{Q_0} = \frac{2I_{B3}}{VTC_1} \tag{21}
\]

We found that the BW can be linearly controlled by \( I_{B3} \). Moreover, the quality factor can be much high by controlling \( I_{B3} \) to be much less than \( I_{B1} \) and \( I_{B2} \). This circuit differs from the conventional current-controlled universal filters in such a way that they use an input bias current to control the quality factor. However, it has a limited value of current in the circuits so that the quality factor is restricted.

### 2.3. DO-CCCDBA internal circuit description

The internal circuit description of the DO-CCCDBA in Figure 3 consists of mixed translinear loop (Q1–Q6). The mixed loops are DC biased by \( I_B \) using current mirrors (Q7–Q10 and Q14–Q16). The output \( z_1 \)- and \( z_2 \)-terminals that generate the current difference of \( p \) and \( n \) terminal is realized using transistors (Q11–Q13 and Q17–Q23). The differential current between \( i_p \) and \( i_n \) flow into \( z \) terminal can be explained as follows. If currents \( i_p \) and \( i_n \) flow into \( p \) and \( n \) terminals, respectively, the currents at different collectors of transistors are \( I_{C5} = I_{C6} = I_{C20} = I_{C21} = I_{C17} = I_B \), \( I_{C2} = I_{C11} = I_B + i_n \) and \( I_{C3} = I_B + i_p \). Because \( i_1 \) is the difference of \( I_{C6} \) and \( I_{C17} \), thus \( i_1 = 0 \) and \( I_{C20} = I_{C19} = I_{C22} = I_B \). The current \( i_2 \) is equal to \( I_{C3} - I_{C11} \), thus \( i_2 = i_p - i_n \). The current \( I_{C12} \) is the summing of \( i_2 \) and \( I_{C21} \), therefore \( I_{C12} = I_B + i_p - i_n \). Then \( I_{C12} \) will be copied to \( I_{C13} \) and \( I_{C23} \) or \( I_{C13} = I_{C23} = I_B + i_p - i_n \). If the directions of current \( i_z \) and \( i_{z2} \) flow into at, \( i_z \) and \( i_{z2} \), which are the currents flowing into \( z_1 \) and \( z_2 \) terminals, then they are equal to \( i_z = I_{C23} - I_{C22} \) and \( i_{z2} = I_{C13} - I_{C19} \) or \( i_z = i_{z2} = i_p - i_n \), respectively. The mathematical accuracy of output current at \( z \) terminals depends on the performances of current mirror and translinear circuits used in the circuit description. Therefore, the careful design of mentioned circuits should be considered to achieve performances that are as high as possible.

### 3. SIMULATION RESULTS

To prove the performances of the proposed circuit, the PSPICE simulation program was used for the examination. The PNP and NPN transistors employed in the proposed circuit were simulated by using the parameters of, respectively, the PR200N and NR200N bipolar transistors of ALA400.
transistor array from AT&T CBIC-R 300 MHz complementary. Figure 3 depicts the schematic description of the DO-CCCDBA used in the simulations. The circuit was biased with ±1.5 V supply voltages and $I_1 = 100 \mu A$. $C_1 = C_2 = 1 nF$ and $I_{B1} = I_{B2} = I_{B3} = 100 \mu A$ are chosen to obtain intrinsic resistance values of 130Ω. It yields the pole frequency of 1.04 MHz, while the calculated value of this parameter from Equation (17) is 1.22 MHz. This deviation stems from non-ideal properties of DO-CCCDBAs employed in the circuit. The results shown in Figure 4 are the gain responses of the proposed biquad filter. It is clearly seen that the proposed biquad filter can provide low-pass, high-pass and band-pass functions without modifying circuit topology. Figure 5 displays
gain responses of band-pass functions for different $I_{B3}$ values. It is shown that the quality factor can be adjusted by the input bias current $I_{B3}$ without affecting the pole frequency as depicted in Equations (19) and (20). Figure 6 shows magnitude responses of band-pass functions where $I_{B1}$, $I_{B2}$ and $I_{B3}$ are set equally. It is found that the pole frequency can be adjusted without affecting the quality factor, as explained in Equations (19) and (20). The results for the large-signal transient response of BP is shown in Figure 7.

4. CONCLUSIONS

The current-mode universal biquadratic filter based on DO-CCCDBAs has been presented. The advantages of the proposed circuit are that it performs low-pass, high-pass and band-pass functions from the same circuit configuration without component matching conditions and changing circuit topology; the quality factor and the pole frequency can be orthogonally controlled via input bias currents, which is easily modified to use in control systems by using a microcontroller [3]. The circuit description comprises only three DO-CCCDBAs and two grounded capacitors, which is attractive for IC implementation. With these mentioned features, it is very suitable to realize the proposed circuits in monolithic chip for use in battery-powered, portable electronic equipments such as wireless communication system devices.

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CURRENT-MODE Biquadratic Filter Using Do-CCCDBAs


