A Cascadable Current-mode Universal Biquadratic Filter Using DO-CCCDBAs

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Abstract

This article presents a current-mode universal biquadratic filter (low-pass, high-pass, band-pass functions), 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 orthogonally via the input bias currents; the circuit description is very simple, consisting of merely 3 DO-CCCDBAs and 2 grounded capacitors. Without any external resistors, without requiring component matching conditions, and using only grounded elements, the proposed circuit is very appropriate to further develop into an integrated circuit. Moreover, the proposed circuit enables easy cascading in current mode, due to high output impedances. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation. The power consumption is approximately 2.86mW at ±1.5V power supply voltages.

Keywords: biquad filter, DO-CCCDBA, current-mode

1. Introduction

In electrical engineering applications, it is well-known that an analog filter is an important building block, widely used for continuous-time signal processing. It can be found in many fields: including, communications, measurement, and instrumentation, and control systems [1-2]. One of most popular analog filters is a universal biquadratic filter, since it can provide several functions. Recently, a universal filter working in current-mode has being been more popular than the voltage-mode type. 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. Since a low-voltage operating circuit becomes necessary, the current-mode technique is ideally suited for this purpose. Actually, a circuit using the current-mode technique has many other advantages, such as, larger dynamic range, higher bandwidth, greater linearity, simpler circuitry and lower power consumption [3-4].

The current differencing buffered amplifier (CDBA) is a reported active component especially suitable for a class of analog signal processing [5]. The fact that 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, freedom from parasitic capacitances, wide bandwidth and simple implementation [6]. However, the CDBA can not control the parasitic resistances at two current input ports so when it is used in some circuits, it must unavoidably require some external passive components, namely the resistors. This makes it inappropriate for IC implementation due to the occupation of more chip area, high power dissipation, and lack of electronic controllability. Recently, Maheshwari and Khan have proposed a modified-version of the CDBA, where the parasitic resistances at two current input ports can be controlled by an input bias current and it is newly named the Current Controlled Current Differencing Buffered amplifier (CCCDBA) [7]. From our survey, it is found that several implementations of current-mode universal filters employing the CDBA and CCCDBA as an active element have been reported [6-12]. Unfortunately, these reported circuits suffer from one or more of following weaknesses

a) Excessive use of the passive elements, especially external resistors [8, 9, 10, 11].

b) Require changing circuit topologies to achieve several functions [7, 8, 10].

c) Lack of electronic adjustability [8, 9, 10, 11].

d) Some outputs of the filter responses are not in high output impedance [6, 7, 9, 10, 12].

e) Use of floating capacitor, which is not convenient to further fabricate in IC [8, 10, 11].

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 circuits are that: the proposed universal filter can provide 3 functions (low-pass, high-pass, band-pass) without changing circuit topology: the circuit description is very simple, it uses only grounded capacitors as passive components, which is suitable for fabricating in monolithic chip: the quality factor and pole frequency can be orthogonally adjusted. The performances of the proposed circuits are illustrated by PSPICE simulations, and they show good agreement with the calculation.

2. Principle of Operation

2.1 The Dual-Output Current Controlled Current Differencing Buffered Amplifier (DO-CCCDBA)

Since the proposed circuit is based on DO-CCCDBAs, a brief review of DO-CCCDBA 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 the DO-CCCDBA has a finite input resistances Rp and Rn 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

\[
\begin{bmatrix}
V_p \\
V_n \\
I_{z1,2} \\
V_w
\end{bmatrix} = \begin{bmatrix}
R_p & 0 & 0 & 0 \\
0 & R_n & 0 & 0 \\
1 & 1 & 0 & 0 \\
0 & 0 & 1 & 0
\end{bmatrix} \begin{bmatrix}
I_p \\
I_n \\
I_{z1} \\
I_w
\end{bmatrix},
\]

(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 CCCCTA are illustrated in Fig. 1(a) and (b), respectively.

2.2 Proposed Current-Mode Universal Biquad Filter

The proposed current-mode universal filter is shown in Fig. 2, where \( I_{B1}, I_{B2}, \) and \( I_{B3} \) are input bias currents of DO-CCCDBA1, DO-CCCDBA2, and DO-CCCDBA3, respectively. Straightforward analysis of the circuit in Fig. 2 and using the DO-CCCDBA properties in section 2.1, we will receive the transfer functions at each terminals as

\[
I_{LP} = \frac{1}{s^2 + s \frac{1}{C_1 R_1} + \frac{1}{C_2 R_1 R_2}},
\]

(3)

\[
I_{HP} = \frac{1}{s^2 + s \frac{1}{C_1 R_1} + \frac{1}{C_2 R_1 R_2}},
\]

(4)

\[
I_{BP} = \frac{-s}{s^2 + s \frac{1}{C_1 R_1} + \frac{1}{C_2 R_1 R_2}}.
\]

(5)

where \( R_{a1}=R_{a2}=R_a \). From Eqs. (3) to (5), it is clearly seen that the proposed circuit can perform low-pass \( (I_{LP}) \), high-pass \( (I_{BP}) \) and band-pass \( (I_{BP}) \) functions at the same time without disturbing circuit topology. Moreover, the band-stop and the all-pass functions can be obtained from the currents \( I_{B1}=I_{B2}, I_{BP}=I_{B3} \) and \( I_{BP}=I_{B3} \). The pole frequency \( (\omega_p) \) and quality factor \( (Q_0) \) of the system can be shown as

\[
\omega_p = \frac{1}{\sqrt{C_1 C_2 R_1 R_2}},
\]

(6)

\[
Q_0 = R_n \frac{C_1}{C_2 R_1 R_2},
\]

(7)

where \( R_n = V_T / 2I_B \). Eqs. (6) and (7) are subsequently modified to

\[
\omega_p = \frac{1}{2V_T} \sqrt{\frac{I_{B1} I_{B2}}{C_1 C_2}},
\]

(8)

and

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

(9)

It is obviously found that, from Eqs. (8) and (9), the quality factor can be adjusted by \( I_{B3} \) without affecting the pole frequency. Furthermore, it can be remarked that if we set \( I_{B1}=I_{B2}=I_B \) and \( I_{B3}=k I_B \) by using a programmable current mirror [13]. The pole frequency and quality factor can be expressed as

\[
\omega_p = \frac{1}{2V_T} \sqrt{\frac{1}{C_1 C_2}},
\]

(10)

and

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

(11)

From Eqs. (10) and (11), it should be remarked that the pole frequency can be electronically adjusted by \( I_B \) without disturbing the quality factor. In addition, the high \( Q_0 \) circuit can be obtained by setting \( k \) to be small value. The bandwidth \( (BW) \) of the system can be expressed by

\[
BW = \frac{\omega_p}{Q_0} = \frac{2I_{B3}}{V_T C_1}.
\]

(12)

We found that the bandwidth can be linearly controlled by \( I_{B3} \).
2.3 Circuit Sensitivities

The sensitivities of the proposed circuit can be found as

\[ S_{i_1}^{\text{th}} = S_{i_2}^{\text{th}} = \frac{1}{2}; S_{i_1}^{\text{th}} = S_{i_2}^{\text{th}} = -\frac{1}{2}; S_{i_1}^{\text{th}} = -1, \]  
and

\[ S_{i_2}^{\text{th}} = S_{i_2}^{\text{th}} = \frac{1}{2}, \quad S_{i_1}^{\text{th}} = -\frac{1}{2}, \quad S_{i_1}^{\text{th}} = -1, \]  

(13)

Therefore, all the active and passive sensitivities are equal or less than unity in magnitude.

2.4 Non-Ideal Case

In practice, the DO-CCCDBA is possible to work with non-ideality. Its properties will change to

\[ I_{1z} = \alpha_z \alpha_p \alpha_n \beta_p \beta_3, \]  

\[ I_{2z} = \gamma_z \gamma_p \gamma_n \gamma_3 \beta_p \beta_3, \]  

and

\[ V_u = \beta \gamma_{z1}, \]  

(17)

where \( \alpha_p, \alpha_n, \gamma_p, \gamma_n, \) and \( \beta \) are transferred error values deviated from one. In the non-ideal case, reanalyzing the proposed filter circuit in Fig. 2 yields the transfer functions as

\[ I_{BP} = \frac{\gamma_n \alpha_p \alpha_n \beta_p \beta_3}{C_C R_m R_p} D_n(s), \]  

(19)

\[ I_{HP} = \frac{\gamma_n \alpha_p \alpha_n \beta_p \beta_3}{s C_C R_m R_p} D_n(s), \]  

and

\[ I_{BP} = \frac{\alpha_p \alpha_n \gamma_p \beta_3}{C_C R_m R_p} \cdot \]  

(20)

Hence,

\[ D_n(s) = s^2 + \frac{\alpha_p \beta_3}{s C_C R_m} + \frac{\alpha_n \alpha_p \alpha_n \beta_p \beta_3}{C_C R_m R_p}. \]  

(22)

In this case, the \( \alpha_0, Q_0, \) and \( BW \) are respectively changed to

\[ \omega_0 = \frac{\alpha_p \alpha_n \alpha_p \alpha_n \beta_p \beta_1}{C_C C_m R_m R_p}, \]  

\[ Q_0 = \frac{R_1}{\alpha_p \beta_1 \alpha_n \beta_3 \alpha_p \beta_3 C_C C_m R_m R_p}, \]  

and

\[ BW = \frac{\alpha_p \beta_3}{Q_0 C_C R_m}. \]  

(23)

Practically, the \( \alpha, \gamma, \) and \( \beta \) originate from intrinsic resistances and stray capacitances in the DO-CCCDBA. These errors affect the sensitivity to temperature and high frequency response of the proposed circuit, thus the DO-CCCDBA should be carefully designed to minimize these errors. Consequently, these deviations should be very small and can be ignored.

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 respectively using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [14]. Fig. 3 depicts the schematic description of the DO-CCCDBA used in the simulations. The circuit was biased with \( \pm1.5V \) supply voltages and \( I_1=100\mu A \). \( C_1=C_2=10nF \) and \( I_{B1}=I_{B2}=I_{B3}=50\mu A \) are chosen to obtain intrinsic resistance values of 260Ω. It yields the natural frequency of 54.075kHz, while the calculated value of this parameter from Eq. (8) is 61.24kHz. The results shown in Fig. 4 are the gain responses of the proposed biquad filter obtained from Fig. 2. This clearly shows that the proposed biquad circuit can provide simultaneous low-pass, high-pass and band-pass functions without modifying circuit topology. Fig. 5 displays gain responses of the band-pass function for different \( I_{B1} \) values, showing that the quality factor can be adjusted by the input bias current \( I_{B1} \), as depicted in Eq. (12) without affecting the pole frequency. Fig. 6 shows the gain responses of the band-pass function where \( I_{B1} \) is set to 20\( \mu A \), 100\( \mu A \), and 500\( \mu A \), respectively, \( C_1=100nF, C_2=1nF \), and \( k=0.5 \). This shows that pole
frequency can be adjusted without affecting the quality factor, as analyzed in Eqs. (10) and (11). Maximum power consumption is about 2.86mW.

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; 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 3 DO-CCCDBAs and 2 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.

References


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