High-input Impedance Voltage-mode Universal Filter Using CCCCTAs

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Abstract—This article presents a voltage-mode universal biquadratic filter (low-pass, high-pass, band-pass functions), based on current controlled current conveyor transconductance amplifiers (CCCCTAs). 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 CCCCTAs and 2 grounded capacitors. Without any external resistors, requiring no 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 voltage-mode, due to high-input impedances. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation. The power consumption is approximately 4.08mW at ±2.5V power supply voltages.

I. INTRODUCTION

In analog signal processing applications, it may be desirable to employ active filters. They can be found in many applications: e.g., communication, measurement and instrumentation and control systems [1-2]. One of most popular analog filters is a multi-function filter since it can provide several functions, depending on desired selections.

The literature surveys show that several voltage-mode multi-function filter circuits [3-13] have been reported. Unfortunately, these reported circuits suffer from one or more of following weaknesses:

- Excessive use of the active and/or passive elements [3, 5-6, 7, 9, 11, 13, 14].
- Requirement for changing circuit topologies to achieve several functions [4, 9, 12].
- Lack of electronic adjustability [3-9, 11-12].
- The pole frequency and quality factor cannot be tuned independently [8-9].

The current conveyor transconductance amplifier (CCTA) is a reported active component, especially suitable for a class of analog signal processing [15-16]. The current conveyor transconductance amplifier (CCTA) is a reported active component, especially suitable for a class of analog signal processing [15-16]. The fact that the 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, high speed, wide bandwidth and simple implementation [15]. However, the CCTA cannot controlled by the parasitic resistance at X ($R_x$) port so when it is used in some circuits, it must unavoidably require some external passive components, especially the resistors. This makes it not appropriate for IC implementation due to occupying more chip area, high power consumption and without electronic controllability. On the other hand, the introduced current-controlled current conveyor transconductor amplifier (CCCCTA) [17] has the advantage of electronic adjustability over the CCTA.

The aim of this paper is to propose a voltage-mode multi-function filter, emphasizing on use of the CCCCTA. The features of proposed circuit are that: the proposed universal filter can provide completely standard functions (low-pass, high-pass and band-pass) without changing circuit topology: the circuit description is very simple, it uses only 2 grounded capacitors as passive elements, which is suitable for fabricating in either monolithic chip or off-the-shelf implementation: quality factor and pole frequency can be independently adjusted. The performances of proposed circuit are illustrated by PSPICE simulations, they show good agreement as mentioned.

II. PRINCIPLE OF OPERATION

A. Basic Concept of CCCCTA

The CCCCTA properties are similar to the conventional CCTA, except that the CCCCTA has finite input resistance $R_x$ at the x input terminal [17-18]. This parasitic resistance can be controlled by the bias current $I_{bi}$ as shown in the following equation

$$
\begin{bmatrix}
I_x \\
V_x \\
I_z \\
V_z
\end{bmatrix}
=
\begin{bmatrix}
0 & 0 & 0 & 0 \\
R_x & 1 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 0 & g_m & 0
\end{bmatrix}
\begin{bmatrix}
I_x \\
V_x \\
I_z \\
V_z
\end{bmatrix},
$$

(1)
where

\[ R_x = \frac{V_T}{2I_{B1}}, \quad (2) \]

and

\[ g_m = \frac{I_{B2}}{2V_T}. \quad (3) \]

\( g_m \) is the transconductance of the CCCCTA, \( V_T \) is the thermal voltage and \( I_{B2} \) is the bias current used to control the transconductance. The symbol and the equivalent circuit of the CCCCTA are illustrated in Figs. 1(a) and (b), respectively.

**B. Proposed Voltage-mode Universal Filter**

The proposed voltage-mode universal filter is shown in Fig. 2. Straightforward analysis of the circuit in Fig. 2 and using the CCCCTA properties in Section II.A, we will receive the transfer functions at each terminal as

\[ V_{LP} = \frac{1}{s^2 + \frac{s}{g_{m2}} + \frac{g_{m3}}{C_iC_2R_{12}R_{23}g_{m1}}}, \quad (4) \]

\[ V_{HP} = \frac{-s^2}{s^2 + \frac{s}{g_{m2}} + \frac{g_{m3}}{C_iC_2R_{12}R_{23}g_{m1}}}, \quad (5) \]

\[ V_{BP} = \frac{-s^m}{s^2 + \frac{s}{g_{m2}} + \frac{g_{m3}}{C_iC_2R_{12}R_{23}g_{m1}}}. \quad (6) \]

Moreover, the band-stop and the all-pass functions can be obtained, combining the currents \( V_{BS}=V_{HP}+V_{LP} \) and \( V_{AP}=V_{BS}-V_{BP} \), respectively. From (4)-(6), it is clearly seen that the proposed circuit can perform low-pass (\( V_{LP} \)), high-pass (\( V_{HP} \)) and band-pass (\( V_{BP} \)) functions at the same time without modifying circuit topology. The pole frequency (\( \omega_0 \)) and quality factor (\( Q_0 \)) of each filter response can be expressed as

\[ \omega_0 = \sqrt{\frac{g_{m3}}{C_iC_2R_{12}R_{23}g_{m1}}}, \quad (7) \]

\[ Q_0 = \frac{1}{\sqrt{\frac{C_iC_2R_{12}g_{m1}g_{m3}}{C_iR_{23}}}}. \quad (8) \]

From (7) and (8), we find that the quality factor can be adjusted independently from the pole frequency by varying \( I_{B4} \). Thus bandwidth (BW) is given by

\[ BW = \frac{\omega_0}{Q_0} = \frac{I_{B3}I_{B4}}{C_iV_IJ_{B2}}. \quad (11) \]

Furthermore, it can be remarked that if \( I_{B2}=I_{B6}=I_{BQ} \) and \( I_{B3}=I_{B5}=I_{B} \). The pole frequency and quality factor can be expressed as...
\[ \omega_0 = \frac{2I_B}{V_T} \sqrt{\frac{1}{C_1C_2}}, \]  

(12)

\[ Q_0 = \frac{I_{BQ}}{I_{B4}} \sqrt{\frac{C_1}{C_2}}, \]  

(13)

From (12), it should be remarked that the pole frequency can be electronically adjusted by \( I_B \) without disturbing the quality factor. Moreover, the quality factor can be tuned by \( I_{BQ} \) or \( I_{B4} \) without effect to pole frequency as shown in (13).

C. Circuit Sensitivities

From (8)-(10), the sensitivities of the proposed circuit can be found as

\[ S_{\omega_0} = S_{Q_0} = S_{\omega_0} = \frac{1}{2}; \quad S_{c_1} = S_{c_2} = S_{r_6} = -\frac{1}{2}; S_{r_7} = -1, \]  

(14)

\[ S_{\omega_0} = S_{Q_0} = S_{\omega_0} = \frac{1}{2}; \quad S_{c_1} = S_{c_2} = S_{r_6} = -\frac{1}{2}; S_{r_7} = -1, \]  

(15)

\[ S_{\omega_0} = S_{Q_0} = 1; \quad S_{r_7} = S_{r_7} = S_{r_7} = -1. \]  

(16)

Therefore, all the active and passive sensitivities are equal or less than unity in magnitude and the circuit exhibits a satisfactory sensitivity performance.

D. Non-Ideal case

For non-ideal case, the CCCCTA can be respectively characterized with the following equations

\[ V_r = \beta V_r + I_r r, \]  

(17)

\[ I_z = \alpha I_z, \]  

(18)

and

\[ I_v = \gamma g_m V_z, \]  

(19)

where \( \alpha \) is the frequency dependent current gain, besides \( \beta \) and \( \gamma \) are the frequency dependent voltage gains. These gains are ideally equal to unity. In practical, they depend on the frequency of operation, temperature and transistor parameters of the CCCCTA.

In the case of non-idea and reanalyzing the proposed filter in Fig. 2, it yields the transfer functions as

\[ V_{LP} = \frac{-\beta_3}{\gamma_3 g_m R_{32} R_{33}} \frac{\beta_3}{\gamma_3 g_m R_{32} R_{33}}, \]  

(20)

In this case, the \( \omega_0 \) and \( Q_0 \) are changed to

\[ \omega_0 = \sqrt{\frac{\gamma_3 \beta_3 g_m R_{32} R_{33}}{\gamma_1 C_1 C_2 R_{32} R_{33} g_m}}, \]  

(23)

\[ Q_0 = \frac{1}{\gamma_3 g_m R_{32} R_{33}} \sqrt{\frac{\gamma_1 C_1 C_2 R_{32} R_{33} g_m}{\beta_3 C_3}}. \]  

(24)

Practically \( \alpha \), \( \gamma \) and \( \beta \) originate from intrinsic resistances and stray capacitances in the CCCCTA. These errors affect the sensitivity to temperature and high frequency response of the proposed filter, then the CCCCTA should be carefully designed to achieve these errors as low as possible. Consequently, these deviations are very small and can be ignored.

III. Simulation Results

To prove and investigate the performances of the proposed circuit, the PSPICE simulation program was used. 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 [19]. Fig. 3 depicts schematic description of the CCCCTA used in the simulations. All CCCCTAs were biased with ±2.5V power supplies, all bias currents are 50µA and \( C_1 = C_2 = 2.2nF \). It yields the pole frequency of 264kHz, while calculated value of these parameter from (9) is 278kHz (deviated by 5.04%). The results shown in Fig. 4 are the gain responses of the universal filter obtained from Fig. 2. There are clearly seen that the proposed filter can provide simultaneous low-pass, high-pass and band-pass functions, without modifying circuit topology. Figs. 5 and 6 display gain responses of band-pass function for different \( I_{B4} \) and \( I_{BQ} \) values, respectively. It is shown that the quality factor can be adjusted by \( I_{B4} \) and \( I_{BQ} \) as depicted in (13) without affecting the pole frequency. Fig. 7 shows the gain responses of the band-pass function where \( I_{B3}=I_{B5}=I_B \) is set to 25µA, 50µA, and 100µA, respectively. This shows that pole frequency can be adjusted without affecting the quality factor, as analyzed in (12). Maximum power consumption is about 4.08mW.
REFERENCES


