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Electronically Tunable Low-Component-Count Current-Mode Biquadratic Filter Using CFTAs

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Abstract. This article presents a current-mode KHN multifunction biquadratic filter performing simultaneous 3 standard functions: low-pass, high-pass and band-pass functions, based on current follower transconductance amplifiers (CFTAs). The features of the circuit are that: the pole frequency and quality factor can be electronically tuned via the input bias currents. The circuit topology is very simple, consisting of merely 2 CFTAs and 2 grounded capacitors. Without any external resistor and using only grounded elements, the proposed circuit is very comfortable to further develop into an integrated circuit. The PSPICE simulation results are shown. The given results agree well with the theoretical anticipation. The maximum power consumption is approximately 4.38W at ±1.25V power supply voltages.

Keywords: KHN filter, Current mode, CFTA

1. Introduction

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 mutifunction filter, since it can provide several functions in the same time. It has been accepted that the Kerwin–Huelsman–Newcomb (KHN) biquad filter is also the more popular multifunction filter structure. Because this structure offers several advantages such as low passive and active sensitivity performance, low component spread and good stability behavior [3-4]. The KHN filters have been realized by employing different high-performance active building blocks.

The voltage-mode KHN filters based on CCIIs [5-6], CDBAs [7], DVCC [8], DDCC [9], and op-amps have been developed. These reported circuits provide good performances but they suffer from some disadvantages for example, excessive use of the passive elements especially external resistors, lack of electronic adjustability, limitation at high frequency performance due to gain-bandwidth of op-amp. The CCCII [10] and OTA [11] based voltage-mode KHN filter enjoy electronic tunability. Unfortunately, the circuit in [10] requires the use of large number of CCCIIs (5 CCCIIs).

Recently, the multifunction filters working in current-mode have 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 [12].

The current-mode KHN filter based on different high-performance current-mode active components are reported in literature [10, 13-15]. But, some of these circuits require more active elements which makes the circuit becoming more complicated and higher power consumption.

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The current follower transconductance amplifier (CFTA) is a recently reported active component. It seem to be a versatile component in the realisation of a class of analog signal processing circuits, especially analog frequency filters [16]. It is really current-mode element whose input and output signals are currents. In addition, it can also adjust the output current gain.

The aim of this paper is to propose a current-mode KHN filter, emphasizing on use of CFTAs and grounded capacitors. The features of the proposed circuit are as follows: It can provide 3 transfer functions such as low-pass, high-pass and band-pass without changing the circuit topology. The circuit configuration is very simple, employing only grounded capacitors as passive components, thus it is suitable for fabricating in monolithic chip. The quality factor and pole frequency can be electronically adjusted.

2. Circuit Principle

2.1. Basic concept of CFTA

The schematic symbol and the ideal behavioural model of the CFTA are shown in Fig. 1(a) and (b). It has one low-impedance current input f port. The current if flows from port z. In some applications, to utilize the current through z terminal, an auxiliary z_c (z-copy) terminal is used [17]. The internal current mirror provides a copy of the current flowing out of the z terminal to the zc terminal. The voltage v_z on z terminal is transferred into current using transconductance gm, which flows into output terminal x. The gm is tuned by IB. In general, CFTA can contain an arbitrary number of x terminals, providing currents Ix of both directions. The characteristics of the ideal CFTA are represented by the following hybrid matrix:

$$\begin{bmatrix} V_f \\ I_{z,zc} \\ I_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & \pm g_m \end{bmatrix} \begin{bmatrix} I_f \\ V_x \\ V_z \end{bmatrix}. \tag{1}$$

For CMOS CFTA, the gm is written as

$$g_m = \sqrt{kI_B}\ , \tag{2}$$

where $k = \mu_O C_{OX}(W/L)$. Here k and I_B are the physical transconductance parameter of the MOS transistor and input bias current, respectively.

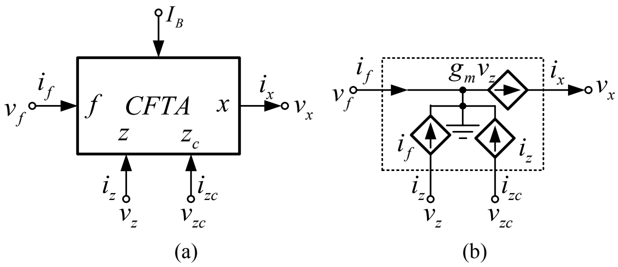

Fig. 1: CFTA (a) Symbol (b) Equivalent circuit.

2.2. General structure of KHN biquad filter

A KHN structure consists of two integrator blocks and a summer block as shown in Fig. 2. From block diagram in Fig. 2, the transfer functions of HP, BP and LP can be respectively expressed as follows:

$$\frac{Y_{HP}}{X_{in}} = \frac{s^2}{s^2 + s\frac{1}{\tau_1} + \frac{1}{\tau_1\tau_2}},\ \frac{Y_{BP}}{X_{in}} = \frac{s\frac{1}{\tau_1}}{s^2 + s\frac{1}{\tau_1} + \frac{1}{\tau_1\tau_2}} \text{ and } \frac{Y_{LP}}{X_{in}} = \frac{\frac{1}{\tau_1\tau_2}}{s^2 + s\frac{1}{\tau_1} + \frac{1}{\tau_1\tau_2}}. \tag{3}$$

From Eq. (3), the pole frequency and quality factor can be expressed as

$$\omega_0 = \sqrt{\frac{1}{\tau_1\tau_2}} \text{ and } Q_0 = \sqrt{\frac{\tau_1}{\tau_2}} . \tag{4}$$

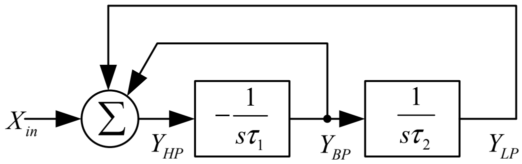

Fig. 2: Fundamental KHN structure.

2.3. Proposed KHN biquad filter

As mentioned in above section, the proposed KHN filter is based on two integrator blocks and a summer block. This topology can be realized by using 2 CFTAs and 2 grounded capacitors as shown in Fig. 3. The current transfer function can be obtained as follows:

$$\frac{I_{HP}}{I_{in}} = \frac{s^2}{s^2 + s\frac{g_{m1}}{C_1} + \frac{g_{m1}g_{m2}}{C_1C_2}}, \quad \frac{I_{BP}}{I_{in}} = \frac{s\frac{g_{m1}}{C_1}}{s^2 + s\frac{g_{m1}}{C_1} + \frac{g_{m1}g_{m2}}{C_1C_2}} \text{ and } \frac{I_{LP}}{I_{in}} = \frac{\frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + s\frac{g_{m1}}{C_1} + \frac{g_{m1}g_{m2}}{C_1C_2}} . \tag{5}$$

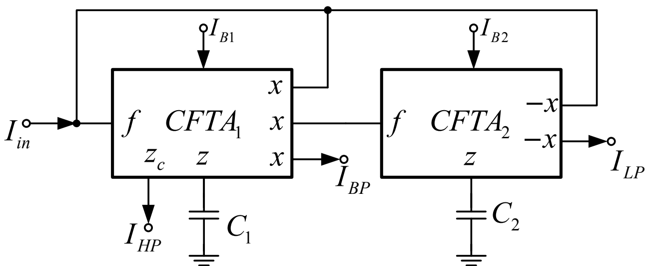

Fig. 3: Proposed current-mode KHN filter.

From Eq. (5), the pole frequency and quality factor can be expressed as

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \text{ and } Q_0 = \sqrt{\frac{C_1 g_{m2}}{C_2 g_{m1}}} . \tag{6}$$

Substituting the transconductance as depicted in Eq. (2) into Eq. (6), it yields pole frequency and quality factor as follows:

$$\omega_0 = \sqrt{\frac{(k_1k_2I_{B1}I_{B2})^{\frac{1}{2}}}{C_1C_2}} \text{ and } Q_0 = \sqrt{\frac{C_1(k_2I_{B2})^{\frac{1}{2}}}{C_2(k_1I_{B1})^{\frac{1}{2}}}} . \tag{7}$$

From Eqs. (7), by maintaining the ratio I_{B1} and I_{B2} to be constant, it can be remarked that the pole frequency can be adjusted by I_{B1} and I_{B2} without affecting the quality factor. Moreover, the circuit can provide high Q_0 by setting value of C_1 more than value of C_2. The filter bandwidth (BW) can be expressed as follows

$$BW = \frac{\omega_0}{Q_0} = \frac{\sqrt{k_1 I_{B1}}}{C_1} . \tag{8}$$

Note that the bandwidth can be controlled by I_{B1}.

2.4. Circuit sensitivities

The sensitivities of the proposed circuit can be found as

$$S_{I_{B1}}^{\omega_0} = S_{I_{B2}}^{\omega_0} = S_{k_1}^{\omega_0} = S_{k_2}^{\omega_0} \frac{1}{4};\ S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = -\frac{1}{2};\ S_{I_{B2}}^{Q_0} = S_{k_2}^{Q_0} = \frac{1}{4}; S_{C_1}^{Q_0} = \frac{1}{2};\ S_{I_{B1}}^{Q_0} = S_{k_1}^{Q_0} = -\frac{1}{4}; S_{C_2}^{Q_0} = -\frac{1}{2}. \quad (9)$$

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

3. Simulation Results

To prove the performances of the proposed filter, the PSPICE simulation program was used for the examinations. The PMOS and NMOS transistors have been simulated by respectively using the parameters of a 0.25µm TSMC CMOS technology [18]. The dimensions of transistors M_1 and M_2 are W=1µm and L=0.25µm, M_{15} and M_{16} are W=25µm and L=0.25µm, other PMOSs and NMOSs are W=5µm and L=0.25µm and W=3µm and L=0.25µm, respectively. Fig. 3 depicts schematic description of the CFTA used in the simulations. The circuit was biased with ±1.25V supply voltages, V_{BB}=-0.55V, C=0.1nF, $I_{B1}=I_{B2}$=110µA. Loads of the circuit are 1Ω of resistor. It yields the pole frequency of 2.34MHz. The results shown in Fig. 5 are the gain responses of the proposed KHN biquad filter. It clearly shows that this circuit can provide simultaneously low-pass, high-pass and band-pass responses without modifying the circuit topology. Fig. 6 displays gain responses of band-pass function with different I_{B1} values. It is shown that the bandwidth of the responses can be adjusted by the input bias current I_{B1}. Fig. 7 shows gain responses of band-pass function where I_{B1} and I_{B2} are equally set to keep the ratio to be constant and changed for several values. It is found that pole frequency can be adjusted without affecting the quality factor. Maximum power consumption is about 4.38mW.

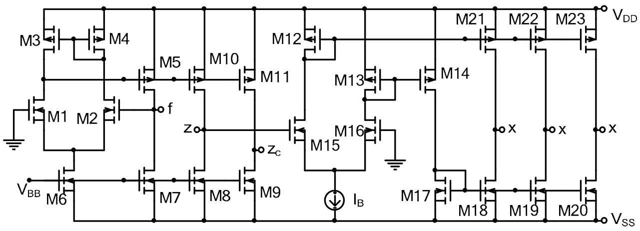

Fig. 4: Internal construction of CFTA.

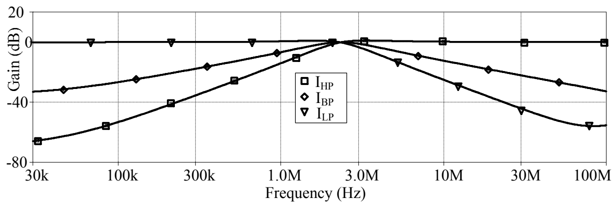

Fig. 5: Gain responses of proposed circuit.

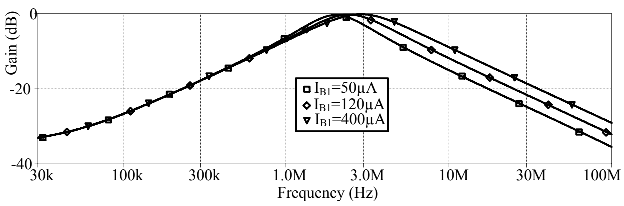

Fig. 6: Band-pass responses for different values of I_{B1}.

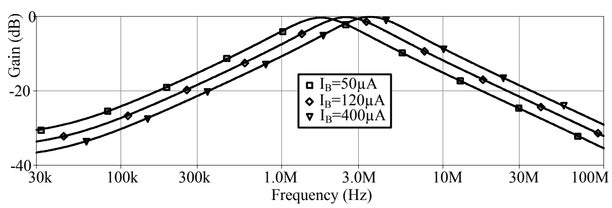

Fig. 7: Band-pass responses for different values of I_{B1} and I_{B2} with keeping their ratios constant ($I_{B1}=I_{B2}=I_B$).

4. Conclusions

A current-mode KHN biquad filter based on CFTA has been presented. The features of the proposed circuit are that: pole frequency and quality factor can be electronically adjusted via input bias currents. The circuit description comprises only 2 CFTAs and 2 grounded capacitors. With mentioned features, it is very suitable to realize the proposed circuit in monolithic chip to use in battery-powered, portable electronic equipments such as wireless communication system devices.

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