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Current-mode KHN Filter Using Single CC-CCTA

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Abstract
This article presents a current-mode KHN multifunction biquadratic filter performing 3 standard functions in the same time: low-pass, high-pass and band-pass functions, based on only single current controlled current conveyor transconductance amplifier (CC-CCTA). 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 single CC-CCTA 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 1.42mW at ±1.5V power supply voltages.

Keywords: KHN filter, CC-CCTA

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 [11] requires the use of large number of CCCIIs (5 CCCIIs). Moreover, the OTA-based circuit is known to be restrained by limited operating range and output voltage swing.

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.

A reported 5-terminals active element, namely current conveyor transconductance amplifier (CCTA) [16] has been proposed in 2005, it seems to be a versatile component in the realization of a class of analog signal processing circuits, especially analog frequency filters. It can be also function in both voltage-mode and current-mode signal processing systems. In addition, its output current gain can also be adjusted. However, the CCTA cannot be controlled by the parasitic resistances at two current input ports [16]. Recently, Jaikla and Siripruchyanun have proposed the modified-version CCTA, whose parasitic resistances at two current input ports can be controlled by an input bias current. It is newly named current controlled current conveyor transconductance amplifier (CC-CCTA) [17]. It seems to be a useful building block, since many circuits and systems can be implemented by employing only single CC-CCTA.

The aim of this paper is to propose a current-mode KHN filter, emphasizing on use of single CC-CCTA 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.

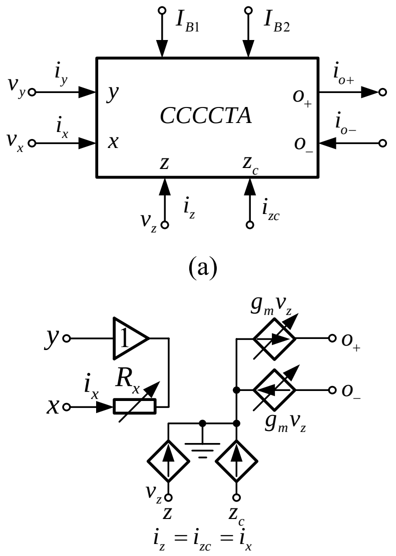

Figure 1. CC-CCTA (a) Symbol (b) Equivalent circuit.

2. Circuit Principle

2.1 Current controlled current conveyor transconductance amplifier (CC-CCTA)

Since the proposed circuit is based on CC-CCTA, a brief review of CC-CCTA is given in this section. Generally, CC-CCTA properties are similar to the conventional CCTA, except that input voltages of CC-CCTA are not zero and the CC-CCTA has finite input resistance R_x at the x input terminal. This parasitic resistance are can be controlled by the bias current I_{B1} as shown in the following equation [17]

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix}. \quad (1)$$

For a BJT CC-CCTA, the R_x and g_m can be expressed to be

$$R_x = \frac{V_T}{2I_{B1}} \quad (2)$$

and

$$g_m = \frac{I_{B1}}{2V_T}, \quad (3)$$

where I_B and V_T are the bias current and the thermal voltage, respectively.

Generally, CC-CCTA can contain an arbitrary number of o terminals, providing currents I_o of both directions. In the same way, the number of z terminals can be arbitrarily included by using the internal current mirror to provide a copy of the current flowing out of the z terminal to the another z terminals (called z_c terminal). As an example, the symbol and the equivalent circuit of the CC-CCTA with a pair of o+ , o-, z, and z_c terminals are illustrated in Fig. 1(a) and (b), respectively..

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:

$$\frac{Y_{HP}}{X_{in}} = \frac{s^2}{s^2 + s\frac{1}{\tau_1} + \frac{1}{\tau_1 \tau_2}}, \quad (4)$$

$$\frac{Y_{BP}}{X_{in}} = \frac{s\frac{1}{\tau_1}}{s^2 + s\frac{1}{\tau_1} + \frac{1}{\tau_1 \tau_2}} \quad (5)$$

and

$$\frac{Y_{LP}}{X_{in}} = \frac{\frac{1}{\tau_1 \tau_2}}{s^2 + s\frac{1}{\tau_1} + \frac{1}{\tau_1 \tau_2}}. \quad (6)$$

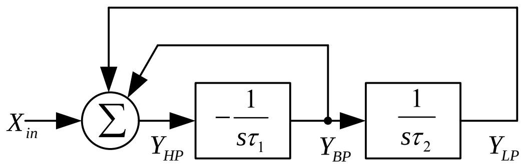

Figure 2. Fundamental KHN structure.

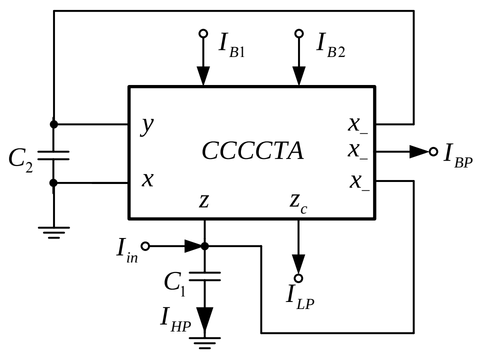

Figure 3. Current-mode KHN filter.

The pole frequency and quality factor can be expressed as

$$\omega_0 = \sqrt{\frac{1}{\tau_1 \tau_2}} \quad (7)$$

and

$$Q_0 = \sqrt{\frac{\tau_1}{\tau_2}} . \quad (8)$$

2.3 The proposed current-mode KHN 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 single CC-CCTA and two grounded capacitors as shown in Fig. 3. The current transfer function can be obtained as follows:

$$\frac{I_{HP}}{I_{in}} = \frac{s^2}{s^2 + s\frac{g_m}{C_1} + \frac{g_m}{C_1 C_2 R_x}} , \quad (9)$$

$$\frac{I_{BP}}{I_{in}} = \frac{s\frac{g_m}{C_1}}{s^2 + s\frac{g_m}{C_1} + \frac{g_m}{C_1 C_2 R_x}} \quad (10)$$

and

$$\frac{I_{LP}}{I_{in}} = \frac{\frac{g_m}{C_1 C_2 R_x}}{s^2 + s\frac{g_m}{C_1} + \frac{g_m}{C_1 C_2 R_x}} . \quad (11)$$

From Eqs. (9)-(11), the pole frequency and quality factor can be expressed as

$$\omega_0 = \sqrt{\frac{g_m}{C_1 C_2 R_x}} \quad (12)$$

and

$$Q_0 = \sqrt{\frac{C_1}{C_2 g_m R_x}} . \quad (13)$$

Substituting the intrinsic resistance and transconductance as depicted in Eqs. (2) and (3) into Eqs. (12) and (13), it yields pole frequency and quality factor as follows:

$$\omega_0 = \frac{1}{V_T}\sqrt{\frac{I_{B1} I_{B2}}{C_1 C_2}} \quad (14)$$

and

$$Q_0 = 2\sqrt{\frac{C_1 I_{B1}}{C_2 I_{B2}}} . \quad (15)$$

From Eqs. (14) and (15), 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:

$$BW = \frac{\omega_0}{Q_0} = \frac{I_{B2}}{2 V_T C_1} . \quad (16)$$

Note that the bandwidth can be linearly controlled by I_{B2}.

2.4 Circuit Sensitivities

The sensitivities of the proposed circuit can be found as

$$S^{\omega_0}_{I_{B1}} = S^{\omega_0}_{I_{B2}} = 1;\ S^{\omega_0}_{C_1} = S^{\omega_0}_{C_2} = -\frac{1}{2};\ S^{\omega_0}_{V_T} = -1 \quad (16)$$

and

$$S^{Q_0}_{I_{B1}} = S^{Q_0}_{C_1} = \frac{1}{2};\ S^{Q_0}_{I_{B2}} = S^{Q_0}_{C_2} = -\frac{1}{2} . \quad (17)$$

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

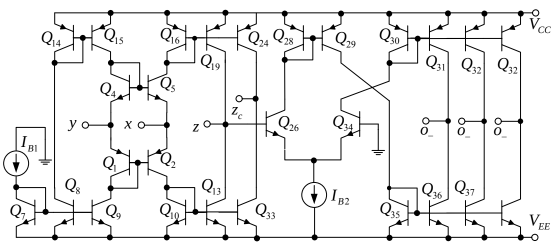

Figure 4. Internal construction of CC-CCTA

3. Simulation Results

To prove the performances of the proposed filter, the PSPICE simulation program was used for the examinations. 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 [18]. Fig. 4 depicts schematic description of the CC-CCTA used in the simulations. The circuit was biased with $\pm 1.5V$ supply voltages. Load of the circuit is 1Ω of resistor. $C_1 = C_2 = 1nF$ and $I_{B1} = 50\mu A$ and $I_{B2} = 200\mu A$ are chosen. It yields the pole frequency of 572kHz, while calculated value of this parameter from Eq. (14) is 612kHz. 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_{B2} values. It is shown that the bandwidth of the responses can be adjusted by the input bias current I_{B2}. 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 1.42mW.

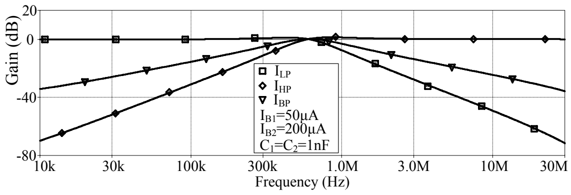

Figure 5. Gain responses of proposed circuit

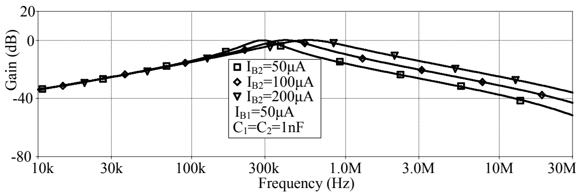

Figure 6. Band-pass responses for different values of I_{B2}.

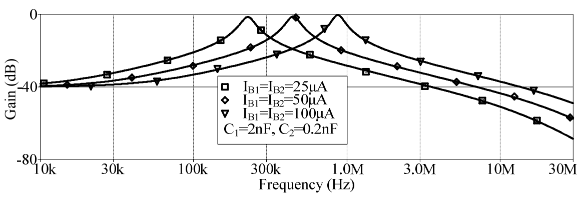

Figure 7. Band-pass responses for different values of I_{B1} and I_{B2} with keeping their ratios constant.

4. Conclusions

A current-mode KHN biquad filter based on single CC-CCTA 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 single CC-CCTA 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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