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Synthesis of a Biquadratic Transadmittance Filter

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ABSTRACT

This paper focuses on a novel biquadratic filter using five kinds of current-mode active elements which are the current differencing buffered amplifier (CDBA), plus-type of differential difference current conveyor (DDCC+), current feedback amplifier (CFA) and plus-type and minus-type of second generation current conveyor (CCII±) to eliminate the redundant terminals. Furthermore it uses two capacitors and eight resistors. All capacitors and resistors in the circuit are grounded and suitable for integrated circuit implementation. The circuit of the proposed filter offers several advantages, such as high input and output impedances, low sensitivities to passive elements, and of use in controlling ω_0 and Q with the values of capacitors and resistors, respectively. An example is given. The active devices of the proposed circuit have been simulated by Hspice using 0.5 μm CMOS technology.

Key words: *CDBA, DDCC+, CFA, CCII±, biquadratic filter, current conveyors.*

I. Introduction

Current-mode circuits techniques have received wide attention due to the high accuracy, inherently wide bandwidth, greater linearity, higher slew-rate, lower power consumption, simple circuit configurations and better dynamic range [1,2]. Moreover, many papers using current-mode devices are published in the literature [3-6], and the above advantages are also verified. This paper proposes a method for realizing transfer functions based on CDBA, DDCC+, CFA, CCII±, two grounded capacitors and eight grounded resistors. The advantages of this proposed circuit are the angular frequency and the quality factor can be adjustable individually through grounded passive elements. The use of grounded capacitors and grounded resistors is particularly attractive for integrated circuit implementation [7,8]. In addition, the circuit has high input and output impedances, so it is cascadable.

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II. Circuit Description and Principle

A. Current Differencing Buffered Amplifier (CDBA)

The current differencing buffered amplifier (CDBA) was introduced by Acar and Ozoguz in 1999 [9]. The circuit symbol and its CMOS implementation are shown in Fig. 1 and Fig. 2, respectively. A CDBA is a four terminal analog building block, and it is characterized by the following set of equations:

$$V_{X1} = V_{X2} = 0$$

$$I_Z = I_{X1} - I_{X2}$$

$$V_O = V_Z$$

B. Differential Difference Current Conveyor (DDCC)

The DDCC was introduced by W. Chiu, S. I. Liu, H. W. Tsao, and J. J. Chen in 1996 [10]. The circuit symbol and its CMOS implementation are shown in Fig. 3 and Fig. 4, respectively.

A DDCC is a five-port network, and it is characterized by the following set of equations:

$$I_{Y1} = I_{Y2} = I_{Y3} = 0$$

$$V_X = V_{Y1} - V_{Y2} + V_{Y3}$$

$$I_Z = \pm I_X$$

The plus and minus signs in above characteristics represent the plus-type or the minus-type of DDCC, respectively. This paper uses the plus-type of DDCC only.

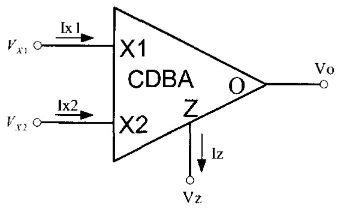

Fig. 1 The circuit symbol of CDBA.

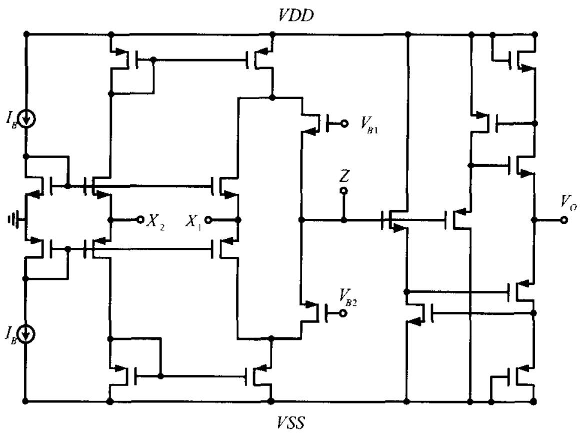

Fig. 2 A CMOS implementation of CDBA.

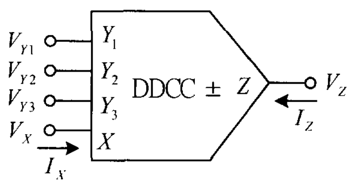

Fig. 3 The circuit symbol of DDCC+.

C. Current Feedback Amplifier (CFA)

Fig. 5 and 6 show the circuit symbol and CMOS implementation of current-feedback amplifier (CFA). Actually, the CFA is equivalent to the combination of a CCII+ and a voltage buffer [11], and it is characterized by the following set of equations:

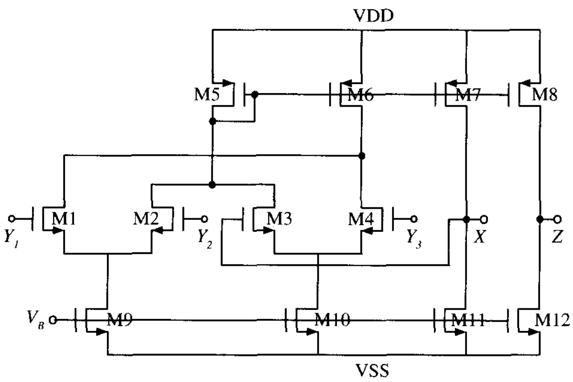

Fig. 4 A CMOS implementation of DDCC+.

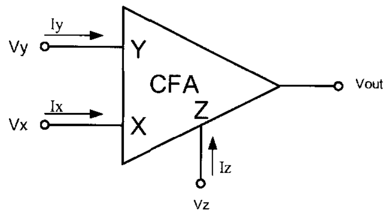

Fig. 5 The circuit symbol of CFA.

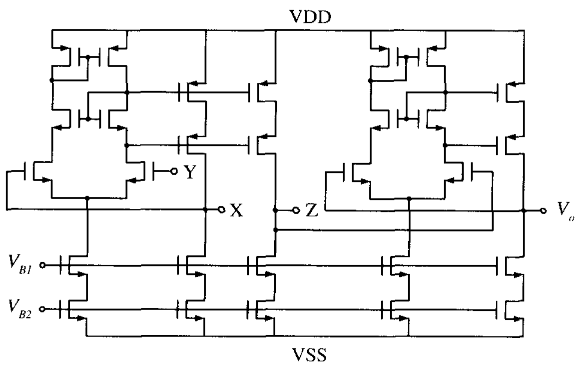

Fig. 6 A CMOS implementation of CFA.

$$V_Y = V_X$$

$$I_Y = 0$$

$$I_Z = I_X$$

$$V_O = V_Z$$

D. Second-Generation Current Conveyor (CCII)

The second-generation current conveyor (CCII) was proposed by Sedra and Smith in 1970 [12]. The circuit symbol and its CMOS implementation are shown in Figs. 7~9, respectively.

The CCII is a three-port network, and it is characterized by the following set of equations:

$$V_X = V_Y$$

$$I_Z = \pm I_X$$

$$I_Y = 0$$

The plus and minus signs in above characteristics represent the plus-type or the minus-type of CCII. This paper uses both plus-type and minus-type of CCII.

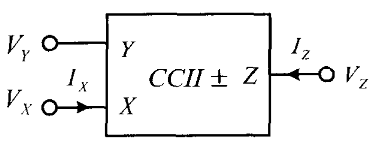

Fig. 7 The circuit symbol of CCII.

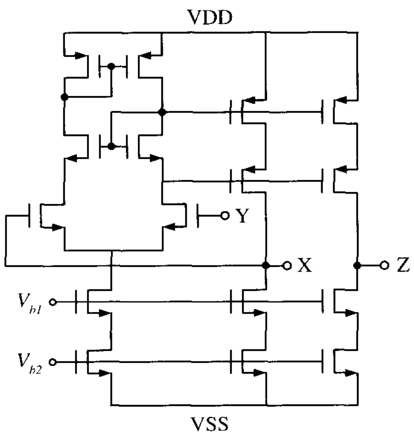

Fig. 8 A CMOS implementation of CCII+.

E. Circuit method

In this section, let us consider the realization of the biquadratic transfer function

$$\frac{I_2}{V_1} = \frac{a_{2b}s^2 + a_{1b}s + a_{0b}}{s^2 + b_{1b}s + b_{0b}} \tag{1}$$

The function can be realized with Fig. 10.

This circuit consists of five kinds of current-mode active elements, two grounded capacitors and eight grounded resistors. In Fig. 10, V_{hp}, V_{bp} and V_{lp} are the highpass, bandpass and lowpass outputs individually. Furthermore, this paper uses R_{a2b}, C_{a2b}, DDCC+ as one group and R_1, C_1, CFA as the other to form an integrator. In addition, it uses R_{b0b}, R_3, CCII- as one group and R_{b1b}, R_2, CCII+, the terminal Y_2 of DDCC+ as the other to form an inverting voltage amplifier. Similarly, this paper uses R_{a2b} as one group and R_{a1b}, CCII+ as the

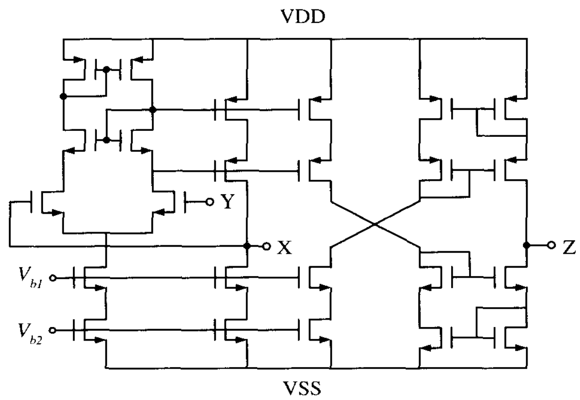

Fig. 9 A CMOS implementation of CCII-.

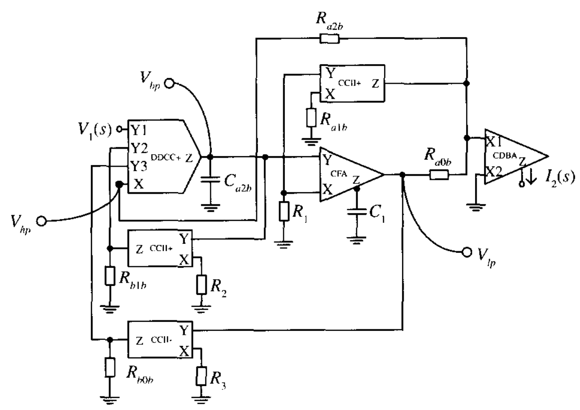

Fig. 10 The proposed biquadratic admittance circuit.

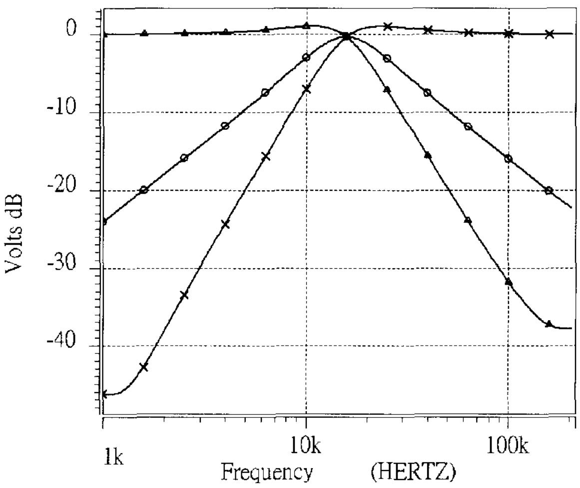

Fig. 11 Hspice simulation results of the proposed circuit. ×, simulated highpass filter response; ○, simulated bandpass filter response; △, simulated lowpass filter response.

other to form a non-inverting transconductance amplifier. As a result, the biquadratic coefficients can be individually controlled through the values of capacitors and resistors. This paper uses a CDBA and a DDCC+ to construct as summers to sum up the signals.

In Fig. 10, we can obtain Eq. (2) and Eq. (3).

$$\frac{V_{bp}(s)}{V_1(s)}=\frac{sC_1R_1R_2R_3}{s^2C_{a2b}C_1R_{a2b}R_1R_2R_3+sC_1R_{b1b}R_1R_3+R_{b0b}R_2} \tag{2}$$

$$\frac{I_2(s)}{V_{bp}(s)}=\frac{s^2C_{a2b}C_1R_{a2b}R_{a1b}R_1+sC_1R_{a0b}R_1+R_{a1b}}{sC_1R_{a0b}R_{a1b}R_1} \tag{3}$$

Multiplying Eq. (2) with Eq. (3), we can obtain Eq. (4). It is the biquadratic transfer functions for the network of Fig. 10.

$$H(s)=\frac{I_2(s)}{V_1(s)}=\frac{\frac{1}{R_{a2b}}s^2+\frac{1}{C_{a2b}R_{a1b}R_{a2b}}s+\frac{1}{C_{a2b}C_1R_{a2b}R_{a0b}R_1}}{s^2+\frac{R_{b1b}}{C_{a2b}R_{a2b}R_2}s+\frac{R_{b0b}}{C_{a2b}C_1R_{a2b}R_1R_3}} \tag{4}$$

Highpass, bandpass and lowpass transfer functions are shown in Eqs. (5), (6), (7), respectively.

$$\frac{V_{hp}}{V_1}=\frac{s^2}{D(s)} \tag{5}$$

$$\frac{V_{bp}}{V_1}=\frac{\frac{1}{C_{a2b}R_{a2b}}s}{D(s)} \tag{6}$$

$$\frac{V_{lp}}{V_1}=\frac{\frac{1}{C_{a2b}C_1R_{a2b}R_1}}{D(s)} \tag{7}$$

Where

$$D(s)=s^2+\frac{R_{b1b}}{C_{a2b}R_{a2b}R_2}s+\frac{R_{b0b}}{C_{a2b}C_1R_{a2b}R_1R_3} \tag{8}$$

The angular frequency ω_0 and quality factor Q are given by

$$\omega_0=\sqrt{\frac{R_{b0b}}{C_{a2b}C_1R_{a2b}R_1R_3}} \tag{9}$$

$$Q=\frac{R_2}{R_{b1b}}\sqrt{\frac{C_{a2b}R_{a2b}R_{b0b}}{C_1R_1R_3}} \tag{10}$$

The sensitivities of ω_0 to passive elements are

$$S^{\omega_0}_{C_{a2b}}=S^{\omega_0}_{C_1}=S^{\omega_0}_{R_{a2b}}=S^{\omega_0}_{R_1}=S^{\omega_0}_{R_3}=-S^{\omega_0}_{R_{b0b}}=-\frac{1}{2} \tag{11}$$

The sensitivities of Q to passive elements are

$$S^{Q}_{R_{b1b}}=-S^{Q}_{R_2}=-1$$

$$S^{Q}_{C_1}=S^{Q}_{R_1}=S^{Q}_{R_3}=-S^{Q}_{C_{a2b}}=-S^{Q}_{R_{a2b}}=-S^{Q}_{R_{b0b}}=-\frac{1}{2} \tag{12}$$

The sensitivities are rather small.

III. Simulation results

In this section, we consider the biquadratic characteristics with the chosen values for the passive elements: $C_{a2b}=C_1=1\text{nF}$; $R_{a1b}=R_{a0b}=1\text{K}\ \Omega$; $R_{a2b}=R_{b1b}=R_{b0b}=R_1=R_2=R_3=10\text{K}\ \Omega$. The results we choose in the center frequency of this filter and its quality factor are measured to be 15.9kHz and 1, respectively. Simulation results are shown in Fig. 11. The measured frequency responses agree well with the theory.

IV. Conclusions

In summary, the universal current-mode filter using five kinds of active elements which are the CDBA, DDCC+, CFA, CCII±, and two grounded capacitors and eight grounded resistors has been presented. The new filter offers several advantages, such as high input and output impedances, low filter sensitivities to passive elements, and of use in controlling ω_0 and Q with the values of capacitors and resistors.

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雙二階轉導濾波器的合成

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摘　要

本篇論文使用了四種型態的電流式元件以避免不必要的端點，這四種型態的元件分別是：電流差分緩衝放大器(CDBA)、差動差分電流傳輸器(DDCC)、電流回授放大器(CFA)及第二代電流傳輸器(CCII)，並且用他們來合成一個新的雙二階轉導濾波器。其中，電路中的所有電容器和電阻器皆爲接地的狀態，因此，適合於IC的製作。此外，本電路還有高輸入/高輸出阻抗、較低的靈敏度等優點，並可經由被動元件值的大小來控制ω_0和Q值。在本文所舉的例子中，主動元件皆以Hspice並套用0.5微米CMOS製程來模擬電路，由模擬結果證明了理論與模擬值是相符的。

關鍵詞：電流差分緩衝放大器，正型差動差分放大器，電流回授放大器，正型與負型第二代電流傳輸器，雙二階濾波器，電流傳輸器。