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Resistor-less Current-mode Universal Biquad Filter Using CCTAs and Grounded Capacitors

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***Abstract*—**This article presents a current-mode universal biquadratic filter. The proposed circuit can apparently provide standard functions of the biquad filter: low-pass, high-pass, band-pass, band-reject and all-pass functions. The circuit uses 4 current controlled transconductance amplifiers (CCTAs) and 2 grounded capacitors. In addition, the pole frequency and quality factor can be adjusted by electronic method by adjusting the bias currents of the CCTA. The proposed circuit uses only grounded capacitors without additional external resistors, the proposed circuit is considerably appropriate to further developing into an integrated circuit. The results of PSPICE simulation program are corresponding to the theoretical analysis.

***Keywords*—**Resistor-less, Current-mode, Biquad filter, CCTA.

I. Introduction

THE active building block (ABB) presented in active devices for electrical and electronics engineering is suitable for a class of analog signal processing for voltage-mode and current-mode technique, for example, current conveyor second generation (CCII) [1], second generation current controlled current conveyor (CCCII) [2], current differencing transconductance amplifier (CDTA) [3] and current conveyor transconductance amplifier (CCTA) [4], etc. Additionally, to help design a circuit and reduce passive devices used in a design process, ABB development has been required to be more qualified, such as, increasing parasitic resistances at input terminal, extending numbers of input and output terminals, etc.

Universal biquadratic filter is one of most popular analog filter circuit which provides several functions (low-pass filter, high-pass filter, band-pass filter, band-reject filter and all-pass filter). In the last decade, a lot of papers in universal filter circuit design have been presented in current-mode technique using the current-mode building block. It is recommended that the circuit designed by current-mode technique can provide advantages such as larger dynamic range, inherently wide bandwidth, higher slew-rate, greater linearity and low power consumption [5-6].

According to the recent research reviews on designing current-mode universal biquadratic filter circuit using active building block, it is found that the most recommended qualifications for an appropriate circuit design: without additional external resistor, using grounded capacitors, reducing active and using passive devices in a design process, and the pole frequency and quality factor can be controlled by electronic method, and etc.

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From literature survey, several implementations of biquadratic filter circuits using active building block devices in [13-25], have been evidently reported. Unfortunately, weakness of these reported circuits has been noticed as well. Many of these applications are the pole frequency and quality factor cannot be electronically controlled by adjusting the bias current [21-25]. The proposed circuits in [18, 22-25] use floating capacitor, which is not convenient for future fabrication in integrated circuits [7]. Excessively used as passive elements, especially external resistors [13-14, 16, 18, 20-21, 23, 25] and the proposed circuit in Refs. [13-15, 19, 22-25] consists of a large number (more than two components) of active components, which are not convenient for future fabrication in integrated circuits. Furthermore, the most of presented works cannot completely provide standard function [14-17, 19, 21-25]. The proposed circuit in Ref. [17-18] used of the parasitic resistances at the input terminal. Unfortunately, the parasitic resistances depend on integrated circuits manufacturing deviations, supply voltage and also obviously on temperature [8-9]

The purpose of this paper is to present the current-mode universal biquadratic filter, based on current conveyor transconductance amplifiers (CCTAs). The proposed universal filter circuit can completely provide standard function. In addition, the pole frequency is a quality factor can be adjusted by electronic method. The proposed circuit consists of two CCTAs and two grounded capacitors and without additional external resistances, which is convenient for future fabrication in integrated circuits [10-11]. The PSPICE simulation program results are also shown which are corresponding to the theoretical analysis.

II. Theory and Principle

A. Basic Concept of CCTA

In 2005, a new active building block namely current conveyor transconductance amplifier (CCTA) is presented for analog signal processing [4], which suitable for a class of analog signal processing for voltage-mode and current-mode techniques. CCTA has been widely applied in current-mode circuit, for example, filter and oscillator circuits. The characteristics of the ideal current conveyor transconductance amplifier are represented by the following hybrid.

$$\begin{bmatrix} I_y \\ V_x \\ I_z \\ I_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 1 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & \pm g_m & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ V_o \end{bmatrix} \tag{1}$$

where g_m is the transconductance of the CCTA. This g_m can be adjusted by external input bias current I_B. For bipolar junction transistor CCTA, the transconductance can be shown in Eq. (2). An ideal CCTA has high input impedances at the y input terminal, consists of voltage buffer circuit in the y input terminal. The symbol and the equivalent circuit of the CCTA are illustrated in Fig. 1 and Fig. 2, respectively.

$$g_m = \frac{I_B}{2V_T} \tag{2}$$

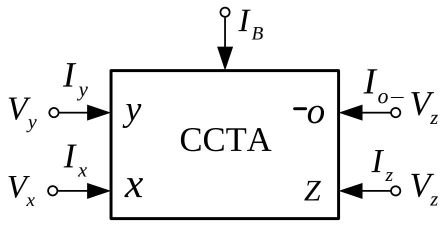


Fig. 1 Symbol of the CCTA

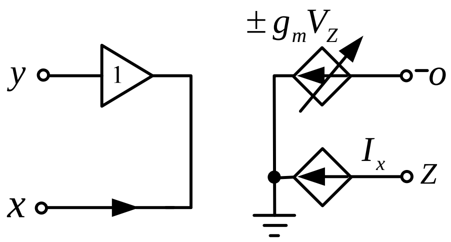


Fig. 2 Equivalent circuit of the CCTA

where V_T is the thermal voltage of the transistor. The bipolar junction transistor implementation of the internal construction of CCTA can be shown in Fig. 3.

B. Proposed current-mode universal biquad filter

The proposed current-mode universal biquadratic filter circuit can be shown in Fig. 4. It consists of 2 CCTAs and 2 grounded capacitors. The circuit does not use external resistors and parasitic resistances, only one grounded capacitor is ideal for integrated circuit. The transferring function of the circuit can be written as

$$I_{out} = \frac{\left(s^2 + \frac{g_{m1}}{C_1}s + \frac{g_{m1}g_{m2}}{C_1C_2}\right)I_{in3} - \frac{g_{m1}g_{m2}}{C_1C_2}I_{in2} - \frac{g_{m1}}{C_1}I_{in1}}{s^2 + \frac{g_{m1}}{C_1}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \tag{3}$$

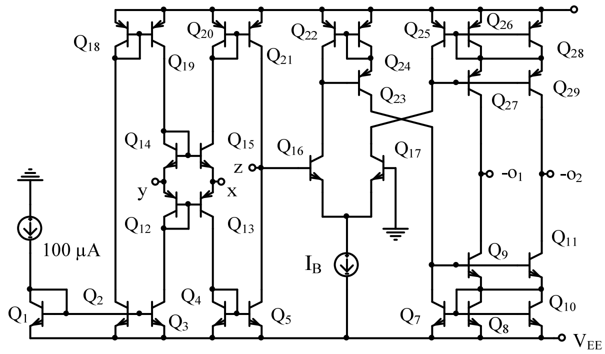


Fig. 3 Internal construction of the CCTA

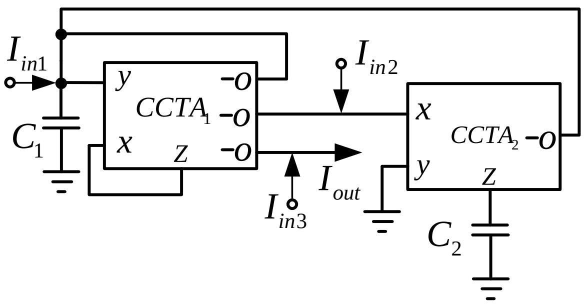


Fig. 4 The proposed current-mode universal biquad filter

From (3), the magnitude of input currents I_{in1}, I_{in2} and I_{in3} is chosen as Table I, digitally choosing by adding digitally selective circuit [12] of the input terminal to achieve standard function of second order networks. From (3), the transferring function of the low-pass (LP), high-pass (HP), band-pass (BP), band-reject (BR) and all-pass (AL) can be written as

$$\text{LP}: T_{LP}(s) = \frac{-\frac{g_{m1}g_{m2}}{C_1C_2}}{s^2 + \frac{g_{m1}}{C_1}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \tag{4}$$

$$\text{HP}: T_{HP}(s) = \frac{s^2}{s^2 + \frac{g_{m1}}{C_1}s + \frac{g_{m1}g_{m2}}{C_1C_2}} \tag{5}$$

$$\text{BP}: T_{BP}(s)=\frac{-\frac{g_{m1}}{C_1}}{s^2+\frac{g_{m1}}{C_1}s+\frac{g_{m1}g_{m2}}{C_1C_2}} \tag{6}$$

$$\text{BR}: T_{BR}(s)=\frac{s^2+\frac{g_{m1}g_{m2}}{C_1C_2}}{s^2+\frac{g_{m1}}{C_1}s+\frac{g_{m1}g_{m2}}{C_1C_2}} \tag{7}$$

and

$$\text{AP}: T_{AP}(s)=\frac{s^2-\frac{g_{m1}}{C_1}+\frac{g_{m1}g_{m2}}{C_1C_2}}{s^2+\frac{g_{m1}}{C_1}s+\frac{g_{m1}g_{m2}}{C_1C_2}} \tag{8}$$

TABLE I
THE I_{in1}, I_{in2} AND I_{in3} VALUES FOR EACH FILTER FUNCTION

Function Type	I_{in1}	I_{in2}	I_{in3}
LP	0	1	0
HP	1	1	1
BP	1	0	0
BR	1	0	1
AP	2	0	1

From (3), the quality factor (Q_0) and cut off frequency (ω_0) can be written as

$$Q_0=\sqrt{\frac{g_{m2}C_1}{g_{m1}C_2}} \tag{9}$$

and

$$\omega_0=\sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \tag{10}$$

From (9) and (10), then substitute $g_{m1}=\frac{I_{B1}}{2V_T}$ and $g_{m2}=\frac{I_{B2}}{2V_T}$, V_T is thermal voltage of the BJTs is approximately 26 mV at 27 ^{O}C.

$$Q_0=\sqrt{\frac{I_{B2}C_1}{I_{B1}C_2}} \tag{11}$$

and

$$\omega_0=\frac{1}{2V_T}\sqrt{\frac{I_{B1}I_{B2}}{C_1C_2}} \tag{12}$$

It can be seen that the Q_0 and ω_0 can be adjusted by varying I_{B1} and I_{B2}. In addition, bandwidth (BW) of the system can be expressed by

$$BW=\frac{\omega_0}{Q_0}=\frac{I_{B1}}{2V_TC_1} \tag{13}$$

From (9), the bandwidth can be controlled by I_{B1}. Sensitivities of the current-mode universal biquadratic filter are shown in Eqs. (14) and (15), respectively.

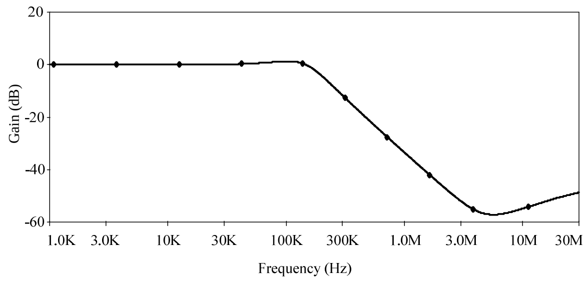
$$S^{Q_0}_{I_{B2},C_1}=\frac{1}{2},\ S^{Q_0}_{I_{B1},C_2}=-\frac{1}{2} \tag{14}$$

and

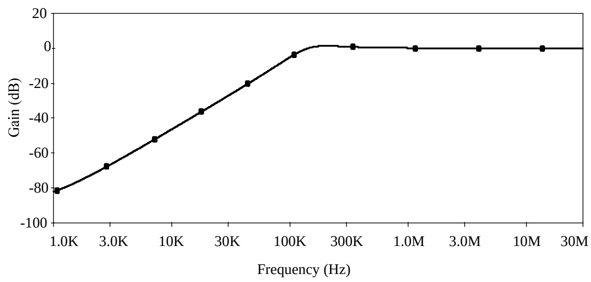
$$S^{\omega_0}_{I_{B1},I_{B2}}=\frac{1}{2},\ S^{\omega_0}_{C_1,C_2}=-\frac{1}{2},\ S^{\omega_0}_{V_T}=-1 \tag{15}$$

III. SIMULATION RESULTS

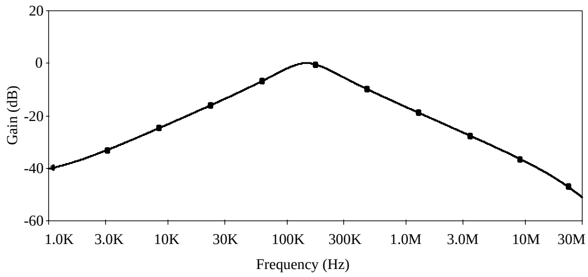
To verify the theoretical prediction of the proposed current-mode universal filter in Fig. 4, the PSPICE simulation was built with $C_1=C_2=1nF$ and $I_{B1}=I_{B2}=50\mu A$. The BJT implementation of the internal construction of CCTA used in simulation is shown in Fig. 3. The PNP and NPN transistors employed in the proposed circuit were simulated by using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor arrayed from AT&T [26]. The circuit was biased with $\pm 2V$ supply voltages. The power consumption of the circuit is about $6.46mW$. Fig. 5 shows the gain responses of the proposed biquad filter obtained from Fig. 4. The proposed biquad filter circuit is able to provide standard functions: low-pass, high-pass, band-pass, band-reject and all-pass depending on digital selection as shown in Table I.



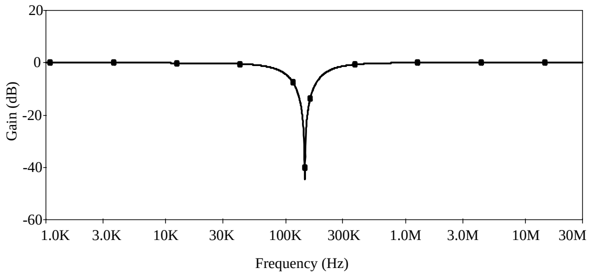
(a) Low-pass filter



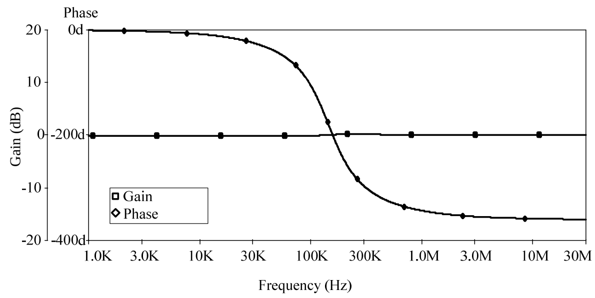
(b) High-pass filter



(c) Band-pass filter



(d) Band-reject filter



(e) All-pass filter

Fig. 5 Gain responses of the proposed biquad filter

Fig. 6 and Fig. 7 shows the gain responses of the band-pass and band-reject functions, where I_{B1} is set to $25\mu A$, $50\mu A$, $75\mu A$ and $100\mu A$, respectively. This shows that the bandwidths of the responses can be adjusted by the input bias current I_{B1} as depicted in (13). Fig. 8 shows simulated gain responses of the band-pass functions with the bias current $I_{B1} = I_{B2}$.

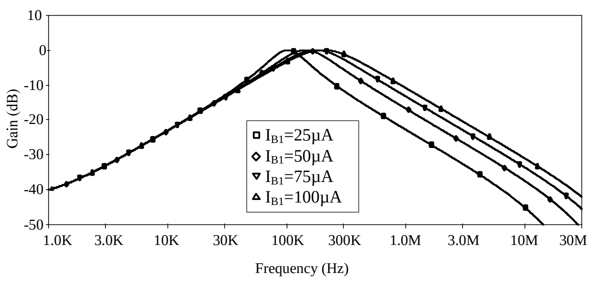


Fig. 6 Band-pass responses at different value of I_{B1}

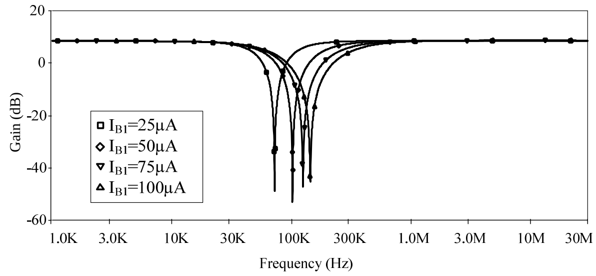


Fig. 7 Band-reject responses at different value of I_{B1}

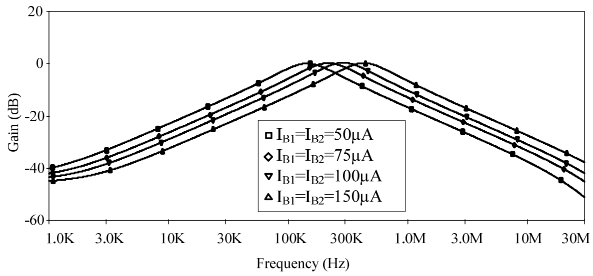


Fig. 8 band-pass responses at different value of $I_{B1} = I_{B2}$

IV. Conclusion

The current-mode universal biquadratic filter has been presented. The proposed universal filter circuit is apparently qualified with the standard functions: low-pass, high-pass, band-pass, band-reject and all-pass dependent on digital selection as shown in Table I. Moreover, the pole frequency and quality factor can be adjusted by electronic method by adjusting the bias currents of the CCTA. The proposed biquad filter circuit consists of CCTAs and grounded capacitors without additional external resistors. This circuit is extremely appropriate to further developing into an integrated circuit. The PSPICE simulations are included to verify the theoretical analysis. The simulation and theoretical results are in close.

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