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Electronically tunable CCCDBA-based current-mode universal biquad circuit

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Abstract: *This paper introduces a current-mode universal biquadratic circuit employing current controlled current differencing buffered amplifiers (CCCDBAs). The circuit is constructed with two CCCDBAs, two current controlled current differencing amplifiers (CCCDAs) and two grounded capacitors. The circuit can realize low-pass, band-pass, high-pass, band-stop and all-pass transfer functions by choosing appropriate current output terminals without any component matching conditions. Additionally, the circuit parameters ω_0 and Q can be set orthogonally through adjusting the bias currents. The biquad circuit enjoys very low sensitivities with respect to the circuit components.*
An example is given together with simulated results by PSPICE.

Keywords: *Analog circuit, Biquad characteristics, CCCBAs, CMOS technology*

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I. INTRODUCTION

High performance active filters have received much attention. Since current-mode circuits have many advantages compared with their voltage-mode counterparts, circuit designs employing active devices such as operational transconductance amplifiers (OTAs), second generation current conveyors (CCIIs) and current differencing buffered amplifiers (CDBAs) have been discussed in the literature [1]-[7].

A CCCDBA is current controlled current source. It is well known that the CCCDBA provides electronic tunability and wide tunable range of p- and n-terminal resistances by the bias currents. Also, the CCCDBA-based circuit requires no resistors, so it is well suited for integration. These features are very attractive to circuit designers. The circuit designs with the performances of the CCCDBA have been discussed previously [8]-[10].

The biquad circuits are capable of realizing more than one basic circuit transfer functions simultaneously with the same topology. In practice, they can be used for active circuit instead of SAW filter circuit, PLL FM stereo demodulator and so on. The biquad circuits employing the CCCDBAs have been reported in the past [8]-[10]. The circuit [8] uses two CCCDBAs, two grounded capacitors. However, more than one resistor is required to achieve desirable characteristics. The circuit [9] is constructed by employing three CCCDBAs and two grounded capacitors. Another circuit [10] uses two CCCDBAs and two grounded capacitors. But, they have no electronic tuning capability for the circuit parameters ω_0 and Q. A biquad circuit with such performance concerning the circuit parameters has not yet been studied sufficiently.

This paper introduces an electronically tunable current-mode universal biquad circuit using the CCCDBAs, CCCDAs and grounded capacitors. The circuit is constructed with two CCCDBAs, two CCCDAs and two grounded capacitors. The circuit can realize the low-pass, band-pass, high-pass, band-stop and all-pass transfer functions by choosing the appropriate current output terminals. The circuit requires no component matching conditions for realizing the circuit transfer functions listed above. Additionally, the circuit parameters ω_0 and Q can be tuned orthogonally by adjusting the bias currents. It is clear from sensitivity analysis that the biquad circuit has very low sensitivities with respect to the circuit components. An example is given together with simulated results by PSPICE.

The biquad circuit configuration is very suitable for implementation in both bipolar and CMOS technologies.

II. CCCDBA

Figure 1 shows the symbol for the CCCDBA.

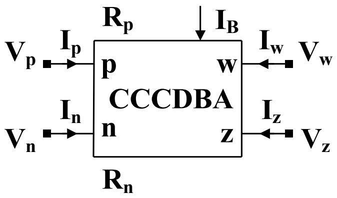


Figure 1. Symbol for CCCDBA.

The standard CCCDBA can be characterized by

$$\begin{bmatrix} V_p \\ V_n \\ V_w \\ I_z \end{bmatrix} = \begin{bmatrix} R_p & 0 & 0 & 0 \\ 0 & R_n & 0 & 0 \\ 0 & 0 & 0 & 1 \\ 1 & -1 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ I_w \\ V_z \end{bmatrix} \tag{1}$$

where R_p and R_n denote the intrinsic resistances at the p- and n-terminals.

Figure 2 shows dual current output CCCDBA (DO-CCCDBA) with MOS transistors [9].

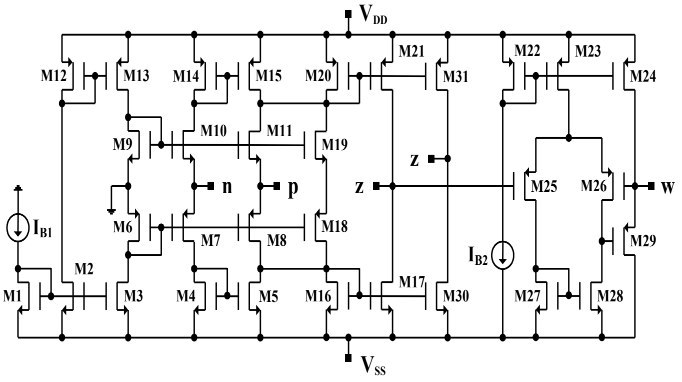


Figure 2. DO-CCCDBA with MOS transistors.

The resistances R_p and R_n are given by

$$R_p, R_n = K\left(\mu C_{ox} \frac{W}{L} I_{B1}\right)^{-\frac{1}{2}} \tag{2}$$

where K, μ, C_{ox}, W/L and I_{B1} are the constant parameter, electron mobility, gate oxide capacitance per unit area, transistor aspect ratio and bias current, respectively. Thus, it is shown that the resistances R_p and R_n can be adjusted by a supplied bias current I_{B1}.

III. BIQUAD CIRCUIT CONFIGURATION AND ANALYSIS

Figure 3 shows the biquad circuit configuration. The circuit is constructed with two CCCDBAs, two CCCDAs and two grounded capacitors.

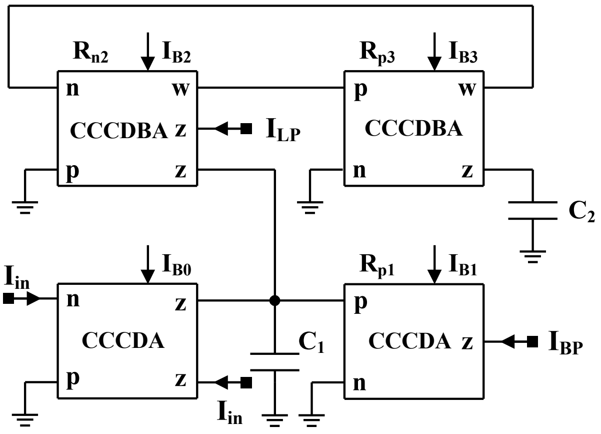


Figure 3. Current-mode biquad circuit configuration.

Routine analysis yields the circuit transfer functions $T_{LP}(s)$ and $T_{BP}(s)$ for three current outputs ($I_{LP}(s)$, $I_{BP}(s)$) given by:

$$T_{LP}(s)=\frac{I_{LP}(s)}{I_{in}(s)}=\frac{1}{s^2C_1C_2R_{n2}R_{p3}+sC_2R_{n2}R_{p3}/R_{p1}+1} \quad (3)$$

$$T_{BP}(s)=\frac{I_{BP}(s)}{I_{in}(s)}=-\frac{sC_2R_{n2}R_{p3}/R_{p1}}{s^2C_1C_2R_{n2}R_{p3}+sC_2R_{n2}R_{p3}/R_{p1}+1} \quad (4)$$

The circuit parameters ω_0, Q and H can be expressed as:

$$\omega_0=\sqrt{\frac{1}{C_1C_2R_{n2}R_{p3}}},\quad Q=R_{p1}\sqrt{\frac{C_1}{C_2R_{n2}R_{p3}}},\quad H=1.0 \quad (5)$$

It can be seen that the circuit can realize the low-pass and band-pass transfer functions at current outputs of $I_{LP}(s)$ and $I_{BP}(s)$, respectively. The parameter ω_0 can be set by R_{n2}, R_{p3}, C_1 and C_2 from (5). Then, the parameter Q can be set by R_{p1} without disturbing ω_0. Thus, the biquad circuit has orthogonal tuning capability for the circuit parameters.

The high-pass, band-stop and all-pass transfer functions $T_{HP}(s)$, $T_{BS}(s)$, $T_{AP}(s)$ below can be easily obtained from the current aditions $I_{HP}(s)=I_{in}(s)+I_{BP}(s)-I_{LP}(s)$, $I_{BS}(s)=I_{in}(s)+I_{BP}(s)$ and $I_{AP}(s)=I_{BS}(s)+I_{BP}(s)$, respectively.

$$T_{HP}(s)=\frac{I_{HP}(s)}{I_{in}(s)}=\frac{s^2C_1C_2R_{n2}R_{p3}}{s^2C_1C_2R_{n2}R_{p3}+sC_2R_{n2}R_{p3}/R_{p1}+1} \quad (6)$$

$$T_{BS}(s)=\frac{I_{BS}(s)}{I_{in}(s)}=\frac{s^2C_1C_2R_{n2}R_{p3}+1}{s^2C_1C_2R_{n2}R_{p3}+sC_2R_{n2}R_{p3}/R_{p1}+1} \quad (7)$$

$$T_{AP}(s)=\frac{I_{AP}(s)}{I_{in}(s)}=\frac{s^2C_1C_2R_{n2}R_{p3}-sC_2R_{n2}R_{p3}/R_{p1}+1}{s^2C_1C_2R_{n2}R_{p3}+sC_2R_{n2}R_{p3}/R_{p1}+1} \quad (8)$$

It can be seen that five different circuit transfer functions can be realized by choosing suitable current outputs without any component matching conditions. But, as the circuit parameter H is 1.0, an additional amplification stage is required to achieve the desirable gain constant.

We consider below the effect of deviation of the circuit components on the biquad characteristic. Table 1 shows the sensitivities with respect to the circuit components (R_{p1}, R_{n2}, R_{p3}, C_1 and C_2). These values demonstrate that the filter circuit enjoys very low sensitivities. It is also noted that the sensitivities do not depend upon the circuit component values.

Table 1. Sensitivities to circuit components.

x	ω_0	Q	H
R_{p1}	0.0	1.0	0.0
R_{n2}	-0.5	-0.5	0.0
R_{p3}	-0.5	-0.5	0.0
C_1	-0.5	0.5	0.0
C_2	-0.5	-0.5	0.0

IV. DESIGN EXAMPLE AND SIMULATION RESULTS

To verify the theoretical analysis, the biquad circuit was simulated using PSPICE simulation program. As an example, we consider realization of a biquad characteristic with the cut-off frequency f_0 (=$\omega_0/2\pi$)=1MHz, quality factor Q=1.0 and gain constant H=1.0.

For the PSPICE simulation, we have used the macro model of the DO-CCCDBA shown in Fig.2. The characteristic of the p-/n-terminal resistance R versus the bias current I_{B1} of the CCCDBA is shown in Fig.4. It can be seen that the resistance is tuned by the bias current.

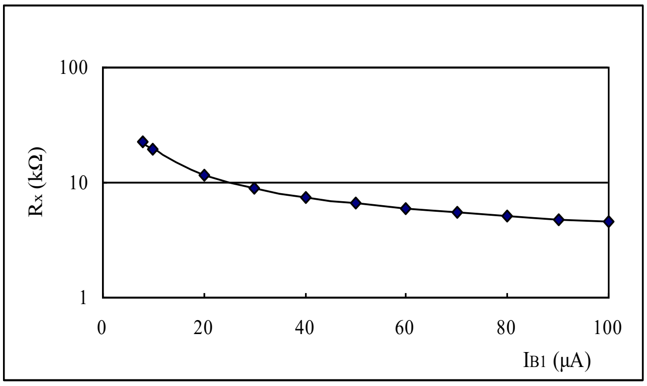


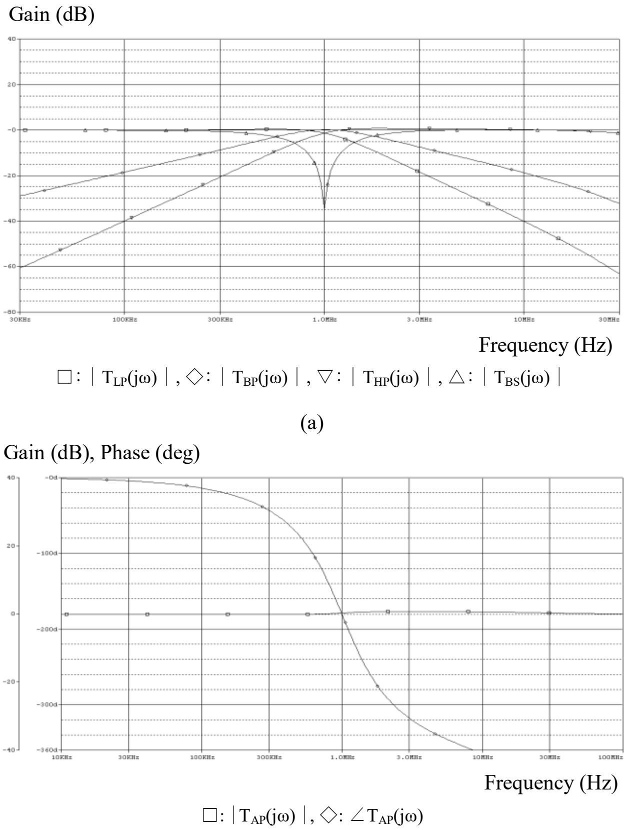
Figure 4. Characteristic of R - I_{B1}.

To realize the biquad characteristic above, we have determined that the bias currents and capacitors were I_{B1}=I_{B21}=I_{B31}=40μA, I_{B0}=I_{B22}=I_{B32}=30μA and C_1=C_2=17.5pF, respectively. Also, we have set the supply voltages and input current at V_{DD}=-V_{SS}=1.8V and I_{in}=10μA. The dimensions of MOS transistors are determined as listed in Table 2.

Table 2. Dimensions of MOS transistors.

Device	Transistors	W / L (μm)
CCCDBA	M1-3,7,8,10-13,16 M17,20,21,30,31	12/3
	M4,5,14,15	12 / 1.6
	M6,9	12 / 0.8
	M18,19	12 / 0.6
	M22,24	10/3
	M23	10/30
	M25-29	5/1
CCCDA 1	M1-3,7,8,10-13	12/3
	M4,5,14,15	12 / 1.6
	M6,9	12 / 0.8
	M16-21	8/4

Figure 5 (a) shows the simulated low-pass, band-pass, high-pass and band-stop responses with PSPICE. The all-pass response is shown in Fig.5 (b). Although small departures occur, the responses are sufficiently favorable over a wide frequency range.



(a)

(b)

Figure 5. Simulated responses.

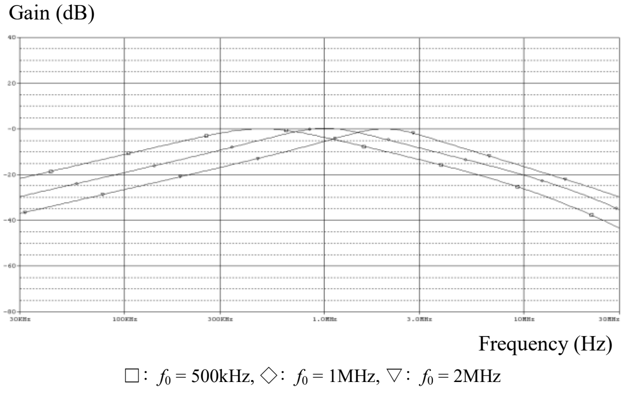


Figure 6. f_0-tuning responses.

Figure 6 shows the simulated band-pass responses with f_0-tuning (i.e. f_0=500kHz, 1MHz and 2MHz), keeping Q=1.0 and H=1.0. In this case, the capacitors and bias currents were $C_1=C_2=13\text{pF}$ and $I_{B0}=I_{B22}=I_{B32}=30\mu\text{A}$, $I_{B1}=I_{B21}= I_{B31}=11\mu\text{A}$, 23μA, 82μA, respectively.

The simulated band-pass responses with Q-tuning (i.e. Q=0.707, 1.0 and 2.0) are also shown in Fig.7, keeping f_0=1MHz and H=1.0. In the responses, the bias currents were $I_{B0}=I_{B21}= I_{B31}=I_{B22}=I_{B32}=30\mu\text{A}$, and $I_{B1}=100\mu\text{A}$, 30μA, 10μA, where $C_1=C_2=17\text{pF}$. It is made clear from the simulation responses that the circuit parameters ω_0 and Q can easily be tuned by adjusting the bias currents.

In this simulation, we have used the model parameters of 0.5 μm MOS technology obtained through MOSIS.

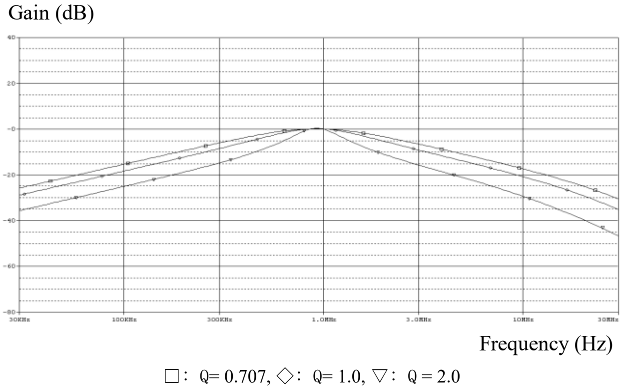


Figure 7. Q-tuning responses.

V. CONCLUSIONS

An electronically tunable current-mode universal biquad circuit using CCCDBAs, CCCDAs and grounded capacitors has been proposed. We have demonstrated that the circuit can realize low-pass, band-pass, high-pass, band-stop and all-pass transfer functions by choosing the current output terminals without any component matching conditions, and that the circuit parameters ω_0 and Q can be set orthogonally by adjusting the bias currents. It has also been clearly demonstrated that the biquad circuit enjoys very low sensitivities with respect to the circuit components. The simulated responses have been quite good over a wide frequency range. It seems that the biquad circuit configuration can be fabricated easily using bipolar and CMOS technologies.

The non-idealities (i.e. voltage- and current-tracking errors) of the CCCDBA may affect the biquad characteristic. A solution to this will be presented in the near future.

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