

# Novel positive current output CCCDBA-based current-mode biquadratic circuit

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**Abstract:** This paper introduces a current-mode biquadratic circuit employing positive current output current controlled current differencing buffered amplifiers (CCCDBAs). The biquadratic circuit is constructed with a positive current output dual current output current controlled current differencing amplifier (DO-CCDA), a positive current output dual current output CCCDBA (DO-CCCDBA) and two grounded capacitors. The circuit can realize low-pass, band-pass, high-pass, band-stop and all-pass characteristics by choosing appropriate input and output terminals. Additionally, the circuit parameters  $Q$  and  $\omega_0$  can be set orthogonally through adjusting the bias currents and grounded capacitors. The biquadratic circuit enjoys very low sensitivities to the circuit components. A design example is given together with simulation results by PSPICE.

**Keywords:** current-mode circuit, positive current output current controlled current differencing buffered amplifiers, biquadratic characteristic

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## I. Introduction

High performance active circuits have received much attention. Since current-mode circuits have many advantages compared with their voltage-mode counterparts, circuit designs using active devices such second generation current conveyors (CCIIs), operational transconductance amplifiers (OTAs) and current differencing buffered amplifiers (CDBAs) have been reported in the literature<sup>[1]-[6]</sup>.

It is well known that a CCCDBA provide electronic tunability and wide tunable range of p- and n-terminal resistances by the bias currents. Also, the CCCDBA-based circuit requires no resistors, hence it is well suited for integration. There is two kind of the CCCDBA. One is the positive current output CCCDBA, and it is composed of a simpler circuit configuration than the negative current output one. Hence it has a wide band operation and low power performance compared with the negative current output CCCDBA. These features are very attractive to circuit designers.

A biquadratic circuit is a very useful second-order function block for realizing high-order circuit transfer functions. The biquadratic circuits employing the CCCDBAs have been reported in the past<sup>[7],[8]</sup>. A biquadratic circuit<sup>[5]</sup> uses two CCCDBAs and two grounded capacitors. However, more one resistor is required to achieve desirable current output. Another circuit<sup>[8]</sup> is constructed by employing three CCCDBAs and two grounded capacitors. A biquadratic circuit employing minimum numbers of CCCDBAs and grounded capacitors has not yet been studied sufficiently.

This paper introduces a novel current-mode biquadratic circuit employing a positive current output CCDA, a positive current output CCCDBA and two grounded capacitors. The circuit can realize standard five circuit transfer functions by choosing the appropriate input and output terminals. The circuit requires no component matching conditions for realizing the transfer functions listed above. Additionally, the circuit parameters  $Q$  and  $\omega_0$  can be tuned orthogonally by adjusting the bias currents and grounded capacitors. The biquadratic circuit enjoys very low sensitivities to the circuit components. A design example is given together with simulation results by PSPICE. The workability was confirmed.

II. CCCDA and CCCDBA

Figure 1 shows the symbol for the positive current output DO-CCCDA and positive current output CCCDBA.

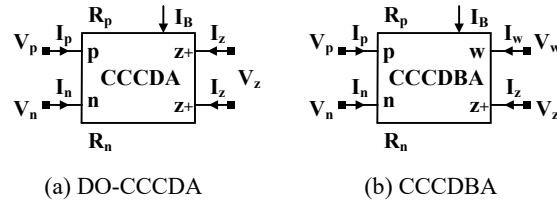


Figure 1. Positive current output CCCDA and CCCDBA

The positive current output CCCDBA can be characterized by

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

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

Figure 2 shows the macro models<sup>[5]</sup> of the positive current output DO-CCCDA and positive current output CCCDBA. The CCCDBA is added a voltage buffer to the CCCDA.

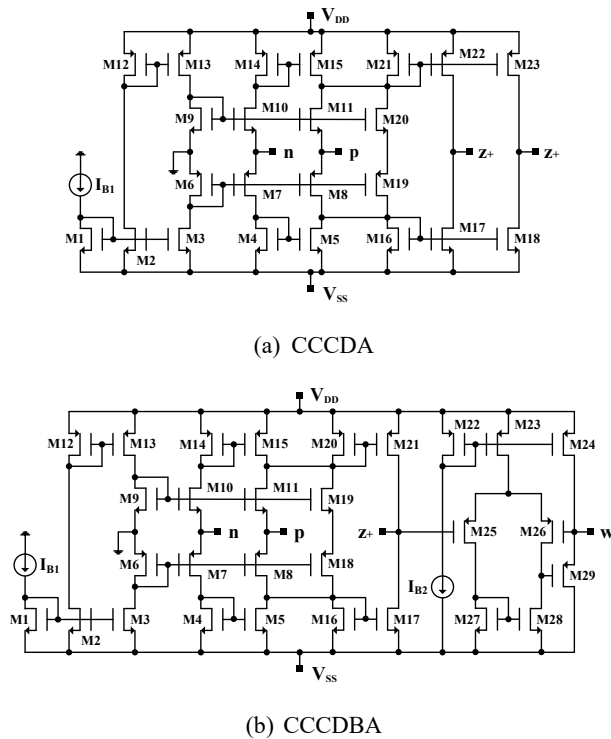


Figure 2. Positive current output DO-CCCDA and CCCDBA with MOS transistors

In the CCCDA and CCCDBA, the intrinsic resistances  $R_p$  and  $R_n$  are given by

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

where  $K$ ,  $\mu$ ,  $C_{ox}$ ,  $W/L$  and  $I_B$  are the constant parameter, electron mobility, gate oxide capacitance per unit area, transistor aspect ratio and bias current, respectively.

### III. Biquadratic circuit configuration

Figure 3 shows a biquadratic circuit configuration. The circuit is constructed with a positive current output DO-CCCDA, a positive current output DO-CCCDBA and two grounded capacitors.

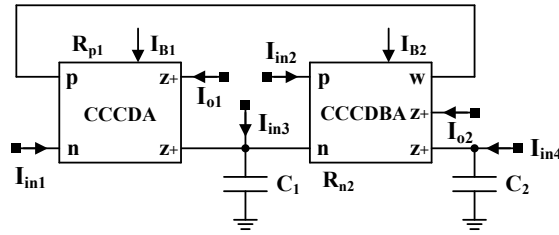


Figure 3. Current-mode biquadratic circuit configuration

Routine analysis yields the current outputs  $I_{o1}(s)$  and  $I_{o2}(s)$  given by

$$I_{o1}(s) = \frac{-sC_2R_{p1}(1+sC_1R_{n2})I_{in1}(s) - (1+sC_1R_{n2})I_{in2}(s) + I_{in3}(s) + (1+sC_1R_{n2})I_{in4}(s)}{s^2C_1C_2R_{p1}R_{n2} + sC_2R_{p1} + 1} \quad (3)$$

$$I_{o2}(s) = \frac{-sC_2R_{p1}I_{in1}(s) + sC_2R_{p1}(1+sC_1R_{n2})I_{in2}(s) - sC_2R_{p1}I_{in3}(s) + I_{in4}(s)}{s^2C_1C_2R_{p1}R_{n2} + sC_2R_{p1} + 1} \quad (4)$$

The equations above imply that the circuit can offer a variety of circuit transfer functions with different input and output terminals. One realization of the low-pass (LP), band-pass (BP), high-pass (HP), band-stop (BS) and all-pass (AP) transfer functions is as follows:

LP:  $I_{in4} = I_{in}$  and  $I_{in1} = I_{in2} = I_{in3} = 0$

$$T_{LP}(s) = \frac{I_{o2}(s)}{I_{in}(s)} = \frac{1}{s^2C_1C_2R_{p1}R_{n2} + sC_2R_{p1} + 1} \quad (5)$$

BP:  $I_{in3} = I_{in}$  and  $I_{in1} = I_{in2} = I_{in4} = 0$

$$T_{BP}(s) = \frac{I_{o2}(s)}{I_{in}(s)} = -\frac{sC_2R_{p1}}{s^2C_1C_2R_{p1}R_{n2} + sC_2R_{p1} + 1} \quad (6)$$

HP:  $I_{in2} = I_{in3} = I_{in}$  and  $I_{in1} = I_{in4} = 0$

$$T_{HP}(s) = \frac{I_{o2}(s)}{I_{in}(s)} = \frac{s^2C_1C_2R_{p1}R_{n2}}{s^2C_1C_2R_{p1}R_{n2} + sC_2R_{p1} + 1} \quad (7)$$

BS:  $I_{in2} = I_{in3} = I_{in4} = I_{in}$  and  $I_{in1} = 0$

$$T_{BS}(s) = \frac{I_{o2}(s)}{I_{in}(s)} = \frac{s^2C_1C_2R_{p1}R_{n2} + 1}{s^2C_1C_2R_{p1}R_{n2} + sC_2R_{p1} + 1} \quad (8)$$

AP:  $I_{in1} = I_{in2} = I_{in3} = I_{in4} = I_{in}$

$$T_{AP}(s) = \frac{I_{o2}(s)}{I_{in}(s)} = \frac{s^2C_1C_2R_{p1}R_{n2} - sC_2R_{p1} + 1}{s^2C_1C_2R_{p1}R_{n2} + sC_2R_{p1} + 1} \quad (9)$$

Under the condition of  $R_{p1}=R_{n2}=R$ , the circuit parameters  $\omega_0$ ,  $Q$  and  $H$  can be expressed as:

$$\omega_0 = \frac{1}{R\sqrt{C_1C_2}}, \quad Q = \sqrt{\frac{C_1}{C_2}}, \quad H = 1.0 \quad (10)$$

It can be seen that five different circuit transfer functions can be realized by choosing the suitable input and output terminals. The circuit parameters  $\omega_0$  and  $Q$  can be set orthogonally by  $R$ ,  $C_1$  and  $C_2$ .

Table 1 shows the sensitivities with respect to the circuit components (R, C<sub>1</sub> and C<sub>2</sub>). These values demonstrate that the biquadratic circuit enjoys very low sensitivities. It is also noted that the sensitivities do not depend upon the circuit component values.

Table 1 Sensitivity to circuit components

x	$\omega_0$	Q	H
R	-1.0	0.0	0.0
C <sub>1</sub>	0.0	0.5	0.0
C <sub>2</sub>	0.0	-0.5	0.0

**IV. Design example and simulation results**

To verify the theoretical analysis, the biquadratic circuit was simulated using PSPICE simulation program. As an example, we consider realization of a biquadratic 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 PSPICE simulation, we have used the macro models of the CCCDA and CCCDBA shown in Fig.2. Figure 4 shows the characteristic of the terminal resistance R versus the bias current I<sub>B</sub> of the CCCDA. It can be seen that the resistance is tuned by the bias current.

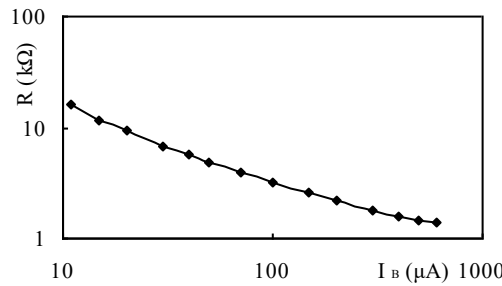
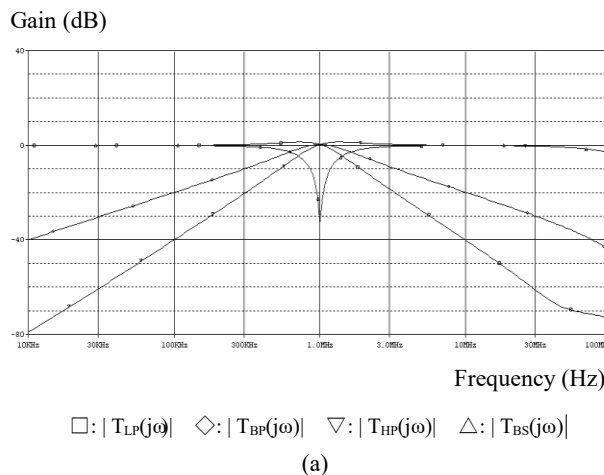


Figure 4. Characteristic of R versus I<sub>B</sub>

To realize the biquadratic characteristic above, we have determined that the bias currents and grounded capacitors were I<sub>B11</sub>=I<sub>B21</sub>=80μA, I<sub>B12</sub>=I<sub>B22</sub>=30μA and C<sub>1</sub>=C<sub>2</sub>=31pF, respectively. Also, we have set the supply voltages and input current at V<sub>DD</sub>=-V<sub>SS</sub>=1.8V and I<sub>in</sub>=5μA.

Figure 5 shows the frequency responses simulated with PSPICE. Figure 5 (a) shows the low-pass, band-pass, high-pass and band-stop responses. The all-pass response is shown in Fig.5 (b). In the results, it is found that small departures from ideal values are occurred at high frequency region. They are favorable enough over a wide frequency range. In this simulation, we have used the model parameters of 0.5μm MOS technology obtained through MOSIS.



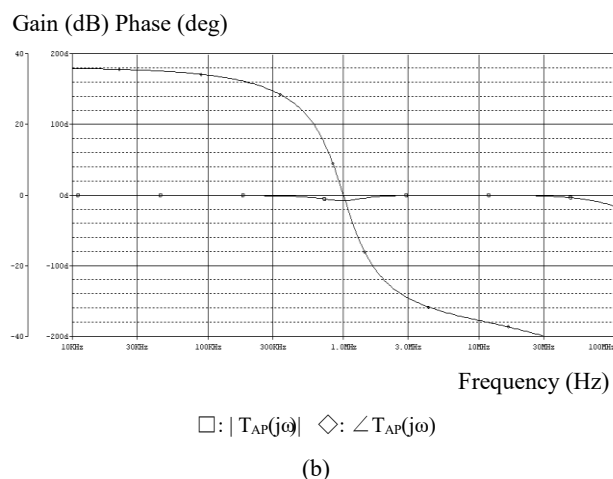


Figure 5. Simulated responses

### V. Conclusions

A novel positive current output CCCDBA-based current-mode biquadratic circuit has been proposed. We have demonstrated that the circuit can realize standard five circuit transfer functions by choosing the input and output terminals, and that the circuit parameters  $Q$  and  $\omega_0$  can be set orthogonally by the bias currents and grounded capacitors. It is made clear that the biquadratic circuit enjoys very low sensitivities to the circuit components. The simulation responses have been quite good over a wide frequency range. The circuit configuration is suitable for implementation in CMOS technologies.

The non-idealities of CCCDBA may affect the biquadratic characteristic. A solution on this must be discussed further.

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