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International
Journal
Of Modern Engineering Research (IJMER)

# A Positive Current Output CC-Based Universal Biquadratic Circuit Configuration

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***ABSTRACT:*** *This paper introduces a universal biquadratic circuit employing positive current output current conveyors (CCs). The circuit can realize low-pass, band-pass, high-pass, band-stop and all-pass responses by suitably choosing or adding the circuit currents. Additionally the circuit parameters* $\omega_0$ *and Q can be set orthogonally adjusting the circuit passive components. The biquadratic circuit enjoys very low sensitivity to the circuit components.*
***Keywords:*** *Analog circuit, Biquadratic response, Positive current output current conveyors, CMOS technology*

Date of Submission: 05-12-2025 Date of acceptance: 15-12-2025

## I. Introduction

High performance active circuits have received significant attention. The circuit designs using active devices such as second generation current conveyors (CCIIs), differential voltage current conveyor (DVCCs), operational trans-conductance amplifiers (OTAs) and so on have been reported in the literature [1]-[9]. The CCs are very useful active devices, and CC-based circuits are suitable for wide band operation. There are several kinds of CCs, e.g. the CCII [1], third generation current conveyor (CCIII) [2], the DVCC [4], etc. The positive current output CC 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 CC.

The biquadratic circuit is a very useful second-order function block for realizing the high-order circuit transfer functions. Several biquadratic circuits using the CCIIs or DVCCs have been previously discussed [1],[3]-[7]. However only the positive current output CC-based circuit [10] hasn't been studied sufficiently. Additionally it is required to have the orthogonal adjusting capability for circuit parameters.

This paper introduces a universal biquadratic circuit employing only the positive current output CCs (i.e. DVCCs and CCIIs) and grounded passive components as mentioned above. First we propose a trans-admittance-mode biquadratic circuit, and then we show current-mode and voltage-mode circuits using the trans-admittance-mode one. The circuit enables low-pass (LP), band-pass (BP), high-pass (HP), band-stop (BS) and all-pass (AP) responses by the selection or addition of the circuit currents. Moreover the circuit has an orthogonal adjusting capability for the circuit parameters $\omega_0$ and Q. It is made clear from sensitivity analysis that the biquadratic circuit has very low sensitivity to the circuit components.

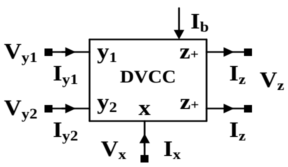
## II. CCS (DVCC And CCII)

The symbols of the positive current output CCs (DVCC and CCII) are given in Fig.1, and hereinto they show dual current output CCs.
The positive current output DVCC and CCII are characterized by the following terminal equations:

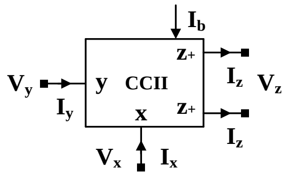
$$V_x = V_{y1} - V_{y2}, \quad I_z = I_x \qquad (1)$$

$$V_x = V_y, \quad I_z = I_x \qquad (2)$$

Moreover the DVCC and CCII with MOS transistors are shown in Fig.2.

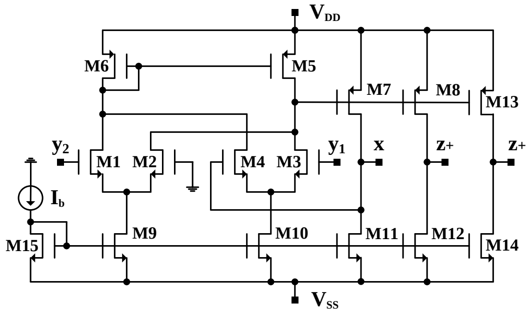



(a) DVCC

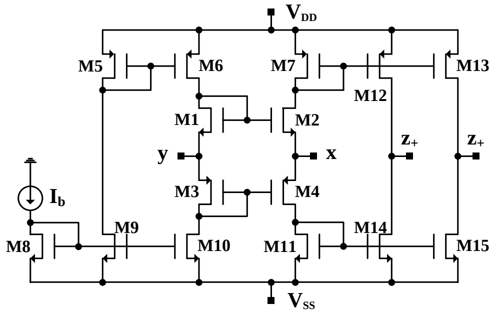



(b) CCII

**Figure 1: Symbols of CCs**




(a) DVCC




(b) CCII

**Figure 2: Positive current output CCs with MOS transistors**

## III. CC-Based Biquadratic Circuit

Figure 3 shows a trans-admittance-mode biquadratic circuit configuration. This circuit is constructed with 4 positive current output CCs and grounded passive components.

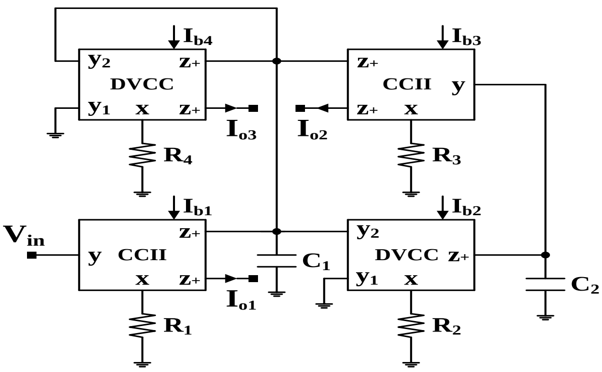



**Figure 3: Trans-admittance-mode biquadratic circuit**

The current outputs $I_{o1}(s)$, $I_{o2}(s)$ and $I_{o3}(s)$ are given by:

$$I_{o1}(s) = \frac{1}{R_1} V_{in}(s) \qquad (3)$$

$$I_{o2}(s) = -\frac{1}{R_1} \frac{1/R_2R_3}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} V_{in}(s) \qquad (4)$$

$$I_{o3}(s) = -\frac{1}{R_1}\frac{sC_2/R_4}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3}V_{in}(s) \qquad (5)$$

The typical current-mode biquadratic circuit is consisted of using the trans-admittance-mode one shown in Fig.4.

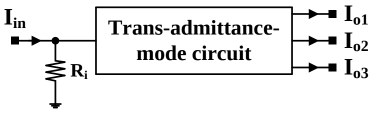



**Figure 4: Current-mode biquadratic circuit**

This circuit enables the LP and BP responses by selection of the output currents. The circuit transfer functions are as follows:

$$T_{LP}(s) = \frac{I_{02}(s)}{I_{in}(s)} = -\frac{R_i}{R_1}\frac{1/R_2R_3}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} \qquad (6)$$

$$T_{BP}(s) = \frac{I_{o3}(s)}{I_{in}(s)} = -\frac{R_i}{R_1}\frac{sC_2/R_4}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} \qquad (7)$$

Moreover the HP, BS and AP responses can be achieved by the current addition of $I_{HP}(s)=I_{o1}(s)+I_{o2}(s)+I_{o3}(s)$, $I_{BS}(s)=I_{o1}(s)+I_{o3}(s)$ and $I_{AP}(s)=I_{BS}(s)+I_{o3}(s)$. The circuit transfer functions are given as:

$$T_{HP}(s) = \frac{I_{HP}(s)}{I_{in}(s)} = \frac{R_i}{R_i}\frac{s^2C_1C_2}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} \qquad (8)$$

$$T_{BS}(s) = \frac{I_{BS}(s)}{I_{in}(s)} = \frac{R_i}{R_1}\frac{s^2C_1C_2 + 1/R_2R_3}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} \qquad (9)$$

$$T_{AP}(s) = \frac{I_{AP}(s)}{I_{in}(s)} = \frac{R_i}{R_1}\frac{s^2C_1C_2 - sC_2/R_4 + 1/R_2R_3}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} \qquad (10)$$

The circuit parameters $\omega_0$, Q and H are represented as below:

$$\omega_0 = \sqrt{\frac{1}{C_1C_2R_2R_3}}, \quad Q = R_4\sqrt{\frac{C_1}{C_2R_2R_3}}, \quad H = \frac{R_i}{R_1} \qquad (11)$$

The circuit parameter $\omega_0$ and Q can be set orthogonally according to the passive components, meanwhile the parameter H is able to set independently. Thus five circuit transfer functions are obtained by the selection and addition of the circuit currents.

**Table 1: Component sensitivity (current-mode circuit)**

| x | $\omega_0$ | Q | H |
|---|---|---|---|
| $R_1$ | 0.0 | 0.0 | -1.0 |
| $R_2$ | -0.5 | -0.5 | 0.0 |
| $R_3$ | -0.5 | -0.5 | 0.0 |
| $R_4$ | 0.0 | 1.0 | 0.0 |
| $R_i$ | 0.0 | 0.0 | 1.0 |
| $C_1$ | -0.5 | 0.5 | 0.0 |
| $C_2$ | -0.5 | -0.5 | 0.0 |

Table 1 shows the sensitivity to the passive components. These values are rather small. We can find from these values that the biquadratic circuit enjoys very low sensitivity to the circuit components. Additionally it is noted that the sensitivities are not dependent on the circuit component values.

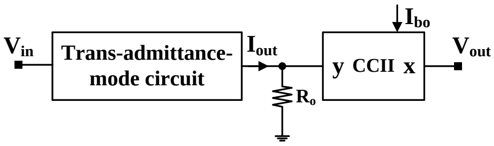



**Figure 5: Voltage-mode biquadratic circuit**

The voltage-mode biquadratic circuit is composed of the trans-admittance-mode one as shown in Fig.5. The current output $I_{out}(s)$ presents any of the current outputs $I_{LP}(s)$, $I_{BP}(s)$ and addition currents $I_{HP}(s)$, $I_{BS}(s)$, $I_{AP}(s)$ in the current-mode circuit. The output voltage $V_{out}(s)$ is obtained by converting the current output $I_{out}(s)$

to voltage.
The circuit transfer functions are as follows:

$$T_{LP}(s)=\frac{V_{0ut}(s)}{V_{in}(s)}=-\frac{R_o}{R_1}\frac{1/R_2R_3}{s^2C_1C_2+sC_2/R_4+1/R_2R_3} \quad (12)$$

$$T_{BP}(s)=\frac{V_{oot}(s)}{V_{in}(s)}=-\frac{R_o}{R_1}\frac{sC_2/R_4}{s^2C_1C_2+sC_2/R_4+1/R_2R_3} \quad (13)$$

$$T_{HP}(s)=\frac{V_{out}(s)}{V_{in}(s)}=\frac{R_o}{R_i}\frac{s^2C_1C_2}{s^2C_1C_2+sC_2/R_4+1/R_2R_3} \quad (14)$$

$$T_{BS}(s)=\frac{V_{out}(s)}{V_{in}(s)}=\frac{R_o}{R_1}\frac{s^2C_1C_2+1/R_2R_3}{s^2C_1C_2+sC_2/R_4+1/R_2R_3} \quad (15)$$

$$T_{AP}(s)=\frac{V_{out}(s)}{V_{in}(s)}=\frac{R_o}{R_1}\frac{s^2C_1C_2-sC_2/R_4+1/R_2R_3}{s^2C_1C_2+sC_2/R_4+1/R_2R_3} \quad (16)$$

The circuit parameters $\omega_0$, Q and H are given as:

$$\omega_0=\sqrt{\frac{1}{C_1C_2R_2R_3}},\quad Q=R_4\sqrt{\frac{C_1}{C_2R_2R_3}},\quad H=\frac{R_o}{R_1} \quad (17)$$

Thus the voltage-mode circuit can achieve the LP, BP, HP, BS and AP responses like the current-mode one. The circuit parameters $\omega_0$ and Q can be set orthogonally, and the parameter H is able to set independently.

Table 2 shows the component sensitivity of the voltage-mode circuit. It has the low sensitivity as well as the current-mode one.

**Table 2: Component sensitivity (voltage-mode circuit)**

| x | $\omega_0$ | Q | H |
|---|---|---|---|
| $R_1$ | 0.0 | 0.0 | -1.0 |
| $R_2$ | -0.5 | -0.5 | 0.0 |
| $R_3$ | -0.5 | -0.5 | 0.0 |
| $R_4$ | 0.0 | 1.0 | 0.0 |
| $R_o$ | 0.0 | 0.0 | 1.0 |
| $C_1$ | -0.5 | 0.5 | 0.0 |
| $C_2$ | -0.5 | -0.5 | 0.0 |

## IV. Concluding Remarks

This paper has described a universal biquadratic circuit employing positive current output CCs and grounded passive components. The circuit can achieve five different circuit responses by selecting or adding the circuit currents. Moreover the circuit parameters $\omega_0$ and Q can be set orthogonally, and the parameter H is able to set independently. It is made clear that the biquadratic circuit enjoys very low sensitivity to the circuit components. The circuit configuration is very suitable for implementation in CMOS technology.

The non-idealities (i.e. voltage and current tracking errors, x-terminal resistance) of the CCs affect the circuit performances. The solution for this will be discussed in the future.

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