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A Plus Type CC-Based Current-Mode Universal Biquad

Takao Tsukutani[1] and Noboru Yabuki[2]

1. National Institute of Technology, Matsue College, Matsue 690-8518, Japan

2. National Institute of Technology, Tsuyama College, Tsuyama 708-8509, Japan

Abstract: This paper introduces a current-mode universal biquad circuit using only plus type CCs (current conveyors) (i.e. DVCCs (differential voltage current conveyors) and CCIIs (second generation current conveyors)). The circuit enables LP (low-pass), BP (band-pass), HP (high-pass), BS (band-stop) and AP (all-pass) responses by the selection and/or addition of the input and output currents without any component matching constraints. Moreover the circuit parameters ω_0 and Q can be set orthogonally adjusting the circuit components. A design example is given together with simulation responses by PSPICE.

Key words: Analog circuit, biquad responses, current conveyors, CMOS technology.

1. Introduction

High performance active circuits have received much attention. The circuit designs using active devices such as the CCs (current conveyors), OTAs (operational trans-conductance amplifiers), OTRAs (operational trans-resistance amplifiers), etc. have been reported in [1-3]. A CC is a very useful active device, and CC-based circuit is suitable for high frequency operation. There are some kinds of CCs (e.g. CCII (second generation current conveyor), CCIII (third generation current conveyor), DVCC (differential voltage current conveyor, etc.). The plus type CCs are composed of simpler circuit configuration than the minus type ones. Hence they have wide frequency operation and low power performance compared with the minus type CCs.

The biquad circuit is a convenient second-order function block. Several biquad circuits using the CCs have been discussed previously [4, 5]. However, the plus type CC-based biquad circuit has not yet been studied sufficiently.

This paper introduces a current-mode universal biquad circuit using only the plus type CCs (i.e. DVCCs and CCIIs) and grounded passive components. First we show a basic current-mode biquad circuit, and then typical current-mode circuit is consisted of using the basic current-mode one. The circuit enables LP, BP, HP, BS and AP responses by the selection and/or addition of the input and output currents with no component matching constraints. Moreover, the circuit parameters ω_0 and Q can be set orthogonally adjusting the circuit components.

A design example is given with PSPICE simulation, and the circuit workability is confirmed.

2. DVCC and CCII

The symbols of the plus type DVCC and CCII are given in Fig. 1. The DVCC and CCII are characterized by the following terminal equations:

$$V_x = V_{y1} - V_{y2} - I_x R_x, \quad I_z = I_x \tag{1}$$

$$V_x = V_y - I_x R_x, \quad I_z = I_x \tag{2}$$

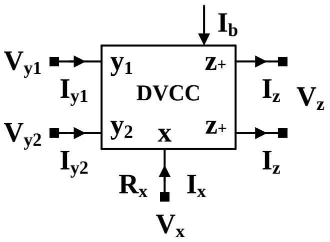
where R_x denotes the parasitic resistance at the x-terminal.

Fig. 2 shows the DVCC [5] and CCII [1] with MOS transistors.

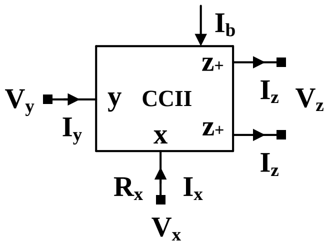
3. CC-Based Current-Mode Biquad

Fig. 3 shows a basic current-mode biquad circuit configuration. In this circuit, all the x-terminals of the CCs are connected to grounded resistors for minimizing the parasitic effects.

Corresponding author: Takao Tsukutani, PhD, research field: analog signal processing.

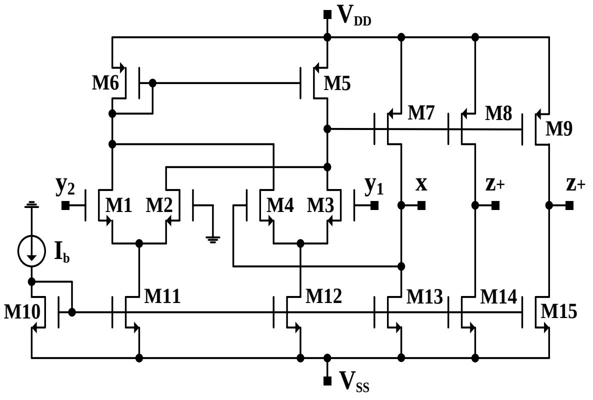


(a) DVCC

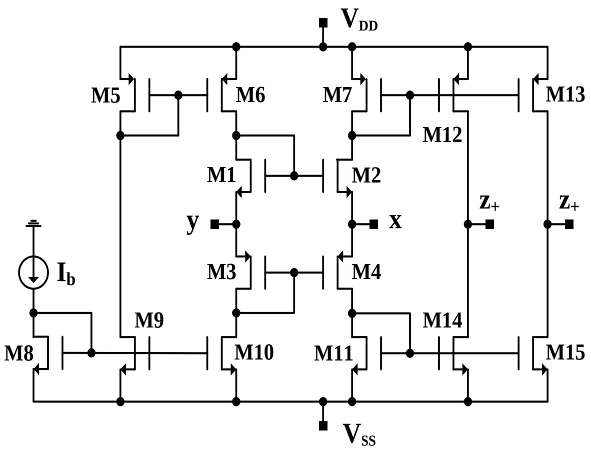


(b) CCII

Fig. 1 Symbols of CCs.



(a) DVCC



(b) CCII

Fig. 2 Plus type CCs with MOS transistors.

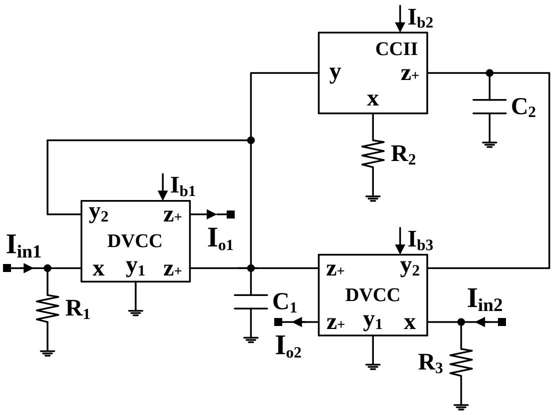


Fig. 3 Basic current-mode biquad circuit.

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

$$I_{o1}(s) = -\frac{(s^2+1/C_1C_2R_2R_3)I_{in1}(s)-(1/C_1R_1)sI_{in2}(s)}{s^2+(1/C_1R_1)s+1/C_1C_2R_2R_3} \quad (3)$$

$$I_{o2}(s) = -\frac{-(1/C_1C_2R_2R_3)I_{in1}(s)+(s^2+(1/C_1R_1)s)I_{in2}(s)}{s^2+(1/C_1R_1)s+1/C_1C_2R_2R_3} \quad (4)$$

This circuit enables the LP, BP and BS responses by selection of the input and output currents as follows:

$$T_{LP}(s) = \frac{I_{o2}(s)}{I_{in1}(s)} = \frac{1/C_1C_2R_2R_3}{s^2+(1/C_1R_1)s+1/C_1C_2R_2R_3} \quad (5)$$

$$T_{BP}(s) = \frac{I_{o1}(s)}{I_{in2}(s)} = \frac{(1/C_1R_1)s}{s^2+(1/C_1R_1)s+1/C_1C_2R_2R_3} \quad (6)$$

$$T_{BS}(s) = \frac{I_{o1}(s)}{I_{in1}(s)} = -\frac{s^2+1/C_1C_2R_2R_3}{s^2+(1/C_1R_1)s+1/C_1C_2R_2R_3} \quad (7)$$

Moreover the HP response can be achieved by the current addition of $I_{HP}(s) = I_{o1}(s) + I_{o2}(s)$, and the AP response is performed selecting the input current $I_{in}(s) = I_{in1}(s) = I_{in2}(s)$. The circuit transfer functions are given as:

$$T_{HP}(s) = \frac{I_{HP}(s)}{I_{in1}(s)} = -\frac{s^2}{s^2+(1/C_1R_1)s+1/C_1C_2R_2R_3} \quad (8)$$

$$T_{AP}(s) = \frac{I_{o1}(s)}{I_{in}(s)} = -\frac{s^2-(1/C_1R_1)s+1/C_1C_2R_2R_3}{s^2+(1/C_1R_1)s+1/C_1C_2R_2R_3} \quad (9)$$

Thus five standard circuit transfer functions can be obtained by choosing the circuit currents.

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

The circuit parameters ω_0, Q and H are represented as below.

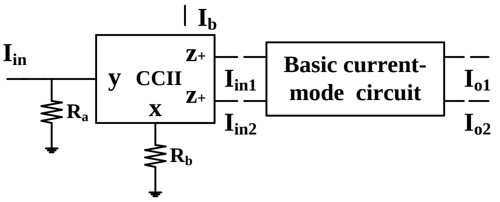


Fig.4 Typical current-mode biquad circuit.

$$\omega_0 = \sqrt{\frac{1}{C_1 C_2 R_2 R_3}}, \quad Q = R_1\sqrt{\frac{C_1}{C_2 R_2 R_3}}, \quad H = \frac{R_a}{R_b} \qquad (10)$$

The circuit parameters ω_0 and Q can be set orthogonally according to the circuit components, and meanwhile the parameter H is set independently.

In addition, voltage-mode biquad circuit can easily be realized utilizing the basic current-mode one.

4. Design Example and Simulation Responses

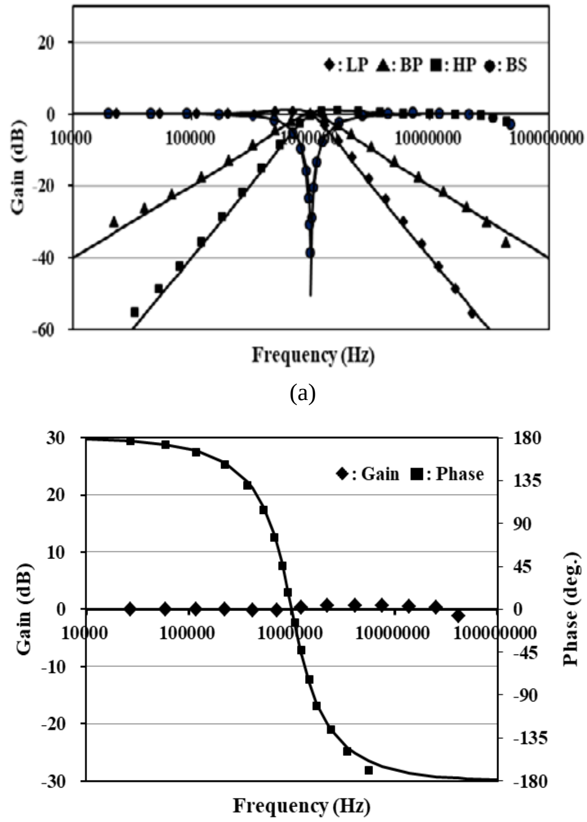
We verified the circuit operation using PSPICE simulation program. As an example, we tried to achieve a current-mode circuit with f_0 (= $\omega_0/2\pi$) = 1 MHz, Q = 1.0 and H = 1.0. To achieve the specification above, we set the circuit resistors listed in Table 1.

Fig. 5 shows the simulation responses. Fig. 5a shows the LP, BP, HP and BS responses, and the AP response is shown in Fig. 5b. In the figures, the marks signify the simulation responses, and the continuous lines show the theoretical responses. This can be viewed as an excellent result over a wide frequency range. Here we set that the capacitors, input current, bias currents and DC supply voltages were C_1 = C_2 = 12 pF, I_{in} = 10 μA, I_{b1} = I_{b2} = I_{b3} = I_b = 10 μA and V_{DD} = -V_{SS} = 1.2 V. The power dissipation was 0.618 mW.

In this simulation, the MOS sizes of the DVCC were set as 20 μm/0.5 μm (M1 to M4), 30 μm/2 μm (M5 to M9), 10 μm/2 μm (M10 to M15), and the aspect ratios were 20 μm/1 μm (M1 to M4) and 10 μm/1 μm (others) in the CCII. And we used the model parameters from MOSIS 0.5 μm.

Table 1 Circuit components.

x	LP	BP	HP	BS	AP
R_1 (kΩ)	10.5	11.5	12	11.2	11
R_2 (kΩ)	10.5	11.5	12	11.2	11
R_3 (kΩ)	10.5	11.5	12	11.2	11
R_a (kΩ)	15	14.8	14.5	15	15.2
R_b (kΩ)	10	10	10	10	10



(a)

(b)

Fig. 5 Simulation responses.

5. Conclusions

A current-mode universal biquad circuit employing plus type CCs and grounded passive components has been proposed. We have demonstrated that the circuit can achieve five circuit responses by selecting and/or adding the input and output currents without the component matching constraints. The achievement example has been given together with simulation results by PSPICE. The simulation responses were appropriate enough over a wide frequency range.

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

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