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A novel positive current output DVCC-based biquad configuration

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Abstract: *This paper introduces a novel biquad circuit employing positive current output differential voltage current conveyors (DVCCs) and grounded passive components. 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 ω_0 and Q can be set orthogonally adjusting the circuit passive components. The biquad circuit enjoys very low sensitivity to the circuit components.*

Keywords: *Analog circuit, Biquad response, Positive current output DVCC, CMOS technology*

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I. Introduction

High performance active circuits have received much attention. The circuit designs using active devices such as second generation current conveyors (CCIIs), the DVCCs, operational trans-conductance amplifiers (OTAs) and so on have been reported in the literature [1]-[9]. A DVCC is a very useful active device, and DVCC-based circuit is suitable for wide band operation. There are two kinds of the DVCC. One is positive current output DVCC, another is negative current output one. A positive current output DVCC is composed of simpler circuit configuration than a negative current output one. Hence it has low power performance and wide band operation compared with the negative current output DVCC.

The biquad circuit is a basic second-order function block and it is utilized to realize higher-order circuit transfer functions. Several biquad circuits employing the DVCCs have been discussed previously [3]-[6]. However the positive current output DVCC-based biquad circuit [10] hasn't been studied sufficiently. Additionally it is required to have the orthogonal adjusting capability for circuit parameters.

This paper focuses on a novel biquad circuit using the positive current output DVCCs and grounded passive components from the mentioned points above. First I show trans-admittance-mode biquad circuit, and then the current-mode and voltage-mode circuits are presented using the trans-admittance-mode one. The biquad 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 with no component matching conditions. Moreover the circuit parameters ω_0 and Q can be set orthogonally by adjusting the circuit passive components. It is made clear from sensitivity analysis that the biquad circuit enjoys very low sensitivity to the circuit components.

1. DVCC

The symbol of the positive current output DVCC is given in Fig.1, and hereinto it shows dual positive current output DVCC.

The DVCC is characterized by the following terminal equations:

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

Moreover the DVCC [6] with MOS transistors is shown in Fig.2. It is an active device modified differential difference current conveyor (DDCC) [7], namely one y-terminal with plus polarity is grounded in the DDCC.

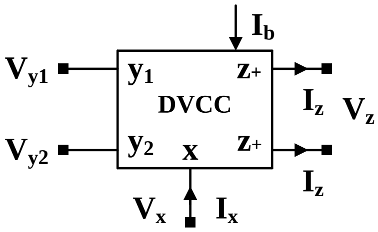

Figure 1: Symbol of DVCC

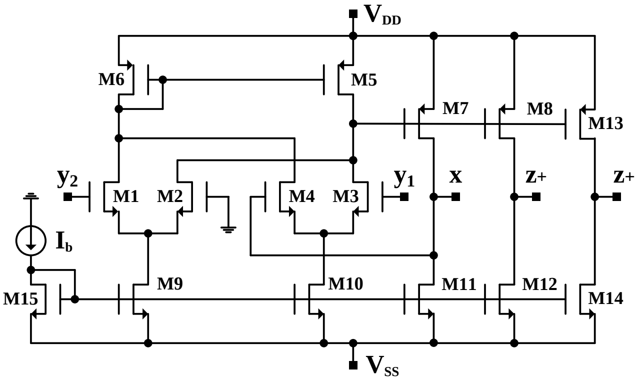

Figure 2: Positive current output DVCC with MOS transistors

2. DVCC-based biquad circuit

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

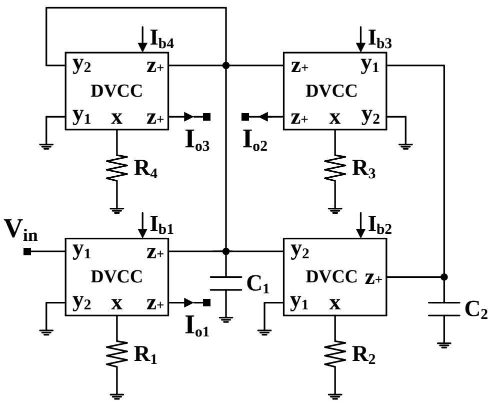

Figure 3: Trans-admittance-mode biquad circuit

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

$$I_{o1}(s) = \frac{1}{R_1} V_{in}(s) \qquad (2)$$

$$I_{o2}(s) = -\frac{1}{R_1} \frac{1/R_2R_3}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} V_{in}(s) \qquad (3)$$

$$I_{o3}(s) = -\frac{1}{R_1} \frac{sC_2/R_4}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} V_{in}(s) \qquad (4)$$

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

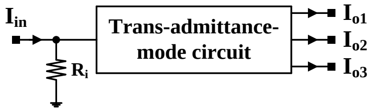

Figure 4: Current-mode biquad circuit

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

$$T_{LP}(s)=\frac{I_{02}(s)}{I_{in}(s)}=-\frac{R_i}{R_1}\frac{1/R_2R_3}{s^2C_1C_2+sC_2/R_4+1/R_2R_3} \qquad (5)$$

$$T_{BP}(s)=\frac{I_{o3}(s)}{I_{in}(s)}=-\frac{R_i}{R_1}\frac{sC_2/R_4}{s^2C_1C_2+sC_2/R_4+1/R_2R_3} \qquad (6)$$

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:

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

$$T_{BS}(s)=\frac{I_{BS}(s)}{I_{in}(s)}=\frac{R_i}{R_1}\frac{s^2C_1C_2+1/R_2R_3}{s^2C_1C_2+sC_2/R_4+1/R_2R_3} \qquad (8)$$

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

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

$$\omega_0=\sqrt{\frac{1}{C_1C_2R_2R_3}},\quad Q=R_4\sqrt{\frac{C_1}{C_2R_2R_3}},\quad H=\frac{R_i}{R_1} \qquad (10)$$

The circuit parameter ω_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	ω_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 biquad circuit enjoys very low sensitivity to the circuit components. Additionally it is noted that the sensitivities are not dependent on the circuit component values.

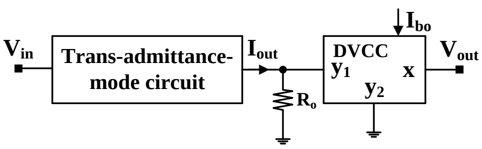

Figure 5: Voltage-mode biquad circuit

The voltage-mode biquad 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 $I_{o1}(s)$, $I_{o2}(s)$, $I_{o3}(s)$ 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:

$$T_{LP}(s) = \frac{V_{0ut}(s)}{V_{in}(s)} = -\frac{R_o}{R_1}\frac{1/R_2R_3}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} \qquad (11)$$

$$T_{BP}(s) = \frac{V_{oot}(s)}{V_{in}(s)} = -\frac{R_o}{R_1}\frac{sC_2/R_4}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} \qquad (12)$$

$$T_{HP}(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{R_o}{R_i}\frac{s^2C_1C_2}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} \qquad (13)$$

$$T_{BS}(s) = \frac{V_{out}(s)}{V_{in}(s)} = \frac{R_o}{R_1}\frac{s^2C_1C_2 + 1/R_2R_3}{s^2C_1C_2 + sC_2/R_4 + 1/R_2R_3} \qquad (14)$$

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

The circuit parameters ω_0, Q and H are given as:

$$\omega_0 = \sqrt{\frac{1}{C_1C_2R_2R_3}}, \quad Q = R_4\sqrt{\frac{C_1}{C_2R_2R_3}}, \quad H = \frac{R_o}{R_1} \qquad (16)$$

Thus the voltage-mode circuit can achieve the LP, BP, HP, BS and AP responses like the current-mode one. The circuit parameters ω_0 and Q can be set orthogonally, and the parameter H can be 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	ω_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

4. Concluding remarks

This paper has described a novel biquad circuit employing positive current output DVCCs and grounded passive components. The circuit can achieve five different circuit responses by selecting or adding the circuit currents without the component matching constraints. Moreover the circuit parameters ω_0 and Q can be set orthogonally, and the parameter H is able to set independently. The biquad 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 DVCC affect the circuit performances. The solution for this will be discussed in the future.

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