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Novel positive current output OTA-based biquad circuits

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Abstract

This paper presents novel biquad circuits employing only positive current output operational trans-conductance amplifiers (OTAs). The circuits enable low-pass (LP), band-pass (BP), high-pass (HP), band-stop (BS) and all-pass (AP) responses by the selection and addition of the circuit currents. Moreover the circuit parameters ω_0 and Q can be set orthogonally by adjusting the bias currents of the OTAs. The circuits enjoy very low sensitivity with respect to the circuit components.

Keywords: Analog circuits, Biquad responses, OTA, CMOS technology

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I. Introduction

High performance active circuits have received considerable attention. Circuit designs using active devices such as second generation current conveyor (CCII), differential voltage current conveyor (DVCC), the OTA and others have been reported in the literature [1-6]. OTA is a very useful active device, and OTA-based circuit has electronic tuning capability for circuit responses by the bias currents. The positive current output OTA 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 OTA.

The biquad circuit is a very useful second-order function block for realizing the high-order circuit transfer functions. Several biquad circuits using the OTAs, DVCCs and CCIIs have been previously discussed [1-6]. However the biquad circuit based on the positive current output OTAs hasn't been studied sufficiently.

This paper introduces novel biquad circuits employing only the positive current output OTAs as mentioned above. First we propose a trans-admittance-mode biquad circuit, and then we show typical current-mode and voltage-mode circuits using the trans-admittance-mode one. The circuits enable the LP, BP, HP, BS and AP responses by the selection and addition of the circuit currents. Moreover the circuit parameters ω_0, Q and H can be set electronically by the bias currents of the OTAs. Moreover it is made clear that the circuits enjoy very low sensitivity to the circuit components.

II. OTA

The symbol of the positive current output OTA is given in Fig.1, and hereinto they show dual current output OTA.

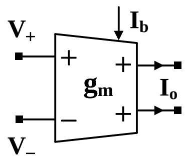

Figure 1: Symbol of OTA

The current output I_o of the OTA is given by:

$$I_o = g_m(V_+ - V_-) \qquad (1)$$

where g_m denotes the trans-conductance gain.

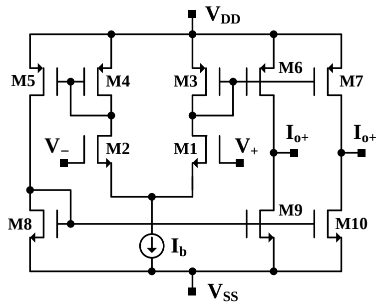

Figure 2: Positive current output OTA with MOS transistors

The positive current output OTA with MOS transistors is shown in Fig.2. The trans-conductance gain g_m is characterized as:

$$g_m = \sqrt{\mu_n C_{ox} \frac{W}{L} I_b} \qquad (2)$$

where μ_n, C_{ox}, W/L and I_b are the electron mobility of NMOS, gate oxide capacitance per unit area, transistor aspect ratio and bias current, respectively. The trans-conductance gain is adjustable by a supplied bias current I_b.

III. Biquad circuit configuration

Figure 3 shows the trans-admittance-mode biquad circuit. This circuit is constructed with four positive current output OTAs and two grounded capacitors.

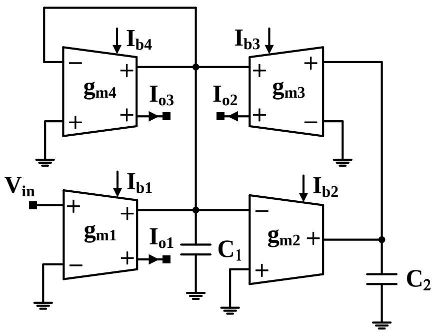

Figure 3: Trans-admittance-mode biquad circuit

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

$$I_{o1}(s) = g_{m1} V_{in}(s) \qquad (3)$$

$$I_{o2}(s) = -\frac{g_{m1} g_{m2} g_{m3}}{s^2 C_1 C_2 + s C_2 g_{m4} + g_{m2} g_{m3}} V_{in}(s) \qquad (4)$$

$$I_{o3}(s) = -\frac{g_{m1} s C_2 g_{m4}}{s^2 C_1 C_2 + s C_2 g_{m4} + g_{m2} g_{m3}} V_{in}(s) \qquad (5)$$

Figure 4 presents the current-mode biquad circuit using the trans-admittance-mode one.

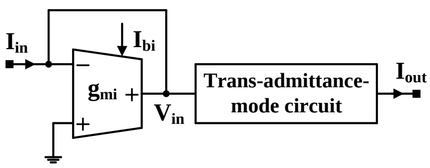

Figure 4: Current-mode biquad circuit

The circuit enables the LP and BP responses by the selection of the output currents $I_{o2}(s)$ and $I_{o3}(s)$. The circuit transfer functions are as follows:

$$T_{LP}(s) = \frac{I_{02}(s)}{I_{in}(s)} = -\frac{g_{m1}}{g_{mi}} \frac{g_{m2}g_{m3}}{s^2C_1C_2 + sC_2g_{m4} + g_{m2}g_{m3}} \quad (6)$$

$$T_{BP}(s) = \frac{I_{o3}(s)}{I_{in}(s)} = -\frac{g_{m1}}{g_{mi}} \frac{sC_2g_{m4}}{s^2C_1C_2 + sC_2g_{m4} + g_{m2}g_{m3}} \quad (7)$$

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 $I_{AP}(s)=I_{o1}(s)+2I_{o3}(s)$, respectively. The circuit transfer functions are given as:

$$T_{HP}(s) = \frac{I_{HP}(s)}{I_{in}(s)} = \frac{g_{m1}}{g_{mi}} \frac{s^2C_1C_2}{s^2C_1C_2 + sC_2g_{m4} + g_{m2}g_{m3}} \quad (8)$$

$$T_{BS}(s) = \frac{I_{BS}(s)}{I_{in}(s)} = \frac{g_{m1}}{g_{mi}} \frac{s^2C_1C_2 + g_{m2}g_{m3}}{s^2C_1C_2 + sC_2g_{m4} + g_{m2}g_{m3}} \quad (9)$$

$$T_{AP}(s) = \frac{I_{AP}(s)}{I_{in}(s)} = \frac{g_{m1}}{g_{mi}} \frac{s^2C_1C_2 - sC_2g_{m4} + g_{m2}g_{m3}}{s^2C_1C_2 + sC_2g_{m4} + g_{m2}g_{m3}} \quad (10)$$

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

$$\omega_0 = \sqrt{\frac{g_{m2}g_{m3}}{C_1C_2}}, \quad Q = \frac{1}{g_{m4}}\sqrt{\frac{C_1g_{m2}g_{m3}}{C_2}}, \quad H = \frac{g_{m1}}{g_{mi}} \quad (11)$$

The circuit parameter ω_0 and Q can be set orthogonally according to the bias currents, while the parameter H is able to set independently.
Table 1 shows the sensitivities with respect to the circuit components. These values are rather small. We can find from them that the circuit enjoys very low sensitivity to the circuit components. It is noted that the sensitivities are not dependent on the circuit component values.

Table 1: Component sensitivity (current-mode circuit)

x	ω_0	Q	H
g_{m1}	0.0	0.0	1.0
g_{m2}	0.5	0.5	0.0
g_{m3}	0.5	0.5	0.0
g_{m4}	0.0	-1.0	0.0
g_{mi}	0.0	0.0	-1.0
C_1	-0.5	0.5	0.0
C_2	-0.5	-0.5	0.0

The voltage-mode biquad circuit is constructed with the trans-admittance-mode one as shown in Fig.5. The current output $I_{out}(s)$ presents any of the current outputs in the trans-admittance-mode circuit. And the output voltage $V_{out}(s)$ is obtained converting the current output $I_{out}(s)$ to voltage.

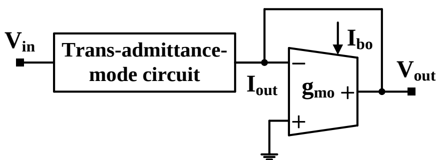

Figure 5: Voltage-mode biquad circuit

The circuit can realize five circuit responses, and the circuit parameters ω_0 and Q are same as the current-mode circuit. The gain constant H is given by $H=g_{m1}/g_{mo}$.
Table 2 shows the sensitivities to the circuit components. It is found that the voltage-mode circuit has very low sensitivity as well as the current-mode one.

Table 2: Component sensitivity (voltage-mode circuit)

x	ω_0	Q	H
g_{m1}	0.0	0.0	1.0
g_{m2}	0.5	0.5	0.0
g_{m3}	0.5	0.5	0.0
g_{m4}	0.0	-1.0	0.0
g_{mo}	0.0	0.0	-1.0
C_1	-0.5	0.5	0.0
C_2	--0.5	-0.5	0.0

IV. Conclusion

This paper has described novel biquad circuits employing only positive current output OTAs. The circuit can achieve five standard circuit responses (i.e. LP, BP, HP, BS and AP responses) by selecting and adding the circuit currents. The circuit parameters ω_0 and Q can be set orthogonally by the bias currents of the OTAs. Moreover it has been made clear that the circuits enjoy very low sensitivity to the circuit components.

The biquad circuit has several advantages concerning the wide band operation, low power dissipation and electronic adjusting of the circuit parameters, etc. The circuit configurations are very suitable for implementation in CMOS technology.

The non-idealities of the OTA affect the circuit performances. The solution for this will be discussed in the future.

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