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A universal biquadratic circuit employing positive current output OTAs and a CCII+

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Abstract: *This paper presents a universal biquadratic circuit employing positive current output operational trans-conductance amplifiers (OTAs) and a positive current output second generation current conveyor (CCII+). The circuit enables 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 can be set orthogonally by adjusting the bias currents of the OTAs. The biquadratic circuit enjoys very low sensitivity with respect to the circuit components.*

Keywords: *Analog circuits, Biquadratic responses, OTA, CCII, CMOS technology*

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I. Introduction

High performance active circuits have received considerable attention. Circuit designs using active devices such as the CCII, differential voltage current conveyor (DVCC), the OTA and others have been reported in the literature [1]-[7]. OTA is a very useful active device, and OTA-based circuit has electronic tuning capability for circuit responses by the bias currents.

The biquadratic circuit is a very useful second-order function block for realizing the high-order circuit responses. Several biquadratic circuits using the OTAs, CCIIs and DVCCs have been previously discussed [1]-[7]. However the biquadratic circuit [8] based on the OTAs and CCIIs hasn't been studied sufficiently.

This paper introduces a universal biquadratic circuit employing the positive current output OTAs and one CCII+ as mentioned above. First we propose a basic current-mode biquadratic circuit, and then we show typical current-mode circuit using the basic current-mode one. The circuit enables 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 biquadratic circuit enjoys very low sensitivity to the circuit components. In addition voltage-mode circuit is introduced using the basic current-mode one.

II. OTA and CCII+

The symbols of the positive current output OTA and CCII+ are given in Fig.1.

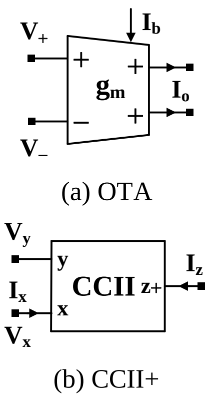


Figure 1: Symbols of OTA and CCII+

The current output I_o of the OTA is given by:

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

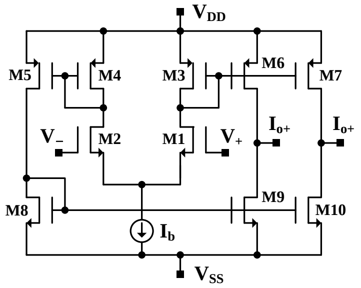
where g_m denotes the trans-conductance gain.
The OTA with MOS transistors is shown in Fig.2 (a). The trans-conductance gain g_m is characterized as:

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

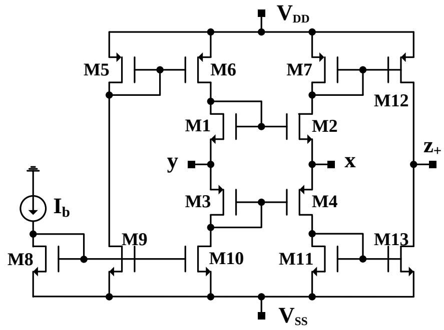
where μ_n, C_{ox}, W/L and I_b are the electron mobility of NMOS, gate oxide capacitance per unit area, transistor aspect ratio and bias current, respectively. The trans-conductance gain is adjustable by a supplied bias current I_b.
The terminal equations of the CCII+ are given by:

$$V_x = V_y, \quad I_z = I_x \quad (3)$$

The CCII+ with MOS transistors is shown in Fig.2 (b).



(a) OTA



(b) CCII+

Figure 2: OTA and CCII+ with MOS transistors

III. Biquadratic circuit configuration

Figure 3 shows the basic current-mode biquadratic circuit. This circuit is constructed with three OTAs, one CCII+ and three grounded capacitors.

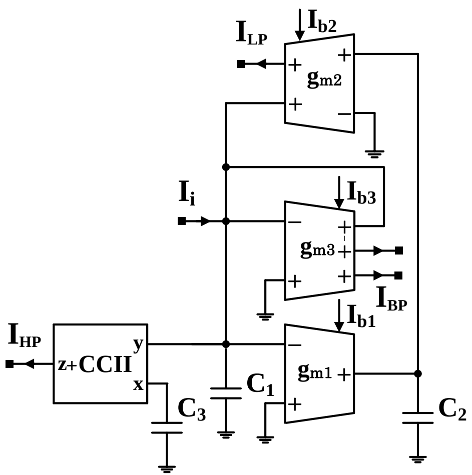


Figure 3: Basic current-mode biquadratic circuit

The current outputs $I_{LP}(s)$, $I_{BP}(s)$ and $I_{HP}(s)$ are given by:

$$I_{LP}(s) = -\frac{g_{m1}g_{m2}}{s^2C_1C_2 + sC_2g_{m3} + g_{m1}g_{m2}} I_i(s) \quad (4)$$

$$I_{BP}(s) = -\frac{sC_2g_{m3}}{s^2C_1C_2 + sC_2g_{m3} + g_{m1}g_{m2}} I_i(s) \quad (5)$$

$$I_{HP}(s) = \frac{s^2C_1C_2}{s^2C_1C_2 + sC_2g_{m3} + g_{m1}g_{m2}} I_i(s) \quad (6)$$

In the circuit, the condition below is required.

$$C_3 = C_1 \quad (7)$$

Figure 4 presents the typical current-mode biquadratic circuit using the basic current-mode one.

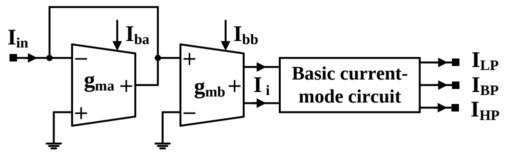


Figure 4: Typical current-mode biquadratic circuit

The circuit enables the LP, BP and HP responses by the selection of the output currents as follows:

$$T_{LP}(s) = \frac{I_{LP}(s)}{I_{in}(s)} = -\frac{g_{mb}}{g_{ma}} \frac{g_{m1}g_{m2}/C_1C_2}{s^2 + (g_{m3}/C_1)s + g_{m1}g_{m2}/C_1C_2} \quad (8)$$

$$T_{BP}(s) = \frac{I_{BP}(s)}{I_{in}(s)} = -\frac{g_{mb}}{g_{ma}} \frac{sC_2g_{m3}}{s^2C_1C_2 + sC_2g_{m3} + g_{m1}g_{m2}} \quad (9)$$

$$T_{HP}(s) = \frac{I_{HP}(s)}{I_{in}(s)} = \frac{g_{mb}}{g_{ma}} \frac{s^2C_1C_2}{s^2C_1C_2 + sC_2g_{m3} + g_{m1}g_{m2}} \quad (10)$$

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

$$T_{BS}(s) = \frac{I_{BS}(s)}{I_{in}(s)} = \frac{g_{mb}}{g_{ma}} \frac{s^2C_1C_2 + g_{m1}g_{m2}}{s^2C_1C_2 + sC_2g_{m3} + g_{m1}g_{m2}} \quad (11)$$

$$T_{AP}(s) = \frac{I_{AP}(s)}{I_{in}(s)} = \frac{g_{mb}}{g_{ma}} \frac{s^2C_1C_2 - sC_2g_{m3} + g_{m1}g_{m2}}{s^2C_1C_2 + sC_2g_{m3} + g_{m1}g_{m2}} \quad (12)$$

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

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}}, \quad Q = \frac{1}{g_{m3}}\sqrt{\frac{C_1g_{m1}g_{m2}}{C_2}}, \quad H = \frac{g_{mb}}{g_{ma}} \quad (13)$$

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}	0.5	0.5	0.0
g_{m2}	0.5	0.5	0.0
g_{m3}	0.0	-1.0	0.0
g_{ma}	0.0	0.0	-1.0
g_{mb}	0.0	0.0	1.0
C_1	-0.5	0.5	0.0
C_2	-0.5	-0.5	0.0
C_3	0.0	0.0	0.0

The voltage-mode biquadratic circuit is constructed with the basic current-mode one as shown in Fig.5. The current output $I_{out}(s)$ presents any of the current outputs in the basic current-mode circuit. And the output voltage $V_{out}(s)$ is obtained converting the current output $I_{out}(s)$ to voltage. 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 $H=g_{ma}/g_{mb}$.

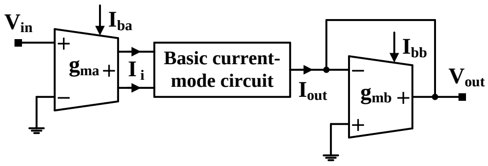


Figure 5: Voltage-mode biquadratic circuit

Table 2 shows the sensitivities to the circuit components. It is found that the voltage-mode biquadratic 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}	0.5	0.5	0.0
g_{m2}	0.5	0.5	0.0
g_{m3}	0.0	-1.0	0.0
g_{ma}	0.0	0.0	1.0
g_{mb}	0.0	0.0	-1.0
C_1	-0.5	0.5	0.0
C_2	-0.5	-0.5	0.0
C_3	0.0	0.0	0.0

In addition, biquadratic circuits on other operation modes (i.e. trans-admittance-mode, trans-impedance-mode) can easily be consisted of using the basic current-mode one.

IV. Conclusion

This paper has described a universal biquadratic circuit employing positive current output OTAs and a CCII+. 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 can be set electronically by the bias currents of the OTAs. Moreover it has been made clear that the biquadratic circuit enjoys very low sensitivity to the circuit components. In addition voltage-mode biquadratic circuit has been presented utilizing the basic current-mode one.

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

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

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