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Novel Voltage-Mode Active-Only Biquad with Two Integrator Loops

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Abstract

This paper introduces a voltage-mode biquadratic circuit using only Operational Amplifiers (OAs) and Operational Transconductance Amplifiers (OTAs). The proposed circuit can realize low-pass, band-pass, high-pass, band-stop and all-pass transfer functions by suitably choosing the input and output terminals. And the circuit characteristics can be electronically tuned through adjusting the transconductance gains of OTAs. Some examples are given together with simulated results by PSpice. The circuit configuration is very suitable for implementation in both bipolar and CMOS technologies.

1. Introduction

High performance active circuits have received much attention. Active circuit designs employing active devices such as OAs, OTAs and second generation current conveyors (CCIIs) have been reported in the literature[1]-[6].

It is well known that active circuits utilizing the finite and complex gain nature of internally compensated OAs are suitable for high-frequency operation. Also, OTAs provide highly linear electronic tunability and wide tunable range of their transconductance gains. Active circuit designs with such OA and OTA performances have been discussed previously[1],[3]-[6].

At present, there is a growing interest in designing active circuits that use only active devices. Such a circuit would facilitate its integratability and programmability. Current-mode biquadratic circuit configurations employing OAs and OTAs have already been reported[7]-[9]. Voltage-mode circuit configuration has also been discussed[10]. Although the voltage-mode biquadratic circuit above can realize the low-pass, the band-pass, the high-pass and the band-stop transfer functions except the all-pass transfer function, the circuit has no independent tuning capability with respect to the circuit parameters. The voltage-mode biquadratic circuit with such tuning capability has not yet been studied sufficiently.

This paper focuses on a realization of the voltage-mode active-only biquadratic circuit. The proposed circuit is constructed solely with OAs and OTAs. The circuit configuration is obtained from a second-order structure with two integrator loops. It is shown that the circuit can realize the low-pass, the band-pass, the high-pass, the band-stop and the all-pass transfer functions by suitably choosing the input and output terminals. And the circuit parameters can be independently set and electronically tuned by the transconductance gains of OTAs. From sensitivity analysis, it is also shown that the biquadratic circuit has very low sensitivity with respect to the circuit active elements.

Some examples are given together with simulated results by PSpice.

2. Circuit Configuration and Analysis

Figure 1 shows a block diagram of two integrator loop structure[1] consisting of loss-less integrators. The characteristic equation $D_p(s)$ is given by

$$D_p(s) = s^2 + \frac{\omega_p}{Q_p}s + \omega_p^2 \tag{1}$$

where the characteristic parameters ω_p and Q_p become, respectively

$$\omega_p = \sqrt{k_{f2}K_1K_2}, \quad Q_p = \frac{1}{k_{f1}}\sqrt{\frac{k_{f2}K_2}{K_1}} \tag{2}$$

From Eq.(2), it is found that ω_p and Q_p can be independently tuned by adjusting the feedback coefficients k_{f1} and k_{f2}.

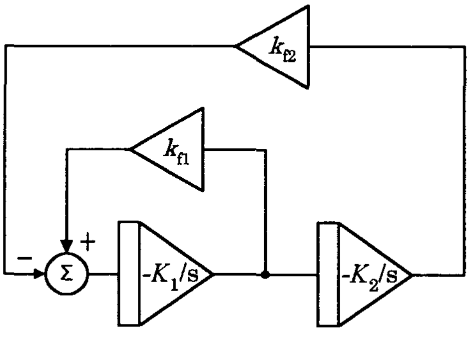


Figure 1 Two integrator loop structure.

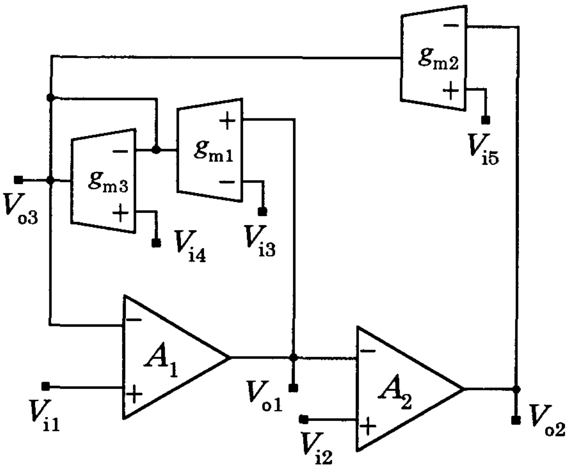


Figure 2 Voltage-mode active-only biquadratic circuit.

Figure 2 shows the biquadratic circuit configuration derived from the block diagram of Fig.1. It can be seen that the circuit is solely constructed with OAs and OTAs.

Assuming the open-loop gain $A_i(s)$ to be of the following form, where B_i is the gain-bandwidth product,

$$A_i(s) = \frac{B_i}{s} \quad (i = 1,2) \tag{3}$$

Routine analysis yields the output voltages $V_{o1}(s)$, $V_{o2}(s)$ and $V_{o3}(s)$ given by

$$\begin{aligned} V_{o1}(s) = \{&B_1sV_{i1}(s) + k_2B_1B_2V_{i2}(s) + k_1B_1sV_{i3}(s) \\ &- B_1sV_{i4}(s) - k_2B_1sV_{i5}(s)\}/D(s) \end{aligned} \tag{4}$$

$$\begin{aligned} V_{o2}(s) = \{&-B_1B_2V_{i1}(s) + (s^2 + k_1B_1s)B_2V_{i2}(s) \\ &- k_1B_1B_2V_{i3}(s) + B_1B_2V_{i4}(s) \\ &- k_2B_1B_2V_{i5}(s)\}/D(s) \end{aligned} \tag{5}$$

$$\begin{aligned} V_{o3}(s) = \{&(k_1s + k_2B_2)B_1V_{i1}(s) - k_2B_2sV_{i2}(s) \\ &- k_1s^2V_{i3}(s) + s^2V_{i4}(s) + k_2s^2V_{i5}(s)\}/D(s) \end{aligned} \tag{6}$$

where

$$\left.\begin{aligned} &D(s) = s^2 + \frac{\omega_0}{Q}s + \omega_0^2 \\ &\omega_0 = \sqrt{k_2B_1B_2}, \quad Q = \frac{1}{k_1}\sqrt{\frac{k_2B_2}{B_1}} \\ &k_1 = \frac{g_{m1}}{g_{m3}}, \quad k_2 = \frac{g_{m2}}{g_{m3}} \end{aligned}\right\} \tag{7}$$

and g_{mx} denotes the transconductance gain of OTA.

The equations formulated above imply that the proposed circuit can offer a variety of circuit characteristics with different input and output terminals. And the circuit parameters ω_0 and Q can be independently set and electronically tuned adjusting the transconductance gains. When B_1 and B_2 are given, the parameter ω_0 can be set by k_2 (i.e. g_{m2} and g_{m3}). The parameter Q can also be set by g_{m1} without disturbing ω_0.

Possible circuit characteristics by choosing the input and output terminals are shown in Table 1. One of the realizations of the low-pass (LP), the band-pass (BP), the high-pass (HP), the band-stop (BS) and the all-pass (AP) transfer functions is as follows :

$$LP: \quad T_{LP}(s) = \frac{V_{o2}(s)}{V_{i5}(s)} = \frac{\omega_0^2}{D(s)} \tag{8}$$

$$BP: \quad T_{BP}(s) = \frac{V_{o1}(s)}{V_{i3}(s)} = \frac{(\omega_0/Q)s}{D(s)} \tag{9}$$

$$HP: \quad T_{HP}(s) = \frac{V_{o3}(s)}{V_{i4}(s)} = \frac{s^2}{D(s)} \tag{10}$$

$$BS: \quad T_{BS}(s) = \frac{V_{o3}(s)}{V_{i124}(s)} = \frac{s^2 + \omega_0^2}{D(s)} \tag{11}$$

Table 1 Realizable circuit characteristics.

	V_{o1}	V_{o2}	V_{o3}
V_{i1}	BP	LP	—
V_{i2}	LP	—	BP
V_{i3}	BP	LP	HP
V_{i4}	BP	LP	HP
V_{i5}	BP	LP	HP
V_{i124}	—	—	BS/AP

$$AP:\quad T_{AP}(s)=\frac{V_{o3}(s)}{V_{i124}(s)}=\frac{s^2-(\omega_0/Q)s+\omega_0^2}{D(s)} \qquad (12)$$

where $V_{i124}(s)$ implies $V_{i1}(s)=V_{i2}(s)=V_{i4}(s)$.

Thus, five different circuit characteristics can be easily realized. However, the realization of the band-stop and the all-pass transfer functions requires matching the conditions below in terms of the gain-bandwidth products and transconductance gains.

$$BS:\quad k_1B_1=k_2B_2 \qquad (13)$$

$$AP:\quad k_2B_2=2k_1B_1 \qquad (14)$$

In the proposed circuit, although the circuit parameters ω_0 and Q can be theoretically set to arbitrary values, the range of ω_0 depends on B_1 and B_2. And it seems that the value of Q is also limited by the dynamic ranges of OA and OTA.

Table 2 Sensitivities with respect to circuit active elements.

x	$S_x^{\omega_0}$	S_x^Q
g_{m1}	0.0	-1.0
g_{m2}	0.5	0.5
g_{m3}	-0.5	0.5
B_1	0.5	-0.5
B_2	0.5	0.5

The sensitivities $S_x^{\omega_0}$ and S_x^Q with respect to the circuit active elements are shown in Table 2. These values are within the range $0\le\left|S_x^y\right|\le 1$. In particular, the sensitivity S_x^Q to the gain-bandwidth product is considered to be zero from Eq.(7) in the case of $B_1=B_2$. From these values, it is found that our proposed circuit has very low sensitivity with respect to the circuit active elements.

3. Design Example

As examples, consider the realization of the low-pass, the band-pass and the high-pass characteristics on Eqs.(8), (9) and (10). In PSpice simulation, a $LM741$ OA with the gain-bandwidth product $B_i=2\pi(1.0027)\times10^6\,rad/\sec$ is used. Also, we have used a CA3080 OTA with a macro model[5] shown in Fig.3. Here, it is assumed that the CA3080 OTA's parameters are $g_i=10.0\mu S$, $C_i=2.6pF$, $g_o=14.3\mu S$ and $C_o=3.6pF$, respectively.

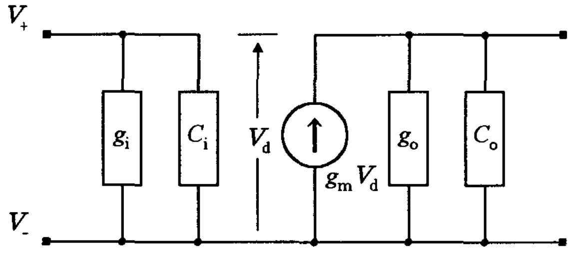


Figure 3 Macro model of CA3080 OTA.

Let us design the characteristics with the cut-off frequency $f_0(=\omega_0/2\pi)=70kHz$ and the quality factor $Q=1.0$. The transconductance gains are listed in Table 3. Figure 4 shows the simulated low-pass, band-pass and high-pass responses. They are favorable enough over a wide frequency range.

Other circuit characteristics can also be obtained easily.

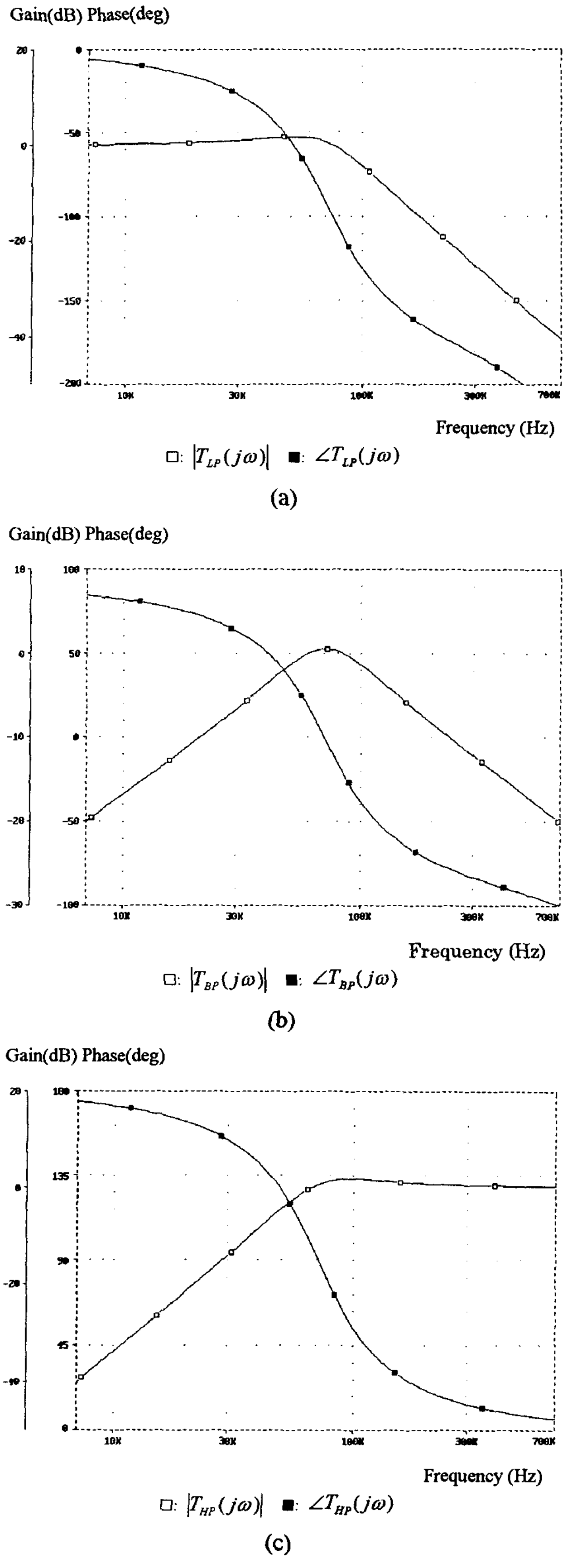
Table 3 Transconductance gains.

g_{mx}	value(mS)
g_{m1}	0.3491
g_{m2}	0.2437×10^{-1}
g_{m3}	5.000

4. Conclusions

A novel voltage-mode active-only biquadratic circuit has been proposed. It has been shown that the circuit can realize five different circuit transfer functions (i.e. the low-pass, the band-pass, the high-pass, the band-stop and the all-pass characteristics) by selecting the input and output terminals, and that the circuit characteristics can be electronically tuned by the transconductance gains. It has been clearly shown from sensitivity analysis that the proposed circuit has very low sensitivities with respect to the circuit active elements. The simulated frequency responses have been quite good over a wide frequency range. It seems that our biquadratic configuration is very suitable for implementation in both bipolar and CMOS technologies.

The non-idealities of active devices may affect the circuit characteristics. The solution on this will be presented in the near future.



(a)

(b)

(c)

Figure 4 Simulated frequency responses ((a) LP, (b) BP, (c) HP characteristics).

References

[1] E. Sanchez-Sinencio, and R.L. Geiger : Generation of continuous-time two integrator loop OTA filter structures, IEEE Trans. Circuits & Syst., 35, 8, 936-946, 1988.

[2] G.W. Roberts, and A.S. Sedra : A general class of current amplifier-based biquadratic filter circuits, ibid., 39, 4, pp.257-263, 1992.

[3] J. Ramirez-Angulo, M. Robimson, and E. Sanchez-Sinencio : Current-mode continuous-time filters : two design approaches, ibid., 39, 6, pp.337-341, 1992.

[4] M. Higashimura : Current-mode lowpass and bandpass filters using the operational amplifier pole, Int. J. Electron., 74, 6, pp.945-949, 1993.

[5] J. Wu : Current-mode high-order OTA-C filters, ibid., 76, 6, pp.1115-1120, 1994.

[6] Y. Sun : Note on two integrator loop OTA-C configurations, Electron. Lett., 34, 16, 1533-1534, 1998.

[7] T. Tsukutani, M. Ishida, S. Tsuiki, and Y. Fukui : Current-mode biquad without external passive elements, ibid., 32, 3, pp.197-198, 1996.

[8] M.T. Abuelma'atti, and H.A. Alzaher : Universal three inputs and one output current-mode filter without external passive elements, ibid., 33, 4, pp.281-283, 1997.

[9] T. Tsukutani, M. Higashimura, Y. Sumi, and Y. Fukui : Electronically tunable current-mode active-only biquadratic filter, Int. J. Electron., 87, 3, pp.307-314, 2000.

[10] K. Singh, and R. Senani : Low-component-count active-only immittances and their application in realising simple multifunction biquads, Electron. Lett., 34, 8, pp.718-719, 1998.