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Current-mode electronically tunable biquadratic filters consisting of only CCCIIs and grounded capacitors

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ABSTRACT

In this paper, a current-mode (CM) analog filter for simultaneously realizing high output impedance low-pass, band-pass and high-pass analog responses besides high output impedance notch and all-pass analog filter responses with interconnection of the relevant output currents, is presented. Also, two CM filters for simultaneously providing high output impedance universal filter responses are derived from the proposed one. All of the introduced CM topologies employ a canonical number of only grounded capacitors without requiring any resistors, and do not need critical component matching conditions. All of the developed circuits have low input impedance and high output impedance resulting in easy cascadability with other CM ones. Frequency dependent non-ideal gain and parasitic impedance effects on the performance of the presented first filter are investigated as examples. In order the show the performance of the filter and verify the theory, simulations are accomplished with SPICE program.

1. Introduction

The use of current-mode (CM) active devices is not only restricted to current processing but also offers certain advantages such as higher usable gain, more reduced voltage excursion at sensitive nodes, greater linearity, less power consumption, wider bandwidth, better accuracy and larger dynamic range compared to that of voltage-mode counterparts for example operational amplifiers [1–4]. Furthermore, addition and subtraction operation in CM process is easy. For this reason, in the literature, much has been devoted to the realization of second-order CM analog filters employing second-generation current controlled conveyors (CCCIIs) and for providing high output impedance currents [5–17]. The filters of [5–9] employ single output CCCIIs while filters of [10–17] use multi output CCCIIs and one of [10] requires two identical input currents. None of the CM filters of [5–15] show the property of low input impedance. Although the filters of [16,17] have low input impedance, and use only grounded capacitors and three CCCIIs, one of their CCCIIs has three Z terminals while other two CCCIIs have two Z terminals. Further, the filter of [12] is composed of six dual output CCCIIs (DO-CCCIIs). It is relatively easy to implement only grounded capacitors in integrated circuit (IC) fabrication [18,19]. External tunability in IC by employing CCCIIs and other active devices is an important topic in open literature [20].

In this paper, a CM universal biquad composed of two lossless integrator loops and the adder is presented. The structure of two lossless integrator loops and the adder is a well-known structure for realizing biquad filter, which was previously reported in [21]. The first one uses three DO-CCCIIs while the second and third ones employ four plus-type CCCIIs (CCCII+s) and three CCCIIs, respectively. Contrary to the previously reported CM analog filters [5–17], the proposed first filter meets all of the following nine important specifications simultaneously: (i) can be tuned electronically, (ii) uses a minimum number of components, two grounded capacitors and three identical DO-CCCIIs so it occupies less area, (iii) does not need any component matching constraints, (iv) has both low input and high output impedances thus it can be easily cascaded with other CM topologies, (v) requires no additional components to give high output impedance filter responses, (vi) has no capacitors bringing extra poles degrading its high frequency performance [15], (vii) can simultaneously realize low-pass, band-pass and high-pass filter responses in addition to notch and all-pass filter responses, (viii) has low component sensitivities, (ix) has a single input current, and does not need any other input currents. The proposed filter satisfying all of the above important nine features simultaneously is compared with previously published ones using multi output CCCIIs [10–17] in Table 1.

2. Proposed second-order universal filters

Equivalent circuit of the versatile active device DO-CCCII depicted in Fig. 1 can be represented with the following

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equations:

$$I_y = 0$$
$$I_z = \pm \alpha I_x$$
$$V_x = I_x R_x + V_y \quad (1)$$

The frequency dependent non-ideal current gain α is ideally equal to unity. The plus and minus sign of α respectively correspond to Z+ and Z− terminals of the DO-CCCII. The series intrinsic resistance R_x in Eq. (1), as defined in [20] for bipolar realization, is given as

$$R_x = \frac{V_T}{2I_o} \quad (2)$$

where V_T and I_o are respectively the thermal voltage and bias current of DO-CCCII. The presented filter in Fig. 2 with sufficiently high I_{o1} resulting in low R_{x1} and input impedance, can provide the standard universal filter transfer functions (TFs) given in Table 2.

Denominator $D(s)$ in Table 2 is evaluated as

$$D(s) = s^2 + s\left(\frac{\omega_o}{Q}\right) + \omega_o^2 \quad (3)$$

Table 1
Comparison of proposed filter with previously published ones [10–17].

Filters	Properties (i)	(ii)	(iii)	(iv)	(v)	(vi)	(vii)	(viii)	(ix)
[10]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	No
[11]	Yes	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes
[12]	Yes	No	Yes	No	Yes	Yes	Yes	Yes	Yes
[13,14]	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
[15]	Yes	No	Yes	No	Yes	No	Yes	Yes	Yes
[16,17]	Yes	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Proposed	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes

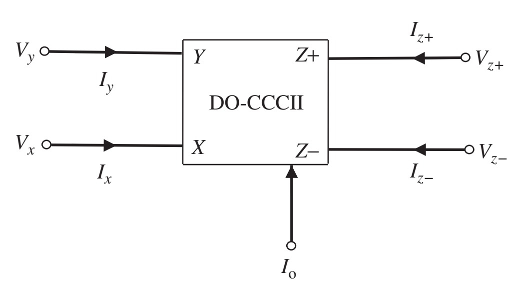

Fig. 1. Equivalent circuit of the DO-CCCII.

The parameters ω_o and Q in Eq. (3) are found as follows:

$$\omega_o = \sqrt{\frac{\alpha_2\alpha_3\alpha_5}{C_1C_2R_{x2}R_{x3}}} \quad (4a)$$

$$Q = \sqrt{\frac{\alpha_3\alpha_5C_1R_{x2}}{\alpha_2C_2R_{x3}}} \quad (4b)$$

It should be noted that the parameters ω_o and Q can be adjusted arbitrarily for the fix-valued capacitors in fully IC technology. It means that ω_o can be chosen arbitrarily without disturbing Q and vice versa, which can be achieved by simultaneously changing R_{x2} and R_{x3} and keeping R_{x2}/R_{x3} constant and vice versa. All of the active and passive element sensitivities of the parameters ω_o and Q in Eqs. (4a) and (4b) are one half in magnitudes. Similarly, the presented filter in Fig. 3 with sufficiently high I_{o1}, derived from the filter of Fig. 2, can provide the universal filter TFs given in Table 3. The effect of R_{x1} can be negligible and the input impedance of the introduced filter becomes low enough. Denominator $D(s)$ in Table 3 is given in Eq. (3). The tunable parameters ω_o and Q in Eq. (3) are calculated as

$$\omega_o = \sqrt{\frac{\alpha_3\alpha_6}{C_1C_2R_{x2}R_{x3}}} \quad (5a)$$

$$Q = \sqrt{\frac{\alpha_6C_1R_{x2}}{\alpha_3C_2R_{x3}}} \quad (5b)$$

The derived filter depicted in Fig. 4 with sufficiently high I_{o1} yielding low R_{x1} and input impedance, can provide the standard universal filter TFs given in Table 4. Denominator $D(s)$ in Table 4 is given in Eq. (3). The electronically tunable parameters ω_o and Q given in Eq. (3) are calculated as

$$\omega_o = \sqrt{\frac{\alpha_4\alpha_7}{C_1C_2R_{x2}R_{x3}}} \quad (6a)$$

$$Q = \sqrt{\frac{\alpha_7C_1R_{x2}}{\alpha_4C_2R_{x3}}} \quad (6b)$$

All the component sensitivities of ω_o and Q in Eqs. (5a), (5b), (6a) and (6b) are one half in magnitudes.

Table 2
The standard universal filter TFs of the suggested filter in Fig. 2.

Names of transfer functions	Transfer functions of proposed filter
Low-pass transfer function	$I_{LP}/I_{in}=(\omega_o^2\alpha_2\alpha_3\alpha_6/D(s))$
Band-pass transfer function	$I_{BP}/I_{in}=-s(\omega_o/Q)\alpha_2\alpha_4/D(s)$
High-pass transfer function	$I_{HP}/I_{in}=(s^2\alpha_1/D(s))$
Notch transfer function	$I_{NF}/I_{in}=(I_{LP}/I_{in})+(I_{HP}/I_{in})$
All-pass transfer function	$I_{AP}/I_{in}=(I_{LP}/I_{in})+(I_{BP}/I_{in})+(I_{HP}/I_{in})$

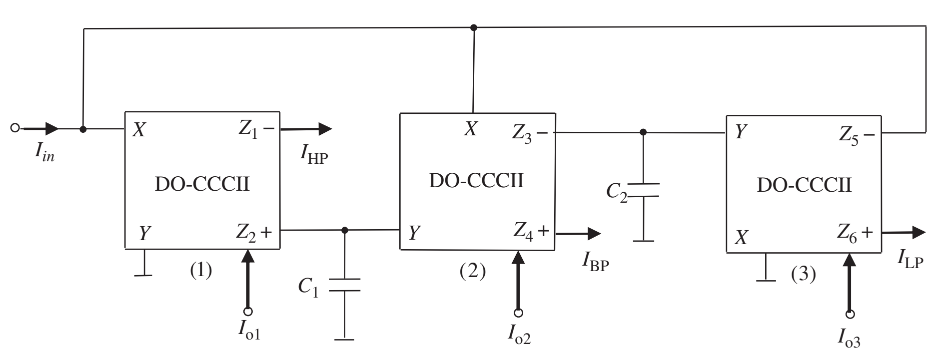

Fig. 2. Proposed current-mode universal biquadratic filter.