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Electronically tunable current-mode biquadratic filter and four-phase quadrature oscillator

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ABSTRACT

This paper presents a current-mode biquadratic filter based on ZC-CFTAs. It employs only three ZC-CFTAs, one resistor and two grounded capacitors. It can simultaneously realize not only highpass and lowpass filtering functions but also two different forms of bandpass ones; one has a pass-band gain of Q, the other, a pass-band gain of unity. Its ω_o and Q can be tuned orthogonally through adjusting bias currents of ZC-CFTAs. Moreover, the proposed circuit can also be modified to be a current controlled four-phase quadrature oscillator with small distortion. Non-ideal analysis and sensitivity analysis are provided. The results of circuit simulations are in agreement with theory.

1. Introduction

The biquadratic filters or the four-phase quadrature oscillators based on operational transconductance amplifiers (OTAs), current conveyors (CCIIs), current differencing buffered amplifier (CDBA), and differential output-current inverter buffered amplifier (DO-CIBA) have been reported [1–12]. Although these circuits perform well, they also suffer from several disadvantages, such as high-impedance current inputs [1–4], the lack of electronic tenability [5–7], the excessive use of passive elements, especially floating resistors and capacitors [8–12]. Moreover, all these circuits do not work in really current mode.

In 2003, Dalibor Biolek proposed current differencing transconductance amplifier (CDTA) [13]. This circuit has found wide applications in electronics community [14–22]. However, most of the earlier reported circuits do not fully use the potential of the CDTA since always one of the input terminals *p* or *n* is not used. This may cause some noise injection into the monolithic circuit. In order to avoid this problem, the CDTA has been simplified by replacing the current differencing unit (CDU) by a simple current follower (CF). The appropriate novel active building block is called current follower transconductance amplifier (CFTA). So far, the CFTA-based filters and oscillators have been reported [23–26], but these reported circuits suffer from one or more of following weaknesses: interactive electronic control of ω_o and Q, excessive use of the passive and active elements, use of floating capacitor, low output impedance, and unavailable realizing both biquadratic filter and quadrature oscillator without changing circuit topology. This is not desirable for CFTA further application.

Recently, a simplified version of the CFTA, called Z-copy CFTA (ZC-CFTA), has been proposed [27–30]. The current-mode filters and oscillators empolying ZC-CFTAs have been reported. Although the circuit proposed in the literature [29] can realize a band-pass filter function, it is an approximated band-pass filter rather than an ideal universal filter. While this circuit can also be modified into a mixed-mode quadrature oscillator, it produces only two current outputs rather than four-phase quadrature current outputs. In order to obtain a current-mode biquadratic filter/four-phase quadrature oscillator using ZC-CFTAs, a current-mode amplifier using ZC-CFTA is first presented. Then a current-mode circuit based on ZC-CFTAs is given. Apart from highpass and lowpass filtering functions, It can simultaneously realize two different forms of bandpass ones, one has a pass-band gain of Q, which is undesirable for high Q filters since high Q readily causes ZC-CFTA to operate in nonlinear regions, and the other, a pass-band gain of unit, which is desirable for high Q filters. Moreover, the proposed circuit can also be tuned into a current controlled four-phase quadrature oscillator. Having used canonic number of components and grounded capacitors, the proposed circuit is easy to be integrated and enjoys low passive and active sensitivities. Having used an automatic amplitude-control (AAC) circuit, the oscillator can sustain an output signal with small distortion. The SPICE simulations confirm the feasibility of the proposed circuits and the results are in good agreement with theory.

2. Basic concept of the ZC-CFTA

A ZC-CFTA is similar to a conventional CDTA, except that the ZC-CFTA has only one input port. Its circuit symbol is shown in

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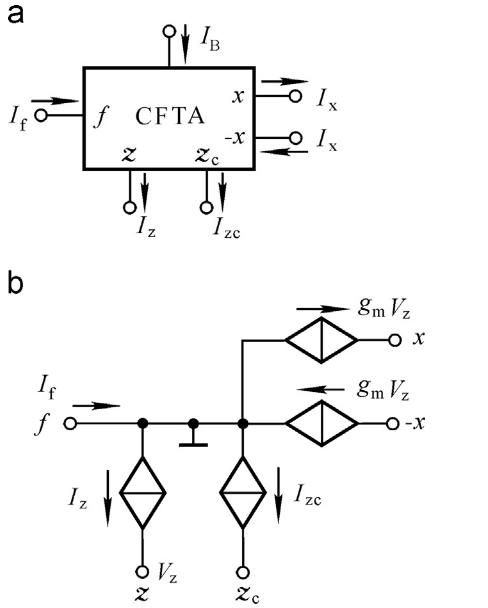

Fig. 1. ZC-CFTA: (a) circuit symbol and (b) equivalent circuit model.

Fig. 1(a) and the equivalent circuit model is given in Fig. 1(b). The terminal relation of the ZC-CFTA can be written as

$$V_f = 0,\ I_{zc} = I_z = I_f,\ I_x = g_m V_z, \tag{1}$$

where, g_m is the transconductance gain of the ZC-CFTA. For a ZC-CFTA implemented with bipolar technology, g_m is given by

$$g_m = \frac{I_B}{2V_T} \tag{2}$$

here, V_T and I_B are the thermal voltage and the bias current of the ZC-CFTA, respectively.

3. The proposed current-mode filter/oscillator

Since the proposed circuit relies a current-mode amplifier using ZC-CFTA, this amplifier is shown in Fig. 2. A routine analysis of the circuit yields the following transfer function:

$$A_i = \frac{I_o}{I_i} = 2 - g_m R, \tag{3}$$

From Eq. (3), it is easily seen that the gain of the circuit can be zero if $g_m R = 2$. This is different from the existing amplifier reported in the literature [17], wherein $A_i = g_m R$, it cannot be zero, this is due to the fact that the BJTs in ZC-CFTA are not in the forward-active mode when $I_B = 0$.

Fig. 3 shows the proposed circuit using ZC-CFTAs. This circuit has global and local feedback loops. The loop gains are $g_{m1}/sC_1 \times (-g_{m2}/sC_2)$ and $-A_i g_{m1}/sC_1$, respectively. The forward transfers from I_i to I_{o1}, I_{o2}, I_{o3}, I_{o4}, and I_{o5} are 1, g_{m1}/sC_1, $g_{m1}g_{m2}/s^2C_1C_2$, $-g_{m1}/sC_1$, and $A_i g_{m1}/sC_1$, respectively. For $g_{m1} = g_{m2} = g_m$, $C_1 = C_2 = C$, using Mason's formula [31], the various transfer functions can be readily derived as:

$$\frac{I_{o1}}{I_i} = \frac{s^2}{s^2 + sA_i g_m/C + g_m^2/C^2}, \tag{4}$$

$$\frac{I_{o2}}{I_i} = \frac{-I_{o4}}{I_i} = \frac{s g_m/C}{s^2 + sA_i g_m/C + g_m^2/C^2}, \tag{5}$$

$$\frac{I_{o3}}{I_i} = \frac{g_m^2/C^2}{s^2 + sA_i g_m/C + g_m^2/C^2}, \tag{6}$$

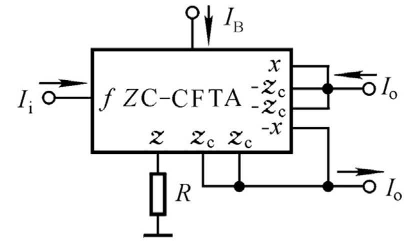

Fig. 2. Proposed current-mode amplifier using a ZC-CFTA.

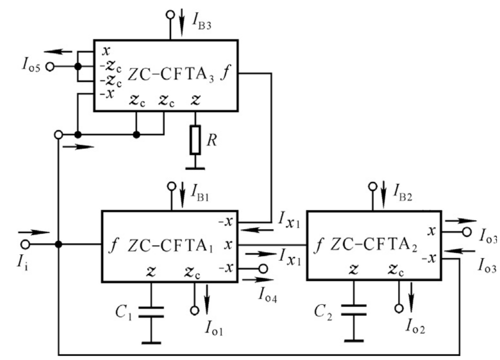

Fig. 3. Proposed current-mode filter/oscillator using ZC-CFTAs.

$$\frac{I_{o5}}{I_i} = \frac{sA_i g_m/C}{s^2 + sA_i g_m/C + g_m^2/C^2} \tag{7}$$

Combining Eqs. (2)–(3), the pole frequency and Q-factor of the circuit are obtained respectively,

$$\omega_o = \frac{g_m}{C} = \frac{I_B}{2V_T C},\ Q = \frac{1}{A_i} = \frac{1}{2 - I_{B3}R/2V_T} \tag{8}$$

Eq. (8) shows that ω_o can be linearly tuned by adjusting bias current I_B, Q can be independently tuned by tuning bias current I_{B3} without influencing ω_o. This means that ω_o and Q can be electronically and independently tuned.

From Eqs. (4)–(7), the corresponding pass-band gain is

$$H_{HP} = 1,\quad H_{BP1} = -H_{BP2} = 1/A_i = Q,\quad H_{BP3} = 1,\quad H_{LP} = 1 \tag{9}$$

From the above equations, it is clearly seen that a second-order universal current-mode filter, namely low pass, high pass, and two different forms of band pass filters with two different pass-band gains, is achieved simultaneously. Moreover, if $I_i = 0$ and A_i is forced to be zero, namely

$$g_{m3} R = 2, \tag{10}$$

Q becomes infinity. Hence the proposed circuit will work as an oscillator of frequency ω_o. This means that the circuit can also work as a current-mode oscillator. Re-analysis of the circuit in Fig. 3 yields the following characteristic equation:

$$s^2 + (2 - g_{m3}R) g_m s/C + g_m^2/C^2 = 0 \tag{11}$$

The oscillation condition and oscillation frequency are then

$$g_{m3} R \ge 2, \tag{12}$$

$$\omega_o = \sqrt{\frac{g_{m1}g_{m2}}{C_1 C_2}} = \frac{g_m}{C} = \frac{I_B}{2V_T C} \tag{13}$$

It is clear that the tuning laws of the condition for oscillation and the oscillation frequency are independent, the oscillation condition can be tuned by the bias current I_{B3}, the oscillation frequency can be tuned by the bias current I_B.