วงจรกรองความถี่โหมดกระแสหลายหน้าที่ที่ควบคุมด้วยวิธีการทางอิเล็กทรอนิกส์โดยใช้ CFTA

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บทคัดย่อ

บทความนี้นำเสนอ วงจรกรองความถี่โหมดกระแสโดยใช้ CFTAs สามารถสังเคราะห์ฟังก์ชันที่จำเป็นได้ทั้งหมด ได้แก่ กรองความถี่ต่ำผ่าน สูงผ่าน แถบความถี่ผ่าน กำจัดแถบความถี่ผ่าน และผ่านทุกความถี่ ซึ่งอุปกรณ์หลักในวงจรได้แก่ อุปกรณ์ขยายความนำตามกระแส (CFTA) จุดเด่นของวงจรคือ สามารถควบคุมความถี่โพล และค่าควอลิตี้แฟกเตอร์ได้ด้วยกระแสไบแอส โครงสร้างไม่ซับซ้อน โดยใช้เพียง CFTAs 3 ตัว ตัวต้านทานที่ต่อลงกราวนด์ 1 ตัว และตัวเก็บประจุที่ต่อลงกราวนด์ 2 ตัว วงจรที่นำเสนอนี้จึงเหมาะสมกับการนำไปพัฒนาเป็นวงจรรวม ผลการจำลองการทำงานด้วยโปรแกรม PSpice พบว่า วงจรทำงานได้สอดคล้องกับที่คาดการณ์ไว้ตามทฤษฎี วงจรมีอัตราสิ้นเปลืองกำลังไฟฟ้าเท่ากับ 6.15mW ที่แหล่งจ่ายกำลังไฟฟ้า ±1.25V

คำสำคัญ: โหมดกระแส วงจรกรองความถี่ CFTA

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A Current-mode Universal Biquadratic Filter with Electronic Controllability Employing CFTAs

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Abstract

This article presents a current-mode universal filter performing all standard functions: low-pass, high-pass, band-pass, band-reject, and all-pass functions. The circuit principle is based on current follower transconductance amplifiers (CFTAs). The principal feature of the circuit is that the pole frequency and quality factor can be electronically tuned via the input bias currents. The circuit topology is very simple, consisting of merely three CFTAs, one grounded resistor, and two grounded capacitors. It is appropriate to further develop the proposed circuit into an integrated circuit architecture. The PSpice simulation results are shown. The given results agree well with the theoretical expectation. The total power consumption was approximately 6.15mW at ±1.25V power supply voltage.

Keywords: Current-mode, Filter, CFTA

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1. Introduction

An analog filter is an important building block, widely used for continuous-time signal processing. It can be found in many fields: including, communications, measurement instrumentation and control systems [1], [2]. One of most popular analog filters is a multifunction biquadratic filter, since it can provide several functions. Recently, a universal filter working in current-mode has been more popular than the voltage-mode type. Since the last decade, there has been much effort to reduce the supply voltage of analog systems. This is due to the demand of portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current–mode technique is ideally suited for this purpose. Actually, a circuit using the current-mode technique has many other advantages, such as, larger dynamic range, higher bandwidth, greater linearity, simpler circuitry and lower power consumption [3],[4].

The current follower transconductance amplifier (CFTA) is a recently reported active component. It seem to be a versatile component in the realization of a class of analog signal processing circuits, especially analog frequency filters [5],[6]. There are many papers presenting various applications using CFTAs such as current or voltage-mode universal filters, current-mode or mixed-mode KHN–equivalent biquads, current-mode all-pass filter, active-C grounded positive inductance simulator, or current-mode quadrature oscillator [5]-[15]. It is really current-mode element whose input and output signals are currents. In addition, its current gain can also be adjusted.

The aim of this paper is to propose a current-mode universal biquadratic filter, emphasizing on use of the three CFTAs one grounded resistor and two grounded capacitors. The features of the proposed circuit are that: the proposed universal biquadratic filter can completely provide five functions (low-pass, high-pass, band-pass, band-reject and all-pass) without changing circuit topology; the circuit description is very simple, employing only one grounded resistor and two grounded capacitors, thus it is suitable for fabricating in monolithic chip. The quality factor and pole frequency can be electronically adjusted. The PSpice simulation results are also shown, which are in correspondence with the theoretical analysis.

2. Principle of Operation

2.1 Basic Concept of CFTA

The schematic symbol and the ideal behavioral model of the CFTA are shown in Fig. 1 (a) and (b), respectively. It has one low impedance current input at f port. The current i_f flows from port z. In some applications, to utilize the current through z terminal, an auxiliary z_c (z-copy) terminal is used [7], [9], [10], [14], [16]. The internal current mirror provides a copy of the current flowing out of the z terminal to the z_c terminal. The voltage v_z on z terminal is transferred into current using transcon ductance (g_m), which flows into output terminal x. The g_m is tuned by I_B. In general, CFTA can contain an arbitrary number of x terminals, providing currents I_x of both directions. The characteristics of the ideal CFTA are represented by the following hybrid matrix

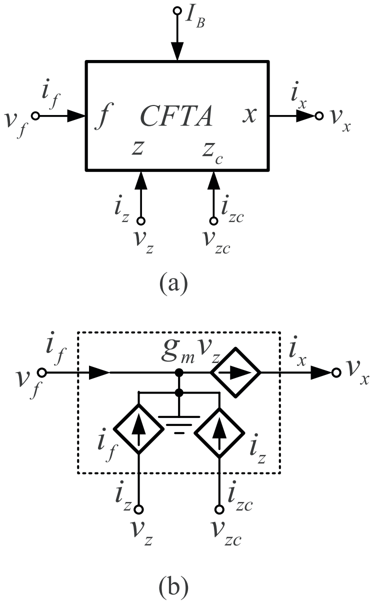

Figure 1 CFTA (a) Symbol (b) Equivalent circuit.

$$\begin{bmatrix} V_f \\ I_{z,zc} \\ I_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & \pm g_m \end{bmatrix} \begin{bmatrix} I_f \\ V_x \\ V_z \end{bmatrix}, \quad (1)$$

For a CMOS CFTA, the gm is written as

$$g_m = \sqrt{kI_B}\ , \quad (2)$$

where $k = \mu_O C_{OX}\left(W/L\right)$. Here k and I_B are physical transconductance parameter of MOS transistor and input bias current, μ_O is the free electron mobility in the channel, C_{OX} is the gate oxide capacitance per unit area. W and L are the channel width and length, respectively.

2.2 Implementation of the Filter

The filter is designed by cascading a current amplifier and the current-mode lossless integrators as systematically shown in Fig. 2 [17]. From block diagram in Fig. 2, we will receive the transfer functions at each terminal as

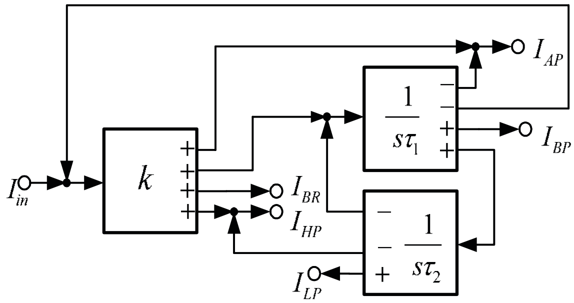

Figure 2 Block diagram for the filter [17].

$$\frac{I_{LP}}{I_{in}} = K\frac{1}{s^2\tau_1\tau_2 + s\tau_2 K + 1}, \quad (3)$$

$$\frac{I_{BP}}{I_{in}} = K\frac{s\tau_2}{s^2\tau_1\tau_2 + s\tau_2 K + 1}, \quad (4)$$

$$\frac{I_{HP}}{I_{in}} = K\frac{s^2\tau_1\tau_2}{s^2\tau_1\tau_2 + s\tau_2 K + 1}, \quad (5)$$

$$\frac{I_{BR}}{I_{in}} = K\frac{s^2\tau_1\tau_2 + 1}{s^2\tau_1\tau_2 + s\tau_2 K + 1}, \quad (6)$$

and

$$\frac{I_{AP}}{I_{in}} = K\frac{s^2\tau_1\tau_2 - s\tau_2 K + 1}{s^2\tau_1\tau_2 + s\tau_2 K + 1}. \quad (7)$$

The pole frequency and quality factor can be respectively as

$$\omega_0 = \sqrt{\frac{1}{\tau_1\tau_2}}\ , \quad (8)$$

and $$Q = \frac{1}{K}\sqrt{\frac{\tau_2}{\tau_1}}\ . \quad (9)$$

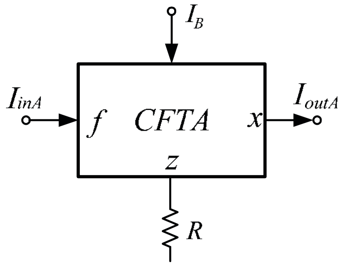

Figure 3 A current amplifier based on CFTA.

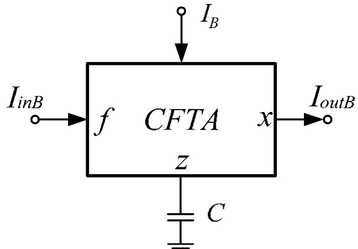

Figure 4 A lossless integrator using CFTA.

It is found that the pole frequency and quality factor can be tuned orthogonally. This means that the pole frequency can be adjusted without affecting the quality factor by τ_1, or τ_2 by keeping its ratio to be constant, whereas the quality factor can be tuned through k without effecting the pole frequency.

2.3 Proposed Current-mode Universal Biquad Filter

As mentioned in last section, the proposed filter is based on current amplifier and the current-mode lossless integrators. In this section, these circuits will be described. The current amplifier based on CFTA is shown in Fig. 3. The output current of the circuit can be written to be

$$I_{outA} = kI_{inA}\,, \tag{10}$$

where $k = g_m R$. Fig. 4 shows the lossless integrator using CFTA. Considering the circuit in Fig. 4 and using CFTA properties, we will receive

$$\frac{I_{outB}}{I_{inB}} = \frac{1}{s\tau} \tag{11}$$

where $\tau = C / g_m$.

The completed current-mode universal filter is shown in Fig. 5. The transfer functions of the circuit in Fig. 5 can be written to be

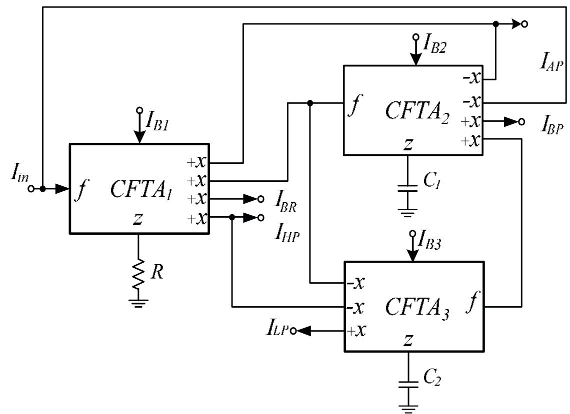

Figure 5 Completely proposed current-mode universal filter.

$$\frac{I_{LP}}{I_{in}} = g_{m1}R\frac{1}{s^2\dfrac{C_1C_2}{g_{m2}g_{m3}} + s\dfrac{C_2g_{m1}R}{g_{m3}} + 1}, \tag{12}$$

$$\frac{I_{BP}}{I_{in}} = g_{m1}R\frac{s\dfrac{C_2}{g_{m3}}}{s^2\dfrac{C_1C_2}{g_{m2}g_{m3}} + s\dfrac{C_2g_{m1}R}{g_{m3}} + 1}, \tag{13}$$

$$\frac{I_{HP}}{I_{in}} = g_{m1}R\frac{s^2\dfrac{C_1C_2}{g_{m2}g_{m3}}}{s^2\dfrac{C_1C_2}{g_{m2}g_{m3}} + s\dfrac{C_2g_{m1}R}{g_{m3}} + 1}, \tag{14}$$

$$\frac{I_{BR}}{I_{in}} = g_{m1}R\frac{s^2\dfrac{C_1C_2}{g_{m2}g_{m3}} + 1}{s^2\dfrac{C_1C_2}{g_{m2}g_{m3}} + s\dfrac{C_2g_{m1}R}{g_{m3}} + 1}, \tag{15}$$

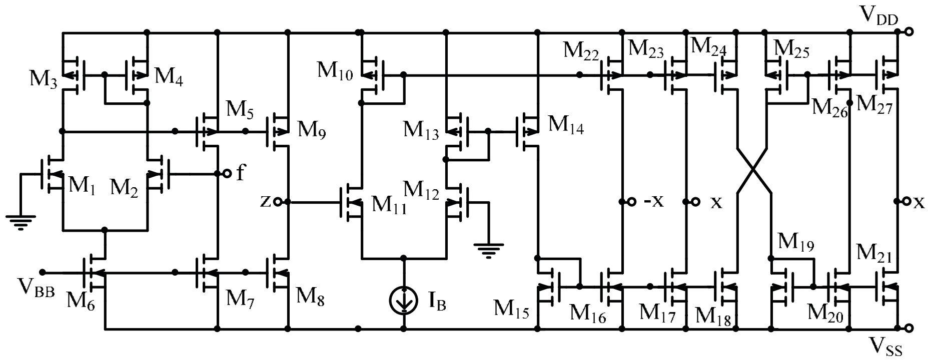

Figure 6 A possible internal construction of CFTA.

and

$$\frac{I_{AP}}{I_{in}} = g_{m1}R\frac{s^2\frac{C_1C_2}{g_{m2}g_{m3}} - s\frac{C_2g_{m1}R}{g_{m3}} + 1}{s^2\frac{C_1C_2}{g_{m2}g_{m3}} + s\frac{C_2g_{m1}R}{g_{m3}} + 1}. \quad (16)$$

From Eq. (12)-(16), the pole frequency and quality factor can be expressed to be

$$\omega_0 = \sqrt{\frac{g_{m2}g_{m3}}{C_1C_2}}, \quad (17)$$

and

$$Q = \frac{1}{g_{m1}R}\sqrt{\frac{C_1g_{m3}}{C_2g_{m2}}}. \quad (18)$$

Substituting the transconductance as depicted in Eq. (2) in Eqs. (17) and (18), it yields pole frequency and quality factor as follows

$$\omega_0 = \sqrt{\frac{\left(k_2k_3I_{B2}I_{B3}\right)^{\frac{1}{2}}}{C_1C_2}}, \quad (19)$$

and

$$Q = \frac{1}{R}\sqrt{\frac{C_1\left(k_3I_{B3}\right)^{\frac{1}{2}}}{C_2k_1I_{B1}\left(k_2I_{B2}\right)^{\frac{1}{2}}}}. \quad (20)$$

It is obviously found that, from Eqs. (19)-(20), by keeping to ratio of I_{B2} and I_{B3} to be equable, the pole frequency can be adjusted by I_{B2} and I_{B3} without affecting the quality factor. Simultaneously, the quality factor can be adjusted by without affecting the pole frequency. Moreover, the circuit can provide high Q_O by reducing the value of R. The filter bandwidth (BW) can be expressed as

$$BW = \frac{\omega_0}{Q_0} = \frac{\left(k_1I_{B1}\right)R\sqrt{k_2I_{B2}}}{C_1}. \quad (21)$$

Note that the bandwidth can be controlled by I_{B1} or I_{B2}.

2.4 Circuit Sensitivity

The sensitivities of the proposed circuit can be found as

$$S_{I_{B2}}^{\omega_0} = S_{I_{B3}}^{\omega_0} = S_{k_2}^{\omega_0} = S_{k_3}^{\omega_0}\frac{1}{4};\ S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = -\frac{1}{2} \quad (22)$$

and

$$S_{I_{B1}}^{Q_0} = S_{k_1}^{Q_0} = -\frac{1}{2}; S_R^{Q_0} = -1,$$
$$S_{C_2}^{Q_0} = \frac{1}{2};\ S_{I_{B2}}^{Q_0} = S_{k_2}^{Q_0} = \frac{1}{4},$$
$$S_{I_{B3}}^{Q_0} = S_{k_3}^{Q_0} = -\frac{1}{4}; S_{C_1}^{Q_0} = -\frac{1}{2} \quad (23)$$

Therefore, all the active and passive sensitivities are less than unity in magnitude.

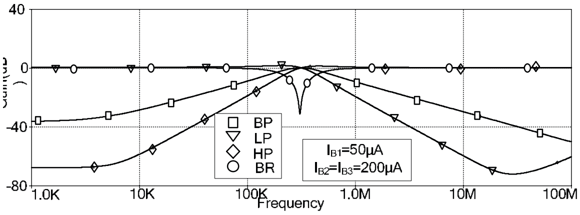

Figure 7 Gain responses of proposed circuit.

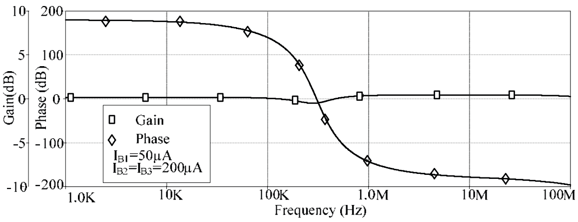

Figure 8 All-pass responses of the proposed circuit in Figure 5.

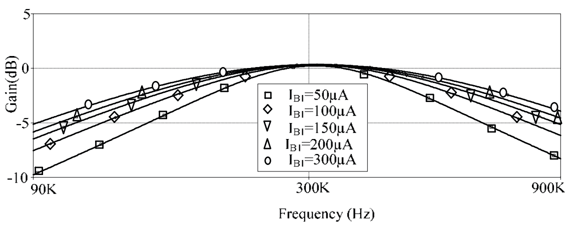

Figure 9 Band-pass responses for different values of I_{B1}, where $I_{B2} = I_{B3} = 200\mu A,\ R = 1k\Omega$

3. Simulation Results

To prove the performances of the proposed filter, the PSpice simulation program is used for the examinations. Fig. 6 depicts schematic description of the CFTA used in the simulations. The PMOS and NMOS transistors have been simulated by using the parameters of a 0.25µm TSMC CMOS technology [18]. The transistor aspect ratios of PMOS and NMOS transistor are indicated in Table 1. The circuit was biased with ±1.25V supply voltages, V_{BB}= -055*V*, C_1=C_2 =I*nF, R*=1*k*Ω, $I_{B1} = 50\mu A$, $I_{B2} = I_{B3} = 200\mu A$. Loads of the circuit are 1Ω of resistor. The results shown in Fig. 7 are the gain responses of the proposed universal filter. Gain and phase responses of the all-pass function are illustrated in Fig. 8. It is clearly seen that it can simultaneously provide low-pass, high-pass, band-pass, band-reject and all-pass functions, without modifying a circuit topology.

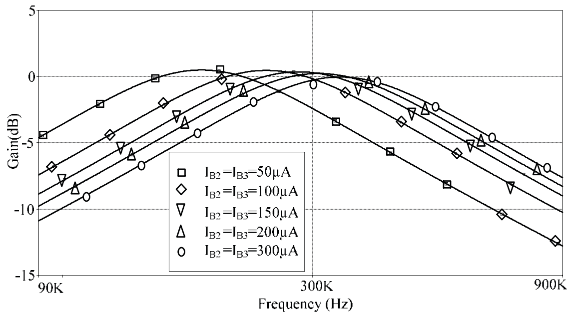

Figure 10 Band-pass responses for different values of I_{B2} and I_{B3} with keeping their ratios to be constant I_{B2},I_{B3} where $I_{B1} = 200\mu A,\ R = 1k\Omega$

Table 1 Dimensions of the transistors

Transistors	W(µm)	L(µm)
M_1-M_2, M_{19}-M_{20}	1	0.25
M_3-M_5, M_9-M_{10}, M_{13}, M_{22}-M_{27}	5	0.25
M_6-M_8, M_{15}-M_{21}	3	0.25
M_{11}-M_{12}	25	0.25
M_{14}	4.5	0.25

Fig. 9 displays gain responses of the band-pass function for different I_{B1} values, showing that the quality factor can be adjusted by the input bias current I_{B1}, as depicted in Eq. (17) without affecting the pole frequency. Fig. 10 shows gain responses of band-pass function, where I_{B2} and I_{B3} are equally set to keep the ratio and changed for several values. This shows that pole frequency can be adjusted without affecting the quality factor, as analyzed in Eqs. (18)-(19). Total power consumption is about 6.15 mW.

4. Conclusion

The current-mode universal biquadratic filter based on CFTA has been presented. The features of the proposed circuit are that: it performs completely standard functions: low-pass, high-pass, band-pass, band-reject and all-pass functions from the same circuit configuration without component matching conditions and changing circuit topology for the same time. The pole frequency and quality factor can be independently/electronically adjusted via corresponding input bias currents. The circuit description comprises only three CFTAs, one grounded resistor and two grounded capacitors, which is attractive for IC implementation. With mentioned features, it is very suitable to realize the proposed circuit in monolithic chip to use in battery-powered, portable electronic equipments such as wireless communication system devices.

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