A Current-mode Multifunction Biquadratic Filter Using CFTAs

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บทคัดย่อ

บทความนี้นำเสนอ วงจรกรองความถี่แบบไบควอเดรทิกหลายหน้าที่โหมดกระแสโดยใช้ CFTA สามารถสังเคราะห์ฟังก์ชันที่จำเป็นได้ทั้งหมด ได้แก่ กรองความถี่ต่ำผ่าน สูงผ่าน แถบความถี่ผ่าน กำจัดแถบความถี่ผ่าน และผ่านทุกความถี่ ซึ่งอุปกรณ์หลักในวงจรได้แก่ อุปกรณ์ขยายความนำตามกระแส (CFTA) จุดเด่นของวงจรคือ สามารถควบคุมความถี่โพลและค่าควอลิตี้แฟกเตอร์ได้ด้วยกระแสไบแอส โครงสร้างไม่ซับซ้อน โดยใช้เพียง CFTA 2 ตัว และตัวเก็บประจุที่ต่อลงกราวนด์ 2 ตัว วงจรที่นำเสนอไม่ต้องการตัวต้านทานมาต่อภายนอกมีเพียงตัวเก็บประจุที่ต่อลงกราวนด์เท่านั้น จึงเหมาะสมกับการนำไปพัฒนาเป็นวงจรรวม ผลการจำลองการทำงานด้วยโปรแกรม PSpice พบว่าวงจรทำงานได้สอดคล้องกับที่คาดการณ์ไว้ตามทฤษฎี วงจรมีอัตราดึงกำลังไฟฟ้าเท่ากับ 4.32 mW ที่แหล่งจ่ายแรงดันไฟฟ้า ±1.25 V

คำสำคัญ: โหมดกระแส วงจรกรองความถี่แบบไบควอเดรทิก วงจรขยายความนำตามกระแส

Abstract

This article presents a current-mode multifunction biquadratic filter performing completely standard functions including low-pass, high-pass, band-pass, band-reject and all-pass functions. The circuit principle is based on current follower transconductance amplifier (CFTA). The dominant features of the circuit are that, the pole frequency and quality factor can be electronically tuned via the input bias currents. Moreover, the circuit topology is unsophisticated, consisting of merely 2 CFTAs and 2 grouned capacitors. Without any external resistor and using only grounded elements, the proposed circuit is thus appropriate to further develop into an integrated circuit architecture. The PSpice simulation results are shown. The given results agree well with the the oretical anticipation, i.e. the maximum power consumption is approximately 4.32mW at ±1.25V power supply voltage.

Keywords: Current-mode, Biquadratic Filter, CFTA

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Received 13 December 2011; Accepted 23 March 2012

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 and 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 being 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 for 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, current-mode quadrature oscillator [5]-[15]. It is really current-mode element whose input and output signals are currents. In addition, it can also adjust the output current gain.

The aim of this paper is to propose a current-mode multifunction biquadratic filter, emphasizing on use of the CFTAs and grounded capacitors. The features of the proposed circuit are that, the proposed multifunction

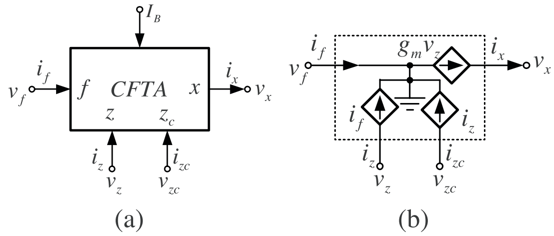


Figure 1 CFTA (a) Symbol (b) Equivalent circuit.

biquadratic filter can completely provide 5 functions low-pass high-pass band-pass band-reject and all-pass without changing circuit topology, the circuit description is very simple, employing only grounded capacitors as passive components, 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 transconductance (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 shown in Eq. (1).

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

For a CMOS CFTA, the gm is written as

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

where $k = \mu_O C_{OX} (W/L)$ and the current I_B is 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 summing currents and the current-mode lossless integrator as systematically shown in Fig. 2. From block diagram in Fig. 2, its transfer function can be found to be [17].

$$I_{out} = \frac{\left(s^2 + sb + ab\right) I_{in3} + sbI_{in2} + abI_{in1}}{s^2 + sb + ab} \quad (3)$$

From Eq. (3), the pole frequency (ω_0) and quality factor (Q_0) of each filter response can be expressed as

$$\omega_o = \sqrt{ab} \quad (4)$$

and

$$Q_o = \frac{\sqrt{ab}}{b} \quad (5)$$

It is found that the pole frequency and the quality factor can be adjusted by a or b.

2.3 Proposed Current-mode Multifunction Biquadratic Filter

The filter is designed by cascading the lossless integrator as systematically shown in Fig. 3. From

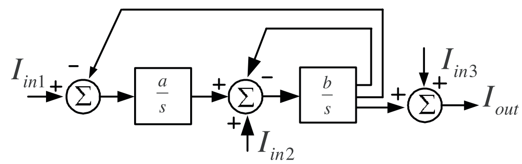


Figure 2 Block diagram for filter implementation [17].

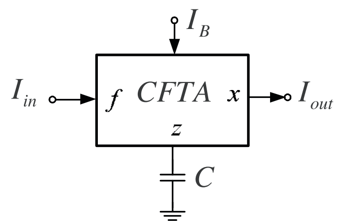


Figure 3 Lossless integrator.

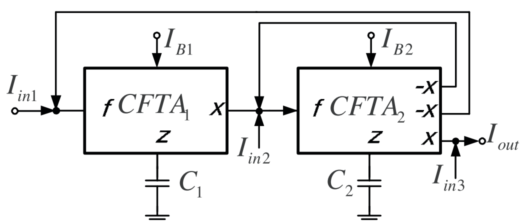


Figure 4 Proposed current-mode multifunction biquadratic filter.

circuit in Fig. 3, the current transfer function can be expressed as

$$\frac{I_{Out}}{I_{in}} = \frac{g_m}{sC} \quad (6)$$

The completed current-mode multifunction biquadratic filter is shown in Fig. 4, based on filter topology in Fig. 2. From Eq. (6), the output current of the circuit in Fig. 4 can be obtained as

$$I_{out} = \frac{\left(s^2 + s\frac{g_{m2}}{C_2} + \frac{g_{m1}g_{m2}}{C_1C_2}\right) I_{in3} + s\frac{g_{m2}}{C_2} I_{in2} + \frac{g_{m1}g_{m2}}{C_1C_2} I_{in1}}{s^2 + s\frac{g_{m2}}{C_2} + \frac{g_{m1}g_{m2}}{C_1C_2}} \quad (7)$$

From Eq. (7), the all standard transfer functions can be obtained by selecting appropriate inputs by conditions as listed in Table 1. The magnitudes of input currents I_{inl}, I_{in3} and I_{in3} can be chosen as in Table 1 to obtain a standard function of the network. The minus sign (-) represents the inverting input current. Also for function AP, I_{in2} must be double of I_{in3}. So to achieve this condition, the current amplifier which has gain of 2 is required.

Table 1 The I_{inl}, I_{in2} and I_{in3}values selection for each filter function response

Filter Responses	Input Selections		
I_o	I_{in1}	I_{in2}	I_{in3}
BP	0	1	0
HP	-1	-1	1
BR	0	-1	1
AP	0	-2	1
LP	1	0	0

From Eq. (7) and substituting the transconductances as depicted in Eq. (2), it yields pole frequency (ω_0) and quality factor (Q_0) as follows:

$$\omega_0 = \sqrt{\frac{\left(k_1 k_2 I_{B1} I_{B2}\right)^{\frac{1}{2}}}{C_1 C_2}} \tag{8}$$

and

$$Q_0 = \sqrt{\frac{C_2\left(k_1 I_{B1}\right)^{\frac{1}{2}}}{C_1\left(k_2 I_{B2}\right)^{\frac{1}{2}}}} \tag{9}$$

From Eqs. (8) and (9), by maintaining the ratio I_{B1} and I_{B2} to be constant, it can be remarked that the pole frequency can be adjusted by I_{B1} and I_{B2} without affecting the quality factor. For example, when I_{B1} is set to equal to I_{B2} , therefore the pole frequency can be electronically adjusted by I_{B1} and I_{B2} without affecting the quality factor. The filter bandwidth (BW) can be expressed as follows

$$BW = \frac{\omega_0}{Q_0} = \frac{\sqrt{k_2 I_{B2}}}{C_2} \tag{10}$$

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

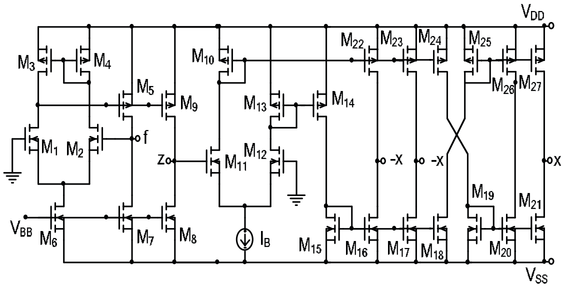


Figure 5 A possible internal construction of the CFTA.

2.4 Circuit Sensitivity

The sensitivities of the proposed circuit can be found as

$$S^{\omega_0}_{I_{B1}} = S^{\omega_0}_{I_{B2}} = S^{\omega_0}_{k_1} = S^{\omega_0}_{k_2} = \frac{1}{4};\ S^{\omega_0}_{C_1} = S^{\omega_0}_{C_2} = -\frac{1}{2} \tag{11}$$

and

$$S^{Q_0}_{I_{B1}} = S^{Q_0}_{k_1} = \frac{1}{4}; S^{Q_0}_{C_2} = \frac{1}{2};\ S^{Q_0}_{I_{B2}} = S^{Q_0}_{k_2} = -\frac{1}{4}; S^{Q_0}_{C_1} = -\frac{1}{2} \tag{12}$$

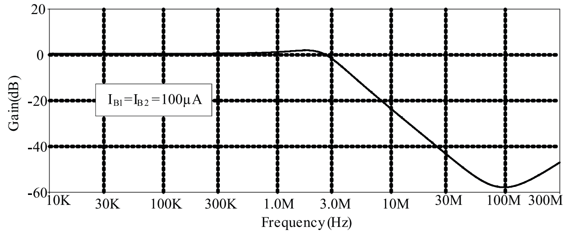
Therefore, all the active and passive sensitivities are less than unity in magnitude.

3. Simulation Results

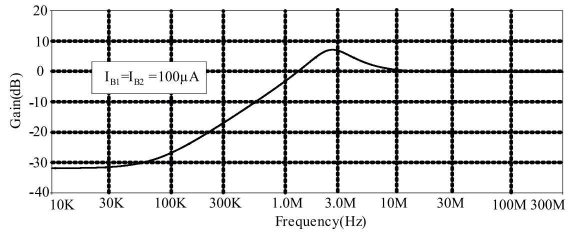
To prove the performances of the proposed filter, the PSpice simulation program was used for the examinations. The PMOS and NMOS transistors have been simulated by respectively using the parameters of a 0.25 μm TSMC CMOS technology [18]. The transistor aspect ratios of PMOS and NMOS transistor are indicated in Table 2. Fig. 5 depicts schematic description of the CFTA used in the simulations. The circuit was biased with ±1.25V power supply voltage, $V_{BB} = -0.55V$, $C_1 = C_2 = 0.1nF$, $I_{B1} = I_{B2} = 100\mu A$., Loads of the circuit are 1Ω of resistor.

Table 2 Dimensions of the transistors

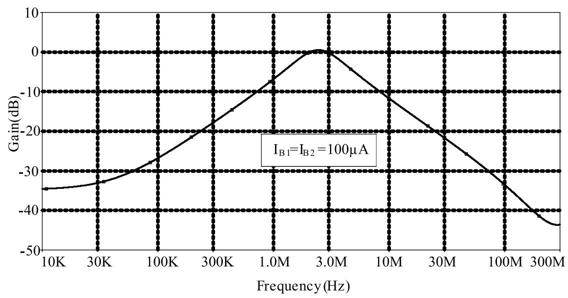
Transistor	W(μm)	L(μm)
M_1-M_2, M_{19}-M_{20}	1	0.25
M_3-M_5, M_9-M_{10}, M_{13}, M_{22}-M_{27}	5	0.25
M_6-M_8, M_{15}-M_{21}	3	0.25
M_{11}-M_{12}	25	0.25
M_{14}	4.5	0.25



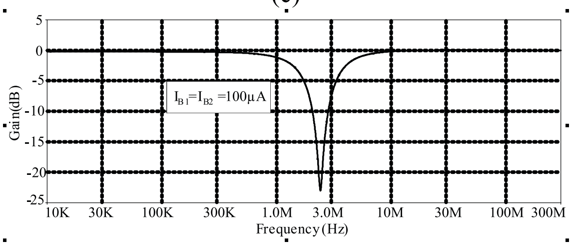
(a)



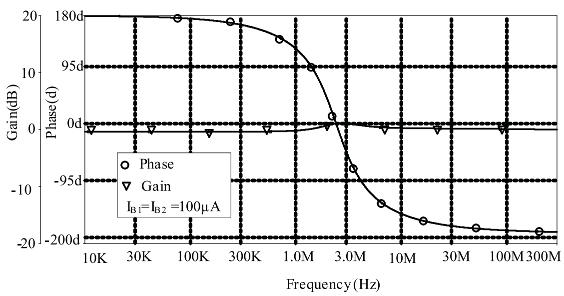
(b)



(c)



(d)



(e)

Figure 6 Gain responses of the biquadratic filter (a) LP (b) HP (c) BP (d) BR (e) AP.

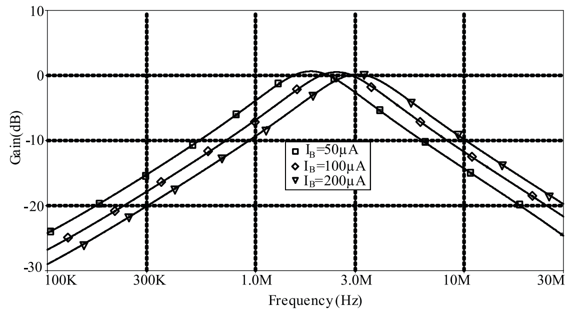


Figure 7 Band-pass responses for different values of I_{B1} and I_{B2} with keeping their ratios constant $I_{B1}= I_{B2}= I_B$.

The results shown in Fig. 6 are the gain responses of the proposed multifunction biquadratic filter. It is clearly seen that it can provide low-pass high-pass band-pass band-reject and all-pass functions dependent on selection in Table 1, without modifying a circuit topology.

Fig. 7 shows gain responses of band-pass function, where I_{B1} and I_{B2} are equally set to keep the ratio to be constant and changed for several values. It is found that pole frequency can be adjusted without affecting the quality factor. Total power consumption obtained from PSpice is about 4.32 mW.

4. Conclusions

The current-mode multifunction 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. The pole frequency and quality factor can be electronically adjusted via two input bias currents. The circuit description comprises only 2 CFTAs and 2 grounded capacitors. 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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