

วงจรรองความถี่โหมดกระแสหลายหน้าที่ที่ควบคุมด้วยวิธีการทางอิเล็กทรอนิกส์ โดยใช้ MO-OTAs

A Current-mode Universal Biquadratic Filter with Electronic Controllability Using MO-OTAs

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บทคัดย่อ

บทความนี้นำเสนอ วงจรรองความถี่หลายหน้าที่โหมดกระแส สามารถสังเคราะห์ฟังก์ชันมาตรฐานทั้งหมด ได้แก่ กรองผ่านความถี่ต่ำ ผ่านความถี่สูง ผ่านแถบความถี่ กำจัดแถบความถี่ผ่าน และผ่านทุกความถี่ ซึ่งอุปกรณ์หลักในวงจร ได้แก่ วงจรขยายความนำถ่ายโอนแบบหลายเอาต์พุต (MO-OTA) จุดเด่นของวงจร คือ สามารถควบคุมความถี่โพล และค่าควอลิตี้แฟกเตอร์ได้ด้วยวิธีการทางอิเล็กทรอนิกส์ ปรับกระแสไบแอส โครงสร้างไม่ซับซ้อน โดยใช้เพียง MO-OTA 4 ตัว และตัวเก็บประจุที่ต่อลงกราวด์ 2 ตัว วงจรที่นำเสนอนี้จึงเหมาะสมกับการนำไปพัฒนาเป็นวงจรรวม ผลการจำลองการทำงานด้วยโปรแกรม PSpice พบว่าวงจรทำงานได้สอดคล้องกับที่คาดการณ์ไว้ตามทฤษฎี วงจรมีอัตราดิ้งกำลังไฟฟ้าเท่ากับ 3.2mW ที่แหล่งจ่ายกำลังไฟฟ้า $\pm 1.5V$

คำสำคัญ : โหมดกระแส, วงจรรองความถี่, วงจรขยายความนำถ่ายโอน

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Abstract

This article presents a current-mode universal filter performing completely standard functions: low-pass, high-pass, band-pass, band-reject and all-pass functions. The circuit principle is based on multiple-output operational transconductance amplifiers (MO-OTAs). The features of the circuit are the ability of the pole frequency and quality factor which can be electronically tuned via the bias currents. The circuit topology is very simple, it consists of 4 MO-OTAs and 2 grounded capacitors. The proposed circuit is very appropriate to further develop into an integrated circuit architecture. The PSpice simulation results agree well with the theoretical anticipation. The total power consumption is approximately 3.2mW at $\pm 1.5V$ power supply voltages.

Keyword : Current-mode, filter, OTA (Operational Transconductance Amplifier)

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 [Sedra A. S. and Smith K.C., 2003; Ibrahim, M. A., et al., 2005]. One of most popular analog filters is a universal 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 two decades, 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 [Toumazou C., 1990; Bhaskar D.R., 1999].

The multiple output operational transconductance amplifier (MO-OTA) is a recently reported active component. It seems to be a versatile component in the realization of a class of analog signal processing circuits, especially analog frequency filters [Bielek D., et al., 2008; Herencsar N., et al., 2009]. There are many papers presenting various applications using OTAs 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 [Biolek D., et al., 2008; Herencsar N., et al., 2009; Herencsar, N., et al., 2008; Herencsar, N., et al., 2008; Herencsar N., et al., 2010; Herencsar N., et al., 2010; Herencsar N., et al., 2010 and Tangsrirat, W., 2010]. In addition, the mentioned element can be found in commercial form.

The aim of this paper is to propose a current-mode universal biquadratic filter, emphasizing on use of the MO-OTAs and grounded capacitors. The features of the proposed circuit are that the proposed universal 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 agree with the theoretical analysis.

Principle of Operation

Basic concept of MO-OTA

Since the proposed circuit is based on OTA, a brief review of OTA is given in this section. Generally, the ratio of voltage to current is transconductance (gm). It is made to be a commercially

available integrated circuit. Basic properties are high input and output impedances. The gm of the OTA can be controlled by external bias current. The relationship between output current and input voltage of OTA is as follows.

$$I_{O1} - I_{O2} = g_m (V_{(+)} - V_{(-)}), \quad (1)$$

and CMOS OTAs, the gm is written as

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

where $k = \mu_o C_{ox} (W / L)$. Here k and I_B are the physical transconductance parameter of the MOS transistor and input bias current. The symbol and the equivalent circuit of the OTA are illustrated in figure 1 (a) and (b), respectively.

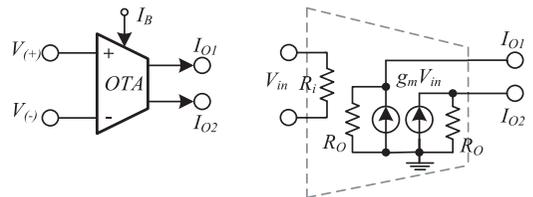


Fig. 1 The OTA (a) symbol (b) equivalent circuit.

Implementation of the filter

The filter is designed by cascading a current amplifier and the current-mode lossless integrators as systematically shown in figure 2 [Chunhua W., et al., 2008]. From block diagram in figure 2, we will receive the transfer functions at each terminal as

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

$$\frac{I_{BP}}{I_{in}} = K \frac{s\tau_2}{s^2\tau_1\tau_2 + s\tau_2K + 1}, \quad (4)$$

$$\frac{I_{HP}}{I_{in}} = K \frac{s^2\tau_1\tau_2}{s^2\tau_1\tau_2 + s\tau_2K + 1}, \quad (5)$$

$$\frac{I_{BR}}{I_{in}} = K \frac{s^2\tau_1\tau_2 + 1}{s^2\tau_1\tau_2 + s\tau_2K + 1}, \quad (6)$$

and

$$\frac{I_{AP}}{I_{in}} = K \frac{s^2\tau_1\tau_2 - s\tau_2K + 1}{s^2\tau_1\tau_2 + s\tau_2K + 1}. \quad (7)$$

The pole frequency and quality factor can be expressed respectively as

$$\omega_0 = \sqrt{\frac{1}{\tau_1\tau_2}}, \text{ and } Q = \frac{1}{K} \sqrt{\frac{\tau_2}{\tau_1}}. \quad (8)$$

There if τ_1 and τ_2 are set to keep its ratio constant, the pole frequency can be adjusted by τ_1 or τ_2 without affecting, the quality factor can be tuned through K without affecting the pole frequency.

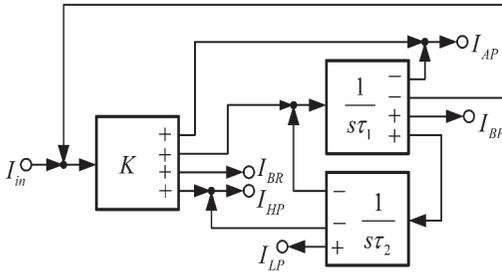


Fig. 2 Block diagram for the proposed filter. (Chunhua, W., et al., 2008)

Proposed current-mode universal biquad filter

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

$$I_{OA} = KI_{inA}. \quad (9)$$

where $K = \frac{I_{B2}}{I_{B1}}$.

Figure 4 shows the lossless integrator using OTAs. Considering the circuit in figure 4 and using OTAs properties, we obtain

$$\frac{I_{OB}}{I_{inB}} = \frac{1}{\tau s}. \quad (10)$$

where $\tau = \frac{I_B}{2CV_T}$.

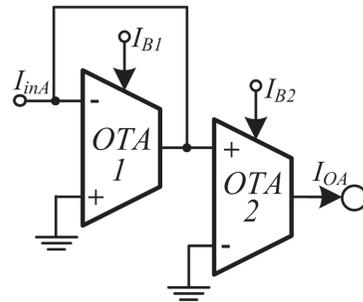


Fig. 3 Current amplifier based on OTAs.

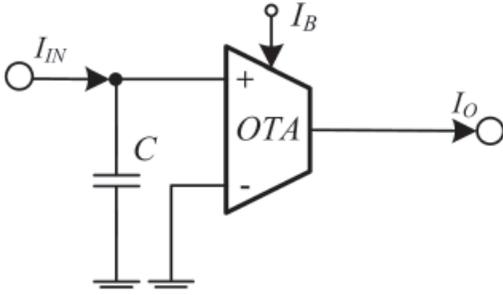


Fig. 4 Lossless integrator using OTA.

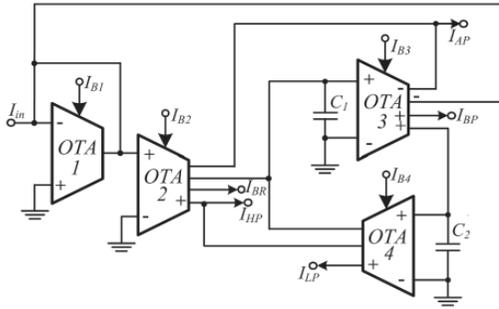


Fig. 5 Completely proposed current-mode universal filter.

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

$$\omega_0 = \sqrt{\frac{C_1 C_2}{g_{m3} g_{m4}}}, \text{ and } Q = \frac{g_{m1}}{g_{m2}} \sqrt{\frac{C_2 g_{m3}}{C_1 g_{m4}}} \quad (16)$$

Substituting the transconductance from in Eq. (2) in Eq. (16), it yields pole frequency and quality factor as follows

$$\omega_0 = \sqrt{\frac{C_1 C_2}{(k_3 k_4 I_{B3} I_{B4})^{\frac{1}{2}}}} \text{ and } Q = \frac{(k_1 I_{B1})^{\frac{1}{2}}}{(k_2 I_{B2})^{\frac{1}{2}}} \sqrt{\frac{C_2 (k_3 I_{B3})^{\frac{1}{2}}}{C_1 (k_4 I_{B4})^{\frac{1}{2}}}} \quad (16)$$

$$\frac{I_{LP}}{I_{in}} = \frac{g_{m2}}{g_{m1}} \frac{1}{s^2 \frac{g_{m3} g_{m4}}{C_1 C_2} + s \frac{g_{m4} g_{m2}}{C_2 g_{m1}} + 1}, \quad (11)$$

$$\frac{I_{BP}}{I_{in}} = \frac{g_{m2}}{g_{m1}} \frac{s \frac{g_{m4}}{C_2}}{s^2 \frac{g_{m3} g_{m4}}{C_1 C_2} + s \frac{g_{m4} g_{m2}}{C_2 g_{m1}} + 1} \quad (12)$$

$$\frac{I_{HP}}{I_{in}} = \frac{g_{m2}}{g_{m1}} \frac{s^2 \frac{g_{m3} g_{m4}}{C_1 C_2}}{s^2 \frac{g_{m3} g_{m4}}{C_1 C_2} + s \frac{g_{m2} g_{m4}}{g_{m1} C_2} + 1} \quad (13)$$

$$\frac{I_{BR}}{I_{in}} = \frac{g_{m2}}{g_{m1}} \frac{s^2 \frac{g_{m3} g_{m4}}{C_1 C_2} + 1}{s^2 \frac{g_{m3} g_{m4}}{C_1 C_2} + s \frac{g_{m2} g_{m4}}{g_{m1} C_2} + 1} \quad (14)$$

and

$$\frac{I_{AP}}{I_{in}} = \frac{g_{m2}}{g_{m1}} \frac{s^2 \frac{g_{m3} g_{m4}}{C_1 C_2} - s \frac{g_{m2} g_{m4}}{g_{m1} C_2} + 1}{s^2 \frac{g_{m3} g_{m4}}{C_1 C_2} + s \frac{g_{m2} g_{m4}}{g_{m1} C_2} + 1} \quad (15)$$

From Eqs. (11)-(15), the pole frequency and quality factor can be respectively expressed

It is obviously found that, from Eq. (17), by keeping to ratio of I_{B3} and I_{B4} to be constant, the pole frequency can be adjusted by I_{B3} and I_{B4} without affecting the quality factor. The quality factor can also be adjusted by I_{B1} and I_{B2} without affecting the pole frequency. Moreover, the circuit can provide high Q_0 by reducing the value of I_{B2} .

Circuit Sensitivity

The sensitivities of the proposed circuit can be found as

$$S_{I_{B3}}^{\omega_0} = S_{I_{B4}}^{\omega_0} = -\frac{1}{2}; S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = \frac{1}{2} \quad (18)$$

and

$$S_{I_{B1}}^{Q_0} = 1, S_{I_{B2}}^{Q_0} = -1; S_{g_{m3}, C_2}^{Q_0} = \frac{1}{2}, S_{g_{m4}, C_1}^{Q_0} = -\frac{1}{2}. \quad (19)$$

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

Simulation Results

To prove the performances of the proposed universal biquadratic filter, the PSpice simulation program was used for the verification. Figure 6 depicts schematic description of the MO-OTAs used in the simulations. The PMOS and NMOS transistors have been simulated by using the parameters of a 0.25 μ m TSMC CMOS technology [Prommee P., et al., 2009]. The transistor aspect ratios of PMOS and NMOS transistors are indicated in Table 1. The circuit was biased with $\pm 1.5V$ supply voltages, $C_1 = C_2 = 10pF$, $I_{B1} = I_{B2} = I_{B3} = I_{B4} = 52 \mu A$. Loads of the circuit are 1 Ω of resistor. The results shown in figure 7 are the gain responses of the proposed universal biquadratic filter. It is clearly seen that the proposed circuit can simultaneously provide low-pass, high-pass, band-pass, band-reject and all-pass functions, without modifying a circuit topology. Gain and phase responses of the all-pass function are illustrated in figure 8.

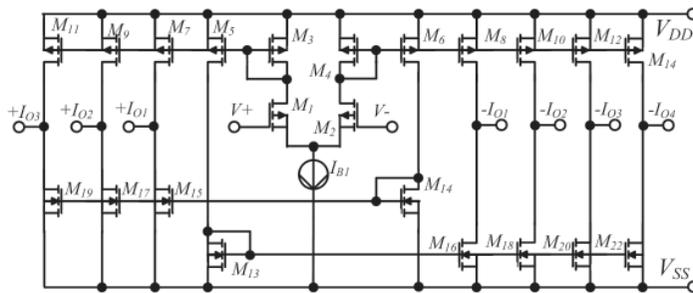


Fig. 6 A possible internal construction of MO-OTA.

Table I : Dimensions of the transistors

Transistors	W (μm)	L (μm)
M1-M2	1	0.25
M3-M4	5	0.25
M5-M6	3	0.25
M13-M14	25	0.25
M7-M12, M15-M22	4.5	0.25

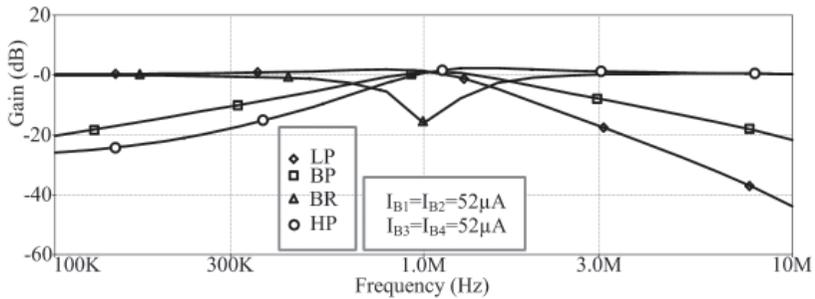


Fig. 7 Gain responses of proposed circuit

Figure 9 displays gain responses of the band-pass function for different I_{B1} and I_{B2} 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. Figure 10 shows gain responses of band-pass function,

where I_{B3} and I_{B4} 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 Eq. (17). Total power consumption is about 3.2mW.

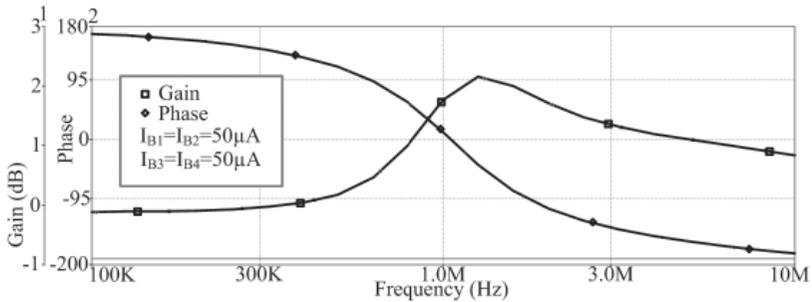


Fig. 8 All-pass responses of the circuit in Fig. 5.

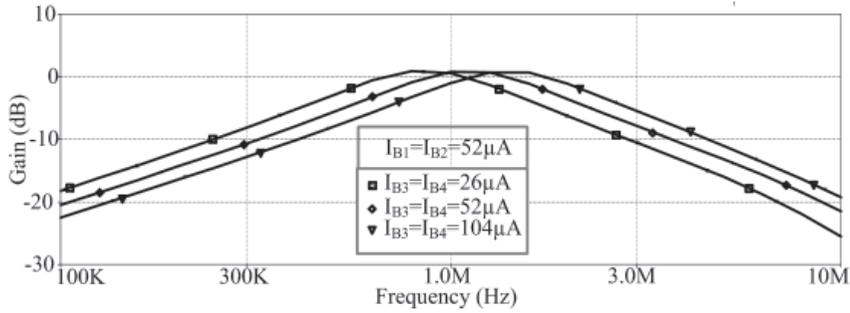


Fig. 9 Band-pass responses for different values of I_{B3} and I_{B4} with keeping their ratios to be constant.

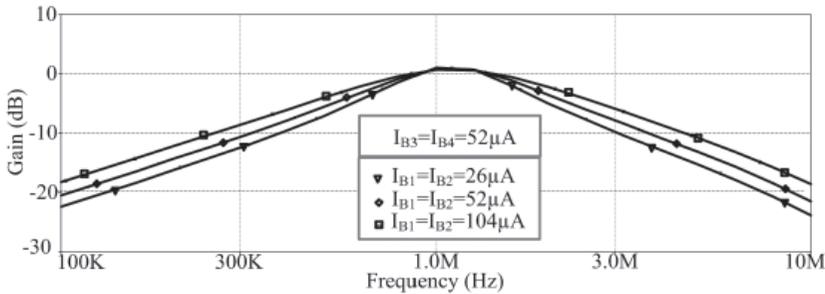


Fig. 10 Band-pass responses for different values of I_{B1} and I_{B2} .

Conclusions

The current-mode universal biquadratic filter based on MO-OTAs 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 4 OTAs and 2 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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