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CCII and OTA based- Current-mode Universal Biquadratic Filter

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Abstract
This article presents a current-mode universal biquadratic filter performing completely standard functions: low-pass, high-pass, band-pass, band-reject and all-pass functions, based on Dual-Output Operational Transconductance Amplifiers (DO-OTAs) and Dual-output Current Conveyor (DO-CCII), which are commercially available. The features of the circuit are that: the pole frequency can be electronically/independently tuned from the quality factor via the input bias currents. The circuit topology is very simple, consisting of merely 3 DO-OTAs, 1 DO-CCII and 2 grounded capacitors. Without any external resistors and using only grounded elements, the proposed circuit is very comfortable to further develop into an integrated circuit. The PSPICE simulation results are shown. The given results agree well with the theoretical anticipation. The maximum power consumption is approximately 2.86mW at ±1.5V power supply voltages.

Keywords: DO-OTA, DO-CCII, current-mode, filter

1. Introduction

Analog filters are important blocks, widely employed in continuous-time signal processing. They can be found in many fields such as communication, measurement and instrumentation, and control systems [1-2]. Universal biquadratic filter belongs to most popular analog filters, providing several functions simultaneously without modifying the circuit topology. Nowadays, the current-mode universal filter becomes more popular than the voltage-mode one. Throughout the last decade, great effort has been spent on reducing the supply voltage. This is due to the demand for portable and battery-powered equipments. Since a low-voltage operating circuits become necessary, the current-mode technique is a good alternative for such purposes. Actually, a circuit utilizing the current-mode technique can offer more advantages, for example, larger dynamic range, higher bandwidth, greater linearity, simpler circuitry and lower power consumption [3-4].

The OTAs have received considerable attention as active components because of the electronically adjustable transconductance which is especially suitable for analog circuits [5]. The flexibility of the devices, operating both in the current and voltage modes, allows for a variety of circuit designs. Also, the applications of DO-OTA and DO-CCII have been useful for constructing the current-mode circuits with a reduced number of active components [6]. From literature reviews, most of proposed current-mode universal filters need to employ a bulk number of passive and active components, requiring the modifications of circuit topology in order to achieve several functions [7-11]. Some of them employ a number of floating capacitors [12-13], which is not appropriate for implementation as a monolithic chip. Furthermore, most of presented circuits provide only low-pass, high-pass and band-pass transfer functions [14-15].

The aim of this paper is to propose a current-mode universal biquadratic filter, emphasizing the use of DO-OTAs and DO-CCII. The features of the proposed circuits are as follows: Providing all standard transfer functions such as low-pass, high-pass, band-pass, band-reject and all-pass without changing the circuit topology. The circuit configuration is very simple, employing only grounded capacitors as passive components, thus suitable for fabricating in monolithic chip. The quality factor and pole frequency can be electronically adjusted. The features of the proposed circuits are illustrated by PSPICE simulations, showing good agreement with the theoretical assumptions.

2. Principle of Operation

2.1 Dual-output operational transconductance amplifier (DO-OTA)

An ideal DO-OTA has infinite input and output impedances. The output current of a DO-OTA is given by the formula (see also Fig. 1 a)

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

where g_m is the transconductance of DO-OTA. For a bipolar DO-OTA, the transconductance can be expressed to be

$$g_m = \frac{I_B}{2V_T}, \quad (2)$$

where I_B and V_T are the bias current and the thermal voltage, respectively. The schematic symbol and the equivalent circuit of DO-OTA are illustrated in Fig. 1(a) and (b), respectively.

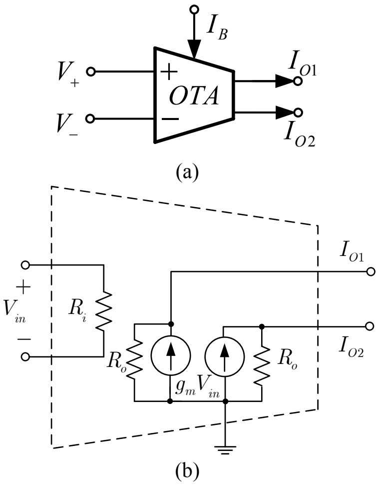

Figure 1. DO-OTA (a) symbol (b) equivalent circuit

2.2 Dual-output second-generation current conveyor (DO-CCII)

The characteristic of ideal DO-CCII can be represented by the following hybrid matrix

$$\begin{bmatrix} I_Y \\ V_X \\ I_{Z1,Z2} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix}, \quad (3)$$

where the ±sign refers to positive or negative types of current conveyor, respectively. The symbol and equivalent circuit of DO-CCII can be illustrated in Fig. 2(a) and (b), respectively.

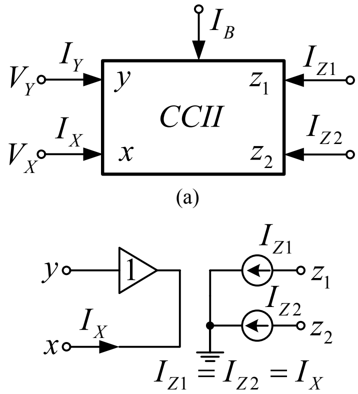

Figure 2. DO-CCII (a) symbol (b) equivalent circuit

2.3 Proposed current-mode universal filter

Fig. (3) shows the proposed current-mode universal filter, where I_{B1}, I_{B2} and I_{B3} are the bias currents of DO-OTA1, DO-OTA2 and DO-OTA3, respectively. Utilizing the properties of DO-OTA and negative-type DO-CCII in Sections 2.1 and 2.2, straightforward analysis of the circuit in Fig. (3) yields the following transfer functions:

$$\frac{I_{BP}}{I_{in}} = \frac{-sC_2 g_m}{s^2 C_1 C_2 + sC_2 g_m + g_m^2}, \quad (4)$$

$$\frac{I_{HP}}{I_{in}} = \frac{s^2 C_1 C_2}{s^2 C_1 C_2 + sC_2 g_m + g_m^2}, \quad (5)$$

and

$$\frac{I_{LP}}{I_{in}} = \frac{g_m^2}{s^2 C_1 C_2 + sC_2 g_m + g_m^2}, \quad (6)$$

where $g_{m1} = g_{m2} = g_{m3} = g_m$. Moreover, the band-stop and the all-pass functions can be obtained, combining the currents $I_{BS}=I_{HP}+I_{LP}$ and $I_{AP}=I_{BS}+I_{BP}$, respectively, where

$$\frac{I_{BS}}{I_{in}} = \frac{s^2 C_1 C_2 + g_m^2}{s^2 C_1 C_2 + sC_2 g_m + g_m^2}, \quad (7)$$

$$\frac{I_{AP}}{I_{in}} = \frac{s^2 C_1 C_2 - sC_2 g_m + g_m^2}{s^2 C_1 C_2 + sC_2 g_m + g_m^2}. \quad (8)$$

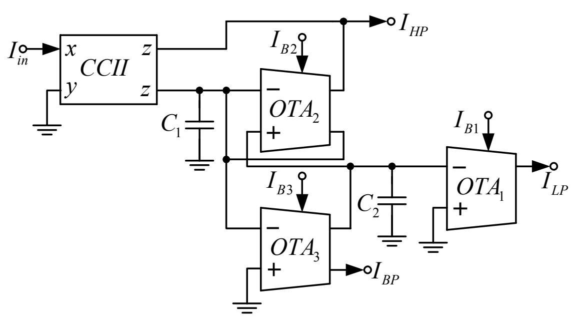

Figure 3. Proposed current-mode universal filter

The pole frequency (ω_0) and the quality factor (Q_0) are given by the formulae

$$\omega_0 = g_m \sqrt{\frac{1}{C_1 C_2}}, \quad (9)$$

and

$$Q_0 = \sqrt{\frac{C_1}{C_2}}. \quad (10)$$

If $g_m = I_B / 2V_T$, Eq. (9) is modified to the form

$$\omega_0 = \frac{I_B}{2V_T} \sqrt{\frac{1}{C_1 C_2}}. \quad (11)$$

As obvious from Eq. (11), the pole frequency can be electronically adjusted by I_B independently from the quality factor. The filter bandwidth (BW) can be expressed as follows:

$$BW = \frac{\omega_0}{Q_0} = \frac{I_B}{2V_T C_1}. \tag{12}$$

Note that the bandwidth can be linearly controlled by I_B.

2.4 Circuit Sensitivities

The sensitivities of the proposed circuit can be found as

$$S_{I_B}^{\omega_0} = 1;\ S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = -\frac{1}{2};S_{V_T}^{\omega_0} = -1 \tag{13}$$

$$S_{C_1}^{Q_0} = \frac{1}{2};\ S_{C_2}^{Q_0} = -\frac{1}{2}; \tag{14}$$

and

$$S_{I_B}^{BW} = 1;\ S_{V_T}^{BW} = S_{C_1}^{BW} = -1 \tag{15}$$

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

3. Simulation Results

To prove the performances of the proposed circuit, a PSPICE simulation was performed for examination. The PNP and NPN transistors employed in the proposed circuit were simulated by using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [16] with the parameters summarized in Table 1. Fig. 4 and Fig. 5 show the respective circuit topologies of the DO-OTA and DO-CCII used in the simulations. The circuits were biased with ±1.5V supply voltages, $C_1=C_2=1nF$, $I_{B1}=I_{B2}=I_{B3}= 50\mu A$, yielding the pole frequency of *143kHz*, whereas the theoretical value from Eq. (11) is *153kHz*. This deviation comes from the parasitic elements in active devices employed in the circuit.

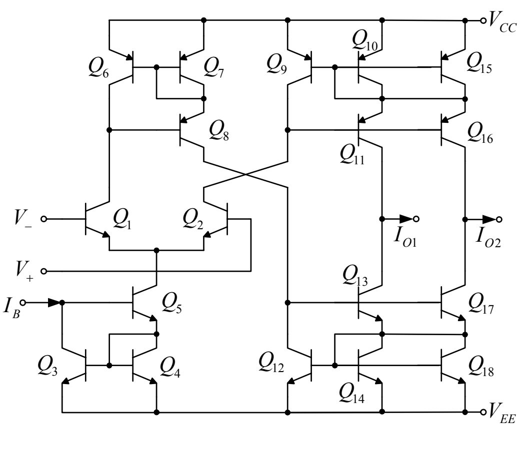

Figure 4. Internal topology of DO-OTA

Fig. 6 shows the simulated gain frequency responses of the proposed universal filter from Fig. 3. It clearly shows that this circuit can provide simultaneously low-pass, high-pass band-pass, band-reject and all-pass transfer functions without modifying the circuit topology. Fig. 7 displays the gain and phase frequency responses of all-pass function. Fig. 8 shows the gain responses of the band-pass function while setting I_B to *50µA*, *100µA*, and *200µA*, respectively. This result shows that the pole frequency can be adjusted without affecting the quality factor, as described in Eqs. (10) and (11). The maximum power consumption is about 2.86mW.

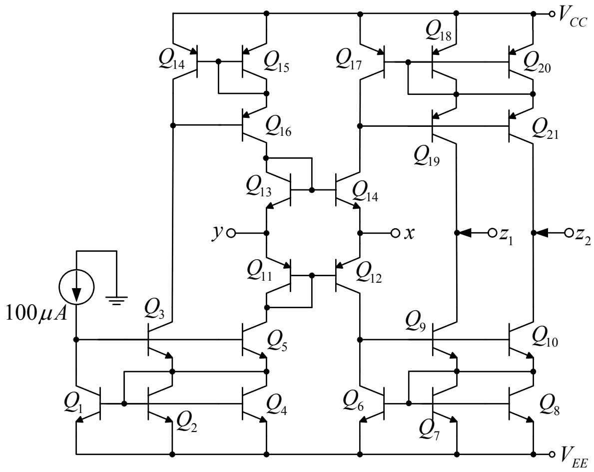

Figure 5. Internal topology of DO-CCII

Table 1. Parameters of the transistors.

```
.model PX PNP
+RB=327 IRB=0 RBM=24.55 RC=50 RE=3
+IS=73.5E-18 EG=1.206 XTI=1.7 XTB=1.866 BF=110
+IKF=2.359E-3 NF=1 VAF=51.8 ISE=25.1E-16 NE=1.650
+BR=0.4745 IKR=6.478E-3 NR=1 VAR=9.96 ISC=0 NC=2
+TF=0.610E-9 TR=0.610E-8 CJE=0.180E-12 VJE=0.5
+MJE=0.28 CJC=0.164E-12 VJC=0.8 MJC=0.4 XCJC=0.037
+CJS=1.03E-12 VJS=0.55 MJS=0.35 FC=0.5
.model NX NPN
+RB=524.6 IRB=0 RBM=25 RC=50 RE=1
+IS=121E-18 EG=1.206 XTI=2 XTB=1.538 BF=137.5
+IKF=6.974E-3 NF=1 VAF=159.4 ISE=36E-16 NE=1.713
+BR=0.7258 IKR=2.198E-3 NR=1 VAR=10.73 ISC=0 NC=2
+TF=0.425E-9 TR=0.425E-8 CJE=0.214E-12 VJE=0.5
+MJE=0.28 CJC=0.983E-13 VJC=0.5 MJC=0.3 XCJC=0.034
+CJS=0.913E-12 VJS=0.64 MJS=0.4 FC=0.5
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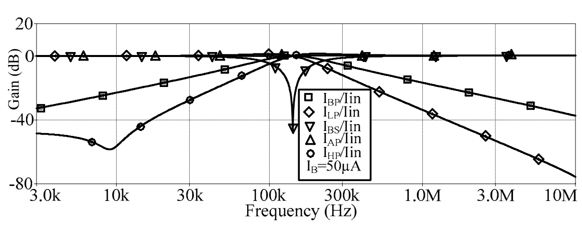

Figure 6. Gain responses of proposed circuit

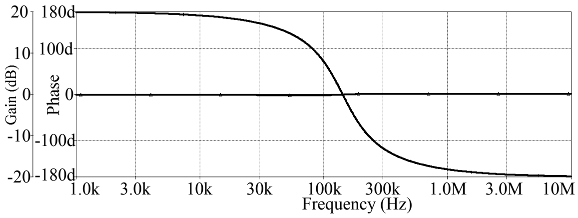

Figure 7. Gain and phase responses of all-pass filter

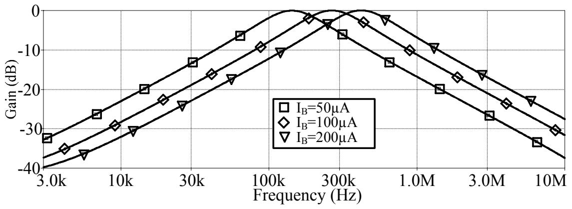

Figure 8. Band-pass responses for different values of I_B

4. Conclusion

The current-mode universal biquadratic filter based on DO-OTAs and DO-CCII has been presented. The advantages of the proposed circuit are as follows: A complete set of standard transfer functions can be obtained from the unique circuit configuration. The pole frequency can be tuned electronically via bias currents independently from the quality factor, which can be easily modified by using a microcontroller [3]. The circuit configuration contains only 3 DO-OTAs, 1 DO-CCII and 2 grounded capacitors, which is attractive for IC implementation. In addition, the DO-CCII can be omited when the HP output is not required. Then the input current is applied directly to the capacitor C_1. Moreover, the OTA1 serves only as a voltage-to-current converter. When the voltage-type of LP output is requested rather than the current-type, the OTA1 can be also removed from the filter circuitry.

With the above features, it is very suitable to implement the proposed circuit as a monolithic chip for use in battery-powered, portable electronic equipments such as wireless communication system devices.

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