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CCCII-based High Input-impedance Current-Mode Universal Filter and Quadrature Oscillator

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Abstract

A circuit which can function both as current-mode quadrature oscillator and as a current-mode universal biquad filter is introduced in this paper. By working as quadrature oscillator, the oscillation condition and oscillation frequency can be adjusted independently with the input bias currents. By functioning as a universal biquad filter, the quality factor and natural frequency can be tuned orthogonally via the input bias currents. The proposed circuit can work as either a quadrature oscillator or a universal biquad filter without changing circuit topology. The proposed circuit description is very simple, consisting of 4 current controlled current conveyors (CCCIIs) and 2 grounded capacitors. Without any external resistors and using only grounded elements, this circuit is thus suitable for IC architecture. The PSPICE simulation results are depicted, and the given results agree well with the theoretical anticipation. The maximum power consumption is approximately at ±1.5V power supplies.

Keywords: filter, oscillator, CCCII

1. Introduction

In electrical engineering works, an oscillator and filter are 2 basic important building blocks which are frequently employed. Among several types of the oscillators, a quadrature oscillator is widely used because the circuit provides two sinusoids with a 90° phase difference, such as in quadrature mixers and single-sideband devices for telecommunications [1]. Similarly, the contemporary applications and advantages in the realization of various active transfer functions, called universal biquad filters, have received considerable attention. A universal filter may be used in phase locked loop FM stereo demodulators, and crossover networks used in three-way high fidelity loudspeakers [2]. However, a current-mode universal filter has been more popular than the voltage-mode variety, due to requirements in low-voltage environments such as portable and battery-powered equipments. Since a low-voltage operating circuit becomes necessary, the current–mode technique is ideally suited to this purpose, more so than the voltage-mode type. Presently, there is a growing interest in synthesizing current-mode circuits because of more their potential advantages such as larger dynamic range, higher signal bandwidth, greater linearity, simpler circuitry, and lower power consumption [3]. However, our investigations show that previous literatures have proposed versatile quadrature oscillator and biquad filter devices using different high-performance active building blocks [4-7], such as current controlled current conveyors [4], current controlled current differencing buffered amplifiers (CCCDBAs) [5], and current controlled current differencing transconductance amplifiers (CCCDTAs) [6-7]. Reportedly, the outputs of these circuits do not have high output impedances, making the cascadeability challenging.

The CCCII has received considerable attention as active components, because the parasitic resistance at *x* terminal can be adjusted electronically, especially suitable for analog circuits [8]. The flexibility of the devices to operate in both current and voltage modes allows for a variety of circuit designs. Also, the application of multiple-output current conveyors has been useful for constructing current-mode circuits from a reduced number of active components [8].

The purpose of this paper is to introduce a current-mode universal biquad filter using CCCIIs, providing three standard transfer functions (lowpass, highpass, and bandpass). It performs an independently adjustable pole frequency and quality factor. In case of no input current and under appropriate conditions, the proposed circuit can provide current-mode quadrature sinusoidal signal. Moreover, the output currents have high impedance, which facilitates cascading in current-mode. The circuit construction consists of 4 CCCIIs and 2 grounded capacitors (beneficial to an IC implementation). The PSPICE simulation results are also shown, which are in correspondence with the theoretical analysis.

2. Circuit Principle

2.1 Current-controlled current conveyor (CCCII)

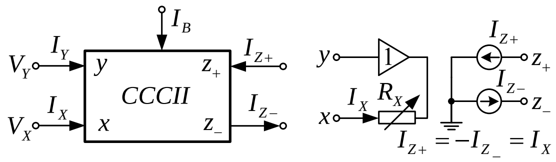
The characteristics of the ideal CCCII are represented by the following hybrid matrix

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & R_X & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix}, \qquad (1)$$

where R_x is the parasitic resistance at x terminal of CCCII. For a bipolar CCCII, the R_x can be expressed to be

$$R_x = \frac{V_T}{2I_B}, \qquad (2)$$

where I_B and V_T are the bias current and the thermal voltage, respectively. In general, CCCII can contain an arbitrary number of z terminals, providing currents I_z of both directions. As an example, the symbol and the equivalent circuit of the CCCII with a pair of $z+$ and $z-$ terminals are illustrated in Figs. 1(a) and (b), respectively.



(a) (b)

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

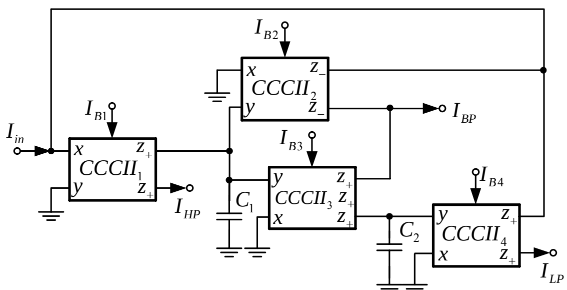


Figure 2. Proposed circuit working as a universal filter.

2.2 The proposed circuit operating as a universal filter

Fig. 2 demonstrates the circuit scheme of the proposed circuit working as the universal filter. From routine analysis of the circuit in Fig. 2, the following current transfer functions are obtained

$$\frac{I_{HP}}{I_{in}} = \frac{s^2}{s^2 + \frac{s}{C_1}\left(\frac{1}{R_{x2}} - \frac{1}{R_{x3}}\right) + \frac{1}{C_1 C_2 R_{x3} R_{x4}}}, \qquad (4)$$

$$\frac{I_{LP}}{I_{in}} = \frac{\frac{1}{C_1 C_2 R_{x3} R_{x4}}}{s^2 + \frac{s}{C_1}\left(\frac{1}{R_{x2}} - \frac{1}{R_{x3}}\right) + \frac{1}{C_1 C_2 R_{x3} R_{x4}}}, \qquad (5)$$

and

$$\frac{I_{BP}}{I_{in}} = \frac{\frac{s}{C_1}\left(\frac{1}{R_{x2}} - \frac{1}{R_{x3}}\right)}{s^2 + \frac{s}{C_1}\left(\frac{1}{R_{x2}} - \frac{1}{R_{x3}}\right) + \frac{1}{C_1 C_2 R_{x3} R_{x4}}}, \qquad (6)$$

From Eqs. (4)-(6), the pole frequency (ω_0) and quality factor (Q_0) can be expressed as

$$\omega_0 = \sqrt{\frac{1}{C_1 C_2 R_{x3} R_{x4}}}, \qquad (7)$$

and

$$Q_0 = \frac{R_{x2} R_{x3}}{R_{x3} - R_{x2}} \sqrt{\frac{C_1}{C_2 R_{x3} R_{x4}}}. \qquad (8)$$

If $R_x = V_T/2I_B$, Eq. (7) and (8) is modified to the form

$$\omega_0 = \frac{2}{V_T} \sqrt{\frac{I_{B3} I_{B4}}{C_1 C_2}}, \qquad (9)$$

and

$$Q_0 = \frac{1}{I_{B2} - I_{B3}} \sqrt{\frac{C_1 I_{B3} I_{B4}}{C_2}}. \qquad (10)$$

From Eqs. (9) and (10), it can be seen that the quality factor can be adjusted independently from the pole frequency by varying I_{B2}. Another advantage of the proposed circuit is that a high Q_0 circuit can be obtained by setting I_{B3} close to I_{B2}, which differs from conventional universal filters in such that the maximum Q_0 is limited by their component values. Thus the bandwidth (BW) is given by

$$BW = \frac{2}{C_1 V_T}\left(I_{B2} - I_{B3}\right). \qquad (11)$$

From Eqs. (9) and (10), if $I_{B3} = I_{B4} = I_B$ and $I_{B2} = kI_B$, which can be easily realized by using a programmable current mirror [9]. The pole frequency and quality factor are subsequently modified to be

$$\omega_0 = \frac{2I_B}{V_T} \sqrt{\frac{1}{C_1 C_2}}, \qquad (12)$$

and

$$Q_0 = \frac{1}{k-1} \sqrt{\frac{C_1}{C_2}}. \qquad (13)$$

From Eqs. (12) and (13), it should be remarked that the pole frequency can be linearly adjusted by I_B

without disturbing the quality factor, while the quality factor can be adjusted independently from the pole frequency by *k*.

2.3 Circuit Sensitivities

The sensitivities of the proposed circuit are low (not more than one) and can be found as

$$S^{\omega_0}_{I_{B3}} = S^{\omega_0}_{I_{B4}} = \frac{1}{2};\ S^{\omega_0}_{C1} = S^{\omega_0}_{C2} = -\frac{1}{2};\ S^{\omega_0}_{V_T} = -1, \quad (14)$$

$$S^{Q_0}_{I_{B4}} = \frac{1}{2}; S^{Q_0}_{I_{B2}} = -\frac{I_{B2}}{I_{B2} - I_{B3}} \quad (15)$$

and

$$S^{Q_0}_{I_{B3}} = \frac{1}{2} + \frac{I_{B3}}{I_{B2} - I_{B3}}; S^{Q_0}_{C_1} = \frac{1}{2}; S^{Q_0}_{C_2} = -\frac{1}{2}. \quad (16)$$

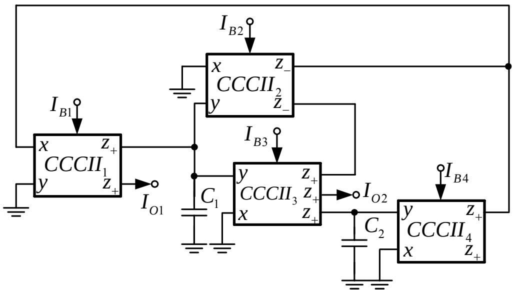


Figure 3. Proposed circuit working as a quadrature oscillator.

2.4 The proposed circuit operating as a quadrature oscillator

If no input current is applied to the circuit as depicted in Fig. 3, the characteristic equation of the system can be expressed as

$$s^2 + \frac{s}{C_1}\left(\frac{1}{R_{x2}} - \frac{1}{R_{x3}}\right) + \frac{1}{C_1 C_2 R_{x3} R_{x4}} = 0. \quad (17)$$

From Eq. (17), it is clear that the proposed circuit can be set as an oscillator if

$$R_{x3} = R_{x2}. \quad (18)$$

Eq. (18) is considered as the condition of oscillation, and this is achieved by setting $I_{B2}=I_{B3}$, then the characteristic equation of the system becomes

$$s^2 + \frac{1}{C_1 C_2 R_{x3} R_{x4}} = 0. \quad (19)$$

From Eq. (19), the oscillation frequency (ω_{osc}) of this system can be obtained as

$$\omega_{osc} = \sqrt{\frac{1}{C_1 C_2 R_{x3} R_{x4}}} = \frac{2}{V_T}\sqrt{\frac{I_{B3} I_{B4}}{C_1 C_2}}. \quad (20)$$

It can be seen that the oscillation condition can be controlled independently from the oscillation frequency by I_{B2} and I_{B3}, while the oscillation frequency can be controlled by I_{B4}. The current-mode quadrature sinusoidal signals can be obtained at I_{O1} and I_{O2}.

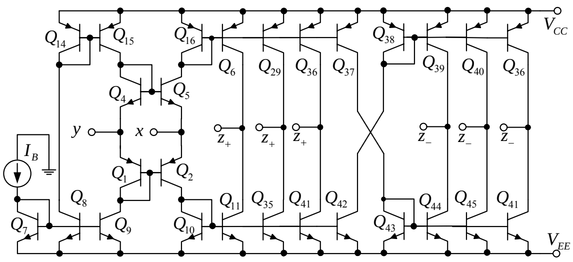


Figure 4. Internal construction of CCCII

3. Simulation Results

To prove the performances of the proposed circuit, a PSPICE simulation was performed for examination and experimentation. The PNP and NPN transistors employed in the proposed circuit were simulated by respectively using the parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [10]. Fig. 4 depicts the respective schematic description of the CCCII used in the simulations. The circuit was biased with ±1.5V supply voltages, $C_1=C_2=1nF$, $I_{B1}=I_{B3}=I_{B4}=50\mu A$, and $I_{B2}=100\mu A$. This yields the pole frequency of 556kHz. The calculated value of this parameter from Eq. (10) yields 612kHz (deviated by 9.15%). Load of the circuit is 1Ω of resistor. The results shown in Fig. 5 are the gain responses of the proposed biquad filter obtained from Fig. 2. It shows that the proposed filter allows simultaneous LP, HP, and BP responses. By varying I_{B2} to be 60μA, 80μA and 120μA, only the quality factor is changed, as shown in Fig. 6. This confirms that the quality factor can be adjusted by I_{B2}, which is independent of the pole frequency, as analyzed in Eqs. (9) and (10). Fig. 7 shows gain responses of the band-pass functions where I_B is set to *40μA*, *80μA*, and *160μA*, respectively, and *k=1.3*. This shows that pole frequency can be adjusted without affecting the quality factor, as analyzed in Eqs. (12) and (13).

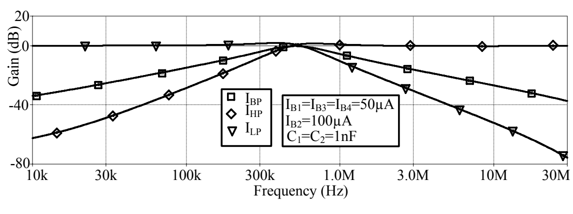


Figure 5. Gain responses of proposed circuit

Figs. 8 and 9 show simulated quadrature output waveforms where $I_{B1}=80\mu A$, $I_{B2}=51\mu A$ and $I_{B3}=I_{B4}=50\mu A$. This yields an oscillation frequency of 500kHz. The calculated value of this parameter from

Eq. (10) is 612Hz (deviated by 18.30%). Fig. 10 shows the simulated output spectrum, where the total harmonic distortion (THD) is about 1.83%.

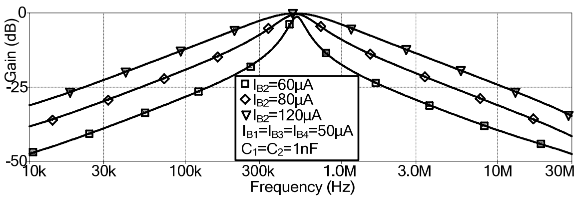


Figure 6. BP responses for different values of I_{B2}

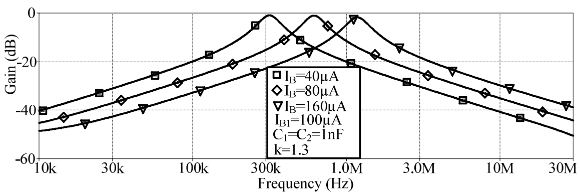


Figure 7. BP responses for different values of I_B

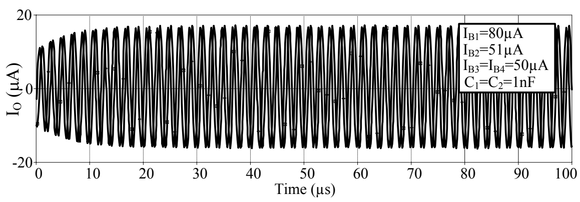


Figure 8. The current-mode sinusoidal signal in transition region

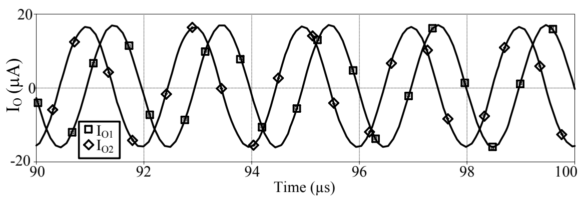


Figure 9. Simulation result of the quadrature outputs

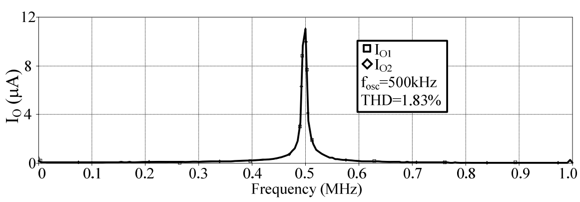


Figure 10. Simulation result of the output spectrum

4. Conclusions

The presented circuit can function, both as a current-mode quadrature oscillator, and as a current-mode universal biquad filter (lowpass, highpass and bandpass functions), without changing the circuit topology. Working as a current-mode universal biquad filter, the quality factor and pole frequency can be tuned orthogonally via the input bias currents. With no input current and under suitable condition, the proposed circuit can function as a quadrature oscillator. The oscillation condition and oscillation frequency can be independently adjusted by the input bias currents. The PSPICE simulation results are congruent with the theoretical anticipation. With the simple construction, requiring 4 CCCIIs and 2 grounded capacitors makes this circuit well-suited for an IC architecture.

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