Abstract
A circuit which can function both as quadrature oscillator and as a universal biquad filter (lowpass, highpass, and bandpass) is introduced in this paper. Working as quadrature oscillator, the oscillation condition and oscillation frequency can be adjusted independently with the input bias currents. 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 merely 2 Current Controlled Current Transconductance Amplifiers (CCCDTAs) 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 1.64mW at ±1V power supply voltages.

1. Introduction
It is well accepted that an oscillator and a filter are 2 important basic building blocks which are frequently employed. A quadrature oscillator is widely used because it can provide two sinusoids with 90° phase difference, for example in telecommunications for quadrature mixers and single-sideband [1]. Similarly the modern 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 type. This is due to operating in low-voltage environment, such as portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current-mode technique is ideally suited for this purpose, more so than the voltage-mode. Presently, there is a growing interest in synthesizing current-mode circuits because of their many potential advantages, such as larger dynamic range, higher signal bandwidth, greater linearity, simpler circuitry, and lower power consumption [3]. However, from our investigations, we have seen that in previous literature, oscillators require too many components and component matching conditions [4]. Some universal filters require a floating capacitor, which is not ideal for IC implementation [5]. In addition, each circuit can work as only one function, either quadrature oscillator or universal filter.

The purpose of this paper is to introduce a novel current-mode universal biquad filter, based on the novel active building block recently proposed [6], providing three standard transfer functions (lowpass, highpass, bandpass). The natural frequency can be adjusted independently from the quality factor. Moreover, in the case of no input current and under appropriated condition, the proposed circuit can provide quadrature sinusoidal signals in both voltage-mode and current-mode simultaneously. The circuit construction consists of 2 CCCDTA and 2 grounded capacitors (beneficial to an IC Implementation [7]). The PSPICE simulation results are also shown, which are in correspondence with the theoretical analysis.

2. Circuit Principle
2.1 The Current Controlled Current Differencing Transconductance Amplifier (CCCDTA)
Generally, the CCCDTA's properties are similar to the conventional CDTA, except that the input voltage of CCCDTA is not zero and the CCCDTA has finite input resistances: \( R_p \) and \( R_n \) at the \( p \) and \( n \) input terminals, respectively. These intrinsic resistances are equal and can be controlled by the bias current, \( I_B \), as shown in the following equation:

\[
\begin{bmatrix}
V_p \\
V_n \\
I_p \\
I_n
\end{bmatrix} =
\begin{bmatrix}
R_p & 0 & 0 & 0 \\
0 & R_n & 0 & 0 \\
1 & -1 & 0 & 0 \\
0 & 0 & 0 & \pm g_m
\end{bmatrix}
\begin{bmatrix}
V_p \\
V_n \\
I_p \\
I_n
\end{bmatrix},
\]  

(1)
when
\[ R_T = R_n = \frac{V_T}{2I_{g1}} \]  
(2)

and
\[ g_m = \frac{I_{g2}}{2V_T} , \]
(3)

where \( g_m \) is the transconductance of the CCCDTA and \( V_T \) is the thermal voltage. The symbol and the equivalent circuit of the CCCDTA are illustrated in Figure 1(a) and (b), respectively.

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

2.2 The proposed circuit with operating as an universal biquad filter

Figure 2 demonstrates the presented circuit schematic working as a universal filter. The depicted bias currents: \( I_{g1} \), \( I_{g2} \), \( I_{g3} \), and \( I_{g4} \) are the input bias currents of CCCDTA1 and CCCDTA2 respectively. From the CCCDTA properties in section 2.1 and routine circuit analysis, the following current transfer functions are obtained

\[ \begin{align*}
I_{gF} &= \frac{I_{g1}}{s^2 + \left( \frac{1 - R_{pi}g_{m2}}{R_{pi}C_1} \right) s + \frac{g_{m1}}{R_{pi}C_1C_2}} , \\
I_{gP} &= \frac{g_{m1}}{R_{pi}C_1C_2} , \\
I_{gH} &= \frac{g_{m1}}{R_{pi}C_1C_2} , \\
I_{gB} &= \frac{s}{R_{pi}C_1} ,
\end{align*} \]

and

\[ \begin{align*}
S^2 + \left( \frac{1 - R_{pi}g_{m2}}{R_{pi}C_1} \right) S + \frac{g_{m1}}{R_{pi}C_1C_2} = 0 .
\]

From Eq. (10), it can be seen that the proposed circuit can be set as an oscillator if

\[ \frac{1}{R_{pi}} = g_{m2} . \]

(11)

Eq. (11) is called the condition of oscillation, and this is achieved when \( 4I_{g1} = I_{g4} \). Thus the characteristic equation of the system becomes

Moreover, the band-stop and the all-pass functions can be obtained from the currents \( I_{g5}=I_{g6}-I_{g7} \), \( I_{g8}=I_{g5}+I_{g9} \). All output responses can be directly obtained by using either multiple-output CCCDTAs or a current follower.

From Eqs. (4), (5) and (6), the parameter \( \omega_0 \) and \( Q_0 \) are expressed as

\[ \begin{align*}
\omega_0 &= \sqrt{\frac{g_{m1}}{R_{pi}C_2}} , \\
Q_0 &= \sqrt{\frac{g_{m1}}{R_{pi}C_2}} \left( 1 - \frac{1}{R_{pi}g_{m1}} \right) ,
\end{align*} \]

(7)

Substituting the intrinsic resistances as depicted in Eqs. (2)-(3) and for easy consideration, if \( C_1 = C_2 = C \) and \( I_{g1} = I_{g2} = I_g \), Eqs.(7) can be reduced to

\[ \omega_0 = \frac{I_g}{V_C} , Q_0 = \frac{2I_g}{4I_g - I_{g4}} . \]

(8)

From Eqs. (8), it can be seen that the natural frequency \( (\omega_0) \) can be adjusted linearly and independently from the quality factor \( (Q_0) \) by varying \( I_g \) or \( C \), while the quality factor can be adjusted by \( I_{g4} \). Thus bandwidth \( (BW) \) is given by

\[ BW = \frac{\omega_0}{Q_0} = \frac{4I_g - I_{g4}}{2V_C} . \]

(9)

2.3 The proposed circuit with operating as a quadrature oscillator

If no input current is applied to the circuit as shown in Figure 3, the system characteristic equation can be expressed as

\[ S^2 + \left( \frac{1 - R_{pi}g_{m2}}{R_{pi}C_1} \right) S + \frac{g_{m1}}{R_{pi}C_1C_2} = 0 . \]

From Eq. (10), it can be seen that the proposed circuit can be set as an oscillator if

\[ \frac{1}{R_{pi}} = g_{m2} . \]

(11)
confirmed that the quality factor can be adjusted by \( I_{B4} \), without disturbing the natural frequency, as depicted in Eq. (8).

\[
I_{B1} = I_{B2} = I_{B3} = 50\mu A \quad \text{and} \quad I_{B4} = 209\mu A,
\]
where the total harmonic distortion (THD) is about 4.18%. Figure 12 depicts the plots of the simulated and theoretical oscillation frequency versus the bias currents, \( I_{B1} \) and \( I_{B2} \), where \( C_1 \) and \( C_2 \) are identical values of 0.1nF, 1nF, and 10nF. It is seen that the simulation results are in accordance with the theoretical analysis as shown in Eq. (13).

\[
I_{B4} = \text{ varied}
\]

3. Simulation Results

To prove the performances of the proposed circuit, the PSPICE simulation program was used for the examination. The PNP and NPN transistors employed in the proposed circuit were simulated by respectively using the parameter of the NR200N and PR200N bipolar transistors of ALA400 transistor array from AT&T [8].

Figure 4 depicts schematic description of the CCCDTA used in the simulations. The CCCDTA was biased with ±1V DC power supplies, the capacitors \( C_1 \) and \( C_2 \) are 1nF. Figure 5 illustrates the magnitude response of the proposed universal filter, where \( I_{B1} = I_{B2} = I_{B3} = 10\mu A \) and \( I_{B4} = 1\mu A \). It shows that the proposed filter provides LP, HP and BP responses at the same time. By varying \( I_{B4} \) at 5\( \mu \)A, 10\( \mu \)A, 15\( \mu \)A, and 20\( \mu \)A, with \( I_{B1} = I_{B2} = I_{B3} = 10\mu A \), only the quality factor is changed, as shown in Figures 6, 7, and 8. Therefore, it is

\[
\omega_0 = \frac{g_m}{R_{p2}C_1C_2} = \sqrt{\frac{I_{B1}I_{B2}}{V_T^2C_1C_2}}.
\]

Figure 5. Normalized magnitude responses of the proposed circuit working as universal biquad filter

Figure 6. Normalized HPF response when \( I_{B4} \) is varied

Figure 7. Normalized LPF response when \( I_{B4} \) is varied

Figure 8. Normalized BPF response when \( I_{B4} \) is varied
4. Conclusion
The novel circuit, which can function both as a quadrature oscillator and as a current-mode universal biquad filter (lowpass, highpass and bandpass) has been presented. The proposed circuit can work as either a quadrature oscillator or a universal biquad filter without changing a circuit topology. Working as a current-mode universal biquad filter, the quality factor and natural frequency can be tuned orthogonally via the input bias currents. With no input current and under suitable condition, the proposed circuit functions as a quadrature oscillator. Its oscillation condition and oscillation frequency can be adjusted independently with the input bias currents. In addition, it is also found that the circuit can be controlled electronically and the useful frequency range up to one hundred megahertz. The simulation results are well agreed with the theoretical anticipation. Since it consists of 2 CCCDTAs and 2 grounded capacitors, this circuit is thus suitable for IC architecture.

References