A Novel Versatile Circuit functioning as both Filter and Oscillator based on CCCCTAs

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Abstract- A circuit which can function both as quadrature oscillator and as a universal biquad filter (low-pass, high-pass, band-pass, band-reject and all-pass functions) 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 conveyor transconductance amplifiers (CCCCTAs) 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 3.78mW at ±1.5V power supplies.

I. 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 systems [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 environments, such as portable and battery-powered equipments. 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. It would be preferable to compact the circuits/systems if a circuit can work for several functions.

Recently, the network which can function both as filter and as oscillator has been firstly reported [6], it is called ‘Filtillator’. Although the circuit description is simple, the output current signals are provided at passive element terminals. Thus, it is needed to employ a current mirror or current buffer to obtain the usable output currents, this makes the circuit more complicated. In addition, the output signals offer a high total harmonic distortion (THD), up to 4.18%.

The purpose of this paper is to introduce a novel current-mode universal biquad filter, based on the novel active building block recently proposed, named as CCCCTA [7], providing five standard transfer functions (low-pass, high-pass, band-pass, band-reject, all-pass functions) to achieve the mentioned requirements. 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 with a low THD without changing any circuit topology. The circuit construction consists of only 2 CCCCTAs and 2 grounded capacitors (beneficial to an IC Implementation [8]). The PSPICE simulation results are also shown, which are in correspondence with the theoretical analysis.

II. CIRCUIT CONFIGURATION

A. Basic Concept of CCCCTA

CCCCTA properties are similar to the conventional CCTA, except that the CCCCTA has finite input resistance $R_x$ at the $x$ input terminal. This parasitic resistance can be controlled by the bias current $I_{BI}$ as shown in the following equation
\[
\begin{bmatrix}
I_y \\
V_y \\
I_z \\
V_z \\
I_o
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 \\
R_s & 1 & 0 & 0 \\
1 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 0 & \pm g_m & 0
\end{bmatrix}
\begin{bmatrix}
I_y \\
V_y \\
I_z \\
V_z \\
I_o
\end{bmatrix},
\]
(1)

where
\[ R_s = \frac{V_T}{2I_{B1}}, \]
(2)

and
\[ g_m = \frac{I_{B2}}{2V_T}, \]
(3)

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

\[ \begin{aligned}
&I_{b1} \quad I_{b2} \\
&V_y \quad \pm i_g V_o \\
&x \quad o \quad z \\
&\uparrow \quad \downarrow \\
&\text{CCCCTA} \\
&V_x \quad I_{b1} \quad I_{b2} \\
&y \quad i_z \\
\end{aligned} \]

(b)

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

Figure 2. Proposed circuit working as universal filter

B. The proposed circuit operating as an universal biquad filter

Fig. 2 demonstrates the presented circuit schematic working as a universal filter. The depicted bias currents: \( I_{B1}, I_{B2}, I_{B3}, \) and \( I_{B4} \) are the input bias currents of CCCCTA1 and CCCCTA2 respectively. From the CCCCTA properties in Section II.A and routine circuit analysis, the following current transfer functions are obtained

\[ I_{BP} = \frac{s^2 + \frac{g_m}{R_s C_2}}{s^2 + \frac{1 - R_{s2} g_m}{R_s C_1} + \frac{g_m}{R_s C_2}}. \]
(4)

\[ I_{LP} = \frac{s^2 + \frac{g_m}{R_s C_2}}{s^2 + \frac{1 - R_{s2} g_m}{R_s C_1} + \frac{g_m}{R_s C_2}}. \]
(5)

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

\[ \begin{aligned}
&I_{b1} \quad I_{b2} \\
&V_y \quad \pm i_g V_o \\
&x \quad o \quad z \\
&\uparrow \quad \downarrow \\
&\text{CCCCTA} \\
&V_x \quad I_{b1} \quad I_{b2} \\
&y \quad i_z \\
\end{aligned} \]

(b)

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

Moreover, the band-stop and all-pass functions can be obtained from the currents \( I_{BS} = I_{BP} - I_{BP}, I_{AP} = I_{BS} - I_{BP} \). All output responses can be directly obtained by using either multiple-output CCCCTAs or a current follower. Consequently, the band-stop and all-pass functions can be obtained as

\[ \begin{aligned}
&I_{BS} = \frac{s^2 + \frac{g_m}{R_s C_2}}{s^2 + \frac{1 - R_{s2} g_m}{R_s C_1} + \frac{g_m}{R_s C_2}}, \quad (7) \\
&I_{AP} = \frac{s^2 + \frac{g_m}{R_s C_2}}{s^2 + \frac{1 - R_{s2} g_m}{R_s C_1} + \frac{g_m}{R_s C_2}}. \quad (8)
\end{aligned} \]

From Eqs. (4)-(8) the parameter \( \omega_0 \) and \( Q_0 \) are expressed as

\[ \omega_0 = \frac{\frac{g_m}{R_s C_2}}{\frac{R_s C_1}{R_s C_2} \left( 1 - R_{s2} g_m \right)}, \quad (9) \]

and

\[ Q_0 = \frac{\frac{g_m}{R_s C_2}}{\frac{R_s C_1}{R_s C_2} \left( 1 - R_{s2} g_m \right)} \]

Substituting the intrinsic resistances as depicted in Eqs. (2)-(3) and for easy consideration, if \( C_1 = C_2 = C \) and \( I_{B3} = I_{B4} = I_B \), Eq. (9) can be reduced to

\[ \omega_0 = \frac{I_B}{V_T}, \quad Q_0 = \frac{\frac{g_m}{R_s C_2}}{\frac{R_s C_1}{R_s C_2} \left( 1 - R_{s2} g_m \right)}. \]
(10)

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

\[ \omega_0 = \frac{I_B}{V_T}, \quad Q_0 = \frac{2I_B}{4I_B - I_{B2}}. \]
(11)

From Eqs. (10)-(11), it can be seen that the natural frequency \( (\omega_0) \) can be adjusted linearly and independently from the quality factor \( (Q_0) \) by varying \( I_B \) or \( C \), while the quality factor can be adjusted by \( k \). Thus, bandwidth \( (BW) \) is given by

\[ BW = \frac{\frac{4I_B}{Q_0}}{2V_T C}. \]
(12)
C. The proposed circuit operating as a quadrature oscillator

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

\[ s^2 + \frac{1}{R_{c2} C_1} s + \frac{g_{m2}}{R_{c2} C_2} = 0. \]  \hspace{1cm} (13)

From Eq. (13), it can be seen that the proposed circuit can be set to be an oscillator if

\[ \frac{1}{R_{c2}} = g_{m1}. \]  \hspace{1cm} (14)

Eq. (14) is called the condition of oscillation, and this is achieved by \( 4I_{B3} = I_{B2} \). Thus, the characteristic equation of the system becomes

\[ s^2 + \frac{g_{m2}}{R_{c2} C_2} = 0. \]  \hspace{1cm} (15)

From Eq. (15), the oscillation frequency of this system can be obtained as

\[ \omega_0 = \frac{g_{m2}}{R_{c2} C_2} = \frac{I_{B3} I_{B4}}{V_o^2 C_1 C_2}. \]  \hspace{1cm} (16)

It can be found that the oscillation frequency \( (\omega_0) \) can be controlled by bias currents. Additionally, the oscillation condition can be tuned by \( I_{B2} \) without affecting the oscillation frequency. The quadrature sinusoidal signals can be simultaneously obtained both as current-mode at \( I_{O1} \) and \( I_{O2} \) and voltage-mode at \( V_{O1} \) and \( V_{O2} \).

Figure 4. Circuit description of current controlled current conveyor transconductance amplifier

III. 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 [11]. Fig. 4 depicts schematic description of the CCCCTA used in the simulations. The CCCCTAs were biased with \( \pm1.5V \) power supplies, the capacitors \( C_1 \) and \( C_2 \) are \( 1nF \). Fig. 5 illustrates the magnitude responses of the proposed universal filter. It shows that the proposed filter provides LP, HP, BP, BS and AP responses at the same time. The result in Fig. 6 confirms that the quality factor can be adjusted by \( I_{B2} \) which is independent of the pole frequency, as analyzed in Eq. (10). Fig. 7 shows gain responses of the band-pass function where \( I_B \) is set to \( 10\muA, 25\muA, \) and \( 60\muA \), respectively. This shows that pole frequency can be adjusted without affecting the quality factor, as depicted in Eq. (11).

Figure 5. Gain responses of the proposed circuit working as universal filter

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

Figure 7. BP responses for different values of \( I_B \)

Figs. 8, 9, and 10 show the responses when the proposed circuit operates as quadrature oscillator with bias currents \( I_{B1} = 100\muA, I_{B2} = 203\muA \) and \( I_{B3} = I_{B4} = 50\muA \),
where the total harmonic distortion (THD) is about 1.09%.

Fig. 11 depicts the plots of the simulated and theoretical oscillation frequencies versus the bias currents, $I_{B}$, 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. (16). The maximum power dissipation is about 3.75mW for ±1.5V supply voltages.

**REFERENCES**


