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CCCDDTA-based Versatile Quadrature Oscillator and Universal Biquad Filter

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Abstract- In this article, a novel circuit, which can function both as quadrature oscillator and universal biquad filter (lowpass, highpass and bandpass functions) is introduced. The features of the circuit are that, working as quadrature oscillator, the oscillation condition and oscillation frequency can be adjusted independently with the input bias currents: functioning as universal biquad filter, the quality factor and natural frequency can be tuned orthogonally via the input bias currents: the circuit can work as either the quadrature oscillator or the universal biquad filter without changing circuit topology: it provides output signals both in current-mode and voltage-mode simultaneously. The circuit description is very simple, consisting of merely 2 Current Controlled Current Differencing Transconductance Amplifiers (CCCDDTA), 1 voltage buffer and 2 grounded capacitors. Without any external resistors and using only grounded elements, this circuit is then suitable for IC architecture. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation. The circuit was biased with ±1.5V supply voltages.

Index Terms- Biquad filter, Current-mode, CCCDTA

I. INTRODUCTION

An oscillator and a filter are 2 basic important building blocks which are frequently employed in electrical engineering works. A quadrature oscillator is widely used because the circuit provides two sinusoids with 90° phase difference, as for example in telecommunications for quadrature mixers and single-sideband [1]. In similar, nowadays, the applications and advantages in the realization of various active transfer functions, called as 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 voltage-mode one. This is due to operating in low-voltage environment as in portable and battery-powered equipment. Since a low-voltage operating circuit becomes necessary, the current–mode technique is ideally suited for this purpose more than the voltage-mode one. Presently, there is a growing interest in synthesizing the 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, from our investigations, there are seen that the previous literatures have proposed the universal filters and the quadrature oscillators require too many components and component matching conditions [4]. Some universal filters require floating capacitors, which is not ideal for IC implementation [5]. In addition, each circuit can work only one function, either quadrature oscillator or universal filter. Recently, the versatile quadrature oscillator and biquad filter using current controlled current differencing buffered amplifier (CCCDBA) was proposed [6]. Unfortunately, it is rather complicated topology, due to consisting of 3 CCCDBAs and 2 grounded capacitors, which results in low frequency of operation and high power consumption.

The purpose of this paper is to introduce a current-mode universal biquad filter, based on CCCDTA as the active building block recently proposed in [7], providing three standard transfer functions (lowpass, highpass and bandpass). The natural frequency can be adjusted independently from the quality factor. Moreover, in case of no input current and appropriated condition, the proposed circuit can provide quadrature sinusoidal signals in both voltage-mode and current-mode simultaneously. The circuit construction consists of 2 CCCCTAs, 1 voltage buffer and 2 grounded capacitors. The PSPICE simulation results are also shown, which are in correspondence with the theoretical analysis.

II. CIRCUIT PRINCIPLE

A. The Current Controlled Current Differencing Transconductance Amplifier (CCCDDTA)

Since the proposed circuit is based on CCCDTAs, a brief review of CCCDTA is given in this section. Basically, the CCCDTA is composed of translinear elements, mixed loops and complementary current mirrors. Generally, CCCDTA properties are similar to the conventional CDTA, except that input voltages of CCCDTA are not zero and the CCCDTA has finite input resistances $R_g$ and $R_n$ at the $p$ and $n$ input terminals, respectively. These parasitic resistances are equal and can be controlled by the bias current $I_{bs}$ as shown in Eq. (1)

$\left[ \begin{array}{c} V_p \\ V_s \\ I_p \\ I_s \end{array} \right] = \left[ \begin{array}{cccc} R_p & 0 & 0 & 0 \\ 0 & R_n & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & g_m \end{array} \right] \left[ \begin{array}{c} I_p \\ I_s \\ V_p \\ V_s \end{array} \right].$
When \[ R_p = R_n = \frac{V_T}{2I_{b1}} \] (2)

and \[ g_m = \frac{I_{b2}}{2V_T} \] (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 Figs. 1(a) and (b), respectively.

![CCCDTA Symbol](image)

![CCCDTA Equivalent Circuit](image)

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

From Eqs. (4)-(6), the parameters \( \omega_0 \) and \( Q_0 \) can be expressed as

\[
\omega_0 = \sqrt{\frac{g_m}{R_{p1}C_1C_2}},
\]

(7)

\[
Q_0 = \frac{C_1}{(2/R_{p2}) - g_m}.
\]

For easy consideration, if \( I_{b3} = I_{b4} = I_B \) and \( C_1 = C_2 = C \), Eqs. (7) and (8) can be reduced to

\[
\omega_0 = \frac{I_B}{V_C},
\]

(9)

\[
Q_0 = \frac{I_B}{4I_{b3} - (I_{b4}/2)}.
\]

(10)

**B. The operation of proposed circuit working as a universal biquad filter**

Fig. 2 demonstrates the circuit scheme of the proposed circuit working as the universal filter. The depicted bias currents; \( I_{b1}, I_{b2}, I_{b3} \) and \( I_{b4} \) are respectively the input bias currents of CCCDTA1 and CCCDTA2. From the circuit and the CCCDTA properties in section A including routine analysis, the following current transfer functions are obtained

\[
I_{LP} = \frac{g_m/C_1C_2R_{p1}}{s^2 + \left( \frac{2}{R_{p2} - g_m} \right) \frac{s}{C_2} + \frac{g_m}{R_{p1}C_1C_2}},
\]

(5)

\[
I_{LP} = \frac{g_m/C_1C_2R_{p1}}{s^2 + \left( \frac{2}{R_{p2} - g_m} \right) \frac{s}{C_2} + \frac{g_m}{R_{p1}C_1C_2}},
\]

(6)

It is obviously found that, from Eqs. (9) and (10), the quality factor can be adjusted by \( I_{b3} \) or \( I_{b4} \) without affecting the pole frequency. Reversely, the pole frequency can be controlled via \( I_B \). In addition, bandwidth (\( BW \)) of the system can be expressed by

\[
BW = \frac{\omega_0}{Q_0} = \frac{4I_{b3} - (I_{b4}/2)}{V_C}.
\]

(11)

In the same view, the bandwidth can be linearly tuned by \( I_{b3} \). Another advantage of the proposed circuit is that the high \( Q_0 \) circuit can be obtained by setting \( I_{b4}/2 \) close to \( 4I_{b3} \), which differs from conventional universal filters in such that the maximum \( Q_0 \) is limited by component values.

**C. Circuit Sensitivities**

The sensitivities of the proposed circuit are low and can be found as

\[
S_{I_{b1}}^{R_{p1}} = 1; \ S_{I_{b2}}^{R_{p2}} = -1,
\]

(12)

and

\[
S_{I_{b3}}^{I_{b3}} = 1; \ S_{I_{b4}}^{I_{b3}} = \frac{-4I_{b3}}{4I_{b3} - (I_{b4}/2)}, \ S_{I_{b3}}^{I_{b4}} = \frac{I_{b4}}{8I_{b3} - I_{b4}}.
\]

(13)

**D. The operation of proposed circuit working as a quadrature oscillator**

If no input current applied to the circuit as shown in Fig. 3, system characteristic equation can be expressed as
\[ s^2 + \left( \frac{2}{R_{p2}} - g_{m2} \right) s + \frac{g_{m1}}{R_{p1}C_1C_2} = 0. \]  
(14)

From Eq. (14), it can obviously be seen that the proposed circuit can be set to be an oscillator if

\[ \frac{2}{R_{p2}} = g_{m2}. \]  
(15)

Eq. (15) is called as condition of oscillation, this is achieved by \( I_{B3} = I_{B4}/8 \), then the oscillation frequency of this system can be obtained as

\[ \omega_b = \sqrt{\frac{g_{m1}}{R_{p1}C_1C_2}}. \]  
(16)

If letting \( I_{B1} = I_{B2} = I_B \) and \( C_1 = C_2 = C \), Eq. (16) can be reduced to

\[ \omega_b = \frac{I_B}{V_C C}. \]  
(17)

It can be seen that the oscillation frequency (\( \omega_b \)) can be linearly controlled by bias current.

Furthermore, the quadrature sinusoidal signals can be simultaneously obtained at \( V_{o1} \) and \( V_{o2} \) as seen in Fig. (3), in current-mode and voltage-mode, respectively. The free terminals of \( I_{o1} \) and \( I_{o2} \) can be achieved by using multiple Z-terminal output CCCDTAs.

E. Non-ideal case

For non-ideal case, the \( I_z \) and \( I_s \) of CCCDTA can be respectively characterized by

\[ I_z = \alpha_z I_p - \alpha_z I_s, \]  
(18)

and

\[ I_s = \beta V_z. \]  
(19)

Where \( \alpha_z \), \( \alpha_z \), and \( \beta \) are transferred error values deviated from one. In the case of non-ideal and brief consideration, the \( \omega_b \) and \( Q_b \) are changed to

\[ \omega_b = \sqrt{\frac{\alpha_z \beta \gamma g_{m1}}{R_{p1}C_1C_2}}. \]  
(20)

\[ Q_b = \frac{\alpha_z}{\left( 1 + \alpha_z \right) / R_{p2} - \beta g_{m2}}. \]  
(21)

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 parameters of the PR200N and NR200N bipolar transistors of ALA400 transistor array from AT&T [6]. Fig. 4 depicts schematic description of the CCCDTA used in the simulations, the ideal voltage buffer was used in the simulations. The CCCDTAs were biased with \( \pm 1.5 \)V power supplies, the capacitor values of \( C_1 \) and \( C_2 \) are 1nF. Firstly, the operation as the universal biquad filter is verified. The gain responses of the proposed universal filter are shown in Fig. 5. It shows that the proposed filter obtains LP, HP and BP responses at the same time. By varying \( I_{B4} \) to 100μA, 200μA and 3000μA, only the quality factor is changed as shown in Fig. 6. Therefore, it is confirmed that the quality factor can be adjusted by \( I_{B3} \) or \( I_{B4} \) which is linearly independent of the pole frequency, as mentioned.

Fig. 7, 8 and 9 show the responses when operating as quadrature oscillator, where the total harmonic distortion (THD) is about 1.12% and the maximum operating frequency is approximately 1.58MHz.
IV. Conclusion

The novel circuit, which can function both as quadrature oscillator and current-mode universal biquad filter has been presented. The proposed circuit can work as either the quadrature oscillator or the universal biquad filter without changing a circuit topology. Working as current-mode universal biquad filter, the quality factor and pole frequency can be tuned orthogonally via the input bias currents. When no input current and suitable condition, the proposed circuit can function as a quadrature oscillator. Its oscillation condition and oscillation frequency can be adjusted independently with the input bias currents. It can provide quadrature sinusoidal signals in both voltage-mode and current-mode simultaneously. The PSPICE simulation results are well agreed with the theoretical anticipation with maximum power dissipation of 1.03mW at ±1.5V supply voltages. Since it consists of merely 2 CCCCTAs, 1 voltage buffer and 2 grounded capacitors, this circuit is then suitable for an IC architecture.

REFERENCES