An Electronically Controllable Voltage-mode First-order All-Pass Filter Using Only Single CCCDTA

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Abstract— **This article presents a voltage-mode first-order all-pass filter based on merely single current controlled current differencing transconductance amplifiers (CCCDTA). The features of the circuit are that: the pole frequency can be electronically controlled via the input bias current: the circuit description is very simple, consisting of merely single CCCDTA and single capacitor, without any matching condition constraint. Consequently, the proposed circuit is very appropriate to further develop into an integrated circuit. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation. The power consumption is approximately 1.01mW at ±1.5V power supply voltages. The application example as a quadrature oscillator is included.**

I. INTRODUCTION

An all-pass filter or phase shifter is one of the most important building blocks of many analog signal processing applications and therefore has received much attention. It is frequently used for introducing a frequency dependent delay while keeping the amplitude of the input signal constant over the desired frequency range. Other type of the active circuits such as oscillators and high-Q band-pass filters are also realized by using all-pass filters [1-5]. The literature surveys show that the voltage-mode first-order all-pass filter circuit using different high-performance active building blocks such as, current conveyors (CCIIs) [3-4, 6-11], OTAs [12], current controlled current conveyors (CCCIIs) [13-15], differential voltage current conveyor (DVCC) [16], differential difference current conveyors (DDCCs) [17-18], current differencing buffered amplifier (CDBA) [19] and operational transresistance amplifiers (OTRAs) [20-22], have been reported. Unfortunately, these reported circuits suffer from one or more of the following weaknesses: excessive use of the active and/or passive elements [3-4, 6-22], lack of electronic adjustability [3-4, 6-11, 16-18, 20-22].

The current differencing transconductance amplifier (CDTA) is a reported active component, especially suitable for a class of analog signal processing [23]. However, the CDTA can not be controlled by the parasitic resistances at input ports so when it is used in some circuits, it must unavoidably require some external passive components, especially the resistors. This makes it not appropriate for IC implementation due to occupying more chip area, high power consumption and without electronic controllability. Recently, the current-controlled CDTA (CCCDTA) [24] has been proposed, it was proved that it can overcome the mentioned limitations of the CDTA.

The aim of this paper is to propose a voltage-mode first-order all-pass filter, emphasizing on the use of the CCCDTA. The features of the proposed circuit are that: the angle pole frequency can be electronically controlled: the circuit description is very simple, it employs only single CCCDTA and single capacitor as passive component, which is suitable for fabricating in monolithic chip. The performances of the proposed circuit are illustrated by PSPICE simulations, they show good agreement with the calculation. The application example of the proposed all-pass filter as a quadrature oscillator is included.

II. PRINCIPLE OF OPERATION

A. *Current Controlled Current Differencing Transconductance Amplifier*

Since the proposed circuit is based on CCCDTA, a brief review of CCCDTA is given in this section. 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_p 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_{B1} as shown in the following equation [24]

$$\begin{bmatrix} V_p \\ V_n \\ I_z \\ I_x \end{bmatrix} = \begin{bmatrix} R_p & 0 & 0 & 0 & 0 \\ 0 & R_n & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 & 0 \\ 0 & 0 & 0 & g_m & 0 \end{bmatrix} \begin{bmatrix} I_p \\ I_n \\ V_x \\ V_z \end{bmatrix}, \quad (1)$$

where

$$R_p = R_n = \frac{V_T}{2I_{B1}}, \quad (2)$$

and

$$g_m = \frac{I_{B2}}{2V_T}. \quad (3)$$

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

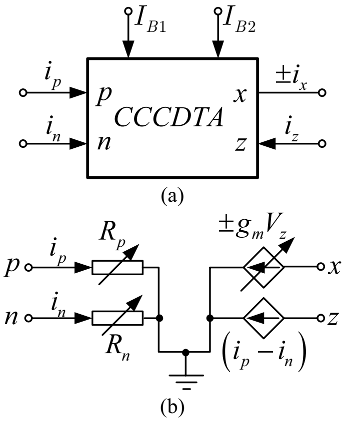

Figure 1. (a) CCCDTA (b) Equivalent circuit.

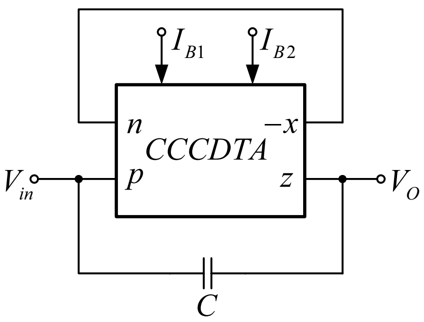

Figure 2. Proposed voltage-mode first-order all-pass filter.

B. Proposed Voltage-Mode First-Order All-Pass Filter

The proposed voltage-mode first-order all-pass filter is illustrated in Fig. 2. The proposed circuit consists of only 1 CCCDTA and 1 capacitor. Considering the circuit in Fig. 2 and using CCCDTA properties in section A, we will receive

$$H(s) = \frac{V_O}{V_{in}} = \frac{sC - 1/R_p}{sC + g_m}. \quad (4)$$

For easy consideration, if $g_m = 1/R_p$, which it can be achieved by setting $I_{B2} = 4I_{B1}$, the transfer function can be rewritten to be

$$H(s) = \frac{sC - g_m}{sC + g_m}. \quad (5)$$

From Eq. (5), the voltage gain of the proposed circuit is unity and it also has the phase response as

$$\angle H(\omega_p) = \phi(\omega_p) = \pi - 2\tan^{-1}(\omega_p C / g_m). \quad (6)$$

If $g_m = I_B / 2V_T$, the phase response can be re-expressed to be

$$\angle H(\omega_p) = \phi(\omega_p) = \pi - 2\tan^{-1}(2V_T \omega_p C / I_B). \quad (7)$$

It can be seen that the circuit gives a phase shift from 180°-0°. Moreover, the angle pole frequency can be electronically controlled by I_B. The ω_p sensitivities of the filter can be written to be

$$S_{V_T}^{\omega_p} = S_C^{\omega_p} = -1; S_{I_B}^{\omega_p} = 1. \quad (8)$$

Therefore, all of active and passive sensitivities are no more than unity in magnitude.

C. Non-Ideal Analysis

Practically, the CCCDTA is possible to operate with non-ideality. Thus, it can be respectively characterized with the following equations.

$$I_z = \alpha_p I_p - \alpha_n I_n, \quad (9)$$

and

$$I_x = -\beta g_m V_z, \quad (10)$$

where α_p, α_n and β are the current/voltage transfer values, deviating from one, stemming from transistors used in the internal circuit construction. In the non-ideal case, a new analysis of the proposed filter circuit in Fig. 2 yields the following transfer function

$$H(s) = \frac{sC - \alpha_p / R_p}{sC + \alpha_n \beta g_m}. \quad (11)$$

If $g_m = 1/R_p$, the transfer function becomes

$$H(s) = \frac{sC - \alpha_p g_m}{sC + \alpha_n \beta g_m}. \quad (12)$$

The voltage gain can be expressed to be

$$|H(\omega_p)| = \sqrt{\frac{\alpha_p^2 + (\omega_p C / g_m)^2}{(\alpha_n^2 \beta)^2 + (\omega_p C / g_m)^2}}. \quad (13)$$

The phase response is

$$\phi(\omega_p) = \pi - \tan^{-1}(\omega_p C / \alpha_p g_m) - \tan^{-1}(\omega_p C / \alpha_n \beta g_m). \quad (14)$$

It is found that parameters; α_p, α_n and β will effect both gain and phase responses. These parameters originate from the intrinsic resistances and stray capacitances in the CCCDTA, which are dependent on temperature variations.

Consequently, these errors affect the sensitivity to temperature and the high frequency response of the proposed circuit, the CCCDTA should be carefully designed to minimize these errors. Considering this fact and make it possible in practice, these deviations are very small and can be ignored in theory. For non-ideal case, the ω_p sensitivities of the all-pass filter become

$$S_{V_T}^{\omega_p} = S_C^{\omega_p} = -1; S_{I_B}^{\omega_p} = S_{\alpha_n}^{\omega_p} = S_{\beta}^{\omega_p} = 1 . \tag{15}$$

It is seen that they are no more than unity in magnitude.

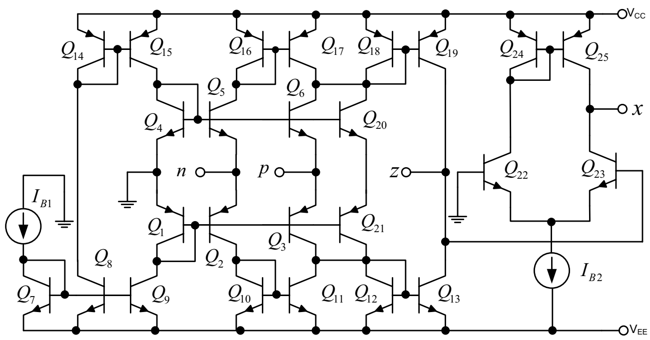

Figure 3. Internal construction of CCCDTA.

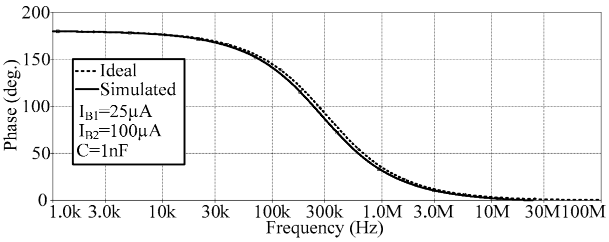

Figure 4. Output phase response.

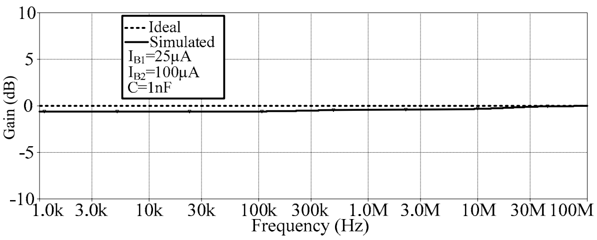

Figure 5. Output gain response.

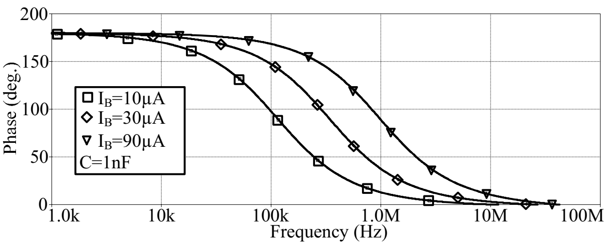

Figure 6. Phase response for different I_B.

III. SIMULATION RESULTS

To prove the performances of the proposed circuit, the PSPICE simulation program was used for the examinations. 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 [25] with ±1.5V power supply voltages. Internal construction of the CCCDTA in Fig. 3 was used in the simulations. Simulated gain and phase responses of the filter against ideal response are given in Fig. 4 and 5, respectively. It can be found that the simulated gain and phase responses are slightly deviated from ideal responses due to the error terms as expressed in Eq. (13) and (14). Phase response for different I_B is shown in Fig. 6. This result confirms that the angle pole frequency can be electronically controlled by setting I_B. The maximum power consumption is approximately 1.01mW.

IV. APPLICATION EXAMPLE AS A QUADRATURE OSCILLATOR

To show an application of the proposed all-pass filter, a quadrature oscillator is synthesized by cascading an all-pass filter and a non-inverting lossless integrator employing the CCCDTA, as shown in Fig. 7. The circuit description of voltage-mode non-inverting lossless integrator is shown in Fig. 8. Considering the circuit in Fig. 8 and using CCCDTA properties, we will receive

$$H(s) = \frac{V_O}{V_{in}} = \frac{g_{m2}}{s2C_2} , \tag{16}$$

where $g_{m2} = I_{B4} / 2V_T$.

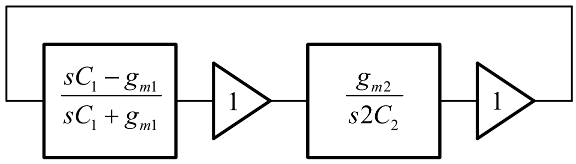

Figure 7. Block diagram for quadrature oscillator.

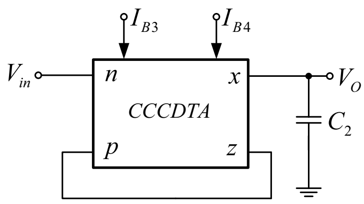

Figure 8. Voltage-mode non-inverting lossless integrator based on CCCDTA.

From the block diagram in Fig. 7, the following characteristic equation can be obtained

$$s^2 + \left(\frac{g_{m1}}{C_1} - \frac{g_{m2}}{2C_2}\right)s + \frac{g_{m1}g_{m2}}{2C_1C_2} = 0 . \tag{17}$$

From Eq. (17), it is found that the quadrature oscillator in Fig. 7 can oscillate, if

$$g_{m2} = 2g_{m1}, \tag{18}$$

where all capacitance values are equal. Eq. (18) is called the oscillation condition. Subsequently, the oscillation frequency can be achieved by

$$\omega_o = \sqrt{\frac{g_{m1}g_{m2}}{2C_1C_2}}. \tag{19}$$

From Eq. (18), the condition of oscillation is achieved by setting $I_B = 2I_{B4}$. It can be found that both oscillation condition and frequency can be electronically controlled. The circuit description of the quadrature oscillator is shown in Fig. 9.

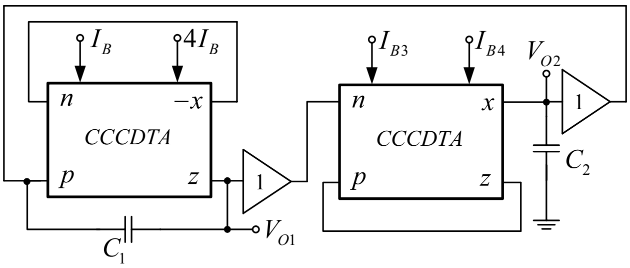

Figure 9. Quadrature oscillator based on CCCDTAs

The confirmed performances of the oscillator can be seen in Fig. 10 and 11, showing the responses of the oscillator, the bias currents I_B, I_{B3} and I_{B4} are respectively set to 10μA, 25μA and 80μA. The voltage buffers used in the simulation are ideal voltage buffers. The total harmonic distortion (THD) is about 5.14%.

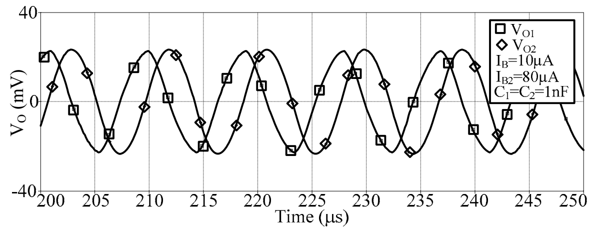

Figure 10. The simulation result of voltage waveforms of the quadrature oscillator

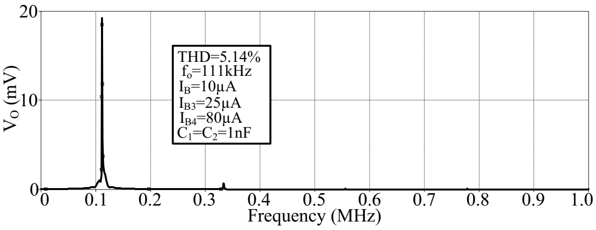

Figure 11. Simulation result of the output spectrum of the oscillator

V. Conclusions

The voltage-mode first-order all-pass filter has been introduced via this paper. The proposed configuration is very simple and can be electronically controlled. It consists of only single CCCDTA and single capacitor. So it is easy to fabricate in IC form to use in battery-powered or portable electronic equipments such as wireless communication devices. The PSPICE simulation results were depicted, and agree well with the theoretical anticipation. The maximum power consumption is approximately 1.01mW at ±1.5V supply voltages. The application example as the quadrature oscillator is included. It shows good usability of the proposed all-pass filter. Our future work is possible to find more applications of the proposed filter.

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