Realization of Electronically Controllable First-order Current-mode Allpass Filter Using CCCIIs and Its Application

Winai Jaikla, Puwamet Singthong, and Montree Siripruchyanun

***Abstract*—This article presents a resistorless current-mode first-order allpass filter based on second generation current controlled current conveyors (CCCIIs). 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 2 CCCIIs and single grounded capacitor, without any external resistors and component matching requirements. Consequently, the proposed circuit is very appropriate to further develop into an integrated circuit. Low input and high output impedances of the proposed configuration enable the circuit to be cascaded in current-mode without additional current buffers. The PSpice simulation results are depicted. The given results agree well with the theoretical anticipation. The application example as a current-mode quadrature oscillator is included.**

***Index Terms*—First-order allpass filter, current-mode, CCCII**

I. Introduction

THE current-mode circuits have been receiving considerable attention due to their potential advantages such as inherently wide bandwidth, higher slew-rate, greater linearity, wider dynamic range, simple circuitry and low power consumption [1]. 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 [2-6]. The literature surveys show that the first-order all-pass filter circuit using different high-performance active building blocks such as, current conveyors (CCIIs) [4-5, 7-12], OTAs [13], current controlled current conveyors (CCCIIs) [14-16], differential voltage current conveyor (DVCC) [17], differential difference current conveyors (DDCCs) [18-19], current differencing buffered amplifier (CDBA) [20] and operational transresistance amplifiers (OTRAs) [21-23], 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 [4-5, 7-23], lack of electronic adjustability [4-5, 7-12, 17-19, 21-23].

The CCII is a reported active component, especially suitable for a class of analog signal processing [24]. The fact that the device can operate in both current and voltage-modes, provides flexibility and enables a variety of circuit designs. In addition, it can offer advantageous features such as high-slew rate, higher speed, wide bandwidth and simple implementation [24-25]. However, the CCII can not control the parasitic resistance at X (Rx) port 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 dissipation and without electronic controllability. On the other hand, the introduced second-generation current-controlled conveyor (CCCII) [26] has the advantage of electronic adjustability over the CCII. Also, the use of dual-output current conveyors is found to be useful in the derivation of current-mode single input three output filters using a reduced number of active components [27-28].

The aim of this paper is to propose a current-mode first-order all-pass filter, emphasizing on the use of the CCCII. The features of the proposed circuit are that: the angle pole frequency can be electronically controlled: the circuit description is very simple, it employs 2 CCCIIs and single grounded 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. Theory and Principle

A. Basic Concept of CCCII

Since the proposed circuit is based on the CCCII, a brief review of CCCII is given in this section. The characteristics of the ideal CCCII are represented by the following hybrid matrix:

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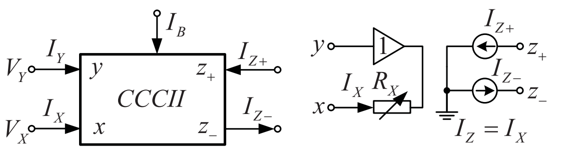
$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & R_X & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix}. \qquad (1)$$

If the CCCII is realized using CMOS technology, R_x can be respectively written as

$$R_x = \sqrt{\frac{1}{kI_B}};\ k = 8\mu_n C_{ox}\left(\frac{W}{L}\right)_{10-11} = 8\mu_n C_{ox}\left(\frac{W}{L}\right)_{12-13}. \qquad (2)$$

Here k is the physical transconductance parameter of the MOS transistor. I_B is the bias current used to control the intrinsic resistance at x port. In general, CCCII can contain an arbitrary number of z terminals; provide both directions of currents I_z. As an example, the symbol and the equivalent circuit of the CCCII with a pair of z+ and z- terminals are illustrated in Fig. 1(a) and (b), respectively. The internal construction of CMOS CCCII is shown in Fig. 2.



(a) (b)

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

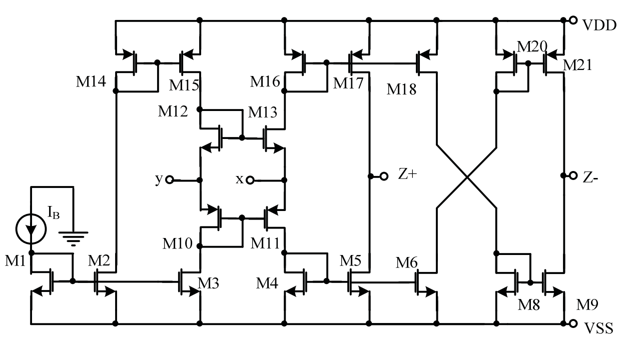


Fig. 2. Schematic of the CMOS CCCII.

B. Proposed current-mode first-order allpass filter

The proposed current-mode first-order allpass filter is illustrated in Fig. 2. It consists of 2 CCCIIs and 1 grounded capacitor. It should be noted that to achieve low input impedance of the filter, the first CCCII should has low impedance (R_{x1}≅0) by setting value of I_{B1} as high as possible. Considering the circuit in Fig. 2 and using CCCII properties in section II.A, the current transfer function can be rewritten to be

$$\frac{I_O}{I_{in}} = -\frac{1 - sCR_{x2}}{1 + sCR_{x2}}. \qquad (3)$$

From Eq. (3), the current gain of the proposed circuit is unity and it also has the phase response as

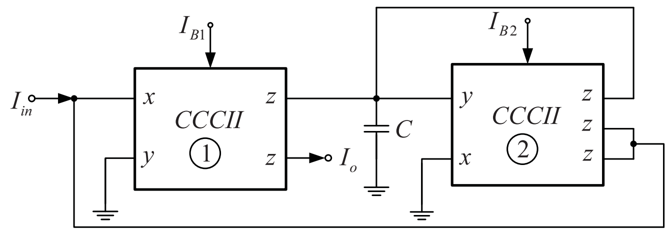


Fig. 3. Proposed current-mode first-order allpass filter.

$$\angle H(\omega_p) = \phi(\omega_p) = 180 - 2\tan^{-1}(\omega_p CR_{x2}). \qquad (4)$$

If $R_{x2} = \sqrt{1/k_2 I_{B2}}$, the phase response can be re-expressed to be

$$\angle H(\omega_p) = \phi(\omega_p) = 180 - 2\tan^{-1}\left(\omega_p C/\sqrt{k_2 I_{B2}}\right). \qquad (5)$$

It can be seen in (5) that the circuit gives a phase shift from 0-(-180°). Moreover, the angle pole frequency can be electronically controlled by I_{B2}. The ω_p sensitivities of the filter can be written to be

$$S_C^{\omega_p} = -1; S_{I_{B2}}^{\omega_p} = S_{k2}^{\omega_p} = \frac{1}{2}. \qquad (6)$$

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

C. Non-ideal analysis

For a complete analysis of the circuit, it is necessary to take into account the following non-idealities of CCCII:

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ \beta & R_X & 0 \\ 0 & \pm\alpha & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix}, \qquad (7)$$

where α is the parasitic current transfer gain from x terminal to z terminal. β is the parasitic voltage transfer gain from y terminal to x terminal. All these gains slightly differ from their ideal values of unity by current tracking errors.

The parasitic resistances and capacitances appear between the high-impedance y and z terminals of the CCCII and ground. The parasitic capacitance $C_{y2} + C_{z1} + C_{z2}$ is absorbed into the external capacitance C as it appears in shunt with them. To alleviate the effects of the parasitic capacitances and resistances the operating frequency ω_{osc} should be chosen such that $\omega_{osc} > \max\left[\frac{1}{(C + C_{y1} + C_{z1} + C_{z2})(R_{y1}//R_{z1}//R_{z2})}\right]$. Moreover, to reduce the effect of C_{z1} ($2C_{z1}$) and R_{z1} appearing at input terminal, the value of R_{x1} must be as low as possible by setting I_{B1}.

In the non-ideal case, a new analysis of the proposed filter circuit in Fig. 3 yields the following transfer function

$$\frac{I_O}{I_{in}} = -\frac{\alpha_1\left(\alpha_2\beta_2 - sCR_{x2}\right)}{\alpha_2\beta_2\left(2\alpha_1 - 1\right) + sCR_{x2}} . \tag{8}$$

The current gain can be expressed to be

$$\left|H\left(\omega_p\right)\right| = \alpha_1\sqrt{\frac{\left(\alpha_2\beta_2\right)^2 + \left(\omega_p CR_{x2}\right)^2}{\left(\alpha_2\beta_2\right)^2\left(2\alpha_1 - 1\right)^2 + \left(\omega_p CR_{x2}\right)^2}} . \tag{9}$$

The phase response is

$$\phi\left(\omega_p\right) = 180 - \tan^{-1}\left(\omega_p CR_{x2} / \alpha_2\beta_2\right) - \tan^{-1}\left\{\omega_p CR_{x2} / \left[\alpha_2\beta_2\left(2\alpha_1 - 1\right)\right]\right\} . \tag{10}$$

It is found that parameters; α and β will effect both gain and phase responses. These parameters originate from the intrinsic resistances and stray capacitances in the CCCII, which are dependent on temperature variations. Consequently, these errors affect the sensitivity to temperature and the high frequency response of the proposed circuit, the CCCII 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.

III. Results of Computer Simulation

The working of the proposed circuit has been verified using PSpice simulation program. The PMOS and NMOS transistors have been simulated by respectively using the parameters of a 0.25µm TSMC CMOS technology [29]. The aspect ratios of PMOS and NMOS transistor are listed in Table 1. Fig. 2 depicts schematic description of the CCCII used in the simulations. The circuit was biased with ±1.25V supply voltages, C=0.1nF, I_{B1}=300µA and I_{B2}=50µA. Simulated gain and phase responses of the filter are given in Fig. 4. 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 Eqs. (9) and (10). Phase response for different I_{B2} is shown in Fig. 5. This result confirms that the angle pole frequency can be electronically controlled by setting I_{B2} as shown in Eq. (5). The time-domain response of the proposed filter is shown in Fig. 6. A sine wave of 20µA amplitude and 2MHz is applied as the input to the filter and the output is 90 phase-shifted.

TABLE I
Dimensions of the Transistors

Transistor	W (µm)	L (µm)
M1-M9	5	0.5
M10-M11	16	0.25
M12-M13	8	0.25
M14-M16, M18-21	15	0.5
M17	15.1	0.5

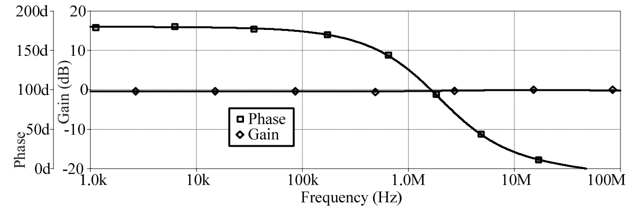


Fig. 4. Gain and phase responses of the proposed allpass filter.

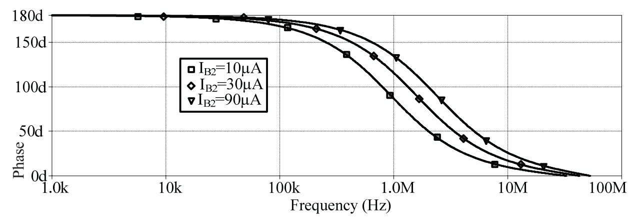


Fig. 5. Simulated phase responses of the proposed allpass filter when I_{B2} is varied.

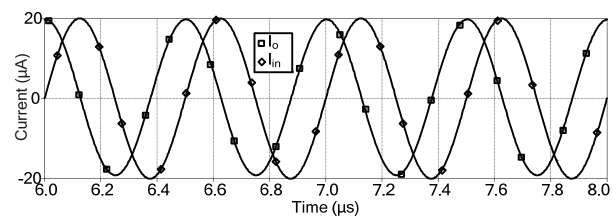


Fig. 6. Filter response to a 2MHz sinusoidal input signal.

IV. Application Example as Quadrature Oscillator

To show an application of the proposed allpass filter, a quadrature oscillator is synthesized by cascading an allpass filter and an inverting lossless integrator employing the CCCII, as shown in Fig. 7. The circuit description of current-mode inverting lossless integrator is shown in Fig. 8. Considering the circuit in Fig. 8 and using CCCII properties, the current transfer function is written as

$$\frac{I_o}{I_{in}} = -\frac{1}{sR_{x3}C_2} . \tag{11}$$

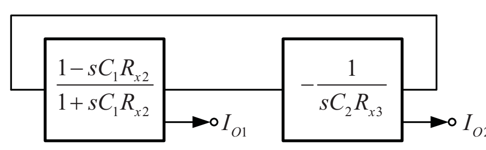


Fig. 7. Block diagram for quadrature oscillator.

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

$$s^2 + \left(\frac{1}{R_{x2}C_1} - \frac{1}{R_{x3}C_2}\right)s + \frac{1}{C_1C_2R_{x2}R_{x3}} = 0 . \tag{12}$$

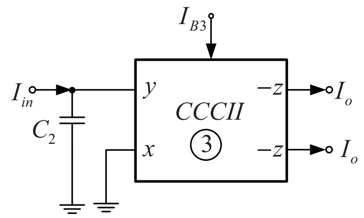


Fig. 8. Current-mode inverting lossless integrator based on CCCII.

From Eq. (12), it can obviously be seen that the system can be set as an oscillator if

$$\frac{C_2}{C_1} = \frac{R_{x2}}{R_{x3}}. \tag{13}$$

Eq. (13) is called the condition of oscillation, this is achieved by setting

$$C_2 = C_1 \text{ and } R_{x3} = R_{x2}. \tag{14}$$

The oscillation frequency of this system can be obtained to be

$$\omega_{osc} = \sqrt{\frac{1}{C_1 C_2 R_{x2} R_{x3}}}. \tag{15}$$

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.

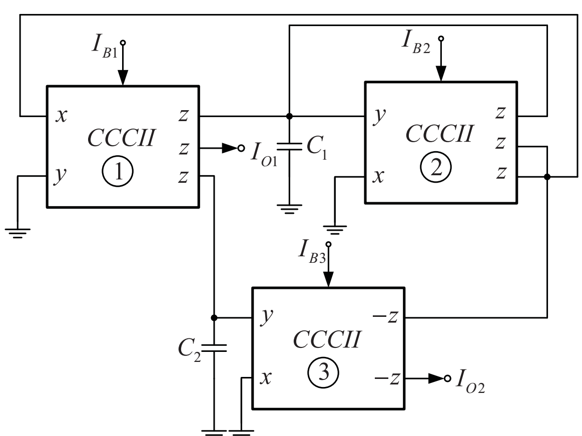


Fig. 9. Quadrature oscillator based on CCCIIs.

The confirmed performances of the oscillator can be seen in Fig. 10 and 11, showing the responses of the oscillator, the bias currents I_{B1}, I_{B2} and I_{B3} are respectively set to 300µA, 150µA and 152µA, C_1=C_2=200pF. This yields oscillation frequency of 1.36MHz. The total harmonic distortion (THD) is about 1.51%.

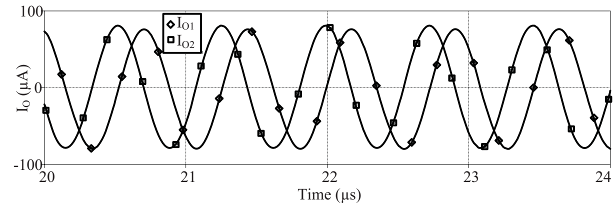


Fig. 10. The simulation result of current waveforms of circuit in Fig. 9.

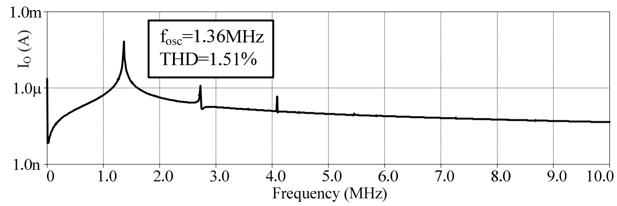


Fig. 11. The output spectrum of the oscillator.

V. CONCLUSIONS

An electronically tunable current-mode first-order allpass filter has been introduced via this paper. The proposed configuration is very simple and can be electronically controlled. It consists of 2 CCCIIs 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 application example as the quadrature oscillator is included. It shows good usability of the proposed all-pass filter.

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