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LETTER

A new current-mode current-controlled SIMO-type universal filter

Chunhua Wang[a,*], Jing Xu[a], Ali Ümit Keskin[b], Sichun Du[a], Qiujing Zhang[a]

[a] School of Computer and Communication, Hunan University, Changsha, 410082, China
[b] Yeditepe University, Department of Biomedical Engineering, Turkey

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ABSTRACT

This paper proposes a new current-mode current-controlled single input multiple output (SIMO) type universal filter. The proposed circuit employs two current-controlled current conveyors (CCCIIs), one MO-CCCA (current-controlled current amplifier with multi-outputs) and two grounded capacitors. The filter can simultaneously realize lowpass, bandpass, highpass, bandstop and allpass filter outputs, and offers an independent electronic control of the natural angular frequency (ω_0) and quality factor (Q) by means of adjusting the bias currents of the CCCIIs. The parameter sensitivities are small. Moreover, a high Q-value filter can be easily obtained by adjusting the ratio of two bias currents of MO-CCCA. PSPICE simulation results are given to demonstrate the advantages of the proposed circuit.

1. Introduction

Current-mode active filters using second-generation current conveyors (CCIIs) have received significant attention in the last decades [1–7]. A variety of CCII-based current-mode universal filters are proposed in [1–6]. However, these filters do not offer electronic adjustment properties, since the input port of CCII cannot be electronically tuned. In order to alleviate this problem, Fabre introduced the concept of second generation current-controlled conveyor (CCCII) [8], and many applications of this element have been reported in the literatures [9–23].

Current-mode current-controlled universal active filters proposed in [9–13,15,17,19–21] are using CCCIIs. The CCCII-based biquadratic filters have the capability of electronic tuning of natural angular frequency (ω_0), and the quality factor (Q) of the circuit. These filters can be either multi-input and multi-output (MIMO) type [11,21], or single input and multi-output (SIMO) structure [9,10,12,13,15,17,19,20]. The MIMO filters can realize multifunction outputs by altering the way in which the input signals are connected. However, such filters can realize multifunction filter outputs only when the input signals meet some constraint conditions. The SIMO filters can realize second-order lowpass (LP), bandpass (BP), highpass (HP), and bandstop (BS) and allpass (AP) filters simultaneously, without changing the connection of the input signal, and without imposing any restrictive conditions on the input signal.

In the CCCII-based SIMO-type current-mode filtering circuits reported in [10,12,13], three CCCII elements and two grounded capacitors are present. However, these filters cannot realize high-impedance outputs except for the BP output in [10]. The circuit in [19] involves two CCCIIs and two capacitors, but it contains floating passive elements (which is relatively disadvantageous from the IC fabrication point of view), and the characteristic parameters ω_0 and Q cannot be tuned orthogonally. The circuit proposed in [9] contains six CCCII elements and two grounded capacitors. The circuit in [17] enjoys very low sensitivities, orthogonal tuning capability of the characteristic parameters ω_0 and Q, grounded capacitors, and high-impedance outputs. However, it requires five CCCIIs and three capacitors. While the circuit in [15] involves three CCCIIs and two capacitors and provide high-impedance outputs, the characteristic parameters (ω_0 and Q) cannot be orthogonally adjusted. Recently, some authors [24] propose a new current-mode current-controlled SIMO universal filter which is based on non-inverting and inverting second-generation current-controlled conveyors (CCCII($\pm$)). This circuit (using four CCCIIs and two grounded capacitors) can provide high-impedance outputs and orthogonal tuning capability of the characteristic parameters ω_0 and Q.

In this paper, a new SIMO-type current-mode universal filter is proposed. The proposed circuit employs only two CCCIIs, one MO-CCCA (current-controlled current amplifier with multi-outputs) [25] and two grounded capacitors. The LP, BP, HP, BS and AP filters can be realized simultaneously. It enjoys orthogonal tuning capability of the characteristic parameters ω_0 and Q, having low component sensitivities. It uses only two grounded capacitors, while providing high impedances at the output terminals. Moreover, high Q filters can be obtained by adjusting the ratio of two independent bias currents.

* Corresponding author. Tel. +86 13973125061; fax: +86 731 8822417.
E-mail address: wch1227164@sina.com (C. Wang).

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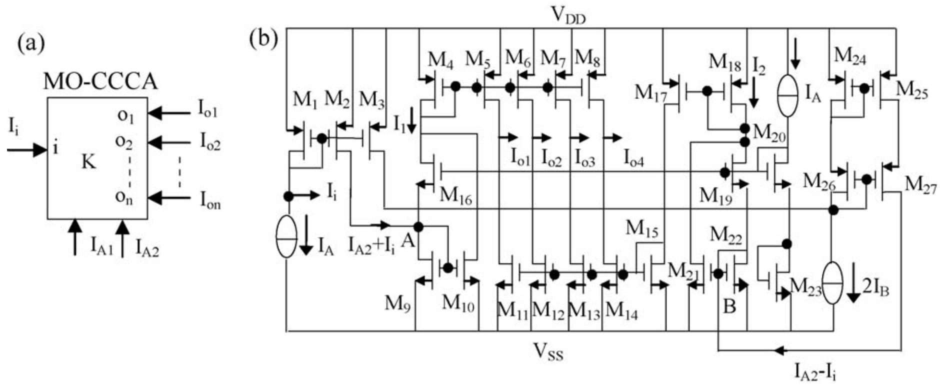

Fig. 1. Current-controlled current amplifier with multi-outputs. (a) The symbol of MO-CCCA. (b) The CMOS based structure of MO-CCCA.

2. MO-CCCA and CCCII(±)

The symbol of MO-CCCA is given in Fig. 1(a), where i represents input, $o_1{\sim}o_n$ are n outputs respectively, and I_{A1} and I_{A2} denote bias DC currents. Fig. 1(b) is a CMOS realization of MO-CCCA which is introduced in [25]. Here I_i denotes the input signal; $I_{o1}, I_{o2}, I_{o3}, I_{o4}$ are the four output currents, respectively.

If the channel lengths of $M5{\sim}M8$ are all n times of that of $M4$, and the channel size of $M17$ is n times that of $M18$, namely $(W/L)_{M5}/(W/L)_{M4} = (W/L)_{M6}/(W/L)_{M4} = (W/L)_{M7}/(W/L)_{M4} = (W/L)_{M8}/(W/L)_{M4} = (W/L)_{M17}/(W/L)_{M18} = n$, the output current expressions can obtained as

$$I_{o1} = I_{o2} = I_{o3} = I_{o4} = \frac{nI_{A2}}{2I_{A1}} I_i = KI_i \tag{1}$$

where K denotes the current gain. It is clear from (1) that the value of K can be set by I_{A2} and I_{A1}.

The circuit symbol of CCCII(±) is shown in Fig. 2. The port relations of the CCCII(±) can be characterized by the following equations:

$$i_y = 0, \quad v_x = v_y + i_x R_x, \quad i_{z+} = i_x, \quad i_{z-} = -i_x \tag{2}$$

where R_x is the parasitic resistance at terminal x.

This paper adopts CMOS CCCII(±) proposed in [26]. The parasitic resistance R_x is

$$R_x = \frac{V_{xy}}{I_x} = \left(2\sqrt{2K_{eff} I_b}\right)^{-1} \tag{3}$$

where $K_{eff} = K_n K_p / (\sqrt{K_n} + \sqrt{K_p})^2$. Here, K_n, and K_p are transconductance coefficients of NMOS and PMOS transistors, respectively.

3. Proposed universal filter and its analysis

Proposed new current-mode current-controlled SIMO CCCII(±) based filter circuit is shown in Fig. 3. The filter contains one MO-CCCA element, two CCCIIs(±) and two grounded capacitors.

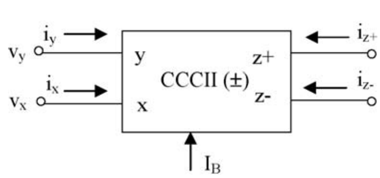

Fig. 2. Circuit symbol of CCCII(±).

Current transfer functions of the circuit are as follows:

$$\frac{I_{o1}}{I_{in}} = K \frac{1}{s^2\tau_1\tau_2 + s\tau_2 K + 1} \tag{4}$$

$$\frac{I_{o2}}{I_{in}} = K \frac{s\tau_2}{s^2\tau_1\tau_2 + s\tau_2 K + 1} \tag{5}$$

$$\frac{I_{o3}}{I_{in}} = K \frac{s^2\tau_1\tau_2}{s^2\tau_1\tau_2 + s\tau_2 K + 1} \tag{6}$$

$$\frac{I_{o4}}{I_{in}} = K \frac{s^2\tau_1\tau_2 + 1}{s^2\tau_1\tau_2 + s\tau_2 K + 1} \tag{7}$$

$$\frac{I_{o5}}{I_{in}} = K \frac{s^2\tau_1\tau_2 - s\tau_2 + 1}{s^2\tau_1\tau_2 + s\tau_2 K + 1} \tag{8}$$

In these equations, I_{o1}, I_{o2}, I_{o3}, I_{o4}, and I_{o5} are the LP, BP, HP, BS and AP current outputs, respectively. The quantities τ_1 and τ_2 are expressed as

$$\tau_1 = R_{x1}C_1, \quad \tau_2 = R_{x2}C_2 \tag{9}$$

Natural angular frequency (ω_0), and the quality factor (Q) of the circuit are

$$\omega_0 = \sqrt{\frac{1}{R_{x1}R_{x2}C_1C_2}}, \quad Q = \frac{I_{A1}}{I_{A2}}\sqrt{\frac{R_{x1}C_1}{R_{x2}C_2}} \tag{10}$$

where $R_{xi} = (2\sqrt{2K_{eff}I_{Bi}})^{-1}$ is the input resistance and I_{Bi} is the bias current of the ith CCCII(±) (i = 1, 2), respectively.

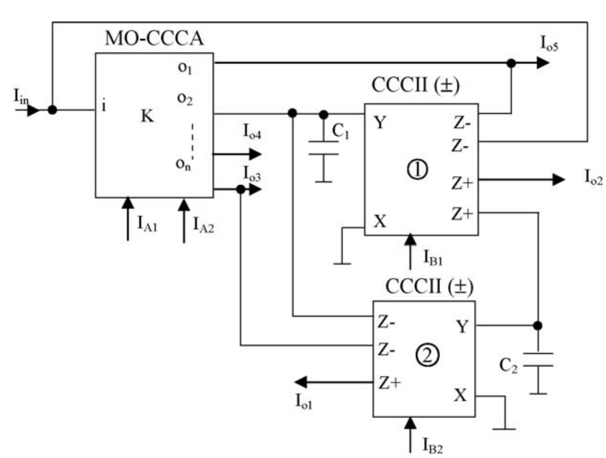

Fig. 3. Proposed current-mode current-controlled SIMO-type universal filter.