A New CCII Based Second-Order Current-Mode Universal Filter Using Only Grounded Passive Components

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***Abstract*— In this study, a new triple output second-generation current conveyor (TO-CCII) based second-order current-mode (CM) universal filter is proposed. The proposed universal filter can simultaneously realize low-pass, band-pass, high-pass and notch filter responses. Moreover, it can provide all-pass responses with interconnection of notch and band-pass currents. One of the main advantages of the proposed universal filter is to include only grounded passive components which are advantageous from integration point of view. It consists of a canonical number of capacitors, which is important for chip area. Also, it can provide high output impedance currents; accordingly, it can be easily connected with other CM structures. Frequency dependent non-ideal gain effects on the proposed filter performances are investigated. However, its input impedance is not low and a single resistive matching condition is required for the notch and all-pass responses. Simulation results based on 0.13 μm CMOS IBM technology parameters are given for the proposed universal filter through SPICE program. Power dissipation of the proposed universal filter is approximately found as 2 mW.**

***Keywords*— Second-order, current-mode, universal filter, CCII, CMOS.**

I. INTRODUCTION

Analog filters [1-11] find wide application areas such as signal processing, control engineering, telecommunications and etc. They can be categorized in integrated circuits (ICs) such as voltage-mode (VM), current-mode (CM), transadmittance-mode, transimpedance-mode and microwave filters. CM filters have several advantages on their VM ones for example the use of a smaller number of active elements, good linearity, wide bandwidth and great dynamic range [12]. Second-generation current conveyor (CCII) was previously presented in [13]. As a current-mode (CM) active device, CCII has better linearity, wider band-width, greater dynamic range, etc. when compared to its voltage-mode counterparts such as operational amplifiers [14].

Some CM universal filter configurations [1-3, 5, 7, 9, 10] have a capacitor connected to X terminal of the CCII; their high frequency performances are limited. The universal filter in [4] uses four DO-CCIIs. The filter configurations in [6] and [8] have three inputs single output so they do not simultaneously provide low-pass (LP), band-pass (BP), high-pass (HP) and notch filter (NF) responses. Also, a CM universal filter configuration in [11], which has one input and two output terminals, employs a differential voltage current conveyor (DVCC) and a triple output CCII (TO-CCII).

In this paper, a new TO-CCII based second-order CM universal filter is proposed. The proposed universal filter can simultaneously provide LP, BP, HP and NF responses. Furthermore, it can realize all-pass (AP) responses with interconnection of notch and band-pass currents. One of the main advantages of the proposed universal filter is to use only grounded passive elements which are advantageous from integration point of view. It is composed of a minimum number of capacitors, which is important for chip area. In addition, it can realize high output impedance currents; thus, it can be easily connected with other CM topologies. No capacitor is connected to X terminal of the TO-CCIIs; thus, the proposed universal filter can be operated at high frequencies [15]. Frequency dependent non-ideal gain effects on the proposed filter performances are investigated. Nevertheless, its input impedance is not low and a single resistive matching constraint is required for the notch and all-pass responses. Simulation results based on 0.13 μm CMOS IBM technology parameters [16] are given for the proposed universal filter through SPICE program. Power consumption of the proposed universal filter is nearly computed as 2 mW through SPICE simulation program.

II. THE PROPOSED UNIVERSAL FILTER

TO-CCII is an active element with five terminals. The electrical symbol of the TO-CCII which is indicated in Fig. 1 is expressed by the following matrix equation:

$$\begin{bmatrix} V_X \\ I_Y \\ I_{Z+} \\ I_{Z1-} \\ I_{Z2-} \end{bmatrix} = \begin{bmatrix} \beta & 0 \\ 0 & 0 \\ 0 & \alpha \\ 0 & -\gamma \\ 0 & -\eta \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \end{bmatrix} \quad (1)$$

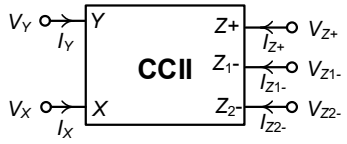

Fig. 1 The electrical symbol of the TO-CCII

Here, β is frequency dependent non-ideal voltage gain which is ideally equal to unity. α, γ and η are frequency dependent non-ideal current gains which are ideally equal to unity.

The proposed second-order CM universal filter is demonstrated in Fig. 2. Ideally, the proposed filter with $R_1 = R_2$ can respectively provide the following LP, BP, HP, NF and AP transfer functions (TFs):

$$\frac{I_{LP}}{I_{in}} = \frac{1}{D(s)} \tag{2.a}$$

$$\frac{I_{BP}}{I_{in}} = \frac{sC_2R_4}{D(s)} \tag{2.b}$$

$$\frac{I_{HP}}{I_{in}} = \frac{s^2C_1C_2R_3R_4}{D(s)} \tag{2.c}$$

$$\frac{I_{NF}}{I_{in}} = -\frac{s^2C_1C_2R_3R_4+1}{D(s)} \tag{2.d}$$

$$\frac{I_{AP}}{I_{in}} = -\frac{s^2C_1C_2R_3R_4-sC_2R_4+1}{D(s)} \tag{2.e}$$

where $D(s)$ is evaluated as

$$D(s) = s^2C_1C_2R_3R_4 + sC_2R_4 + 1 \tag{3}$$

From equation (3), angular resonance frequency (ω_o) and quality factor (Q) are respectively calculated as

$$\omega_o = \sqrt{\frac{1}{C_1C_2R_3R_4}} \tag{4.a}$$

$$Q = \sqrt{\frac{C_1R_3}{C_2R_4}} \tag{4.b}$$

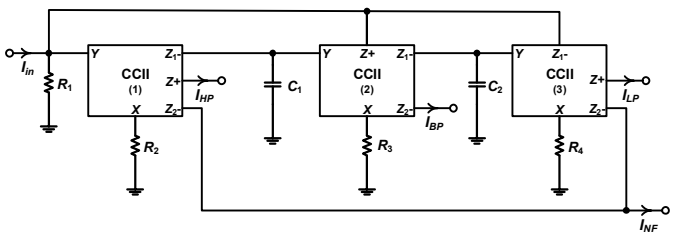

Fig. 2 The proposed second-order current-mode universal filter employing only grounded passive components

If frequency dependent non-ideal gains are considered, the proposed filter without taking into account any passive element matching conditions can respectively realize the following LP, BP, HP, NF and AP TFs:

$$\frac{I_{LP}}{I_{in}} = \frac{R_1\alpha_3\beta_1\beta_2\beta_3\gamma_1\gamma_2}{D_n(s)} \tag{5.a}$$

$$\frac{I_{BP}}{I_{in}} = \frac{sC_2R_1R_4\beta_1\beta_2\gamma_1\eta_2}{D_n(s)} \tag{5.b}$$

$$\frac{I_{HP}}{I_{in}} = \frac{s^2C_1C_2R_1R_3R_4\alpha_1\beta_1}{D_n(s)} \tag{5.c}$$

$$\frac{I_{NF}}{I_{in}} = -\frac{R_1\beta_1(s^2C_1C_2R_3R_4\eta_1+\beta_2\beta_3\gamma_1\gamma_2\eta_3)}{D_n(s)} \tag{5.d}$$

$$\frac{I_{AP}}{I_{in}} = -\frac{R_1\beta_1(s^2C_1C_2R_3R_4\eta_1-sC_2R_4\beta_2\gamma_1\eta_2+\beta_2\beta_3\gamma_1\gamma_2\eta_3)}{D_n(s)} \tag{5.e}$$

where $D_n(s)$ is evaluated as

$$D_n(s) = s^2C_1C_2R_2R_3R_4 + sC_2R_1R_4\alpha_2\beta_1\beta_2\gamma_1 + R_1\beta_1\beta_2\beta_3\gamma_1\gamma_2\gamma_3 \tag{6}$$

From equation (6), ω_{on} and Q_n are respectively computed as

$$\omega_{on} = \sqrt{\frac{R_1\beta_1\beta_2\beta_3\gamma_1\gamma_2\gamma_3}{C_1C_2R_2R_3R_4}} \tag{7.a}$$

$$Q_n = \frac{1}{\alpha_2}\sqrt{\frac{C_1R_2R_3\beta_3\gamma_2\gamma_3}{C_2R_1R_4\beta_1\beta_2\gamma_1}} \tag{7.b}$$

III. Simulation Results

Simulations of the proposed universal filter in Fig. 2 are performed by SPICE program in which 0.13 μm IBM CMOS technology parameters [16] are used. The internal structure of the TO-CCII derived from one in [17] is given in Fig. 3. The symmetrical DC power supply voltages are chosen as ±0.75 V. Also, bias voltage V_B in Fig. 3 is chosen as 0.37 V. Dimensions of the MOS transistors of the internal structure in Fig. 3 are given in Table 1.

Passive components of the proposed universal filter in Fig. 2, $R_1 = R_2 = R_3 = R_4 = 1$ kΩ (the effect of parasitic impedance, R_X is included), and $C_1 = C_2 = 100$ pF resulting in $f_o \cong 1.59$ MHz and $Q = 1$ are chosen in all the simulations. Therefore, ideal and simulated low-pass, band-pass, high-pass and notch TFs are shown in Fig. 4.

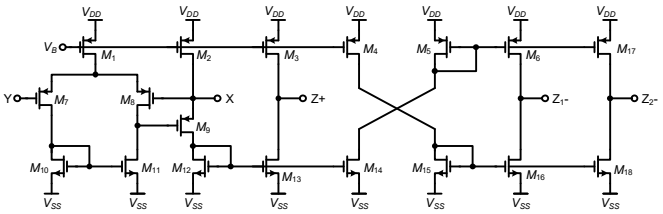

Fig. 3 Internal structure of the TO-CCII derived from one in [17]

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Ideal and simulated gain and phase responses of the all-pass filter are demonstrated in Fig. 5. Time domain responses for the all-pass filter are depicted in Fig. 6 where a sinusoidal current input signal with 50 μA peak at resonance frequency is applied. Total harmonic distortion (THD) variations for the all-pass filter with respect to applied peak input current signals at resonance frequency are given in Fig. 7 in which a 1 kΩ resistor is connected to the output. Moreover, input and corresponding output noises for the all-pass filter versus frequency are demonstrated in Fig. 8 where a 1 kΩ resistor is connected to the output.

TABLE I
ASPECT RATIOS OF THE MOS TRANSISTORS

Transistor Type	Aspect Ratio (W / L)
PMOS transistors, M_1-M_8, M_{17}	41.6 μm / 0.52 μm
PMOS transistor, M_9	83.2 μm / 0.52 μm
NMOS transistors, M_{10}-M_{16}, M_{18}	13.0 μm / 0.52 μm

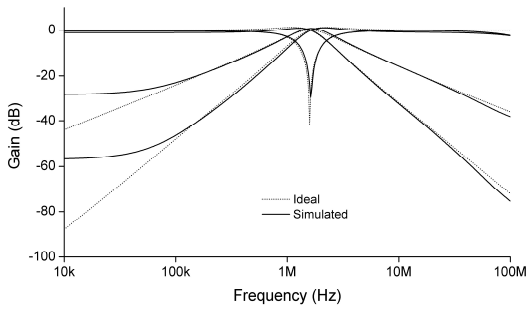

Fig. 4 Ideal and simulated low-pass, band-pass, high-pass and notch transfer functions

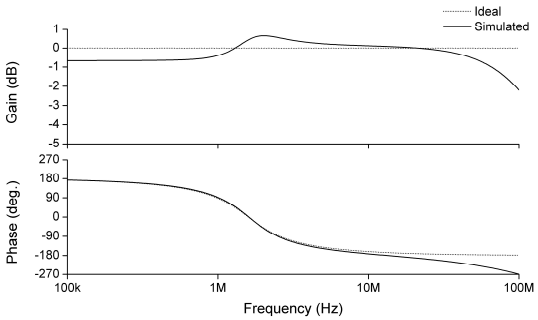

Fig. 5 Ideal and simulated gain and phase responses of the all-pass filter

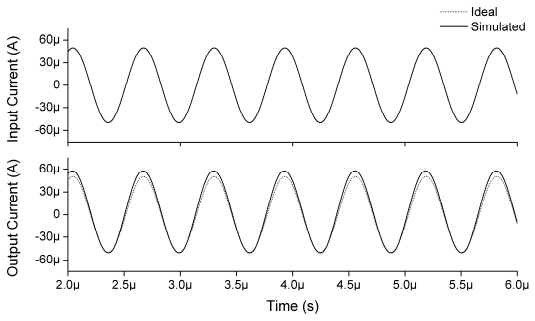

Fig. 6 Time domain responses for the all-pass filter

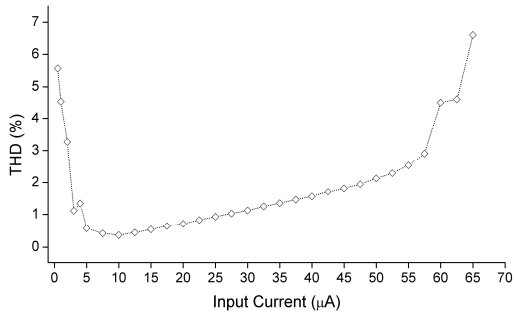

Fig. 7 Total harmonic distortion variations against applied peak input current signals

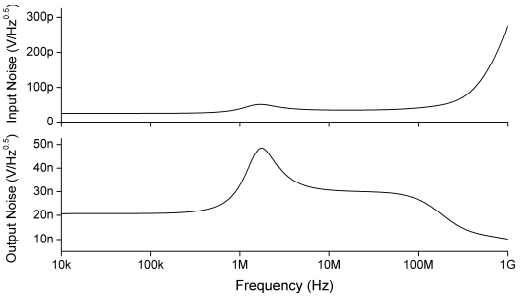

Fig. 8 Input and corresponding output noises for the all-pass filter against frequency

IV. CONCLUSION

In this work, a new TO-CCII based second-order CM universal filter employing only grounded passive elements which are advantageous from integrated circuit point of view is proposed. The proposed biquadratic universal filter can simultaneously provide low-pass, band-pass, high-pass and notch filter responses. It can also realize all-pass responses with interconnection of notch and band-pass currents. Moreover, it can realize high output impedance currents; thus, it can be easily connected with other CM topologies. No capacitor is connected to X terminal of the TO-CCIIs. Therefore, the proposed universal filter can be operated at high frequencies. Nonetheless, its input impedance is not low and a single resistive matching condition is needed for the notch and all-pass responses. Simulation results based on 0.13 μm CMOS IBM technology parameters confirm the theory well.

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