High-Order Current-Mode and Transimpedance-Mode Universal Filters with Multiple-Inputs and Two-Outputs Using MOCCIIs

Jiun-Wei HORNG

Dept. of Electronic Engineering, Chung Yuan Christian University, Chung-Li, 32023, Taiwan

jwhorng@cycu.edu.tw

Abstract. *A high-order current-mode and transimpedance-mode universal filter with multiple-inputs and two-outputs based on multiple output second-generation current conveyors (MOCCIIs) is introduced. By choosing the input current terminals appropriately, the current-mode and transimpedance-mode lowpass, bandpass, highpass, notch or allpass filters can be obtained without component matching conditions. The proposed nth order universal filter requires (n+1) MOCCIIs, (n+1) resistors and n grounded capacitors. As examples, the first-order, biquadratic and third-order universal filters are given and compared with previous published works.*

Keywords

Current conveyor, high-order filter, current-mode, transimpedance-mode.

1. Introduction

The applications and advantages in the realization of various active transfer functions using current conveyors have received considerable attention. This is attributed to their high signal bandwidths, greater linearity and larger dynamic range than Op Amp based ones [1].

Recently, several synthesis methods for realizing high-order voltage-mode filter using second-generation current conveyors (CCIIs) or current feedback amplifiers (CFAs) were presented. Two synthesis methods for realizing high-order voltage-mode lowpass filters were discussed in Hwang et al. [2] and Acar [3]. The synthesis methods for realizing general high-order voltage-mode filters were discussed in Anday and Gunes [4], Gunes and Anday [5], Acar and Ozoguz [6] and Gunes and Anday [7]. Note that [7] uses AD844 type CFAs in the design of high-order voltage-mode filter. The AD844 type CFA is equivalent to a plus-type CCII with a voltage follower [8].

On the other hand, some synthesis methods for realizing high-order current-mode filters using CCIIs were presented in Nandi [9], [10], Gunes and Anday [11] Wu and El-Masry [12] and Hwang et al. [13]. However, [9]-[10] only discussed third-order current-mode filters and all these methods ([9]-[13]) only synthesis lowpass transfer functions.

In this paper, a high-order current-mode and transimpedance-mode universal filter with multiple-inputs and two-outputs based on multiple output second-generation current conveyors (MOCCIIs) is introduced. By choosing the input current terminals appropriately, the current-mode and transimpedance-mode lowpass, bandpass, highpass, notch or allpass filters can be obtained without component matching conditions. The proposed circuit employs only grounded capacitors. The use of only grounded capacitors is ideal for IC implementation [14]. With respect to the previous current-mode high-order filters in [9]-[13], bandpass, highpass, notch and allpass can be obtained from the proposed circuit structure. Moreover, the transimpedance-mode filters can also be simultaneously obtained from the proposed circuit.

2. Proposed Circuits

Using standard notation, the port relations of a MOCCII can be characterized by $v_x = v_y$, $i_{zk} = \pm i_x$ and $i_y = 0$. The proposed high-order current-mode and transimpedance-mode universal filter is shown in Fig. 1. The output voltage, V_{out}, and output current, I_{out}, can be expressed as

$$V_{out} = \frac{\dfrac{s^n(I_n - I_n')}{G_n} + \sum_{i=1}^{n-1} \dfrac{s^i a_i (I_i - I_i')}{G_n} + [\prod_{l=0}^{n-1}(\dfrac{G_l}{C_{l+1}})]\dfrac{I_0}{G_n}}{s^n + \sum_{i=0}^{n-1} s^i a_i}, \quad (1)$$

$$I_{out} = \frac{s^n(I_n - I_n') + \sum_{i=1}^{n-1} s^i a_i (I_i - I_i') + [\prod_{l=0}^{n-1}(\dfrac{G_l}{C_{l+1}})]I_0}{s^n + \sum_{i=0}^{n-1} s^i a_i} \quad (2)$$

where
$$a_i = \prod_{l=i}^{n-1}(\frac{G_l}{C_{l+1}}). \quad (3)$$

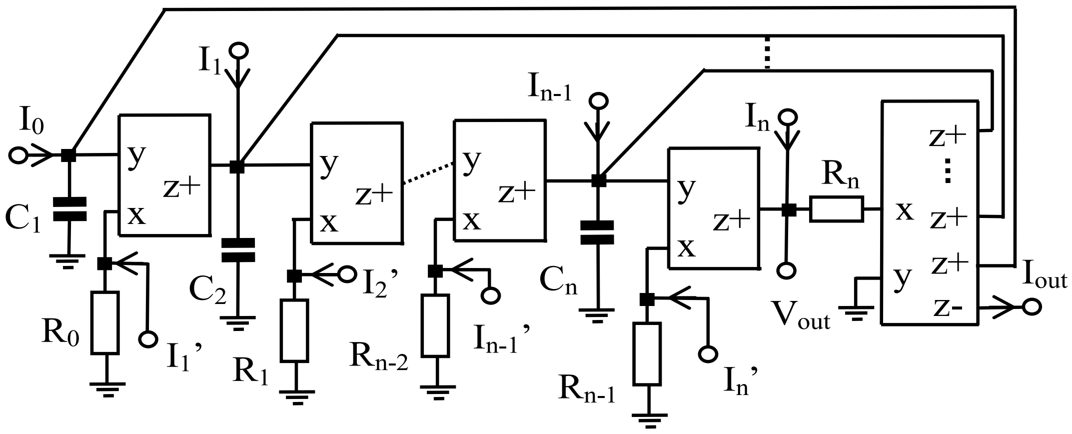

Fig. 1. The proposed CCIIs based high-order universal filter.

(a) If $I_1 = I_2 = I_3 = \ldots = I_n = I_1' = I_2' = I_3' = \ldots = I_n' = 0$ and $I_{\text{in}} = I_0$, then the non-inverted transimpedance-mode and current-mode lowpass filters can be obtained.

(b) If n is even, then $I_{\text{in}} = I_{(n/2)}$ or $I_{(n/2)}'$, whilst all the other input currents are zero. If n is odd, then $I_{\text{in}} = I_{[(n/2)-(1/2)]}$, $I_{[(n/2)+(1/2)]}$, $I_{[(n/2)-(1/2)]}'$ or $I_{[(n/2)+(1/2)]}'$, whilst all the other input currents are zero. The non-inverted or inverted transimpedance-mode and current-mode bandpass filters can be obtained.

(c) If $I_0 = I_1 = I_2 = \ldots = I_{n-1} = I_1' = I_2' = I_3' = \ldots = I_{n-1}' = 0$ and $I_{\text{in}} = I_n$ or I_n', then the non-inverted or inverted transimpedance-mode and current-mode highpass filters can be obtained.

(d) If $I_1 = I_2 = I_3 = \ldots = I_{n-1} = I_1' = I_2' = I_3' = \ldots = I_n' = 0$ and $I_{\text{in}} = I_0 = I_n$, then the transimpedance-mode and current-mode notch filters can be obtained.

(e) If n is even, then $I_1 = I_3 = I_5 = \ldots = I_{n-1} = I_2' = I_4' = I_6' = \ldots = I_n' = 0$ and $I_{\text{in}} = I_0 = I_1' = I_2 = I_3' = \ldots = I_n$. If n is odd, then $I_1 = I_3 = I_5 = \ldots = I_n = I_2' = I_4' = I_6' = \ldots = I_{n-1}' = 0$ and $I_{\text{in}} = I_0 = I_1' = I_2 = I_3' = \ldots = I_n'$. The transimpedance-mode and current-mode allpass filters can be obtained.

The proposed nth order universal filter requires $(n+1)$ MOCCIIs, $(n+1)$ resistors and n grounded capacitors. The current-mode and transimpedance-mode filters can be obtained from the circuit configuration simultaneously. All standard filter types can be obtained by choosing the input current terminals appropriately without component matching conditions. The I_{out} output terminal has the advantage of high output impedance. The high output impedance makes the output current, I_{out}, easy to be connected to next stage without any buffer. Note that the notch and allpass filters require additional copies of input current signals at the realizations. This solution requires an additional current follower to duplicate the input current signal. Moreover, since the output impedance of V_{out} terminal is not small, voltage follower is needed while cascaded the voltage output signal to the next stage.

3. The First-Order, Biquadratic and Third-Order Transfer Functions

Consider the first-order filter based on the high-order filter in Fig. 1. If $n = 1$, the first-order circuit is given in Fig. 2. The output voltage and current are given by

$$V_{out} = \frac{s\dfrac{I_1 - I_1'}{G_1} + \dfrac{G_0 I_0}{C_1 G_1}}{s + \dfrac{G_0}{C_1}}, \tag{4}$$

$$I_{out} = \frac{s(I_1 - I_1') + \dfrac{G_0 I_0}{C_1}}{s + \dfrac{G_0}{C_1}}. \tag{5}$$

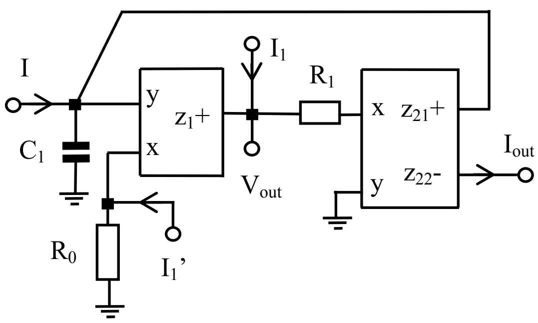

Fig. 2. The first-order filter based on the high-order filter in Fig. 1.

Inspection of (4) and (5) shows that various inverted or non-inverted transimpedance-mode and current-mode first-order filters can be realized. For example:

(a) If $I_1 = I_1' = 0$ and $I_{in} = I_0$, then the non-inverted transimpedance-mode and current-mode first-order lowpass filters can be obtained.

(b) If $I_0 = 0$ and $I_{in} = I_1$ or I_1', then the non-inverted or inverted transimpedance-mode and current-mode first-order highpass filters can be obtained.

(c) If $I_1 = 0$ and $I_{in} = I_0 = I_1'$, then the transimpedance-mode and current-mode first-order allpass filters can be obtained.

To evaluate high frequency performance of MOCCII, the frequency dependency of the current and voltage transfer ratios should be taken into account. The relationship of the terminal voltages and currents can be rewritten as: $i_y = 0$, $v_x = \beta_j(s)\ v_y$, $i_{zk} = \pm\alpha_k(s)\ i_x$, where $\alpha_k(s)$ and $\beta_j(s)$ represent the frequency transfers of the internal current and voltage followers of the MOCCII, respectively. They can be approximated by the following first order lowpass functions [15].

$$\alpha_k(s) = \frac{\alpha_k}{1 + s/\omega_{\alpha k}}, \tag{6}$$

$$\beta_j(s) = \frac{\beta_j}{1 + s/\omega_{\beta j}} \tag{7}$$

where α_k and β_j are the values of the current and voltage transfer ratios at low frequencies (ideally equal to unity) and $\omega_{\alpha k}$ and $\omega_{\beta j}$ represent their corresponding poles [15]. The non-ideal denominator of Fig. 2 becomes

$$D(s) = s + \frac{G_0\alpha_1\alpha_{21}\beta_1}{C_1(1 + s/\omega_{\alpha 1})(1 + s/\omega_{\alpha 21})(1 + s/\omega_{\beta 1})}. \tag{8}$$

The non-ideal effect leads to several higher-order terms from equation (8). If the operational 3 dB frequency is much less than the corner frequencies of $\alpha_k(s)$ and $\beta_j(s)$, all $\alpha_k(s)$ and $\beta_j(s)$ can be considered as real values slightly less than unity. Equation (8) is approximately equal to

$$D(s) = s + \frac{G_0\alpha_1\alpha_{21}\beta_1}{C_1}. \tag{9}$$

The cutoff frequency ω_c is obtained by

$$\omega_c = \frac{\alpha_1\alpha_{21}\beta_1}{C_1 R_0}. \tag{10}$$

The active and passive sensitivities are low and obtained as

$$S^{\omega_c}_{\alpha_1,\alpha_{21},\beta_1} = -S^{\omega_o}_{C_1,R_0} = 1$$

A non-ideal MOCCII model with parasitic impedances is shown in Fig. 3 [15]. It is shown that the real MOCCII has parasitic resistors (R_y and R_z, ideally equal to infinity) and capacitors (C_y and C_z, ideally equal to zero) from the y and z terminals to the ground, and also, a series resistor at the input terminal x (R_x, ideally equal to zero). Taking into account the non-ideal MOCCIIs and assuming the circuit is working at frequencies much lower than the corner frequencies of $\alpha_k(s)$ and $\beta_j(s)$, namely, $\alpha_k(s) \cong \alpha_k$ and $\beta_j(s) \cong \beta_j$. Use the non-ideal MOCCII model, the output current of Fig. 2 becomes

$$I_{out} \cong \frac{(sC'_1G'_1 + G'_1G_3)\alpha_{22}I_1 - (sC'_1G'_1 + G'_1G_3)\alpha_1\alpha_{22}I'_1 + G_0G'_1\alpha_1\alpha_{22}\beta_1 I_0}{s^2 b_2 + s b_1 + b_0} \tag{11}$$

where $b_2 = C'_1 C_{z1}(1 + G_0/G_{x1}) \cong C'_1 C_{z1}$,

$b_1 = C'_1 G'_1 + C'_1 G_{z1} + C_{z1}G_3 + (C'_1 G'_1 + C'_1 G_{z1} + C_{z1}G_3)G_0/G_{x1} \cong C'_1 G'_1$

$b_0 = G_0 G'_1 \alpha_1\alpha_{21}\beta_1 + G'_1 G_3 + G_{z1}G_3 + (G'_1 + G_{z1})G_0 G_3/G_{x1} \cong G_0 G'_1 \alpha_1\alpha_{21}\beta_1$

$R'_1 = R_1 + R_{x2}$, $G_3 = G_{y1} + G_{z21}$, $C'_1 = C_1 + C_{y1} + C_{z21}$.

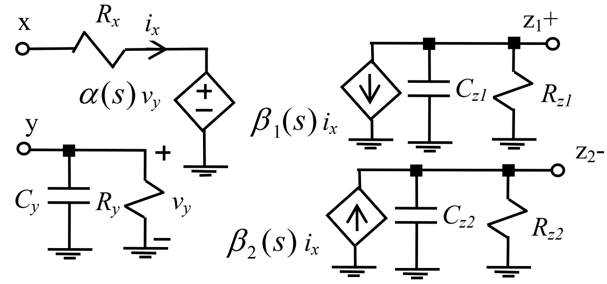

Fig. 3. The non-ideal MOCCII model [15].

In equations (11), undesirable factors are yielded by the non-idealities of the MOCCIIs. The effect of capacitance C_{z1} becomes non-negligible at very high frequencies; the conductance G_3 becomes non-negligible at very low frequencies. To minimize the effects of the MOCCIIs' non-idealities, the operation angular frequency should restricted to the following conditions

$$\frac{1}{C'_1 R_3} << \omega << \frac{b_1}{b_2}. \tag{12}$$

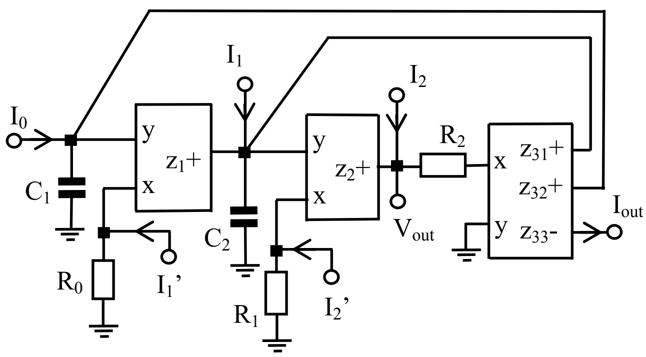

Fig. 4. The second-order filter based on the high-order filter in Fig. 1.

If $n = 2$, the biquadratic filter based on the high-order filter in Fig. 1 can be obtained in Fig. 4. The output voltage and current are given by

$$V_{out} = \frac{s^2 \frac{I_2 - I_2'}{G_2} + s\frac{G_1(I_1 - I_1')}{C_2 G_2} + \frac{G_0 G_1 I_0}{C_1 C_2 G_2}}{s^2 + \frac{sG_1}{C_2} + \frac{G_0 G_1}{C_1 C_2}}, \tag{13}$$

$$I_{out} = \frac{s^2 (I_2 - I_2') + s\frac{G_1(I_1 - I_1')}{C_2} + \frac{G_0 G_1 I_0}{C_1 C_2}}{s^2 + \frac{sG_1}{C_2} + \frac{G_0 G_1}{C_1 C_2}} \tag{14}$$

Inspection of (13) and (14) shows that various inverted or non-inverted transimpedance-mode and current-mode biquadratic filters can be realized. For example:

(a) If I_1 = I$_1$' = I_2 = I_2' = 0 and $I_{in} = I_0$, then the non-inverted transimpedance-mode and current-mode biquadratic lowpass filters can be obtained.

(b) If $I_0 = I_2 = I_2' = 0$ and $I_{in} = I_1$ or I_1', then the non-inverted or inverted transimpedance-mode and current-mode biquadratic bandpass filters can be obtained.

(c) If $I_0 = I_1 = I_1' = 0$ and $I_{in} = I_2$ or I_2', then the non-inverted or inverted transimpedance-mode and current-mode biquadratic highpass filters can be obtained.

(d) If $I_1 = I_1' = I_2' = 0$ and $I_{in} = I_0 = I_2$, then the transimpedance-mode and current-mode biquadratic notch filters can be obtained.

(e) If $I_1 = I_2' = 0$ and $I_{in} = I_0 = I_1' = I_2$, then the transimpedance-mode and current-mode biquadratic allpass filters can be obtained.

Taking the non-ideal current and voltage transfer ratios of the MOCCIIs into account and assuming the operational 3 dB frequency is much less than the corner frequencies of $\alpha_k(s)$ and $\beta_j(s)$, the denominator of the transfer functions in Fig. 3 becomes

$$D(s) = s^2 + s\frac{G_1 \alpha_2 \alpha_{31} \beta_2}{C_2} + \frac{G_0 G_1 \alpha_1 \alpha_2 \alpha_{32} \beta_1 \beta_2}{C_1 C_2}. \tag{15}$$

The resonance angular frequency ω_o and quality factor Q are obtained by

$$\omega_o = \sqrt{\frac{\alpha_1 \alpha_2 \alpha_{32} \beta_1 \beta_2}{C_1 C_2 R_0 R_1}}, \tag{16}$$

$$Q = \frac{1}{\alpha_{31}} \sqrt{\frac{C_2 R_1 \alpha_1 \alpha_{32} \beta_1}{C_1 R_0 \alpha_2 \beta_2}}. \tag{17}$$

The active and passive sensitivities are low and obtained as

$$S^{\omega_o}_{\alpha_1,\alpha_2,\alpha_{32},\beta_1,\beta_2} = -S^{\omega_o}_{C_1,C_2,R_0,R_1} = \frac{1}{2}, \quad S^{Q}_{\alpha_{31}} = -1,$$

$$S^{Q}_{C_2,R_1,\alpha_1,\alpha_{32},\beta_1} = -S^{Q}_{C_1,R_0,\alpha_2,\beta_2} = \frac{1}{2}.$$

Recently, several current-mode universal biquadratic filters with three-inputs and single-output using current conveyors (CCs) were proposed. However, the circuits in Chang and Chen [16], Chang et al. [17], Abuelma'atti and Tasadduq [18], Chang [19] Abuelma'atti et al. [20] require at least four CCs. The current-mode universal biquad in Wang and Lee [21] with three-inputs and single-output requires three CCs, two grounded resistors and two grounded capacitors. However, a capacitor of this circuit is connected to the x port of a CCII. When the CCII is implemented from a mixed translinear loop composed of complementary bipolar transistor, it presents a non-negligible output parasitic resistance on the x port [22]. When the x port is connected to a capacitor, this parasitic resistance leads to conversion errors especially at high frequencies.

From the proposed high-order universal filter, a new current-mode and transimpedance-mode universal biquadratic filter with five-inputs and two-outputs is obtained in Fig. 4. The proposed circuit employs three MOCCIIs, three resistors and two grounded capacitors and can realize all the standard filter types without component matching conditions. With respect to the previous current-mode universal biquadratic filter in [16]-[20], the proposed circuit requires less active components. With respect to the current-mode biquad in [21], the x port of each CCII in Fig. 4 does not connect to a capacitor.

If $n = 3$, the third-order filter based on the high-order filter in Fig. 1 can be obtained in Fig. 5. The output voltage and current are given by

$$V_{out} = \frac{s^3 \frac{I_3 - I_3'}{G_3} + s^2 \frac{G_2(I_2 - I_2')}{C_3 G_3} + s\frac{G_1 G_2 (I_1 - I_1')}{C_2 C_3 G_3} + \frac{G_0 G_1 G_2 I_0}{C_1 C_2 C_3 G_3}}{s^3 + s^2 \frac{G_2}{C_3} + s\frac{G_1 G_2}{C_2 C_3} + \frac{G_0 G_1 G_2}{C_1 C_2 C_3}} \tag{18}$$

$$I_{out} = \frac{s^3 (I_3 - I_3') + s^2 \frac{G_2(I_2 - I_2')}{C_3} + s\frac{G_1 G_2 (I_1 - I_1')}{C_2 C_3} + \frac{G_0 G_1 G_2 I_0}{C_1 C_2 C_3}}{s^3 + s^2 \frac{G_2}{C_3} + s\frac{G_1 G_2}{C_2 C_3} + \frac{G_0 G_1 G_2}{C_1 C_2 C_3}} \tag{19}$$

Inspection of (18) and (19) shows that various inverted or non-inverted transimpedance-mode and current-mode third-order filters can be realized. For example:

(a) If $I_1 = I_1' = I_2 = I_2' = I_3 = I_3' = 0$ and $I_{in} = I_0$, then the non-inverted transimpedance-mode and current-mode third-order lowpass filters can be obtained.

(b) If $I_0 = I_3 = I_3' = 0$ and $I_{in} = I_1$ or I_1' or I_2 or I_2', then the non-inverted or inverted transimpedance-mode and current-mode third-order bandpass filters can be obtained.

(c) If $I_0 = I_1 = I_1' = I_2 = I_2' = 0$ and $I_{in} = I_3$ or I_3', then the non-inverted or inverted transimpedance-mode and current-mode third-order highpass filters can be obtained.

(d) If $I_1 = I_1' = I_2 = I_2' = I_3' = 0$ and $I_{in} = I_0 = I_3$, then the transimpedance-mode and current-mode third-order notch filters can be obtained.

(e) If $I_1 = I_2' = I_3 = 0$ and $I_{in} = I_0 = I_1' = I_2 = I_3'$, then the transimpedance-mode and current-mode third-order allpass filters can be obtained.

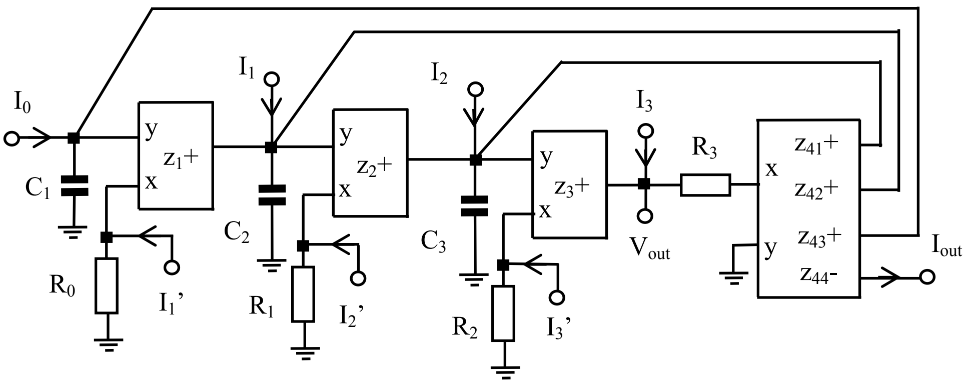

Fig. 5. The third-order filter based on the high-order filter in Fig. 1.

Taking the non-ideal current and voltage transfer ratios of the MOCCIIs into account and assuming the operational 3 dB frequency is much less than the corner frequencies of $\alpha_k(s)$ and $\beta_j(s)$, the denominator of the transfer functions in Fig. 5 becomes

$$D(s) = s^3 + s^2 \frac{G_2\alpha_3\alpha_{41}\beta_3}{C_3} + s\frac{G_1G_2\alpha_2\alpha_3\alpha_{42}\beta_2\beta_3}{C_2C_3} + \frac{G_0G_1G_2\alpha_1\alpha_2\alpha_3\alpha_{43}\beta_1\beta_2\beta_3}{C_1C_2C_3}$$
$$= s^3 + s^2 b_2 + s b_1 + b_0 . \quad (20)$$

The active and passive sensitivities of the polynomial coefficients are obtained as

$$S^{b_0}_{\alpha_1,\alpha_2,\alpha_3,\alpha_{43},\beta_1,\beta_2,\beta_3} = -S^{b_0}_{C_1,C_2,C_3,R_0,R_1,R_2} = 1,$$
$$S^{b_1}_{\alpha_2,\alpha_3,\alpha_{42},\beta_2,\beta_3} = -S^{b_0}_{C_2,C_3,R_1,R_2} = 1,$$
$$S^{b_0}_{\alpha_3,\alpha_{41},\beta_3} = -S^{b_0}_{C_3,R_2} = 1$$

Note that the influence of the parasitic elements on the frequency responses of the filters in Fig. 4 and Fig. 5 can be studies by similar procedures as in the first-order circuit.

4. Simulation Results

HSPICE simulations were carried out to demonstrate the feasibility of the proposed circuit in Fig. 5. The MOCCII was realized by the Surakampontorn et al.'s CMOS implementation [23] and is redrawn in Fig. 6. The aspect ratios of the MOS transistors are given in Tab. 1 using 0.18 μm, level 49, MOSFET from TSMC (Taiwan Semiconductor Manufacturing Company, Ltd.). Fig. 7 represents the frequency responses for the third-order current-mode Butterworth allpass filter, designed with $I_1 = I_2' = I_3 = 0$, $I_{in} = I_0 = I_1' = I_2 = I_3'$, $C_1 = C_2 = C_3$ =50 pF and $R_0 = 4\ \mathrm{k}\Omega$, $R_1 = 2\ \mathrm{k}\Omega$, $R_2 = 1\ \mathrm{k}\Omega$, $R_3 = 2\ \mathrm{k}\Omega$. The supply voltages are $V+$ = +1.25 V, $V-$ = -1.25 V and V_{b1} = -0.65 V.

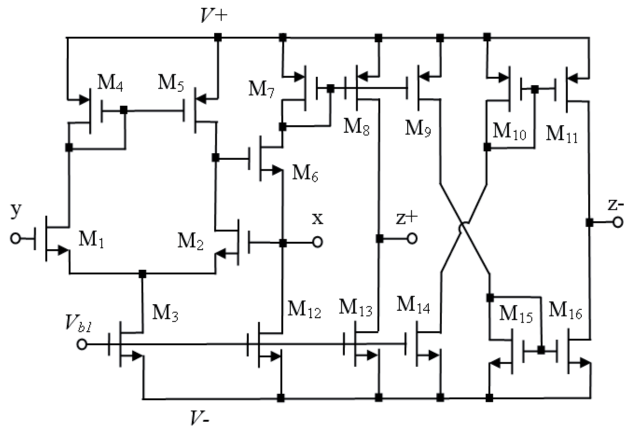

Fig. 6. The implementation of MOCCII [23].

MOS transistors	W/L
M1,M2	36/0. 9
M3	63/0. 9
M4,M5	54/0. 9
M6	72/0. 9
M7~M16,	18/0. 9

Tab. 1. Aspect ratios of the MOSs in Fig. 6.

5. Conclusions

In this paper, a high-order current-mode and transimpedance-mode universal filter with multiple-inputs and two-outputs based on MOCCIIs is introduced. By choosing the input current terminals appropriately, the current-mode and transimpedance-mode lowpass, bandpass, highpass, notch or allpass filters can be obtained without component matching conditions. The proposed nth order universal filter requires (n+1) MOCCIIs, (n+1) resistors and n grounded capacitors.

The first-order, biquadratic and third-order universal filters based on the proposed high-order filter are discussed and compared with previous published works.

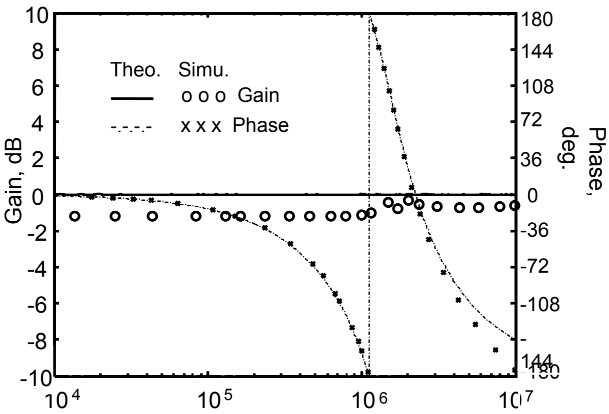

Fig. 7. Simulation frequency responses of the current-mode signal in Fig. 4 design with $I_1 = I_2' = I_3 = 0$, $I_{in} = I_0 = I_1' = I_2 = I_3'$, $C_1 = C_2 = C_3 = 50$ pF, $R_0 = 4$ kΩ, $R_1 = 2$ kΩ, $R_2 = 1$ kΩ and $R_3 = 2$ kΩ.

Acknowledgment

The National Science Council, Republic of China supported this work under grant number NSC 98-2221-E-033-054. The author would like to thank the reviewers for their constructive comments.

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About Author ...

Jiun-Wei HORNG was born in Tainan, Taiwan, Republic of China, in 1971. He received the B.S. degree in Electronic Engineering from Chung Yuan Christian

University, Chung-Li, in 1993, and the Ph.D. degree from National Taiwan University, Taipei, in 1997. From 1997 to 1999, he served as a Second-Lieutenant in China Army Force. From 1999 to 2000, he joined CHROMA ATE INC. where he worked in the area of video pattern generator technologies. From 2000, he was with the Department of Electronic Engineering, Chung Yuan Christian University, Chung-Li, Taiwan as an Assistant Professor. He is now an Associate Professor. His teaching and research interests are in the areas of Circuits and Systems, Analog and Digital Electronics, Active Filter Design and Current-Mode Signal Processing.

Prof. Ing. Jiří Svačina, CSc. – In Memoriam 1948 – 2009

On August 22, 2009, the distinguished Czech scientist and university teacher Professor Jiří Svačina passed away at the age of 61.

Professor Svačina was born in Nové Město na Moravě, Czech Republic in 1948. In 1966 he started studying electrical engineering at the Brno University of Technology. Having received his MSc degree in 1971, he joined the Department of Radio Electronics of his Alma Mater. In 1978 he received his Ph.D. degree, in 1983 became Associate Professor and in 1995 Professor in Electronics and Communication.

From 1990 to 2006, Professor Svačina was the Head of the Department of Radio Engineering, BUT. During these sixteen years the Department became a prestigious academic center connecting both education and research on up-to-date communication systems and technology. It was Professor Svačina's wide scientific overview and his sense for new really perspective topics what helped introducing courses on mobile communications, electromagnetic compatibility, computer aided design and modeling of electrical circuits and structures, etc.

Both scientific and educational interests of Professor Svačina were focused on microwave techniques and EMC. In these areas, he was a teacher and tutor of several hundreds of master's and doctoral students. Today's structure and content of bachelor's, master's and doctoral study programmes at the Faculty of Electrical Engineering and Communication, BUT, and especially the specialization in Electronics and Communication, are deeply influenced by Professor Svačina's view on education in electrical engineering.

Professor Svačina was a worldwide reputable scientist. The conclusions of his work on application of conformal mapping techniques to analytical modeling of planar transmission lines are generally well-known and often cited as Svačina's relations. Professor Svačina's pioneering contributions in the field of EMC are also highly regarded. Professor Svačina authored or co-authored more than 160 papers in journals and conference proceedings, three special books, and more than 100 textbooks and educational tools. More than 350 citations and quotations in international and/or national books and papers declare the acceptance of his work.

Professor Svačina was a Senior Member of IEEE, Fellow of IET (formerly IEE), Chartered Engineer (UK), and Committee member of the Czech-Slovak Radioengineering Society. He acted as a member of the Scientific Boards of the Faculty of Electrical Engineering and Communication, Brno University of Technology, and the Faculty of Electrical Engineering, University of West Bohemia in Pilsen. He was a review board member of the IEEE Transactions on Microwave Theory and Techniques (USA). Professor Svačina was awarded the Golden Medal of the Brno University of Technology, the Medal of the Technical University of Košice, and the Medal of the Slovak University of Technology in Bratislava.

Besides his excellent scientific and educational work, Professor Svačina did a great deal in publicity and popularization of research results, particularly in the field of wireless communication. In 1991 he organized the first national symposium Radioelektronika which during two decades became the respectable central-European international conference with proceedings indexed in worldwide databases. Eighteen years ago, Professor Svačina belonged to the founders of the Radioengineering journal, and with dedication was supporting its advancement as the member of its Editorial board, author of interesting papers, and a careful reviewer.

The Radio Engineering Society has lost its outstanding member, kind and helpful colleague. We will never forget.

Zbyněk Raida

Professor Zbyněk Raida
Editor-in-Chief
Head of the Dept. of Radio Electronics
Brno University of Technology