Universal Active Current Filter Using Single Second-Generation Current Controlled Conveyor

Chun-Ming Chang, Tzu-Hao Huang, Shu-Hui Tu, Chun-Li Hou, and Jiun-Wei Horng

Abstract**—**The realization of the second-order universal (low-pass, band-pass, high-pass, band-reject, and all-pass) active current filter using a single second-generation current controlled conveyor (CCCII), two grounded capacitors, and one resistor is proposed in this paper. Three input signals and the bias current of the active element determine the filtering type of the output signals. H-Spice simulations with 0.35μm process are used to validate the theoretical predictions of the filtering signal, very low sensitivities, and the correction for the deviation of the output signals using the result of the sensitivity.

Keywords**—**analog circuit design, active filters, continuous-time filters, low-pass filters, band-pass filters, high-pass filters, band-reject filters, all-pass filters

I. INTRODUCTION

In 1989, it was presented that circuits based on current amplifiers operate at higher signal bandwidths, greater linearity and larger dynamic range, than their voltage-based circuit counter-parts [1]. Current-mode circuits have emerged over the last two decades as an important class of analogue circuits. A universal (low-pass, band-pass, high-pass, band-reject, and all-pass) current-mode (current input and current output) biquad which employs seven second-generation current conveyors (CCIIs) in addition to two grounded capacitors and three grounded resistors was presented [2]. This biquad suffers from the following two disadvantages: requirement of one matching condition to realize an all-pass signal, and no orthogonal control of ω_0 and Q. The improved universal filter does not need any component matching conditions and enjoys the orthogonal control of ω_0 and Q although with the same structure complexity [3]. The condensed universal filter employs only five CCIIs in addition to two grounded capacitors and three grounded resistors [4] was proposed which enjoys the advantageous features: (i) no component matching, and (ii) the independent control of ω_0 and Q. The active component count of the universal filter was reduced to four but with the addition of one more grounded capacitor [5, 6], or using two floating capacitors and two floating resistors [7], or employing two grounded capacitors and two grounded resistors [8]. Then, a high output impedance multifunction filter employing three CCIIs, two grounded /floating capacitors and three grounded/ floating resistors was presented [9] which cannot enjoy low active sensitivities as high quality factor is necessary. And then, a versatile multi-input-multi-output universal biquad structure was supplied using three current conveyors, two grounded capacitors, and two grounded resistors, which still has the two advantages: no orthogonal control of ω_0 and Q and the limitation for high frequency operation [10]. The last universal filter was improved to be an insensitive one using three dual output current conveyors, two grounded capacitors, and three grounded resistors which, again, suffered from the limitation for high frequency operation [11]. The current-mode universal biquad without any matching conditions was condensed to the three-input and three-output structure with the minimum number of components, two plus type CCIIs, two grounded capacitors, and two grounded resistors [12]. The single-current conveyor-based universal biquads with low quality factor [13] or high quality factor [14] were proposed using three capacitors and four/five resistors. The five generic filter (low-pass, band-pass, high-pass, band-reject, and all-pass) signals are obtained by adjusting the values of one grounded capacitor and one grounded resistor appropriately. In this paper, a new current-mode universal biquad employing a single second-generation current controlled conveyor (CCCII) [15], whose internal resistance, denoted by R_x, at the input terminal X can be varied by tuning its bias current, two grounded capacitors, and one floating resistor is presented whose structure is much simpler than the previous two single-current conveyor-based universal biquads [13, 14]. Three input signals and the variable R_x determine the five different generic filtering signals obtained from the output terminal. H-Spice simulation using 0.35 μm process is used to validate the theoretical predictions of the new simple universal biquad including its five generic filtering

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output signals, very low individual component sensitivities, and the possibility of the refinement for deviation of the output signals.

II. UNVERSAL ACTIVE CURRENT BIQUAD

The universal active current filter with a single second-generation current controlled conveyor (CCCII), two grounded capacitors, and one resistor is shown in Fig 1.

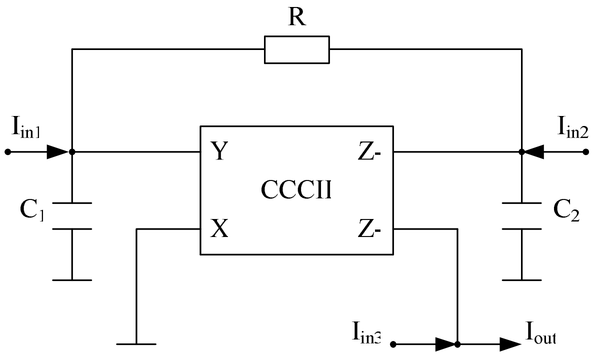

Fig. 1 Universal active current filter

A negative-type second-generation current controlled conveyor is characterized by the following matrix equation [15].

$$\begin{bmatrix} I_y \\ I_{z-} \\ V_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ -1 & 0 & 0 \\ R_x & 1 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \end{bmatrix} \qquad (1)$$

where R_x is the finite input resistance at the X-terminal of the CCCII and is given by $V_T/2I_o$, where V_T is the thermal voltage and I_o is the bias current of the CCCII. The dual output signals of the CCCII can be easily realized by using current mirror for duplicating the output signal of the Z- terminal. The new single-current conveyor-based universal active current filter is shown in Fig. 1 using one fewer capacitor and three/four fewer resistors than the previous ones [13, 14]. Circuit analysis for Fig. 1 gives the following output current

$$I_{out} = \frac{I_{in3}\begin{bmatrix} s^2C_1C_2 + \\ s\left(C_1+C_2\right)G + \\ G_xG \end{bmatrix} - I_{in2}\begin{pmatrix} sC_2G_x + \\ G_xG \end{pmatrix} - I_{in1}\left(G_xG\right)}{s^2C_1C_2 + s\left(C_1+C_2\right)G + G_xG} \qquad (2)$$

The specifications of (2) give the following five generic filtering signals.

(i) Low-pass: $I_{in3}=I_{in2}=0$, and $I_{in1}=I_{in}$;
(ii) Band-pass: $I_{in3}=0$, and $I_{in2}=-I_{in1}=I_{in}$ or $I_{in2}=-I_{in1}=-I_{in}$;
(iii) High-pass: $I_{in1}=0$, $I_{in3}=I_{in2}=I_{in}$, and $(C_1+C_2)G=C_2G_x$;
(iv) Band-reject: $I_{in3}=I_{in2}=-I_{in1}=I_{in}$, and $(C_1+C_2)G=C_2G_x$;
(v) All-pass: $I_{in3}=I_{in2}=-I_{in1}=I_{in}$, and $2(C_1+C_2)G=C_2G_x$.

Note that the finite input conductance G_x at the X-terminal of the CCCII is tunable. The non-ideal characteristic of the input-and-output relationship of a CCCII is shown in the following matrix equation.

$$\begin{bmatrix} I_y \\ I_{z-} \\ V_x \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ -\alpha_i & 0 & 0 \\ R_x & \alpha_v & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \end{bmatrix} \qquad (3)$$

Hence, the non-ideal output current signal is

$$I_{out} = \frac{I_{in3}\begin{bmatrix} s^2C_1C_2 + \\ s\left(C_1+C_2\right)G \\ +\alpha_v\alpha_iG_xG \end{bmatrix} - I_{in2}\begin{pmatrix} sC_2G_x \\ +G_xG \end{pmatrix} - I_{in1}\left(G_xG\right)}{s^2C_1C_2 + s\left(C_1+C_2\right)G + \alpha_v\alpha_iG_xG} \qquad (4)$$

The resonant angular frequency and the quality factor are

$$\omega_0 = \sqrt{\frac{\alpha_v\alpha_iG_xG}{C_1C_2}} \qquad (5) \qquad Q = \frac{\sqrt{\alpha_v\alpha_iC_1C_2G_x}}{\left(C_1+C_2\right)\sqrt{G}} \qquad (6)$$

both of which are deviated by the α_i and the α_v. The sensitivities of ω_o to the passive component, C_1, C_2, G_x, and G, and the active parameter, α_v, and α_i, are 0.5, a very low value, which is the same as the sensitivities of Q to G_x, G, α_v, and α_i. The sensitivities of Q to C_1 and C_2 are shown in (7) and (8), respectively.

$$S_{C_1}^{Q} = \frac{1}{2} - \frac{C_1}{C_1+C_2} \qquad (7) \qquad S_{C_2}^{Q} = \frac{1}{2} - \frac{C_2}{C_1+C_2} \qquad (8)$$

If we adopt equal capacitance design, i.e., $C_1=C_2$, the sensitivities of Q to C_1 and C_2 are theoretically equal to null. The universal active current filter shown in Fig. 1 is then insensitive.

III. H-SPICE SIMULATIONS

The filtering performance of the new universal active current filter shown in Fig. 1 is shown in Figs. 3 to 7 by the TSMC035 level-49 H-Spice simulation (using the CMOS implementation of the CCCII [15], shown in Fig. 2, with the supply voltages V_{DD}=1.65V, V_{SS}=-1.65V, and W/L=5μ/1μ and 10μ/1μ for NMOS and PMOS transistors, respectively), and with element values R_1=9kΩ, G_2=222.14μS (for all-pass, G_2=444.28μm), and C_1=50 pF, C_2= 50 pF for the 3dB frequency at 500kHz and C_1=25 pF, C_2=25 pF for the 3dB frequency at 1MHz, respectively. The simulation results of the 3dB frequency of the low-pass, band-pass, high-pass, band-reject, and all-pass output signals are 544.6kHz (error 8.91%) and 1.0924MHz (error 9.24%); 524.8kHz (error 4.96%) and 1.0471MHz (error 4.71%); 498.6kHz (error -0.28%) and 0.9855MHz (error -1.45%); 524.8kHz (error 4.96%) and 1.0471MHz (error 4.71%); And

716.1kHz (error 43.23%) and 1.4372MHz (error 43.72%), respective- ly. As we increase (resp. Decrease) the capacitance value, the resonant frequency is lower (resp. higher). The low-pass, band-pass, high-pass, band-reject, and all-pass responses are shown in Figs. 8 to 12 with the frequency range from 10Hz to 302MHz (low-pass), 10Hz to 110MHz (band-pass), 10Hz to 66MHz (high-pass), 10Hz to 77.6MHz (band-reject), and 10Hz to 237MHz (all-pass). The higher the operation frequency, the larger the distortion (such as the higher the peak) due to the parasitic effect.

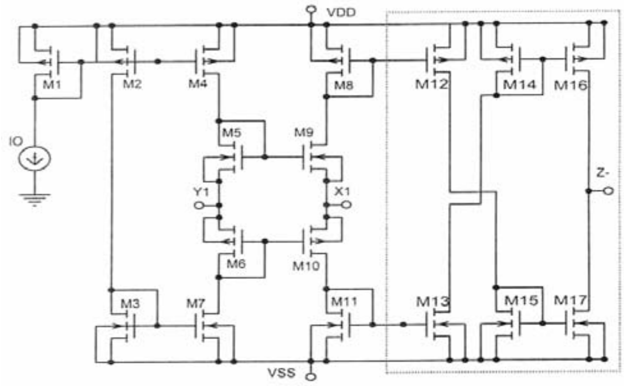

Fig. 2 CMOS implementation of the CCCII-

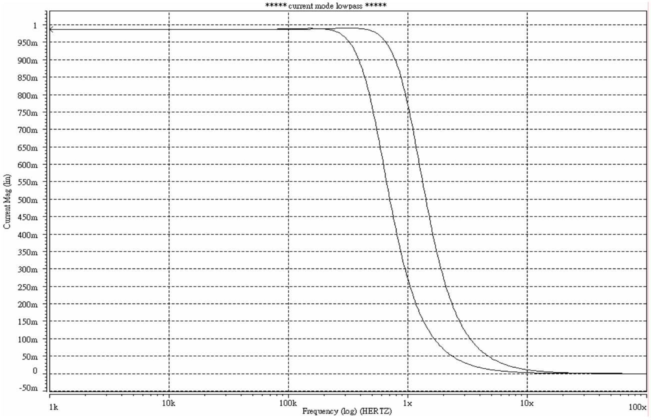

Fig. 3 Low-pass simulations at 500kHz and 1MHz

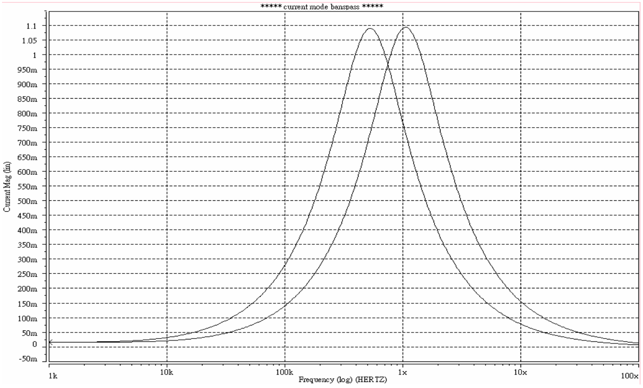

Fig. 4 Band-pass simulations at 500kHz and 1MHz

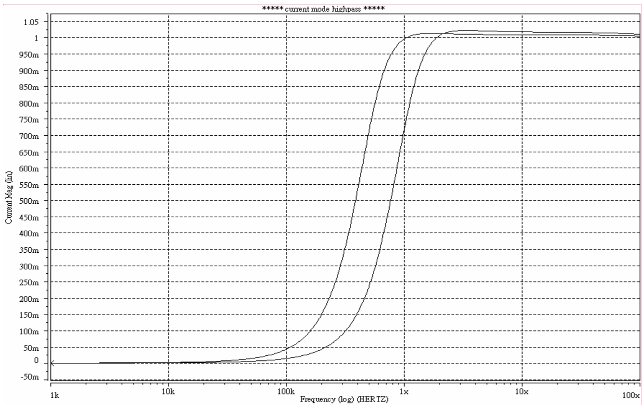

Fig. 5. High-pass simulations at 500kHz and 1MHz

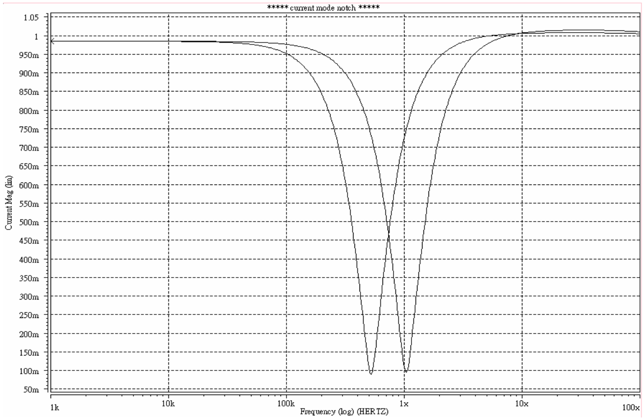

Fig. 6 Band-reject simulations at 500kHz and 1MHz

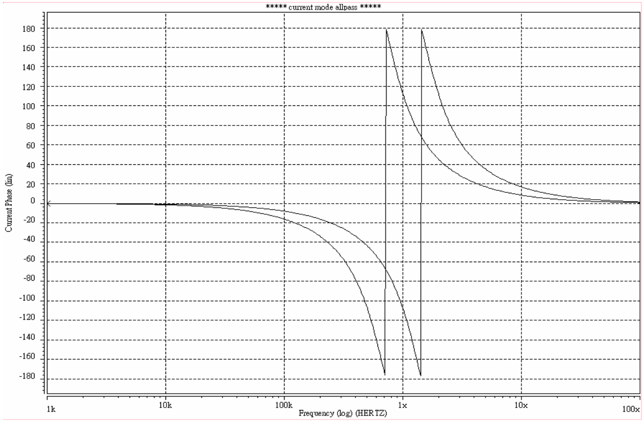

Fig. 7 All-pass simulations at 500kHz and 1MHz

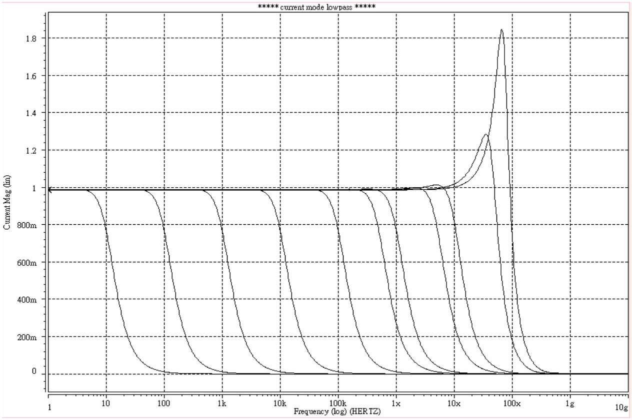

Fig. 8 Low-pass responses from 10Hz to 302MHz

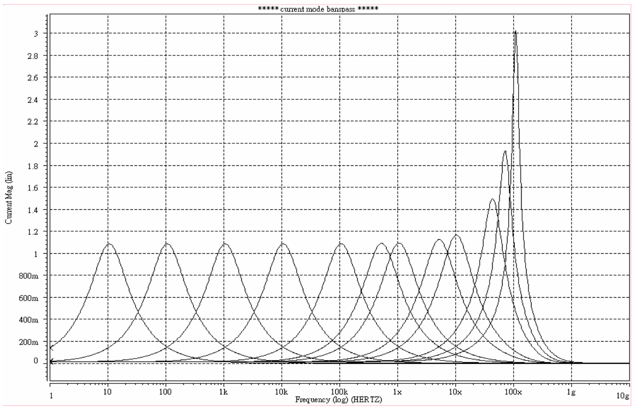

Fig. 9 Band-pass responses from 10Hz to 110MHz.

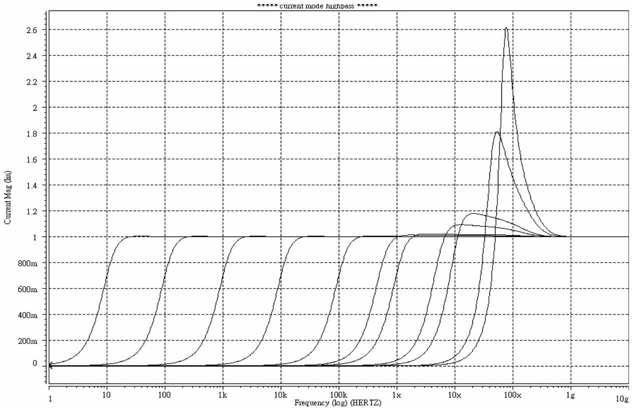

Fig. 10 High-pass responses from 10Hz to 66MHz

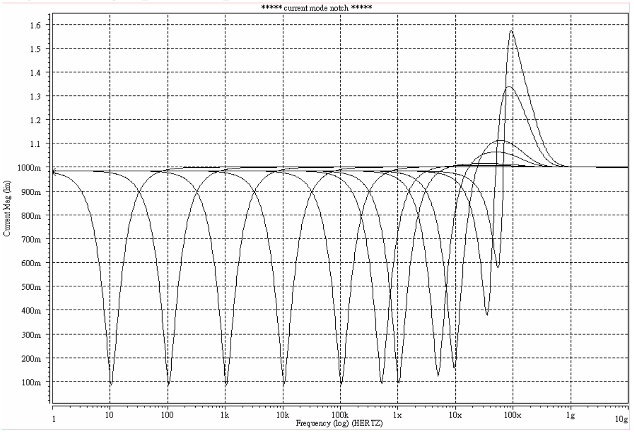

Fig. 11 Band-reject responses from 10Hz to 77.6MHz

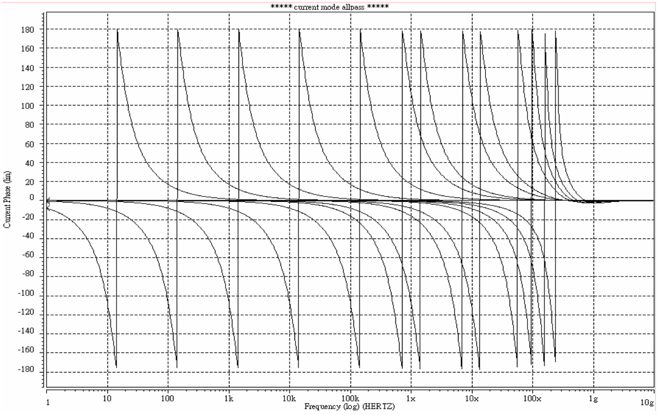

Fig. 12 All-pass responses from 10Hz to 237MHz

The sensitivity frequency responses of the 3dB frequency and the peak for the low-pass and high-pass output signals are shown in Figs. 13 to 16. As can be seen, the sensitivity of the peak is very low (lower than 0.2), and only the high-pass sensitivity of the 3dB frequency is a little bit larger (the largest absolute value is 1.072).

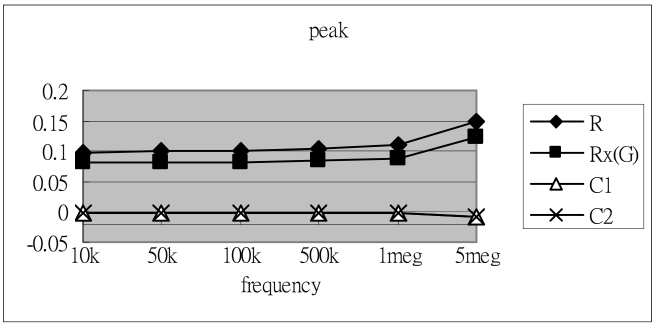

Fig. 13 Low-pass sensitivity of the peak

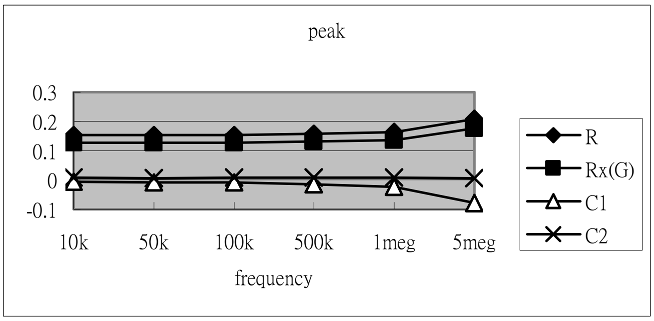

Fig. 14 High-pass sensitivity of the peak

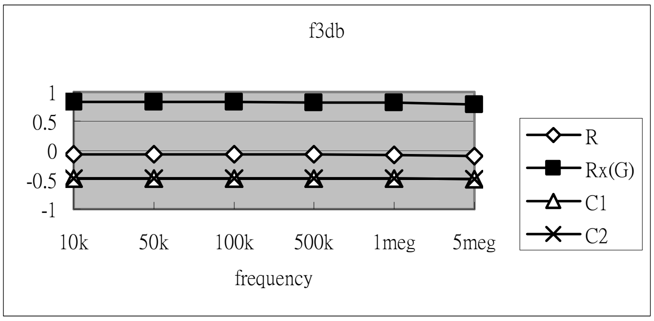

Fig. 15 Low-pass sensitivity of the 3dB frequency

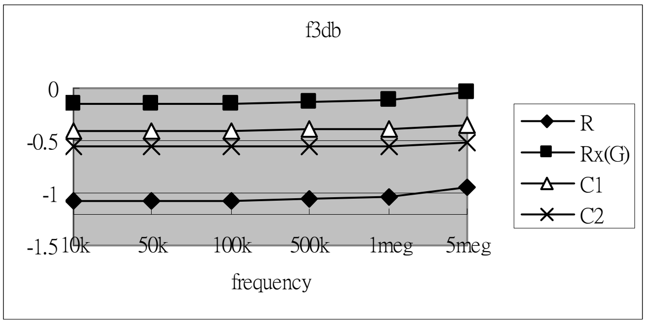

Fig. 16 High-pass sensitivity of the 3dB frequency

Only tuning the values of the input resistance at the X terminal of the CCCII shown in Fig. 1 from 222.14 μm to 200.48 μm (low-pass), 200.37 μm (band-pass), 207.34 μm (high-pass), 201.45 μm (band-reject), and from 444.28 μm to 224.45 μm (all-pass), the deviations of the 3dB frequency are then corrected. Figs. 17 and 18 show the simulation results before and after tunings for the low-pass, band-pass, high-pass, and band-reject amplitude frequency responses, and the all-pass phase frequency response, respectively.

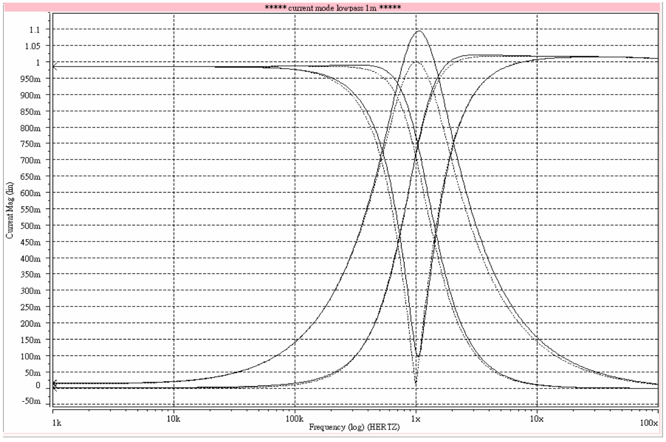

Fig. 17 Simulation results before and after tunings

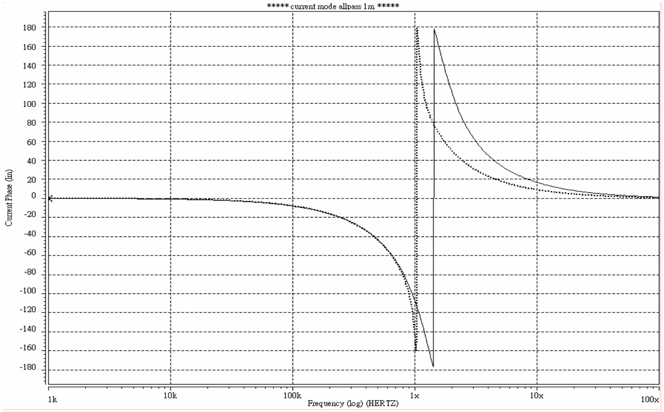

Fig. 18 Simulation results before and after tunings

IV. CONCLUSION

The single current conveyor based universal active current-mode filter using one fewer capacitor and three/four fewer resistors than the previous ones is proposed. Due to the controllability of the finite input resistance at the X terminal of a second- generation current controlled conveyor (CCCII) by its bias current, the five generic filtering (low-pass band-pass, high-pass, band-reject, and all-pass) signals can be obtained by proper choice of the three input current signals. TSMC 0.35 μm process H-Spice simulations are included to validate the theoretical predictions of the filtering performance component sensitivities, and the technique to correct the deviation.

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