Design of a Current-Mode CCII-Based Bandpass Filter from Immittance Function Simulator using Commercial Available CCII (AD844)

Songphan Prakobnoppakao[1], Boonruk Chipipop[1], Wanlop Surakampontorn[2] and Kenzo Watanabe[3]
[1] VLSI and Signal Processing Laboratory,
Department of Computer Engineering, Faculty of Engineering,
King Mongkut's University of Technology Thonburi,
91 Pracha-Uthit Road, Bangkok 10140, Thailand
Tel. +66-2-470-9083, +66-2-470-9085, Fax.: +66-2-872-5050
[2] Department of Electronics, Faculty of Engineering,
King Mongkut's Institute of Technology Ladkrabang,
Ladkrabang District, Bangkok 10520, Thailand
Tel. +66-2-326-7723, Fax.: +66-2-326-9968
[3] Research Institute of Electronics, Shizuoka University,
3-5-1 Johoku, Hamamatsu 432-8011, Japan
Tel. +81-53-478-1326, Fax.: +81-53-478-1326
e-mail : boonruk@cpe.eng.kmutt.ac.th, kswanlop@kmitl.ac.th, watanabe-k@rie.shizuoka.ac.jp

Abstract: This paper proposes the design of a current-mode CCII-based 2nd-order bandpass biquad filter from a grounded series capacitor and frequency-dependent negative conductor (C-D) immittance function simulator using the macro model of a commercial available CCII+, AD844, from Analog Devices,Inc. The results are compared with the other results those are designed using ideal model of CCII-. The gain and phase deviations; due to the effects of passive sensitivity, active sensitivity, gain sensitivity and component variability; are considered using Monte-Carlo analysis of PSpice program.

1. Introduction

CCII has been proposed since 1970 by A. Sedra and K.C. Smith [1]. Now, it is a famous and versatile current-mode device. One important class of its application is continuous-time filter. Filter can be designed by many methods. One method uses immittance function simulator [2-5]. But the method proposed by T. Sattaya-aphitan,et. al. [6] uses less components, component matching is not required and more generalized method than the previous papers. Nevertheless, they use ideal model of CCII-.

Nowadays, there are only CCII+ in the market. We must use 2-CCII+ connected in cascade to form CCII-. The real characteristics of CCII+ and CCII- are not exactly the same as the ideal cases. In this paper, we use off-the-shelf integrated circuit no. AD844 of Analog Devices,Inc. functions as CCII+, and use macro model [7] in design a current-mode 2nd-order bandpass biquad filter from a grounded series capacitor and frequency-dependent negative conductor (C-D) immittance function simulator.

2. Theory

2.1 CCII ±

In general, the characteristic of an ideal second generation current conveyor (CCII) is given by the following hybrid matrix :

$$\begin{bmatrix} i_Y \\ v_X \\ i_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} v_Y \\ i_X \\ v_Z \end{bmatrix} \tag{1}$$

+1 in equation(1) is referred to CCII+ and –1 is referred to CCII-. All currents go into the terminals of CCII+.

The macro (or real) model of AD844 functions as CCII+ is shown in figure 1.

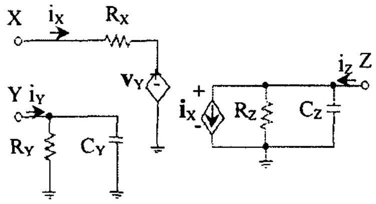


Figure 1. Macro model of AD844.

Where $R_X = 50\ \Omega$, $R_Y = 10\ M\Omega$, $R_Z = 3\ M\Omega$, $C_Y = C_Z = 4.5$ pF. The two-cascaded AD844 functions as CCII- is shown in figure 2.

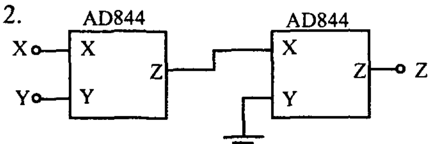


Figure 2. AD844 implementation as CCII-.

2.2 Grounded Series Immittance Function Simulator

The grounded series immittance function simulator [6] is shown in figure 3 and its input impedance is shown in equation (2).

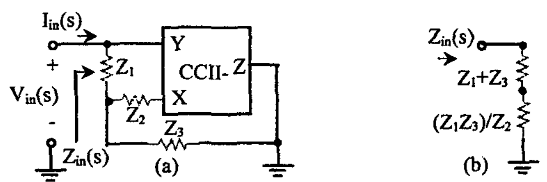


Figure 3. (a) Grounded series immittance function simulator.
(b) Equivalent circuit.

$$Z_{in}(s)=\frac{1}{Y_{in}(s)}=\frac{V_{in}(s)}{I_{in}(s)}=Z_1+Z_3+\frac{Z_1Z_3}{Z_2} \quad (2)$$

Given $Z_1 = 1/sC_1$, $Z_2 = R_2$ and $Z_3 = 1/sC_3$. We obtain the grounded series C-D immittance function as shown in equation (3).

$$Z_{in}(s)=\frac{1}{sC_{eq}}+\frac{1}{s^2D_{eq}} \quad (3)$$

where $C_{eq} = C_1C_3/(C_1+C_3)$ and $D_{eq} = C_1C_3R_2$
which D_{eq} = equivalent frequency-dependent negative conductance (FDNG)

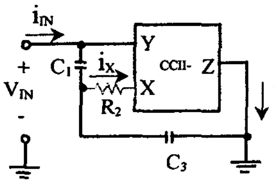


Figure 4. Grounded series C-D immittance function simulator.

We substitute the macro model of AD844 of figure 1 into the blocks of figure 2, after that, substitute it in CCII- of figure 4. We will obtain the input admittance as shown in equation (4) below.

$$Y_{in}(s)=\frac{I_{in}(s)}{V_{in}(s)}=\frac{As^2+Bs+C}{Ds+E} \quad (4)$$

where

$$A=C_1C_3+C_1C_Y+C_3C_Y+C_1C_YG_2R_X+C_3C_YG_2R_X+C_1C_3G_2R_X$$
$$B=C_1G_Y+C_YG_2+C_3G_Y+C_1G_2G_YR_X+C_3G_2G_YR_X$$
$$C=G_2G_Y$$
$$D=C_1+C_3+C_1G_2R_X+C_3G_2R_X$$
$$E=G_2$$

3. The Practical Bandpass Filter

We construct the practical bandpass filter as shown in figure 5 and the obtained current-mode bandpass transfer function is shown in equation (5).

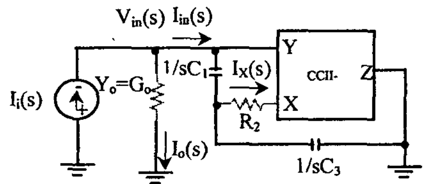


Figure 5. The practical bandpass filter.

$$T_{BP}(s)=\frac{I_x(s)}{I_i(s)}=\frac{K\frac{\omega_p}{Q_p}s}{s^2+\frac{\omega_p}{Q_p}s+\omega_p^2} \quad (5)$$

where $\omega_p=\sqrt{(C+EG_o)/A}=\omega_0$ (for BP filter)

$$Q_p=\sqrt{A(C+EG_o)}/(B+DG_o)$$
$$K=-C_3G_2/(B+DG_o)$$

4. Simulation Results

We use PSpice program as the tool for simulation. First, given $C_1 = C_3 = 22.5$ pF, $R_2 = 5$ kΩ and $R_o = 10$ kΩ. The gain and phase responses are shown in figure 6 and important data are shown in table 1.

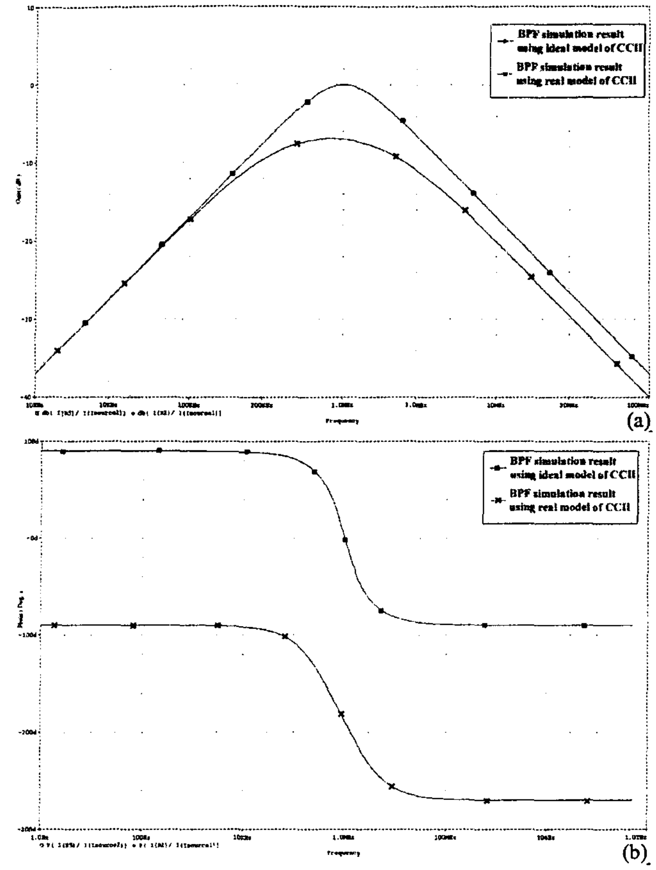


Figure 6. Uncompensated BP filter vs ideal-model BP filter.

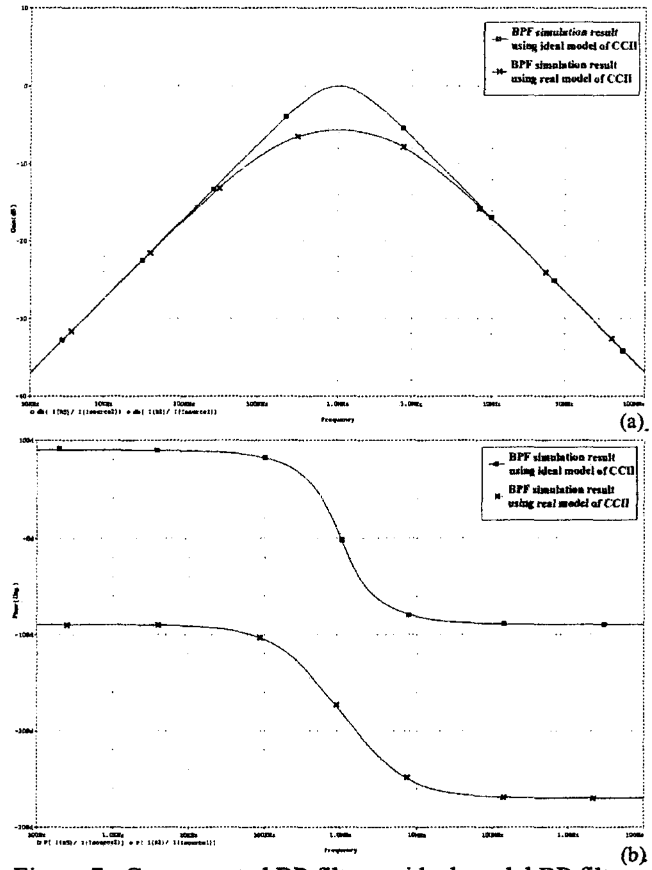


Figure 7. Compensated BP filter vs ideal-model BP filter.

Table 1. Bandpass filter characteristics of figure 6.

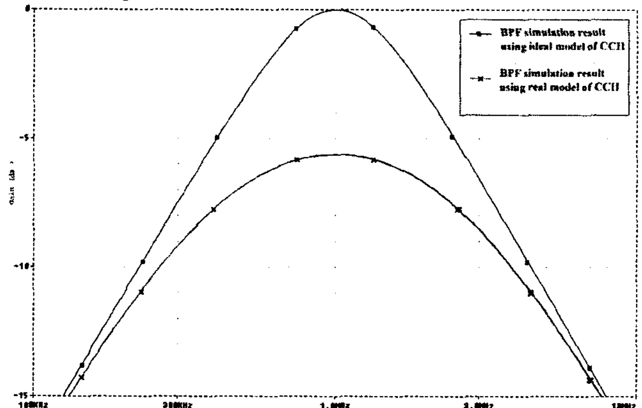
	BPF using ideal model of CCII-	BPF using real model of CCII-
f_0 = center frequency	1.0 MHz	833.28 kHz
Lower and upper cutoff frequency (f_1 and f_2)	515 kHz and 1.93 MHz	284 kHz and 2.48 MHz
Bandwidth (BW)	1.415 MHz	2.196 MHz
Quality factor (Q)	0.707	0.38
Gain at f_0 (dB)	75.04n	-6.89

Second, given $C_1 = C_3 = 22.5$ pF, $R_o = 10$ kΩ and adjust R_2 to be 3.5 kΩ. The gain and phase responses of the compensated BP filter are shown in figure 7 and important data are shown in Table 2.

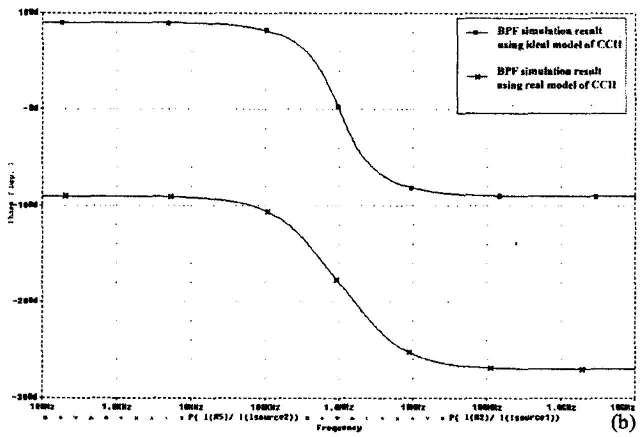
Table 2. Bandpass filter characteristics of figure 7.

	BPF using ideal model of CCII-	BPF using real model of CCII-
f_0 = center frequency	1.0 MHz	1.0 MHz
Lower and upper cutoff frequency (f_1 and f_2)	515 kHz and 1.93 MHz	330 kHz and 3 MHz
Bandwidth (BW)	1.415 MHz	2.67 MHz
Quality factor (Q)	0.707	0.375
Gain at f_0 (dB)	75.04n	-5.62

If all values of components in the model of CCII- are changed within ±1%, the gain and phase deviations are shown in figure 8 and table 3.



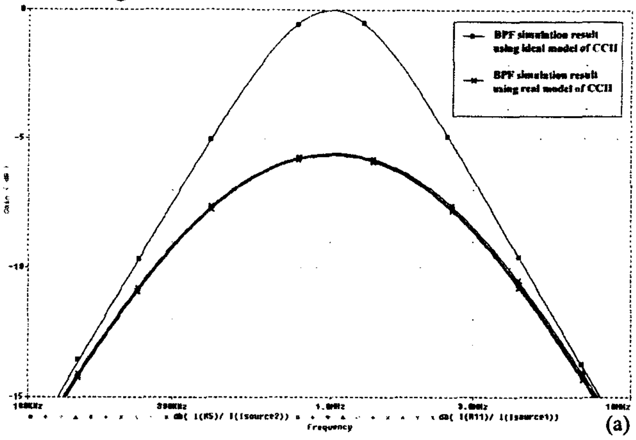
(a)



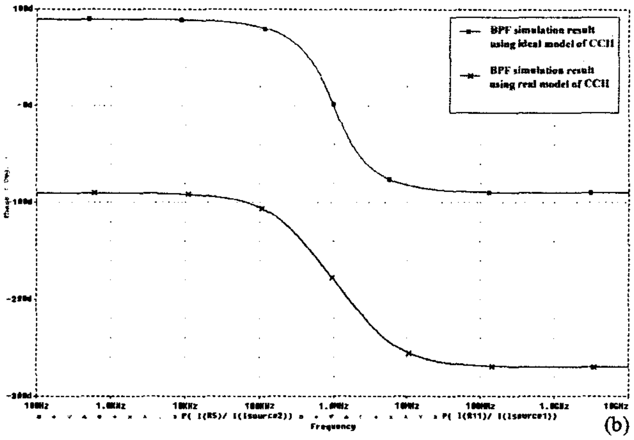
(b)

Figure 8. Gain and phase deviations due to active devices

If all values of other passive components are also changed within ±1%, the gain and phase deviations are shown in figure 9 and table 3.



(a)



(b)

Figure 9. Gain and phase deviations due to passive elements.

Table 3. ΔG and Δϕ at lower and upper cutoff frequency and at center frequency.

(a) Due to active elements only.

frequency	330 kHz	1 MHz	3 MHz
ΔG (dB)	0.0046	0.0139	0.0281
Δϕ (degree)	0.061	0.093	0.096

(b) Due to passive elements only.

frequency	330 kHz	1 MHz	3 MHz
ΔG (dB)	0.1155	0.0779	0.1878
Δϕ (degree)	0.666	0.785	0.818

(c) Due to both active and passive elements .

frequency	330 kHz	1 MHz	3 MHz
ΔG (dB)	0.1317	0.636	0.1041
Δϕ (degree)	0.708	0.78	0.64

If all values of active devices and passive elements are changed within ±1%, the gain and phase deviations are shown in figure 10 and table 3.

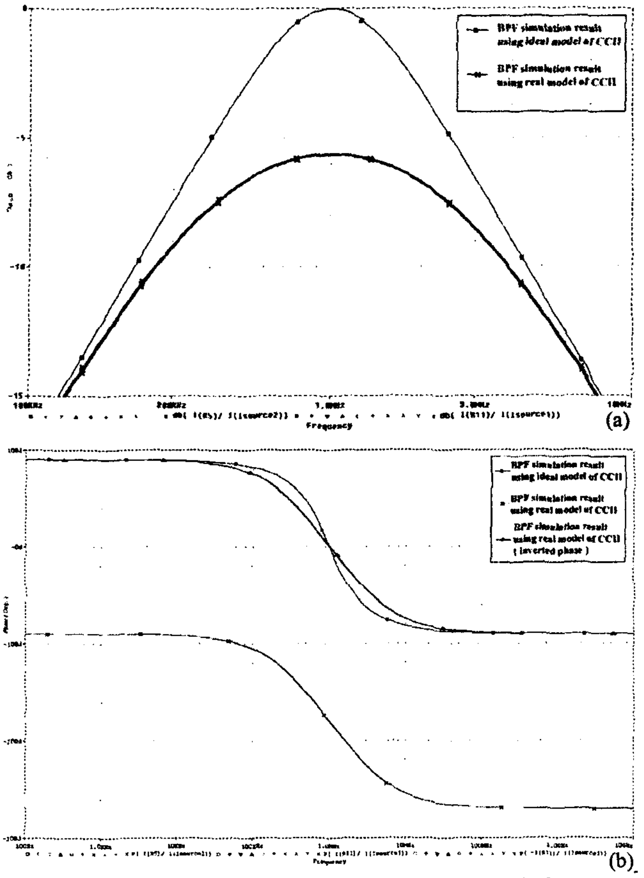


Figure 10. Gain and phase deviations due to all elements.

5. Discussion & Conclusion

Real model of commercial CCII- (2-cascaded AD844) causes the gain and phase responses deviate from the responses of the prototype that uses ideal model of CCII-, although we use the same values of passive components.

We can see the effect in figure 6 that we call "uncompensated BP filter". The phase response is shifted about 180° for all frequency range.

After trying to adjust all components and observed the effects that happened. We found that it will give the best results when adjust R_2 only. The results is shown in figure 7 that we call "compensated BP filter". Nevertheless, the phase response is still shifted about 180° for all frequency range.

The right way to correct the phase response is to use 180°-phase shifter at the source or at the output.

In this design, we use Butterworth approximation for the clear picture of graphs.

There are still deviations both gain and phase responses around center frequency due to the effects of nonidealities of the real CCII-.

The effects of passive sensitivity, active sensitivity, gain sensitivity and component variability to the gain and phase deviations are very small. We can observe the effects in the graphs of figure 8 to figure 10 and table 3.

i_X is drawn from the BP filter by wide band current amplifier and is transmitted to a load.

If we break terminal Z from ground to draw current i_Z instead of i_X as the output current, the responses are not as good as we do because of the effect of R_Z and C_Z.

References

[1] A. Sedra and K.C. Smith, "A second-generation current conveyor and its applications," *IEEE Trans. Circuit Theory*, vol. CT-17, no.2, pp. 132-134, 1970.

[2] M. Higashimura and Y. Fukui, " Novel method for realizing lossless floating immittance using current conveyors," *Electron. Lett.*, vol. 23, no. 10, pp. 498-499,1987.

[3] C.-L.Hou, R.-D. Chen, Y.-P. Wu and F.-C. Hu, "Realization of grounded and floating immittance function simulators using current conveyors," *Int. J. Electron.*, vol. 74, no. 6, pp. 917-923, 1993.

[4] A. Fabre and O. Saaid, "Novel translinear impedance converter and bandpass filter applications," *Electron. Lett.*, vol. 29, no. 9, pp. 746-747, 1993.

[5] J. Malhotra and R. Senani, "Class of floating, generalized, positive/negative immittance converters/inverters realized with operational mirrored amplifiers," *Electron. Lett.*, vol. 30, no. 1,pp. 3-5, 1994.

[6] T. Sattaya-aphitan, Boonruk Chipipop and Booncharoen Sirinaovakul, "Realization of grounded immittance functions using a single CCII and their applications to current-mode biquad synthesis," *Ladkrabang Engineering Journal*, vol. 17, no. 1, pp. 138-143, 2000.

[7] J.A. Svoboda, "Comparison of RC Op-Amp and RC current conveyor filters," *Int. J. Electron.*, vol. 76, no. 4, pp. 615-626, 1994.

Acknowledgement

This work is partly funded by the Thailand Research Fund (TRF) under the Senior Research Scholar Program, grant number RTA/04/2543. The support provided by the Japan International Cooperation Agency (JICA), the Japan Society for the Promotion of Sciences (JSPS), and King Mongkut's University of Technology Thonburi are also acknowledged.

Besides, the authors would like to thank Miss Trungjai Tangsakul, Mr. Parinya Disorntetiwatana, Mr. Pantin Nantajiwakornchai, Mr. Rangsan Chaisrichareon, Mr. Seksan Mathulaprung-san, Mr. Tanya Sattaya-aphitan, Associate Professor Dr. Booncharoen Sirinaovakul, and Associate Professor Dr. Kobchai Dejhan for their support.