A Realization of Biquadratic Voltage Transfer Functions Using Three CCIIs

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Abstract: This paper proposes a novel circuit configuration realizing biquadratic voltage transfer functions using three CCIIs and six passive elements. The circuits realize high-pass, band-pass, low-pass, band-stop and all-pass functions by selecting input voltages. The circuit has low passive sensitivities and permits orthogonal adjustment of quality factor Q and cutoff angular frequency ω_0. The effects of non-ideal CCIIs on biquadratic transfer functions are also given.

1. Introduction

Current conveyors (CCIIs) as active elements received great attention in recent years as an alternative to classical voltage-mode operational amplifiers. Many circuits for the realization of voltage transfer function using current conveyors have been published [1]-[4]. The authors reported circuits for realizing biquadratic transfer functions using four CCIIs and grounded passive elements [5]-[7]. This paper proposes novel circuit configuration for realizing biquadratic voltage transfer functions using three CCIIs and six passive elements. The circuits realize high-pass (HP), band-pass (BP), low-pass (LP), band-stop (BS) and all-pass (AP) functions by selecting input voltages. The circuits has low passive sensitivities and permit orthogonal adjustment of quality factor Q and cutoff angular frequency ω_0. The circuits are simulated with PSpice to verify the theoretical analysis. The effects of non-ideal CCIIs on biquadratic transfer functions are also given.

2. Circuit Configuration

The proposed circuit configuration for realizing voltage transfer functions is shown in Fig.1. When the relations between voltages and currents of CCIIs are given ideally by $I_y=0$, $V_x=V_y$ and $I_z=\pm I_x$, the output voltages (V_{O1} and V_{O2}) are given by the following equations using input voltages (V_{i1}, V_{i2}, V_{i3}, V_{i4}, V_{i5} and V_{i6}).

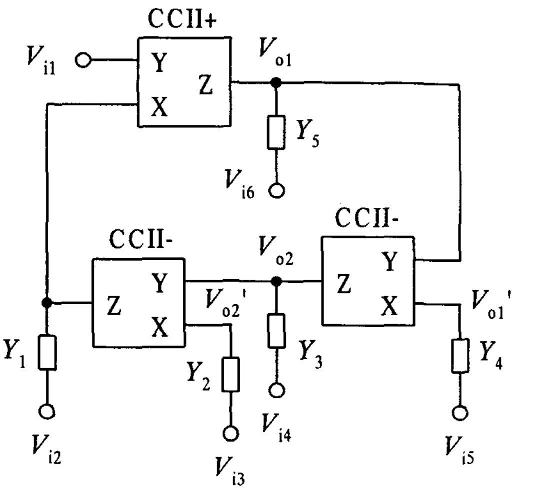

Fig.1 Proposed circuit configuration for realizing biquadratic voltage transfer function

$$V_{O1}=\frac{Y_1Y_3(V_{i1}-V_{i2})-Y_2Y_3V_{i3}+Y_2Y_3V_{i4}+Y_2Y_4V_{i5}+Y_3Y_5V_{i6}}{Y_3Y_5+Y_2Y_4} \quad (1)$$

$$V_{O2}=\frac{Y_1Y_4(V_{i2}-V_{i1})+Y_2Y_4V_{i3}+Y_3Y_5V_{i4}+Y_4Y_5V_{i5}-Y_4Y_5V_{i6}}{Y_3Y_5+Y_2Y_4} \quad (2)$$

Therefore, by suitably choosing input voltages and kinds of admittances, we can obtain several voltage transfer functions.

2.1. Circuit I

Firstly, let us consider the circuit (in Fig.2) with grounded admittances Y_1, Y_3 and Y_5. Then, the output voltage is given by

$$V_{O1}=\frac{Y_1Y_3V_{i1}-Y_2Y_3V_{i3}+Y_2Y_4V_{i5}}{Y_3Y_5+Y_2Y_4} \quad (3)$$

By suitably choosing the input voltages and the kinds of admittances of Eq.(3), we can obtain variable voltage transfer functions.

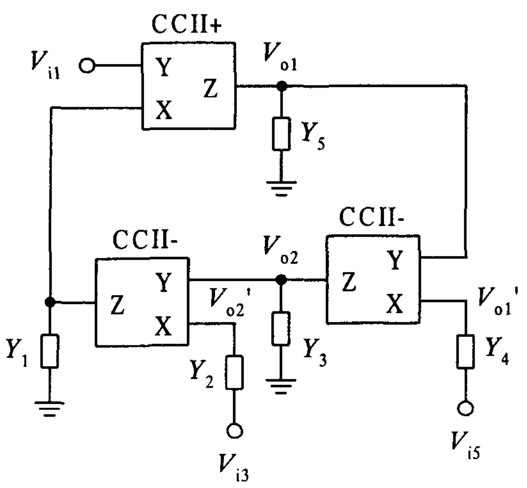

Fig.2 Circuit I

For example, when admittances are given by the following forms:

$$Y_1=sC_1,\ Y_2=G_2,\ Y_3=sC_3,\ Y_4=G_4 \text{ and } Y_5=sC_5+G_5 \qquad (4)$$

Then, from Eqs.(3) and (4), we obtain the following voltage transfer function.

$$V_{O1}=\frac{s^2C_1C_3V_{i1}-sC_3G_2V_{i3}+G_2G_4V_{i5}}{s^2C_3C_5+sC_3G_5+G_2G_4} \qquad (5)$$

$$\omega_0=(G_2G_4/C_3C_5)^{1/2} \qquad (6)$$

$$Q=1/G_5(C_5G_2G_4/C_3)^{1/2} \qquad (7)$$

Thus, the circuit realizes high-pass, band-pass and low-pass transfer functions by choosing input voltages. Q can be adjusted independent of ω_0 through G_5.

High-pass (HP), band-pass (BP), low-pass (LP), band-stop (BS) and all-pass (AP) characteristics are realized as follows:

(1) HP: $V_{O1}/V_{i1}=s^2C_1C_3/D(s)$
(2) BP: $V_{O1}/V_{i3}=-sC_3G_2/D(s)$
(3) LP: $V_{O1}/V_{i5}=G_2G_4/D(s)$
(4) BS: $V_{O1}/V_{i15}=(s^2C_1C_3V_1+G_2G_4)/D(s)$
(5) AP: $V_{O1}/V_{i135}=(s^2C_1C_3V_1-s\,C_3G_2+G_2G_4)/D(s)$,

$$C_1G_5=C_5G_2$$

Where $D(s)=s^2C_3C_5+sC_3G_5+G_2G_4$

V_{i15} mean that V_{i1} and V_{i5} are connected together and provided by the same source voltage V_{i15}, and V_{i135} mean that V_{i1}, V_{i3} and V_{i5} are connected together and provided by the same source voltage V_{i135}

The output voltage V_{O2} is given by

$$V_{O2}=\frac{s(C_5G_4V_{i5}-C_1G_4V_{i1})+G_2G_4V_{i3}+G_4G_5V_{i5}}{s^2C_3C_5+sC_3G_5+G_2G_4} \qquad (8)$$

Therefore, when an input voltage V_{i1} is given, V_{O1}/V_{i1} is a high-pass transfer function, while V_{O2}/V_{i1} is a band-pass transfer function. Thus high-pass and band-pass transfer functions are realized simultaneously. Similarly, by selecting input voltages, band-pass/low-pass or band-stop/low-pass transfer functions are realized simultaneously as shown in Table1.

Table 1. The possible transfer functions from Eqs.(5) and (8).

Input	Output	
	V_{O1}	V_{O2}
V_{i1}	HP	BP
V_{i3}	BP	LP
V_{i5}	LP	LP
V_{i1}, V_{i5}	BS	LP
V_{i1}, V_{i3}, V_{i5}	AP	LP

Sensitivities of ω_0, Q to passive elements are given by

$$S^{\omega_0}_{G_2,G_4}=-S^{\omega_0}_{C_3,C_5}=1/2,\qquad S^{Q}_{G_5}=-1$$

$$S^{Q}_{C_5,G_2,G_4}=-S^{Q}_{C_3}=1/2,$$

The sensitivities are rather small.

Table 2 presents the possible realizations for realizing five types of transfer functions using two or three capacitors.

Table.2. The possible realizations from CCII configuration in Fig.2

	Admittances					Transfer functions				
	Y_1	Y_2	Y_3	Y_4	Y_5	HP	BP	LP	BS	AP
Circuit 1	sC_1	G_2	sC_3	G_4	sC_5+G_5	V_{O1}/V_{i1}	V_{O1}/V_{i3}	V_{O1}/V_{i5}	V_{O1}/V_{i15}	V_{O1}/V_{i135}
Circuit 2	sC_1	G_2	sC_3+G_3	G_4	sC_5	V_{O1}/V_{i135}	V_{O1}/V_{i35}	V_{O1}/V_{i5}	V_{O1}/V_{i135}	V_{O1}/V_{i135}
Circuit 3	G_1	sC_2	G_3	sC_4	sC_5+G_5	V_{O1}/V_{i5}	V_{O1}/V_{i3}	V_{O1}/V_{i1}	V_{O1}/V_{i15}	V_{O1}/V_{i135}
Circuit 4	G_1	sC_2	G_3	sC_4+G_4	G_5	V_{O1}/V_{i35}	V_{O1}/V_{i3}	V_{O1}/V_{i1}	V_{O1}/V_{i135}	V_{O1}/V_{i135}
Circuit 5	G_1	sC_2+G_4	G_3	sC_4	G_5	V_{O1}/V_{i135}	V_{O1}/V_{i13}	V_{O1}/V_{i1}	V_{O1}/V_{i135}	V_{O1}/V_{i135}

2.1. Circuit Ⅱ

Secondly, let us consider the circuit (in Fig.3) with grounded admittances Y_2 and Y_4. Then, the output voltage is given by

$$V_{O2} = \frac{Y_1Y_4V_{i2} + Y_3Y_5V_{i4} - Y_4Y_5V_{i6}}{Y_3Y_5 + Y_2Y_4} \qquad (9)$$

By suitably choosing the input voltages and the kind of admittances of Eq.(9), we can obtain variable voltage transfer functions. For example, when admittances are given by the following forms:

$$Y_1=sC_1,\ \ Y_2=sC_2+G_2,\ \ Y_3=G_3,\ \ Y_4=sC_4,\ \ Y_5=G_5 \qquad (10)$$

Then, from Eqs.(9) and (10), we obtain the following voltage transfer function.

$$V_{O2} = \frac{s^2C_1C_4V_{i2} + G_3G_5V_{i4} - sC_4G_5V_{i6}}{s^2C_2C_4 + sC_4G_2 + G_3G_5} \qquad (11)$$

$$\omega_0 = (G_1G_5/C_2C_4)^{1/2} \qquad (12)$$

$$Q = 1/G_2(C_2G_1G_5/C_4)^{1/2} \qquad (13)$$

Thus, the circuit realizes high-pass, band-pass and low-pass transfer functions by choosing input voltages. Q can be adjusted independent of ω_0 through G_2.

High-pass (HP), band-pass (BP), low-pass (LP), band-stop

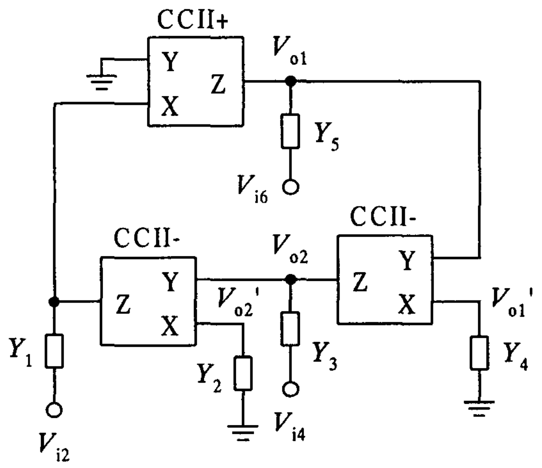

Fig.3 Circuit Ⅱ

(BS) and all-pass (AP) characteristics are realized as follows:

(1) HP: $V_{O2}/V_{i2} = s^2C_1C_4/D(s)$

(2) BP: $V_{O2}/V_{i6} = -sC_4G_5/D(s)$

(3) LP: $V_{O2}/V_{i4} = G_3G_5/D(s)$

(4) BS: $V_{O2}/V_{i24} = (s^2C_1C_4V_1 + G_3G_5)/D(s)$

(5) AP: $V_{O2}/V_{i246} = (s^2C_1C_4 - sC_4G_5 + G_3G_5)/D(s)$

$C_1G_2 = C_2G_5$

where $D(s) = s^2C_2C_4 + sC_4G_2 + G_3G_5$

The output voltage V_{O1} is given by

$$V_{O1} = \frac{-sC_1G_3V_{i2} - (s\,C_2G_3 + G_2G_3)V_{i4} + G_3G_5V_{i6}}{s^2C_3C_5 + sC_3G_5 + G_2G_4} \qquad (14)$$

Therefore, when an input voltage V_{i2} is given, V_{O2}/V_{i2} is a HP transfer function, while V_{O1}/V_{i2} is a band-pass transfer function. Thus high-pass and band-pass transfer functions are realized simultaneously. Similarly, by selecting input voltages, band-pass/low-pass or band-stop/low-pass transfer functions are realized simultaneously as shown in Table3.

Table 3. The possible transfer functions from Eqs.(11) and (14).

Input	Output	
	V_{O1}	V_{O2}
V_{i2}	BP	HP
V_{i6}	LP	BP
V_{i4}	HP	LP
V_{i2}, V_{i4}	LP	BS
V_{i2}, V_{i4}, V_{i6}	BP	AP

Sensitivities of ω_0, Q to passive elements are given by

$$S^{\omega_0}_{G_1, G_5} = -S^{\omega_0}_{C_2, C_4} = 1/2$$

$$S^{Q}_{C_2, G_1, G_5} = -S^{Q}_{C_4} = 1/2, \quad S^{Q}_{G_2} = -1$$

The sensitivities are rather small.

Table 4 presents the possible realizations for realizing five types of transfer functions using two or three capacitors.

Table.4. The possible realizations from CCII configuration in Fig.3

	Admittances					Transfer functions				
	Y_1	Y_2	Y_3	Y_4	Y_5	HP	BP	LP	BS	AP
Circuit 6	sC_1	sC_2+G_2	G_3	sC_4	G_5	V_{O2}/V_{i2}	V_{O2}/V_{i6}	V_{O2}/V_{i4}	V_{O2}/V_{i24}	V_{O2}/V_{i246}
Circuit 7	sC_1	sC_2	G_3	sC_4+G_4	G_5	V_{O2}/V_{i246}	V_{O2}/V_{i46}	V_{O2}/V_{i4}	V_{O2}/V_{i246}	V_{O2}/V_{i246}
Circuit 8	G_1	sC_2+G_2	sC_3	G_4	sC_5	V_{O2}/V_{i4}	V_{O2}/V_{i6}	V_{O2}/V_{i2}	V_{O2}/V_{i24}	V_{O2}/V_{i246}
Circuit 9	G_1	G_2	sC_3+G_3	G_4	sC_5	V_{O2}/V_{i46}	V_{O2}/V_{i6}	V_{O2}/V_{i2}	V_{O2}/V_{i246}	V_{O2}/V_{i246}
Circuit 10	G_1	G_2	sC_3	G_4	sC_5+G_5	V_{O2}/V_{i246}	V_{O2}/V_{i46}	V_{O2}/V_{i2}	V_{O2}/V_{i246}	V_{O2}/V_{i246}

3. Effects of non-ideal CCIIs on Transfer Functions

Assuming that the characteristics of a non-ideal CCII are I_y=0, V_x=K_vV_y+R_xI_x and Iz=$\pm K_iI_x$, we obtain the following output voltage in place of Eq.(5).

$$V_{O1} = \frac{a_2 V_{i1} - a_1 V_{i3} + a_0 V_{i5}}{b_3 s^3 + b_2 s^2 + b_1 s + b_0} \qquad (15)$$

where $a_2 = s^2 C_1 C_3 K_i K_v (1+R_x G_4)$, $a_1 = s C_3 G_2 K_i (1+R_x G_4)$

$a_0 = G_2 G_4 K_i^3 K_v$, $b_3 = C_1 C_3 C_5 R_x (1+R_x G_4)$

$b_2 = C_3 C_5 (1+R_x G_4)(1+K_i R_x G_2) + C_1 C_3 R_x G_5 (1+R_x G_4)$

$b_1 = C_3 G_5 (1+R_x G_4)(1+K_i R_x G_2)$

$b_0 = K_i^3 K_v^2 G_2 G_4$

An example of effects of non-ideal CCIIs on a band-pass transfer function (V_{O1}/V_{i3}) is shown in Tables 5 and 6.

Table 5 Effect of K_i on a band-pass transfer functions (K_v=1.0 and R_x=60Ω)

f	100Hz	1kHz	10kHz	100kHz	1MHz
K_i=1.00	-38.0dB	-18.0dB	-0.14dB	-16.0dB	-36.6dB
K_{ii}=0.95	-37.5dB	-17.5dB	-0.93dB	-16.9dB	-37.5dB
K_i=0.90	-37.1dB	-17.1dB	-1.87dB	-17.9dB	-38.4dB

Table 6 Effect of K_v on a band-pass transfer functions (K_i=1.0 and R_x=60Ω)

f	100Hz	1kHz	10kHz	100kHz	1MHz
K_v=1.00	-38.0dB	-18.0dB	-0.14dB	-16.0dB	-36.6dB
K_v=0.95	-37.1dB	-17.1dB	-0.06dB	-16.0dB	-36.6dB
K_v=0.90	-36.1dB	-16.2dB	-0.03dB	-16.0dB	-36.6dB

4. Simulation Results

To verify the study, we simulated the circuit 1 with CCII AD844/AD, C_1=C_3/2=C_5=1nF and R_2=R_4=R_5=10kΩ by PSpice. Two examples of simulation results are shown in Figs.4 and 5. The simulation results agree well with the theoretical characteristics.

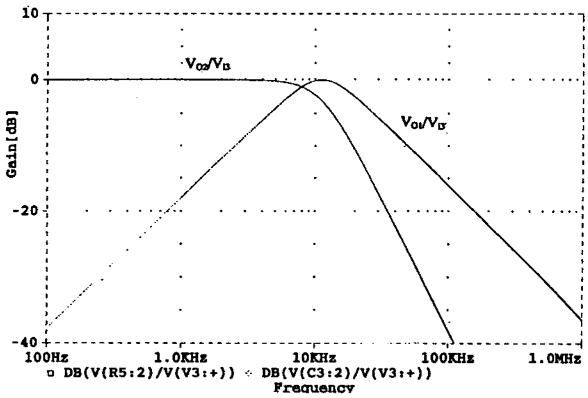

Fig.4 Frequency responses of band-pass and low-pass filters (V_{O1}/V_{i3}: BP and V_{O2}/V_{i3}: LP)

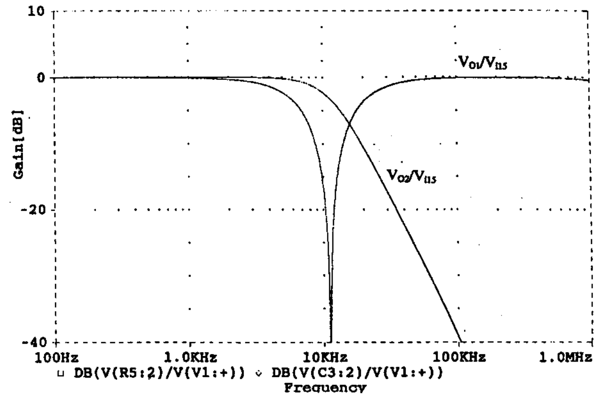

Fig.5 Frequency responses of band-stop and low-pass filters (V_{O1}/V_{i15}: BS and V_{O2}/V_{i15}: LP)

5. Conclusion

Novel circuits for realizing voltage transfer function using three CCIIs and six grounded passive elements have been given. The circuits realize high-pass, band-pass, low-pass, band-stop and all-pass transfer functions. The circuits offer several advantages, such as low filter sensitivities to passive elements, use of grounded capacitors (in the case of the circuit 1 and 2) and independent control of ω_0, Q.

References

[1] H. Tek and F. Anday, "Voltage transfer function synthesis using current conveyors", *Electron. Lett.*, vol.25, no.23, pp.1552-1553, Nov. 1989.

[2] M. Higashimura, M. Ishida, M. Hara and Y. Fukui, "Realization of biquadratic transfer function using a single current conveyor", *IEICE Trans.*, vol.J71-A, no.2, pp.228-234, Feb. 1988.

[3] C. M. Chang, "Multifunction biquadratic filters using current conveyors", *IEEE Trans. Circuits Syst. II*, vol.CAS-44, no.11, 956-958, Nov. 1997.

[4] O. Cicekoglu, "New multifunction filter implemented with current conveyors", Microelectronics J., vol.30, pp.105-107 1999.

[5] M. Higashimura and Y. Fukui, "Realization of biquadratic transfer functions using current conveyors", *Proc.IEEE ISCAS'91*, Singapore, pp.1424-1427, May 1991.

[6] M. Higashimura and Y. Fukui, "Universal voltage-mode filter using four CCIIs with grounded passive elements", *Proc.ITC-CSCC'98*, Sokcho, Korea, pp.1543-1547, July 1998.

[7] M. Higashimura and Y. Fukui, "An approach for the realization of universal filters using null four CCIIs and grounded passive elements", *ISPACS'99*, Phuket, Thailand, no.FMD-06, pp.513-516, Dec. 1999.