Novel Voltage-Mode Universal Filters Using Two Current Conveyors

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Abstract

A novel configuration for realizing voltage-mode universal biquad filters with three inputs and two outputs is presented. The configuration uses only two second-generation current conveyors and four passive RC elements. The active and passive sensitivities are quite small. Simulation results that confirm the theoretical analysis are obtained.

1. Introduction

Current-mode circuits have been receiving significant attention because they have the potential advantages of accuracy and wide bandwidth over their voltage-mode counterparts [1] . A number of current-mode amplifiers have been introduced to realize voltage-mode universal filters with three inputs and one output [2]-[6]. Despite the number of active components, those voltage-mode universal filters needed at least five or six passive elements.

Among those current-mode amplifiers, second-generation current conveyors (CCIIs) are found useful to realize voltage-mode biquad filters. Over the past few years, several universal filter schemes employing only two CCIIs have been developed [7]-[9]. Horng *et al.* [8] proposed the filter using only four passive RC elements.

We propose a novel configuration for realizing voltage-mode universal biquad filters using only two second-generation current conveyors.The configuration provides three inputs and two outputs employing four passive elements. A number of universal filters can be obtained from the configuration. The proposed filters can realize highpass, bandpass, lowpass, notch, and allpass filters without changing circuit topology and elements. The active and passive sensitivities are quite low. PSpice simulation are given to verify the theoretical analysis.

2. Circuit Description

The port relations of a CCII can be shown as

$$\begin{bmatrix} v_x \\ i_z \\ i_y \end{bmatrix} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & \pm 1 & 0 \\ 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} v_y \\ i_x \\ v_z \end{bmatrix} \qquad (1)$$

where the plus and minus signs denote CCII+ and CCII-, respectively. The network symbol and nullor model of CCII ± are shown in Fig.1.

The proposed configuration shown in Fig.2 has three inputs and two outputs. By a routine circuit analysis, the transfer functions of two outputs are given by the following equations:

$$V_{o1} = \frac{Y_1 Y_2 V_{i1} + 2Y_2 Y_4 V_{i2} + 2Y_3 Y_4 V_{i3}}{Y_1 Y_2 + 2Y_2 Y_4 + 2Y_3 Y_4} \qquad (2a)$$

$$V_{o2} = \frac{-Y_1 Y_3 V_{i1} + (Y_1 + 2Y_4)(Y_2 V_{i2} + Y_3 V_{i3})}{Y_1 Y_2 + 2Y_2 Y_4 + 2Y_3 Y_4} \qquad (2b)$$

According to the nullor model, the first novel voltage-mode universal filter as shown in Fig.3 is presented for $Y_1=sC_1$, $Y_2=sC_2$, $Y_3=1/R_3$, and $Y_4=1/R_4$. The universal filter, which is called Circuit A, comprises only two CCIIs, CCII+ and CCII-. The transfer functions of two output terminals, V_{o1} and V_{o2}, can be expressed as

$$V_{o1} = \frac{s^2 C_1 C_2 R_3 R_4 V_{i1} + 2sC_2 R_3 V_{i2} + 2V_{i3}}{s^2 C_1 C_2 R_3 R_4 + 2sC_2 R_3 + 2} \qquad (3a)$$

$$V_{o2} = \frac{-sC_1 R_4 V_{i1} + (sC_1 R_4 + 2)(sC_2 R_3 V_{i2} + V_{i3})}{s^2 C_1 C_2 R_3 R_4 + 2sC_2 R_3 + 2} \qquad (3b)$$

From Equations (3a) and (3b), five kinds of biquad filters can be realized. They are summarized as follows:

(i) If $V_{i2}=V_{i3}=0$ (grounded), a second-order highpass filter can be obtained from V_{o1} and a second-order bandpass filter can be obtained from V_{o2}.

(ii) If $V_{i1}=V_{i3}=0$ (grounded), a second-order bandpass filter can be obtained from V_{o1} .

(iii) If $V_{i1}=V_{i2}=0$ (grounded), a second-order lowpass filter can be obtained from V_{o1} .

(iv) If $V_{i2}=0$ (grounded) and $V_{i1}=V_{i3}=V_{in}$, a second-order notch filter can be obtained from V_{o1} and a lowpass filter can be obtained from V_{o2}.

(v) If $V_{i1}=-V_{i2}=V_{i3}=V_{in}$, a second-order allpass filter can be obtained from V_{o1}.

(vi) If $V_{i3}=0$ (grounded) and $V_{i1}=V_{i2}=V_{in}$, a second-order highpass filter can be obtained from V_{o2} with matching condition $C_1R_4=2C_2R_3$.

This universal filter is particularly attractive for realizing lowpass filter obtained from V_{o1} because two

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capacitors are grounded. The natural frequency ω_0 and quality factor Q are given by

$$\omega_0 = \sqrt{\frac{2}{C_1C_2R_3R_4}}\ \text{, and } Q = \sqrt{\frac{C_1R_4}{2C_2R_3}} \qquad (4)$$

The natural frequency ω_0 can be controlled by R_3 or R_4. Moreover, the quality factor Q can be controlled by the ratio of R_4/R_3 or C_1/C_2.

The second universal filter also shown in Fig.3 is called Circuit B. Its transfer functions, natural frequency ω_0, and the quality factor Q are the same as those of Equations (3a), (3b), and (4), respectively.

If we exchange the RC elements of Circuit A, a new universal filter called Circuit C in Fig.3 can be achieved. Its transfer functions, natural frequency ω_0, and the quality factor Q are given as

$$V_{o1} = \frac{2s^2C_3C_4R_1R_2V_{i3} + 2sC_4R_1V_{i2} + V_{i1}}{2s^2C_3C_4R_1R_2 + 2sC_4R_1 + 1} \qquad (5a)$$

$$V_{o2} = \frac{-sC_3R_2V_{i1} + (1 + 2sC_4R_1)(V_{i2} + sC_3R_2V_{i3})}{2s^2C_3C_4R_1R_2 + 2sC_4R_1 + 1} \qquad (5b)$$

$$\omega_0 = \sqrt{\frac{1}{2C_3C_4R_1R_2}}\ \text{, and } Q = \sqrt{\frac{C_3R_2}{2C_4R_1}} \qquad (5c)$$

The natural frequency ω_0 can be controlled by R_1 or R_2. Moreover, the quality factor Q can be controlled by the ratio of R_2/R_1 or C_3/C_4. Note that, if $V_{i3}=0$ and $V_{i1}=V_{i2}=V_{in}$, a second-order lowpass filter can be obtained from V_{o2} with matching condition $C_3R_2 = 2C_4R_1$.

Five kinds of biquad filters obtained from V_{o1} and V_{o2} , concerning Circuit A, B, and C, are listed in Table 1. From Table 1, one can see that the highpass, bandpass, lowpass, notch and allpass filters can be synthesized from the same output terminal V_{o1}. However, the output terminal V_{o2} can provide only highpass, bandpass, and lowpass filters. The filters require no matching condition except for few applications of V_{o2} Similarly, if the RC elements of Circuit B are exchanged, another universal filter can also be obtained. The transfer functions, natural frequency ω_0 , and the quality factor Q are the same as those of Equations (5a), (5b),and (5c).

3.Sensitivities

Taking into account the nonideal CCIIs, there are two nonideal factors $\alpha=1 \pm \varepsilon_1$ (ε_1 denotes the current tracking error from port x to port z) and $\beta=1 \pm \varepsilon_2$ (ε_2 denotes the voltage tracking error from port y to port x). Note that ε_1 and ε_2 are frequency-dependent compound functions. At low frequency they are real, and exhibit magnitudes that are much lower than unity ($\varepsilon_1 \ll 1$, $\varepsilon_2 \ll 1$). The port relations of a nonideal CCII can be given by $i_z = \pm \alpha i_x$, and $v_x = \beta v_y$. Hence the natural frequency ω_0 and the quality factor Q of Circuit A become

$$\omega_0 = \sqrt{\frac{(1+\alpha_1)}{\alpha_1\alpha_2\beta_1\beta_2C_1C_2R_3R_4}} \qquad (6a)$$

$$Q = \sqrt{\frac{\alpha_1C_1R_4}{(1+\alpha_1)\alpha_2\beta_1\beta_2C_2R_3}} \qquad (6b)$$

The active and passive sensitivities are

$$S^{Q}_{C_1,R_4} = -S^{\omega_0}_{\alpha_2,\beta_1,\beta_2,C_1,C_2,R_3,R_4} = -S^{Q}_{\alpha_2,\beta_1,\beta_2,C_2,R_3} = \frac{1}{2} \qquad (7a)$$

$$S^{\omega_0}_{\alpha_1} = -S^{Q}_{\alpha_1} = -\frac{1}{2}\left(\frac{1}{1+\alpha_1}\right) \qquad (7b)$$

all of which are small since a value is approximately equal to 1. Hence, the proposed universal filters are insensitive to the passive elements they used.

4.Simulation Results

In PSpice simulation, AD844 ICs from Analog Devices have been used to implement CCIIs. To evaluate the performance of the Circuit A, consider the typical values for passive elements: $C_1=C_2=1$nF, $R_3 = 1$kΩ, and $R_4=2$kΩ. This choice leads to f_0= 159.2kHz, and Q=1. Fig.4(a) shows the frequency responses of the highpass, bandpass, and lowpass filters obtained from V_{o1} of Circuit A. Circuit B is demonstrated by choosing $C_1 = C_2 = 1$nF, $R_3 = 1$kΩ, and $R_4 = 2$kΩ. Fig.4(b) shows the frequency responses of the notch filter obtained from V_{o1} and lowpass filter obtained from V_{o2} of Circuit B. The gain and phase responses of allpass filter obtained from V_{o1} of Circuit C are shown in Fig 4(c) with $C_3 = C_4 = 1$nF, $R_1 = 0.5$kΩ, and $R_2 = 1$kΩ. This choice also leads to f_0= 159.2 kHz, and Q = 1.The simulation results are in excellent agreement with the theoretical analysis.

5.Conclusion

A novel configuration for realizing voltage-mode universal filters with three inputs and two outputs is presented. The proposed configuration uses only two second-generation current conveyors and four passive elements. A number of voltage-mode universal filters can be developed from the configuration. The universal filters can realize the highpass, bandpass, lowpass, notch, and allpass filters without changing circuit topology and elements. The proposed configuration provides the following advantages: (i) a number of universal filters can be developed from the configuration, (ii) minimum active and passive elements, (iii) realizing the highpass, bandpass, lowpass, notch, and allpass filters without changing circuit topology and elements, (iv) low active and passive sensitivities. The universal filters require no matching condition except for few applications. All simulation results verified the theoretical analysis.

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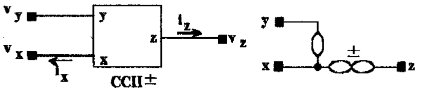


Fig. 1 Symbol and nullor model of CCII±

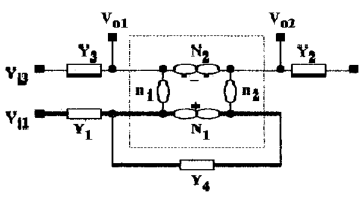


Fig. 2 Configuration for realizing voltage-mode universal biquad filter

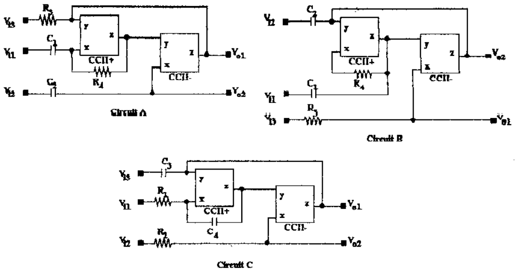
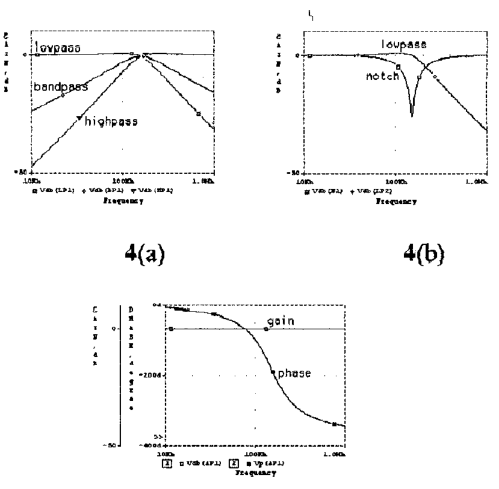


Fig. 3 Proposed voltage-mode universal biquad filters (Circuit A, B, and C)



4(a)

4(b)

4(c)

Fig. 4 Simulation results of (a)highpass, lowpass, and bandpass responses from V_{o1} of Circuit A (b) notch filter from V_{o1} and lowpass filter from V_{o2} of Circuit B (c) gain and phase responses of allpass filter from V_{o1} of Circuit C.

V_{i1}	V_{i2}	V_{i3}	Circuit A (or B)		Circuit C	
			V_{o1}	V_{o2}	V_{o1}	V_{o2}
V_{in}	0	0	HP	BP	LP	BP
0	V_{in}	0	BP	-	BP	-
0	0	V_{in}	LP	-	HP	-
V_{in}	0	V_{in}	notch	LP	notch	HP
V_{in}	$-V_{in}$	V_{in}	AP	-	AP	-
V_{in}	V_{in}	0	-	*HP	-	**LP

HP=highpass,BP=bandpass,LP=lowpass,AP=allpass

*matching condition: $C_1R_4=2C_2R_3$

**matching condition: $C_3R_2=2C_4R_1$

Table 1. Five types of biquad filters obtained from V_{o1} and Y_{o2} concerning Circuit A, B, and C.