A Realization of Biquadratic Current Transfer Functions Using Multiple-Output CCIIs

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Abstract: Circuit configurations for realizing of biquadratic current transfer functions using current conveyors (CCIIs) are presented. The circuits are composed of three multiple-output CCIIs and four passive elements (two resistors and two grounded capacitors), and when current controlled conveyors (CCCIIs) in place of CCIIs are employed, the circuit can be realized using three multiple-output CCCIIs and two grounded capacitors. Use of grounded capacitors is suitable for integrated implementation. The cutoff frequency of a realized filter with current gain K can be tuned independently of Q by the value of K.

1. Introduction

Many circuits for realizing voltage-mode transfer functions using operational amplifiers as active elements have been published. Recently, current-mode circuits have been much attention, and many circuits for realizing current-mode transfer functions using operational transconductance amplifiers (OTAs) and current conveyors(CCIIs) as active elements have been also published [1]-[6]. At present OTAs and CCIIs which have two or more outputs, that is, multiple-outputs, are much attention. Use of multiple-outputs elements may lead to reduction of numbers of active elements for circuit realization. In this paper, we present novel current-mode one-input/three-output type configurations using grounded passive elements and multiple-output CCIIs (MOCCIIs). These circuits realize highpass, bandpass and lowpass transfer functions simultaneously all at high output impedances. All the circuits are composed of grounded capacitors [7]. The cutoff frequency of a realized filter can be tuned independently of Q by the value of current gain K. The circuits have high output impedances that are suitable for current outputs.

2. Multiple-Output CCII (MOCCII)

The symbol of MOCCII is shown in the Figure 1, and the characteristic is given by

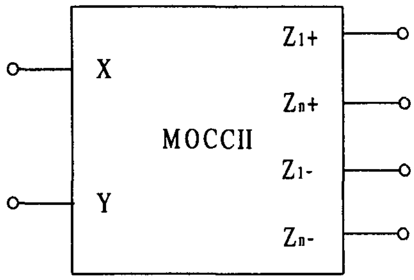

Fig.1 Multiple-output CCII

$$V_X=V_Y,\quad I_Y=0,\quad I_{Zn}=\pm K_n I_X \qquad (1)$$

where, K_n denotes the current gain of the X terminal and the Z terminal [9].

3. Circuit Configuration

The proposed circuit configuration for realizing a biquadratic filter is shown in Fig.2. The transfer functions are given as follows:

$$\frac{I_{HP}}{I_{IN}} = \frac{s^2K_1}{s^2+sK_1K_2/(C_1R_1)+K_1K_2K_3/(C_1C_2R_1R_2)} \qquad (2)$$

$$\frac{I_{BP}}{I_{IN}} = \frac{-sK_1K_2/(C_1R_1)}{s^2+sK_1K_2/(C_1R_1)+K_1K_2K_3/(C_1C_2R_1R_2)} \qquad (3)$$

$$\frac{I_{LP}}{I_{IN}} = \frac{K_1K_2K_3/(C_1C_2R_1R_2)}{s^2+sK_1K_2/(C_1R_1)+K_1K_2K_3/(C_1C_2R_1R_2)} \qquad (4)$$

$$\omega_0=\{K_1K_2K_3/(C_1C_2R_1R_2)\}^{1/2}$$

$$Q=(K_3C_1R_1/K_1K_2C_2R_2)^{1/2}$$

Where K_n(n=1, 2, 3) denotes the gain of MOCCII1, MOCCII2 and MOCCII3, respectively, and K_1K_2 and $K_1K_2K_3$ are positive, respectively. If K_2=1 and K_1=K_3=K, ω_0 can be adjusted independently of Q by the value of current gain K [8], and if K_1=1 and K_1=K_2=K, ω_0 can be also adjusted independently of Q by the value of current gain K. Thus, highpass, bandpass and lowass responses can be simultaneously obtained. Furthermore, by connecting the highpass and lowpass output

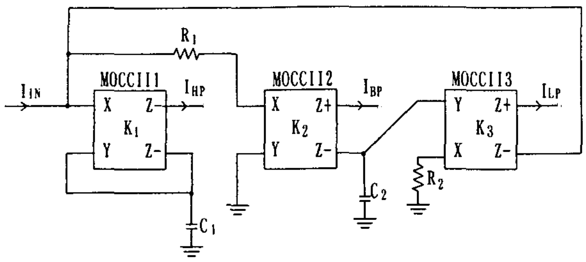

Fig.2 Circuit configuration 1

terminals, a notch response can be obtained as follows:

$$\frac{I_{BS}}{I_{IN}} = \frac{s^2K_1 + K_1K_2K_3/(C_1C_2R_1R_2)}{s^2 + sK_1K_2/(C_1R_1) + K_1K_2K_3/(C_1C_2R_1R_2)} \quad (5)$$

Similarly, by connecting all the outputs and K_1=1, an allpass response can be also obtained.

$$\frac{I_{BS}}{I_{IN}} = \frac{s^2 - sK_1K_2/(C_1R_1) + K_1K_2K_3/(C_1C_2R_1R_2)}{s^2 + sK_1K_2/(C_1R_1) + K_1K_2K_3/(C_1C_2R_1R_2)} \quad (6)$$

The sensitivities of ω_0 and Q to passive elements are given by

$$S^{\omega_0}_{K_1, K_2, K_3} = -S^{\omega_0}_{C_1, C_2, R_1, R_2} = 1/2,$$

$$S^{Q}_{K_3, C_1, R_1} = -S^{Q}_{K_1, K_2, C_2, R_2} = 1/2$$

The sensitivities are rather small.

Current gains K_n are set as shown in Fig.3, the current transfer functions given by

$$\frac{I_{HP}}{I_{IN}} = \frac{s^2}{s^2 + sK_1/(C_1R_1) + K_1K_2/(K_3C_1C_2R_1R_2)} \quad (7)$$

$$\frac{I_{BP}}{I_{IN}} = \frac{-sK_1/(C_1R_1)}{s^2 + sK_1/(C_1R_1) + K_1K_2/(K_3C_1C_2R_1R_2)} \quad (8)$$

$$\frac{I_{LP}}{I_{IN}} = \frac{K_1K_2/(C_1C_2R_1R_2)}{s^2 + sK_1/(C_1R_1) + K_1K_2/(K_3C_1C_2R_1R_2)} \quad (9)$$

$$\omega_0 = \{K_1K_2/(K_3C_1C_2R_1R_2)\}^{1/2}$$

$$Q = (K_2C_1R_1/K_1K_3C_2R_2)^{1/2}$$

When K_3=1 and K_1=K_2=K, ω_0 can be adjusted independently

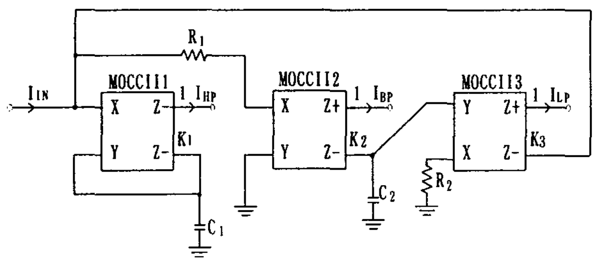

Fig.3 Circuit configuration 2

of Q by the value of current gain K, and when K_2=1 and K_1=K_3=K, Q can be adjusted independently of ω_0 by the value of current gain K.

Figure 4 shows a circuit using three MOCCCIIs and grounded passive elements. A CCCII is equivalent to an active element connecting a resistor to x-terminal of a CCII. Resistors R_1 and R_2 of the circuit of Fig.2 are included in MOCCCIIs, and they can be variable by bias currents, when R_1=R_2=R, the cutoff frequency of a realized filter can be tuned independently of Q by the value of current gain K.

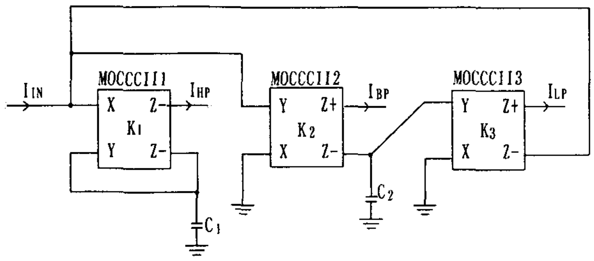

Fig.4 A circuit composed of MOCCCII

Next, let us consider the circuit configurations of Figs.5-7. composed of grounded passive elements. The transfer functions are given by

$$\frac{I_{O1}}{I_{IN}} = \frac{-Y_1Y_3}{Y_2Y_4+Y_3Y_5} \quad (10)$$

$$\frac{I_{O2}}{I_{IN}} = \frac{Y_2Y_3}{Y_2Y_4+Y_3Y_5} \quad (11)$$

$$\frac{I_{O3}}{I_{IN}} = \frac{-Y_2Y_4}{Y_2Y_4+Y_3Y_5} \quad (12)$$

By suitably choosing the kinds of admittances, we can obtain biquadratic transfer functions.

As an example, when admittances are given by the following form:

$$Y_1 = sC_1,\ Y_2 = G_2,\ Y_3 = sC_3,\ Y_4 = G_4,\ Y_5 = sC_5 + G_5 \quad (13)$$

The routine analysis yields the following transfer functions.

$$\frac{I_{O1}}{I_{IN}} = \frac{-s^2C_1C_3}{s^2C_3C_5+sC_3G_5+G_2G_4} \quad (14)$$

$$\frac{I_{O2}}{I_{IN}} = \frac{sC_3}{s^2C_3C_5+sC_3G_5+G_2G_4} \quad (15)$$

$$\frac{I_{O3}}{I_{IN}} = \frac{-G_2G_4}{s^2C_3C_5+sC_3G_5+G_2G_4} \quad (16)$$

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

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

Q can be adjusted independent of ω_0 through G_5. Thus,

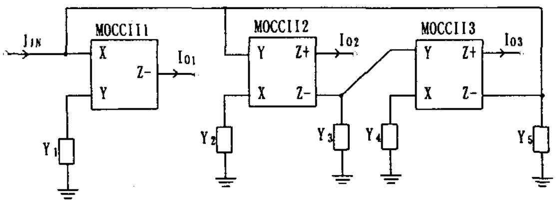

Fig.5 Circuit configuration 3

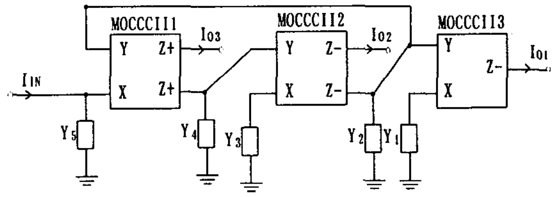

Fig.6 Circuit configuration 4

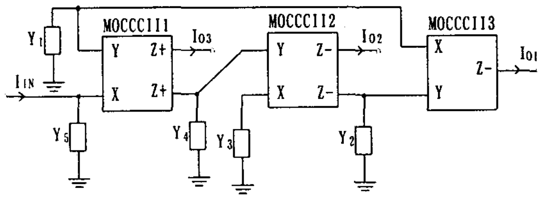

Fig.7 Circuit configuration 5

highpass, bandpass and lowass responses can be simultaneously obtained. Furthermore, by connecting the highpass and lowpass output terminals, a notch response can be obtained

$$\frac{I_{O1}+I_{O3}}{I_{IN}} = \frac{-(s^2C_1C_3+G_2G_4)}{s^2C_3C_5+sC_3G_5+G_2G_4} \tag{17}$$

. Similarly, by connecting all the outputs, an allpass response can be also obtained.

$$\frac{I_{O1}+I_{O2}+I_{O3}}{I_{IN}} = \frac{-(s^2C_1C_3-sC_3G_2+G_2G_4)}{s^2C_3C_5+sC_3G_5+G_2G_4} \tag{18}$$

The sensitivities of ω_0 and Q to passive elements are given by

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

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

The sensitivities are rather small.

When admittances are given by the following form:

$$Y_1=G_1,\ Y_2=sC_2,\ Y_3=G_3,\ Y_4=sC_4,\ Y_5=sC_5+G_5 \tag{19}$$

The routine analysis yields the following transfer functions.

$$\frac{I_{O1}}{I_{IN}} = \frac{-G_1G_3}{s^2C_2C_4+sC_5G_3+G_3G_5} \tag{20}$$

$$\frac{I_{O2}}{I_{IN}} = \frac{sC_2G_3}{s^2C_2C_4+sC_5G_3+G_3G_5} \tag{21}$$

$$\frac{I_{O3}}{I_{IN}} = \frac{-s^2C_2C_4}{s^2C_2C_4+sC_5G_3+G_3G_5} \tag{22}$$

$$\omega_0 = (G_3G_5/C_2C_4)^{1/2}$$

$$Q = (1/C_5)(C_2C_4G_5/G_3)^{1/2}$$

Q can be adjusted independent of ω_0 through C_5. Thus, highpass, bandpass and lowass responses can be simultaneously obtained. Furthermore, by connecting the highpass and lowpass output terminals, a notch response can be obtained.

$$\frac{I_{O1}+I_{O3}}{I_{IN}} = \frac{-(s^2C_2C_4+G_1G_3)}{s^2C_2C_4+sC_5G_3+G_3G_5} \tag{23}$$

Similarly, by connecting all the outputs, an allpass response can be also obtained.

$$\frac{I_{O1}+I_{O2}+I_{O3}}{I_{IN}} = \frac{-(s^2C_2C_4-sC_2G_3+G_1G_3)}{s^2C_2C_4+sC_5G_3+G_3G_5} \tag{24}$$

The sensitivities of ω_0 and Q to passive elements are given by

$$S^{\omega_0}_{G_3,G_5} = -S^{\omega_0}_{C_2,C_4} = 1/2$$

$$S^{Q}_{C_2,C_4,G_5} = -S^{Q}_{G_3} = 1/2, \quad -S^{Q}_{G_5} = 1$$

The sensitivities are rather small.

4. Experimental Results

To verify the theoretical study, the circuit of Fig.2 (K_n=1, n=1, 2, 3) was built in order to realize HP, BP, LP, BS and AP transfer functions. Figure 6 shows an example of MOCCII composed of bipolar transistors [9]. By using CMOSs in place of bipolar transistors in Fig.2, we can also obtain a MOCCII using CMOSs. The experimental frequency responses of lowpass, bandpass, highpass filters with $R_1=R_2=1\text{k}\Omega$, $C_1=C_2/2=10\text{nF}$, $K_1=K_2=K_3=1$, $f_0=11.254\text{kHz}$ and $Q=0.707$ are shown in Figs.7-9. The experimental results agree fairly well with the theoretical characteristics. By experimenting or simulating with transistors which have higher transition frequency, we may obtain better results [10].

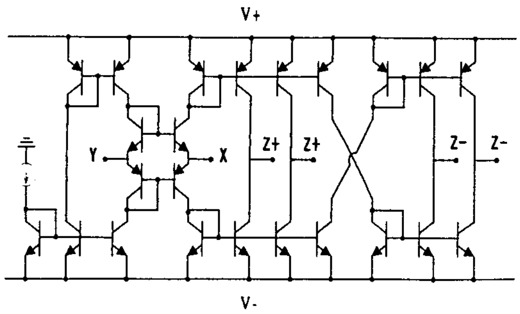

Fig.6 MOCCII composed of bipolar transistors

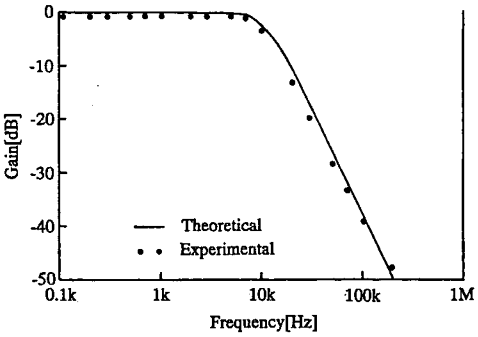

Fig.7 Frequency response of a lowpass filter

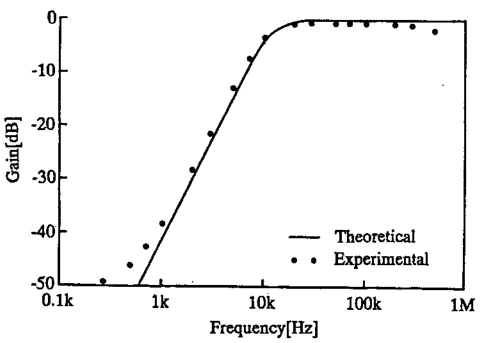

Fig.8 Frequency response of a highpass filter

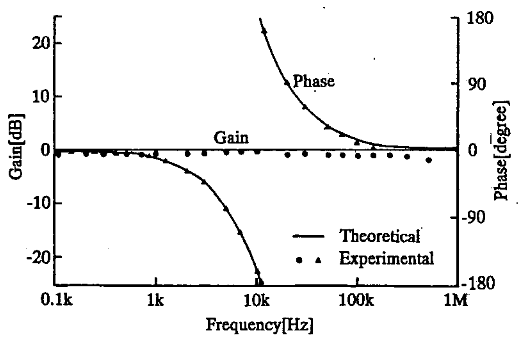

Fig.9 Frequency response of an allpass filter

5. Conclusion

Several circuits for realizing biquadratic transfer functions have been proposed. The circuits realize highpass, bandpass and lowpass transfer functions simultaneously all at high output impedances, by adding output currents, bandstop and allpass transfer functions can be also realized. The cutoff frequency of a realized filter can be tuned independently of Q by the value of current gain K. The circuits have high output impedances that are suitable for current outputs. All the circuits are composed of grounded capacitors. Use of grounded capacitors may be suitable for integrated implementation. The effects of non-ideal MOCCIIs on the transfer functions and the realization of MOCCIIs with good characteristics are future subjects.

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