PROGRAMMABLE CURRENT-MODE UNIVERSAL ACTIVE FILTERS EMPLOYING CURRENT CONVEYORS

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(Received 1 February 1998; In final form 15 April 1998)

Novel current-mode active filter circuits using current-conveyors are presented. The proposed circuits can realize all standard second-order filter functions. The circuits enjoy high output impedances and can, therefore, be easily cascaded to produce higher order filters. Moreover, the realized filter function can be easily programmed using at most a 13-bit digital number without changing the circuit topology.

Keywords: Active filters; current conveyors

1. INTRODUCTION

At present there is a growing interest in designing analog current-mode signal processing circuits. In these circuits the current, rather than the voltage, is used as the active variable either throughout the whole circuit or only in certain critical areas [1]. The use of current as the active parameter can result in circuits operating with higher bandwidths, greater linearity and larger dynamic range than voltage-mode circuits [1, 2]. The current conveyor; a powerful analog building block with a current-mode capability, is therefore a highly potential candidate for implementation of current-mode circuits, and recently a number of realizations has been presented using the first-generation (CCI) and the second-generation (CCII) current-conveyors [3–31].

Despite the fact that many current-conveyor-based universal filters, which implement the lowpass (LP), highpass (HP), bandpass (BP),

bandreject (BR) and allpass (AP) second-order transfer functions, have been presented, no attempt has been reported for investigating the feasibility of programming the filter function. Many applications require filter programmability. For example in analog signal processing the need may arise for the adaptive programming of the filter function.

The major intention of this paper is, therefore, to present two circuit configurations for realizing current-conveyor-based filters with programmable functions. Each circuit uses a single current-conveyor and a number of resistors, capacitors and digitally-controlled switches. Using a 13-bit digital number, both circuits can be configured to provide any of the five basic filter functions.

2. PROPOSED NETWORKS

2.1. First Configuration

Consider the circuit shown in Figure 1(a). Assuming ideal current conveyors with $i_x = i_y = i_z$, $v_x = v_y$ for the CCI and $i_x = i_z$, $i_y = 0$, $v_x = v_y$ for the CCII, routine analysis yields

$$F = \frac{i_o}{i_i} = \frac{-1}{1 + \frac{z_1}{z_2} + \frac{z_1}{z_3} + \frac{z_1 z_4}{z_2 z_3} - \frac{z_4}{z_2}} \quad (1)$$

$$G = \frac{i_1}{i_i} = \frac{-\left(\frac{z_1}{z_3} - 1\right)}{1 + \frac{z_1}{z_2} + \frac{z_1}{z_3} + \frac{z_1 z_4}{z_2 z_3} - \frac{z_4}{z_2}} \quad (2)$$

when the CCI is used, and

$$H = \frac{i_o}{i_i} = \frac{-1}{1 + \frac{z_1}{z_2} + \frac{z_1}{z_3} + \frac{z_1 z_4}{z_2 z_3}} \quad (3)$$

$$K = \frac{i_1}{i_i} = \frac{-\frac{z_1}{z_3}}{1 + \frac{z_1}{z_2} + \frac{z_1}{z_3} + \frac{z_1 z_4}{z_2 z_3}} \quad (4)$$

when the CCII is used.

FIGURE 1 First Configuration.

The current $i_o = -i_z$ is directly obtained through the z -port of the current-conveyor and the current i_1 is obtained through another current conveyor which must exhibit a virtual ground on input. Using Eqs. (1)–(4) all the standard biquads can be realized. Figure 1(b) shows a possible realization of the impedances $Z_1 - Z_4$ and Table I shows the various characteristics of current transfer-functions (TF) which can be obtained by varying the nature of the impedances $Z_1 - Z_4$ using the switches $S_0 - S_9$. From Table I it is easy to see that the current transfer-function (TF) can be programmed by changing the digital number applied to switches $S_0 - S_9$. From Table I it can also be seen that it is possible to adjust parameter ω_o for cases 1–6 without disturbing the parameter ω_o/Q_o . However, the parameter ω_o/Q_o cannot be adjusted without disturbing the parameter ω_o . Thus, these realizations enjoy orthogonal tuning of the parameters ω_o and ω_o/Q_o .

2.2. Second Configuration

Consider the circuit shown in Figure 2(a). Assuming ideal current conveyor, routine analysis yields

$$A = \frac{i_o}{i_i} = \frac{-1}{1 + \frac{z_2}{z_1} + \left(1 + \frac{z_2}{z_1} + \frac{z_3}{z_1}\right) \left(\frac{z_4 - z_5}{z_3}\right)} \quad (5)$$

$$B = \frac{i_1}{i_i} = \frac{-\left(\frac{z_4 - z_5}{z_3}\right)}{1 + \frac{z_2}{z_1} + \left(1 + \frac{z_2}{z_1} + \frac{z_3}{z_1}\right) \left(\frac{z_4 - z_5}{z_3}\right)} \quad (6)$$

when the CCI is used, and

$$M = \frac{i_o}{i_i} = \frac{-1}{1 + \frac{z_2}{z_1} + \left(1 + \frac{z_2}{z_1} + \frac{z_3}{z_1}\right) \frac{z_4}{z_3}} \quad (7)$$

$$N = \frac{i_1}{i_i} = \frac{-\frac{z_4}{z_3}}{1 + \frac{z_2}{z_1} + \left(1 + \frac{z_2}{z_1} + \frac{z_3}{z_1}\right) \frac{z_4}{z_3}} \quad (8)$$

when the CCII is used.

TABLE I Transfer function characteristics for the configuration of Figure 1

Function	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	TF	ω_o^2	$\omega_o Q_o$	Gain	Remarks
1 BP	On	Off	Off	On	On	Off	Off	Off	On	On	K	$\frac{1}{C_1 C_4 R_2 R_3}$	$\frac{R_3 + R_4}{C_1 R_2 R_3}$	$\frac{-R_2}{R_2 + R_3}$	$R_1 = R_4$ $C_1 R_3 = C_1 R_1 + C_3 R_3$
2 BP	Off	On	On	Off	Off	On	X	On	Off	On	K	$\frac{1}{C_2 C_3 R_1 R_4}$	$\frac{C_2 + C_3}{R_4 C_2 C_3}$	$\frac{-C_3}{C_2 + C_3}$	
3 LP	Off	On	On	Off	On	Off	X	On	Off	On	F	$\frac{1}{C_2 C_3 R_1 R_4}$	$\frac{1}{C_2 R_4}$	-1	
4 BR	Off	Off	X	X	On	Off	On	On	On	Off	G	$\frac{1}{C_1 C_3 R_1 R_3}$	$\frac{2}{C_3 R_1}$	-1	
5 LP	Off	On	On	Off	Off	On	X	On	Off	On	H	$\frac{1}{C_2 C_3 R_1 R_4}$	$\frac{C_2 + C_3}{R_4 C_2 C_3}$	-1	
6 HP	On	Off	Off	On	On	Off	Off	Off	On	On	H	$\frac{1}{C_1 C_4 R_2 R_3}$	$\frac{R_3 + R_4}{C_1 R_2 R_3}$	-1	
7 AP	Off	On	Off	Off	Off	Off	Off	On	Off	On	F	$\frac{1}{C_2 C_3 R_2 R_3}$	$\frac{C_2 R_3 + C_3 R_3}{C_2 C_3 R_2 R_3}$	-1	

X = On or Off.

$$R_3 = R_1 \left(1 + \frac{R_2}{R_4} + \frac{R_3}{R_4} \right)$$

$$C_2 R_4 = R_1 (C_2 + C_3) + 2(C_2 R_3 + C_3 R_3)$$

FIGURE 2 Second Configuration.

Using Eqs. (5)–(8) all the standard biquads can be realized. Figure 2(b) shows a possible realization of the impedances $Z_1 - Z_5$ and Table II shows the various characteristics of current transfer-functions (TF) which can be obtained by varying the nature of the impedances $Z_1 - Z_5$ using the switches $S_0 - S_{12}$. From Table II it is easy to see that the current transfer-function (TF) can be programmed by changing the digital number applied to switches $S_0 - S_{12}$. From Table II it can also be seen that it is possible to adjust parameter ω_o for case 1 without

TABLE II Transfer function characteristics for the configuration of Figure 2

	<i>Function</i>	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9	S_{10}	S_{11}	S_{12}	TF	ω_o^2	ω_o/Q_o	<i>Gain</i>	<i>Remarks</i>
1	BP	X	X	On	On	On	Off	On	On	On	Off	Off	Off	Off	A	$\frac{1}{C_3 C_4 R_3 R_5}$	$\frac{1}{C_3 R_5}$	$\frac{R_3}{R_5}$	$C_3 = C_5$
2	Osc.	X	X	On	On	On	Off	On	On	On	Off	Off	Off	Off	A	$\frac{1}{C_2 C_3 R_1 R_4}$			$C_3 R_3 + C_5 R_5 = C_3 R_3$
3	HP	On	Off	Off	On	On	Off	Off	On	Off	On	On	X	On	A	$\frac{1}{C_2 C_4 R_1 R_5}$	$\frac{C_4 R_3 + C_5 R_1 + C_5 R_5}{C_2 C_4 R_1 R_5}$	-1	
4	LP	Off	On	On	Off	Off	On	X	Off	On	On	On	X	On	M	$\frac{1}{C_1 C_3 R_3 R_5}$	$\frac{C_1 R_3 + C_3 R_1 + C_5 R_4}{C_1 C_3 R_3 R_4}$	-1	
5	BR	X	X	On	On	On	Off	On	Off	Off	On	Off	On	Off	B	$\frac{1}{C_4 C_5 R_4 R_5}$	$\frac{2}{C_5 R_4}$		$R_3 = 2R_5, C_3 = \frac{1}{2}C_5,$ $C_4 R_4 + C_5 R_5 = C_4 R_5$
6	AP	X	X	On	On	On	Off	Off	On	On	On	Off	On	Off	A	$\frac{1}{C_2 C_5 R_3 R_5}$	$\frac{C_4 R_3 + C_5 R_5}{C_2 C_5 R_3 R_5}$	-1	$C_3 R_3 + C_5 R_5 = \frac{1}{2}C_3 R_5$
7	LP	Off	On	On	Off	On	Off	Off	On	Off	On	On	X	On	B	$\frac{1}{C_1 C_4 R_3 R_5}$	$\frac{C_4 R_3 + C_1 R_5 + C_1 R_5}{C_1 C_4 R_3 R_5}$	-1	
																N			

X = On or Off.

disturbing the parameter ω_o/Q_o . However, the parameter ω_o/Q_o cannot be adjusted without disturbing the parameter ω_o . Thus, this realization enjoys orthogonal tuning of the parameters ω_o and ω_o/Q_o .

Finally, Table II shows that a sinusoidal oscillator can be realized in case 2.

3. FIRST-ORDER FILTER SECTIONS

First-order highpass and lowpass filter actions can be obtained from the circuit of Figure 1(a) by setting $Z_2 = \infty$, thus Eqs. (3) and (4) reduce to

$$H = \frac{i_0}{i_i} = \frac{-Z_3}{Z_1 + Z_3} \quad (9)$$

and

$$K = \frac{i_1}{i_i} = \frac{-Z_1}{Z_1 + Z_3} \quad (10)$$

respectively. Therefore, by choosing $Z_1 = R_1$ and $Z_3 = 1/sC_3$, Eqs. (9) and (10) reduce to

$$H(s) = \frac{I_0}{I_i} = \frac{-1}{1 + sC_3R_1} \quad (11)$$

and

$$K(s) = \frac{I_1}{I_i} = \frac{-sC_3R_1}{1 + sC_3R_1} \quad (12)$$

respectively. Equation (11) corresponds to the current transfer-function (TF) of the first-order LPF and Eq. (12) corresponds to the transfer function of a first-order HPF. Similar results can be obtained by setting $Z_1 = \infty$ in Figure 2(a).

4. DISCUSSION AND CONCLUSION

From Tables I and II it is obvious that all the standard biquads can be obtained from the configurations of Figures (1) and (2) by closing or

opening the appropriate switches using, at most, a 13-bit digital word. The first order highpass and lowpass filter sections, can also be obtained.

By defining the sensitivity of a parameter F to the element of variation x_i by

$$S_{x_i}^F = \frac{x_i}{F} \frac{dF}{dx_i}$$

it is easy to show that the sensitivity of the parameters ω_o and ω_o/Q_o are less than unity. Thus the proposed configurations enjoy low sensitivities.

By using CMOS-SPST switches and if the control voltages of these switches are obtained from the output port of a microprocessor, then the implementation of a microprocessor-controlled universal current-mode filter networks is feasible.

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