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Research note

Mixed-mode biquad circuits

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Two new mixed-mode biquad circuits are given. Each circuit employs four current conveyors, two grounded capacitors and four resistors. The biquad circuits are designed to be driven by currents and to realize highpass, bandpass and lowpass voltage responses at three different outputs. All the ω_0 and the Q passive and active sensitivities are very low ($\leqslant 1$). Copyright © 1996 Elsevier Science Ltd.

1. Introduction

Recently two new realizations of the Kerwin–Huelsman–Newcomb (KHN) biquad [1] have been introduced in the literature [2]. The active element used is the current conveyor (CC II) which is defined by the following matrix equation [3]:

$$\begin{bmatrix} i_y \\ v_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ B & 0 & 0 \\ 0 & K & 0 \end{bmatrix} \begin{bmatrix} v_y \\ i_x \\ v_z \end{bmatrix} \tag{1}$$

For positive K the CC II is defined as a non-inverting CC II. On the other hand, if K is negative the CC II is defined as an inverting CC II. In the ideal case $B = |K| = 1$. Practically, B and K are frequency dependent and for frequencies much less than the f_{3dB} of the CC II, B and K are real quantities of magnitudes slightly less than one. For the commercially available CC II01, both B and K have a $f_{3dB} = 100\,\text{MHz}$ [4]. In analog signal processing applications it may be desirable to have active filters with input currents and output voltages [5], defined here as mixed-mode filters.

In this research note two new realizations of the mixed-mode biquad filters are given. Each biquad circuit employs four CC IIs and is capable of realizing the highpass, bandpass and lowpass voltage responses at three alternative outputs.

2. The biquad circuits

The proposed circuits are based on using the summer circuit of Fig. 1, which employs a CC II and two resistors. This summer circuit is driven by the current source I_i and the two voltages V_a and V_b. The voltage V_1 is given by:

$$V_1 = K_1\left[\frac{B_1 V_a}{R_3} - \frac{V_b}{R_3} - I_i\right] R_4 \tag{2}$$

Figure 2 represents the class I mixed-mode biquad circuit in which the summer input V_a is driven from the output of the first voltage integrator. The second summer input V_b is connected to the X terminal of a fourth CC II acting as a voltage follower feeding-back V_3 to the summer circuit. It is seen that the two capacitors as well as three of the four resistors employed are grounded. The mixed-mode transfer functions (assuming $B_i = 1$) are given by:

$$\frac{V_1}{I_i} = \frac{-K_1 R_4 s^2}{D(s)} \tag{3}$$

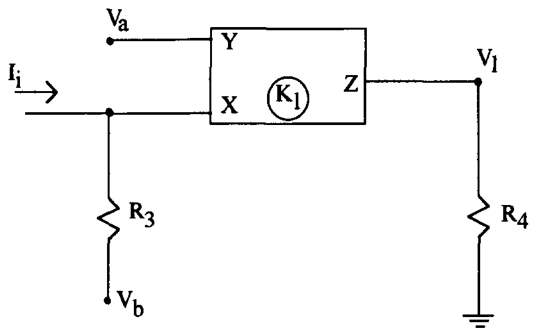

Fig. 1. The summer circuit.

$$\frac{V_2}{I_i} = \frac{\frac{-K_1K_2R_4}{C_1R_1}s}{D(s)} \quad (4)$$

$$\frac{V_3}{I_i} = \frac{\frac{-K_1K_2K_3R_4}{C_1C_2R_1R_2}}{D(s)} \quad (5)$$

where

$$D(s) = s^2 + \frac{-K_1K_2R_4}{C_1R_1R_3}s + \frac{K_1K_2K_3R_4}{C_1C_2R_1R_2R_3} \quad (6)$$

From the above equation it is seen that the necessary conditions for the stability of the circuit are that $K_1K_2K_3$ must be positive and K_1K_2 must be negative. This implies that K_3 must be negative. The two possible sets of the signs combinations of the CC IIs together with the corresponding signs of the transfer functions are given in Table 1.

From eq. (6) and assuming $|K_i| = 1$, the ω_0 and the Q of the filter are given by:

$$\omega_0 = \sqrt{\frac{R_4}{C_1C_2R_1R_2R_3}} \quad (7)$$

$$Q = \sqrt{\frac{C_1R_1R_3}{C_2R_2R_4}} \quad (8)$$

The ω_0 and the Q sensitivities to all resistors and capacitors are very small and equal to ± 0.5.

For a given ω_0 and Q and in order to limit the resistors spread to Q the design equations are given by:

$$C_1 = C_2 = C \quad (9)$$

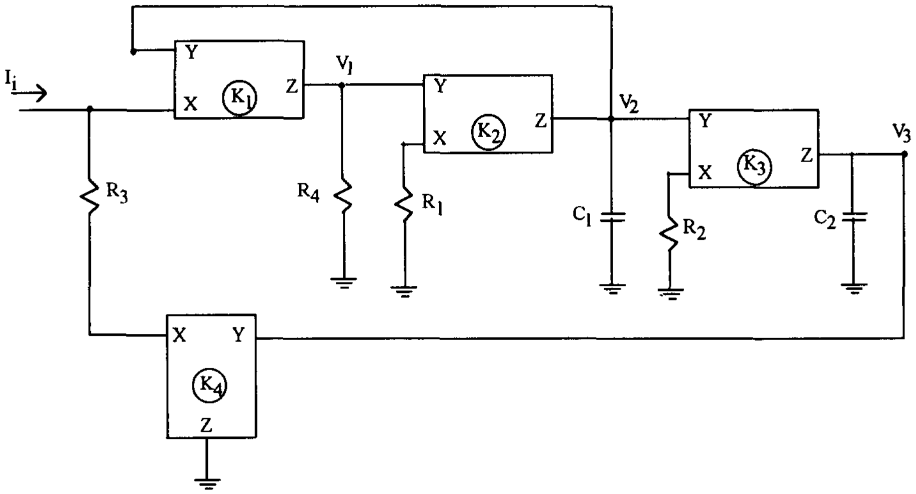

Fig. 2. The class I mixed-mode biquad circuit.

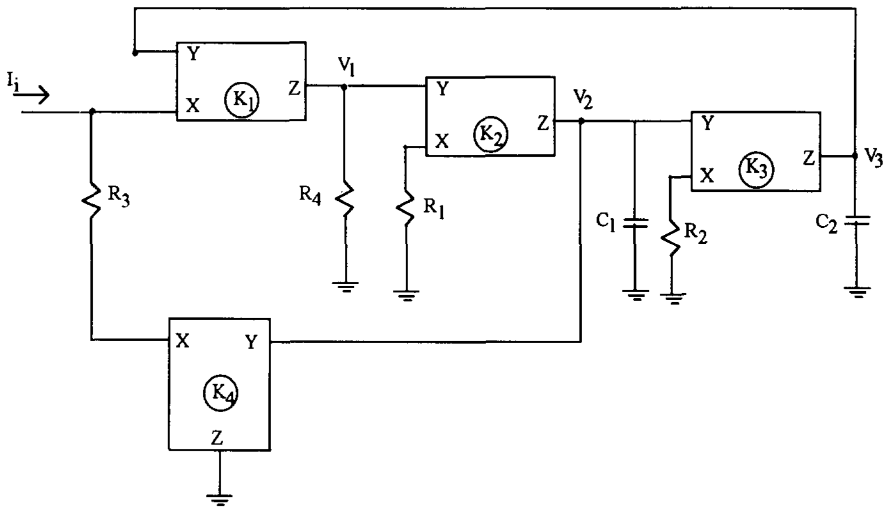

Fig. 3. The class II mixed-mode biquad circuit.

TABLE 1 The CC II polarity and the corresponding transfer function signs

Biquad Circuit		CC II polarity			Transfer function sign		
Class	Type	K_1	K_2	K_3	HP	BP	LP
I Fig.2	A	-	+	-	+	+	-
	B	+	-	-	-	+	-
II Fig.3	A	-	-	-	+	-	+
	B	+	+	-	-	-	+

$$R_1 = R_3 = \frac{1}{\omega_0 C} \qquad (10)$$

$$R_2 = R_4 = \frac{1}{Q\omega_o C} \qquad (11)$$

Taking the effect of non-ideal CC IIs into consideration it is seen that all the ω_0 and the Q active sensitivities have magnitudes $\leqslant 1$ as given in Table 2.

TABLE 2 The ω_0 and the Q active sensitivities

Biquad Circuit	S_x \ x	K_1	K_2	K_3	B_1	B_2	B_3	B_4
Class I Fig.2	$S_x^{\omega_o}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
	S_x^{Q}	$-\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	-1	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$
Class II Fig.3	$S_x^{\omega_o}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	0
	S_x^{Q}	$-\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	$\frac{1}{2}$	$-\frac{1}{2}$	$\frac{1}{2}$	-1

Figure 3 represents the class II biquad circuit. In this case V_3 is fedback to the summer circuit at its Y terminal, whereas V_2 is connected to the Y terminal of the fourth CC II. The CC II polarities are given in Table 1, the design equations are the same as in the class I biquad and the active sensitivities are given in Table 2.

References

[1] W. Kerwin, L. Huelsman and R. Newcomb, State variable synthesis for insensitive integrated circuit transfer functions, *IEEE J. Solid State Circuits*, SC-2 (1967) 87–92.

[2] A.M. Soliman, Kerwin–Huelsman–Newcomb circuit using current conveyors, *Electron. Lett.*, 30 (1994) 2019–2020.

[3] A. Sedra and K.C. Smith, A second generation current conveyor and its applications, *IEEE Trans.*, CT-17 (1970) 132–134.

[4] LTP Electronics, Current conveyor amplifier CC II 01, *Data sheet*, 1.1–1.11.

[5] J. Ramirez-Angulo, M. Robinson and E. Sanchez-Sinencio, Current mode continuous time filters, *IEEE Trans.*, CAS-39 (1992) 337–341.