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A NOVEL MIXED-MODE CURRENT-CONTROLLED CURRENT-CONVEYOR-BASED FILTER

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A new mixed-mode biquad circuit is presented. The circuit uses four dual-output second-generation current-controlled current-conveyors (DOCCCIIs) and two grounded capacitors and can realize lowpass, highpass, bandpass and notch responses from the same topology. The circuit can be driven by voltage or current and its output can be voltage or current. The parameters ω_o and ω_o/Q_o enjoy independent electronic tunability. Simulation results are included.

Keywords: Active filters; Current conveyors

1 INTRODUCTION

Recently, the second-generation current-controlled conveyor (CCCII) was introduced [1]. This CCCII allows current conveyor applications to be extended to the domain of electronically programmable functions. Electronic programmability of the CCCII is attributed to the dependence of the parasitic resistance at port x on the bias current of the current-conveyor. Figure 1(a) shows the electrical symbol of the CCCII±. Using the CCCII± several realizations either in current-mode, where the input and output variables are currents, or in voltage-mode, where the input and output variables are voltage, have been reported; see for example [1–18] and the references cited therein.

In analog signal processing applications it may be desirable to have active filters with input currents and/or voltages and output currents and/or voltages, that is mixed-mode filters [19, 20]. Careful inspection of the available literature shows that while mixed-mode realizations with input current and output voltage are available [19, 20], no circuit realization is available for realizing a generalized mixed-mode active filter with input current or voltage and output current or voltage. It is the aim of this paper to present such a generalized mixed-mode circuit using the CCCII±.

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2 PROPOSED CIRCUIT

The proposed circuit is shown in Figure 1(b). Using the standard notations, the CCCII± can be characterized by [1] $i_y = 0, v_x = i_x R_x + v_y$ and $i_{z\pm} = \pm i_x$, where

$$R_x = \frac{V_T}{2I_b} \tag{1}$$

is the input resistance at port x, V_T is the thermal voltage and I_b is the bias current of the CCCII±. Routine analysis of the circuit of Figure 1(b) yields the transfer functions given by

$$V_{out1} = \frac{N_1(s)}{D(s)} \tag{2}$$

$$V_{out2} = -\frac{N_2(s)}{D(s)} \tag{3}$$

$$V_{out3} = \frac{V_{in1} - V_{out2}}{sC_2R_{x2}} + \frac{1}{sC_2} I_{in2} \tag{4}$$

$$I_{out1} = \frac{1}{R_{x1}} \frac{N_1(s)}{D(s)} \tag{5}$$

$$I_{out2} = \frac{1}{R_{x2}} \frac{N_3(s)}{D(s)} \tag{6}$$

$$I_{out3} = \frac{V_{out3}}{R_{x3}} \tag{7}$$

and

$$I_{out4} = \frac{1}{R_{x4}} \frac{N_4(s)}{D(s)} \tag{8}$$

where

$$N_1(s) = s^2C_1C_2R_{x1}R_{x2}R_{x3}I_{in1} + sC_1R_{x1}R_{x2}I_{in2} - sC_1R_{x1}V_{in1} - s^2C_1C_2\frac{R_{x1}R_{x2}R_{x3}}{R_{x4}}V_{in2} \tag{9}$$

$$N_2(s) = sC_2R_{x2}R_{x3}I_{in1} + R_{x2}I_{in2} - V_{in1} - sC_2\frac{R_{x2}R_{x3}}{R_{x4}}V_{in2} \tag{10}$$

$$N_3(s) = sC_2R_{x2}R_{x3}I_{in1} + R_{x2}I_{in2} + \left(sC_2\frac{R_{x2}R_{x3}}{R_{x4}} + s^2C_1C_2R_{x2}R_{x3}\right)V_{in1} - sC_2\frac{R_{x2}R_{x3}}{R_{x4}}V_{in2} \tag{11}$$

$$N_4(s) = sC_2R_{x2}R_{x3}I_{in1} + R_{x2}I_{in2} - V_{in1} + (1 + s^2C_1C_2R_{x2}R_{x3})V_{in2} \tag{12}$$

and

$$D(s) = 1 + sC_2\frac{R_{x2}R_{x3}}{R_{x4}} + s^2C_1C_2R_{x2}R_{x3}. \tag{13}$$

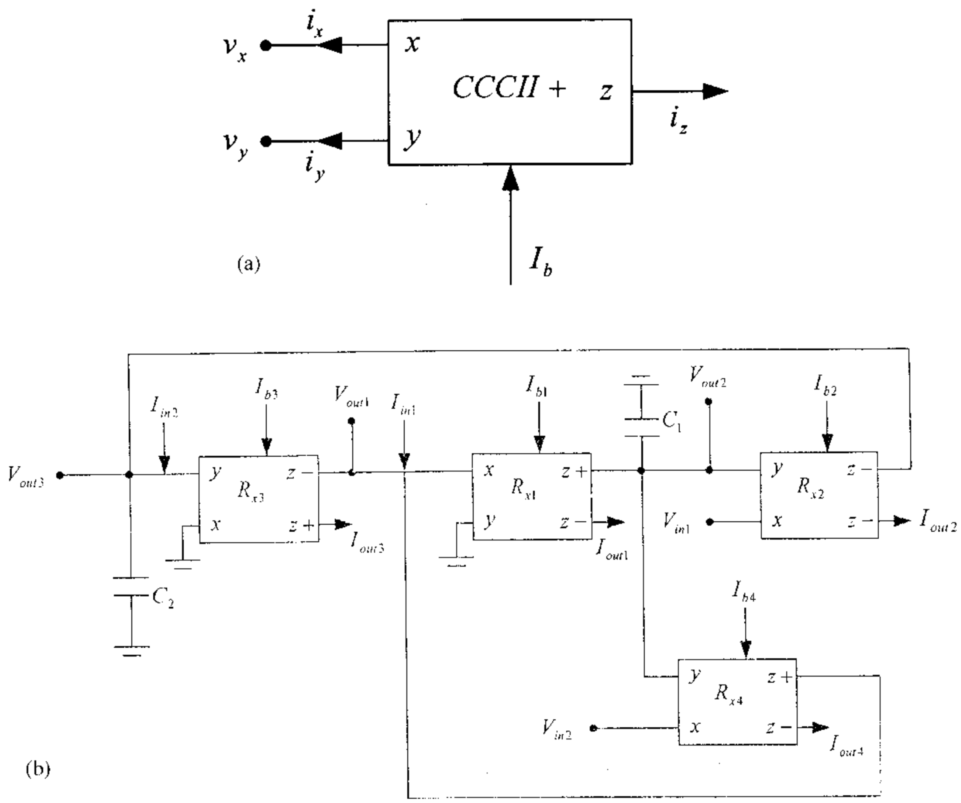

FIGURE 1 (a) Electrical symbol of the CCCII$\pm$; (b) Proposed circuit.

Inspection of Eqs. (2)–(12) shows that various inverted and non-inverted mixed-mode filter functions, with input voltage or current and output voltage or current, can be realized. For example:

1. With $I_{in1} = I_{in2} = V_{in2} = 0$, the following voltage-mode responses with input voltage and output voltages, and mixed-mode responses with input voltage and output currents are obtained:

   a. inverted bandpass-filters (BPFs) from V_{out1} and I_{out1},
   b. non-inverted lowpass-filter (LPF) from V_{out2},
   c. inverted lowpass-filter (LPF) from I_{out4}.

2 With $I_{in1} = I_{in2} = V_{in1} = 0$, the following voltage-mode responses with input voltage and output voltages, and mixed-mode responses with input voltage and output currents are obtained:

   a. inverted highpass-filters (HPFs) from V_{out1} and I_{out1},
   b. non-inverted bandpass-filter (BPF) from V_{out2} and inverted BPF from I_{out2},
   c. non-inverted notch filter (NF) from I_{out4},
   d. inverted lowpass-filter (LPF) from V_{out3} and I_{out3}.

3. With $I_{in1} = I_{in2} = 0$ and $V_{in1} = V_{in2}$, a non-inverted mixed-mode highpass-filter (HPF) is obtained from I_{out2}.

4. With $V_{in1} = V_{in2} = I_{in2} = 0$, the following current-mode responses with input current and output currents, and mixed-mode responses with input current and output voltages are obtained:
   a. non-inverted highpass-filters (HPFs) from V_{out1} and I_{out1},
   b. inverted bandpass-filter (BPF) from V_{out2},
   c. non-inverted bandpass-filters (BPFs) from I_{out2} and I_{out4},
   d. non-inverted lowpass-filter (LPF) from V_{out3} and I_{out3}.
5. With $V_{in1} = V_{in2} = I_{in1} = 0$, the following current-mode responses with input current and output currents, and mixed-mode responses with input current and output voltage are obtained:
   e. non-inverted bandpass-filters (BPFs) from V_{out1} and I_{out1},
   f. inverted lowpass-filter (LPF) from V_{out2},
   g. non-inverted lowpass-filters (LPFs) from I_{out2} and I_{out4}.

Inspection of Eq. (13) shows that in all cases, the parameters ω_o^2 and ω_o/Q_o are given by

$$\omega_o^2 = \frac{1}{C_1 C_2 R_{x2} R_{x3}} \tag{14}$$

and

$$\frac{\omega_o}{Q_o} = \frac{1}{C_1 R_{x4}}. \tag{15}$$

Thus the parameter ω_o^2 can be controlled by adjusting the biasing currents I_{b2} and/or I_{b3} without disturbing the parameter ω_o/Q_o, and the parameter ω_o/Q_o can be controlled by adjusting the biasing current I_{b4} without disturbing the parameter ω_o^2. Thus, the proposed circuit enjoys the attractive feature of independent electronic tunability of the parameters ω_o^2 and ω_o/Q_o.

3 SIMULATION RESULTS

The proposed circuit was simulated using the PSPICE circuit simulation program. The DOCCCII± were modelled using the realization reported in [2]. The results obtained from a current-mode LPF, a current-mode HPF, a current-mode BPF and a mixed-mode notch filter (NF), with $C_1 = C_2 = 0.5\,\mu F$, $I_{b1} = 50\,\mu A$, $I_{b2} = 625\,\mu A$, $I_{b3} = 62.5\,\mu A$ and $I_{b4} = 31.2\,\mu A$ are shown in Figures 2–5. Figures 2–5 also show calculations made using Eqs. (2)–(13). It appears from Figures 2–5 that the simulated and calculated results are in fairly good agreement.

4 CONCLUSIONS

In this paper a new mixed-mode biquad circuit has been presented. The circuit uses four dual-output second-generation current-controlled current-conveyors and can realize lowpass, highpass, bandpass and notch biquad filter responses. The parameters of the filter responses enjoy independent electronic tunability and low passive sensitivities. The circuit can realize mixed mode filter responses. Thus, a voltage input may result in either a current or a voltage output. Also, a current input may result in either a current or a voltage output. While the simulation results confirm the theory presented in this paper, the discrepancies between the calculated and simulated results are attributed to the simplified model used in the analysis.

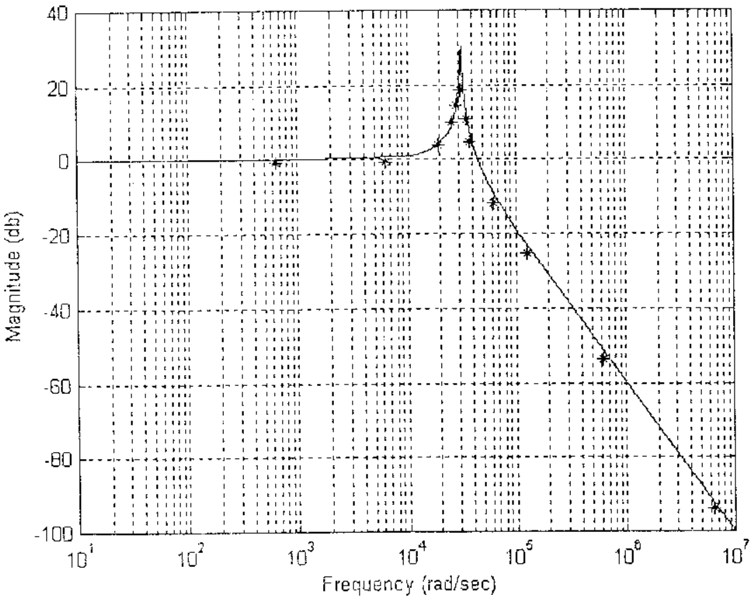

FIGURE 2 Calculated (____) and simulated (**) characteristics of the current-mode LPF obtained from I_{out3} with $V_{in1} = V_{in2} = I_{in2} = 0$.

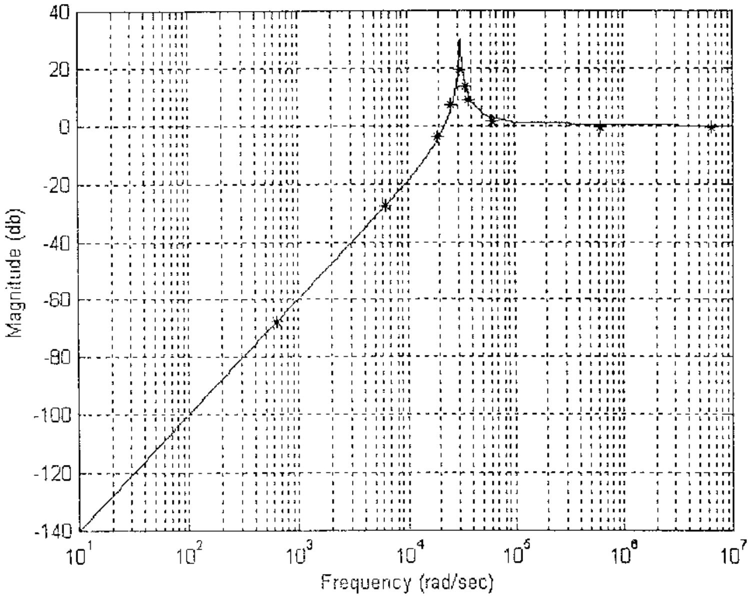

FIGURE 3 Calculated (____) and simulated (**) characteristic of the current-mode HPF obtained from I_{out1} with $V_{in1} = V_{in2} = I_{in2} = 0$.

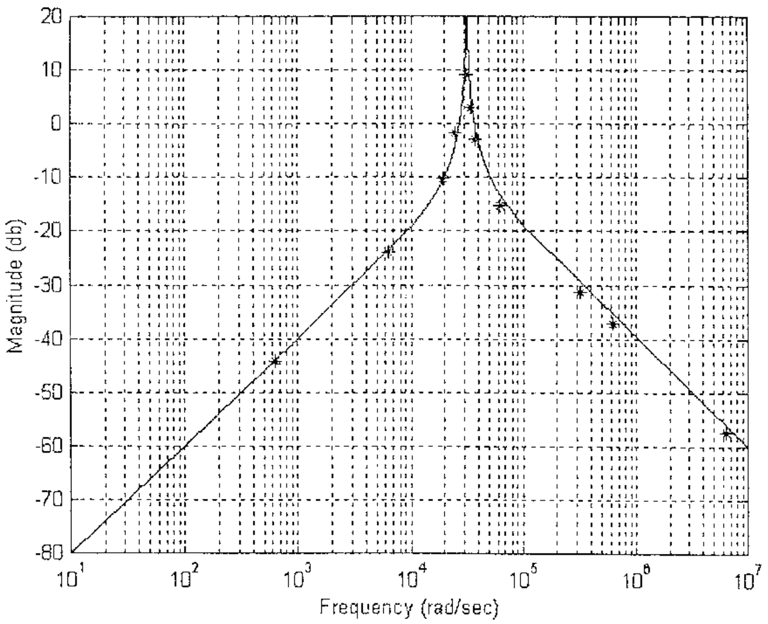

FIGURE 4 Calculated (____) and simulated (**) characteristics of the current-mode BPF obtained from I_{out2} with $V_{in1} = V_{in2} = I_{in2} = 0$.

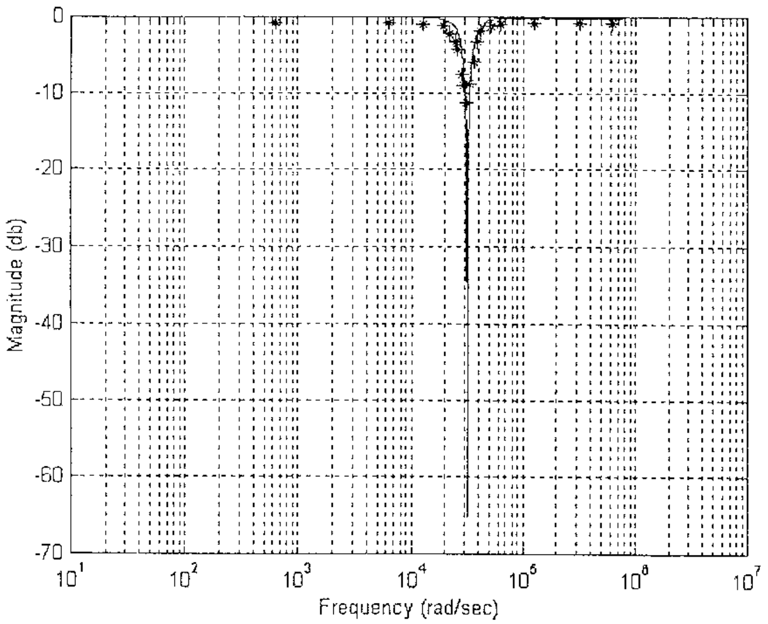

FIGURE 5 Calculated (____) and simulated (**) characteristic of the mixed-mode notch filter (NF) obtained from I_{out4} with $I_{in1} = I_{in2} = V_{in1} = 0$.

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