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A NOVEL MIXED-MODE CCII-BASED FILTER

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A new mixed-mode biquad circuit is presented. The circuit uses five second-generation current conveyors, seven resistors, and two grounded capacitors and can realize lowpass, highpass, bandpass, notch, lowpass notch, highpass notch and allpass 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

At present, there is a growing interest in designing various active filter transfer functions using current conveyors. This is attributed to their low power consumption, low-supply voltages, higher signal bandwidths, greater linearity, and larger dynamic range [1, 2]. Thus, a number of circuit realizations for universal current-mode and voltage-mode filters were proposed; see, for example, Refs. [3–23] and the references cited therein. While some of these realizations use single-output plus- and/or minus-type second-generation current conveyors (CCIIs) to realize current- and voltage-mode transfer functions [3–9, 16–21, 23], other realizations use dual- and/or multiple-output CCIIs [10–15, 22].

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 [24–26]. Careful inspection of the available literature shows that while mixed-mode realizations with input current and output voltage are available [24–26], 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 major intention of this article to present such a generalized mixed-mode circuit using single- and dual-output plus- and minus-type CCIIs.

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2 PROPOSED CIRCUIT

The proposed circuit is shown in Figure 1. Routine analysis yields the transfer functions given by

$$V_{\text{out}} = \frac{R_4 R_7}{R_2 R_3} \frac{N(s)}{D(s)} \tag{1}$$

and

$$I_{\text{out}} = -\frac{R_4}{R_2 R_3} \frac{N(s)}{D(s)}, \tag{2}$$

where

$$\begin{aligned} N(s) = s^2 V_{\text{in3}} - \frac{sV_{\text{in4}}}{C_1 R_6} - \frac{sV_{\text{in2}}}{C_1 R_5} + \frac{V_{\text{in1}}}{C_1 C_2 R_1 R_5} \\ + s^2 R_3 I_{\text{in3}} - \frac{sI_{\text{in2}}}{C_1} + \frac{I_{\text{in1}}}{C_1 C_2 R_5} \end{aligned} \tag{3}$$

and

$$D(s) = s^2 + \frac{sR_4}{C_1 R_3 R_6} + \frac{R_4}{C_1 C_2 R_1 R_3 R_5}. \tag{4}$$

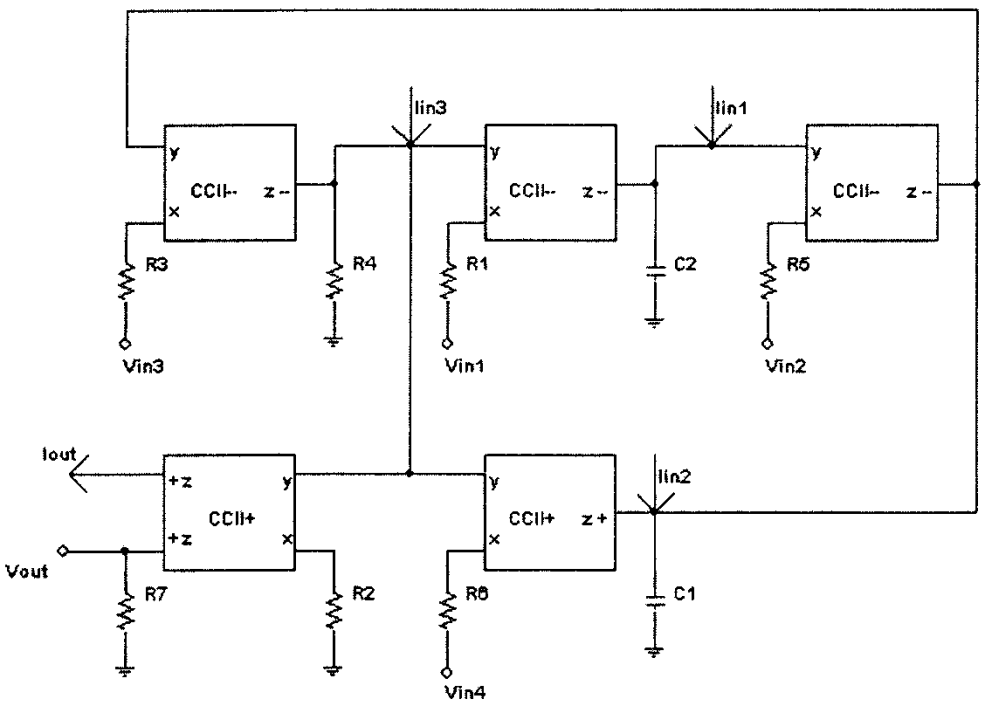

FIGURE 1 Proposed mixed-mode CCII-based filter.

Inspection of Eqs. (3) and (4) 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 $I_{in1} = I_{in2} = I_{in3} = 0$, the following voltage-mode responses, with input voltages and output voltage, and mixed-mode responses, with input voltages and output current are obtained:
   a. A non-inverted highpass filter (HPF) with $V_{in1} = V_{in2} = V_{in4} = 0$.
   b. A non-inverted lowpass filter (LPF) with $V_{in2} = V_{in3} = V_{in4} = 0$.
   c. An inverted bandpass filter (BPF) with $V_{in1} = V_{in3} = V_{in2} = 0$ or $V_{in1} = V_{in3} = V_{in4} = 0$.
   d. A non-inverted notch filter (NF) with $V_{in1} = V_{in3}$ and $V_{in2} = V_{in4} = 0$.
   e. In case d, a notch, lowpass notch, and highpass notch can be obtained by adjusting R_3 and R_4.
   f. A non-inverted allpass filter (APF) with $R_3 = R_4$ and $V_{in2} = 0$, $V_{in1} = V_{in3} = V_{in4}$ or with $R_3 = R_4$, $R_5 = R_6$, and $V_{in4} = 0$, $V_{in1} = V_{in2} = V_{in3}$.

   In cases 1a–f, the polarities are referred to the voltage-mode outputs. For the mixed-mode outputs, the polarities are the opposite; for example, in case la an inverted HPF will be obtained.
2. With $V_{in1} = V_{in2} = V_{in3} = 0$, the following current-mode responses, with input currents and output current, and mixed-mode responses, with input currents and output voltage, are obtained:
   a. A non-inverting LPF with $I_{in2} = I_{in3} = 0$.
   b. An inverting BPF with $I_{in1} = I_{in3} = 0$.
   c. A non-inverting HPF with $I_{in1} = I_{in2} = 0$.
   d. A non-inverting NF with $I_{in1} = I_{in3}$ and $I_{in2} = 0$.
   e. In case d, a notch, lowpass notch, and high pass notch can be obtained by adjusting R_1 and R_5.
   f. A non-inverting APF with $I_{in1} = I_{in2} = I_{in3}$ and $R_1 = R_4 = R_6$.

   Again in cases 2a–f, the polarities are referred to the mixed-mode outputs. For the current-mode outputs, the polarities are the opposite; for example, in case 2a an inverted LPF will be obtained.

Inspection of Eq. (4) shows that in all cases the parameters ω_o^2 and ω_o/Q_o are given by

$$\omega_o^2 = \frac{R_4}{R_1 R_3 R_5 C_1 C_2} \tag{5}$$

and

$$\frac{\omega_o}{Q_o} = \frac{R_4}{R_3 R_6 C_1}. \tag{6}$$

Thus the parameter ω_o^2 can be controlled by adjusting the resistances R_1 and/or R_5 without disturbing the parameter ω_o/Q_o, and the parameter ω_o/Q_o can be controlled by adjusting resistance R_6 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.

Using Eqs. (5) and (6), it is easy to show that all the passive sensitivities of the parameters ω_o and ω_o/Q_o are less than unity. Thus the circuit parameters enjoy low passive sensitivities.

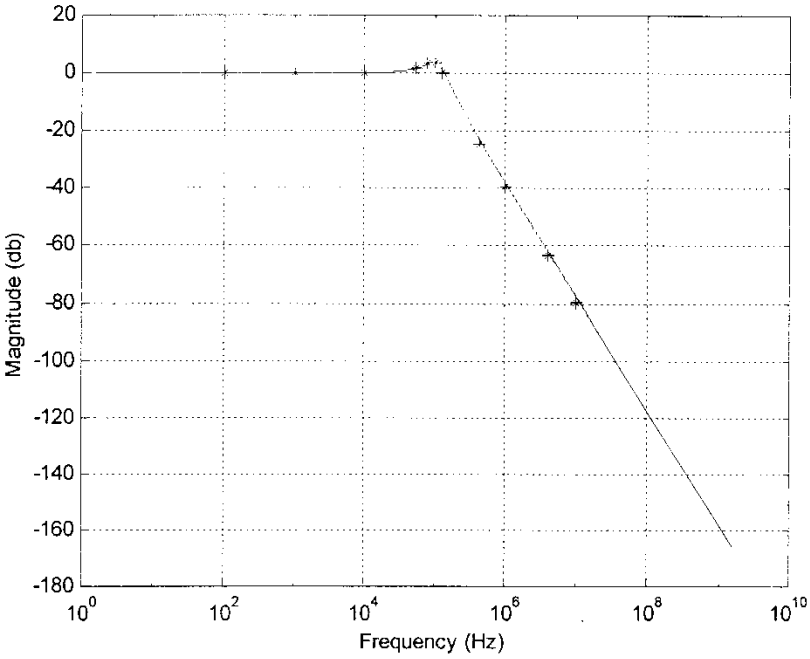

FIGURE 2 Calculated (——) and simulated (∗∗) current-mode lowpass response.

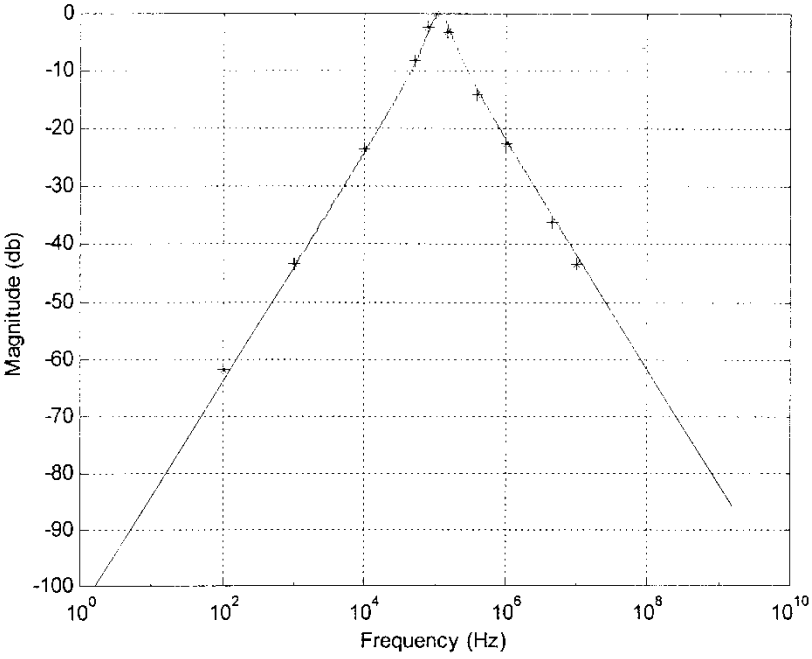

FIGURE 3 Calculated (——) and simulated (∗∗) current-mode bandpass response.

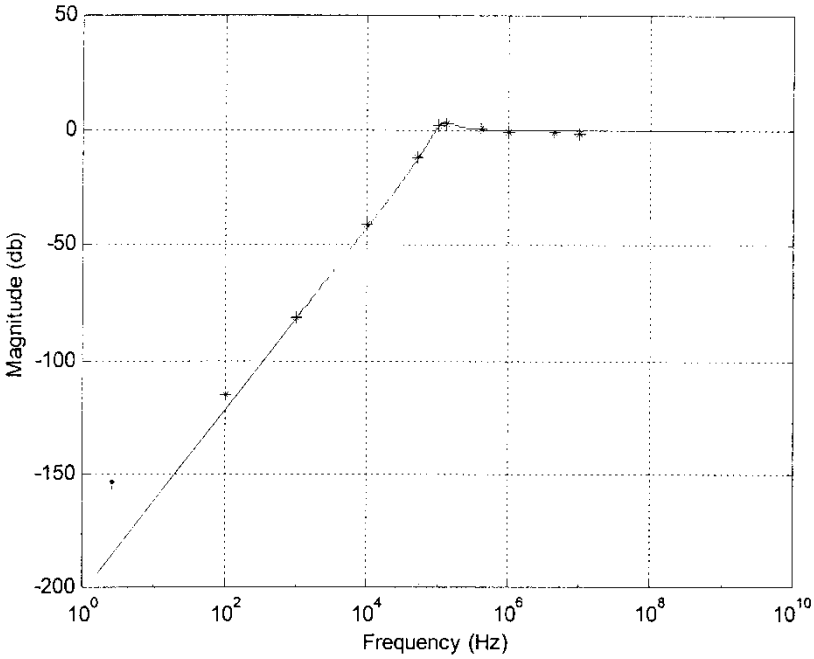

FIGURE 4 Calculated (——) and simulated (∗∗) current-mode highpass response.

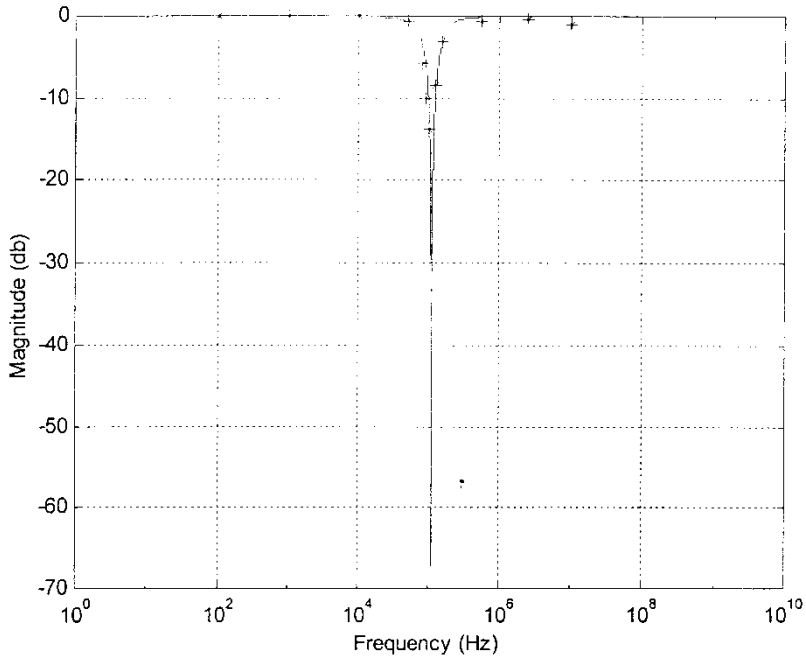

FIGURE 5 Calculated (——) and simulated (∗∗) current-mode notch response.

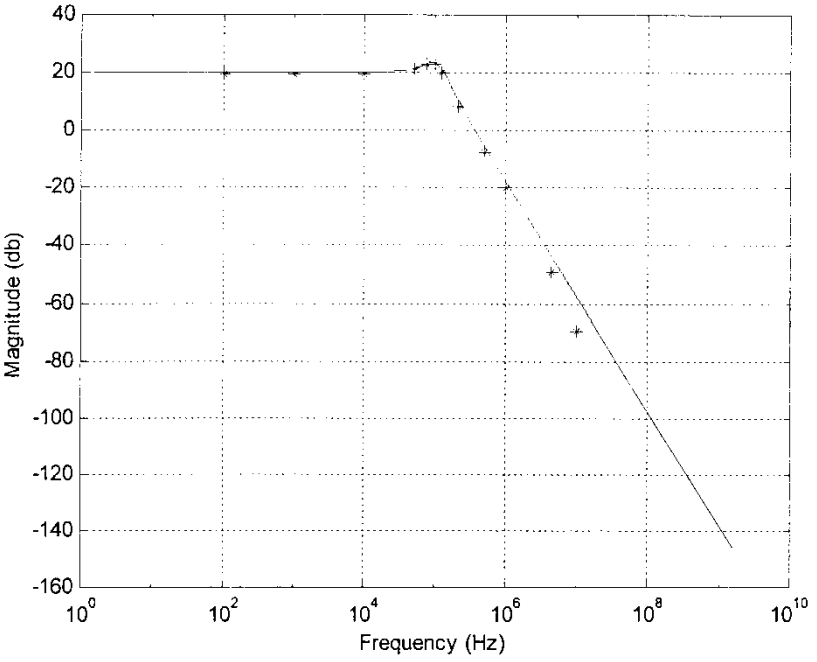

FIGURE 6 Calculated (——) and simulated (∗∗) voltage-mode lowpass response.

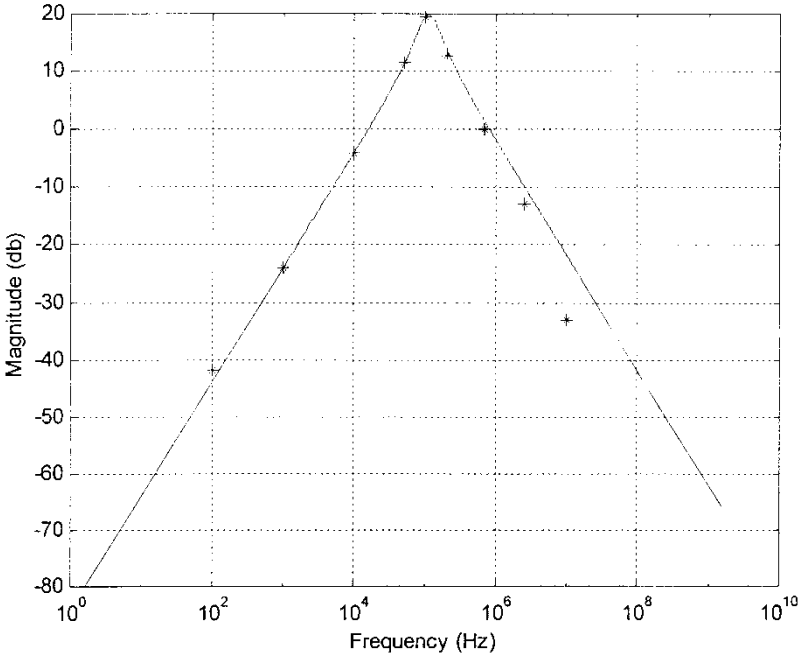

FIGURE 7 Calculated (——) and simulated (∗∗) voltage-mode bandpass response.

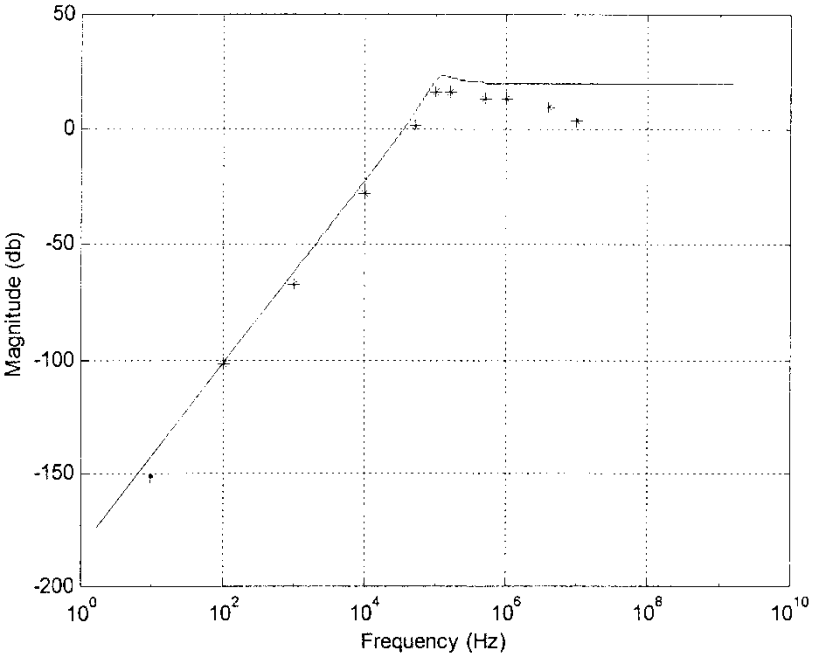

FIGURE 8 Calculated (——) and simulated (∗∗) voltage-mode highpass response.

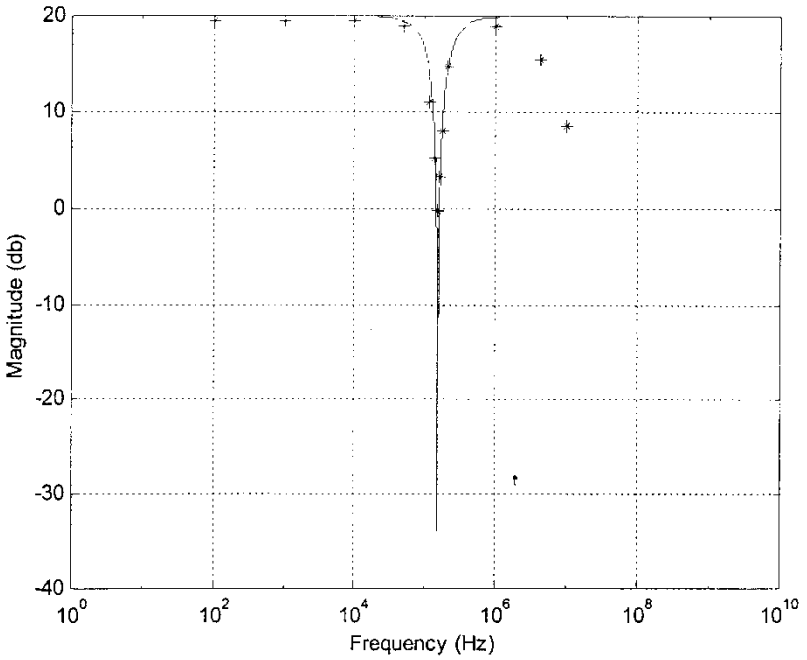

FIGURE 9 Calculated (——) and simulated (∗∗) voltage-mode notch response.

3 SIMULATION RESULTS

The proposed circuit was simulated using the PSPICE circuit simulation program. The CCIIs were modeled using the model reported in Ref. [27] with $R_x = 50\,\Omega$, $R_y = 10\,\mathrm{M}\Omega$, $R_z = 3\,\mathrm{M}\Omega$, and $C_z = 4.5\,\mathrm{pF}$. The results obtained from a current-mode LPF, current-mode BPF, current-mode HPF, and current-mode notch with $C_1 = C_2 = 1\,\mathrm{nF}$, $R_1 = R_2 = R_4 = R_5 = R_6 = 1\,\mathrm{k}\Omega$, and $R_3 = 2\,\mathrm{k}\Omega$ are shown in Figures 2–5. The results obtained from a voltage-mode LPF, voltage-mode BPF, and voltage-mode HPF with $C_1 = C_2 = 1\,\mathrm{nF}$, $R_1 = R_2 = R_4 = R_5 = R_6 = 1\,\mathrm{k}\Omega$, $R_3 = 2\,\mathrm{k}\Omega$, and $R_7 = 10\,\mathrm{k}\Omega$ are shown in Figures 6–8. The results obtained from a notch with $C_1 = C_2 = 1\,\mathrm{nF}$, $R_1 = R_2 = R_5 = R_6 = 1\,\mathrm{k}\Omega$, $R_3 = R_4 = 2\,\mathrm{k}\Omega$, and $R_7 = 10\,\mathrm{k}\Omega$ are shown in Figure 9. Figures 2–9 also show calculations made using Eqs. (1) and (3)–(6). It appears from Figures 2–9 that the simulated and calculated results are in fairly good agreement.

4 CONCLUSIONS

In this article, a new mixed-mode biquad circuit has been presented. The circuit uses five CCIIs and can realize all the standard 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 voltage output. While the simulation results confirm the theory presented in this article, the discrepancies between the calculated and simulated results are attributed to the simplified model used in the analysis.

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