Abstract—Despite the extensive literature on current conveyor-based voltage-mode multifunction biquadratic filter with single input and three outputs, no filter circuits have been reported to date which simultaneously achieve all of the advantageous features: (i) the employment of only one differential voltage current conveyor (DVCC), (ii) the employment of only two grounded capacitors, (iii) the employment of only three resistors, (iv) simultaneous realization of voltage-mode highpass, bandpass and lowpass filter signals from the three output terminals, respectively, (v) no need to employ inverting type input signals, (vi) no need to impose component choice, (vii) low passive sensitivity performance and (viii) simpler configuration due to the use of single DVCC only. This paper describes a novel voltage-mode multifunction biquadratic filter with single input and three outputs. The proposed configuration employs a single DVCC, two grounded capacitors and three resistors. The use of grounded capacitors makes the circuit suitable for integration because grounded capacitor circuit can compensate for the stay capacitances at their nodes. The proposed circuit has all the above features simultaneously, and without trade-offs. HSPICE simulation results based on using TSMC 0.35µm CMOS model are included to verify the theoretical analysis.

Index Terms— Active filters, Current conveyors, Analog Electronics.

I. INTRODUCTION

As a current-mode active device, the differential voltage current conveyors (DVCC) has the advantages of both of the second generation current conveyor (CCII) (such as large signal bandwidth, great linearity, wide dynamic range) and the differential difference input amplifier (DDA) (such as high input impedance and arithmetic operation capability) [1]. Also, the design of filter circuits employing current-mode active elements may be used in phase-locked look frequency modulation stereo demodulators, touch-tone telephone tone decoder and cross-over networks in a three-way high fidelity loudspeaker [2-3]. With the increasing emphasis on the voltage-mode universal biquad filters with single input and multiple outputs [4-7], there is still a need to develop new biquad filters that offer new advantages. In 1997, Horng et al. [4] proposed a voltage-mode multifunction filter with a single input and three outputs, which can realize lowpass, bandpass and highpass filter transfer functions, using four CCII’s, three grounded capacitors and five grounded resistors. In the same year, Chang proposed five voltage-mode multifunction biquadratic filters using four CCII’s, two grounded capacitors and three-five resistors [5]. However, these two proposed configurations required at least four active components. In 1999, Chang and Lee proposed a voltage-mode lowpass, bandpass and highpass biquadratic filters with a single input and three outputs using only two compound current conveyors, two grounded capacitors and three resistors [6]. Then, Horng et al. proposed a voltage-mode highpass, bandpass and lowpass biquadratic filters using two DDCC’s, two grounded capacitors and two grounded resistors [7]. However, these two proposed configurations required at least two (not one) active components. From the point view of the advantages of low cost, space saving and power dissipation, the filters using single active element receive more attention at present. Although, the multifunction filter with a single input and four outputs was proposed by Chang et al. [8], which can realize highpass, bandpass and lowpass filters using a single FDCCII, two grounded capacitors and two grounded resistors. However, the use of FDCCII can be divided into two separate DVCCs. It leads to the use of a single DVCC which is simpler than the use of a single FDCCII. Moreover, the CMOS model of DVCC is simpler than FDCCII. In this paper, the authors propose a new voltage-mode lowpass, bandpass and highpass biquad filter with a single input and three outputs. The proposed circuit employs one fewer current conveyor than the recent one [7] in addition to two grounded capacitors and three resistors. The use of grounded capacitors is particularly attractive for integrated circuit implementation [9]. Anyway, the use of only one DVCC and five passive components is a simpler configuration than Horng et al. [7].

II. CIRCUIT DESCRIPTION

The DVCC can be characterized by the port relations with \( V_5 = V_{Y1}, V_{12}, I_1 = I_{Y1} = 0, I_{2} \approx I_{Y2} \) and \( I_{2} \approx I_{X} \) [1]. The proposed biquad filter, based on the differential voltage current conveyor, is shown in Fig. 1. It is composed of a single DVCC, two grounded capacitors and three resistors. The use of grounded capacitors makes the circuit suitable for integration because grounded capacitor circuit can compensate for the stay capacitances at their nodes [9-11]. Circuit analysis yields the following voltage-mode filter transfer function:

\[
\frac{V_{out}}{V_{in}} = \frac{G_1G_2}{s^2C_1C_2 + sC_1(G_1 + G_2) + G_1G_2}
\]  

\[
\frac{V_{out}}{V_{in}} = \frac{-sC_1G_1}{s^2C_1C_2 + sC_1(G_1 + G_2) + G_1G_2}
\]  

\[
\frac{V_{out}}{V_{in}} = \frac{-sC_1G_1}{s^2C_1C_2 + sC_1(G_1 + G_2) + G_1G_2}
\]  

\[
\frac{V_{out}}{V_{in}} = \frac{-sC_1G_1}{s^2C_1C_2 + sC_1(G_1 + G_2) + G_1G_2}
\]
\[
\frac{V_{\text{out}}}{V_{\text{in}}} = \frac{G_1}{G_3} s^2 C_1 C_2 + s C_1 (G_1 + G_2) + G_4 G_2
\]

(3)

Fig. 1 The proposed voltage-mode multifunction biquad.

Thus, we can obtain a non-inverting lowpass, an inverting bandpass, and a non-inverting highpass filter response at the output voltages, \( V_{\text{out}} \), \( V_{\text{ov2}} \) and \( V_{\text{ov3}} \), respectively. Examining (1)-(3) shows that the resonance angular frequency \( \omega_0 \) and the quality factor \( Q \) of the biquad filter are given by

\[
\omega_0 = \frac{G_1 G_2}{\sqrt{C_1 C_2}} \quad \text{and} \quad Q = \frac{1}{G_1 + G_2} \sqrt{\frac{C_1 G_2}{C_2}}
\]

(4)

A sensitivity study forms an important index of the performance of any active network. The formal definition of sensitivity is \( S'_F = \frac{x}{F} \frac{\partial F}{\partial x} \), where \( F \) represents one of \( \omega_0 \), \( Q \) and \( x \) represents any of the passive elements \( (G_1, G_2, C_1, C_2) \). The passive sensitivities of the proposed circuit shown in Fig. 1 are given as

\[
S_{G_1}^{\text{th}} = S_{G_2}^{\text{th}} = -S_{G_1}^{\text{th}} = -S_{G_2}^{\text{th}} = \frac{1}{2}
\]

\[
-\frac{S_{C_1}^{G_1}}{S_{C_2}^{G_1}} = \frac{1}{2}, \quad \frac{S_{G_1}}{S_{G_2}} = \frac{1}{2} - \frac{G_1}{G_1 + G_2}, \quad \frac{S_{G_2}}{S_{G_1}} = \frac{1}{2} - \frac{G_2}{G_1 + G_2}
\]

and \( S_{G_1}^{\text{th}} = S_{G_1}^{\text{th}} = 0 \). All passive sensitivities are small.

III. SIMULATION RESULTS

Finally, to verify the theoretical prediction of the proposed biquad filter, a simulation by using HSPICE simulation with TSMC 035 \( \mu \) m process was performed and the CMOS implementation of a DVCC is shown in Fig. 2 [1] with the NMOS and PMOS transistor aspect ratios \( \frac{W}{L} = \frac{5\mu m}{1\mu m} \) and \( \frac{W}{L} = \frac{10\mu m}{1\mu m} \), respectively. The supply voltages are \( V_{\text{DD}} = V_{\text{SS}} = 1.65 \) V, and the biasing voltages are \( V_{\text{BI}} = 0.25 \) V and \( V_{\text{BS}} = 0.75 \) V. The proposed circuit was designed for \( f_0 = 1 \) MHz and \( Q = 1.58 \) by choosing \( R_1 = R_2 = R_3 = 10 \) k\( \Omega \), \( C_1 = 5 \) pF and \( C_2 = 50 \) pF. Fig. 3 shows the simulated and theoretical response of lowpass, bandpass and highpass of Fig. 1. As can be seen, there is a good close agreement between the theory and the simulation.

IV. CONCLUSION

In 2004, Horng et al. presented a voltage-mode multifunction filter with a single input and three outputs employing two DDCCs, two grounded capacitors and two grounded resistors [7]. It can simultaneously obtain highpass, bandpass and lowpass filter responses. In this paper, the authors also proposed a voltage-mode multifunction filter with a single input and three outputs. The new one is simpler in configuration than the old filter [7] due to the use of single DVCC only. Moreover, the proposed circuit still enjoys no requirements for component matching conditions, no need to employ inverting type input signals and employs two grounded capacitors suitable for integrated circuit implementation.

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REFERENCES


