Current-Mode Multifunction Filters Using a Single FDCCII

Firat Kaçar[1], Bilgin Metin[2], Hakan Kuntman[3] and Oguzhan Cicekoglu[4]

[1]Istanbul University, Electrical and Electronics Engineering Dept., Istanbul, Turkey

[2]Bogazici University, Management Information Systems Dept., Istanbul, Turkey

[3]Istanbul Technical University, Faculty of Electrical and Electronics Eng., Istanbul, Turkey

[4]Bogazici University, Electrical and Electronic Engineering Dept., Istanbul, Turkey

Abstract

Two new current mode multifunction filter configurations are proposed with a single fully differential current conveyor (FDCCII). The first proposed current mode filter with single input and three outputs, which can simultaneously realize current-mode low-pass (LP), band-pass (BP), high-pass (HP), filter responses. The second proposed current mode filter with two inputs and two outputs, realize current-mode low-pass (LP), band-pass (BP), high-pass (HP) filter responses. Moreover, each of the proposed circuits employment two resistors and two capacitors. The presented circuits do not have element matching restriction. We performed simulations with SPICE simulation program using 0.35µm TSMC CMOS technology. Simulation results are found in close agreement with theoretical results.

1. Introduction

Analog filters are important building blocks and widely used for continuous-time signal processing. They can find application in several areas such as communication systems, measurement and instrumentation, and control systems [1-2]. In 2000, a new active element called the fully differential current conveyor (FDCCII) was proposed [3] to improve the dynamic range in mixed-mode applications where fully differential signal processing was required. In the literature several voltage-mode biquad filters are presented with three inputs and one output using current conveyors [4-11]. FDCCII that is a relatively new active element compared to classical current conveyor [12] has been used in analog filter design [12-14]. The circuits in [12] use three FDCCIIs. The filter circuits in [13-14] use single FDCCII.

In this paper, current mode multifunction filter have been presented. The proposed current mode biquad filters contain single FDCCII and two capacitors and two resistors. The proposed filter topologies can generate all the standard filter functions, LP, BP and HP from the same circuit configuration. A fourth-order band-pass filter is realized to illustrate the practical use of the proposed topologies as an application example. The performances of the proposed filters can be checked and simulated by PSPICE.

2. Fully Differential Current Conveyor (FDCCII)

The FDCCII is basically a fully differential device as shown in Fig.1. The Y_1 and Y_2 terminals are high impedance terminals while X_1 and X_2 terminals are low impedance ones. The differential input voltage V_{Y12} applied across Y_1 and Y_2 terminals is conveyed to differential voltage across the X_1 and X_2 terminals; i.e., ($V_{X12} = V_{Y12}$). The input currents applied to the X_1 and X_2 are conveyed to the Z_1 and Z_2 terminals that is, ($Iz_1 = Ix_1$ and $Iz_2 = Ix_2$). The Z_1 and Z_2 terminals are high impedance nodes suitable for current outputs.

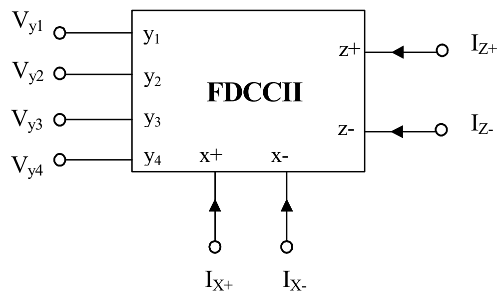

Fig.1 The circuit symbol of the FDCCII

Considering the non-idealities arising from the physical implementation of the FDCCII, its terminal relationship can be characterized by:

$$\begin{bmatrix} V_{X+} \\ V_{X-} \\ I_{Z+} \\ I_{Z-} \end{bmatrix} = \begin{bmatrix} 0 & 0 & \beta_1 & -\beta_2 & \beta_3 & 0 \\ 0 & 0 & -\beta_1 & \beta_2 & 0 & \beta_4 \\ \alpha_p & 0 & 0 & 0 & 0 & 0 \\ 0 & \alpha_N & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_{X+} \\ I_{X-} \\ V_{Y1} \\ V_{Y2} \\ V_{Y3} \\ V_{Y4} \end{bmatrix} \quad (1)$$

where ideally $\beta_1 = \beta_2 = \beta_3 = \beta_4 = 1$ and $\alpha_N = \alpha_P = 1$ that represent the voltage and current transfer ratios of the FDCCII respectively. The CMOS realization of the cascode FDCCII is shown in Fig.2 [15].

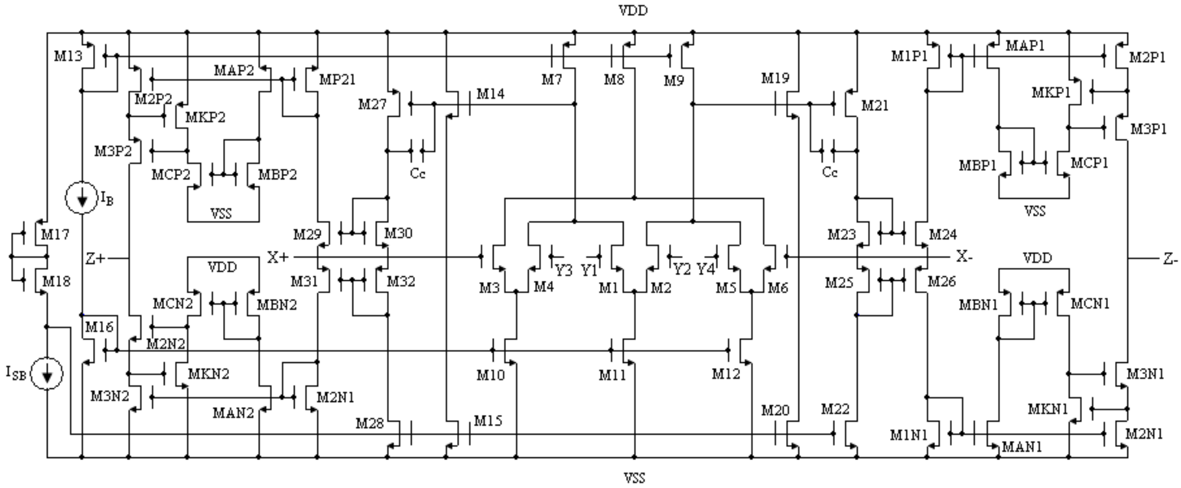

Fig.2 CMOS FDCCII implementation [15]

3. Proposed Multifunction Filters

The proposed two current-mode multifunction filters, employing a single fully differential current conveyor, are shown in Fig.3 and Fig.4. Two of these configurations use two capacitors and two resistors.

The first proposed current-mode multifunction filter is shown in Fig.3.

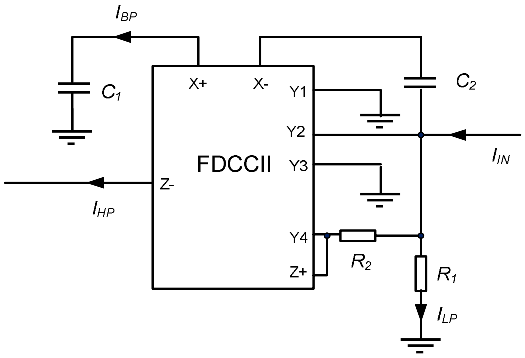

Fig.3. First proposed biquad filter employing FDCCII.

Circuit analysis yields the following current-mode filter transfer functions:

High-Pass:

$$\frac{I_{HP}}{I_{In}} = \frac{s^2 C_1 C_2}{s^2 C_1 C_2 + s(C_1 - C_2)G_2 + G_1 G_2} \tag{1a}$$

Low-Pass:

$$\frac{I_{LP}}{I_{In}} = \frac{G_1 G_2}{s^2 C_1 C_2 + s(C_1 - C_2)G_2 + G_1 G_2} \tag{1b}$$

Band-Pass:

$$\frac{I_{BP}}{I_{In}} = \frac{s C_1 G_2}{s^2 C_1 C_2 + s(C_1 - C_2)G_2 + G_1 G_2} \tag{1c}$$

Quality factor (Q) and pole frequency (ω_0) can be given as follows

$$Q = \frac{1}{C_1 - C_2}\sqrt{\frac{G_1 C_1 C_2}{G_2}} \tag{2a}$$

$$\omega_0 = \sqrt{\frac{G_1 G_2}{C_1 C_2}} \tag{2b}$$

Equation 2(a) shows that presented filters are suitable for obtaining high-Q values. First, a high Q value is obtained when the ratios of the passive elements are large. Secondly, difference of the capacitor values in the denominator of the Q values in 2(a) can be made sufficiently low considering tolerance of element parameters against the risk of oscillation of the filter (Q<0).

The second proposed circuit can be used as either two input and two output current-mode multifunction filter is shown in Fig.4. Circuit analysis yields the following for the outputs current functions:

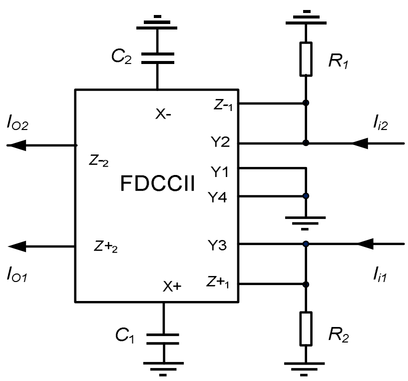

Fig.4. Second proposed biquad filter employing FDCCII.

$$I_{O2} = \frac{sC_2G_1I_{i1}}{s^2C_1C_2 + C_1G_1 + G_1G_2} + \frac{s^2C_2C_1I_{i2}}{s^2C_1C_2 + C_1G_1 + G_1G_2} \quad (3a)$$

$$I_{O1} = \frac{G_2G_1I_{i1}}{s^2C_1C_2 + C_1G_1 + G_1G_2} + \frac{sG_2C_1I_{i2}}{s^2C_1C_2 + C_1G_1 + G_1G_2} \quad (3b)$$

Depending on the status of $I_{i1}$and I_{i2}, following filter functions are realized:

1) For $I_{i2} = 0$, I_{O1} / I_{i1} is a low-pass and I_{O2} / I_{i1} is a band-pass filter transfer function.
2) For $I_{i1} = 0$, I_{O1} / I_{i2} is a band-pass and I_{O2} / I_{i2} is a high-pass filter transfer function.

The pole angular frequency ω_0 and quality factor Q are given by

$$Q = \sqrt{\frac{G_2C_2}{G_1C_1}} \quad (4a)$$

$$\omega_0 = \sqrt{\frac{G_1G_2}{C_1C_2}} \quad (4b)$$

Finally, to verify the theoretical prediction of the proposed biquad filters, SPICE simulations with 0.35µm TSMC process were performed. The CMOS implementation of a FDCCII is shown in Fig. 2 [15]. The aspect ratios of the MOS transistors are given in Table 1. The supply voltages were taken as ±1.3 V.

Table.1: Transistors aspect ratios for the FDCCII

Transistors	W(µm)	L(µm)
M_1-M_6, M_{BP},M_{CP}, M_{1N}-M_{3N}, M_{AN},M_{KN}	8.75	0.7
M_7-M_9,M_{13}	70	0.7
M_{10}-M_{12},M_{16}	17.5	0.7
M_{14},M_{15},M_{19},M_{20}	0.7	0.7
M_{17}, M_{21}, M_{27}, M_{25}-M_{26}, M_{31}-M_{32}, M_{1P}-M_{3P}, M_{AP},M_{KP}, M_{BN},M_{CN}	35	0.35
$M_{18,}$ M_{22}-M_{24}, M_{28}-M_{30}	8.75	0.35
M_{31},M_{32}	105	0.7

Fig.4 current-mode biquad was designed for f_0=1.59 MHz by choosing R_1=R_2=1kΩ and C_1=C_2= 0.1nF. The Fig.5 shows the simulated and theoretical response of low-pass, band-pass, and high-pass of Fig.4. As can be seen, there is a good close agreement between theory and simulations.

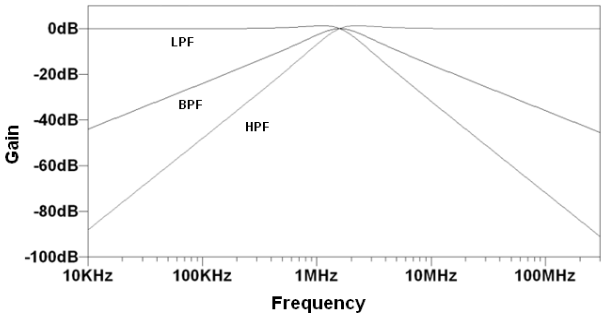

Fig.5. Simulated frequency responses for the circuit in Fig.4.

4. Application Example and Simulation Results

The aim is to construct a double-tuned amplifier with band-pass characteristic using circuits constructed with FDCCIIs and passive elements. The center frequency f_0 and the bandwidth B are given as f_0=1.15MHz and B=2MHz, respectively. There are many applications that require a narrow band band-pass tuned amplifiers such as video signal processing, TV receivers and wireless communications stages. By using the filter topology shown in Fig. 4, a fourth order band-pass filter was implemented which is shown in Fig. 6. To obtain a filter with a center frequency of 1.15MHz and a bandwith of 2.1MHz, the pole frequencies and the quality factors of resonant circuits are chosen as f_{P1} = 815kHz, f_{P2} =1.59MHz, Q_{P1}=1 and Q_{P2}=1, respectively. Ideal and simulation results of the filter response are given in Fig. 7, which is good agreement with theoretical predictions.

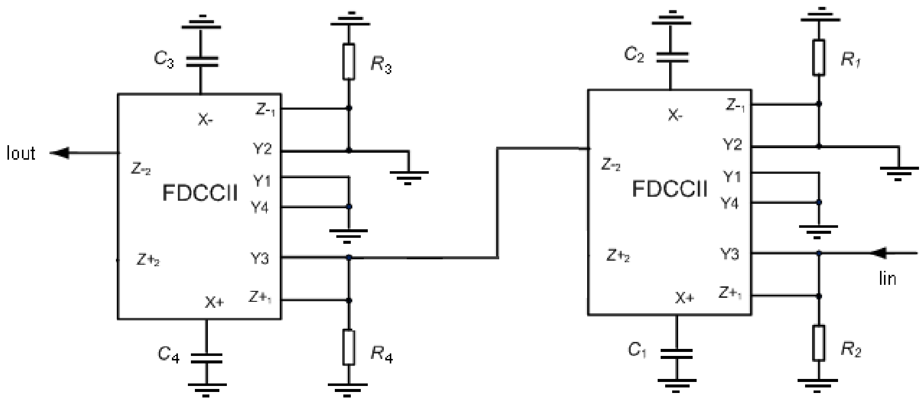

Fig. 6: A fourth-order band-pass filter realized with FDCCIIs

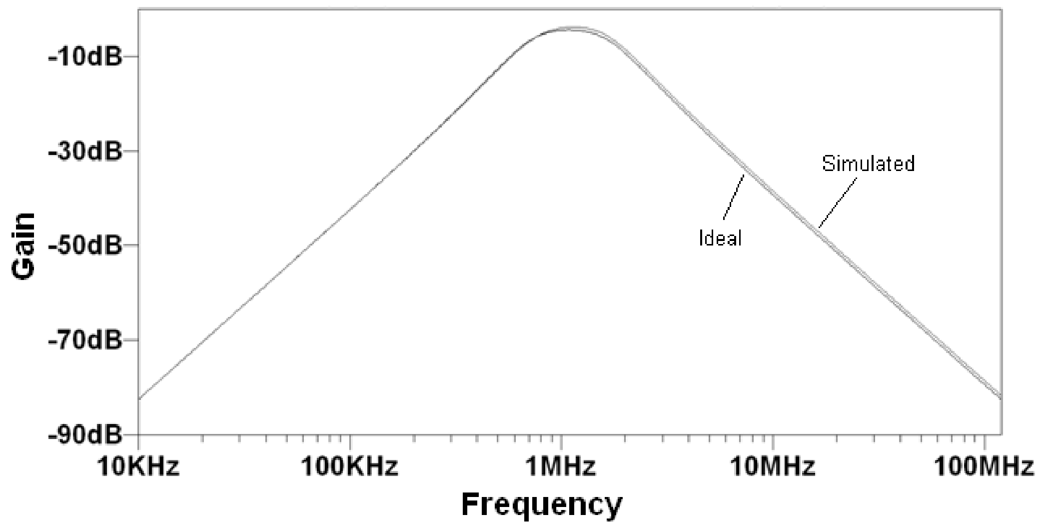

Fig.7: PSPICE simulation results of frequency response of the fourth-order band-pass filter

5. Conclusion

In this paper, two current mode multifunction filters with one input three output and with two input two output have been presented. The proposed current mode biquads contain only one FDCCII, two capacitors and two resistors. LP, BP, and HP filtering functions are obtained from the same configuration. A fourth-order band-pass filter is realized to illustrate the practical use of the proposed topologies as an application example. We performed simulations with PSPICE simulation program using 0.35μm TSMC CMOS technology. PSPICE simulation results of the filter responses are in good agreement with the predicted theory. Proposed topologies will provide new possibilities for analog IC designers.

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