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Nth Order Voltage Mode Active-C Filter Employing Current Controlled Current Conveyor

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Abstract

This paper proposes an nth order (where $n = 2,3,\cdots,n$) voltage mode active-C filter using n number of current controlled current conveyors (CCCIIs) and n number of equal valued grounded capacitors. The proposed topology can implement both band pass and low pass responses without alteration of any components. The filters offer the following important features: use of minimum number of current controlled current conveyors (CCCIIs) and passive components, no matching constraint, use of all grounded capacitors and absence of external resistor suitable for integration, cut off frequency can easily be electronically adjusted using AMS 0.35 µm CMOS technology. PSPICE simulation results of third order band pass and low pass responses are provided. The results are found to agree well with the theory.

Keywords: Analog Filters, Active-C Filter, Higher Order Voltage Mode Filter, CCCII

1. Introduction

Nowadays, current conveyors play an important role for the realization of various analog signal processing circuits and systems. They are accepted to have high performance properties such as wide signal bandwidth, high dynamic range, low power consumption and occupy less chip area [1,2]. The basic second generation current conveyor (CCII) does not have in built tuning property, whereas second generation current controlled current conveyor (CCCII) possesses this property because of the adjustability of intrinsic resistance at port X of CCCII by bias current [3-5]. Already a number of analog biquadratic filters have been reported in [6-9] and references cited there in. However, the nth order filter can be flexibly used to realize any higher order filter function and hence serves a wide range of applications. Higher order filters can be obtained by various methods such as cascading of lower order filters or state variable technique or signal flow graph. Already a number of current conveyor (CCII or CCCII) based higher order current mode [10-14] and voltage mode [15-18] filters have been reported. As this paper is concerning higher order voltage mode filters, hence only the study of the features of already reported higher order voltage mode filters [15-18] are made in **Table 1**.

In this work, an attempt is made to propose a new nth order (where, $n = 2,3,\cdots,n$) voltage mode filter. Both low pass and band pass responses can be obtained from the same topology using n CCCIIs and grounded n capacitors. It does not require any resistor. The proposed topology is an active-C filter and hence ideal for IC implementation. The use of CCCIIs in the circuit provides electronic tunability [5] of the filter parameters.

2. Circuit Description

The circuit symbol of the DOCCCII is shown in **Figure 1** The port relationship of a DOCCCII can be defined as

$$I_Y = 0,\ V_X = V_Y + I_X|R_X|,\ \ I_{Z\pm} = \pm I_X \tag{1}$$

where, the positive and negative signs define a positive and a negative DOCCCII respectively. In this equation R_X, the intrinsic series input resistance of the conveyor at X port is electronically tunable via I_0 of the CMOS based CCCII shown in **Figure 2** and R_X may be defined as [5]

$$R_x = \frac{1}{g_{m2} + g_{m4}} \tag{2}$$

$$g_{mi} = \sqrt{2\beta_i I_0} \quad (i = 2,4) \tag{3}$$

$$\beta_i = \frac{\varepsilon_0 \varepsilon_{ins} \mu_i W_i}{t_{ox} L_i} \tag{4}$$

Table 1. Comparative study of the available nth order voltage mode filter.

Ref. No.	Active element used and number of active elements required	Number of capacitors required	Number of resistors required	All passive elements are grounded	In built tunability of filter parameters	Types of filter implemented	Require to change the hardware to change filter type
15	CCII, 3*n*–2	*n*+1	3*n*–1	Yes	No	Universal filter	Yes
16	CCII, *n*+1	*n*	*n*+2	No	No	Low pass	Not Applicable
17	CCII, *n*+2	Minimum	2*n*+3	No	No	Universal filter	Yes
18	CCCII, *n*+1	*n*	1	Yes	Yes	Low pass	Not Applicable
Proposed	CCCII, *n*	*n*	Nil	Yes	Yes	Low pass & Band pass	No

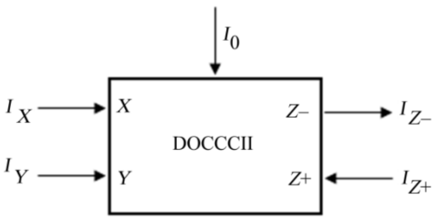

Figure 1. Block diagram of DOCCCII.

where, g_{m2} and g_{m4} are the transconductances of M_2 and M_4 respectively, I_0 is bias current of DOCCCII. The proposed voltage mode nth order filter circuit is shown in **Figure 3**.

The routine analysis of the circuit of **Figure 3** gives the transfer function for an nth order filter as

$$V_{out} = \frac{V_{in1} - sV_{in2}R_xC}{D(S)} \tag{5}$$

where

$$D(S) = a_{nn}\left(R_x^nC^n\right)s^n + \left[\sum_{j=1}^{n-2} a_{n(n-j)}\left(R_xC\right)^{n-j}s^{n-j}\right] + a_{n1}R_xC\,s + a_{n0} \tag{6}$$

$$n = 2,3,\cdots,n \tag{7}$$

$$a_{nn} = 1 \tag{8}$$

$$a_{n(n-j)} = a_{(n-j)(n-j)} + a_{(n-j)(n-j-1)} \quad (\, j = 1,2,\cdots,n-2\,) \tag{9}$$

$$a_{n1} = 2 \tag{10}$$

$$a_{n0} = 1 \tag{11}$$

From above equations we can see that specialization in the numerator of (5) results in the following filter responses:

1) Low pass Response

- At V_{out} with $V_{in1} = V_{in}$ and $V_{in2} = 0$

2) Band pass Response

- At V_{out} with $V_{in1} = 0$ and $V_{in2} = V_{in}$

Hence, the proposed circuit gives an inverted nth order band pass filter and nth order low pass filter from the same topology.

As an example, a third order transfer function

$$V_{out} = \frac{V_{in1} - sV_{in2}R_xC}{s^3R_x^3C^3 + 3s^2R_x^2C^2 + 2sR_xC + 1} \tag{12}$$

is realized using (5)–(11) and the corresponding third order circuit obtained from the nth order circuit of **Figure 3** is given in **Figure 4**.

With $V_{in1} = V_{in}$ and, Equation (12) simplifies to

$$V_{out} = \frac{V_{in}}{s^3R_x^3C^3 + 3s^2R_x^2C^2 + 2sR_xC + 1} \tag{13}$$

which is a low pass response.

Similarly, with $V_{in1} = 0$ and, Equation (12) simplifies to

$$V_{out} = \frac{-sV_{in}R_xC}{s^3R_x^3C^3 + 3s^2R_x^2C^2 + 2sR_xC + 1} \tag{14}$$

which is a band pass response.

The forth order filters is obtained by adding section shown in **Figure 5** between 2nd and 3rd CCCII- of **Figure 4**. Similarly, fifth and higher order filters are obtained by adding one section shown in **Figure 5** for each higher order.

Comparision of the available nth order filters [15-18] and the proposed one is given in **Table 1**. It reveals that the proposed circuit uses minimum number of current conveyors and passive components and no resistor. It can realize both band pass and low pass responses in contrast to only low pass response in [16,18] and does not require to change any hardware to change filter type. The uni-

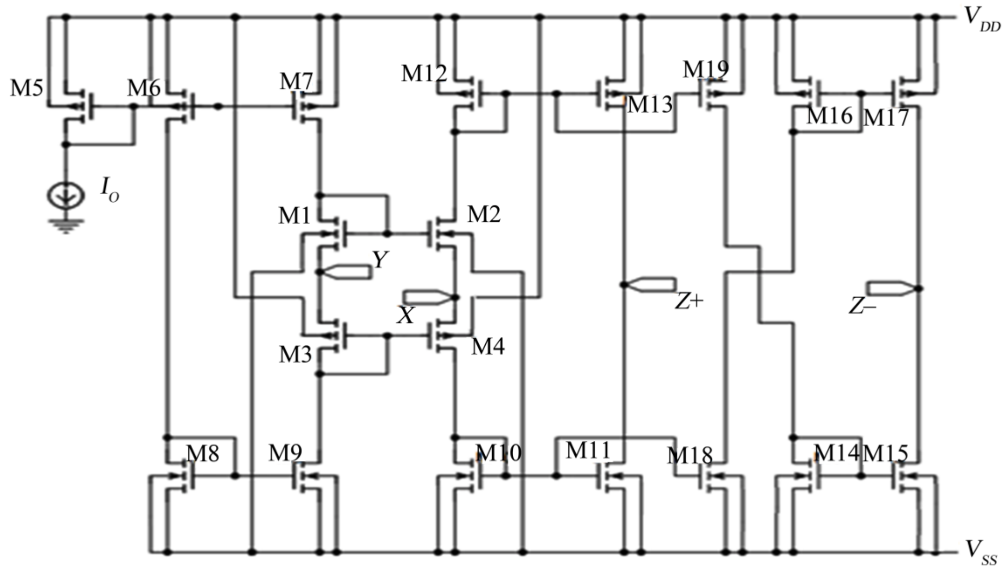

Figure 2. Internal structure of DOCCCII.

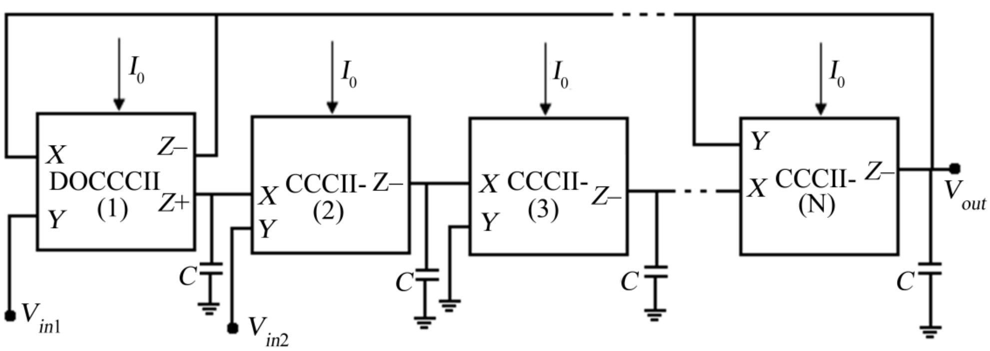

Figure 3. Proposed voltage mode nth order low pass and band pass filters.

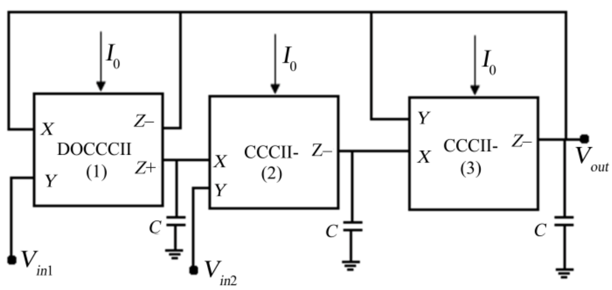

Figure 4. Proposed voltage mode third order low pass and band pass filters.

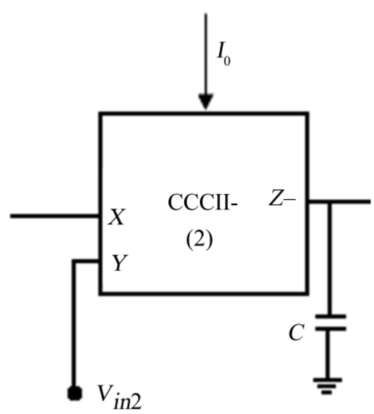

Figure 5. Section to be added for higher order filter.

versal filters realized by structures in [15,17] are attractive, but the changing of the filter type would required the change of hardware of the filter circuits. Hence they are not suitable for monolithic IC implementation.

3. Simulation and Results

To verify the theory, the proposed voltage mode nth order filter circuit is simulated with PSPICE using 0.35 µm AMS CMOS based CCCII circuit given in **Figure 2** [5] with supply voltage of ±2.5 volts and aspect ratio of transistors as given in **Table 2**.

As an example, a third order low pass filter and a band

Table 2. MOS dimensions used in the circuit.

Transistors	W(μm)	L(μm)
M_1, M_2	20	0.35
M_3, M_4	60	0.35
M_5, M_6, M_7	30	2
M_8, M_9	10	2
M_{10}, M_{11}, M_{14}, M_{15}	10	1
M_{12}, M_{13}, M_{16}, M_{17}	30	1

pass filter are obtained with C = 50 pF and I_0 = 200 μA. Frequency responses of the proposed low pass and band pass filters are shown in **Figure 6** and **Figure 7** respectively. The response for the low pass filter exhibits a –60 dB/dec slope for frequencies higher than f_0. The response for the band pass filter, as shown in **Figure 7**, exhibits an asymmetrical third order nature with a slope of 20 dB/dec for frequencies lower than f_0 and −40 dB/dec for frequencies higher than f_0. The results show a close matching with the theoretical values. The deviation at higher frequency may be due to parasites of DOCCCII/CCCIIs. The time-domain response of the band pass filter is shown in **Figure 8**. Large signal behavior of the proposed filter is investigated by observing the dependence of the output total harmonic distortion (%THD) upon the level of input signal. The result as illustrated in **Figure 9**, shows that the %THD is well within the reasonable limit of 4% [19] for input peak-to-peak voltage level of 2 V. Responses as shown in **Figures 8** and **9** reveal that the output is of good quality.

4. Conclusions

In this paper a generalized nth order (where $n = 2,3,\cdots,n$) voltage mode active-C filter topology is proposed. Both nth order band pass and low pass responses may be realized using same topology. The topology uses n equal value grounded capacitors, single dual output current controlled current conveyor (DOCCCII) and (n-1) current controlled current conveyors (CCCIIs). The verification of the theory is performed by using AMS 0.35 μm CMOS based DOCCCII/CCCII. Comparison with the reported publications [15-18] reveals that the proposed topology uses minimum number of active analog building blocks and minimum passive components. All of the used capacitors are grounded. It does not use any resistor and there is no requirement of changing any hardware for changing filter type from low pass to band pass or

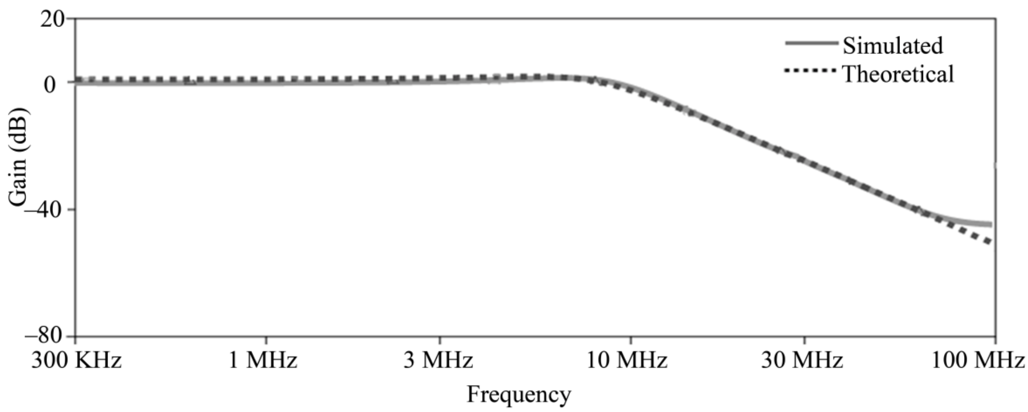

Figure 6. Frequency response of the third order low pass filter.

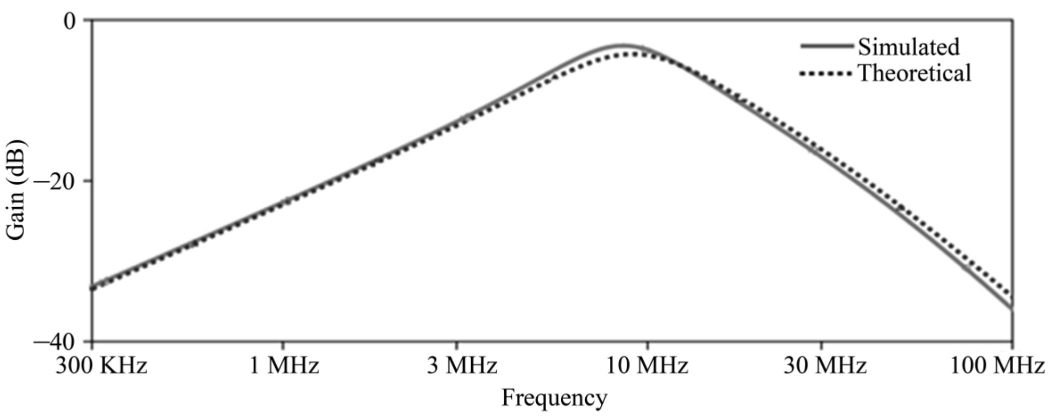

Figure 7. Frequency response of the third order band pass filter.

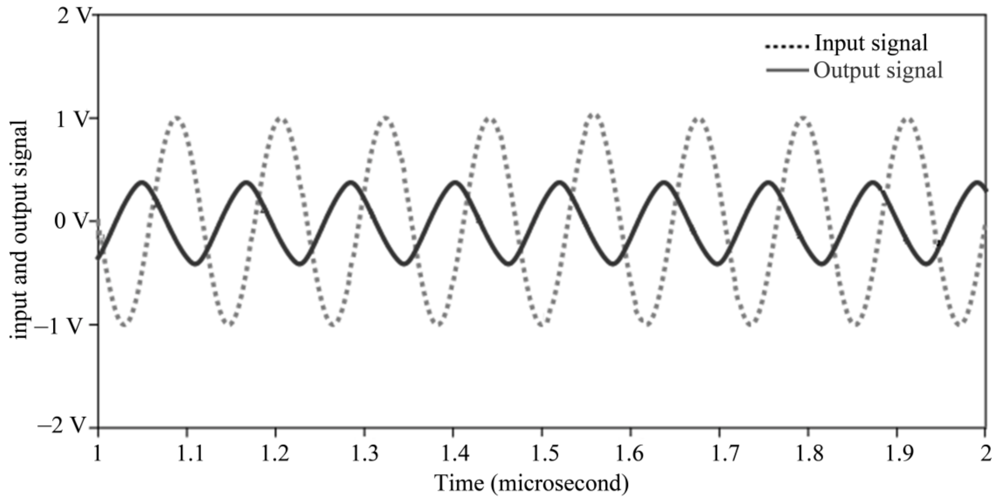

Figure 8. Time response of the band pass filter for input peak-to-peak voltage of 2 V.

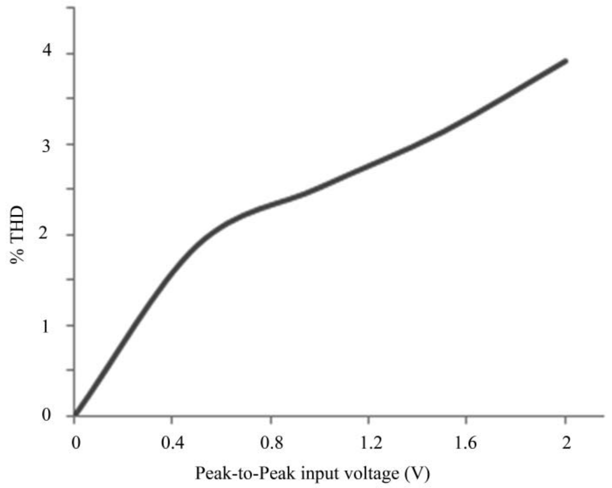

Figure 9. %THD verses input voltage at 10 MHz.

vice-versa, hence suitable for monolithic IC implementation.

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