Circuits and Systems, **2010, 1, 54-58**
doi:10.4236/cs.2010.12009 Published Online October 2010 (http://www.SciRP.org/journal/cs)

SIMO Transadmittance Mode Active-C Universal Filter

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Received August 6, 2010; *revised September* 10, 2010; *accepted September* 13, 2010

Abstract

This paper presents two transadmittance mode universal filters having single voltage input and multiple current outputs. The filter employs three multiple output current controlled conveyors (MOCCCII) and two grounded capacitors. It can realize low pass, high pass, band pass, notch and all pass responses. As desired, the input voltage signal is inserted at high impedance input terminal and the output currents are obtained at high impedance output terminals and hence eases cascadability. The filter enjoys low sensitivity performance and low component spread; and exhibits electronic and orthogonal tunability of filter parameters via bias currents of MOCCCII. SPICE simulation results confirm the workability of the proposed structure.

Keywords: Universal Filter, Transadmittance Mode, Current Controlled Conveyor

1. Introduction

There has been substantial emphasis on development of current conveyor based filters in the recent past which can be attributed to its high performance properties such as wider signal bandwidths, greater linearity, larger dynamic range, lower power consumption, simple circuitry and occupy lesser chip area than their voltage mode counterparts [1]. The filters employing operational transconductance amplifier (OTA) possess lower dynamic range with power supply scaling as its input are voltage dependent. The need for lower power consumption requires low bias current and hence lower output current [2]. The OTA requires bias current of four times the current needed by current controlled conveyor (CCCII) [3] for the same transconductance. Thus circuits based on CCCII consume lesser power than OTA based circuits. The maximum usable frequency range depends strongly on bias current, hence high frequency response of CCCII based implementations are expected to be better than OTA. Already a number of voltage and current mode filter structures based on current conveyor have been reported in the literature [3-13] and references cited therein. A voltage-mode (VM) circuit is one whose signal states are computed as node voltages while a current-mode (CM) circuit is one whose signal states defined by its branch currents. In some applications there is need of filtering a voltage signal and then converting it to current signal by using a voltage to current converter (V→I) interfacing circuit. The total effectiveness of the electronic circuitry can be increased if signal processing can be combined with V→I interfacing. A transadmittance mode filter is suitable for such applications and finds usage in receiver base band blocks of modern radio system [14]. A careful study indicates that a limited literature is available on transadmittance mode filter [14-18]. These circuits can nicely perform the operation of transadmittance mode filter, but still there is scope to improve them in the following fronts: use of floating passive components [14-18] which is not considered good for IC implementation point of view; input voltages are not applied at high impedance terminal [14,16,18]; availability of output currents through passive components [17] thus there is requirement of additional hardware; and filter parameters are not electronically tunable [17]. It thus reveals that no literature is available on transadmittance mode universal filter that can simultaneously possess the following advantageous features: 1) use of all grounded passive components, 2) high impedance terminal for input excitation, 3) output at high impedance and 4) electronic tunability of filter parameters.

In this work, two current controlled conveyor based transadmittance mode universal filter circuits are proposed based on [10-13] that use only three MOCCCIIs and two grounded capacitors. The first structure provides band pass, high pass and notch responses simultaneously and all pass and low pass responses can be obtained by connecting together appropriate outputs. The low pass, band pass, high pass and notch responses are simultaneously available in the second proposed structure and all pass response can be obtained by connecting together suitable outputs. As desired, in both the structures, the input voltage signal is inserted at high impedance input terminal and the output currents are obtained at high impedance output terminals. The filter parameters are adjustable through bias currents of MOCCCII. The filter, under all operations, exhibits low active and passive sensitivities. The function of the proposed structure has been confirmed by SPICE simulations.

2. Circuit Description

The port relationships of a MOCCCII as shown in **Figure 1** can be characterized by

$$v_X = v_Y + i_X \,|R_X(I_0)|, \quad i_Y = 0, \quad i_{Z\pm} = \pm i_X$$

where the positive and negative signs denote the positive and negative current transfers. R_x is the input resistance at x port which can be controlled via bias current I_0 [3]. The MOCCCII can be realized using bipolar transistor or CMOS (**Figure 2**), the value of R_x is given as $R_X = V_T / 2I_0$ for bipolar realization or MOS transistors operating in weak inversion region, where V_T is the thermal voltage; whereas $R_X = 1/(g_{m2} + g_{m4})$ for MOS transistors operating in strong inversion [19], where $g_{mi} = \sqrt{2\mu_i C_{ox}(W_i / L_i) I_0}$.

The first proposed transadmittance mode universal filter is shown in **Figure 3**, which employs three MOCCCIIs and two grounded capacitors. The routine analysis of the circuit yields the following transfer functions:

$$\frac{I_{out1}}{V_{in}} = -\frac{1}{R_{x1}D(s)}, \frac{I_{out2}}{V_{in}} = \frac{sC_2R_{x2}}{R_{x1}D(s)},$$

$$\frac{I_{out3}}{V_{in}} = -\frac{s^2C_1C_2R_{x2}}{D(s)}, \frac{I_{out4}}{V_{in}} = \frac{s^2C_1C_2R_{x1}R_{x2}+1}{R_{x1}D(s)} \quad (1)$$

where $$D(s) = s^2C_1C_2R_{x1}R_{x2} + sC_2R_{x2} + 1 \quad (2)$$

Thus the proposed structure of **Figure 3** can be viewed

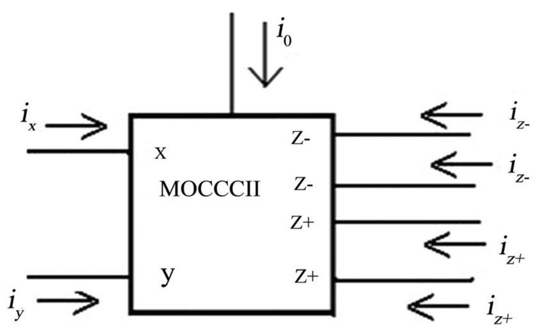

Figure 1. Circuit symbol of MOCCCII.

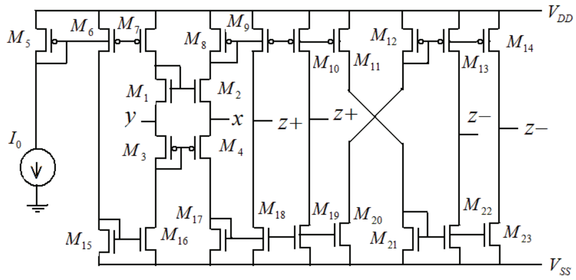

Figure 2. CMOS representation of MOCCCII [19].

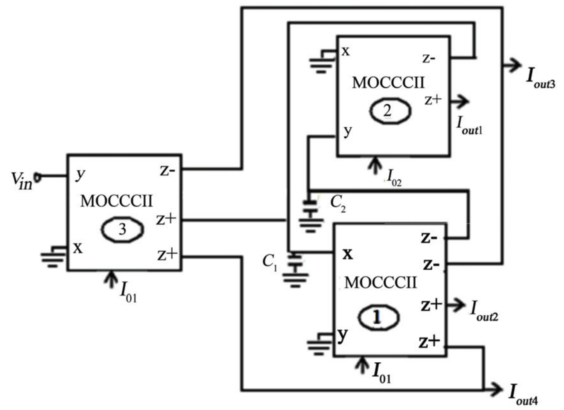

Figure 3. First proposed structure.

as single-input four-output transadmittance mode universal filter. It provides low pass, band pass, high pass and notch responses at I_{out1}, I_{out2}, I_{out3} and I_{out4} respectively. The all pass responses can easily be obtained by adding I_{out1}, I_{out2} and I_{out3}. Furthermore, the input voltage is applied at high impedance y-port and all the current outputs are available at high impedance z-port of current controlled conveyors that enable easy cascadability without the need of supplementary buffer circuit.

All the filters are characterized by

$$\omega_0 = \left(\frac{1}{R_{x1}R_{x2}C_1C_2}\right)^{1/2}, \quad \frac{\omega_0}{Q_0} = \frac{1}{R_{x1}C_1} \quad \text{and}$$

$$Q_0 = \left(\frac{R_{x1}C_1}{R_{x2}C_2}\right)^{1/2} \quad (3)$$

It may be noted from (3) that ω_0 can be adjusted by varying bias current I_{02} (or R_{x2}) without disturbing ω_0 / Q_0 and similarly ω_0 and Q_0 are orthogonally adjustable with simultaneous adjustment of I_{01} and I_{02}.

The second proposed structure is shown in **Figure 4**, which uses two MOCCCIIs and a minus type CCCII and two grounded capacitors. The transfer functions for the circuit of **Figure 4** can be expressed as

$$\frac{I_{out1}}{V_{in}} = \frac{s^2C_1C_2R_{x2}}{D(s)}, \quad \frac{I_{out2}}{V_{in}} = \frac{sC_1}{D(s)}, \quad \frac{I_{out3}}{V_{in}} = \frac{D(s) - sC_1R_{x1}}{R_{x1}D(s)} \quad (4)$$

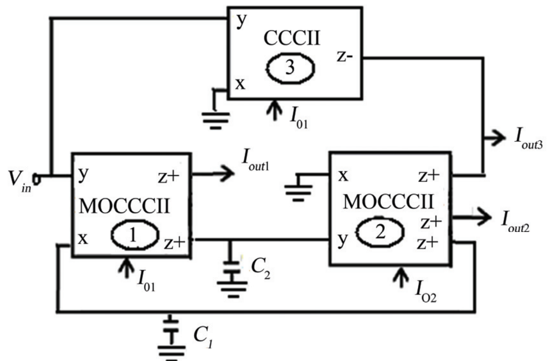

Figure 4. Second proposed structure.

where

$$D(s) = s^2 C_1 C_2 R_{x1} R_{x2} + sC_2 R_{x2} + 1 \quad (5)$$

Thus the second structure can also be viewed as single-input three-output transadmittance mode universal filter. It provides high pass and band pass responses at I_{out1} and I_{out2}. The notch response is available at I_{out3} for equal capacitors $C_1 = C_2$ and bias currents $I_{01} = I_{02}$. The low pass and all pass responses can easily be obtained by adding I_{out1} and I_{out3}; and I_{out2} and I_{out3} respectively. Like the previous one, both the input and output impedances are high for input voltage and output currents respectively.

The results of active and passive sensitivity analysis of various parameters for both the proposed filters are given as

$$S_{R_{x1}}^{\omega_0} = S_{R_{x2}}^{\omega_0} = S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = -1/2,$$

$$S_{R_{x1}}^{Q_0} = -S_{R_{x2}}^{Q_0} = S_{C_1}^{Q_0} = -S_{C_2}^{Q_0} = 1/2$$

Hence the sensitivities of pole ω_0 and quality factor Q_0 are low and within unity in magnitude. Thus the proposed structure can be classified as insensitive.

The Equation (3) also indicates that high values of Q-factor will be obtained from moderate values of ratios of passive components *i.e.*, from low component spread [20]. These ratios can be chosen as $(R_{x1} / R_{x2}) = (C_1 / C_2) = Q_0$. Hence the spread of the component values becomes of the order of $\sqrt{Q_0}$. This feature of the filter related to the component spread allows the realization of high Q_0 values more accurately compares to the topologies where the spread of passive components becomes Q_0 or Q_0^2.

3. Comparison

Table 1 shows the comparison of the present work with the previously reported works [14-18]. The study of **Table 1** reveals the following.

1) [14] uses the same number of active components as that of present work, whereas the number of passive components are more in [14] and most of them are floating. Input impedance is low which is not desirable for a circuit having input as voltage signal. The NF and AP responses are not obtainable from this circuit.

2) [15] uses more number of active and passive components than that of the present work and most of the passive components are floating. Input impedance is low and NF and AP responses are not possible as that of [14].

3) Although [16] and [17] use single active component, the number of passive components are more and some of them are floating. [16] has low input impedance and can implement only AP response. [17] can implement only LP and BP responses which are available through passive components, hence requires some more active components (opamps, CC etc.) to use these responses.

Table 1. Comparison of the present work with the previously reported works.

Ref.	No. and type of active components	No. and type of passive components	No. of inputs and input impedance	Possible output responses and output impedance	Simultaneous outputs
[14]	3 CCII	2 floating R 1 grounded R 2 floating C	Single, low input impedance	LP, BP, HP all at high output impedance; NF and AP not possible	3
[15]	3 PFTFN realized using 6 CFOA	2 floating R 1 grounded R 2 floating C	Single, low input impedance	LP, BP, HP all at high output impedance; NF and APF not possible	3
[16]	single CCIII	2 floating R 1 grounded R 1 grounded C	Single, low input impedance	Only AP response at high output impedance	1
[17]	Single opamp	1 floating R 1 grounded R 1 grounded C	Single, high input impedance	LP and BP output Current through passive components; HP, AP, NF not possible	2
[18]	2CDTA	2 floating R 1 floating C 1 grounded C	Three, low input impedance	LP, HP, BP, AP, NF all at high output impedance	1
Present work	3CCCII	2 grounded C	Single, high input impedance	LP, HP, BP, AP, NF all at high output impedance	4 & 3

4) [18] is a good proposition which uses only two active components and implements all responses of universal filter. However, it suffers form the drawback of using excessive numbers of passive components and most of them are floating and also input impedance is low which is not desirable for a transadmittace mode filter.

Hence it reveals that the present work removes most of the drawback which were prevailing in transadmittance mode universal filter reported till date.

4. Simulation Results

To validate the theoretical predictions, the proposed filter is simulated with SPICE using schematic of MOCCCII as given in **Figure 2** [19] using AMS 0.35 μm CMOS technology with dimensions of the NMOS and PMOS transistors as that of [19] and supply voltages of ±1.5 volts. **Figure 5** shows the simulation results for circuit of **Figure 3** with the component values of $C_1 = C_2 = 10$ pF and $I_{01} = I_{02} = 100$ μA. The total power dissipation of the proposed filter is found to be approximately 10 mW.

The simulations have also been carried out to show the dependence of f_0 on bias current and results are shown in **Figure 6** for band pass response. It is found that f_0 depends linearly for low bias currents whereas for higher bias current the dependence is approximately proportional to the square root of the bias current. The percentage total harmonic distortion (%THD) variation with the sinusoidal input signal is also studied and the results are shown in **Figure 7**. It shows that the %THD is low and remains within the acceptable limit of 5% [21] till the considerable high input signal of 800 mV.

5. Conclusions

Two new single-input mutiple-output transadmittance mode universal filters using three MOCCCII and two grounded capacitors have been presented. The simulation results verify the theory. It is found from the comparison that the present work removes most of the drawback of the previously reported works [14-18]. The salient features of the proposed circuits are as follows: use of only three MOCCCIIs and two capacitors, uses grounded passive components, low sensitivity performance, orthogonal and electronic tunability of ω_0 and Q_0, high input and output impedances which ease cascadability and low component spread for high Q application.

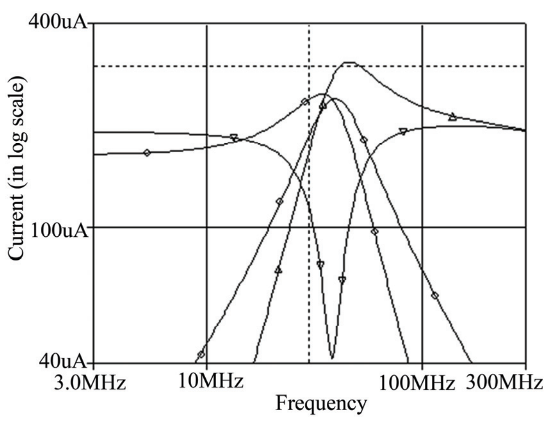

Figure 5. Simulated results for low pass, band pass, high pass and notch responses.

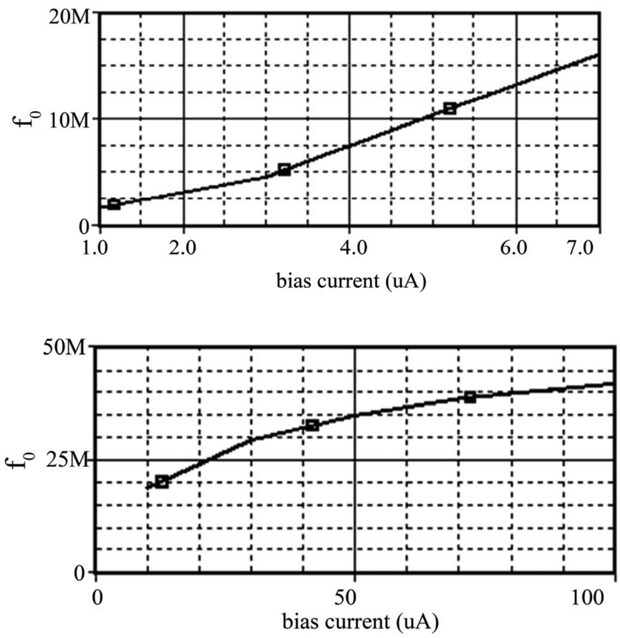

Figure 6. Dependence of central frequency on bias current.

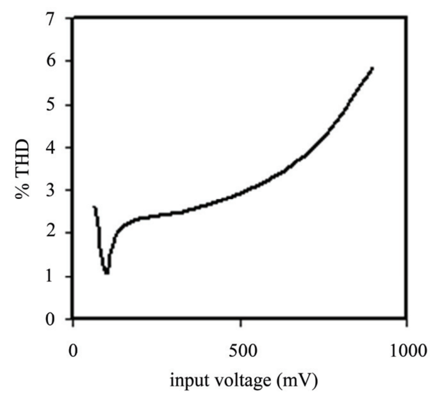

Figure 7. Variation of THD with input signal amplitude.

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