Universal Current-Mode Biquad with Minimum Components

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***Abstract*—A current controllable current-mode universal filter with four inputs and one output employing multi-output current-controlled current conveyors (MOCCCIIs) is described. The proposed circuit offers the following attractive features: employment the minimum number of active and passive components, i.e., two MOCCCIIs and two grounded capacitors; simultaneous realization of all the standard filtering functions; independent current-control of the natural angular frequency (ω_o) and bandwidth (BW); no requirement of component matching conditions; employment of only two grounded passive capacitors which is suitable for integrated circuit (IC) implementation; and low passive and active sensitivities.**

***Index Terms*— current-controlled current conveyor (CCCII), biquadratic filter, current-mode circuit, minimum components**

I. Introduction

As a result of the well-known advantages of current-mode operation, several realizations of various current-mode active filters using second-generation current conveyors (CCIIs) have received wide attention. Among these existing filters, a number of current-mode CCII-based universal filters also exist in the technical literature [1]-[5], where most of them have been realized in the form of the single-input multiple-output filter configuration. A little work has been developed for the multiple-input single-output current-mode universal filters. Although some current-mode CCII-based universal filters with multiple inputs and one output were recently proposed in [6]-[11], however, their structures suffer from the use of excessive numbers of active and passive components, and the lack of electronic tunability. From the point of ease of IC fabrication process, it is preferable to realize the active filters by using a minimum number of active and passive components.

In this paper, a low-component count current-controlled current-mode universal biquadratic filter with four inputs and one output is introduced. The proposed filter requires only two MOCCCIIs and two grounded capacitors and provides the advantage of an electronic tuning capability, which is especially interested from the IC fabrication point of view [12]. By proper selecting the input signals, the circuit can realize all the standard biquadratic filtering functions, i.e., lowpass (LP), bandpass (BP), highpass (HP), bandstop (BS) and allpass (AP), from the same circuit configuration. The natural angular frequency (ω_o) and bandwidth (BW) can be orthogonally and electronically tuned through adjusting the bias current of the MOCCCII. No critical matching conditions are required, and all the incremental parameter sensitivities are low. The performances of the proposed circuit are simulated with PSPICE to confirm the theoretical analysis.

II. Circuit Configuration

Generally, a MOCCCII is a versatile active building block as shown in Fig. 1. The port relations of the plus/minus-type MOCCCII can be characterized by the following equation [13].

$$i_y = 0, \quad v_x = v_y + i_x R_x, \quad i_{z+} = +i_x, \quad i_{z-} = -i_x \qquad (1)$$

The schematic bipolar realization of the MOCCCII is shown in Fig. 2. In this case, the parasitic resistance R_x at the terminal x can be expressed by

$$R_x = \frac{V_T}{2I_O} \qquad (2)$$

where V_T is the thermal voltage, and I_O is the bias current of the conveyor.

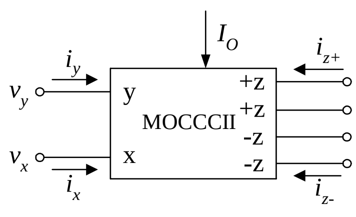

Fig.1 : Circuit symbol of the MOCCCII.

The realization of the proposed current-mode universal filter with four input terminals and one output terminal that requires only two MOCCCIIs and two grounded capacitors is shown in Fig.3. Since all the grounded capacitors are employed, the circuit is suitable for IC implementation [12].

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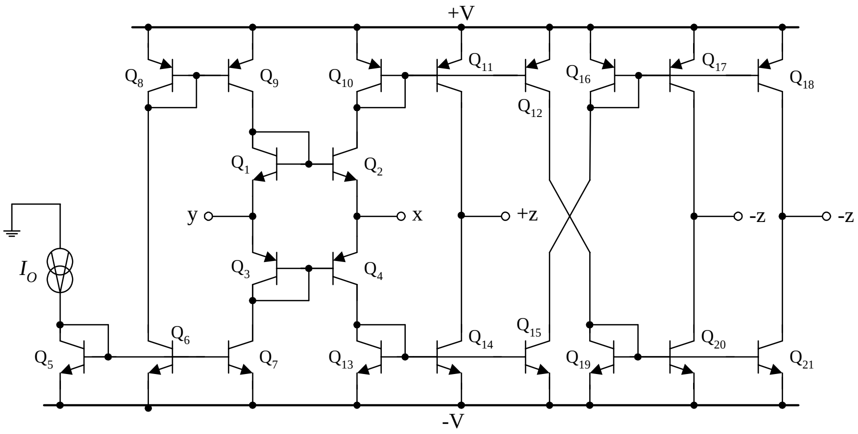

Fig.2 : Schematic bipolar implementation of the MOCCCII.

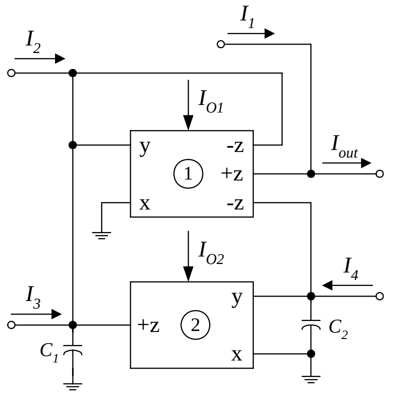

Fig.3 : Proposed current-controlled current-mode universal filter.

By routine circuit analysis using equation (1), the current transfer function of the proposed filter can be given by :

$$I_{out} = \frac{(s^2 R_{x1} R_{x2} C_1 C_2 + sR_{x2} C_2 + 1) I_1 + (sR_{x2} C_2)(I_2 + I_3) + I_4}{(s^2 R_{x1} R_{x2} C_1 C_2 + sR_{x2} C_2 + 1)} \tag{3}$$

It can be seen from equation (3) that the circuit can realize five types of the biquadratic filter, which are summarized as follows:

1) LP : $I_1 = I_2 = I_3 = 0$ and I_4 = an input current signal I_{in}.

2) BP : $I_1 = I_2 = I_4 = 0$ and $I_3 = I_{in}$, or
$I_1 = I_3 = I_4 = 0$ and $I_2 = I_{in}$.

3) HP : $I_2 = 0$ and $I_1 = -I_3 = -I_4 = I_{in}$, or
$I_3 = 0$ and $I_1 = -I_2 = -I_4 = I_{in}$.

4) BS : $I_2 = I_4 = 0$ and $I_1 = -I_3 = I_{in}$, or
$I_3 = I_4 = 0$ and $I_1 = -I_2 = I_{in}$.

5) AP : $I_4 = 0$ and $I_1 = -I_2 = -I_3 = I_{in}$.

Note that there are no critical component matching conditions in the realization of all the filter responses. The parameters ω_o and BW of this filter are given by :

$$\omega_o = \frac{1}{\sqrt{R_{x1} R_{x2} C_1 C_2}} \tag{4}$$

and

$$BW = \frac{\omega_o}{Q} = \frac{1}{R_{x1} C_1} \tag{5}$$

From equations (4) and (5), it can be seen that the ω_o for all the filter responses can electronically be tuned by varying the resistance R_{x2} through the bias current I_{O2} without affecting the bandwidth BW. Therefore, the filter parameters ω_o and BW can independently controllable over a wide range by electronic means.

The incremental sensitivities of the parameters ω_o and BW are calculated as :

$$S^{\omega_o}_{R_{x1}, R_{x2}, C_1, C_2} = -\frac{1}{2} \tag{6}$$

$$S^{BW}_{R_{x1}, C_1} = -1 \tag{7}$$

and

$$S^{BW}_{R_{x2}, C_2} = 0 \, . \tag{8}$$

All of the parameter sensitivities are within unity in magnitude.

III. Non-ideal Effects

The effects of MOCCCII non-idealities on the filter performance have been now considered in this section. By considering the non-ideal MOCCCII characteristics, the port relation in equation (1) are rewritten as :

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$$i_y = 0,\ \ v_x = \alpha v_y + i_x R_x,\ \ i_{z+} = +\beta_p i_x,\ \ i_{z-} = -\beta_n i_x \quad (9)$$

where $\alpha = 1 - \varepsilon_v$ and ε_v ($|\varepsilon_v| << 1$) represents the voltage tracking error from y to x terminal, $\beta_p = 1 - \varepsilon_{ip}$ and ε_{ip} ($|\varepsilon_{ip}| << 1$) denotes the current tracking error from x to +z terminal, and $\beta_n = 1 - \varepsilon_{in}$ and ε_{in} ($|\varepsilon_{in}| << 1$) denotes the current tracking error from x to -z terminal of the MOCCCII, respectively. Re-analysis of Fig.3 with equation (9), the parameters ω_o and BW for this case are rewritten by :

$$\omega_o = \sqrt{\frac{\alpha_1\alpha_2\beta_{n1}\beta_{p2}}{R_{x1}R_{x2}C_1C_2}} \quad (10)$$

and

$$BW = \frac{\alpha_1\beta_{n1}}{R_{x1}C_1} \quad (11)$$

In this case, the active and passive sensitivities of the proposed circuit are

$$S^{\omega_o}_{\alpha_1,\alpha_2,\beta_{n1},\beta_{p2}} = -\frac{1}{2} \quad (12)$$

$$S^{\omega_o}_{\beta_{p1},\beta_{n2}} = 0 \quad (13)$$

$$S^{BW}_{\alpha_1,\beta_{n1}} = 1 \quad (14)$$

and

$$S^{BW}_{\alpha_2,\beta_{p1},\beta_{p2},\beta_{n2}} = 0 \quad (15)$$

which are no more than unity in magnitude.

IV. Simulation Results

PSPICE simulations were carried out to prove the validity of the proposed circuit of Fig.3. The MOCCCII was performed by the schematic bipolar implementation given in Fig.2 with the transistor model of PR100N (PNP) and NP100N (NPN) of the bipolar arrays ALA400 from AT&T [14], and DC supply voltage = ±3V.

The simulation results shown in Fig.4 for the LP, BP, HP and BS responses verify the presented theory. For this purpose, the components of the filter were chosen as $I_{O1} = I_{O2} = 100\ \mu$A and $C_1 = C_2 = 10$ nF. This setting has been selected to obtain the filter responses with $f_o = \omega_o/2\pi \cong 122$ kHz and $Q = 1$. Fig.5 shows the simulated frequency responses and the theoretical behavior of the gain and phase characteristics of the AP filter at $f_o = \omega_o/2\pi \cong 122$ kHz, which agrees very well with the theory. It is observed form both figures that the proposed filter performs all the standard biquadratic filtering functions well.

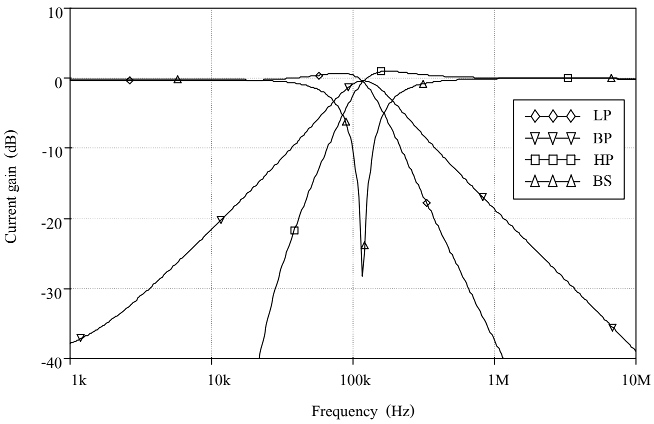

Fig.4 : Simulated frequency characteristics of LP, BP, HP and BS filters of the proposed circuit in Fig.3.

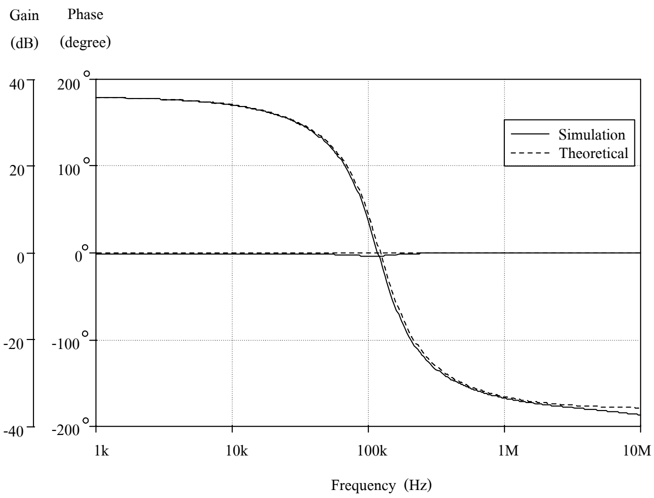

Fig.5 : Gain and phase characteristics of the AP filter at $f_o \cong 122$ kHz.

To demonstrate the current tuning of f_o, the resulting responses of the BP filter for different bias currents I_O (= $I_{O1} = I_{O2}$) are given in Fig.6. In this setting, the f_o-values calculated from equation (4) are equal to 30.61 kHz, 61.20 kHz and 122.4 kHz, respectively. From the simulations, the corresponding f_o are measured as 30.87 kHz, 61.40 kHz and 119.07 kHz, respectively.

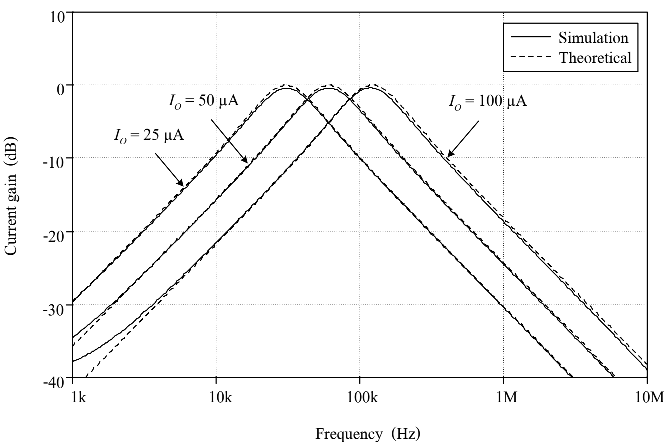

Fig.6 : Simulated frequency responses of the BP filter when I_O (= $I_{O1} = I_{O2}$) is varied.

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For the electronically controllability property of the phase shift, Fig.7 shows the simulated phase responses of the proposed the AP filter when I_O is respectively varied to 25 μA, 50 μA and 100 μA. The results obtained from the simulations show that the corresponding f_o are about at 30.62 kHz, 61.4 kHz and 117.5 kHz, which are in good agreement with theoretical values : f_o = 30.61 kHz, 60.49 kHz and 122.4 kHz, respectively.

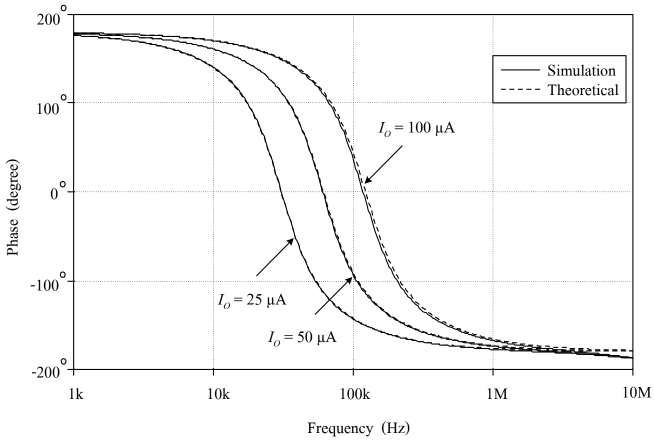

Fig.7 : Simulated phase responses of the AP filter when I_O (= I_{O1} = I_{O2}) is varied.

V. Conclusion

This paper describes a novel current-controlled current-mode universal filter using only two MOCCCIIs and two grounded capacitors, which is a canonical structure, and suitable for IC implementation. The filter can realize LP, BP, HP, BS and AP filter responses from the same topology. The parameter ω_o of the proposed filter can electronically be controlled without disturbing the BW. The circuit also requires no component matching conditions, and has low passive and active sensitivities. Both its active and passive sensitivities are low.

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