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Universal Current-Mode Biquad Employing Dual Output Current Conveyors and MO-CCCA with Grounded Passive Elements

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ABSTRACT

A new universal multiple input multiple output (MIMO) type current-mode biquad employing two dual output current conveyors (DOCCII), one multiple output current controlled current amplifier (MOCCCA) and four passive grounded elements is proposed which can realize all the five basic filtering functions namely, low-pass (LP), high-pass (HP), band-pass (BP), band-stop (BR) and all-pass (AP) in current mode from the same configuration. The centre frequency ω_o can be set by the passive elements of the circuit and the quality factor Q_o is electronically tunable through bias currents of the MOCCCA. Therefore, the biquad filter has independent tenability for the ω_o and Q_o. The active and passive sensitivities of Q_o and ω_o are low. The workability of the new configuration has been demonstrated by PSPICE simulation results based upon a CMOS CCII in 0.35 µm technology.

Keywords: Current-Mode Filters; Current Conveyors; Analog Circuit Design; CMOS Circuits

1. Introduction

Recently, Chunhua, Hiaguang and Yan presented two new universal multiple input single output (MISO) current-mode (CM) biquadatic filters using one MOCCCA, two grounded capacitors (GC) and two grounded resistors (GR) and realize all the five generic filter responses in CM (*i.e.* with current as input and current as output) [1].

The purpose of this paper is to introduce a new configuration which although uses exactly same number of active and passive components but in contrast to the circuit of reference [1] realizes a MIMO-type biquad and hence, does not require any additional hardware to duplicate/invert current inputs which is required in case of MISO-type filters of [1].

In the literature there are SIMO-type filter circuits which have three active devices but suffer from the independent tunability as in [2-5] or have more passive or active elements as in [4-9]. The circuits in [10-12] need double inputs and outputs to realize all five generic filters. The circuit in [13] has two MO-CCCIIs and one DO-CCCII, the draw back of this circuit is the control currents $I_{oi}, i = 1,2,3$ are temperature dependent. The circuit in [14] has two MO-CCCIIs and one MOCCCA but realizes only SIMO-type biquad.

2. The Proposed Configuration

The proposed configuration is shown in **Figure 1**.

Assuming the CCIIs to be characterized by

$$\begin{bmatrix} I_Y \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_Y \\ I_X \\ V_Z \end{bmatrix} \tag{1}$$

The symbolic notation of MO-CCCA is given in **Figure 2(a)**, where i represent input, $(I_{o1} - I_{on})$ are n outputs respectively, and I_A and I_B denote DC bias currents. **Figure 2(b)** is a CMOS realization of MO-CCCA. Here I_i denotes the input signal; I_{o1}, I_{o2}, I_{o3} are the three output currents, respectively.

If the channel lengths of M_5-M_8 are all n times of that of M_4, and the channel size of M_{17} is n times that of M_{18}, namely

$$\begin{aligned} &(W/L)_{M_5} / (W/L)_{M_4} \\ &= (W/L)_{M_6} / (W/L)_{M_4} = (W/L)_{M_7} / (W/L)_{M_4} \\ &= (W/L)_{M_8} / (W/L)_{M_4} = (W/L)_{M_{17}} / (W/L)_{M_{18}} = n, \end{aligned}$$

the output current expressions can be obtained as

$$I_{o1} = I_{o2} = \cdots = I_{on} = \frac{nI_B}{2I_A} = KI_i \tag{2}$$

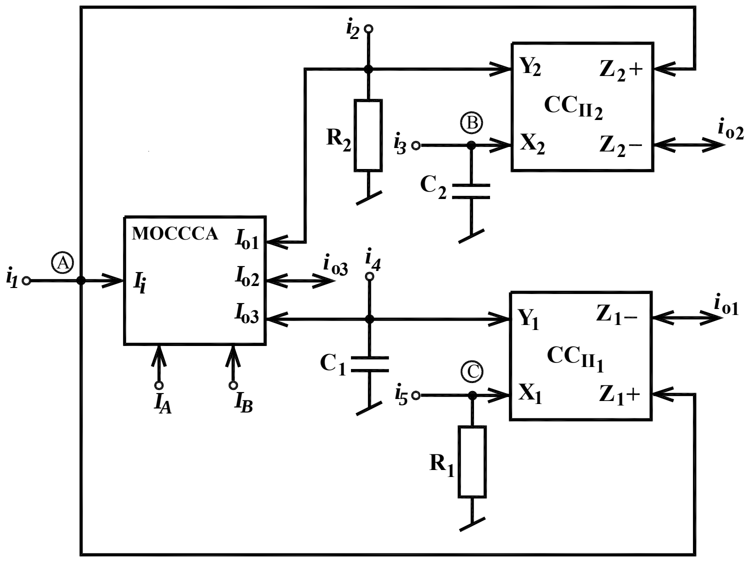
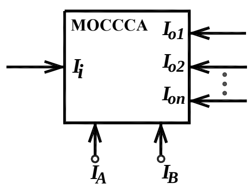
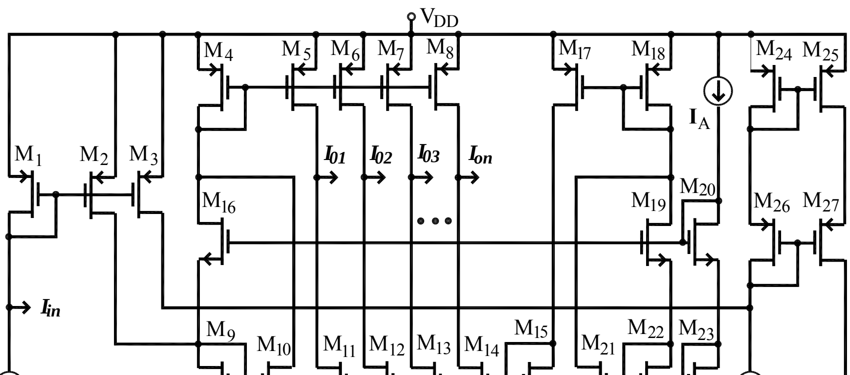


Figure 1. The proposed configuration.



(a)



(b)

Figure 2. (a) Symbolic notation of MO-CCCA (b) CMOS realization of the MO-CCCA.

where K represents the current gain. It is clear from Equation (2) that the value of K can be set by I_B and I_A.

Consider now the following special cases:

2.1. MISO Type:

When i_1, i_2, i_3, i_4 and i_5 are input currents and taking i_{03} as output current, then a routine analysis of the circuit reveals the following expression of the output current i_{03} in terms of the five input currents i_1, i_2, i_3, i_4 and i_5:

$$i_{03} = \frac{1}{\Delta}\left[i_2 s^2 C_1 C_2 + i_4 G_1 G_2 + \left(i_1 - i_3 - i_5 \right) s C_1 G_2 \right] \quad (3)$$

where $\Delta = s^2 C_1 C_2 + \frac{1}{K} s C_1 G_2 + G_1 G_2,$, $G_1 = 1/R_1$ and $G_2 = 1/R_2$.

Then, the various filter responses can be realized from the circuit are:

LPF: when $i_4 = i_{in}$ (non-inv.) and $i_1 = i_2 = i_3 = i_5 = 0$.

HPF: when $i_2 = i_{in}$ and $i_1 = i_3 = i_4 = i_5 = 0$.

BPF: when $i_1 = i_{in}$ and $i_2 = i_3 = i_4 = i_5 = 0$ or $i_3 = i_{in}$ and $i_1 = i_2 = i_4 = i_5 = 0$ or $i_5 = i_{in}$ and $i_1 = i_2 = i_3 = i_4 = 0$.

Notch: when $i_2 = i_4 = i_{in}$ and $i_1 = i_3 = i_5 = 0$.

APF: when $i_2 = i_3 = i_4 = i_{in}$ and $i_1 = i_5 = 0$ or $i_2 = i_4 = i_5 = i_{in}$ and $i_1 = i_3 = 0$.

2.2. SIMO Type

If i_1 is input current, $i_2 = i_3 = i_4 = i_5 = 0$ (open circuited) then, the various filter responses realized are given by:

$$\text{LPF: } \frac{i_{01}}{i_1} = \frac{-1}{\Delta}\left[G_1 G_2\right] \tag{4}$$

$$\text{HPF: } \frac{i_{02}}{i_1} = \frac{-1}{\Delta}\left[s^2 C_1 C_2\right] \tag{5}$$

$$\text{BPF: } \frac{i_{03}}{i_1} = \frac{1}{\Delta}\left[s C_1 G_2\right] \tag{6}$$

$$\text{Notch: } \frac{i_{01} + i_{02}}{i_1} = \frac{-1}{\Delta}\left[s^2 C_1 C_2 + G_1 G_2\right] \tag{7}$$

$$\text{APF: } \frac{i_{01} + i_{02} + i_{03}}{i_1} = \frac{-1}{\Delta}\left[s^2 C_1 C_2 - s C_1 G_1 + G_1 G_2\right] \tag{8}$$

The various parameters of the realized filters are given by

$$\omega_o = \sqrt{\frac{1}{C_1 C_2 R_1 R_2}}, BW = \frac{1}{K C_2 R_2}, Q_o = K\sqrt{\frac{C_2 R_2}{C_1 R_1}} \tag{9}$$

From Equation (9), the centre frequency ω_o can be set by varying R_1 without disturbing ω_o/Q_o. The Q_o can also be set by I_B and I_A without disturbing ω_o. Therefore, the biquad filter has independent tenability for the ω_o and Q_o.

From the above, the active and passive sensitivities of the transfer function are given as

$$S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = S_{R_1}^{\omega_o} = S_{R_2}^{\omega_o} = -\frac{1}{2}, S_{C_2}^{Q_o} = S_{R_2}^{Q_o} = \frac{1}{2}$$
$$S_{C_1}^{Q_o} = S_{R_1}^{Q_o} = -\frac{1}{2}, S_{K}^{Q_o} = 1 \tag{10}$$

The active and passive sensitivities of ω_o and Q_o are found to be in the range $-\frac{1}{2} \le S_x^F \le 1$, and the circuit, thus, enjoys low sensitivities.

3. Simulation Results

To verify the validity of the various modes of operation of the proposed configuration, circuit simulation of the current mode filters (MISO and SIMO) have been carried out using the CMOS CCII implementation with multiple outputs shown in **Figure 3** (as in [15], modified from [16]).

The model parameters of n-channel and p-channel MOSFETs are given in [17], whereas aspect ratios of the CCII MOSFETs are shown in **Table 1**, and aspect ratios of the MO-CCCA MOSFETs are shown in **Table 2**.

The CMOS CCII was biased with DC power supply voltages $V_{DD} = +1.5$ V, $V_{SS} = -1.5$ V, $V_1 = -0.5$ V, and $V_2 = -0.9$ V.

To achieve the MISO type filters with $f_o = 1$ MHz and quality factor of $Q_o = 1$, the component values were selected $K = 1(n = 1,\ I_A = 50\ \mu\text{A},\ I_B = 100\ \mu\text{A})$, $R_1 = R_2 = 1\ \text{k}\Omega$ and $C_1 = C_2 = 159\ \text{pF}$. The frequency responses of LPF, BPF, HPF, Notch and APF (theoretical and simulation) are shown in **Figure 4**.

To test the input dynamic range of the proposed filters, the simulation of the band-pass filter as an example has

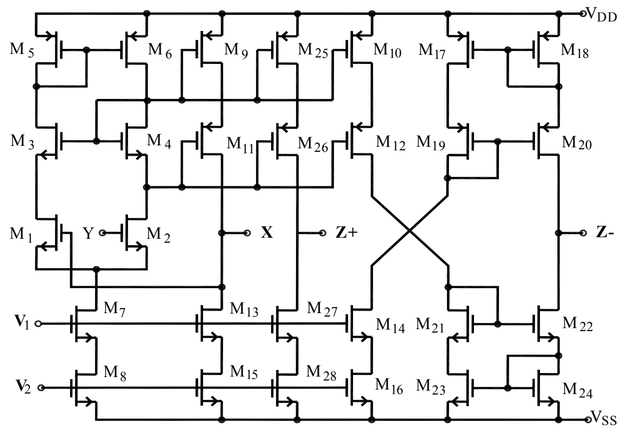


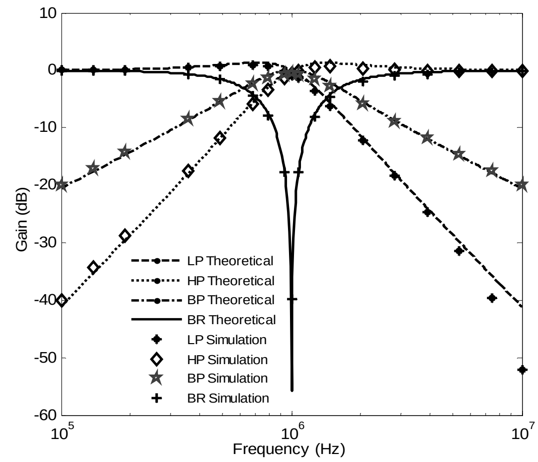
Figure 3. CMOS realization of the CCII.

Table 1. Aspect ratios of CCII MOSFETs.

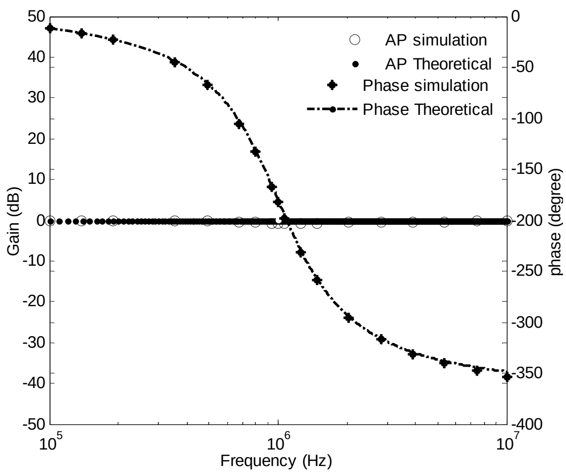
MOS transistors	W/L
M_1 - M_4	10/0.35
M_5, M_6	16/0.35
M_7, M_8, M_{13} - M_{16}, M_{21} - M_{24}, M_{27}, M_{28}	16/0.35
M_9 - M_{12}, M_{17} - M_{20}, M_{25}, M_{26}	30/0.35

Table 2. Aspect ratios of MO-CCCA MOSFETs.

MOS transistors	W/L
M_1 - M_3	9.5/0.55
M_4 - M_8, M_{17}, M_{18}, M_{24} - M_{27}	27.5/1.5
M_{10} - M_{15}, M_{21} - M_{23}	9.5/1.35
M_{16}, M_{19}, M_{20}	4.5/0.7



(a)



(b)

Figure 4. PSPICE Simulation results (a) Gain response of LPF, BPF, HPF and Notch; (b) Gain and Phase response of APF.

been done for a sinusoidal input signal at $f_o = 1$ MHz. **Figure 5** shows that the input dynamic range of the filter response extends up to amplitude of 105 μA without significant distortion. The dependence of the output harmonic distortion on the input signal amplitude is illustrated in **Figure 6**. For input signal amplitudes lower than 110 μA, the total harmonic distortion (THD) is of the order of less than 1% after that rapidly increasing is occurred. The obtained results show that the circuit operates properly even at signal amplitudes of about 120 μA and THD less than 4%.

To achieve the SIMO type filters with $f_o = 1$ MHz and quality factor of $Q_o = 2$, the component values were selected $K = 2(n = 1, I_A = 25\ \mu\text{A}, I_B = 100\ \mu\text{A})$, $R_1 = R_2 = 1\ \text{k}\Omega$ and $C_1 = C_2 = 159$ pF. The circuit realizes LP, HP, and BP responses, respectively, at $i_{01}; i_{02}$ and i_{03} simultaneously. The frequency responses of Notch and AP can be realized by, respectively, $(i_{01} + i_{02})$ and $(i_{01} + i_{02} + i_{03})$. Four filter responses are shown in **Figure 7**.

Figure 8 shows the simulation results for control of Q_o while keeping f_o fixed (1MHz) with $C_1 = C_2 = 159$ pF for different values of Q_o as shown in **Table 3**. **Figure 9** shows the simulation results for control of f_o while keeping $Q_o = 1$ with $C_1 = C_2 = 53$ pF for different values of f_o as shown in **Table 3**. The current mode band pass filter

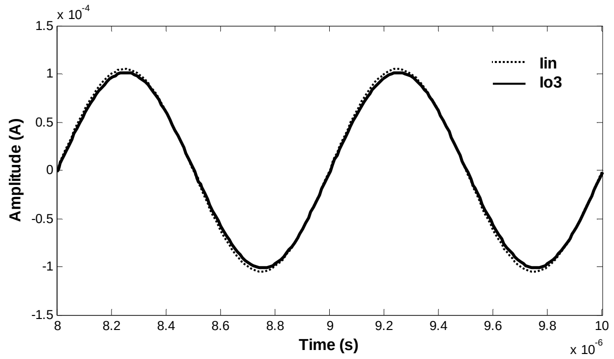


Figure 5. Time domain response of the input and output waveforms of the band-pass filter of the proposed circuit for 1 MHz sinusoidal input current of 105 μA.

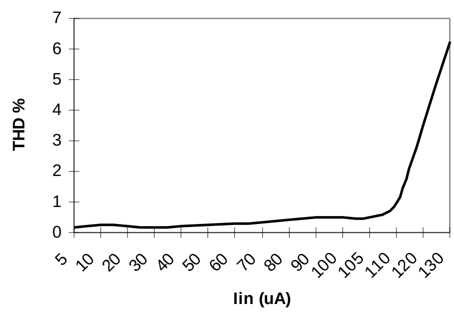


Figure 6. Dependence of output current harmonic distortion on input current amplitude of the band-pass filter of proposed circuit.

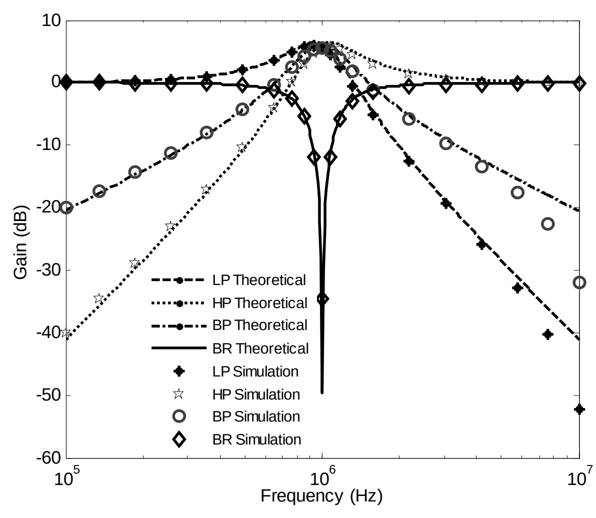


Figure 7. PSPICE Simulated gain responses of LP, BP, HP and Notch for SIMO type filter.

Table 3. The R_1 and R_2 values for controlling of Q_o and C_1 and C_2 values for controlling f_o.

Fixed f_o			Fixed Q_o		
Q_o	R_1 kΩ	R_2 kΩ	f_o MHz	R_1 kΩ	R_2 kΩ
1	1	1	1	3	3
2	0.7	1.43	2	1.5	1.5
4	0.5	2	3	1	1

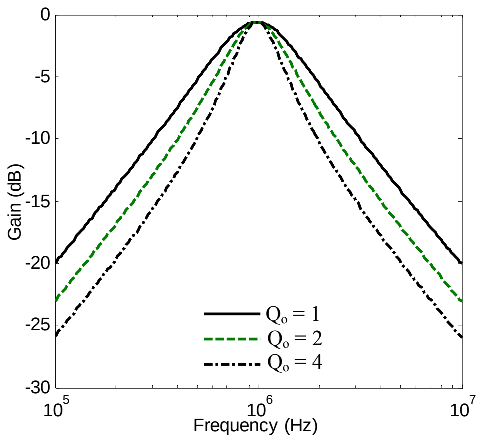


Figure 8. Simulation results for control of Q_o while keeping f_o fixed (1 MHz) for band pass filter.

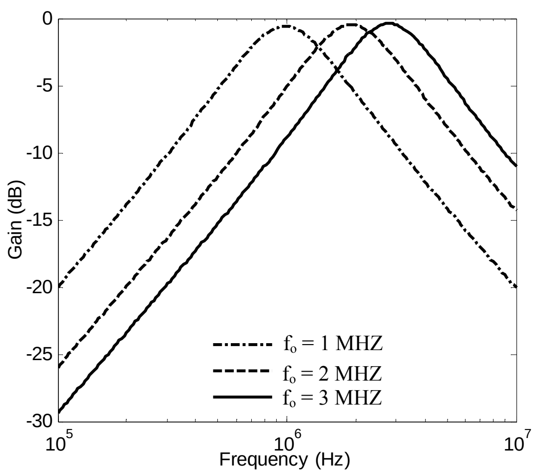


Figure 9. Simulation results for control of f_o while keeping Q_o (=1) fixed for band pass filter.

is tested for gain and quality factor tuning while keeping pole frequency constant at 1 MHz. $R_1 = R_2 = 1\ \text{k}\Omega$, $C_1 = C_2 = 159\ \text{pF}$ and $K = 1, 2, 4$ are taken for gain = quality factor $= 1, 2, 4$, respectively. The simulated results are shown in **Figure 10**.

A very good correspondence between design values and values determined from PSPICE simulations is observed, which confirms the workability of the current mode filters realized from the proposed configuration.

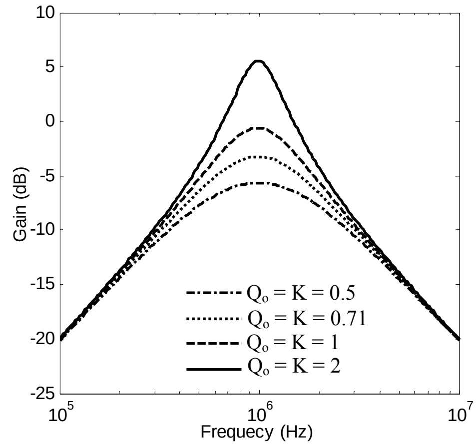


Figure 10. Simulation results for control of Q_o and gain while keeping f_o = 1 MHz fixed for band pass filter.

4. Concluding Remarks

A new universal MISO/SIMO type current-mode biquad employing two DOCCII, one MOCCCA and four passive grounded elements is proposed in this paper. The purpose of this paper as to introduce a new configuration which although uses exactly same number of active and passive components but in contrast to the circuit of reference [1] realizes a MIMO-type biquad and hence, does not require any additional hardware duplicate/invert current inputs which is required in case of MISO-type filters of [1]. The centre frequency ω_o can be set by the passive elements of the circuit and the quality factor Q_o is electronically tunable through bias currents of the MOCCCA. Therefore, the biquad filter has independent tenability for the ω_o and Q_o. The active and passive sensitivities Q_o and ω_o are low.

The workability of the new configuration has been demonstrated by PSPICE simulation results based upon a CMOS CCII in 0.35 μm technology

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