Electronically Tunable Current-Mode SIMO/MISO Universal Biquad Filter Using MO-CCCCTAs

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Abstract—This paper presents an electronically tunable current-mode SIMO/MISO universal biquad filter using multi-output current controlled current conveyor transconductance amplifiers (MO-CCCCTAs). The proposed filter employs only two CCCCTAs and two grounded capacitors. The proposed configuration can be used as either single input multi-output (SIMO) or multi (three) input single output (MISO) current mode filter. It can realize all five different standard filter functions i.e. low-pass (LP), band-pass (BP), high-pass (HP), band-reject (BR) and all-pass (AP). The circuit enjoys an independent current control of pole frequency and bandwidth. Both the active and passive sensitivities are no more than unity. The validity of proposed filter is verified through computer simulations using PSPICE, the industry standard tool.

IndexTerms—CCCCTA, current-mode, universal, biquad, filter

I. INTRODUCTION

The current-mode active filter, where information is represented by the branch currents of the circuits rather than the nodal voltages as of voltage-mode active filter, posses many unique and attractive characteristics over their voltage-mode counterpart parts including small nodal time constant, high current swing in the presence of a low supply voltage, reduced distortion and better ESD immunity [1]. During the last one decade and recent past a number of current-mode active filters have been reported in the literature [2-23], using different current conveyors (CCs). These current-mode active filters are broadly classified as SIMO [2-14, 22-23] or MISO [15-21, 22-23] current-mode filters. The SIMO current-mode filters can realize second order LP, BP, HP, BR and AP responses simultaneously, without changing the connection of the input current signal and without imposing any restrictive conditions on the input signal. The MISO current-mode filters can realize all the standard filter function through appropriate selection of the signals without any matching conditions. Unfortunately these reported circuits [2-23] suffer from one or more of the following drawbacks:

(i) Lack of electronic tunability [2-3, 15-17, 22].

(ii) Excessive use of active and/or passive elements [2-5, 7-18, 21-23].

(iii) Can not provide completely standard filter functions [4-6, 10].

(iv) Can not provide explicit current outputs [4-6].

(v) Use of floating passive elements [6-7, 19].

(vi) Require minus input current signal and/or double input current signal to realize AP filter function [19-21].

In spite of fact that most of these current-mode filters are either SIMO or MISO. However, the circuit reported in refs. [22-23] can be used as SIMO as well as MISO current-mode filter from the same configuration but these circuits [22-23] uses excessive number of active and passive components. CCCCTA is relatively new active element [24] and has received considerable attentions as current mode active element, because its trans-conductance and parasitic resistance can be adjusted electronically, hence it does not need a resistor in practical applications. This device can be operated in both current and voltage modes, providing flexibility. In addition, it can offer several advantages such as high slew rate, high speed, wider bandwidth and simpler implementation. All these advantages together, its current-mode operation makes the CCCCTA, a promising choice for realizing active filters [24]. In this paper an electronically tunable current-mode SIMO/MISO universal biquad filter employing two MO-CCCCTAs and two grounded capacitors.

The proposed configuration can be used as either SIMO or MISO current-mode filter, without change in circuit configuration. It can realize all five different standard filter functions i.e. LP, BP, HP, BR and AP. The circuit enjoys an independent current control of pole frequency and bandwidth. The circuit possesses low active and passive sensitivity performance. The performances of proposed circuit are illustrated by PSPICE simulations.
II. CIRCUIT DESCRIPTION

The CCCCTA properties can be described by the following equations

\[ V_\text{x}_i = V_\text{y}_i + I_{\text{x}_i} R_{\text{x}_i}, I_{\text{z}_i} = I_{\text{x}_i}, I_{\text{z}_i} = -I_{\text{x}_i}, I_\text{o} = g_{\text{m}_i} V_\text{z}_i \]  
\[ (1) \]

where \( R_{\text{x}_i} \) and \( g_{\text{m}_i} \) are the parasitic resistance at \( x \) terminal and transconductance of the \( i \)th CCCCTA respectively. \( R_{\text{x}_i} \) and \( g_{\text{m}_i} \) depend upon the biasing currents \( I_\text{B}_i \) and \( I_\text{S}_i \) of the \( i \)th CCCCTA respectively. The schematic symbol of CCCCTA is illustrated in Fig.1. The implementation of MO-CCCCTA with CMOS transistors [25] is shown in Fig.2. For CMOS model of CCCCTA shown in Fig.2, \( R_{\text{x}_i} \) and \( g_{\text{m}_i} \) can be expressed as

\[ R_{\text{x}} = \frac{1}{\sqrt{8\beta e I_B}} \]  
\[ (2) \]

and

\[ g_m = \sqrt{\beta n I_s} \]  
\[ (3) \]

Where \( \beta_n = \mu_n C_{\text{OX}} \frac{W}{L} \)  
\[ (4) \]

where \( \mu_n \), \( C_{\text{OX}} \) and \( W/L \) are the electron mobility, gate oxide capacitance per unit area and transistor aspect ratio, respectively.

III. PROPOSED FILTER CIRCUIT

The proposed electronically tunable current-mode SIMO/MISO universal biquad filter circuit is shown in Fig.3. It is based on two MO-CCCCTAs and two grounded capacitors. Routine analysis of the proposed circuit yields the following current transfer functions:

\[ I_{\text{OUT}_1} = \frac{-\left( I_{\text{in}_1} + I_{\text{in}_2}\right) C_2 s + I_{\text{in}_1} g_{\text{m}_2}}{D(s)} \]  
\[ (5) \]

\[ I_{\text{OUT}_2} = \frac{g_{\text{m}_2}\left[ I_{\text{in}_1} R_{\text{x}_2} s + I_{\text{in}_1} - I_{\text{in}_2}\right]}{D(s)} \]  
\[ (6) \]

\[ I_{\text{OUT}_3} = \frac{I_{\text{in}_1} \left(D(s) - C_2s\right) - I_{\text{in}_2} C_2 s - I_{\text{in}_3} g_{\text{m}_2}}{D(s)} \]  
\[ (7) \]

\[ I_{\text{OUT}_4} = \frac{g_{\text{m}_1} R_{\text{x}_2} \left[I_{\text{in}_1} + I_{\text{in}_2}\right] C_2 s + I_{\text{in}_3} g_{\text{m}_2}}{D(s)} \]  
\[ (8) \]

Where \( D(s) = s^2 C_1 C_2 R_{\text{x}_2} s + s C_2 + g_{\text{m}_2} \)  
\[ (9) \]

It can be seen from (7) that proposed filter circuit can be used as three input single output (TISO) current-mode filter and realizes five standard filter functions at current output \( I_{\text{OUT}_3} \) which are follow as:

(i). An inverted BP with \( I_{\text{in}_2} = I_{\text{in}} \) and \( I_{\text{in}_3} = I_{\text{in}_1} = 0 \).

(ii). A non-inverted HP with \( I_{\text{in}_2} = 0 \) and \( I_{\text{in}_3} = I_{\text{in}_1} = I_{\text{in}} \).

(iii). A non-inverted LP with \( I_{\text{in}_2} = I_{\text{in}_1} = 0 \) and \( I_{\text{in}_3} = I_{\text{in}} \).

(iv). A non-inverted BR with \( I_{\text{in}_1} = I_{\text{in}} \) and \( I_{\text{in}_3} = I_{\text{in}_2} = 0 \).

(v). A non-inverted AP with \( I_{\text{in}_1} = I_{\text{in}_2} = I_{\text{in}} \) and \( I_{\text{in}_3} = 0 \).

In this design we can note that there are no need of any component matching conditions, inverting-type input current signal(s) and double input current signal(s) to realize the above standard filter functions. Moreover, above proposed filter circuit can also be used as single input multi-output current-mode filter if \( I_{\text{in}_2} = I_{\text{in}_3} = 0 \) and by taking \( I_{\text{in}_1} \) as single input current terminal. From (5) to (8) the following current transfer functions can be obtained.

\[ \frac{I_{\text{OUT}_1}}{I_{\text{in}_1}} = -\frac{C_2 s}{D(s)} \]  
\[ (10) \]

\[ \frac{I_{\text{OUT}_2}}{I_{\text{in}_1}} = -\frac{g_{\text{m}_2}}{D(s)} \]  
\[ (11) \]

\[ \frac{I_{\text{OUT}_3}}{I_{\text{in}_1}} = \frac{C_1 C_2 R_{\text{x}_2} s^2 + g_{\text{m}_2}}{D(s)} \]  
\[ (12) \]
It can be seen from (10) to (13) that inverting BP, an inverting LP, non-inverting BR and non-inverting BP filter responses are obtained from output currents $I_{OUT1}$, $I_{OUT2}$, $I_{OUT3}$ and $I_{OUT4}$ respectively. HP and AP filter responses can be easily obtained from the currents $I_{HP} = I_{OUT2} + I_{OUT3}$ and $I_{AP} = I_{OUT1} + I_{OUT3}$ respectively. Obviously, it is a single-input six-outputs current mode universal biquad filter. The pole frequency ($\omega_o$), the quality factor ($Q$) and Bandwidth ($BW$) of each filter can be expressed as

$$\omega_o = \frac{1}{C_1C_2} \left( \frac{1}{\beta} \right)^\frac{1}{2} \left( 8I_{B2}I_{S2} \right)^\frac{1}{2}, \quad Q = \frac{C_1}{C_2} \left( \frac{I_{S2}}{8I_{B2}} \right)^\frac{1}{2}$$

From (15), by maintaining the ratio $I_{B2}$ and $I_{S2}$ to be constant, it can be remarked that the pole frequency can be electronically adjusted by $I_{B2}$ and $I_{S2}$ without affecting the quality factor. In addition, bandwidth (BW) of the system can be expressed by

$$BW = \frac{Q}{\omega_o} \left( \frac{8\beta_o I_{B2}}{C_1} \right)^\frac{1}{2}$$

Equation (15) shows that the bandwidth can be controlled by $I_{B2}$. From (15) and (16), it is clear that parameter $\omega_o$ can be controlled electronically by adjusting bias current $I_{S2}$ with out disturbing parameter $\omega_o/Q$.

IV. NON-IDEAL ANALYSIS

Taking the non-idealities of CCCCTA into account, the relationship of the terminal voltages and currents can be rewritten as follow.

$$V_{Xi} = \beta_i V_{Yi} + I_{Xi} R_{Xi}, \quad I_{Zi} = \alpha_{pi} I_{Xi}, \quad I_{-Zi} = -\alpha_{ni} I_{Xi},$$

$$I_o = \gamma_i g_{mn} V_{zi}$$

Where $\beta_i = 1 - \epsilon_{vi}$ and $\epsilon_{vi}$ ( $|\epsilon_{vi}| << 1$) represents the voltage tracking error from Y to X terminal, and $\alpha_{pi} = 1 - \epsilon_{pi}$ and $\epsilon_{pi}$ ( $|\epsilon_{pi}| << 1$) represents the current tracking error from X to $+Z$ terminal and $\alpha_{ni} = 1 - \epsilon_{ni}$ and $\epsilon_{ni}$ ( $|\epsilon_{ni}| << 1$) represents the current tracking error from X to $-Z$ terminal and $\gamma_i$ is the trans-conductance inaccuracy factor from Z to X terminal. The non-ideal analysis of the proposed filter in Fig.3 yields the denominator of the transfer functions as

$$D(s) = s^2 \alpha_m C_1C_2 R_{X2} + s\alpha_m \beta_2 R_2 C_2 + \alpha_m \alpha_{m2} \beta_2 \gamma_i g_{mn}$$

$$= s^2 \alpha_m C_1C_2 R_{X2} + s\alpha_m \beta_2 R_2 C_2 + \alpha_m \alpha_{m2} \beta_2 \gamma_i g_{mn}$$

$$(18)$$

Substituting intrinsic resistances as depicted in (2) - (3), it yields

$$\omega_o = \left( \frac{1}{C_1C_2} \right)^\frac{1}{2} \left( \frac{1}{\beta} \right)^\frac{1}{2} \left( 8I_{B2}I_{S2} \right)^\frac{1}{2}, \quad Q = \frac{C_1}{C_2} \left( \frac{I_{S2}}{8I_{B2}} \right)^\frac{1}{2}$$

(15)
In this case, the \( \omega_0 \) and \( Q \) are changed to
\[
\omega_0 = \left( \frac{\alpha_n \beta_2 \alpha_1}{C_1 C_2 R_{X_2}} \right)^{\frac{1}{2}}, \quad Q = \frac{\alpha_n}{\alpha_1} \left( \frac{\gamma_2 C_1 g_{m2} R_{X_2}}{\alpha_n \beta_2 C_2} \right)^{\frac{1}{2}}
\] (19)

The active and passive sensitivities of the proposed circuit as shown in Fig.3, can be found as
\[
S_{C_1, C_2, R_{X_2}}^{\omega_0} = -\frac{1}{2}, \quad S_{\gamma_2, \alpha_2, \beta_2, S_{\infty}}^{\omega_0} = \frac{1}{2},
\]
\[
S_{\alpha_n, \alpha_p, \gamma_1, R_{S}}^{\omega_0} = 0
\] (20)
\[
S_{C_2, \alpha_2, \beta_2}^{\omega_0} = -\frac{1}{2}, \quad S_{R_{X_2}, C_2, \gamma_2, S_{\infty}}^{\omega_0} = \frac{1}{2}, \quad S_{\alpha_1}^{\omega_0} = -1,
\]
\[
S_{\gamma_1, \gamma_1, R_{S}}^{\omega_0} = 1, \quad S_{R_{s}, S_{\infty}}^{\omega_0} = 0
\] (21)

From the above results, it can be observed that all the sensitivities are low and no longer than one in magnitude.

V. SIMULATION RESULTS

P-spice simulations are carried out to demonstrate the feasibility of the proposed circuit using CMOS implementation as shown in Fig.2. The simulations use a 0.35\( \mu \)m MOSFET from TSMC (the model parameters are given in Table1). The dimensions of PMOS are determined as \( W=3\mu m \) and \( L=2\mu m \). In NMOS transistors, the dimensions are \( W=3\mu m \) and \( L=4\mu m \). Fig.4 shows the simulated current gain responses of the LP, BP, BR, HP and AP of SIMO configuration of the proposed circuit in Fig.3. Fig.5 shows the simulated current gain and phase responses of the LP, BP, BR, HP and AP of MISO configuration of the proposed circuit in Fig.3. The proposed filter is designed with \( I_{B1}=I_{B2}=6\mu A, \quad I_{S1}=I_{S2}=54.5\mu A \) and \( C_1=C_2=35pf \). The supply voltages are \( V_{DD}=V_{SS}=1.85V \). The simulated pole frequency is obtained as 333 KHz. The simulation results agree quite well with the theoretical analysis.

Figure 4. Current gain responses of the LP, BP, BR, HP and AP of SIMO configuration of the proposed circuit in Fig.3

Figure 5. Current gain and phase responses of the (a) BP, (b) HP, (c) LP, (d) BR and (e) AP of MISO configuration of the proposed circuit in Fig.3.
Further simulations are carried out to verify the total harmonic distortion (THD). The circuit is verified by applying a sinusoidal current of varying frequency and amplitude 20µA. The THD are measured at the LP output (I\textsubscript{OUT2}). The THD is found to be less than 5% while frequency is varied from 10 KHz to 150 KHz. The time domain response of LP output (I\textsubscript{OUT2}) is shown in Fig.6. It is observed that 40µA peak to peak input current sinusoidal signal levels are possible with out significant distortions.

Figure 6. Time domain input and LP output (I\textsubscript{OUT2}) waveforms of the proposed circuit in Fig.3.

Table 1. 0.35µm level 3 MOSFET parameters

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V1. CONCLUSION

An electronically tunable current-mode SIMO/MISO universal quad filter using only two MO-CCCCTAs and two grounded capacitors is proposed. The proposed filter offers the following advantages

(i). Simultaneously realizes LP, BP, HP, BR and AP responses with the single input three output or three input single output from same configuration.

(ii). Both the capacitors are grounded and ideal for integrated circuit implementation.

(iii). Low sensitivity figures.

(iv). Filter parameters - \( \omega_0 \), Q and \( \omega_0 / Q \) are electronically tunable with bias current(s) of CCCCTA(s)

(v). \( \omega_0 \) and \( \omega_0 / Q \) are orthogonally tunable.

(vi). No need to use inverting-type input current signals or double input current signals to realize all five standard filter functions.

(vii). Availability of explicit current outputs (i.e. high impedance output nodes) without requiring any additional active elements.

With above mentioned features it is very suitable to realize the proposed circuit in monolithic chip to use in battery powered, portable electronic equipments such as wireless communication system devices.
REFERENCES


