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Single MO-CCCCTA-Based Electronically Tunable Current/Trans-Impedance-Mode Biquad Universal Filter

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Abstract

This paper presents an electronically tunable current/trans-impedance-mode biquad universal filter employing only single multi-output current controlled current conveyor trans-conductance amplifier (MO-CCCCTA) and two grounded capacitors. The proposed filter realizes all the standard filter functions *i.e.* low pass (LP), band pass (BP) and high pass (HP), notch and all pass (AP) filters in the current form at high impedance output through appropriate selection of the input signals, without any matching conditions. Simultaneously, it can also realize all the standard filter functions in trans-impedance form from the same circuit topology. The circuit does not require inverting-type input current signal(s) and double input current signal(s) to realize all the responses in the design. The validity of proposed filter is verified through PSPICE simulations.

Keywords: Universal, Current-Mode, Trans-Impedance-Mode, Biquad Filter

1. Introduction

Analog electronic filters are important blocks, widely employed in continuous time signal processing. They are present in just about every piece of electronic equipment that are obvious types of equipments, such as radios, televisions and stereo systems. Test equipments such as spectrum analyzers and signal generators also need filters even where signals are connected into digital form, using digital to analog converters; analog filters are usually needed to prevent aliasing. Universal biquadratic filters belong to most popular analog filters, providing all standard filter functions (LP, BP, HP, Notch and AP), without modifying the circuit topology. Several filter realizations either in current-mode, where the input and the output variables are current, or in voltage-mode, where the input and output variables are voltage, have been reported using different active elements [1-22]. These filter circuits are classified as single input multiple output (SIMO) [1-10], multiple input single output (MISO) [11-19] and multiple input multiple output (MIMO) [20-22]. However, there are a number of applications in analog signal processing where it may be desirable to have active filters with input variable as current and output variable as voltage that is trans-impedance filters. Such filters can be used as an interface circuit connecting a current-mode circuit to a voltage-mode circuit and find direct applications with some sensors, the receiver base band (BB) blocks of modern radio systems and D/A converters which provide a current as output signal, avoiding a current to voltage conversion [23,24]. There are a small number of filter topologies operating in trans-impedance-mode reported in the literature [25-27]. These filter topologies reported in [24-26] cannot realize all the standard filter functions (LP, BP, HP, Notch and AP). As far as the topic of this paper is concerned, the filter circuits operated in either current-mode or trans-impedance-mode or in both modes simultaneously, using a single active element, are of interest. Single active element based current-mode filters with multi-input are reported in [18-20]. The circuits in references [18,19] use three inputs and one output and realize all the standard filter functions at high impedance output terminal. The filter circuit of [18] employs single CCCII, two grounded capacitors and one floating resistor and suffers from the following disadvantages: 1) requirement of passive component matching conditions, 2) requirement of inverting-type input current signal, 3) use of floating resistor which is not suitable for IC fabrications while other filter circuit of [19] uses single CCCCTA, two grounded capacitors and suffers from the following two disadvantages: requirement of double input current signal to obtain an all-pass response and use of one capacitor at port X which limits the use of filter in high frequency range since it effectively appears in series with *X* terminal resistance [28]. Lastly, a three inputs and two outputs current-mode single DO-CCCDTA based filter circuit [20] also realizes all the standard filter functions at high impedance outputs but it still require double input current signal to obtain an all-pass response. Up until now, no previous paper has reported a filter based on single active element which can realize all the standard responses in current as well as trans-impedance form, together, without any matching conditions, from the same topology. In this paper a single MO-CCCCTA-based electronically tunable current/trans-impedance-mode biquad universal filter is proposed. It also uses two grounded capacitors. The proposed filter realizes all the standard filter functions *i.e.* LP, BP, HP, notch and AP filters in the current form at high impedance output through appropriate selection of the input signals, without any matching conditions. Simultaneously, it can also realize all the standard filter functions in trans-impedance form from the same circuit topology. The proposed circuit does not require inverting-type input current signal(s) and double input current signal(s) to realize all the responses in the design. The proposed circuit does not use capacitor at port *X* so this circuit is suitable in high frequency range. The circuit possesses low active and passive sensitivity. Moreover, the pole frequency (ω_o) can be independently tuned without disturbing the parameter ω_o/Q through adjusting the bias current of MO-CCCCTA. The performance of proposed circuit is illustrated by PSPICE simulation using 0.35 µ CMOS parameters.

2. Proposed Circuit

CCCCTA is relatively new proposed current mode active building block [19] which is the modified version of CCTA. 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. Moreover, in the CCCCTA one can control the parasitic resistance at *X* (R_X) port by input bias current. The MO-CCCCTA properties can be described in the following matrix equation

$$\begin{bmatrix} I_Y \\ V_X \\ I_{-Za,-Zc} \\ I_{Zb} \\ I_{-Ob} \\ I_{-Oc} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 & 0 \\ R_x & 1 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -g_{mb} & 0 & 0 & 0 \\ 0 & 0 & 0 & -g_{mc} & 0 & 0 \end{bmatrix} \begin{bmatrix} I_X \\ V_Y \\ V_{Zb} \\ V_{-Zc} \\ V_{-Ob} \\ V_{-Oc} \end{bmatrix} \quad (1)$$

where R_X is the parasitic resistance at *X* terminal. g_{mb} and g_{mc} are trans-conductance of CCCCTA. The schematic symbol of MO-CCCCTA is illustrated in **Figure 1**. CMOS implementation of MO-CCCCTA is shown in **Figure 2**. For a CMOS CCCCTA [29], the R_X, g_{mb} and g_{mc} can be expressed to be

$$R_X = \frac{1}{\sqrt{8\beta_n I_B}}, \quad g_{mb} = \sqrt{\beta_n I_{Sb}} \quad \text{and } g_{mc} = \sqrt{\beta_n I_{Sc}} \quad (2)$$

where

$$\beta_n = \mu_n C_{OX} \frac{W}{L} \quad (3)$$

where μ_n, C_{OX} and W/L are the electron mobility, gate oxide capacitance per unit area and transistor aspect ratio, respectively. I_B, I_{Sb} and I_{Sc} are the biasing currents of MO-CCCCTA.

The proposed biquad filter circuit as shown in **Figure 3** uses only single MO-CCCCTA and two grounded capacitors. By routine analysis of the circuit in **Figure 3**, the output current I_O and output voltage V_O can be obtained as

$$I_O = \frac{I_1 s^2 C_1 C_2 - I_2 s C_2 g_{mc} + I_3 g_{mb} g_{mc}}{s^2 C_1 C_2 + s C_2 g_{mc} + g_{mb} g_{mc}} \quad (4)$$

$$V_O = \frac{R_x \left(I_1 s^2 C_1 C_2 - I_2 s C_2 g_{mc} + I_3 g_{mb} g_{mc} \right)}{s^2 C_1 C_2 + s C_2 g_{mc} + g_{mb} g_{mc}} \quad (5)$$

From Equations (4) and (5), various filter responses in current form as well as in trans-impedance form can be

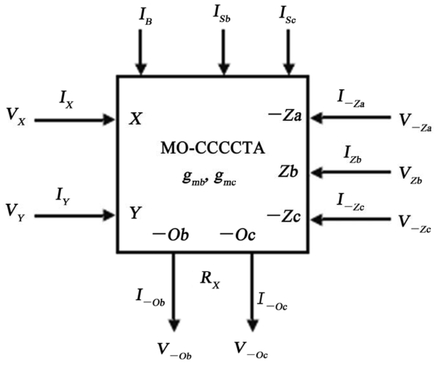


Figure 1. MO-CCCCTA symbol.

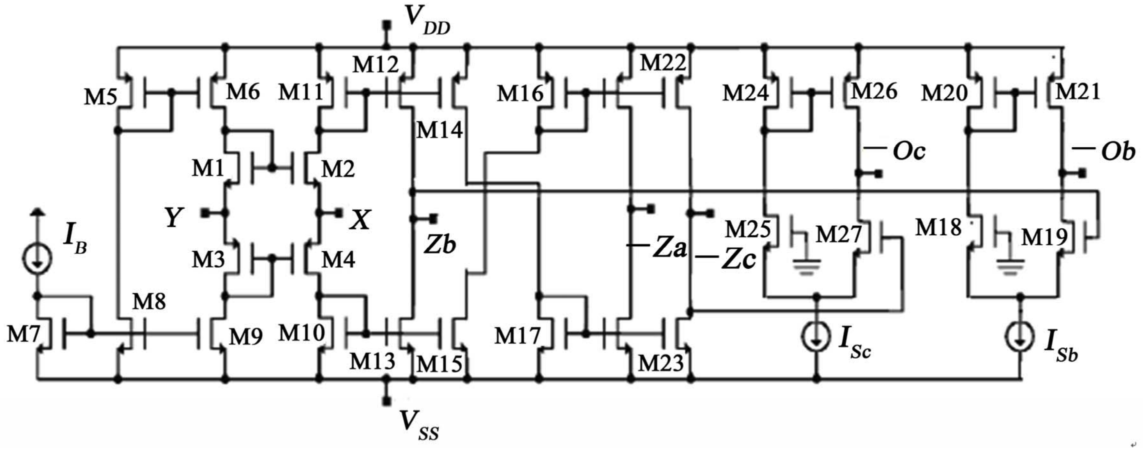


Figure 2. CMOS implementation of MO-CCCCTA.

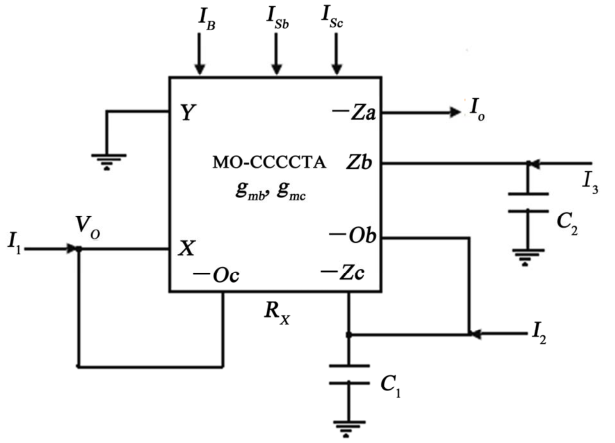


Figure 3. proposed current/trans-impedance-mode universal filter.

obtained through appropriate selection of input currents.

1) High pass response in current form as well as in trans-impedance form, with $I_1 = I_{in}, \ I_2 = I_3 = 0$.

2) Low pass response in current form as well as in trans-impedance form, with $I_1 = I_2 = 0, \ I_3 = I_{in.}$.

3) Inverted band pass response in current form as well as in trans-impedance form, with $I_1 = I_3 = 0, \ I_2 = I_{in.}$.

4) Notch response in current form as well as in trans-impedance form, with $I_1 = I_3 = I_{in}, \ I_2 = 0$.

5) All pass response in current form as well as in trans-impedance form, with $I_1 = I_2 = I_3 = I_{in}$.

Thus, the circuit is capable of realizing all the standard filter responses in current as well as in trans-impedance-mode from the same configuration, without any matching constraints. Moreover, there is no requirement of inverting-type input current signal(s) and double input current signal(s) to realize all the responses in the design.

The filter parameters pole frequency (ω_o), the quality factor (Q) and bandwidth (BW) ω_o/Q can be expressed as

$$\omega_o = \left(\frac{g_{mc}g_{mb}}{C_1C_2}\right)^{\frac{1}{2}} = \left(\frac{1}{C_1C_2}\beta_n\right)^{\frac{1}{2}} \left(I_{Sc}I_{Sb}\right)^{\frac{1}{4}},$$

$$Q = \left(\frac{C_1 g_{mb}}{C_2 g_{mc}}\right)^{\frac{1}{2}} = \left(\frac{C_1}{C_2}\right)^{\frac{1}{2}} \left(\frac{I_{Sb}}{I_{Sc}}\right)^{\frac{1}{4}} \tag{6}$$

and

$$BW = \frac{\omega_O}{Q} = \frac{g_{mc}}{C_1} = \frac{1}{C_1}\left(\beta_n I_{Sc}\right)^{\frac{1}{2}} \tag{7}$$

From (6) by maintaining the ratio I_{Sb} and I_{Sc} to be constant, it can be remarked that the pole frequency can be adjusted by I_{Sb} and I_{Sc} without affecting the quality factor. In addition, pole frequency can be controlled by I_{Sb} without affecting bandwidth (BW) of the system. To see the effects of non idealities, the defining equations of the MO-CCCCTA can be rewritten as the following.

$$V_X = \beta V_Y + I_X R_X, \quad I_{-Za} = -\alpha_a I_X, \quad I_{Zb} = \alpha_b I_X \tag{8}$$

$$I_{-Zc} = -\alpha_c I_X, \quad I_{-Ob} = -\gamma_b g_{mb} V_{Zb}, \quad I_{-Oc} = -\gamma_c g_{mc} V_{-Zc} \tag{9}$$

where β, α_a, α_b, α_c, γ_b and γ_c are transferred error values deviated from one. In the case of non-ideal and re-analyzing the proposed filter in **Figure 3**, it yields the current output and voltage output as

$$I_O = \frac{\alpha_a\left(I_1 s^2 C_1 C_2 - I_2 s\gamma_c C_2 g_{mc} + I_3 \gamma_b \gamma_c g_{mb} g_{mc}\right)}{s^2 C_1 C_2 + s\gamma_c \alpha_c C_2 g_{mc} + \gamma_b \gamma_c \alpha_b g_{mb} g_{mc}} \tag{10}$$

$$V_O = \frac{\alpha_a R_X\left(I_1 s^2 C_1 C_2 - I_2 s\gamma_c C_2 g_{mc} + I_3 \gamma_b \gamma_c g_{mb} g_{mc}\right)}{s^2 C_1 C_2 + s\gamma_c \alpha_c C_2 g_{mc} + \gamma_b \gamma_c \alpha_b g_{mb} g_{mc}} \tag{11}$$

In this case, the ω_o and Q are changed to

$$\omega_o = \left(\frac{\gamma_b \gamma_c \alpha_b g_{mb} g_{mc}}{C_1 C_2}\right)^{\frac{1}{2}}, \quad Q = \frac{1}{\alpha_c}\left(\frac{\gamma_b \alpha_b C_1 g_{mb}}{\gamma_c C_2 g_{mc}}\right)^{\frac{1}{2}} \tag{12}$$

The all active and passive sensitivities can be found as

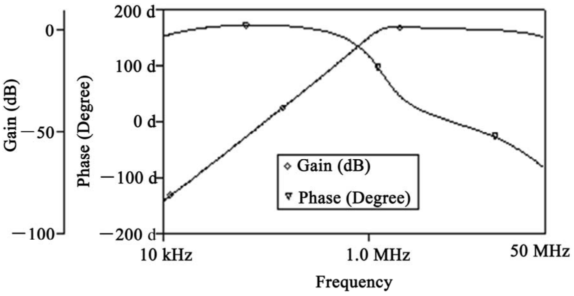
$$S^{\omega_o}_{C_1,C_2} = -\frac{1}{2},\quad S^{\omega_o}_{\gamma_b,\gamma_c,\alpha_b,g_{mb},g_{mc}} = \frac{1}{2},\quad S^{\omega_o}_{\alpha_a,\alpha_c,\beta,R_X} = 0 \quad (13)$$

$$S^{Q}_{C_2,g_{mc},\gamma_c} = -\frac{1}{2},\quad S^{Q}_{C_1,\alpha_b,\gamma_b,g_{mb}} = \frac{1}{2},\quad S^{Q}_{\alpha_c} = -1 \quad S^{Q}_{\alpha_a,\beta,R_X} = 0 \quad (14)$$

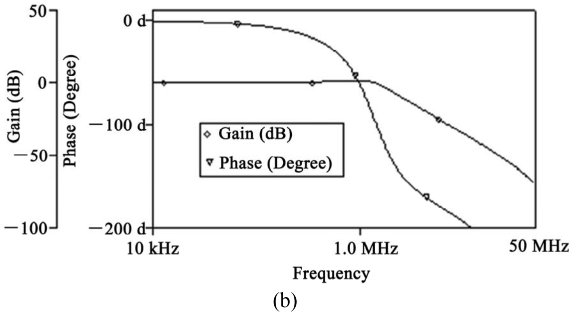
From the above results, it can be observed that all the active and passive sensitivities are equal or less than 1 in magnitude.

3. Simulation Results

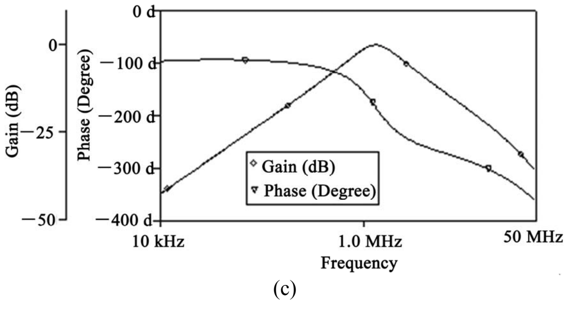
The PSPICE simulations are carried out to demonstrate the feasibility of the proposed circuit using CMOS implementation as shown in **Figure 2.** The simulations use a 0.35 µm MOSFET [30] from TSMC. The dimensions of PMOS are determined as $W = 3$ µm and $L = 2$ µm. In NMOS transistors, the dimensions are $W = 3$ µm and $L = 4$ µm. The circuit is designed for $Q = 1$ and $f_o = \omega_o/2\pi = 1.57$ MHz. The active and passive components are chosen as $I_B = 7.5$ µA, $I_{Sb} = I_{Sc} = 30.65$ µA and $C_1 = C_2 = 7.5$ pF. **Figure 4** Shows the simulated gain and phase responses of the HP, LP, BP, Notch and AP in the current form, of the proposed circuit in **Figure 3**. The supply voltages are $V_{DD} = -V_{SS} = 2.5$ V. The simulated pole frequency is obtained as 1.35 MHz. It is noted that simulation results agree quite well with theoretical ones as expected, whereas the difference between them arises from non-idealities such as non ideal gain and parasitic elements. The power dissipations of the proposed circuit for the design values is found as 0.629 mW that is a low value.



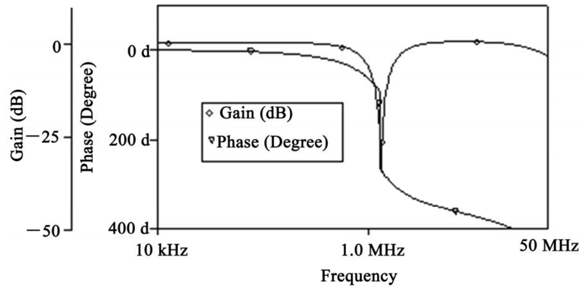
(a)



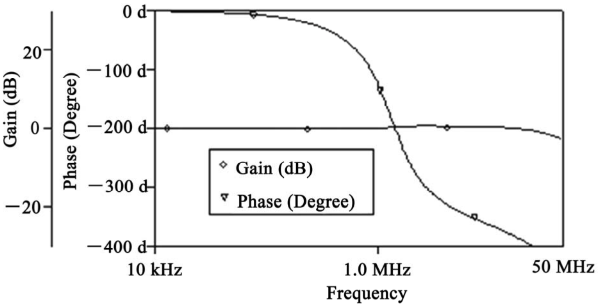
(b)



(c)



(d)



(e)

Figure 4. Current gain and Phase responses of the proposed filter (a) HP, (b) LP, (c) BP, (d) Notch and (e) AP.

Next, the frequency tuning aspect of the circuit is verified for a constant Q (= 1) value for the BP response in current-mode. The bias currents I_{Sb} and I_{Sc} are varied simultaneously, by keeping its ratio to be constant. The pole frequency variation, for $Q = 1$, is shown in **Figure 5**. The frequency is found to vary as 650 kHz, 990 kHz, 1.34 MHz and 1.8 MHz for four values of $I_{Sb} = I_{Sc} = 6$ µA, 15 µA, 30 µA and 60 µA, respectively. Further simulations are carried out to verify the total harmonic distortion (THD). The circuit is simulated for THD analysis at BP output in current-mode, by applying sinusoidal input current of varying amplitude and constant frequency. The THD values for the input current signal having amplitude less than 40 µA, at frequency 1.35 MHz remain in acceptable limits *i.e.* 4%. The time domain response of band-pass output in current form is shown in **Figure 6**. It is observed that 40 µA peak to peak input current sinusoidal signal levels are possible without significant distortions. Thus both THD analysis and time domain response of BP output in current-mode confirm the practical utility of the proposed circuit.

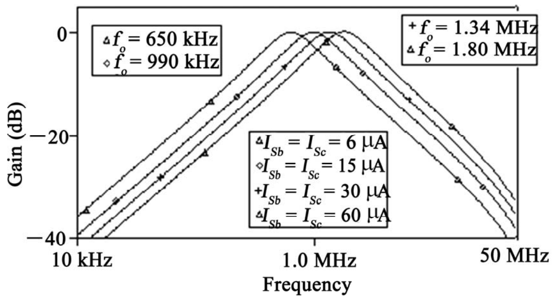


Figure 5. Band pass responses in current-mode for different values of $I_{Sb} = I_{Sc}$ of the proposed filter.

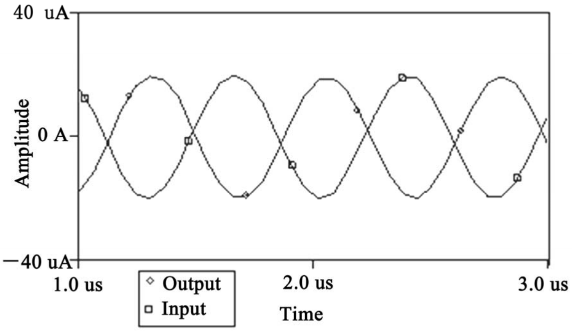


Figure 6. The sinusoidal input having frequency of 1.35 MHz and corresponding band pass output waveforms in current-mode of the proposed filter.

4. Conclusions

This paper presents an electronically tunable current/trans-impedance-mode biquad universal filter using single MO-CCCCTA. The proposed filter offers the following advantages: 1) realization of LP, HP, BP, Notch and AP responses in current form as well as in trans-impedance form without changing the circuit topology; 2) both the capacitors being permanently grounded; 3) low sensitivity figures, low THD and low power consumptions; 4) independent current control of ω_o without disturbing ω_o/Q; 5) no requirement of components matching conditions to get all filter responses; 6) no requirements of inverting-type input current signal(s) and double input current signal(s) to realize the response(s) in the design; 7) single active element.

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