Current Controlled Current-Mode SITO Biquad Universal Filter Using CCTAs

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Abstract

This paper presents a current controlled current-mode single input three output (SITO) biquad universal filter employing current conveyor trans-conductance amplifiers (CCTAs) as active element. It consists of two CCTAs, two grounded capacitors and three grounded resistors. The proposed filter simultaneously realizes low pass (LP), band pass (BP) and band reject (BR) in current-mode at high impedance outputs. It can also realize high pass (HP) and all pass (AP) filtering functions with interconnection of relevant output currents. In addition, the quality factor and bandwidth can be controlled independently of pole frequency through single bias current. The circuit possesses low active and passive sensitivity performance. The validity of proposed filter is verified through PSPICE simulations.

Keywords: Universal, current-mode, CCTA, biquad filter.

1. Introduction

In analog signal processing, continuous time (CT) filters[1-2] play an important role for realizing frequency selective circuits. However, one critical issue with CT filters[3] is the RC time constant variation problem due to process tolerance, the environmental effects of temperature drift, humidity and aging of the components. As a consequence, the performance of the filter circuit differs from the nominal design. The continuous-time filter approach typically compensates for this problem with the tunable filter, by electronically varying the time constant so there is a growing interest towards designing of electronically tunable filters to compensate for deviation in the circuit due to process tolerance, parasitic, temperature drift and aging. During the last one decade and recent past, several electronically tunable current-mode active filters have been proposed in the literature[4-17], using different current-mode active elements such as second generation current controlled current conveyor (CCCII)[4-5, 11-13], current differencing transconductance amplifier (CDTA)[9-10], current follower transconductance amplifier (CFTA)[6-8], current controlled current conveyor transconductance amplifier (CCCCTA)[14-15] and second generation current conveyor transconductance amplifier (CCTA)[16-17]. These electronically tunable filters can be either single-input multiple-output (SIMO) or multiple-input single output (MISO). SIMO filters[4-10, 14-16] simultaneously realize multi-function filter outputs, without changing the connection of the input signal and without input signal matching. On the hand MISO filters[11-13, 17] can realize multifunction filter outputs by altering the way in which input signals are connected. However, most of the current-mode filters[4-8, 10-15] reported above uses excessive active elements. As far as the topic of this paper is concerned, the current-mode filter

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[*] Typeset names in 10 pt Times Roman, uppercase. Use the footnote to indicate the present or permanent address of the author.

circuits based on CCTA are of interest. In my best knowledge, till now, only two current-mode filters using CCTA(s) are reported in the literature[16-17]. The first current-mode filter circuit[16] based on CCTA uses only single CCTA as active element and two resistors, two capacitors as passive elements but it realizes only three filtering functions simultaneously. In addition, two filtering functions are available across the passive element which is not suitable for cascading of current-mode filter to achieve higher order filter. On the other hand, the second current-mode filter[17] consists of two CCTAs and two grounded capacitors and realizes all standard filtering functions. However, only one filtering function is realized at a time which is not favorable in the applications where two or more than two filtering outputs are simultaneously required. Moreover, filter parameters like quality factor and bandwidth can not be controlled independently of pole frequency through single bias current.

In this work, a new current-mode biquad universal filter with single input three outputs is proposed. It uses two CCTAs, three grounded resistors and two grounded capacitors. The proposed filter can simultaneously realize all the standard filter functions i.e. LP, BP, HP, BR and AP filters in the current form at high impedance outputs. The circuit possesses low active and passive sensitivity performance. Moreover, the quality factor can be independently tuned without disturbing the pole frequency through adjusting the single bias current of CCTA only. The performance of proposed circuit is illustrated by PSPICE simulation using 0.35µ CMOS parameters.

2. CCTA and Proposed Filter Circuit

The CCTA[16-17] is a combination of second generation current conveyor (CCII) and operation transconductance amplifier (OTA). The block diagram of the CCTA is shown in Fig.1. It consists of two input terminals (*X, Y*) and two output terminals (*Z, -O*). Port X is low input impedance terminal while port Y is the high input impedance terminal. Port *Z* and port *-O* are two type of high output impedance terminals. The input-output current-voltage relationship between different terminals of the CCTA can be described by the following equations.

$$V_X = V_Y\,,\ I_Y = 0\,, I_Z = I_X\,,\ I_{-O} = -g_m V_Z \quad (1)$$

where g_m is the trans-conductance of CCTA and g_m depends upon the biasing current I_S of the CCTA. The Schematic symbol of CCTA is shown in Fig.1. For a MOS implementation of CCTA as shown in Fig.2, the g_m can be expressed to be

$$g_m = \sqrt{\beta_n I_s} \quad (2)$$

where β_n is given by

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

where μ_n, C_{OX} and W/L are the electron mobility, gate oxide capacitance per unit area and transistor aspect ratio of NMOS, respectively.

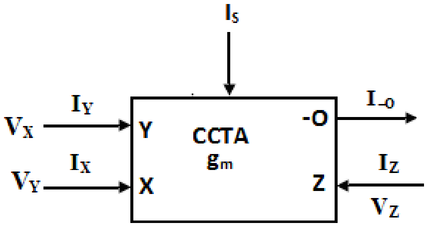

Fig.1. CCTA Symbol.

The proposed current-mode biquad universal filter with single input three output is shown in Fig.3. It is constructed with two CCTAs, three grounded resistors and two grounded capacitors. Circuit analysis of proposed filter in Fig.3 yields three circuit transfer functions T_{LP}, T_{BP} and T_{BR} for the current outputs I_{LP}, I_{BP}, and I_{BR} and can be expressed as

$$T_{LP} = \frac{I_{LP}}{I_{in}} = \frac{-g_{m2}R_a}{s^2C_1C_2R_bR_c + sg_{m1}R_cR_aC_2 + g_{m2}R_b} \quad (4)$$

$$T_{BP} = \frac{I_{BP}}{I_{in}} = \frac{-sg_{m1}R_cR_aC_2}{s^2C_1C_2R_bR_c + sg_{m1}R_cR_aC_2 + g_{m2}R_b} \quad (5)$$

$$T_{BR} = \frac{I_{BR}}{I_{in}} = \frac{s^2C_1C_2R_aR_c + g_{m2}R_a}{s^2C_1C_2R_bR_c + sg_{m1}R_cR_aC_2 + g_{m2}R_b} \quad (6)$$

Transfer function for HP filter function can be realized simply by connecting or adding currents I_{LP} and I_{BR}. Transfer function for HP response can be expressed as

$$T_{HP} = \frac{I_{HP}}{I_{in}} = \frac{s^2C_1C_2R_aR_c}{s^2C_1C_2R_bR_c + sg_{m1}R_cR_aC_2 + g_{m2}R_b} \quad (7)$$

Moreover, transfer function for AP filter function can also be realized simply by connecting or adding currents I_{BP} and $I_{BR,}$ together and keeping condition R_a=R_b. Transfer function for AP response can be expressed as

$$T_{AP} = \frac{I_{AP}}{I_{in}} = \frac{s^2 C_1 C_2 R_b R_c - s g_{m1} R_c R_a C_2 + g_{m2} R_b}{s^2 C_1 C_2 R_b R_c + s g_{m1} R_c R_a C_2 + g_{m2} R_b} \quad (8)$$

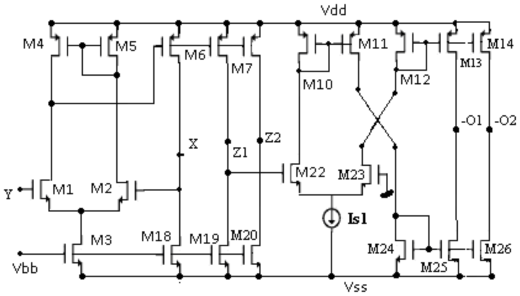

Fig.2. MOSFET implementation of CCTA.

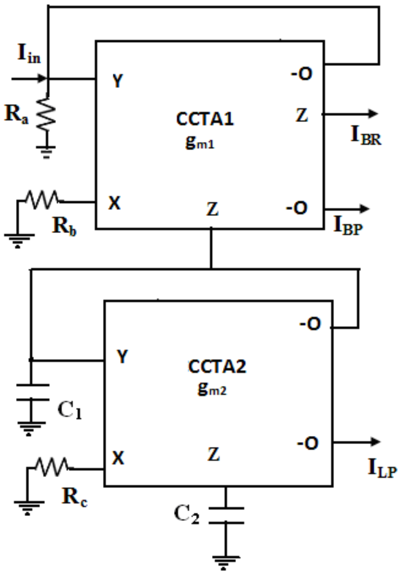

Fig.3. Proposed current-mode SITO biquad universal filter using CCTAs.

The pole frequency (ω_0), the quality factor (Q) and Bandwidth (BW) ω_0 /Q of each filter response can be calculated as

$$\omega_0 = \left(\frac{g_{m2}}{C_1 C_2 R_c} \right)^{\frac{1}{2}} = \left(\frac{\sqrt{\beta_n I_{S2}}}{C_1 C_2 R_c} \right)^{\frac{1}{2}} \quad (9)$$

$$BW = \frac{\omega_0}{Q} = \frac{g_{m1} R_a}{C_1 R_b} = \frac{\sqrt{\beta_n I_{S1}} R_a}{C_1 R_b} \quad (10)$$

$$Q = \frac{R_b}{g_{m1} R_a} \left(\frac{C_1 g_{m2}}{C_2 R_c} \right)^{\frac{1}{2}} = \frac{R_b}{R_a \sqrt{I_{S1}}} \left(\frac{C_1}{C_2 R_c} \sqrt{\frac{I_{S2}}{\beta_n}} \right)^{\frac{1}{2}} \quad (11)$$

It can also be noted from Eqs. (9), (10) and (11) that the quality factor Q and Bandwidth can be electronically controlled independent of ω_0 through only single bias current (I_{S1}). To see the effects of non idealities, the defining equations of the CCTA can be rewritten as the following

$$V_{Xi} = \beta_i V_{Yi}, I_{Zi} = \alpha_i I_{Xi}, \; I_{-Oi} = -\gamma_i g_{mi} V_{Zi} \quad (12)$$

where β_i, α_i and γ_i are transferred ratios of i^{th} CCTA (i=1,2) which deviate from 'unity' by the transfer errors. In the case of non-ideal and re-analyzing the proposed filter in Fig.3, the ω_o and Q are changed to

$$\omega_0 = \left(\frac{\gamma_2 \beta_2 g_{m2}}{\alpha_2 C_1 C_2 R_c} \right)^{\frac{1}{2}} \quad (13)$$

$$Q = \frac{\alpha_1 R_b}{\beta_1 \gamma_1 g_{m1} R_a} \left(\frac{\gamma_2 \beta_2 C_1 g_{m2}}{\alpha_2 C_2 R_c} \right)^{\frac{1}{2}} \quad (14)$$

The active and passive sensitivities of the proposed circuit can be found as

$$S^{\omega_o}_{C_1, C_2, R_c, \alpha_2} = -\frac{1}{2}, S^{\omega_o}_{g_{m2}, \beta_2, \gamma_2} = \frac{1}{2},$$
$$S^{\omega_o}_{R_a, R_b, g_{m1}, \alpha_1, \beta_1, \gamma_1} = 0 \quad (15)$$

$$S^{Q}_{C_2, \alpha_2, R_c} = -\frac{1}{2}, S^{Q}_{g_{m2}, C_1, \beta_2, \gamma_2} = \frac{1}{2},$$
$$S^{Q}_{\gamma_1, \beta_1, g_{m1}, R_a} = -1, S^{Q}_{\alpha_1, R_b} = 1 \quad (16)$$

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

3. Simulation Result

The proposed universal current-mode filter in Fig.3 was verified through PSPICE simulations. In simulation, the CCTA was realized using the MOS implementation as shown in Fig.2, with the transistor model of 0.35µm MOSFET from TSMC[18]. The circuit was designed for Q=1 and $f_0=\omega_0/2\pi$=1.05 MHz. In the simulation the active and passive components were selected as $R_a=R_b=R_c$=2.8k, $I_{S1}=I_{S2}$= 80µA and $C_1=C_2$=53pF, V_{dd} = -V_{ss}= 1.5V and V_{bb}= -1V. The aspect ratios of MOS transistors are given in Table 1. The simulated gain responses of the LP, HP, BP, BR and AP are shown in Fig.4. Fig.5 shows the phase and gain response of BR. Fig. 6 shows the phase and gain response of AP. The simulated pole frequency is obtained as 1.04 MHz which is much closed to designed value as 1.05 MHz. The tuning aspect of the quality factor by single bias current $I_{S1,}$ without affecting the pole frequency is shown in Fig.7 which shows the various responses of current-mode BR and BP for different values of I_{S1}.

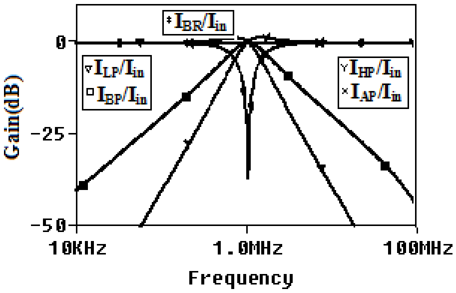

Fig.4. Current gain response of LP, BP, BR, HP and AP of the proposed filter circuit in Fig.3.

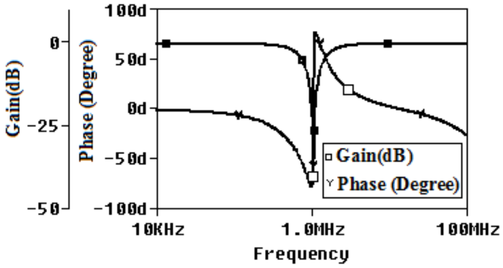

Fig.5. Current gain and phase response of BR for the proposed filter circuit in Fig.3

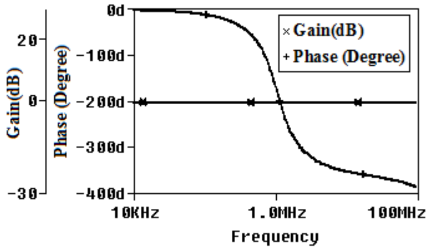

Fig.6. Current gain and phase response of AP for the proposed filter circuit in Fig.3.

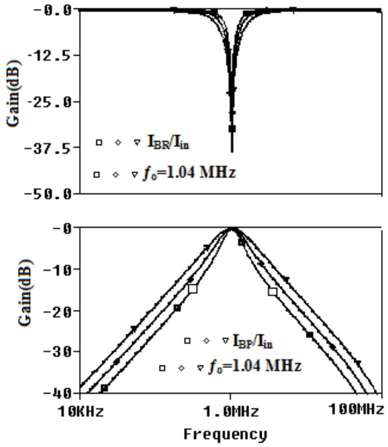

Fig.7. Various responses of BR and BP, showing the tuning aspect of quality factor.

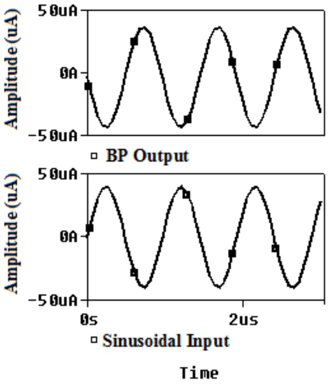

Fig.8. Time domain sinusoidal input current signal and corresponding BP output.

The time domain behavior of the proposed current-mode filter is also investigated by applying a 1.04MHz sinusoidal input current signal. The time domain response of BP output is shown in Fig.8. It is observed that 80μA peak to peak input current sinusoidal signal levels are possible without significant distortions. Thus, time domain response of BP output and tuning aspect of quality factor confirm the practical utility of the proposed circuit.

Table 1. Aspect ratio of MOS

MOS transistors	Aspect-ratio [W(μm)/L(μm)]
M1,M2	10/0.5
M3	27.25/0.5
M4,M5	5/0.5
M6-M8	8.5/0.5
M18-M20	44/0.5
M10-M14 and M22-M26	5/0.5

4. Conclusion

In this work, a new current-mode biquad universal filter with single input three outputs is implemented. It uses two CCTAs, three grounded resistors and two grounded capacitors. The current-mode transfer functions of presented filter have been derived and their circuit parameters such as pole frequency and quality factor are described which are orthogonal current tunable. The presented filter can realize all the standard filter functions i.e. LP, HP, BP, BR and AP at high impedance outputs. All the passive elements (resistors and capacitors) used in the filter circuit are grounded which is attractive feature for the fabrication point of view of any integrated circuit. Grounded resistors can be easily implemented by two MOS transistors[3]. PSPICE simulation results for the proposed filter circuit have been studied.

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