Realization of Voltage-mode Multifunction Biaquadratic Filter Using Minimum Number of Active Element

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Abstract. The realization of voltage-mode multifunction biquadratic filter has been presented in this research contribution. The proposed circuit contains three input voltage nodes and one output voltage node. The structure of proposed filter is simple consisting of one modified current controlled current conveyor transconductance amplifier (M-CCCCTA) as active building block with one resistor and two capacitors. With electronically controllable property of M-CCCCTA, the parameters, natural frequency ($\omega_0$) and quality factor ($Q$) are electronically controlled by changing the external DC bias currents of the M-CCCCTA. The tuning characteristic of $Q$ is also done without effect the $\omega_0$. In the same circuit construction, five second order filter responses, all-pass, high-pass (HP), band-reject (BR), low-pass (LP) and band-pass (BP) functions are obtained. The output filter responses are obtained with applying appropriate input voltage to input node without the matching condition of active and passive elements. The performances of the proposed biquadratic filter have been verified through Pspice simulation in TSMC 0.25\mum CMOS technology parameters.

1. Introduction

The realization of second order multifunction active filters which contain several filter responses such as band-pass, low-pass and high-pass functions in the same circuit topology receives high attention in analog signal processing system. Generally, the filter has been important in many fields for example in communication, instrument and sound systems etc. [1-2]. The active filter which uses the electronically controllable active building block can be easily adjusted the filter parameters such as the cut-off frequency, the quality facer, bandwidth and gain with microcontroller or microcomputer. This control is important in modern electronic systems [3].

The controlled current conveyor transconductance amplifier (CCCCTA) is a versatile active building block [4]. The CCCCTA can be employed to realize both current and voltage mode configurations. The transconductance gain and its parasitic resistance are electronically tunable. With this characteristic, the CCCCTA based circuits can be easily controlled by microcomputer. A lot of electronic circuits employing CCCCTA have been proposed in the open literature. These circuits include analog multiplier [4], sinusoidal oscillator [5-9], inductance simulator [4, 10, 11] and first order filter [12-15] etc.

The voltage-mode second order multifunction filters using CCCCTA have been found in [16-24]. These filters include multiple inputs single output configuration [16, 19] and single input multiple outputs configuration [17, 18, 20, 21, 22, 23, 24]. However, these filters provide following drawbacks:
• Require more than one active building block [17, 19, 20, 22, 23, 24].
• Require CCCCTA with multiple current output terminals [17, 18, 20, 21, 22].
• Require the matching condition to obtain output filter response [18, 20, 22].
• The control of parameter $Q$ is not done without affecting the parameter $\omega_0$ [16].
• Five filter responses are not obtained in the same circuit [18, 21, 23, 24].

This paper presents the design and analysis of the biquadratic filter emphasizing on the use of single active building block. The proposed filter is sort of multiple inputs and single output configuration with three inputs voltage and one output voltage. The selection of output voltage filter functions is done without the requirement of the critical matching condition of passive and passive elements. The quality factor of the proposed multifunction filter is tuned without effect the natural frequency.

2. Realization of Biquad Filter

The specifications of the M-CCCCTA used in this design, proposed filter, performance circuit analysis will be given in this section.

2.1. Active building block

The conventional CCCCTA [4] is the four terminals active building block. The two input terminals are $y$ and $x$. The impedance at $y$ terminal is high, while the resistance at $x$ terminal ($R_x$) is controllable. The high impedance output terminals are $z$ and $o$. The transconductance at $o$ terminal ($g_m$) is also controllable. Generally, the $R_x$ and $g_m$ of CCCCTA are electronically controlled. To extend the use of CCCCTA, in this design, the high impedance voltage terminal ($v$) is added to the operational transconductance amplifier section and it will be called as modified current controlled current conveyor transconductance amplifier (M-CCCCTA). Figure 1 shows the circuit symbol of M-CCCCTA. While the equivalent circuit of M-CCCCTA is illustrated in Fig. 2. The terminal relationship of current/voltage in M-CCCCTA is defined by

$$I_y = 0; \ V_x = R_x I_x + V_y; \ I_z = I_x; \ I_o = 0; \ I_v = g_m (V_i - V_y)$$

In this design, the M-CCCCTA is implemented from CMOS transistors as drawn in Fig. 3. The parasitic resistance, $R_x$ and transconductance, $g_m$ are given by

$$R_x = \frac{1}{\sqrt{8 \mu C_m (W/L) I_{B1}}} \quad \text{and} \quad g_m = \sqrt{\mu C_m (W/L) I_{B2}}$$

2.2. Proposed Second Order Voltage-Mode Multifunction Filter

In Fig. 4, the proposed biquad multifunction filter with single M-CCCCTA is shown. Only three passive elements are required. This includes two capacitors $C_1$ and $C_2$, single resistor $R$. The proposed filter contains three input voltages, $v_{i1}, v_{i2}$ and $v_{i3}$ with single output voltage $v_o$. The proposed biquadratic filter is designed from the basic parallel RLC circuit where the M-CCCCTA and $C_1$ operate as inductance simulator. Using M-CCCCTA properties as described in section 2.1 and routine circuit analysis, the following output voltage is obtained

**Figure 1.** Symbol of M-CCCCTA  
**Figure 2.** Equivalent circuit of M-CCCCTA.
The biquadratic high-pass filter (HP) is realized by \( v_{i1}=v_{in} \) and \( v_{i2}=v_{i3}=0 \).

The biquadratic band-pass filter (BP) is realized by \( v_{i2}=v_{in} \) and \( v_{i1}=v_{i3}=0 \).

The biquadratic low-pass filter (LP) is realized by \( v_{i3}=v_{in} \) and \( v_{i1}=v_{i2}=0 \).

The biquadratic band-reject filter (BR) is realized by \( v_{i1}=v_{i3}=v_{in} \) and \( v_{i2}=0 \).

The biquadratic all-pass filter (AP) is realized by \( v_{i1}=v_{i2}=v_{i3}=v_{in} \).

It should be noted from (3) that all standard filter responses are obtained from the proposed biquadratic filter with same circuit configuration. Also, it is appeared that the voltage gain for each filter response is unit. The parameters \( \omega_0 \) and \( Q \) are given by

\[
\omega_0 = \frac{g_m}{R C_2} \quad \text{and} \quad Q = R \sqrt{\frac{g_m C_2}{R C_1}}
\]

It is found from (4) that the parameter \( Q \) can be controlled by resistor \( R \) without effect the \( \omega_0 \). Also \( \omega_0 \) and \( Q \) can be electronically adjusted by mean of \( R \) or \( g_m \) by adjusting the auxiliary DC bias current \( I_{B1} \) or \( I_{B2} \).

3. Simulation Results

Based on the 0.25\( \mu \)m TSMC CMOS process model (Level 3) [25], the presented three-inputs single-output multifunction second order filter in Fig. 4 was performed via PSpice program. The internal construction of CMOS M-CCCCTA in Fig. 3 was constructed. The symmetrical voltage supplies applied to the circuit were \( V_{DD}=-V_{SS}=1.25V \). The channel width and length (W/L) of the NMOS and PMOS transistors are listed in Table 1. The external DC bias currents \( I_{B1} \) employed to control \( Rx \) and \( IB2 \) used to control \( gm \) were set to 80\( \mu \)A and 55\( \mu \)A, respectively. The value of resistor \( R \) was chosen as 1k\( \Omega \) and capacitors \( C_1 \) and \( C_2 \) were chosen as 47pF. In Fig. 5, the simulated frequency response of voltage gain for low-pass, high-pass and band-pass functions is shown. It is found that the simulated natural frequency obtained from the proposed filter is 3MHz. For the band-reject and all-pass responses, the gain and phase responses are respectively shown in Fig. 6 and 7. It is clear from the results in Fig. 5 to Fig. 7 that the filter structure can completely provide five second order filter responses in the same configuration. By changing the values of resistor (R) to 1k\( \Omega \), 3k\( \Omega \) and 10k\( \Omega \) while other active and passive elements were same as mentioned above, the quality factors are respectively obtained as 0.63, 1.12 and 5.61 as appeared in Fig. 8. It is clearly that the tuning characteristic of parameter \( Q \) is controlled by resistor without distorting the parameter \( \omega_0 \) as analyzed in Eq. (4). The time domain response of band-pass function is shown in Fig. 9 where the sinusoidal waveform with 100mVp-p and \( f=3 \)MHz was fed to be the input voltage signal. The total harmonic distortion (THD) of the sinusoidal output voltage signal is 0.573\%. 
### Table 1. Aspect ratio of MOS transistors

| Transistor         | W/L (µm) |
|--------------------|----------|
| M1, M2, M13, M14   | 16/0.5   |
| M3 – M4, M5 – M12  | 10/0.5   |
| M15 – M21          | 6/0.5    |

### Figure 5. Simulated amplitude frequency responses of high-pass, band-pass, and low-pass functions.

### Figure 6. Simulated amplitude and phase frequency response of band-reject function.

### Figure 8. Simulated gain and phase response

### 4. Conclusion

The active filter is designed in this paper. The proposed multifunction filter consists of an M-CCCCTA with one resistor and two capacitors. It has three input voltages and one output voltage. It can provide five voltage transfer functions of second order filter. The selection of the output filter responses can be performed without any matching condition requirement. The tuning property of $\omega_0$ and $Q$ is electronically done. The performances of the proposed biquadratic filter were performed through Pspice program in 0.25µs TSMC CMOS process. Simulation results for all filter functions agree well as theoretical analysis. Moreover, the control of quality factor is achieved without disturbing the natural frequency as analyzed in (4) and verified via simulation result in Fig. 8.

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