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Voltage Mode First Order Filter Based on Current Controlled Current Conveyor Transconductance Amplifier

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ABSTRACT

A new voltage mode first order multifunction filter configuration using current controlled current conveyor transconductance amplifier is presented. In addition the proposed filter circuit employs one active element, three resistors and one grounded capacitor which makes it suitable for IC implementation. The circuit facilitates electronic control of the pole frequency with the help of bias current. Sensitivity study and the non idealities of the proposed circuit have been included. The circuit enjoys low sensitivity figures. The performances of the proposed circuit are verified using PSpice simulations with attractive results.

Keywords: All pass filter, voltage mode, current controlled current conveyor transconductance amplifier, pole frequency

1. Introduction

The analog filter circuits are an essential component in electrical and electronic engineering. These circuits have been widely used in communication systems, measuring tool systems, control systems and signal processing for instance [1−3]. Voltage mode active filters with high input impedance are of great interest due to the fact that they can be directly connected in cascade to implement higher order filters [4]. The all pass filters can offer a reliable and telling method for shifting the phase of an electronic signal without affecting the amplitude over the frequency in controlling and communicating applications. For the above reason all pass filters cannot be replaced by any others filters [5]. All pass filters have been used in the realization of dual element frequency controlled oscillator with certain benefits in harmonic rejection and quadrature property, multiphase oscillators and high quality frequency selective filters [6]. For these reasons many first and high order filters have been researched and reported since 1966. Of particular concern here is the first order multifunction filter. From literature survey, it is found that several implementations of first order filter have been reported [4−5, 7−11]. Unfortunately, a close observation of these structures reveals that the reported circuits suffer from one or more of the following weaknesses. The pole frequency cannot be controlled electronically by adjusting the bias current [4−5, 7−8, 10−11]. The proposed circuits use floating capacitor [8] which is not convenient for further fabrication in integrated circuits as unlike grounded capacitances they cannot compensate for stray capacitances at these nodes. The proposed circuit consists of large number (more than four components) of passive components [9]. Also several circuits use multiple active blocks [7, 9, 11] which are not convenient for further fabrication in integrated circuits.

Recently, a first order filter using current controlled current conveyor transconductance amplifier have been published [12]. However, the configuration uses two active blocks. This limitation makes the circuit inappropriate for monolithic implementation as they occupy more chip area. This paper presents a voltage mode first order multifunction filter based on the current controlled current conveyor transconductance amplifier. The proposed multifunction filter enjoys the following advantageous features (i) use of only one active element, (ii) use of only grounded capacitor, (iii) the angular pole frequency of the multi function filter can be tuned electronically by input bias current and (iv) low active and passive sensitivities.

2. Proposed circuit

2.1. Basic concept of the CCCCTA

The current conveyor transconductance amplifier (CCTA), a new active building block has been introduced in 2005 for analog signal processing [13]. This is suitable for a class of analog signal processing for voltage mode as well as current mode technique. The current controlled current conveyor transconductance amplifier (CCCCTA) is a modified-version of the CCTA. This consists of two principal building blocks, a second generation translinear current controlled current conveyor at the front end and operational transconductance amplifiers at the rear end [14]. The properties of the CCCCTA are similar to the conventional CCTA, except that the CCCCTA has finite input resistance R_x at the x input terminal. The schematic symbol and the equivalent circuit of the CCCCTA are depicted in figure 1. The port relationship of the CCCCTA can be characterized by the following equations

$$\begin{pmatrix} I_y \\ V_x \\ I_{z_1} \\ I_{z_2} \\ I_{o_+} \\ I_{o_-} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ R_x & 1 & 0 \\ 1 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 0 & +g_m \\ 0 & 0 & -g_m \end{pmatrix} \begin{pmatrix} I_x \\ V_y \\ V_{z1} \end{pmatrix} \quad (1)$$

where g_m is the transconductance of the CCCCTA. For bipolar implementation of the CCCCTA as shown in figure 2, the parasitic resistance R_x can be controlled by the bias current I_{B1} and transconductance g_m can be controlled by the bias current I_{B2} as shown in the following equations

$$R_x = \frac{V_T}{2I_{B_1}} \quad (2)$$

$$g_m = \frac{I_{B_2}}{2V_T} \quad (3)$$

where V_T is the thermal voltage whose value is 26mV at 27ºC.

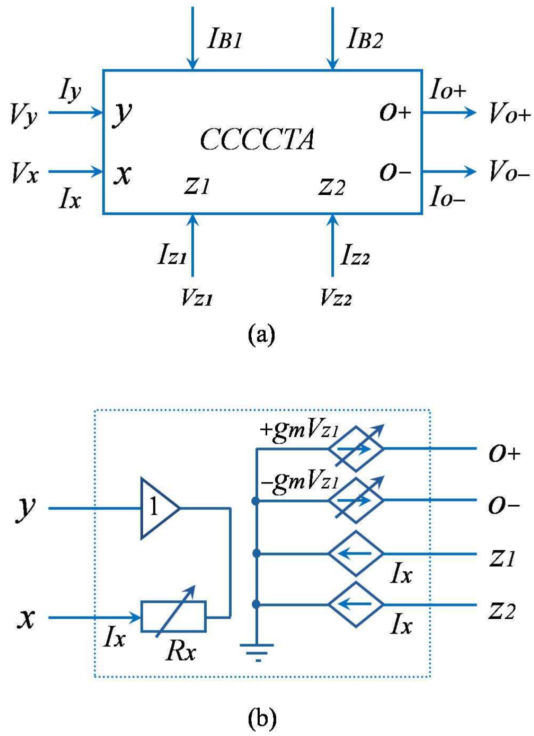


Figure 1: The CCCCTA (a) schematic symbol (b) equivalent circuit.

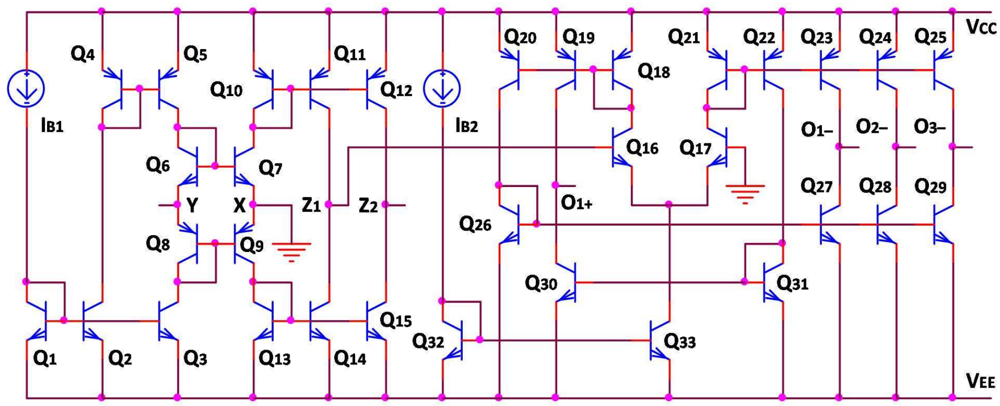


Figure 2: Internal structure of the CCCCTA using bipolar transistors.

2.2. Proposed first order multifunction filter

The proposed first order voltage mode multifunction filter circuit is shown in figure 3. It consists of single CCCCTA, three resistors and one grounded capacitor. The circuit can provide low-pass, high-pass and all-pass responses. The routine circuit analysis for

$R_1=2R_x$, $R_2=R_3=R_x$ yields the following voltage transfer functions for all-pass, high-pass and low-pass responses as follows

$$\frac{V_{ap}}{V_{in}} = \frac{sC - g_m}{sC + g_m} \tag{4}$$

$$\frac{V_{hp}}{V_{in}} = \frac{sC}{sC + g_m} \tag{5}$$

$$\frac{V_{lp}}{V_{in}} = \frac{g_m}{sC + g_m} \tag{6}$$

The pole frequency of the proposed multifunction filter and the phase response of the all-pass function can be expressed as follows

$$\omega_o = \frac{g_m}{C} \tag{7}$$

$$\phi = 180^0 - 2\arctan\left(\frac{\omega C}{g_m}\right) \tag{8}$$

Substituting the value of the transconductance as depicted in (3) the pole frequency and phase response can be modified as

$$\omega_o = \frac{I_{B2}}{2V_T C} \tag{9}$$

$$\phi = 180^0 - 2\arctan\left(\frac{2V_T \omega C}{I_{B_2}}\right) \tag{10}$$

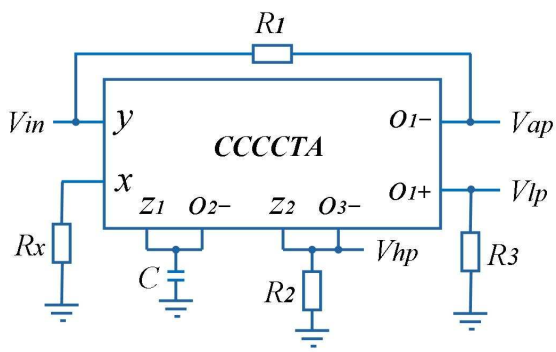


Figure 3: The proposed voltage mode first order multifunction filter.

Therefore the pole frequency of the proposed filter and the phase of the proposed filter can be tuned electronically by simultaneous adjustment of the transconductance g_m and therefore by the bias current I_{B2}.

By taking into account the following non idealities of the proposed CCCCTA, the relationship of the terminal behavior can be rewritten as

$$\begin{pmatrix} I_y \\ V_x \\ I_{z_1} \\ I_{z_2} \\ I_{o_{1+}} \\ I_{o_{1-}} \\ I_{o_{2-}} \\ I_{o_{3-}} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ R_x & \beta & 0 \\ \alpha_1 & 0 & 0 \\ \alpha_2 & 0 & 0 \\ 0 & 0 & +\gamma_1 g_m \\ 0 & 0 & -\gamma_2 g_m \\ 0 & 0 & -\gamma_3 g_m \\ 0 & 0 & -\gamma_4 g_m \end{pmatrix} \begin{pmatrix} I_x \\ V_y \\ V_{z1} \end{pmatrix} \tag{11}$$

where β is the voltage transfer gain; α_1, α_2, γ_1, γ_2, γ_3 and γ_4 are the current transfer gains. They depend on the transistor parameters, frequency of operation and temperature. In practical, $\beta=1-\varepsilon_1$, $\alpha_1=1-\varepsilon_2$, $\alpha_2=1-\varepsilon_3$, $\gamma_1=1-\varepsilon_4$, $\gamma_2=1-\varepsilon_5$, $\gamma_3=1-\varepsilon_6$ and $\gamma_4=1-\varepsilon_7$. The parameter ε_1 ($|\varepsilon_1| \langle\langle 1$) denotes the voltage tracking error of the voltage inverting stage and ε_2, ε_3, ε_4, ε_5, ε_6 and ε_7 ($|\varepsilon_2|,|\varepsilon_3|,|\varepsilon_4|,|\varepsilon_5|,|\varepsilon_6|,|\varepsilon_7| \langle\langle 1$) are the current tracking error of the current inverting stage of the CCCCTA. These gains are ideally equal to unity. Taking into account the following non idealities the transfer functions become

$$\frac{V_{ap}}{V_{in}} = \frac{sCR_x + \gamma_3 g_m R_x - \alpha_1 \beta \gamma_2 g_m R_1}{R_x (sC + \gamma_3 g_m)} \tag{12}$$

with $\alpha_1 \beta \gamma_2 R_1 = 2\gamma_3 R_x$, it reduces to the form as

$$\frac{V_{ap}}{V_{in}} = \frac{sC - \gamma_3 g_m}{sC + \gamma_3 g_m} \tag{13}$$

with $R_2 = R_x$ and $\alpha_1 \gamma_4 = \alpha_2 \gamma_3$ the high-pass filter transfer function becomes

$$\frac{V_{hp}}{V_{in}} = \frac{\alpha_2 \beta sC}{sC + \gamma_3 g_m} \tag{14}$$

with $R_3 = R_x$ the low-pass filter transfer function becomes

$$\frac{V_{lp}}{V_{in}} = \frac{\alpha_1 \beta \gamma_1 g_m}{sC + \gamma_3 g_m} \tag{15}$$

The pole frequency is modified as

$$\omega_o = \frac{\gamma_3 g_m}{C} \tag{16}$$

The sensitivity study forms an important index of the performance of any active network. The sensitivity of any active network is given as

$$S_e^F = \frac{e}{F} \frac{\partial F}{\partial e} \tag{17}$$

where *F* represents a network function and *e* represents the element of variation of the filter. Based on the sensitivity expression, the active and passive sensitivities of the pole frequency (ω_o) are given as

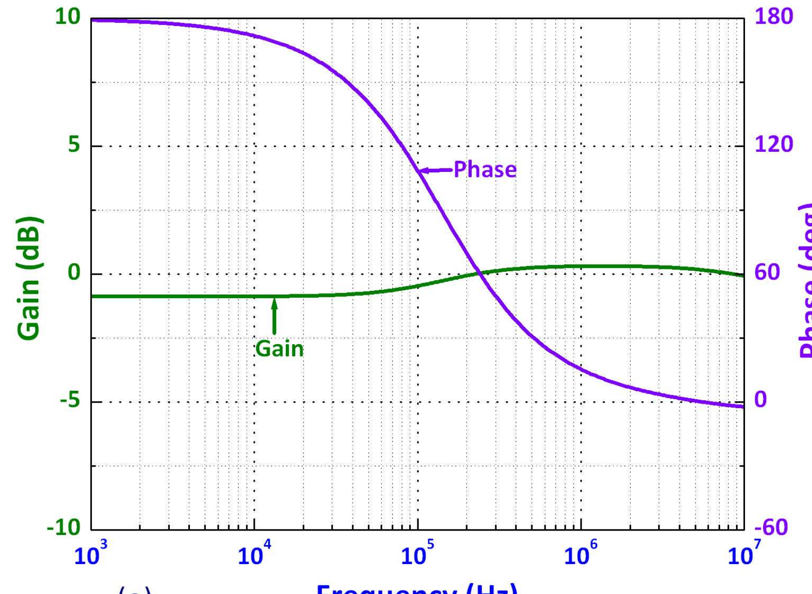
$$S_{\gamma_3}^{\omega_o} = S_{g_m}^{\omega_o} = 1 \tag{18}$$

$$S_C^{\omega_0} = -1 \tag{19}$$

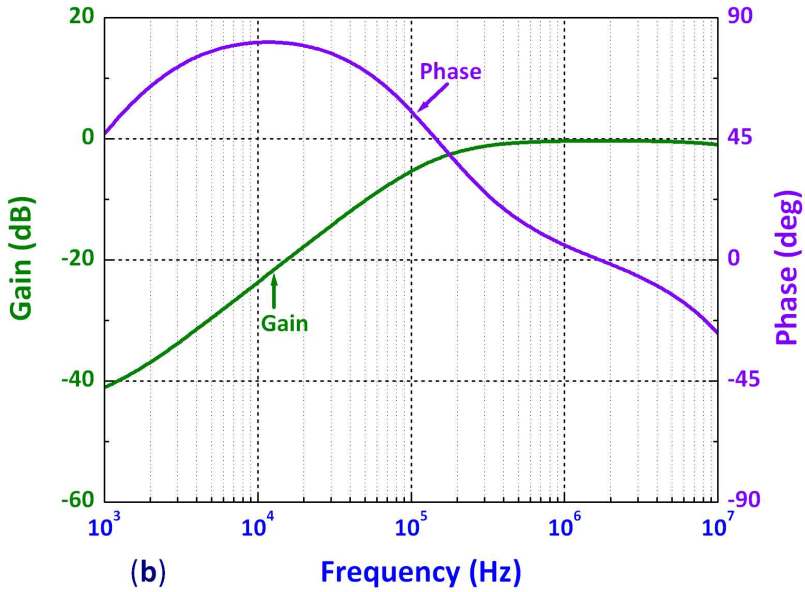
Therefore it is evident that the sensitivities of the active and passive components for pole frequency are less than 1 in relative amplitude axis.

3. Simulation results

The proposed first order multifunction filter of Figure 3 has been simulated using the PSpice circuit simulation program with bipolar transistors Q2n2907 (pnp) and Q2n2222 (npn). The bias currents were chosen as I_{B1}=50µA (R_x=260Ω) and I_{B2}=50µA (g_{m1}=0.96mS). The filter circuit was designed by using the following set of passive elements: C= 1nF, R_1=520Ω and R_2=260Ω and R_3=260Ω. The circuit was biased with ±1.5V supply voltages. This yields the pole frequency of 147.91 kHz, where the calculated value of this parameter from (7) yields 153.03 kHz (deviated by 3.346%). In this case, the value of the parameter changes because the BJT implementation used in the circuit deviates from the ideal properties and the effect of parasitic elements. The results shown in figure 4 are the magnitude and phase responses of the proposed first order multi function filter. This clearly shows that the proposed circuit can provide low-pass, high-pass and all-pass responses. The variation of voltage gain with frequency for the high-pass and low-pass function for different values of the bias current I_{B2} are shown in figure 5 and figure 6 respectively. Figure 7 shows the electronic tunability of the pole frequency of the low-pass filter. This graph confirms that there is a direct proportionality between the pole frequency and the bias current I_{B2}. Therefore the pole frequency can be electronically controlled by the bias current.



(a)



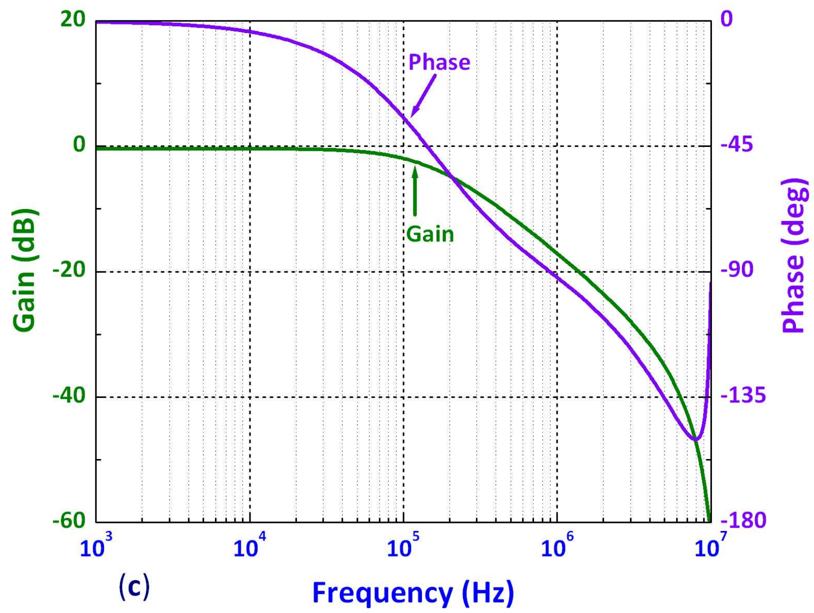


Figure 4: Gain and phase responses of the first order filter (a) all-pass, (b) high-pass and (c) low-pass.

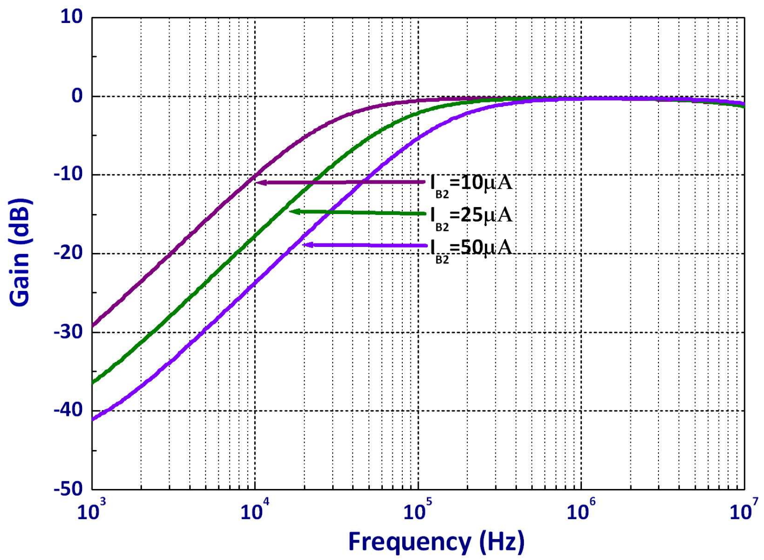


Figure 5: Magnitude response of the high pass filter for different values of bias current I_{B2}.

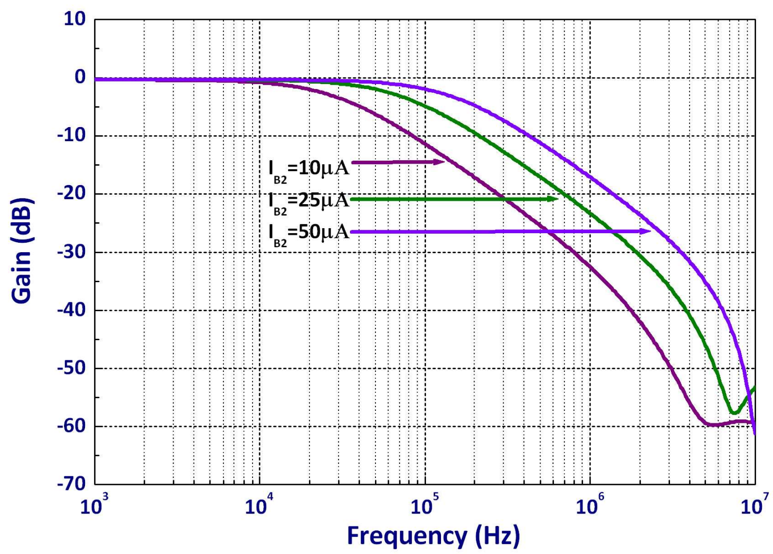


Figure 6: Magnitude response of the low pass filter for different values of bias current I_{B2}.

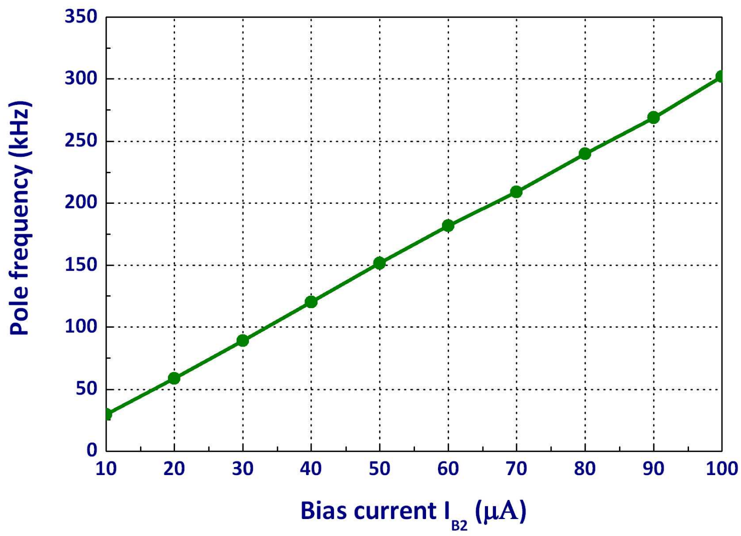


Figure 7: Electronic tunability of the pole frequency.

4. Conclusion

A new first order voltage-mode filter has been presented. It can provide low-pass, high-pass and all-pass functions. The proposed configuration employs single CCCCTA, one grounded capacitor and three resistors. It offers the advantages of electronic control of the pole frequency and the phase of the all-pass response. The circuit also possesses low sensitivity performance. The PSpice simulations were carried out to ascertain the working of the proposed filters and the results are found to match with the theoretical results.

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