Single DVCCCTA Based Voltage Mode First Order Multifunction Filter

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Abstract - This paper introduces a first order multifunction filter configuration based on recently reported current mode active building block called the differential voltage current controlled conveyor transconductance amplifier (DVCCCTA). The proposed filter configuration employs single active element and four grounded passive components which makes it suitable for monolithic IC implementation. The input impedance is high and output impedance is low, hence this circuit is suitable for cascading. The pole frequency of the proposed circuit can be controlled electronically with the help of bias current. The operation of the proposed filter has been verified through PSpice simulation results which confirm the theoretical analysis.

Keywords - Active block, First order filter, Voltage mode, Differential voltage current controlled conveyor transconductance amplifier (DVCCCTA), Pole frequency.

1. INTRODUCTION

In the field of electrical and electronics engineering, analog filter is an essential component and widely used in many applications, e.g. in high-speed data communication systems, measurement and instrumentation, regulation, electro acoustics and control systems [1–3]. Current mode active elements have several distinct advantages such as, high speed, low power consumption at high frequency, high signal dynamic range, high slew rate, greater linearity, low cross-talk and switching noise [4]. 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 [5]. Due to this reason designing analog filters that can operate in the voltage mode has been gaining increasing interests. Therefore, it is advantageous to implement voltage mode filters using current mode active building blocks [6]. 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 desired range of frequency in controlling and communicating applications. For this reason all-pass filters cannot be replaced by any other filters [7]. 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 [8]. For these reasons numerous first and high order filters have been researched and reported. Of particular concern here is the first order multifunction filter.

In the recent past various first order filters based on different active elements have been reported in the literature [5, 7, 9–13]. A close observation of these structures reveals that the reported filter circuits suffer from one or more of the following weaknesses

i). The pole frequency cannot be controlled electronically by adjusting the bias current [5, 7, 9–10, 12–13].
ii). Use floating capacitor [10] which is not convenient for further fabrication in integrated circuits as unlike grounded capacitances they cannot compensate for stray capacitances at these nodes.
iii). Consists of large number (more than four components) of passive components [11] and use multiple active blocks [9, 11 13] which are not convenient for further fabrication in integrated circuits.

Recently, a voltage mode first order all pass filter using differential voltage current conveyor transconductance amplifier (DVCCTA) has been reported [14]. The circuit employs one grounded capacitor and one grounded external resistor. But the filter circuit does not have the inherent electronic tuning properties of the oscillation frequency. This limitation makes the circuit inappropriate for application in communication and signal processing circuits.

This paper presents a single input and multiple output first order multifunction filter working in voltage mode using a single differential voltage current controlled conveyor transconductance amplifier (DVCCCTA) and four grounded passive elements. The proposed filter circuits provide low-pass, high-pass and all-pass responses without changing the circuit topology. The pole frequency can be controlled electronically by the input bias current. To validate the theoretical analysis the filter circuits have been simulated using PSpice simulation.

2. BASIC CONCEPT OF THE DVCCCTA

Differential voltage current controlled conveyor transconductance amplifier (DVCCCTA) consists of a differential voltage current controlled conveyor at front end and operational transconductance amplifiers at the rear end [15]. The schematic symbol of the DVCCCTA is shown in Fig. 1. The port relationship can be characterized by the following equations

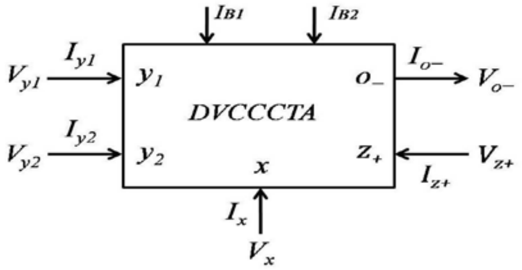


Fig. 1: Schematic symbol of the DVCCCTA.

$$\begin{pmatrix} I_{y_1} \\ I_{y_2} \\ V_x \\ I_{z_+} \\ I_{o_-} \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ R_x & 1 & -1 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & -g_m \end{pmatrix} \begin{pmatrix} I_x \\ V_{y_1} \\ V_{y_2} \\ V_{z_+} \end{pmatrix} \tag{1}$$

where R_x represents the finite parasitic resistance at x input terminal and g_m represents the transconductance gain from z_+ terminal to o_- terminal of the DVCCCTA. For bipolar implementation of the DVCCCTA as shown in the Fig. 2 the values of these parameters are

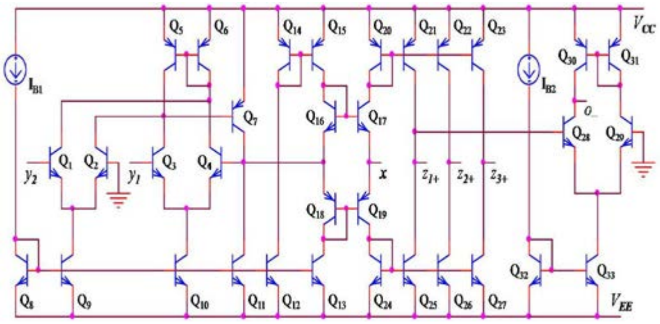


Fig. 2: Used bipolar implementation of the proposed DVCCCTA.

$$R_x = \frac{V_T}{2I_{B_1}}, \quad g_m = \frac{I_{B_2}}{2V_T} \tag{2}$$

where I_{B1} and I_{B2} are the bias currents and V_T is the thermal voltage.

3. PROPOSED FIRST ORDER FILTER

The proposed single input and multiple output first order filter is shown in Fig. 3. Using (1) and doing routine analysis of the circuit for $R_1=R_2=R_x/2$ yields the following characteristic equation

$$\frac{V_{ap}}{V_{in}} = -\frac{sC - g_m}{sC + g_m} \tag{3}$$

$$\frac{V_{lp}}{V_{in}} = -\frac{2}{R_x(sC + g_m)} \tag{4}$$

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

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

$$\omega_o = \frac{g_m}{C} \tag{6}$$

$$\phi(\omega) = -2\tan^{-1}\left(\omega C/g_m\right) \tag{7}$$

It reveals that the circuit can simultaneously deliver first order low-pass, high-pass and all-pass responses which are characterized by pole frequency as given in (6) and thus have electronically tunable characteristics.

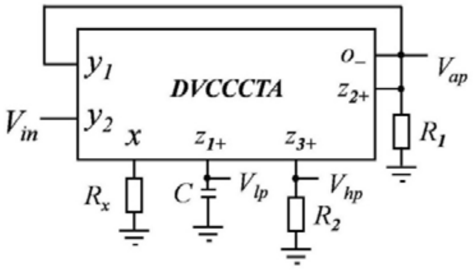


Fig. 3: Proposed first order multifunction filter.

4. NON–IDEAL ANALYSIS

In this section the proposed first order filter is analyzed for the following DVCCCTA non–idealities

$$\begin{pmatrix} V_x \\ I_{z_{1+}} \\ I_{z_{2+}} \\ I_{z_{3+}} \\ I_{o_-} \end{pmatrix} = \begin{pmatrix} R_x & \alpha_1 & -\alpha_2 & 0 \\ \beta_1 & 0 & 0 & 0 \\ \beta_2 & 0 & 0 & 0 \\ \beta_3 & 0 & 0 & 0 \\ 0 & 0 & 0 & -\gamma g_m \end{pmatrix} \begin{pmatrix} I_x \\ V_{y_1} \\ V_{y_2} \\ V_{z_{1+}} \end{pmatrix} \tag{8}$$

where α_1, α_2 represent the voltage transfer gains from y_1 and y_2 terminals to x terminal, β_1, β_2, β_3 represent the current transfer gains from x terminal to z_{1+}, z_{2+}, z_{3+} terminals and γ represents the current transfer gain from z_{1+} terminal to o_- terminal. They depend on the transistor parameters, frequency of operation and temperature. These gains are ideally equal to unity. Taking into account the following non–idealities the transfer functions become

$$\frac{V_{ap}}{V_{in}} = -\frac{sC\alpha_2\beta_2 - \alpha_2\beta_1\gamma g_m}{sC(2-\alpha_1\beta_2) + \alpha_1\beta_1\gamma g_m} \tag{9}$$

$$\frac{V_{lp}}{V_{in}} = -\frac{2\alpha_2\beta_1}{R_x[sC(2-\alpha_1\beta_2) + \alpha_1\beta_1\gamma g_m]} \tag{10}$$

$$\frac{V_{hp}}{V_{in}} = -\frac{\alpha_2\beta_3 sC}{sC(2-\alpha_1\beta_2)+\alpha_1\beta_1\gamma g_m} \tag{11}$$

with $\alpha_1 = \alpha_2,\ \beta_1 = \beta_2,\ \alpha_1\beta_2 = 1,$ these reduce to the form as

$$\frac{V_{ap}}{V_{in}} = -\frac{sC-\gamma g_m}{sC+\gamma g_m} \tag{12}$$

$$\frac{V_{lp}}{V_{in}} = -\frac{2\alpha_2\beta_1}{R_x(sC+\gamma g_m)} \tag{13}$$

$$\frac{V_{hp}}{V_{in}} = -\frac{\alpha_2\beta_3 sC}{sC+\gamma g_m} \tag{14}$$

Then the pole frequency is modified as

$$\omega_o = \gamma g_m / C \tag{15}$$

The sensitivity of any active network is given as

$$S_e^F = \frac{e}{F}\frac{\partial F}{\partial e} \tag{16}$$

where *F* represents a network function and *e* represents 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

$$S_\gamma^{\omega_o} = S_{g_m}^{\omega_o} = 1,\ S_C^{\omega_o} = -1 \tag{17}$$

Therefore it is evident that the sensitivities for the active and passive components of the pole frequency are not more than unity in relative amplitude axis.

5. SIMULATION RESULTS

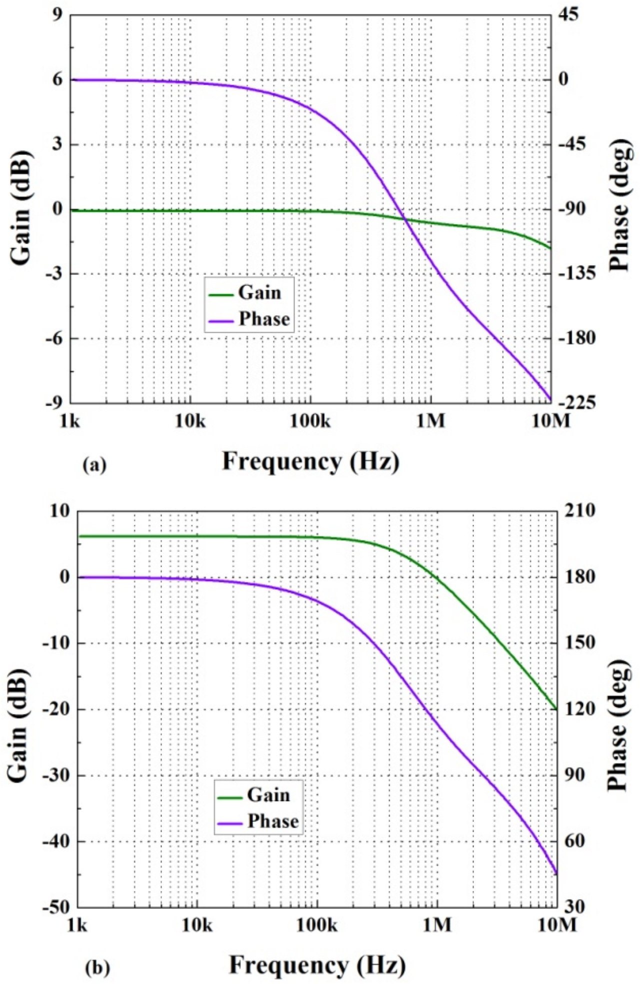
To verify the theoretical analysis, the behavior of the proposed voltage mode multifunction filter has been verified by PSpice simulations. In the simulation process the bipolar implementation of the DVCCCTA as shown in Fig. 2 has been used. For this purpose the transistor model parameters of Q2N2222 (NPN) and Q2N2907 (PNP) have been used which are listed in Table 1. The DC power supply voltages are equal to ±1.5 V and bias currents are chosen as I_{B1}=50µA (R_x=260Ω) and I_{B2}=200µA (g_m=3.84mS). The filter circuit was designed by using the following set of passive elements: C= 1nF, R_1=130Ω and R_2=130Ω. The simulated gain and phase responses of the proposed first order filter are shown in Fig. 4. It clearly shows that the proposed circuit can provide low-pass, high-pass and all-pass responses. This yields the pole frequency of 543.54kHz, where the calculated value of this parameter yields 611.46kHz. The total power dissipation of the circuit is found to be 2.61mW.

Table-1: Q2N2222 and Q2N2907 transistor model parameters

.model Q2N2907 PNP (Is=650.6E-18 Xti=3 Eg=1.11 Vaf=115.7 Bf=231.7 Ne=1.829 Ise=54.81f Ikf=1.079 Xtb=1.5 Br=3.563 Nc=2 Isc=0 Ikr=0 Rc=.715 Cjc=14.76p Mjc=.5383 Vjc=.75 Fc=.5 Cje=19.82p Mje=.3357 Vje=.75 Tr=111.3n Tf=603.7p Itf=.65 Vtf=5 Xtf=1.7 Rb=10)

.model Q2N2222 NPN (Is=14.34f Xti=3 Eg=1.11 Vaf=74.03 Bf=255.9 Ne=1.307 Ise=14.34f Ikf=.2847 Xtb=1.5 Br=6.092 Nc=2 Isc=0 Ikr=0 Rc=1 Cjc=7.306p Mjc=.3416 Vjc=.75 Fc=.5 Cje=22.01p Mje=.377 Vje=.75 Tr=46.91n Tf=411.1p Itf=.6 Vtf=1.7 Xtf=3 Rb=10)

The electronic tunability of the oscillation frequency of the low-pass function is depicted in Fig. 5. This graph is a straight line which confirms that there is a direct proportionality between the pole frequency and the bias current I_{B2} which has been proved theoretically. The simulated results are in close agreement with the theoretical values. The slight deviation from the ideal results can be attributed to the stray capacitances and other non ideal properties in the circuit elements.



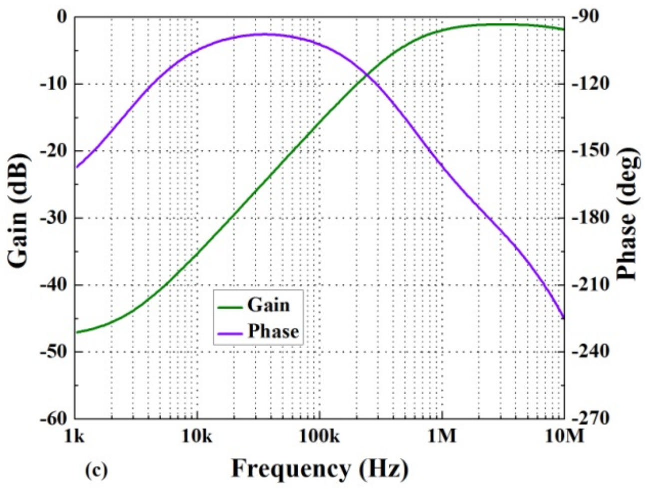


Fig. 4: Gain and phase responses of the (a) all-pass, (b) low-pass and (c) high-pass filter.

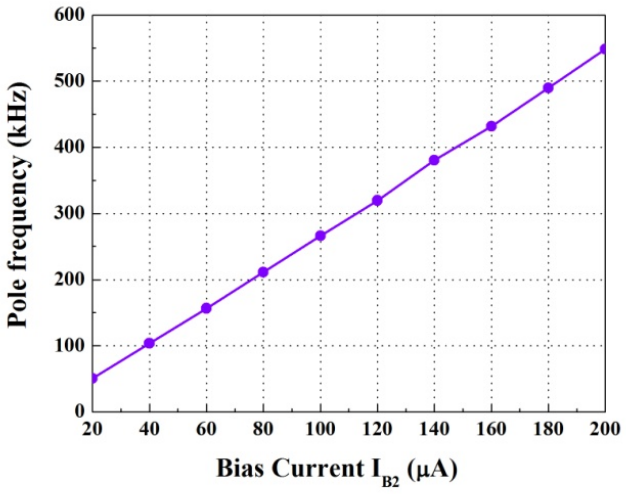


Fig. 5: Electronic tunability of the pole frequency.

6. CONCLUSION

A new first order electronically tunable voltage mode multi function filter has been introduced in this paper. The circuit employs single active element, DVCCCTA and all grounded passive components. The pole frequency can be controlled electronically. The circuit also possesses low sensitivity performances. 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.

7. ACKNOWLEDGEMENT

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