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Single VDTA-based Current-mode Electronically-tunable Multifunction Filter

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Abstract

This paper presents an electronically tunable current-mode multifunction biquadratic filter which employs a single new active device namely voltage differencing transconductance amplifier (VDTA). The presented filter with single input and three outputs consists of only one VDTA and two grounded capacitors. It can simultaneously realize lowpass (LP), bandpass (BP) and highpass (HP) current responses without the need to impose component choice. The circuit also provides the advantage features of the use of only one active component and minimum number of passive components, and electronic controllability of its important parameters, as well as low sensitivity characteristic. The performance of the proposed filter is tested using PSPICE simulation program, and the simulation results agree well with the theoretical analysis.

Keywords : Voltage Differencing Transconductance Amplifier (VDTA), multifunction filter, current-mode circuit

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1. Introduction

Recently, some new analog active building blocks providing the potentiality in analog circuit design were and are being introduced [1], such as current differencing transconductance amplifier (CDTA) [2], current conveyor transconductance amplifier (CCTA) [3], difference current conveyor transconductance amplifier (DDCCTA) [4], and so on [1]. Among these, the voltage differencing transconductance amplifier (VDTA) is a recently introduced active element. This element can be compared with the previously introduced CDTA element, in which the current differencing unit at the front-end is replaced by the voltage differencer. This means that the VDTA is composed of the current source controlled by the difference of two input voltages and a multiple-output transconductance amplifier, providing electronic tuning ability through its transconductance gains. Therefore, the VDTA device is very suitable for electronically tunable active circuit synthesis. Another advantageous feature of the use of the VDTA as an active element is that compact structures in some application can be achieved easily [1],[5].

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From the point view of the advantages of simplicity, cost reduction, low power consumption and space saving, it is important to design these filters using only single active component and canonical number of passive components. Recently, current-mode multifunction biquadratic filters with single input and multiple output using a single active component have been reported in open literature [6]-[14]. However, all the filters needed one or more external passive resistors.

This paper deals with the design of the current-mode electronically tunable multifunction filter with single input and three outputs based on the use of the VDTA as a novel active element. The proposed filter use single VDTA and two grounded capacitors, which provides the advantage of the use of only one active component and minimum number of passive components. Moreover, the advantage of an electronic tuning capability and is especially interested from the integrated circuit fabrication [15].The circuit realizations LP, BP and HP current responses simultaneously with no need to impose component choice. The natural angular frequency (ω_o) and bandwidth (BW) can be orthogonally and electronically tuned through adjusting the transconductance gain of the VDTA. The circuit also has low sensitivity characteristic.

2. Description of VDTA

The schematic symbol of the VDTA is represented in Fig.1, where the port relations can be defined by the following expression [1], [5].

$$\begin{bmatrix} i_z \\ i_{z-} \\ i_{x+} \\ i_{x-} \end{bmatrix} = \begin{bmatrix} +g_{mF} & -g_{mF} & 0 & 0 \\ -g_{mF} & +g_{mF} & 0 & 0 \\ 0 & 0 & +g_{mS} & 0 \\ 0 & 0 & -g_{mS} & 0 \end{bmatrix} \begin{bmatrix} v_p \\ v_n \\ v_z \\ v_{z-} \end{bmatrix} \tag{1}$$

In equation (1), g_{mF} and g_{mS} are the first and second transconductance gains of the VDTA respectively. The differential input voltage from the terminals p and n (v_p - v_n) is transformed into output currents at the terminals z and z- with first transconductance g_{mF}. The voltage drop at the terminal z (v_z) is transformed into output currents at the terminals x+ and x- with second transconductance g_{mS}.

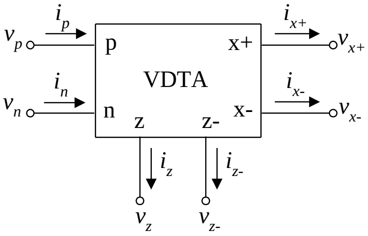

Fig. 1. Electrical symbol of the VDTA

The CMOS-based internal structure of the VDTA is shown in Fig.2. For this structure, the circuit employs two Arbel–Goldminz transconductance [16]. The first and second transconductances are determined by the transconductance of output transistors, which can be expressed as, respectively:

$$g_{mF} = \frac{g_1 g_2}{g_1 + g_2} + \frac{g_3 g_4}{g_3 + g_4} \cong (g_{1,2} + g_{3,4})/2 \tag{2}$$

$$g_{mS} = \frac{g_5 g_6}{g_5 + g_6} + \frac{g_7 g_8}{g_7 + g_8} \cong (g_{5,6} + g_{7,8})/2 \tag{3}$$

In above equations, g_i is the transconductance value of the i-th transistor, which is given as:

$$g_i = \sqrt{I_{Bi}\mu C_{ox}\frac{W}{L}} \tag{4}$$

where I_{Bi} is the dc bias current, μ is effective carrier mobility, C_{ox} is the gate oxide capacitance per unit area and W and L are the effective width and length of the i-th MOS transistor, respectively.

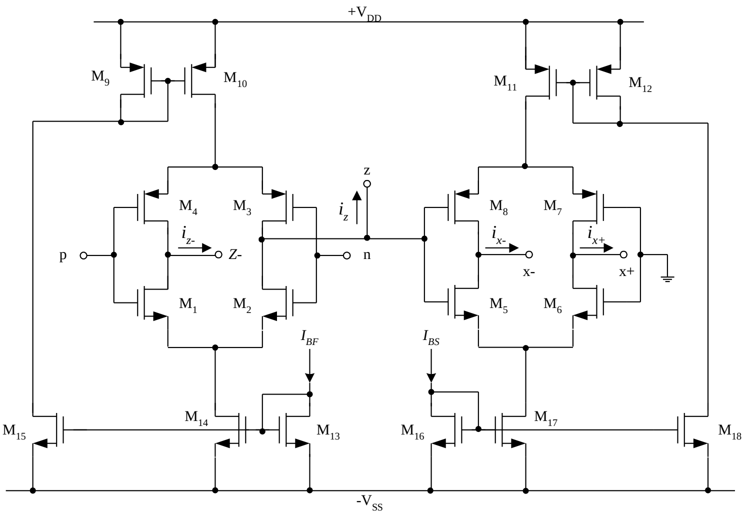

Fig. 2. CMOS implementation of the VDTA

3. Proposed Filter Configuration

The proposed current-mode multifunction biquadratic filter using single VDTA is shown in Fig. 3. The circuit comprises only one VDTA and two grounded capacitors, thus it is canonical in the number of active and passive components. The routine analysis of the circuit in Fig. 3 gives the current transfer function as the follows.

$$LP(s) = \frac{I_{LP}(s)}{I_{in}(s)} = \frac{\left(\dfrac{g_{mF}g_{mS}}{C_1C_2}\right)}{D(s)} \tag{5}$$

$$BP(s) = \frac{I_{BP}(s)}{I_{in}(s)} = \frac{\left(\dfrac{g_{mF}}{C_1}\right)s}{D(s)} \tag{6}$$

$$HP(s) = \frac{I_{HP}(s)}{I_{in}(s)} = \frac{s^2}{D(s)} \tag{7}$$

where $D(s)$ is found to be

$$D(s) = s^2 + \left(\frac{g_{mF}}{C_1}\right)s + \left(\frac{g_{mF}g_{mS}}{C_1C_2}\right) \tag{8}$$

It can easily be observed from equation (5)-(8), that the suggested filter simultaneously realizes LP, BP and HP current responses at I_{LP}, I_{BP} and I_{HP} respectively, without requiring any passive component matching constrains. However, since the BP and HP output signals are available on the grounded passive capacitors C_1 and C_2 additional active elements are required to sense the current I_{BP} and I_{HP}. Thus, scheme can be classified as a current-mode single multifunction filter.

All the above three filters posses the same important parameters ω_o and BW which can be given by

$$\omega_0 = \sqrt{\frac{g_{mF} g_{mS}}{C_1 C_2}} \tag{9}$$

$$BW = \frac{g_{mF}}{C_1} \tag{10}$$

It should be noted from equations (9) and (10) that the parameter ω_o can be adjusted electronically without affecting the parameter BW by tuning the g_{mS}-value.

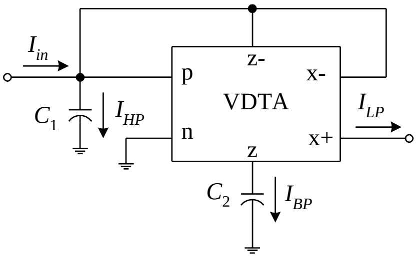

Fig. 3. Proposed current-mode universal biquad filter

4. Tracking Error and Sensitivity Analyses

Considering the non-ideal characteristics of the VDTA, the port relations of current and voltage in equation (1) can be rewritten as:

$$\begin{bmatrix} i_z \\ i_{z-} \\ i_{x+} \\ i_{x-} \end{bmatrix} = \begin{bmatrix} +\beta_F g_{mF} & -\beta_F g_{mF} & 0 & 0 \\ -\beta_F g_{mF} & +\beta_F g_{mF} & 0 & 0 \\ 0 & 0 & +\beta_S g_{mS} & 0 \\ 0 & 0 & -\beta_S g_{mS} & 0 \end{bmatrix} \begin{bmatrix} v_p \\ v_n \\ v_z \\ v_{z-} \end{bmatrix} \tag{11}$$

where β_F and β_S are respectively the tracking errors for the first and second stages of the VDTA. Re-analysis the proposed circuit in Fig.3 using equation (11) yields the following non-ideal filter parameters.

$$\omega_0 = \sqrt{\frac{\beta_F \beta_S g_{mF} g_{mS}}{C_1 C_2}} \tag{12}$$

$$BW = \frac{\beta_F g_{mF}}{C_1} \tag{13}$$

It is evident that the values of ω_0 and BW may be slightly changed by the effect of the VDTA's tracking errors. However, the small deviation in equations (12) and (13) can be minimized by properly adjusting the VDTA's transconductance values. Hence, the desired parameter values can still be satisfied.

The active and passive relative sensitivities of ω_o and BW parameter of the filter in Fig.3 are derived to be

$$S^{\omega_0}_{\beta_F, \beta_S} = S^{\omega_0}_{g_{mF}, g_{mS}} = \frac{1}{2} \tag{14}$$

$$S^{\omega_0}_{C_1, C_2} = -\frac{1}{2} \tag{15}$$

$$S_{\beta_S}^{BW} = S_{g_{mS}}^{BW} = 0 \quad (16)$$

$$S_{C_1}^{BW} = -1 \quad (17)$$

$$S_{\beta_F}^{BW} = S_{g_{mF}}^{BW} = 1 \quad (18)$$

$$S_{C_2}^{BW} = 0 \quad (19)$$

Consequently, all of the component sensitivities of ω_0 and BW are very low and not more than unity in magnitude.

5. Simulation Results

To prove the theoretical validity of the filter given in Fig. 3, this filter was simulated with PSPICE program. The VDTA was simulated using the CMOS implementation structure given in Fig. 2 based on the 0.35-μm TSMC process parameters. The aspect ratios of the MOS transistor are given in Table 1. The supply voltages are +V =–V = 2 V. For all simulations, the capacitance values were chosen as: $C_1 = C_2 = 20$ pF.

Table 1. Transistor dimensions of the CMOS VDTA circuit in Fig.2.

Transistors	W (μm)	L (μm)
M1-M2, M5-M6	16.1	0.7
M3-M4, M7-M8	28	0.7
M9-M12	21	0.7
M13-M16	7	0.7
M14-M15, M17-M18	8.5	0.7

To realize the filter responses with a natural frequency of $f_0 = \omega_0/2\pi \cong 3.03$ MHz and a quality factor of $Q = 1$, the following setting for the presented filter in Fig.3 has been selected as: $g_{mF} = g_{mS} = 381$ μA/V ($I_{BF} = I_{BS} \cong 40$ μA), which results in the total power consumption of about 1 mW. Fig. 4 shows the simulation results for HP, BP and LP filter characteristics.

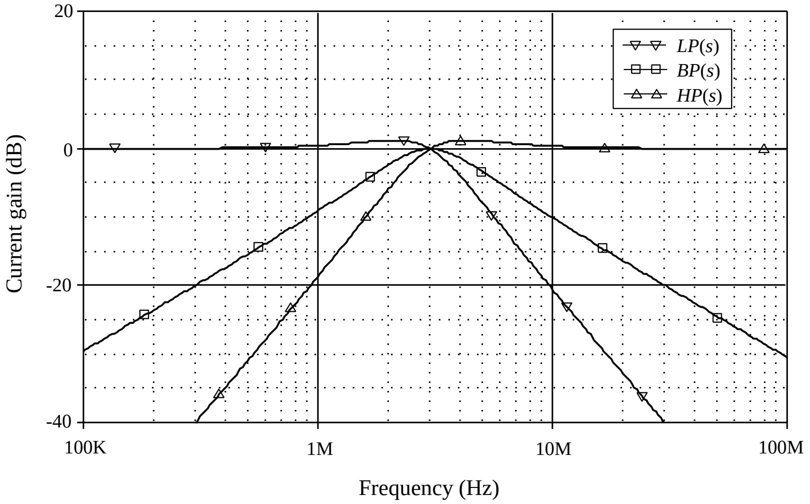

Fig. 4. Simulated LP, BP and HP responses for the proposed filter in Fig.3

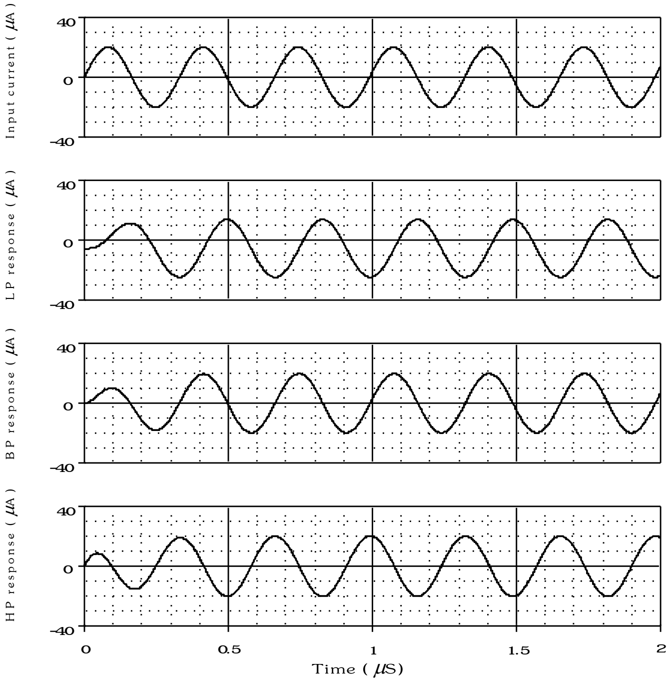

Fig.5. Time responses for LP, BP and HP characteristic of the proposed filter in Fig.3

Fig.5 shows the time-domain simulation results for the LP, BP and HP response in which a 3.03-MHz sinusoidal input current signal with amplitude of 20 μV (peak) is applied to the filter.

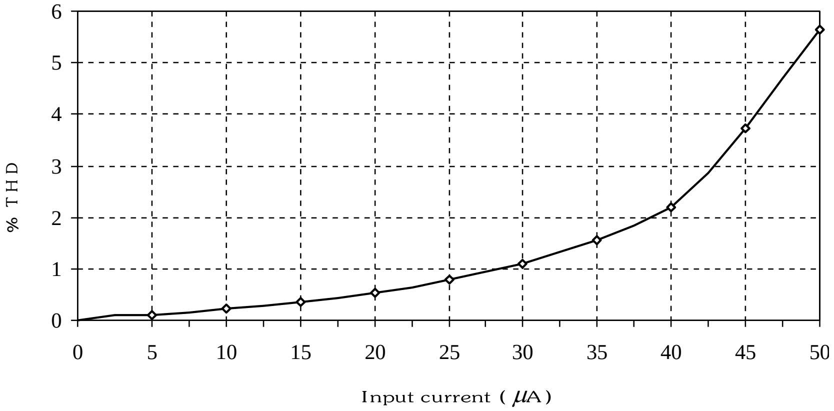

Fig.6. THD variation of BP filter against amplitude of the applied sinusoidal current signal at 3.03 MHz

The total harmonic distortion (THD) variations of the BP response on the amplitude of the sinusoidal current signal at 3.03 MHz are shown in Fig.6. It is observed that the percentage THD is low and remains below 6 % for an input signal with 50 μA (peak).

6. Conclusion

The realization of an electronically tunable current-mode electronically multifunction filter with single input and three outputs using VDTA has been described. The circuit structure employs single VDTA and two grounded capacitors, which is convenient for integration. The proposed circuit can realize LP, BP and HP current responses in the same time from the same circuit topology. It provides the advantage of non-interactive electronic control of the parameter ω_0 and BW, and exhibits low sensitivity. It has been demonstrated that the ideal and simulated responses are in good agreement.

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