Multi-functional Active Filter Design Using Three VDTAs

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Abstract. This paper suggests a single-input multi-output (SIMO) multi-function current mode active filter design using three voltage differencing transconductance amplifiers (VDTAs) as an active element. The filter is realized in current-mode (CM) and delivers several filter operations such as HP, LP, BP, BR and AP filter functions with appropriate connections of input signal. The filter consists of three VDTAs and two capacitors, which are grounded. The significance of the suggested filter is that it provides electronic and independent controllability of filter parameters i.e. pole frequency (ω_p) and Q-factor (Q). The filter design is analyzed using Virtuoso Analog Design Environment of Cadence.

Keywords: VDTA · Current-mode · Universal filter · SIMO

1 Introduction

Over the last few decades or so, the design of multi-functional active filters has evolved enormously in areas of communication, electronics, instrumentation systems, etc. Multi-function filter is the filter that can implement multiple filter operations such as low-pass (LP), high-pass (HP), band-pass (BP), band-reject (BR) and all-pass (AP) filters from one configuration with appropriate connections of input signal. Several multi-functional active filters based on distinct active elements for example operational transresistance amplifier [1], current-conveyor [2], OTA [3], etc., have been suggested. Either of these filters is of voltage-mode (VM) filters or of current-mode (CM) filters. Current-mode filters are preferred over the voltage-mode filters due to their lower cost, simpler circuitry, lower power consumption and wider bandwidth [4]. Further, the filters are also classified as single input multiple output (SIMO) [5], multiple input single output (MISO) [6] and multiple input multiple output (MIMO) [7] filters, based on the number of input and outputs.

This paper introduces a multi-functional single-input multi-output (SIMO) filter based on current-mode (CM) and is using voltage differencing transconductance amplifier (VDTA). VDTA is a fairly new active element with the capability of operation in both VM and CM [8]. In this paper, the multi-function active filter is designed with three VDTAs and two grounded capacitors. Using only one input signal, five

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different functions i.e. LP, HP, BP, BR and AP filters are realized. Electronic and independent controllability of filter specifications i.e. the pole frequency (ω_p) and Q-factor (Q) are provided through the DC bias currents of VDTA. The filter configuration is absolutely resistor-less and finds its suitability in fully integrated circuit operations.

The arrangement of the paper is described below. In Sect. 2, the description of VDTA is discussed. Section 3 presents the suggested multi-functional active filter configuration. In Sect. 4, the simulation results are provided. Lastly, in Sect. 4, conclusion is drawn.

2 Description of VDTA

The modern active element, VDTA has been recommended by Biolek in [9]. Several applications of VDTA have been reported, most notably the filters [10] and oscillators [11]. VDTA is a two-stage transconductance amplifier, which contains two Arbel-Goldminz transconductances (g_{mf} and g_{mf}). The first stage transforms the differential voltages from input ports "p" and "n" into output current at intermediate port "z" with first transconductance (g_{mf}). While, the second stage transforms the voltage at intermediate port "z" into output currents at output ports "$x-$" and "$x+$" with second transconductance (g_{ms}). The block level representation of VDTA showing the associated port voltages and currents is depicted in Fig. 1. The various port voltages and currents of VDTA are related as

$$\begin{bmatrix} i_z \\ i_{x+} \\ i_{x-} \end{bmatrix} = \begin{bmatrix} g_{m1} & -g_{m1} & 0 \\ 0 & 0 & g_{m2} \\ 0 & 0 & -g_{m2} \end{bmatrix} \begin{bmatrix} v_p \\ v_n \\ v_z \end{bmatrix}, \tag{1}$$

where, the Arbel-Goldminz transconductances (g_{mf} and g_{ms}) are defined as [12]

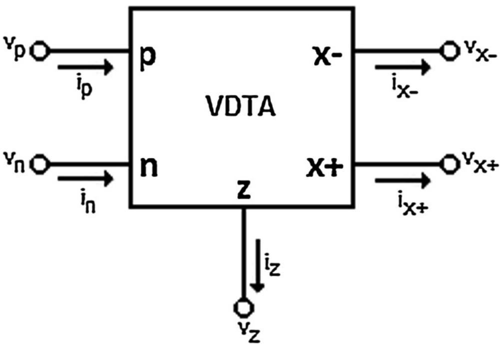

Fig. 1. Block level representation of VDTA.

$$g_{mf} = \frac{g_1 g_2}{g_1 + g_2} + \frac{g_3 g_4}{g_3 + g_4}, \quad (2)$$

$$g_{ms} = \frac{g_5 g_6}{g_5 + g_6} + \frac{g_7 g_8}{g_7 + g_8}. \quad (3)$$

$$\text{where, } g_j = \sqrt{\mu C_{ox} (W/L)_j I_{bias}} \quad (4)$$

is the transconductance and $(W/L)_j$ is the aspect ratio of j^{th} MOS transistor. The value of j varies from 1 to 6. μ is carrier mobility; C_{ox} is the gate oxide capacitance and I_{bias} is external DC bias current of VDTA. Figure 2 represents the transistor level representation of VDTA and is displayed below.

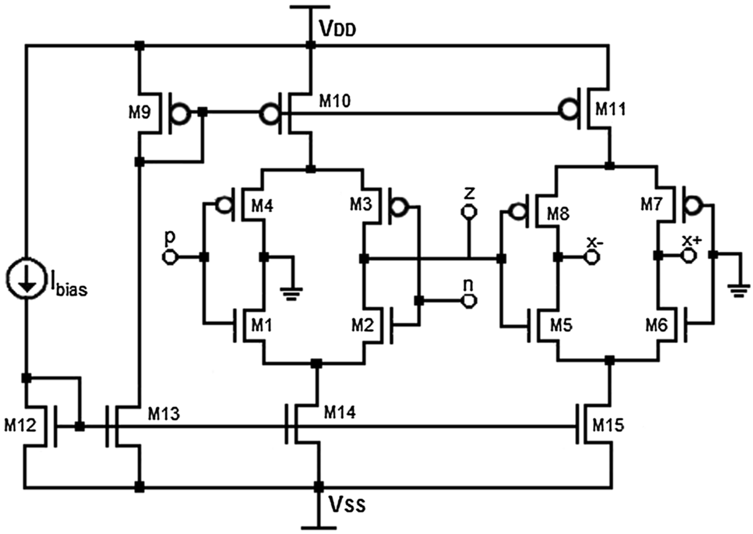

Fig. 2. Transistor level representation of VDTA.

3 Suggested Filter Configuration

The suggested VDTA based multi-functional current-mode (CM) single-input multi-output (SIMO) active filter configuration is shown in Fig. 3. The configuration comprises three VDTAs and two grounded capacitors (C_1 and C_2). The filter operates in current-mode (CM) and has one input current (i_{in}) and five corresponding output currents (i_{LP}, i_{HP}, i_{BP}, i_{BR} and i_{AP}). Routine analysis of the filter configuration using (1) yields the following current transfer functions

$$\frac{i_{LP}}{i_{in}} = \frac{g_{ms2} g_{ms3} g_{mf3}}{D(s)}, \quad (5)$$

$$\frac{i_{HP}}{i_{in}} = \frac{s^2 C_1 C_2 g_{mf2}}{D(s)}, \tag{6}$$

$$\frac{i_{BP}}{i_{in}} = \frac{s C_2 g_{ms2} g_{mf2}}{D(s)}. \tag{7}$$

The band-reject (BR) filter current transfer function is achieved by addition of output currents of HP and LP filter i.e. $i_{BR} = i_{HP} + i_{LP}$. The filter's current transfer function is achieved as

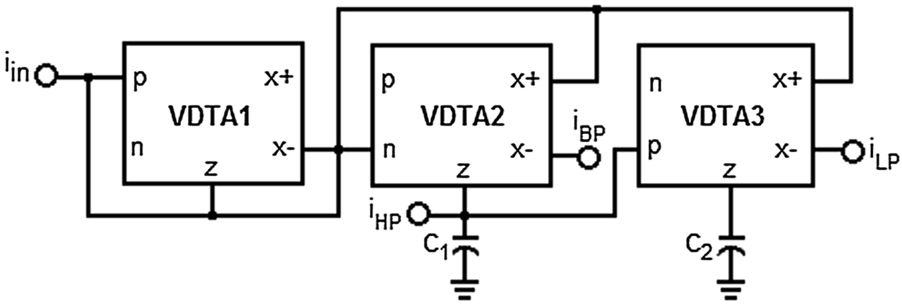

Fig. 3. Suggested filter configuration.

$$\frac{i_{BR}}{i_{in}} = \frac{s^2 C_1 C_2 g_{mf2} + g_{ms2} g_{ms3} g_{mf3}}{D(s)}. \tag{8}$$

The all-pass (AP) filter current transfer function is achieved by addition of output currents of HP, LP filter and inverted BP filter i.e. $i_{AP} = i_{HP} + i_{LP} - i_{BP}$. The filter's current transfer function is achieved as

$$\frac{i_{AP}}{i_{in}} = \frac{s^2 C_1 C_2 g_{mf2} + g_{ms2} g_{ms3} g_{mf3} - s C_2 g_{ms2} g_{mf2}}{D(s)}, \tag{9}$$

where,

$$D(s) = s^2 C_1 C_2 (g_{mf1} + g_{ms1}) + s C_2 g_{mf2} g_{ms2} + g_{mf2} g_{mf3} g_{ms3}. \tag{10}$$

Here g_{mf1}, g_{mf2}, g_{mf3} and g_{ms1}, g_{ms2}, g_{ms3} are the first stage and second stage transconductances of first, second and third VDTA respectively.

Therefore, from (5)–(9), it is observed that the designed multi-functional filter realizes LP, HP, BP, BR and AP filters with appropriate connection of input signals. The filter parameters i.e. the pole frequency (ω_p) and Q-factor (Q) for the suggested filter can be obtained from (10) as

$$\omega_0 = \sqrt{\frac{g_{mf2} g_{mf3} g_{ms3}}{(g_{mf1} + g_{ms1}) C_1 C_2}}, \tag{11}$$

$$Q = \frac{1}{g_{ms2}} \sqrt{\frac{g_{mf3} g_{ms3} (g_{mf1} + g_{ms1}) C_1}{g_{mf2} C_2}}. \tag{12}$$

It can be observed from (11) and (12) that the pole frequency (ω_0) and Q-factor (Q) of the designed filter are controllable through transconductances of VDTA. Since the transconductances of VDTA depend on external DC bias current from (4). Therefore, the pole frequency (ω_p) and Q-factor (Q) are electronically controllable via external DC bias current. Moreover, the Q-factor (Q) of the designed filter can be self-controlled from the pole frequency (ω_p) through transconductance g_{ms2}.

4 Simulation Results and Discussion

The functionality of the designed multi-functional CM SIMO active filter using VDTA is investigated through Virtuoso Analog design Environment of Cadence. The simulations are performed at 45-nm technology node. The supply voltage is taken as V_{DD} (or $-V_{SS}$) = ± 900 mV. The bias currents are selected as I_{BIAS} = 150 µA. The overall power dissipation of the designed configuration is 1.8 mW. The following filter outputs realizing LP, HP, BP, BR and AP filter are achieved and is shown in Fig. 4. All the filters have the same pole frequency (ω_p) of 1 MHz. The transient response of the current-mode filter is shown in Fig. 5. The output sinusoidal current (i_{out}) as obtained by applying a input sinusoidal current having a total amplitude of 20 mA and frequency of 1 MHz. As shown in Fig. 5, the output transient waveform need some clock cycles to settle down and then after produces a stable current waveform. The table of comparison of the suggested filter configuration with other filter configuration is presented in Table 1.

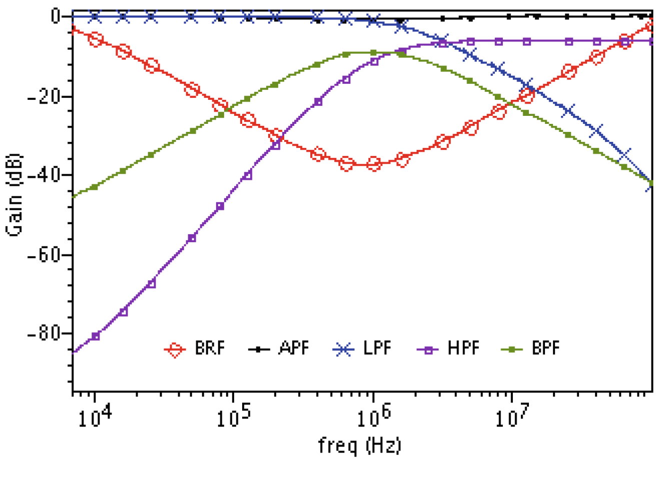

Fig. 4. Gain response of current-mode filters.

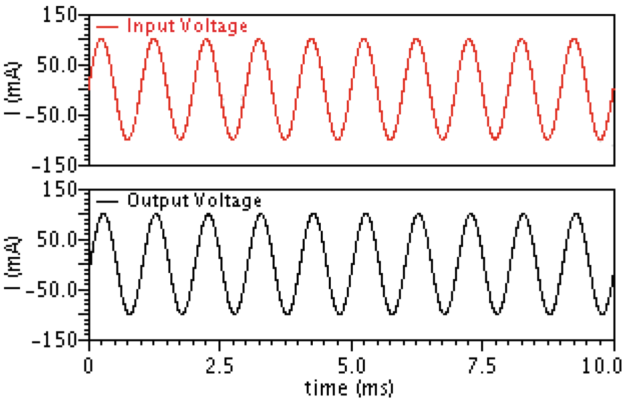

Fig. 5. Transient response of the suggested current-mode filter.

Table 1. Performance comparison with other reported works

Ref.	Standard filter functions	Passive components	Supply voltage	ω_0
[8]	LP, HP, BP (VM and CM mode)	Three C and One R	±0.9 V	1 MHz
[13]	LP, HP, BP, BR, AP	Two C and Two R	±2 V	3.03 MHz
[14]	LP, HP, BP (in VM mode) and LP, HP, BP, BR, AP (in TA mode)	Two C	±1.25 V	3.04 MHz
This work	LP, HP, BP, BR, AP (in CM mode)	Two C	±0.9 V	1 MHz

5 Conclusion

In the suggested paper, we have shown CM SIMO multi-functional active filter consisting of three VDTAs and two capacitors, which are grounded. The presented filter configuration realizes LP, HP, BP, BR and AP filters with relevant connections of input currents. The electronic and independent controllability pole frequency (ω_p) and Q-factor (Q) is provided depending upon the DC bias currents of VDTA. The suggested filter can be employed in communication, electronics, and instrumentation systems.

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