A VDIBA Based Voltage-Mode Highpass and Bandpass Filter

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Abstract. A VDIBA based voltage-mode (VM) highpass and bandpass filter topology is presented. The topology utilizes two VDIBA blocks, two capacitors and one resistor. The topology has three voltage inputs, two voltage output and can realize highpass (HP) and bandpass (BP) filter operation from the similar structure. The corner frequency and quality factor of VDIBA based filter is electronically tuneable by virtue of bias current of the internal transconductance. The topology operates with very low supply voltage of ±600 mV and external DC bias current of 150 µA. The simulations are carried out at 45-nm CMOS technology using Virtuoso Analog design Environment of Cadence.

Keywords: VDIBA · Biquadratic filter · Voltage-mode · MISO

1 Introduction

Analog (continuous-time) active filters are the significant components for analog signal processing operations and are extensively used for applications such as communications, instrumentations, measurements, control systems, biomedical applications etc., [1]. Several kinds of active elements have been utilized in the recent past for implementing the analog filters [2]. Such active elements are categorized into two classes based on differential inputs. The active elements which operate with differential input currents are Current Differencing Buffered Amplifiers (CDBA) [3], Current Differencing Transconductance Amplifiers (CDTA) [4], etc., whereas the active elements which operate with differential input voltages are Voltage Differencing Transconductance Amplifier (VDTA) [5–7], Voltage Differencing Current Conveyor (VDCC) [8], Voltage Differencing Buffered Amplifier (VDBA) [9], etc. Voltage Differencing Inverting Buffered Amplifier (VDIBA) is a state-of-the-art active element which is introduced recently in [10]. VDIBA has gained popularity owing to its simpler structure, electronic tunability feature and has been utilized in a variety of applications [11].

This work proposes a VDIBA based voltage-mode (VM) highpass and bandpass filter topology. The filter topology contains three voltage inputs, two voltage output and incorporates two VDIBA blocks, two capacitors and one resistor for realizing filter

functions. With appropriate connections of input signals, highpass (HP) and bandpass (BP) filters can be implemented. The filter parameters of suggested filters especially the corner frequency (ω_C) and Q-factor or quality factor (Q) are electronically tunable via the bias currents of VDIBA.

The organization of the paper is done in the following way. Section 2 explains the concepts of VDIBA. In Sect. 3, the suggested VDIBA based filter topology is presented. Section 4 demonstrates the responses of the suggested VDIBA based filter topology. Eventually, the conclusion is drawn in Sect. 5.

2 Voltage Differencing Inverting Buffered Amplifier (VDIBA)

VDIBA is a 4-port active element. Its schematic representation is shown in Fig. 1. VDIBA consists of two input ports (p, n), one output port (z) and one inverting output port (w^-). The ports p, n and z are of high impedance whereas port w^- is of low impedance. The ports p, n and w^- are voltage ports whereas port z is a current port. The relation between the voltages and currents of VDIBA may be represented by the subsequent sequence of equations as

$$i_p = 0, \tag{1}$$

$$i_n = 0, \tag{2}$$

$$i_z = g_m(v_p - v_n), \tag{3}$$

$$v_{w-} = -\beta v_z. \tag{4}$$

Here, g_m and β stand for transconductance and parasitic voltage gain of VDIBA respectively. For ideal VDIBA, β is unity. Figure 2 depicts the transistor-level representation of conventional VDIBA.
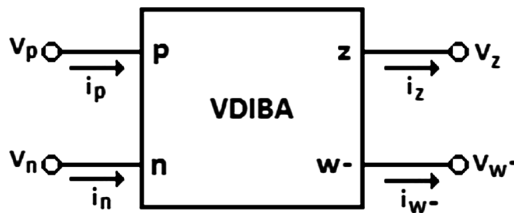

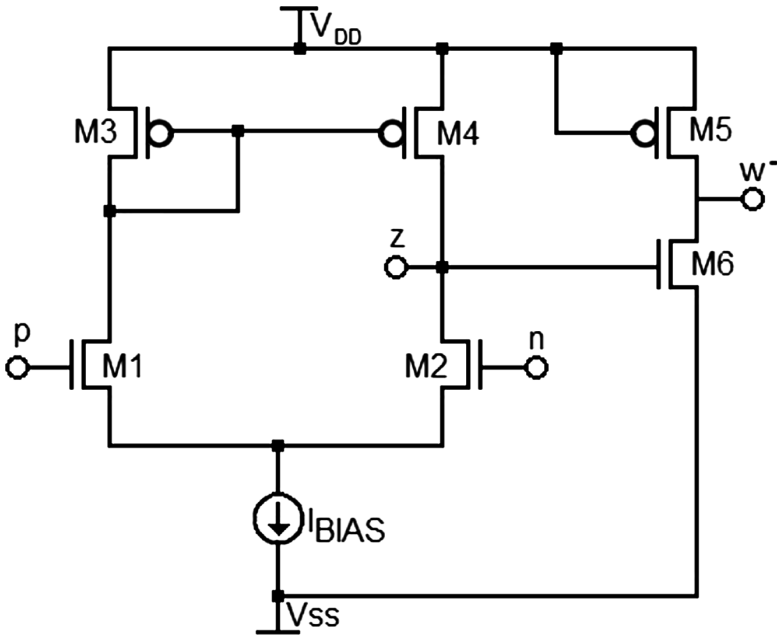**Fig. 1.** Schematic representation of VDIBA.

Fig. 2. Transistor-level representation of conventional VDIBA.

3   VDIBA Based Filter Topology

Figure 3 exhibits the suggested VDIBA based biquadratic filter topology. The filter topology comprises two VDIBA blocks, two capacitors (C_1, C_2) and one resistor (R). The filter is of multiple-input single-output (MISO) type and operates in voltage-mode (VM). The filter topology has three voltage inputs (v_{in1}, v_{in2}, v_{in3}) and one voltage output (v_{out}).
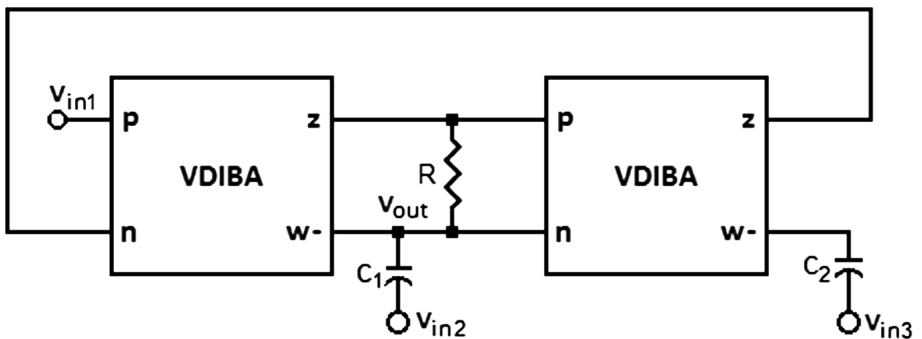

Fig. 3. VDIBA based filter topology.

Routine circuit analysis of the filter topology yields the subsequent expression of transfer function

$$v_{out} = \frac{s^2 C_1 C_2 R v_{in2} + s(C_2 R g_{m1} v_{in1} + \beta_2 C_2 R g_{m1} g_{m2} v_{in3})}{s^2 C_1 C_2 R + s(1 + \beta_1) C_2 + \beta_2 (1 + \beta_1) g_{m1} g_{m2} R}. \tag{5}$$

where β_1 and β_2 are the parasitic voltage gain of the 1st and 2nd VDIBA respectively.

In order to realize the highpass and bandpass transfer function, the different combinations of voltage inputs (v_{in1}, v_{in2}, v_{in3}) are varied in such a way that they realize only one type of filter function (highpass or bandpass) at a time. The input combinations are given below:

(a) If $v_{in2} = v_{in}$ and $v_{in1} = v_{in3} = 0$, then highpass filter (HPF) transfer function is obtained.
(b) If $v_{in1} = v_{in3} = v_{in}$ and $v_{in2} = 0$, then bandpass filter (BPF) transfer function is obtained.

The filter parameters i.e. the corner frequency (ω_C) and Q-factor (Q) for the suggested filters can be obtained from (5) as

$$\omega_c = \sqrt{\frac{\beta_2(1 + \beta_1)g_{m1}g_{m2}}{C_1 C_2}}, \tag{6}$$

$$Q = R\sqrt{\frac{\beta_2}{(1 + \beta_1)}\frac{C_1}{C_2} g_{m1}g_{m2}}. \tag{7}$$

Considering $\beta_1 = \beta_2 = 1$, the transfer function can be re-written as

$$v_{out} = \frac{s^2 C_1 C_2 R v_2 + s(C_2 R g_{m1} v_1 + C_2 R g_{m1} g_{m2} v_3)}{s^2 C_1 C_2 R + 2s C_2 + 2 g_{m1} g_{m2} R}, \tag{8}$$

Similarly, the filter parameters i.e. the corner frequency (ω_C) and Q-factor (Q) from (8) can be expressed as

$$\omega_c = \sqrt{\frac{2 g_{m1} g_{m2}}{C_1 C_2}}, \tag{9}$$

$$Q = R\sqrt{\frac{C_1}{2C_2} g_{m1}g_{m2}}. \tag{10}$$

As observed from (6), (9) and (7), (10), that the corner frequency (ω_C) and Q-factor (Q) of the suggested filter are controllable through transconductances (g_{m1}, g_{m2}) of VDIBA. Since the transconductances of VDIBA depend on external DC bias current

(I_{BIAS}), the corner frequency (ω_C) and Q-factor (Q) are electronically controllable. Further, the Q-factor (Q) of the suggested filter may be independently controlled from the corner frequency (ω_C) through resistor (R).

4   Simulation Result

For justifying the speculative analyses obtained and discussed in the above sections, the filter is designed and simulated in Virtuoso Analog design Environment of Cadence at CMOS 45-nm CMOS process node. The suggested filter topology is biased with a supply voltage ($V_{\text{DD}} = -V_{\text{SS}}$) of ±600 mV. The bias current of VDIBA is taken as 150 µA. The gain response of the suggested highpass filter (HPF) and bandpass filter (BPF) is depicted in Fig. 4. Further, the transient response of the band-pass filter is also shown in Fig. 5. The transient response manifests that for 10 mV (peak-to-peak) input sinusoidal voltage, the filter produces 10 mV (peak-to-peak) output sinusoidal voltage, which validates the stability of the suggested filter.
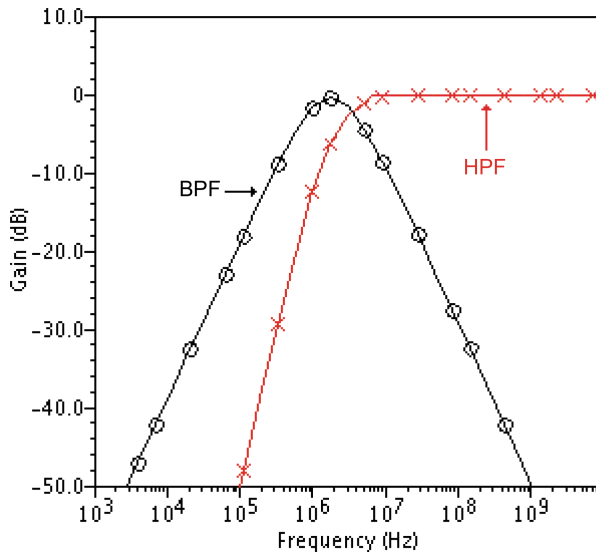
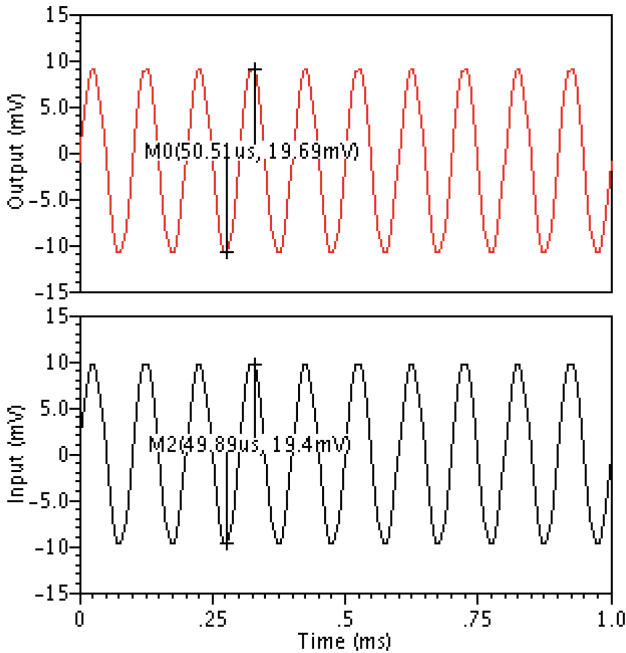**Fig. 4.** Gain response of highpass and bandpass filter.

Fig. 5. Transient response of bandpass filter.

5   Conclusion

A VDIBA based voltage-mode (VM) highpass and bandpass filter topology is presented. The filter parameters of suggested filters i.e. corner frequency (ω_C) and Q-factor (Q) are electronically tunable via the bias currents of VDIBA. Both the filter parameters are also independently tunable through the resistor.

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