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Research Article

A New MISO-Type Voltage-Mode Universal Biquad Using Single VD-DIBA

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A new multiple-input single-output-(MISO-)-type multifunction voltage-mode universal biquadratic filter employing single voltage differencing differential input buffered amplifier (VD-DIBA), two capacitors, and one resistor are proposed. The proposed structure can realize second-order low pass, high pass, band pass, band stop, and all pass filter responses without altering the circuit topology. The proposed new filter configuration also provides the following advantageous features, not available simultaneously in any of the single active device /element-based universal biquad in realizing all the five filter functions known earlier so far: (i) no requirement of any passive component(s) matching condition or inversion of input signal(s), (ii) independent electronic control of angular frequency (ω_0) and bandwidth (BW), and (iii) low active and passive sensitivities. SPICE simulation results have been included using 0.35 μm TSMC technology to confirm the validity of the proposed new universal biquadratic filter configuration.

1. Introduction

Several multiple-input single-output (MISO) or single-input multiple-output (SIMO) type current-mode (CM) or voltage-mode (VM) universal active filters have been described in the literature because of their flexibility and versatility for practical applications. Among these, MISO-type filters are particularly attractive because the same filter structure can be used for different filter functions. Recently, considerable attention has been devoted for the realization of VM or CM filter structures using different types of single active building block/device [1–9]. However, these filter configurations have the drawback of passive component-matching requirement(s) or inversion of input signal(s). Although the MISO-type filter configuration presented in [10] can realize all filter functions without component(s) matching or inversion of input signal(s), it employs no device (only (7 + 1) MOSFETs, two capacitors, and two resistors). VD-DIBA is one of the new active building blocks proposed in [11] and has been used in the realization of (i) first-order all-pass filter [12], (ii) simulated inductance circuits [13], and (iii) electronically controllable sinusoidal oscillator [14].

The purpose of this paper is, therefore, to propose a new MISO-type VM universal biquad employing a single VD-DIBA, two capacitors, and a resistor to realize (by appropriate selection of input signal voltage(s)) all the five standard filter functions, namely, low pass (LP), high pass (HP), band pass (BP), band stop (BS), and all pass (AP) without any passive component-matching requirement(s) or inversion of input signal(s) from the same circuit topology. The presented filter configuration also provides (i) independent electronic control of angular frequency (ω_0) and bandwidth (BW) and (ii) low active and passive sensitivities. The validity of the proposed biquad has been confirmed by SPICE simulations using 0.35 μm TSMC technology.

2. New Filter Configuration

The symbolic notation and behavioral model of the VD-DIBA (−) are shown in Figures 1(a) and 1(b), respectively. The model uses two controlled sources: the current source, controlled by differential voltage ($V_+ - V_-$), with the transconductance g_m, and the voltage source, controlled by differential

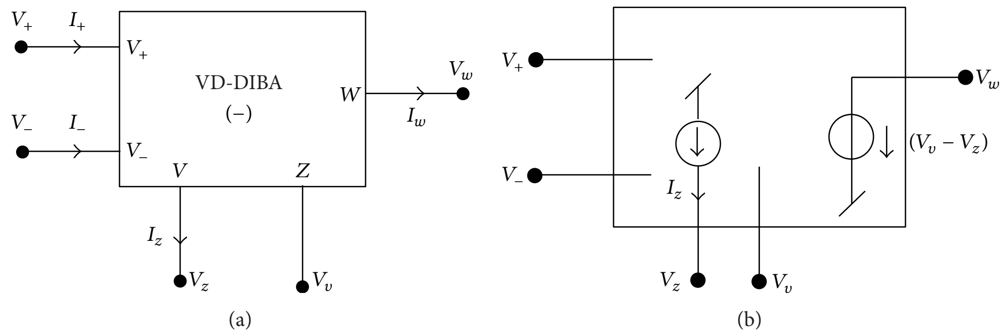

FIGURE 1: (a) Symbolic notation, (b) behavioral model of VD-DIBA [12].

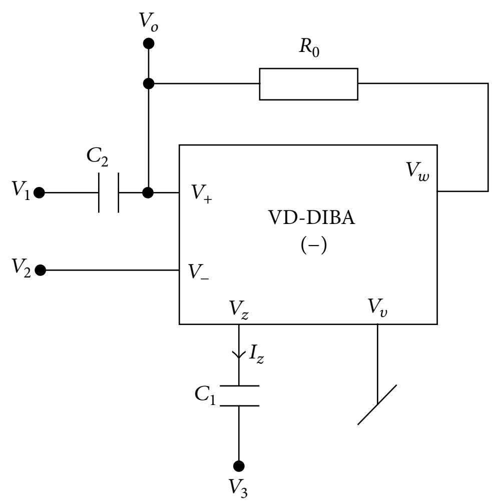

FIGURE 2: The proposed MISO-type voltage-mode universal biquad.

voltage $(V_v - V_z)$, with the unity voltage gain. The VD-DIBA [12] can be described by the following set of equations:

$$\begin{pmatrix} I_+ \\ I_- \\ I_z \\ I_v \\ V_w \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ g_m & -g_m & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & -1 & 1 & 0 \end{pmatrix} \begin{pmatrix} V_+ \\ V_- \\ V_z \\ V_v \\ I_w \end{pmatrix}. \quad (1)$$

The proposed MISO-type voltage-mode universal biquadratic filter using single VD-DIBA, two capacitors, and a resistor are shown in Figure 2.

A routine circuit analysis (assuming ideal VD-DIBA) of Figure 2 gives the following expression for the output voltage in terms of input voltages:

$$V_o = \frac{V_1 s^2 - V_3 s\left(1/R_0C_2\right) + V_2\left(g_m/R_0C_1C_2\right)}{s^2 + s\left(1/R_0C_2\right) + g_m/R_0C_1C_2}. \quad (2)$$

From (2), various filter responses can be realized as

(i) If $V_1 = V_3 = 0$ (grounded) and $V_2 = V_{\text{in}}$, a low pass filter can be realized as follows.

(ii) If $V_2 = V_3 = 0$ and $V_1 = V_{\text{in}}$, a high pass filter can be realized.

(iii) If $V_1 = V_2 = 0$ and $V_3 = V_{\text{in}}$, an inverting band pass filter can be realized.

(iv) If $V_3 = 0$ and $V_1 = V_2 = V_{\text{in}}$, a band stop filter can be realized.

(v) If $V_1 = V_2 = V_3 = V_{\text{in}}$, an all-pass filter can be realized.

TABLE 1

Transistor	W/L (μm)
M_1–M_6	14/1
M_7–M_9	14/0.35
M_{10}–M_{18}	4/1
M_{19}–M_{22}	7/0.35

The expressions for natural frequency (ω_0) and band width (BW) are given by

$$\omega_0 = \sqrt{\frac{g_m}{R_0C_1C_2}}, \qquad \text{BW} = \frac{1}{R_0C_2}. \quad (3)$$

From (3), it can be observed that after adjusting BW, ω_0 can independently be controlled electronically through the transconductance g_m. Furthermore, it is seen that no passive component(s) matching or inversion of input signal(s) is required in any of the five filter realizations.

3. Nonideal Analysis and Sensitivity Performance

Considering the nonidealities of the VD-DIBA, let R_Z and C_Z denote the parasitic resistance and parasitic capacitance of the Z-terminal and $V_W = (-\beta^+ V_Z + \beta^- V_V)$, where $\beta^+ = (1 - \varepsilon_p)$, ($\varepsilon_p \ll 1$), and $\beta^- = (1 - \varepsilon_n)$, ($\varepsilon_n \ll 1$) denote the voltage tracking errors, respectively, then the output voltage in terms of inputs is given by

$$V_0 = \left(V_1\left\{s^2 + s\frac{1}{(C_1 + C_z)R_z}\right\} - V_3\left\{\frac{\beta^+ C_1}{(C_1 + C_z)R_0C_2}\right\}s + V_2\frac{\beta^+ g_m}{(C_1 + C_z)R_0C_2}\right)$$

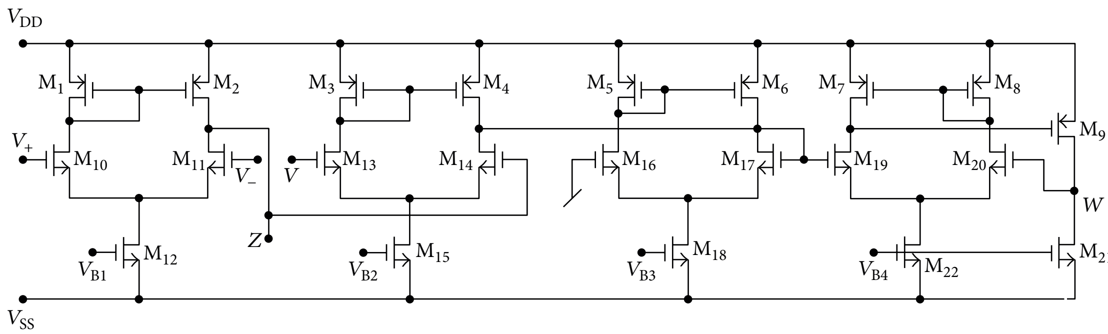

FIGURE 3: Proposed CMOS implementation of VD-DIBA, $V_{DD} = -V_{SS} = 2$ V, $V_{B1} = 1.4$ V, $V_{B2} = 0.22$, $V_{B3} = 0.38$ V, and $V_{B4} = 0.9$ V.

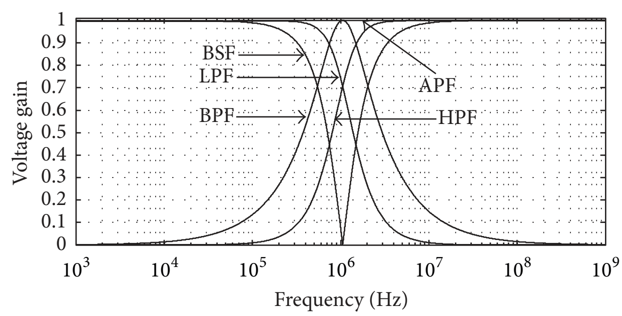

FIGURE 4: Frequency response.

$$\times \left(s^2 + s \left\{ \frac{1}{R_0 C_2} + \frac{1}{(C_1 + C_z) R_z} \right\} + \frac{1}{(C_1 + C_z) C_2 R_0 R_z} \left\{ 1 + \beta^+ g_m R_z \right\} \right)^{-1},$$

$$\omega_0 = \sqrt{\frac{(1 + \beta^+ g_m R_z)}{(C_1 + C_z) C_2 R_0 R_z}},$$

$$Q_0 = \frac{\sqrt{(1 + \beta^+ g_m R_z)(C_1 + C_z) C_2 R_0 R_z}}{(C_1 + C_z) R_z + R_0 C_2}. \tag{4}$$

Its active and passive sensitivities can be found as

$$S_{C_1}^{\omega_0} = -\frac{1}{2} \frac{C_1}{(C_1 + C_z)},$$

$$S_{C_z}^{\omega_0} = -\frac{1}{2} \frac{C_z}{(C_1 + C_z)},$$

$$S_{C_2}^{\omega_0} = -\frac{1}{2} = S_{R_0}^{\omega_0},$$

$$S_{R_z}^{\omega_0} = S_{\beta^+}^{\omega_0} = S_{g_m}^{\omega_0} = \frac{1}{2} \frac{\beta^+ g_m R_z}{(1 + \beta^+ g_m R_z)},$$

$$S_{g_m}^{Q_0} = \frac{1}{2} \frac{\beta^+ g_m R_z}{(1 + \beta^+ g_m R_z)} = S_{\beta^+}^{Q_0},$$

$$S_{C_1}^{Q_0} = \frac{1}{2} \frac{C_1}{(C_1 + C_z)} \left\{ \frac{R_0 C_2 - R_z (C_1 + C_z)}{R_0 C_2 + R_z (C_1 + C_z)} \right\},$$

$$S_{C_2}^{Q_0} = -\frac{1}{2} \left\{ \frac{R_0 C_2 - R_z (C_1 + C_z)}{R_0 C_2 + R_z (C_1 + C_z)} \right\} = S_{R_0}^{Q_0},$$

$$S_{C_z}^{Q_0} = \frac{1}{2} \frac{C_z}{(C_1 + C_z)} \left\{ \frac{R_0 C_2 - R_z (C_1 + C_z)}{R_0 C_2 + R_z (C_1 + C_z)} \right\},$$

$$S_{R_z}^{Q_0} = \frac{1}{2} \frac{R_0 (C_1 + C_z) C_2^2 \left\{ (1 + \beta^+ g_m R_z) - R_z (C_1 + C_z) \right\}}{R_0 (C_1 + C_z) C_2 (1 + \beta^+ g_m R_z) \left\{ R_0 C_2 + R_z (C_1 + C_z) \right\}}. \tag{5}$$

From (4), it is clearly observed that all passive and active sensitivities are no more than one half in magnitudes for the proposed MISO-type VM universal biquad.

4. Simulation Results

To confirm workability of the proposed biquad filter, the circuit was simulated using CMOS VD-DIBA (as shown in Figure 3). For this purpose, the passive elements were selected as $C_1 = C_2 = 0.01$ nF, $R_0 = 10.56$ KΩ. The transconductance of VD-DIBA was controlled by bias voltage V_{B1}. The SPICE simulated frequency responses of the proposed biquad are shown in Figure 4. Figures 5 and 6 represent the phase and

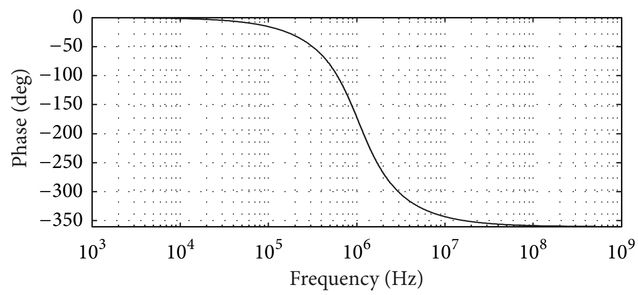

Figure 5: Phase plot of APF.

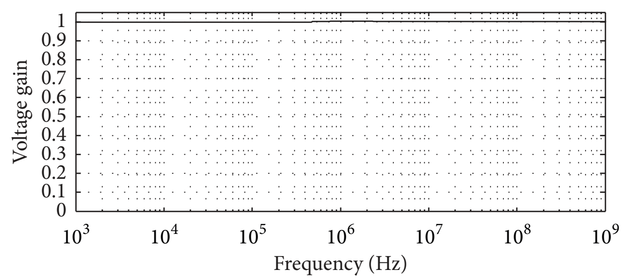

Figure 6: Frequency response of APF.

Table 2

Reference	Number of active elements/devices	Number of capacitors	Number of resistors	Is the realization free from matching condition(s)?	Number of standard filters realized
[1]	1	2	2	NO	Five
[2]	1	2	3	NO	Five
[3]	1	2	2	NO	Five
[4]	1	4	4	NO	Five
[5]	1	2	4	NO	Five
[6]	1	2	3	NO	Five
[7]	1	2	2	NO	Five
[8]	1	2	3	NO	Five
[9]	1	2	1	NO	Five
Proposed	1	2	1	YES	Five

.MODEL N NMOS (LEVEL = 3 TOX = 7.9E − 9 NSUB = 1E17 GAMMA = 0.5827871 PHI = 0.7 VTO = 0.5445549 DELTA = 0 UO = 436.256147 ETA = 0 THETA = 0.1749684 KP = 2.055786E − 4 VMAX = 8.309444E4 KAPPA = 0.2574081 RSH = 0.0559398 NFS = 1E12 TPG = 1 XJ = 3E − 7 LD = 3.162278E − 11 WD = 7.046724E − 8 CGDO = 2.82E − 10 CGSO = 2.82E − 10 CGBO = 1E − 10 CJ = 1E − 3 PB = 0.9758533 MJ = 0.3448504 CJSW = 3.777852E − 10 MJSW = 0.3508721)

.MODEL P PMOS (LEVEL = 3 TOX = 7.9E − 9 NSUB = 1E17 GAMMA = 0.4083894 PHI = 0.7 VTO = −0.7140674 DELTA = 0 UO = 212.2319801 ETA = 9.999762E − 4 THETA = 0.2020774 KP = 6.733755E − 5 VMAX = 1.181551E5 KAPPA = 1.5 RSH = 30.0712458 NFS = 1E12 TPG = −1 XJ = 2E − 7 LD = 5.000001E − 13 WD = 1.249872E − 7 CGDO = 3.09E − 10 CGSO = 3.09E − 10 CGBO = 1E − 10 CJ = 1.419508E − 3 PB = 0.8152753 MJ = 0.5 CJSW = 4.813504E − 10 MJSW = 0.5)

Box 1

magnitude plots of APF, respectively. Thus, these simulation results confirm the validity of the proposed biquad filter. A comparison with other previously known single active element/device-based MISO-type VM universal biquads has been presented in Table 2.

The CMOS VD-DIBA is implemented using 0.35 μm TSMC real transistors models which are listed in Box 1. Aspect ratios of transistors used in Figure 3 are given in Table 1.

5. Conclusions

A new second-order voltage-mode MISO-type universal biquad filter has been presented. The proposed configuration employs single VD-DIBA, two capacitors, and one resistor. The presented biquad (by proper selection of input voltages) can yield second-order low pass, high pass, band pass, notch and all pass-filter responses without altering the circuit topology. The proposed filter configuration also provides the following advantages which are not available simultaneously in any of the single active device/element-based universal MISO-type VM biquads realizing all the five filter functions: (i) no requirement of any passive component(s) matching condition or inversion of input signal(s), (ii) independent electronic control of angular frequency (ω_0) and bandwidth (BW), and (iii) low active and passive sensitivities. Simulation results using 0.35 μm TSMC technology have been included to confirm the feasibility of the new proposed biquad filter.

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