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Voltage-Mode Universal Biquad Filter Employing Single Voltage Differencing Differential Input Buffered Amplifier

Kanhaiya Lal Pushkar[1], Data Ram Bhaskar[2*], Dinesh Prasad[2]
[1]Department of Electronics and Communication Engineering, Maharaja Agrasen Institute of Technology, New Delhi, India
[2]Department of Electronics and Communication Engineering, Faculty of Engineering and Technology, Jamia Millia Islamia, New Delhi, India
Email: klpushkar@rediffmail.com, *dbhaskar@jmi.ac.in, dprasad@jmi.ac.in

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ABSTRACT

A new multi function voltage-mode universal biquadratic filter using single Voltage Differencing Differential Input Buffered Amplifier (VD-DIBA), two capacitors and one resistor is proposed. The proposed configuration has four inputs and one output and can realize all the five standard filters from the same circuit configuration. The presented biquad filter offers low active and passive sensitivities. The validity of proposed universal biquadratic filter has been verified by SPICE simulation using 0.35 μm MIETEC technology.

Keywords: Voltage Differencing Differential Input Buffered Amplifier; Analog Filter; Voltage-Mode

1. Introduction

Recently, attention has been devoted to the design of multi-input single output (MISO) or single input multi-output (SIMO) current-mode or voltage-mode universal biquadratic filters because of their versatility and flexibility for practical applications as the same circuit topology can be employed for different filter responses. Several voltage-mode/current-mode universal biquadratic filters using different types of single active building block/device have been presented in [1-8]. In reference [9] number of new active building blocks have been introduced, VD-DIBA is one of them which is emerging as a flexible and versatile active element for analog signal processing. The applications, advantages and usefulness of VD-DIBA have been recognized in [10,11]. They have been used in the realization of first order all pass filter [10], and in the realization of grounded and floating inductances as presented in [11]. The various filter configurations proposed in [1-8] and [10,11] although employ single active device/element, but use two to four capacitors and two to four resistors. Therefore, the purpose of this paper is to introduce a new voltage-mode universal biquadratic filter using single VD-DIBA, two capacitors and only one resistor. The proposed configuration has four inputs and one output and can realize all the five standard filters (low pass (LPF), high pass (HPF), band pass (BPF), band reject (BRF) and all pass (APF)) by proper selection of input voltages from the same circuit configuration without altering the circuit topology. The active and passive sensitivities of the realized filters are low. The validity of the proposed configuration has been verified by SPICE simulation using 0.35 μm MIETC technology.

2. The Proposed Biquadratic Filter Configuration

The symbolic notation and equivalent model of the VD-DIBA (+) are shown in **Figures 1(a)** and **(b)** respectively [1]. The model includes two controlled sources: the current source controlled by differential voltage $(V_+ - V_-)$, with the transconductance g_m, and the voltage source controlled by differential voltage $(V_z - V_v)$ with the unity voltage gain.

The VD-DIBA (+) 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 voltage-mode universal biquadratic filter is shown in **Figure 2**.

A routine circuit analysis of **Figure 2** yields the following expression for the output voltage in terms of the input voltages

*Corresponding author.

$$V_o = \frac{V_1\left(\frac{g_m}{C_1}s + \frac{g_m}{R_0C_1C_2}\right) + V_2\left(s^2 + s\left(\frac{1}{R_0C_2}\right)\right) - V_3s^2 - V_4s\left(\frac{1}{R_0C_2}\right)}{s^2 + s\left(\frac{1}{R_0C_2} + \frac{g_m}{C_1}\right) + \frac{g_m}{R_0C_1C_2}} \quad (2)$$

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

1) If $V_1 = V_2 = V_4 = 0$ (grounded) and $V_3 = V_{in}$, then an inverting HPF can be realized

2) If $V_1 = V_2 = V_3 = 0$ and $V_4 = V_{in}$, then an inverting BPF can be realized

3) If $V_2 = V_3 = 0$ and $V_1 = V_4 = V_{in}$ and $C_1 = C_2$, $1/R_0 = g_m$, then a LPF can be realized

4) If $V_3 = 0$, $V_1 = V_2 = V_{in}$ and $V_4 = 2V_{in}$ and $C_1 = C_2$, $1/R_0 = g_m$, then BRF can be realized

5) If $V_3 = 0$, $V_1 = V_2 = V_{in}$ and $V_4 = 4V_{in}$ and $C_1 = C_2$, $1/R_0 = g_m$, then APF can be realized

The expressions for natural frequency (ω_0) and quality factor (Q_0) are given by

$$\omega_0 = \sqrt{\frac{g_m}{R_0C_1C_2}} \quad (3)$$

$$Q_0 = \frac{\sqrt{g_mR_0C_1C_2}}{C_1 + g_mR_0C_2} \quad (4)$$

3. Non-Ideal Analysis and Sensitivity Performance

Let R_Z and C_Z denote the parasitic resistance and parasitic capacitance of the *Z*-terminal. Taking the non-idealities into account, namely $V_W = \left(\beta^+V_Z - \beta^-V_V\right)$ where $\beta^+ = 1 - \varepsilon_p\left(\varepsilon_p \ll 1\right)$ and $\beta^- = 1 - \varepsilon_n\left(\varepsilon_n \ll 1\right)$ denote the voltage tracking errors, respectively, then the output voltage in terms of inputs is given by:

$$V_o = \frac{V_1\left(\frac{\beta^+g_m}{C_1'}s + \frac{\beta^+g_m}{R_0C_1'C_2}\right) + V_2\left(s^2\beta^+ + \frac{C_1\beta^+}{R_0C_1'C_2}\right) - V_3\left(s^2\beta^- + \frac{\beta^-}{R_zC_1'C_2}\right) - V_4\left(s\frac{\beta^-}{R_0C_2} + \frac{\beta^-}{R_0R_zC_1'C_2}\right)}{s^2 + s\left(\frac{1}{R_0C_2} + \frac{1}{R_zC_1'} + \frac{\beta^+g_m}{C_1'}\right) + \frac{1}{R_0R_zC_1'C_2} + \frac{\beta^+g_m}{R_0C_1'C_2}} \quad (5)$$

where $C_1' = \left(C_1 + C_z\right)$

$$\omega_0 = \sqrt{\frac{1 + R_zg_m\beta^+}{R_0R_z\left(C_1 + C_z\right)C_2}} \quad (6)$$

$$Q_0 = \frac{\sqrt{\left(1 + R_zg_m\beta^+\right)R_0R_z\left(C_1 + C_z\right)C_2}}{R_z\left(C_1 + C_z\right) + R_0C_2\left(1 + R_zg_m\beta^+\right)} \quad (7)$$

Its active and passive sensitivities can be found as:

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

$$S_{C_z}^{\omega_0} = -\frac{1}{2}\frac{C_z}{\left(C_1 + C_z\right)},\ S_{R_0}^{\omega_0} = -\frac{1}{2} = S_{C_2}^{\omega_0},\ S_{C_1}^{\omega_0} = -\frac{1}{2}\frac{C_1}{\left(C_1 + C_z\right)},\ S_{\beta^+}^{Q_0} = \frac{1}{2}\frac{R_zg_m\beta^+}{\left(1 + R_zg_m\beta^+\right)} = S_{g_m}^{Q_0} \quad (8)$$

$$S_{C_2}^{Q_0} = \frac{1}{2}\left\{\frac{\left(C_1 + C_z\right) - C_2R_0\left(\frac{1}{R_z} + \beta^+g_m\right)}{\left(C_1 + C_z\right) + C_2R_0\left(\frac{1}{R_z} + \beta^+g_m\right)}\right\} = S_{R_0}^{Q_0} = S_{R_z}^{Q_0} = -S_{C_1}^{Q_0} = -S_{C_z}^{Q_0}$$

From Equation (8), it is clearly observed that all passive and active sensitivities are no more than one half in magnitudes for the proposed multi-input single-output voltage-mode universal biquad.

4. Simulation Results

To confirm feasibility of the proposed universal biquad filter of **Figure 2**, the circuit was simulated using CMOS VD-DIBA (as shown in **Figure 3**). For simulation the passive elements of **Figure 2** were selected as $C_1 = C_2 =$ 0.005 nF and R_0 = 102 KΩ. The transconductance of VD-DIBA was controlled through the bias voltage V_{B1}. The SPICE simulated frequency response of various proposed filters biquad is shown in **Figure 4**. **Figure 5** shows the phase plot of APF. These SPICE simulated

results, thus, confirm the validity of the proposed biquad filter.

The CMOS VD-DIBA is implemented using 0.35 µm MIETEC real transistor models which are listed in **Table 1**. Aspect ratios of transistors used in **Figure 3** are given in **Table 2**. A comparison with other previously known single active element/device-based MISO-type universal biquads has been shown in **Table 3**.

5. Conclusion

A new second-order voltage-mode MISO-type universal

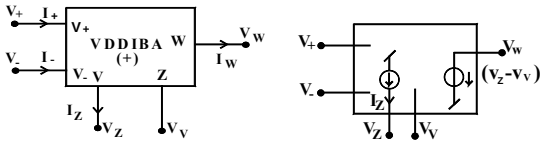

Figure 1. (a) Symbolic notation; (b) Equivalent model of VD-DIBA.

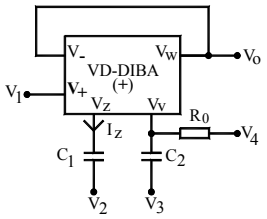

Figure 2. The proposed voltage-mode universal biquad.

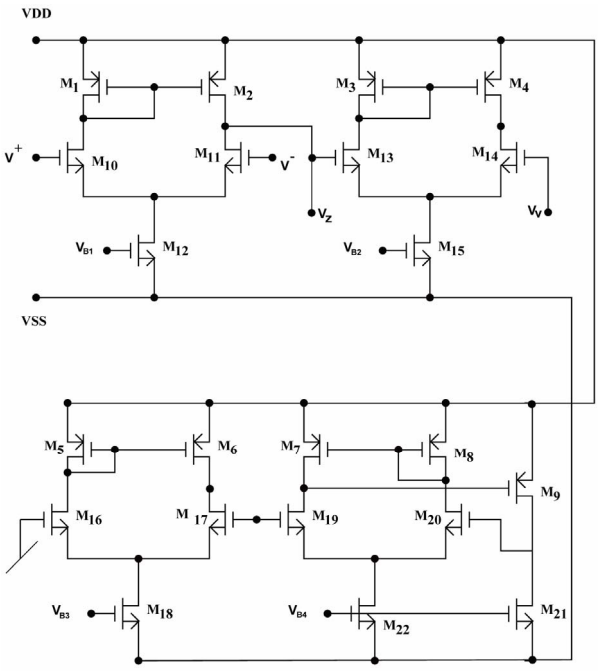

Figure 3. Proposed CMOS implementation of VD-DIBA, $V_{DD} = -V_{SS} = 2$ V, $V_{B1} = -1.45$ V, $V_{B2} = 0.52$, $V_{B3} = -0.62$ V and $V_{B4} = -0.3$ V.

Table 1. 0.35 µm MIETEC real transistor models parameters.

NMOS	PMOS
LEVEL = 3	LEVEL = 3
TOX = 7.9E−9	TOX = 7.9E−9
NSUB = 1E−17	NSUB = 1E−17
GAMMA = 0.5827871	GAMMA = 0.4083894
PHI = 0.7	PHI = 0.7
VTO = 0.5445549	VTO = −0.7140674
DELTA = 0	DELTA = 0
UO = 436.256147	UO = 212.2319801
ETA = 0	ETA = 9.999762E−4
THETA = 0.1749684	THETA = 0.2020774
KP = 2.055786E−4	KP = 6.733755E−5
VMAX = 8.309444E−4	VMAX = 1.181551E−5
KAPPA = 0.2574081	KAPPA = 1.5
RSH = 0.0559398	RSH = 30.0712458
NFS = 1E−12	NFS = 1E−12
TPG = 1	TPG = −1
XJ = 3E−7	XJ = 2E−7
LD = 3.162278E−11	LD = 5.000001E−13
WD = 7.046724E−8	WD = 1.249872E−7
CGDO = 2.82E−10	CGDO = 3.09E−10
CGSO = 2.82E−10	CGSO = 3.09E−10
CGBO = 1E−10	CGBO = 1E−10
CJ = 1E−3	CJ = 1.419508E−3
PB = 0.9758533	PB = 0.8152753
MJ = 0.3448504	MJ = 0.5
CJSW = 3.777852E−10	CJSW = 4.813504E−10
MJSW = 0.3508721	MJSW = 0.5

Table 2. Aspect ratios of transistors used in Figure 3.

Transistor	W/L (µm)
M_1-M_6	35/0.35
M_7-M_9	56/0.35
M_{10}-M_{18}	4.2/1.05
M_{19}-M_{22}	12.25/0.35

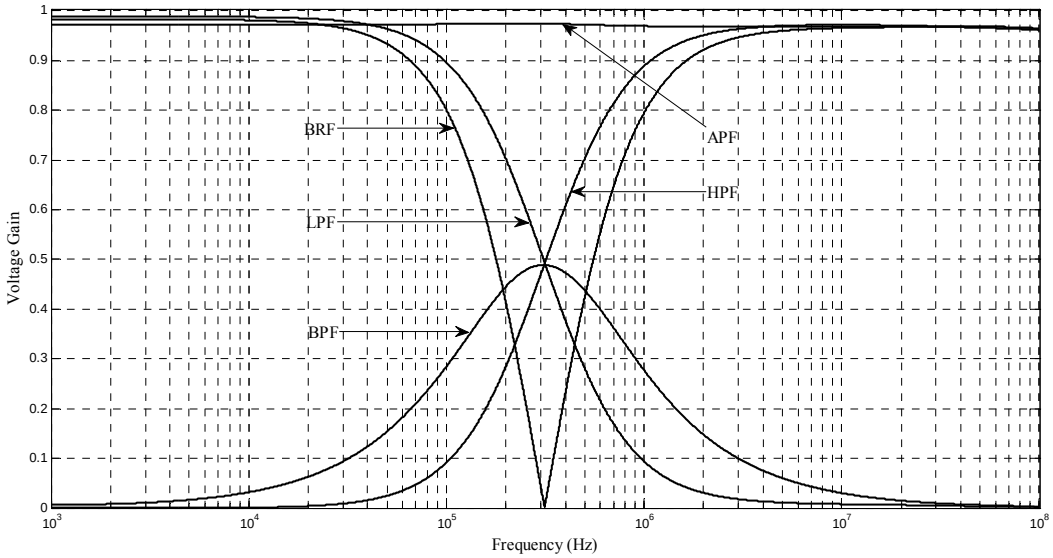

Figure 4. Frequency response.

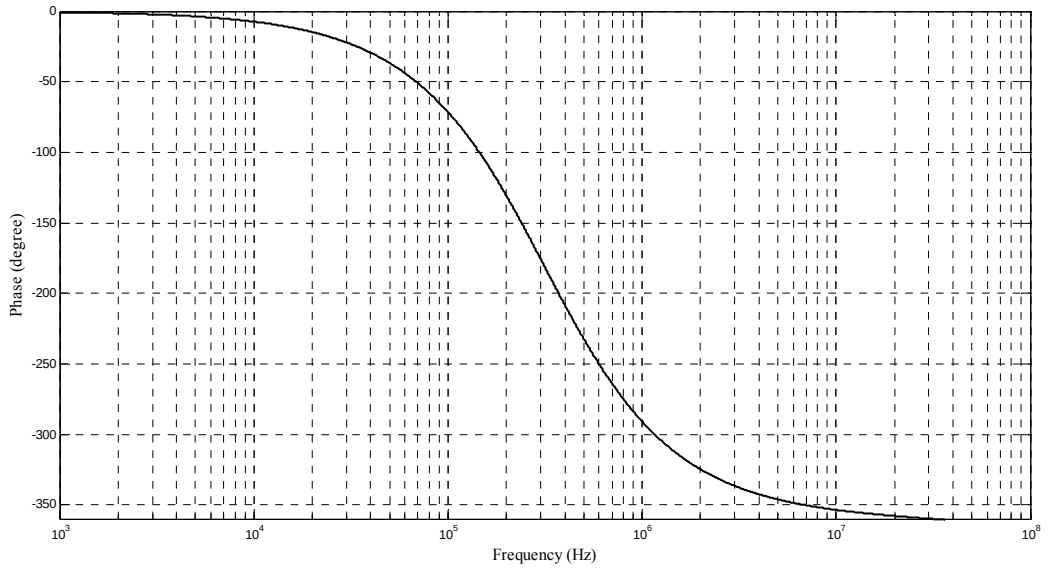

Figure 5. Phase plot of APF.

Table 3. Comparison with other previously known single active element/device-based MISO-type universal biquads.

Reference	No. of active components	No. of capacitors	No. of resistors	Requirement of matching condition(s)	Number of standard filter realized
[1]	1	2	2	Yes	Five
[2]	1	2	3	Yes	Five
[3]	1	2	2	Yes	Five
[4]	1	4	4	Yes	Five
[5]	1	2	4	Yes	Five
[6]	1	2	3	Yes	Five
[7]	1	2	2	Yes	Five
[8]	1	2	3	Yes	Five
Proposed	**1**	**2**	**1**	**YES**	**Five**

biquad filter has been presented. The proposed configuration employs single VD-DIBA with minimum number of passive elements, namely two capacitors and only one resistor. The presented biquad can yield second-order low pass, high pass, band pass, notch and all pass filter responses without altering the circuit topology. The passive and active sensitivities are low. Simulation results using 0.35 μm MIETEC technology have been presented which prove the feasibility of the proposed new biquad filter.

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