

THREE INPUT SINGLE OUTPUT VOLTAGE-MODE MULTIFUNCTION FILTER WITH INDEPENDENT CONTROL OF POLE FREQUENCY AND QUALITY FACTOR

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Abstract. This paper presents a voltage-mode bi-quadratic filter performing completely standard functions: low-pass, high-pass, band-pass, band-reject and all-pass functions, based on single voltage differencing transconductance amplifier (VDTA). The proposed filter has three input voltage and a single output voltage. The features of the circuit are that; the quality factor and natural frequency can be tuned independently; the circuit description is very simple, consisting of merely one VDTA, one resistor and two capacitors; the pole frequency can be electronically adjusted. Additionally, each function response can be selected by suitably selecting input signals with digital method; the double input voltage is not required. Using only single active element, the proposed circuit is very suitable to further develop into an integrated circuit. The PSPICE simulation results are depicted. The given results agree well with the theoretical anticipation.

Keywords

Filter, integrated circuit, VDTA, voltage-mode.

1. Introduction

Filters are important blocks in many integrated circuit applications such as radio frequency applications, data conversion in A/D and D/A systems and many others [1], [2], [3]. One of most popular analog filters is a multiple-input single-output biquadratic filter (MISO) which different output filter functions can be realized simply by different combinations of switching on or off the input currents where the selection can be done digitally using a microcontroller.

The synthesis and design of analog filters using modern electronically controllable active building blocks (ABBs) give flexibility and convenience for designer. These filters can be easily controlled by microcomputer or microcontroller. Also some filter circuits which use active building block can avoid the use of the external resistors. This will reduce the cost and chip area. Yesil et al [4] proposed several circuit ideas of building blocks for voltage-, current- and mixed mode applications. One of them is the voltage differencing transconductance amplifier (VDTA). This device allows applications with interesting features, especially those providing the electronic controllability.

Numerous techniques using active building block for designing the MISO voltage-mode filters have been developed in the past two decades [5], [6], [7], [8], [9], [10], [11], [12], [13], [14], [15], [16], [17], [18], [19], [20], [21], [22], [23], [24], [25], [26], [27], [28], [29], [30], [31]. These MISO filters are based on current conveyor (CCII) [5], [6], [7], [8], [9], [10], [11], current feedback amplifier (CFA) [12], [13], [14], differential difference current conveyor (DDCC) [15], [16], operational transconductance amplifier (OTA) [17], [18], fully differential current conveyor (FDCCII) [19], [20], [21], operational transresistance amplifier (OTRA) [22], current conveyor transconductance amplifier (CCTA) [23], current follower transconductance amplifier (CFTA) [24], dual X second-generation current conveyor (DXCCII) [25], current controlled CCII (CCCII) [26], differential voltage current conveyor (DVCC) [27], [28], current differencing buffered amplifier (CDBA) [29], and voltage differencing differential input buffered amplifier (VD-DIBA) [30] and VDTA [31]. The advantages of the proposed MISO voltage-mode filter are compared with several previous MISO voltage-mode filters which the results are shown in Tab. 1.

Tab. 1: Comparison between various MISO voltage-mode filters.

Ref	ABB	No. of ABB	No. of R+C	Electronic control	Independent tune of ω_0 and Q	No need of double input	No need of matching condition
[5]	CCII	2	3+2	No	Yes	Yes	Yes
[6]	CCII	3	5+2	No	Yes	Yes	Yes
[7]	CCII	2	2+2	No	No	Yes	Yes
[8]	CCII	3	3+3	No	No	Yes	No
[9]	CCH	2	2+2	No	No	Yes	Yes
[10]	CCII	2	3+2	No	Yes	Yes	No
[11]	CCII	3	2+2	No	No	Yes	No
[12]	CFA	1	3+2	No	No	Yes	Yes
[13]	CFA	1	3+2	No	Yes	Yes	No
[14]	CFA	1	2+2	No	No	Yes	Yes
[15]	DDCC	2	2+2	No	No	Yes	Yes
[16]	DDCC	3	2+2	No	No	Yes	Yes
[17]	OTA	2	0+2	Yes	No	Yes	Yes
[18]	OTA	6	0+2	Yes	No	Yes	Yes
[19]	FDCCII	1	3+2	No	Yes	Yes	Yes
[20]	FDCCII	2	2+2	No	No	Yes	Yes
[21]	FDCCII	2	2+2	No	No	Yes	Yes
[22]	OTRA	1	4+4	No	No	Yes	No
[23]	CCTA	1	2+2	Yes	Yes	Yes	Yes
[24]	CFTA	1	2+2	Yes	No	Yes	No
[25]	DXCCII	1	4+2	No	No	Yes	No
[26]	CCCII	2	0+2	Yes	No	Yes	Yes
[27]	DVCC	1	2+2	Yes	No	Yes	No
[28]	DVCC	3	4+2	No	Yes	Yes	No
[29]	CDBA	2	4+2	No	Yes	Yes	Yes
[30]	VD-DIBA	1	1+2	Yes	No	Yes	Yes
[31]	VDTA	1	0+2	Yes	No	No	No
Proposed filter	VDTA	1	1+2	Yes	Yes	Yes	Yes

The aim of this paper is to propose a MISO voltage-mode filter, emphasizing on the use of single voltage differencing transconductance amplifier (VDTA) as the active element. The features of the proposed circuit are that:

- The natural frequency and the quality factor are orthogonally tunable.
- Obtains a minimum number of components required to achieve a second-order transfer function; low pass (LP), high pass (HP), band pass (BP), band stop (BS) and all pass (AP) functions are obtained without any change in the filter topology.
- Passive and active elements enjoy low sensitivities.
- No need of matching condition of passive elements.
- No need of double input voltage to achieve all pass function.

2. Principle of Operation

There are two topics in this section as follows:

2.1. VDTA Overview

The circuit symbol of VDTA is shown in Fig. 1, where V_P and V_N are the input terminals, Z and X are the output ones. Hence, Z is the current output terminal; current through Z terminal follows the difference of the voltages at V_P and V_N terminals by transconductances g_{m1} . The voltage V_Z on Z terminal is transferred into current using transconductance g_{m2} , which flows into output terminal X. The g_{m1} and g_{m2} are tuned by I_{B1} and I_{B2} , respectively. In general, VDTA can contain an arbitrary number of x terminals, providing currents I_X of both directions. All terminals of VDTA exhibit high impedance values [4]. The characteristics of VDTA are represented by the following hybrid matrix:

$$\begin{bmatrix} I_Z \\ I_{X+} \\ I_{X-} \end{bmatrix} = \begin{bmatrix} g_{m1} & -g_{m1} & 0 \\ 0 & 0 & g_{m2} \\ 0 & 0 & -g_{m2} \end{bmatrix} \begin{bmatrix} V_P \\ V_N \\ V_Z \end{bmatrix}. \quad (1)$$

If the VDTA is realized using CMOS technology, g_{m1} and g_{m2} can be respectively written as

$$g_{m1} = \sqrt{kI_{B1}}, \quad (2)$$

and

$$g_{m2} = \sqrt{kI_{B2}}. \quad (3)$$

Here k is the physical transconductance parameter of the CMOS transistor. I_{B1} and I_{B2} are the bias current

used to control the g_{m1} and g_{m2} , respectively. The internal construction of CMOS VDTA is shown in Fig. 2.

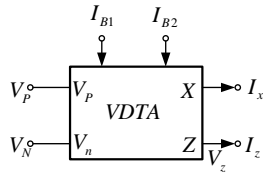


Fig. 1: Circuit symbol of VDTA.

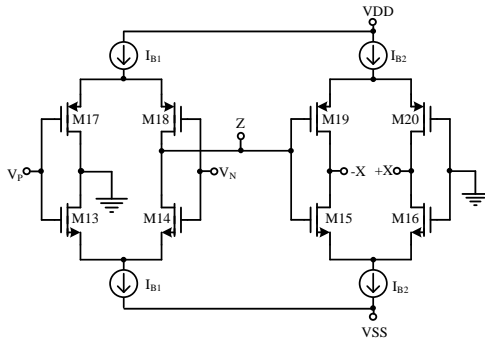


Fig. 2: Internal construction of VDTA.

2.2. Proposed MISO Voltage-Mode Filter

The proposed biquad filter is illustrated in Fig. 3. It consists of one VDTA, one resistor and two capacitors. Considering the circuit in Fig. 3 and using VDTA properties in section 2.1, the output voltage of the proposed filter can be written as

$$V_o = \frac{s^2 C_1 C_2 V_1 + s C_1 G V_2 + g_{m1} g_{m2} V_3}{s^2 C_1 C_2 + s C_1 G + g_{m1} g_{m2}}, \quad (4)$$

where $G=1/R$. The following relations are valid for the pole frequency and the quality factor:

$$\omega_0 = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}}, \quad (5)$$

and

$$Q = R \sqrt{\frac{g_{m1} g_{m2} C_2}{C_1}}. \quad (6)$$

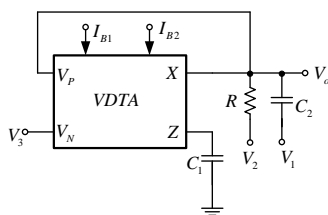


Fig. 3: Proposed filter.

From Eq. 5 and Eq. 6, if the g_{m1} and g_{m2} are equal to Eq. 2 and Eq. 3, the pole frequency and quality factor are re-written as

$$\omega_0 = \sqrt{\frac{k(I_{B1} I_{B2})^{\frac{1}{2}}}{C_1 C_2}}, \quad (7)$$

and

$$Q = R \sqrt{\frac{C_2 k(I_{B1} I_{B2})^{\frac{1}{2}}}{C_1}}. \quad (8)$$

It is apparent from Eq. 8 that the quality factor could be controlled by R without affecting the pole frequency. Also the pole frequency can be electronically tuned by I_{B1} and I_{B2} . It should remark that the parameter k is proportional to mobility and mobility falls with increasing temperature. Then the temperature variation will affect the ω_0 and Q_0 .

Depending on the voltage status of V_1 , V_2 , and V_3 in the numerator of Eq. 4, one of the following five filter functions is obtained.

- If $V_1=V_2=0$ (grounded), and $V_3=V_{in}$ (connected to the input voltage source), a second-order low pass filter can be obtained.
- If $V_2=V_3=0$ (grounded) and $V_1=V_{in}$ (connected to the input voltage source) a second-order high pass filter can be obtained.
- If $V_1=V_3=0$ (grounded) and $V_2=V_{in}$ (connected to the input voltage source), a second-order inverting band pass filter can be obtained.
- If $V_3=0$ and $V_1=V_2=V_{in}$, a second-order notch filter can be obtained.
- If $V_1=V_2=V_3=V_{in}$ a second-order all pass filter can be obtained.

From above conditions, the filter respond selections can be shown in Tab. 2, where number 1 is the magnitude of input voltage and it also represent the digital logic that means the proposed filter can be digitally controlled. It should be remarked that for all pass response, the inverting unit gain amplifier is required. The ω_0 -sensitivity analysis with respect to the parameters of the active and passive element used can be given by:

$$S_{C_1, C_2}^{\omega_0} = -\frac{1}{2}, S_{g_{m1}, g_{m2}}^{\omega_0} = \frac{1}{2}. \quad (9)$$

3. Analysis of Non-Ideal Case

In practice, the influences of voltage and current tracking errors and also the parasitic terminal impedances

$$\begin{bmatrix} I_Z \\ I_{X+} \\ I_{X-} \end{bmatrix} = \begin{bmatrix} \alpha_P g_{m1} & \alpha_N g_{m1} & 0 \\ 0 & 0 & \beta g_{m2} \\ 0 & 0 & -\beta g_{m2} \end{bmatrix} \begin{bmatrix} V_P \\ V_N \\ V_Z \end{bmatrix}. \tag{10}$$

$$V_o = \frac{\alpha_N \beta g_{m2} g_{m1} V_3 + (sC_1^* + G_Z) G V_2 + (sC_1^* + G_Z) s C_1 V_2}{[s^2(C_e^* C_1^* + C_1^* C_2) + s(C_1^* G_e^* + G_Z C_e^* + G C_1^* + C_2 G_Z) + G_Z G_e^* + G G_Z + \alpha_P \beta g_{m1} g_{m2}]}. \tag{11}$$

of VDTA will affect the filter performance. In this Section, these parameters will be taken into account. For non-ideal voltage buffer, the VDTA can be respectively characterized with the Eq. 10, where α_P and α_N are the transconductance error gains from P and N ports to z port. β is the transconductance error gain from z port to x port. The influences of parasitic impedances are resistive and capacitive parts affecting the P, N, Z and X ports of VDTA. Let us denote them $R_P, C_P, R_N, C_N, R_Z, C_Z,$ and $R_X, C_X,$ respectively.

Considering into these effects, the output voltage will be modified to the more general forms in the Eq. 11, where $C_1^* = C_1 + C_Z, C_e^* = C_X + C_P,$ and $G_e^* = G_X + G_P.$ In this case, the pole frequency and quality factor is modified to

$$\omega_0^* = \sqrt{\frac{G_Z G_e^* + G G_Z + \alpha_P \beta g_{m2} g_{m1}}{C_e^* C_1^* + C_1^* C_2}}, \tag{12}$$

and

$$Q_0^* = \frac{C_e^* C_1^* + C_1^* C_2}{C_1^* G_e^* + G_Z C_e^* + G C_1^* + C_2 G_Z} \cdot \sqrt{\frac{G_Z G_e^* + G G_Z + \alpha_P \beta g_{m2} g_{m1}}{C_e^* C_1^* + C_1^* C_2}}. \tag{13}$$

It should be mentioned that the stray/parasitic z-terminal capacitances are absorbed by C_1 as it appears in shunt with them. However, the parasitic resistance R_z and capacitance C_z not only affect the pole frequency and Q but they also add parasitic zeros to all transfer functions (except LP). The parameters α_P, α_N and β of the VDTA affect the gain of low pass filter.

4. Simulation Results

To prove the performances of the proposed filter, the PSPICE simulation program was used for the examination. Internal construction of VDTA used in the simulation is from [4]. The PMOS and NMOS transistors have been simulated by respectively using the parameters of a 0,25 μm TSMC CMOS technology [32]. The aspect ratios of PMOS and NMOS transistor are $W/L = 8 \mu\text{m}/0,25 \mu\text{m}$ and $W/L = 5 \mu\text{m}/0,25 \mu\text{m},$ respectively. The circuit was biased with $\pm 1,25 \text{ V}$ supply voltages, $C_1 = C_2 = 20 \text{ pF}, I_{B1} = I_{B2} = 40 \mu\text{A},$

$R = 4,7 \text{ k}\Omega.$ It yields the natural frequency of 2,376 MHz. The results shown in Fig. 4 are the gain and phase responses of the proposed biquad filter from Fig. 3.

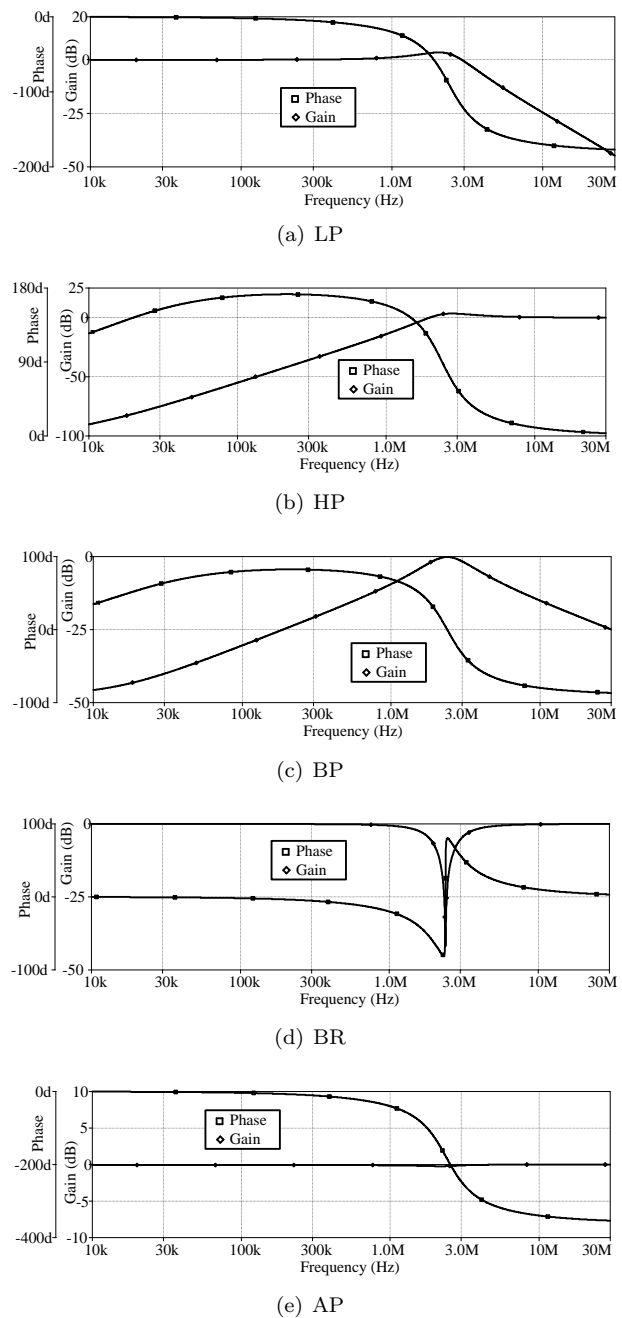


Fig. 4: Gain and phase responses of proposal VM biquad filter.

There are seen that the proposed filter can provide low-pass, high-pass, band-pass, band-reject and all-pass functions dependent on selection as shown in Tab. 2, without modifying circuit topology. Figure 5 shows gain responses of band-pass function where R is set for several values. It is found that quality factor can be adjusted without affecting pole frequency as shown in Eq. 6. The transient response of the proposed filter from band-pass function for the center frequency of 2,376 MHz can be seen in Fig. 6. The total harmonic distortion (THD) is about 0,0786 %.

Tab. 2: The V_1 , V_2 and V_3 values selection for each filter function response.

Filter Responses	Input selections		
	V_1	V_2	V_3
LP	0	0	1
HP	1	0	0
BP	0	1	0
BR	1	0	1
AP	1	-1	1

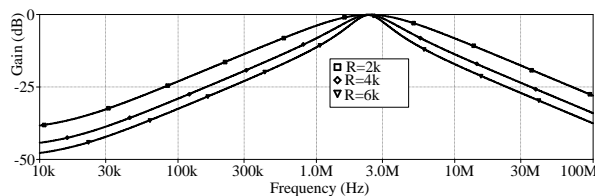


Fig. 5: Voltage-mode band-pass response for different values of R .

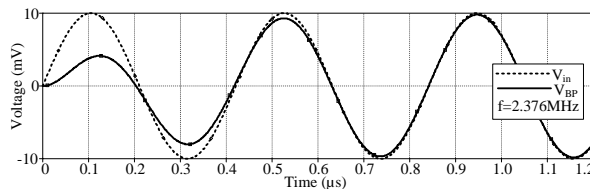


Fig. 6: Time domain response for BP filter.

5. Conclusion

The multiple-inputs single-output biquadratic filter based on single VDTA is presented. The advantages of the proposed circuit are that: it performs low-pass, high-pass, band-pass, band-reject and all-pass functions dependent on an appropriate selection of three input signals: the natural frequency can be electronically controlled via input bias currents, it is easily modified to use in control systems using a microcontroller: the quality factor can be adjusted without affecting natural frequency. The circuit description comprises only one VDTA, one resistor two capacitors. With mentioned features, it is very suitable to realize the

proposed circuit in monolithic chip to use in battery-powered, portable electronic equipment such as wireless communication system devices.

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