

# Universal Current-Mode Biquad Filter Using a VDTA

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## ABSTRACT

This paper presents a new current-mode single input multi output (SIMO) type biquad employing one voltage differencing transconductance amplifier (VDTA), two grounded capacitors and a single grounded resistor. The configuration realizes all basic filter functions (*i.e.* Low Pass (LP), High Pass (HP), Band Pass (BP), Notch (BR) and All Pass (AP)). The natural frequency ( $\omega_0$ ) and bandwidth (BW) are independently tunable. The workability of proposed configuration has been verified using SPICE simulation with TSMC CMOS 0.18  $\mu\text{m}$  process parameters.

**Keywords:** Current Mode Filter; Voltage Differencing Transconductance Amplifier

## 1. Introduction

Active filters are important basic building blocks, which are frequently employed in electrical engineering applications. The current-mode approach [1] in designing active filters has become more popular due to its advantageous features such as larger dynamic range and wider bandwidth as compared to voltage-mode counterparts (particularly for the high frequency operations), simpler filtering configurations and lower power consumption. During the past few years, active filters using different current-mode/voltage-mode building blocks have been employed in which VDTA, recently introduced in [2], appears to be a useful active building block for an easy CMOS implementation of current-mode signal processing/signal generation [3-5].

Various SIMO-type active filters using different active elements are available in the literature see [6-13] and the references cited therein. In references [6-9], SIMO-type filter configurations employing 2/4 resistors and 2/3 capacitors have been presented. These proposed filter structures do not realize all the five filter responses. The configurations presented in [10] and [11] although use one resistor and two capacitors but fail to realize all the basic filter functions. Although the biquads proposed in [12] and [13] realize all the five filter functions but they use two capacitors along with 2/3 resistors. Therefore, the purpose of this communication is to propose a new SIMO-type current-mode universal biquad filter employing one VDTA, two grounded capacitors and a sin-

gle grounded resistor, which realizes all the basic filter functions *i.e.* LP, HP, BP, BR and AP. The natural frequency  $\omega_0$  and BW are independently tunable. The proposed circuit also offers low active and passive sensitivities. The workability of proposed configuration has been verified using SPICE simulation with TSMC CMOS 0.18  $\mu\text{m}$  process parameters.

## 2. The Proposed New Configurations

The symbolic notation of the VDTA is shown in **Figure 1**, where  $V_P$  and  $V_N$  are input terminals and  $Z$ ,  $X^+$  and  $X^-$  are output terminals. All terminals of VDTA exhibit high impedance values [2]. The VDTA can be described by the following set of equations:

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

The proposed circuit configuration is shown in **Figure 2**.

A routine circuit analysis of **Figure 2** yields the following filter transfer functions:

$$T_1(s)|_{LP} = \frac{I_{o1}}{I_{in}} = \frac{g_{m1}g_{m2}}{D(s)} \quad (2)$$

$$T_2(s)|_{BP} = \frac{I_{o2}}{I_{in}} = -\frac{s\left(\frac{g_{m1}}{C_1}\right)}{D(s)} \quad (3)$$

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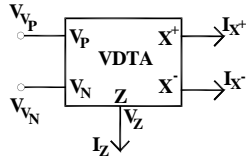


Figure 1. The symbolic notation of VDTA.

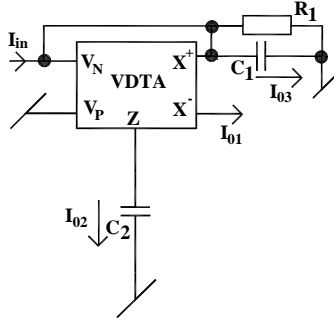


Figure 2. The proposed configuration.

$$T_3(s)|_{HP} = \frac{I_{o3}}{I_{in}} = \frac{s^2}{D(s)} \quad (4)$$

$$T_4(s)|_{NOTCH} = \frac{(I_{o3} + I_{o1})}{I_{in}} = \frac{\left( s^2 + \frac{g_{m1}g_{m2}}{C_1C_2} \right)}{D(s)} \quad (5)$$

$$T_5(s)|_{AP} = \frac{(I_{o3} + I_{o2} + I_{o1})}{I_{in}} = \frac{\left\{ s^2 - s \left( \frac{g_{m1}}{C_1} \right) + \frac{g_{m1}g_{m2}}{C_1C_2} \right\}}{D(s)} \quad (6)$$

where

$$D(s) = s^2 + s \left( \frac{1}{R_1C_1} \right) + \frac{g_{m1}g_{m2}}{C_1C_2} \quad (7)$$

The natural frequency  $\omega_0$ , BW and quality factor  $Q_0$  are given by:

$$\omega_0 = \sqrt{\frac{g_{m1}g_{m2}}{C_1C_2}} \quad (8)$$

$$BW = \frac{1}{R_1C_1} \quad (9)$$

$$Q_0 = \sqrt{\frac{g_{m1}g_{m2}C_1R_1^2}{C_2}} \quad (10)$$

### 3. SPICE Simulation Results

To verify the theoretical analysis, the proposed configuration was simulated using CMOS VDTA from [2]. Power supply voltages were taken as  $V_{DD} = -V_{SS} = 1$  V

and  $I_{B1} = I_{B2} = 150 \mu\text{A}$ ,  $I_{B3} = I_{B4} = 42.38 \mu\text{A}$  biasing currents are used. The passive elements of the configuration were selected as  $C_1 = C_2 = 0.01$  nF and  $R_1 = 1.58$  K $\Omega$ . The transconductances of VDTA were controlled by bias currents. **Figure 3** shows the simulated filter responses of LP, BP, HP, BR and AP. These results, thus, confirm the validity of the proposed configuration. A comparison with other SIMO-type current-mode biquads using a single active device is presented in **Table 1**.

### 4. Conclusion

A new current-mode SIMO-type biquad filter has been presented which uses only one VDTA and three grounded passive elements. The proposed filter can realize the second-order LP, BP, HP, BR and AP responses. The circuit employs all grounded passive components (which is desirable for IC implementation) and offers low active and passive sensitivities. The natural frequency ( $\omega_0$ ) and bandwidth (BW) are independently tunable. SPICE simulations have established the workability of the proposed formulation.

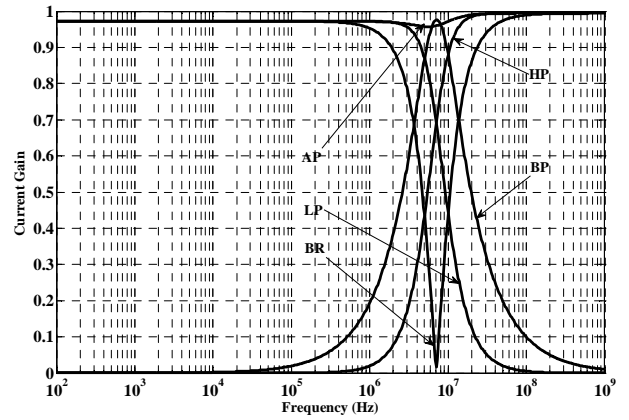


Figure 3. Frequency response.

Table 1. Comparison with other SIMO-type current-mode biquads using a single active device.

Reference	No. of active component	No. of resistors	No. of capacitors	All five filter function realized
[6]	1	4	2	NO
[7]	1	3/4	3	NO
[8]	1	2	2	NO
[9]	1	2	2	NO
[10]	1	1	2	NO
[11]	1	1	2	NO
[12]	1	3	2	YES
[13]	1	2	2	YES
<b>Proposed</b>	<b>1</b>	<b>1</b>	<b>2</b>	<b>YES</b>

#### 4. Acknowledgements

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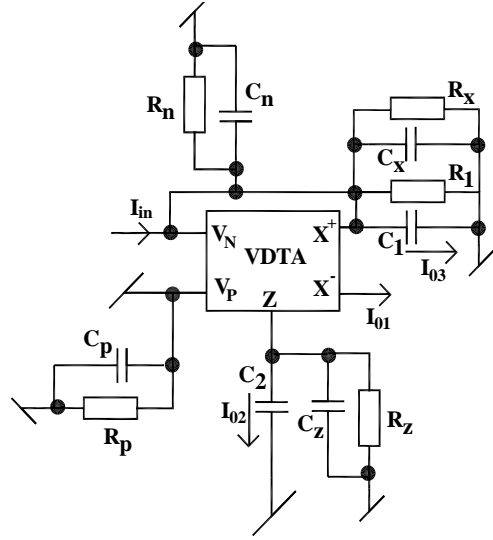
## Appendix: Non-Ideal Analysis

Considering the non-ideal effect of various parameters of VDTA *i.e.*, the finite  $X$ -terminal parasitic impedance consisting of a resistance  $R_x$  in parallel with capacitance  $C_x$ , the parasitic impedance at the  $Z$ -terminal consisting of a resistance  $R_z$  in parallel with capacitance  $C_z$ , the parasitic impedance at the  $V_p$ -terminal consisting of a resistance  $R_p$  in parallel with capacitance  $C_p$  and the parasitic impedance at the  $V_n$ -terminal consisting of a resistance  $R_n$  in parallel with capacitance  $C_n$ . The parasitic impedances belong to the circuit shown in **Figure 2** are indicated in **Figure A1**.

Considering the above parasitic impedances, the natural frequency  $\omega_0$  and quality factor  $Q_0$  are found to be:

$$\omega_0 = \sqrt{\frac{\left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right) \frac{1}{R_z} + g_{m1} g_{m2}}{(C_1 C_2 + C_1 C_z + C_2 C_x + C_z C_x + C_2 C_n + C_n C_z)}} \quad (\text{a})$$

$$Q_0 = \frac{\sqrt{\left\{ \left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right) \frac{1}{R_z} + g_{m1} g_{m2} \right\} * (C_1 C_2 + C_1 C_z + C_2 C_x + C_z C_x + C_2 C_n + C_n C_z)}}{\left( \frac{C_1}{R_z} + \frac{C_x}{R_z} + \frac{C_n}{R_z} + \frac{C_2}{R_1} + \frac{C_z}{R_1} + \frac{C_2}{R_x} + \frac{C_z}{R_x} + \frac{C_2}{R_n} + \frac{C_z}{R_n} \right)} \quad (\text{b})$$



**Figure A1.** Parasitic impedances of VDTA affecting the circuit of **Figure 2**.

The sensitivity of  $\omega_0$  and quality factor  $Q_0$  with respect to its active and passive elements are given as:

$$S_{g_{m1}}^{\omega_0} = S_{g_{m2}}^{\omega_0} = \frac{g_{m1} g_{m2}}{2 \left\{ \left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right) \frac{1}{R_z} + g_{m1} g_{m2} \right\}}, \quad S_{R_1}^{\omega_0} = -\frac{\frac{1}{R_1 R_z}}{2 \left\{ \left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right) \frac{1}{R_z} + g_{m1} g_{m2} \right\}}$$

$$S_{R_x}^{\omega_0} = -\frac{\frac{1}{R_x R_z}}{2 \left\{ \left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right) \frac{1}{R_z} + g_{m1} g_{m2} \right\}}, \quad S_{R_n}^{\omega_0} = -\frac{\frac{1}{R_n R_z}}{2 \left\{ \left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right) \frac{1}{R_z} + g_{m1} g_{m2} \right\}}$$

$$S_{R_z}^{\omega_0} = -\frac{\frac{1}{R_z} \left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right)}{2 \left\{ \left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right) \frac{1}{R_z} + g_{m1} g_{m2} \right\}}, \quad S_{C_1}^{\omega_0} = -\frac{C_1 (C_2 + C_z)}{2 (C_1 C_2 + C_1 C_z + C_2 C_x + C_z C_x + C_2 C_n + C_n C_z)}$$

$$S_{C_2}^{\omega_0} = -\frac{C_2 (C_1 + C_x + C_n)}{2 (C_1 C_2 + C_1 C_z + C_2 C_x + C_z C_x + C_2 C_n + C_n C_z)}, \quad S_{C_z}^{\omega_0} = -\frac{C_z (C_1 + C_x + C_n)}{2 (C_1 C_2 + C_1 C_z + C_2 C_x + C_z C_x + C_2 C_n + C_n C_z)}$$

$$S_{C_x}^{\omega_0} = -\frac{C_x (C_2 + C_z)}{2 (C_1 C_2 + C_1 C_z + C_2 C_x + C_z C_x + C_2 C_n + C_n C_z)}, \quad S_{C_n}^{\omega_0} = -\frac{C_n (C_2 + C_z)}{2 (C_1 C_2 + C_1 C_z + C_2 C_x + C_z C_x + C_2 C_n + C_n C_z)}$$

$$S_{g_{m1}}^{Q_0} = S_{g_{m2}}^{Q_0} = \frac{g_{m1} g_{m2}}{2 \left\{ \left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right) \frac{1}{R_z} + g_{m1} g_{m2} \right\}}, \quad S_{R_1}^{Q_0} = \frac{\frac{1}{R_1} \left[ -\frac{1}{2R_z} (D) + \left\{ \left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right) \frac{1}{R_z} + g_{m1} g_{m2} \right\} (C_2 + C_z) \right]}{(D) \left\{ \left(\frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n}\right) \frac{1}{R_z} + g_{m1} g_{m2} \right\}}$$

$$\begin{aligned}
 S_{R_x}^{Q_0} &= \frac{\frac{1}{R_x} \left[ -\frac{1}{2R_z}(D) + \left\{ \left( \frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n} \right) \frac{1}{R_z} + g_{m_1} g_{m_2} \right\} (C_2 + C_z) \right]}{(D) \left\{ \left( \frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n} \right) \frac{1}{R_z} + g_{m_1} g_{m_2} \right\}}, \\
 S_{R_n}^{Q_0} &= \frac{\frac{1}{R_n} \left[ -\frac{1}{2R_z}(D) + \left\{ \left( \frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n} \right) \frac{1}{R_z} + g_{m_1} g_{m_2} \right\} (C_2 + C_z) \right]}{(D) \left\{ \left( \frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n} \right) \frac{1}{R_z} + g_{m_1} g_{m_2} \right\}}, \\
 S_{R_z}^{Q_0} &= \frac{\frac{1}{R_z} \left[ -\frac{1}{2} \left( \frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n} \right) (D) + \left\{ \left( \frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n} \right) \frac{1}{R_z} + g_{m_1} g_{m_2} \right\} (C_1 + C_x + C_n) \right]}{(D) \left\{ \left( \frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n} \right) \frac{1}{R_z} + g_{m_1} g_{m_2} \right\}}, \\
 S_{C_1}^{Q_0} &= \frac{C_1 \left[ \frac{1}{2} (C_2 + C_z)(D) - (E) \frac{1}{R_z} \right]}{(D)(E)}, \quad S_{C_2}^{Q_0} = \frac{C_2 \left[ \frac{1}{2} (C_1 + C_x + C_n)(D) - (E) \left( \frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n} \right) \right]}{(D)(E)}, \\
 S_{C_z}^{Q_0} &= \frac{C_z \left[ \frac{1}{2} (C_1 + C_x + C_n)(D) - (E) \left( \frac{1}{R_1} + \frac{1}{R_x} + \frac{1}{R_n} \right) \right]}{(D)(E)}, \quad S_{C_x}^{Q_0} = \frac{C_x \left[ \frac{1}{2} (C_2 + C_z)(D) - (E) \frac{1}{R_z} \right]}{(D)(E)}, \\
 S_{C_n}^{Q_0} &= \frac{C_n \left[ \frac{1}{2} (C_2 + C_z + C_p)(D) - (E) \frac{1}{R_z} \right]}{(D)(E)},
 \end{aligned} \tag{c}$$

where

$$(D) = \left( \frac{C_1}{R_z} + \frac{C_x}{R_z} + \frac{C_n}{R_z} + \frac{C_2}{R_1} + \frac{C_z}{R_1} + \frac{C_2}{R_x} + \frac{C_z}{R_x} + \frac{C_2}{R_n} + \frac{C_z}{R_n} \right), \quad (E) = (C_1 C_2 + C_1 C_z + C_2 C_x + C_z C_x + C_2 C_n + C_n C_z). \tag{d}$$

From the above mentioned sensitivity values, it is easy to figure out that all the active and passive sensitivities are no more than half in magnitude.