A new voltage mode multi input single output (MISO) type biquad is proposed. The proposed configuration employs one voltage differencing transconductance amplifier (VDTA) as the active element, two capacitors and a grounded resistor. The configuration realizes all five filter functions [i.e. Low Pass (LP), High Pass (HP), Band Pass (BP), Notch (BR) and All Pass (AP)] without any matching condition. 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$\mu$m process parameters.

**Keywords:** Voltage mode filter, Voltage differencing transconductance amplifier, Analog signal processing, MISO-type

**1 Introduction**

Multifunction active filters are versatile because the same circuit topology can be utilized for different filter responses. Recently, a new active building block named VDTA is introduced$^1$ and various types of applications are reported$^2-5$. MISO-type active filters using different active elements such as current conveyor, current differencing buffered amplifier, differential-input buffered and transconductance amplifier, differential voltage current conveyor, current feedback operational amplifier and current differencing transconductance amplifier etc. are available in the literature$^6-15$. Therefore, a voltage-mode universal biquad is proposed having three inputs and one output employing one VDTA, two capacitor and a grounded resistor. The proposed configuration realizes all the basic filter functions from the same circuit topology. The LP response enjoys an additional advantage of having both the capacitors grounded. The natural frequency $\omega_0$ and BW are independently tunable. The workability of proposed configuration has been verified using SPICE simulation with TSMC CMOS 0.18$\mu$m process parameters.

**2 Proposed Configuration**

The symbolic notation of the VDTA is shown in Fig. 1, where $V_i$ and $V_o$ 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:

$$
\begin{bmatrix}
I_Z \\
I_{X^+} \\
I_{X^-}
\end{bmatrix} =
\begin{bmatrix}
g_{m_1} & -g_{m_2} & 0 \\
0 & 0 & g_{m_2} \\
0 & 0 & -g_{m_2}
\end{bmatrix}
\begin{bmatrix}
V_i \\
V_{in} \\
V_{in}
\end{bmatrix}
\quad \text{... (1)}
$$

A routine circuit analysis of Fig. 2 yields the following filter responses:

1. LPF; if $V_{in1} = V_{in}$ and $V_{in2} = V_{in3} = 0$
2. BPF; if $V_{in2} = V_{in}$ and $V_{in1} = V_{in3} = 0$
3. HPF; if $V_{in3} = V_{in}$ and $V_{in1} = V_{in2} = 0$
4. BRF; if $V_{in1} = V_{in3} = V_{in}$ and $V_{in2} = 0$
5. APF; if $V_{in1} = V_{in2} = V_{in3} = V_{in}$

**3 Filter Responses**

$$
T_1(s) = \frac{V_o(s)}{V_i(s)} = \frac{g_{m_2}g_{m_1}}{C_1C_2 D(s)} \quad \text{... (2)}
$$

$$
T_2(s) = \frac{V_o(s)}{V_{in}(s)} = -\frac{g_{m_2}}{C_2 D(s)} \quad \text{... (3)}
$$

$$
T_3(s) = \frac{V_o(s)}{V_{in}(s)} = \frac{S^2}{D(s)} \quad \text{... (4)}
$$
3 Non-ideal Analysis

Consider the effect of various VDTA non-ideal parameters the finite X-terminal parasitic impedance consisting of a resistance \( R_X \) in parallel with capacitance \( C_X \) and the parasitic impedance at the Z-terminal consisting of a resistance \( R_Z \) in parallel with capacitance \( C_Z \) then the natural frequency \( \omega_0 \) and quality factor \( Q_0 \) are given by:

\[
\omega_0 = \sqrt{\frac{g_m g_{m2}}{C_X C_Z} + \left( \frac{1}{R_X} + \frac{1}{R_Z} \right) \frac{1}{R}} \quad \ldots (11)
\]

\[
Q_0 = \sqrt{\left( C_X + C_Z \right) \left( C + C_Z \right) \left[ \frac{g_m g_{m2}}{C_X C_Z} + \left( \frac{1}{R_X} + \frac{1}{R_Z} \right) \frac{1}{R} \right]}
\]

\[
\left[ \left( C_X + C_Z \right) \left( \frac{1}{R_X} + \frac{1}{R_Z} \right) + \left( C + C_Z \right) \right]
\]

\[
\quad \ldots (12)
\]

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

\[
S_{\omega_0}^{R_X} = \frac{1}{2R_X R_Z} \left[ \frac{g_m g_{m2}}{C_X C_Z} + \left( \frac{1}{R_X} + \frac{1}{R_Z} \right) \frac{1}{R} \right]
\]

\[
S_{\omega_0}^{R_X} = \frac{1}{2R_X R_Z} \left[ \frac{g_m g_{m2}}{C_X C_Z} + \left( \frac{1}{R_X} + \frac{1}{R_Z} \right) \frac{1}{R} \right]
\]

\[
S_{\omega_0}^{R_Z} = \frac{1}{2R_X R_Z} \left[ \frac{g_m g_{m2}}{C_X C_Z} + \left( \frac{1}{R_X} + \frac{1}{R_Z} \right) \frac{1}{R} \right]
\]

\[
S_{\omega_0}^{g_{m2}} = \frac{1}{2} \left[ \frac{g_m g_{m2}}{C_X C_Z} + \left( \frac{1}{R_X} + \frac{1}{R_Z} \right) \frac{1}{R} \right]
\]

\[
S_{\omega_0}^{g_{m2}} = \frac{1}{2} \left[ \frac{g_m g_{m2}}{C_X C_Z} + \left( \frac{1}{R_X} + \frac{1}{R_Z} \right) \frac{1}{R} \right]
\]

\[
S_{\omega_0}^{g_m} = \frac{1}{2} \left[ \frac{g_m g_{m2}}{C_X C_Z} + \left( \frac{1}{R_X} + \frac{1}{R_Z} \right) \frac{1}{R} \right]
\]

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

\[
\omega_0 = \sqrt{\frac{g_m g_{m2}}{C_X C_Z}} \quad \ldots (8)
\]

\[
BW = \frac{1}{R_X C_Z} \quad \ldots (9)
\]

\[
Q_0 = \sqrt{\frac{g_m g_{m2} C_R^2}{C_X}} \quad \ldots (10)
\]
\[ S_{C_x}^{\text{th}} = -\frac{C_x}{2(C_1 + C_z)} \]

\[ S_{C_z}^{\text{th}} = -\frac{C_z}{2(C_1 + C_z)} \]

\[ S_{C_1}^{\text{th}} = \frac{C_1}{\sqrt{(C_1 + C_z)}} \]

\[ \left\{ \left( C_1 + C_z \right) \left( \frac{1}{R_1} + \frac{1}{R_z} \right) + \frac{C_z + C_1}{R_z} \right\} \]

\[ \times \frac{1}{2\sqrt{(C_1 + C_z)}} \left( \frac{1}{R_1} + \frac{1}{R_z} \right) \]

\[ \left( C_1 + C_z \right) \left( \frac{1}{R_1} + \frac{1}{R_z} \right) + \frac{C_z + C_1}{R_z} \]

\[ S_{C_2}^{\text{th}} = \frac{C_2}{\sqrt{(C_2 + C_z)}} \]

\[ \left\{ \left( C_1 + C_z \right) \left( \frac{1}{R_1} + \frac{1}{R_z} \right) + \frac{C_z + C_1}{R_z} \right\} \]

\[ \times \frac{1}{2\sqrt{(C_2 + C_z)}} \left( \frac{1}{R_1} + \frac{1}{R_z} \right) \]

\[ \left( C_1 + C_z \right) \left( \frac{1}{R_1} + \frac{1}{R_z} \right) + \frac{C_z + C_1}{R_z} \]

\[ S_{R_1}^{\text{th}} = \frac{C_1}{\sqrt{(C_1 + C_z)}} \]

\[ \left\{ \left( C_1 + C_z \right) \left( \frac{1}{R_1} + \frac{1}{R_z} \right) + \frac{C_z + C_1}{R_z} \right\} \]

\[ \times \frac{1}{2\sqrt{(C_1 + C_z)}} \left( \frac{1}{R_1} + \frac{1}{R_z} \right) \]

\[ \left( C_1 + C_z \right) \left( \frac{1}{R_1} + \frac{1}{R_z} \right) + \frac{C_z + C_1}{R_z} \]

\[ S_{R_2}^{\text{th}} = \frac{C_2}{\sqrt{(C_2 + C_z)}} \]

\[ \left\{ \left( C_1 + C_z \right) \left( \frac{1}{R_1} + \frac{1}{R_z} \right) + \frac{C_z + C_1}{R_z} \right\} \]

\[ \times \frac{1}{2\sqrt{(C_2 + C_z)}} \left( \frac{1}{R_1} + \frac{1}{R_z} \right) \]

\[ \left( C_1 + C_z \right) \left( \frac{1}{R_1} + \frac{1}{R_z} \right) + \frac{C_z + C_1}{R_z} \]

\[ S_{R_3}^{\text{th}} = \frac{C_3}{\sqrt{(C_3 + C_z)}} \]

\[ \left\{ \left( C_1 + C_z \right) \left( \frac{1}{R_1} + \frac{1}{R_z} \right) + \frac{C_z + C_1}{R_z} \right\} \]

\[ \times \frac{1}{2\sqrt{(C_3 + C_z)}} \left( \frac{1}{R_1} + \frac{1}{R_z} \right) \]

\[ \left( C_1 + C_z \right) \left( \frac{1}{R_1} + \frac{1}{R_z} \right) + \frac{C_z + C_1}{R_z} \]
A new voltage-mode biquad filter has been proposed which employs only one VDTA and three passive elements. The proposed filter can realize the second-order LP, BP, HP, BR and AP responses without changing the circuit topology and without any matching condition. The LP response enjoys an additional advantage of having both the capacitors grounded. The circuit offers low active and passive sensitivities. SPICE simulations have established the workability of the proposed formulation.

\[
S_{bp}^{th} = \frac{g_{m1} g_{m2}}{2 \left( g_{m1} g_{m2} + \frac{1}{R_1} + \frac{1}{R_2} \right) R_f} \quad \ldots(13)
\]

4 SPICE Simulation Results
To confirm theoretical analysis, the proposed configuration was simulated using CMOS VDTA. The passive elements of the configuration were selected as \( C_1 = C_2 = 0.01 \text{nF} \) and \( R_1 = 1.57 \text{k}\Omega \). The transconductances of VDTA were controlled by bias currents, \( I_{b1} = I_{b2} = 42.3 \mu\text{A} \) and \( I_{b3} = I_{b4} = 150 \mu\text{A} \). Thus, the transconductances were found to be \( g_{m1} = 315.58 \mu\text{A/V} \) and \( g_{m2} = 631.702 \mu\text{A/V} \). Fig. 3 shows the simulated filter responses of LP, BP, HP, BR and AP. These results, thus, confirm the validity of the proposed configuration. Table 1 presents the comparison with other MISO-type voltage-mode biquads using only a single active element.

5 Conclusions
A new voltage-mode biquad filter has been proposed which employs only one VDTA and three passive elements. The proposed filter can realize the second-order LP, BP, HP, BR and AP responses without changing the circuit topology and without any matching condition. The LP response enjoys an additional advantage of having both the capacitors grounded. The circuit offers low active and passive sensitivities. SPICE simulations have established the workability of the proposed formulation.

References


