High input impedance trans-admittance mode biquad universal filter employing DVCCTAs and grounded passive elements

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In this paper a new high input impedance trans-admittance-mode biquad filter has been proposed and investigated which has been designed using two differential voltage current conveyor trans-conductance amplifiers (DVCCTAs) and all grounded passive elements in the form of two capacitors and three resistors only. The proposed TAM filter has the ability to realize all five standard filtering functions, simultaneously. Apart from these characteristics, the proposed filter also enjoys the desirable features such as low active and passive sensitivities, low power consumption, high impedance for both input voltage and output current signal and orthogonal electronic tunability of pole frequency and quality factor. The overall performance of the presented filter has been investigated using mathematical analysis, pre-layout and post-layout simulation results obtained by PSPICE in 0.18 µm CMOS process technology.

Keywords: DVCCTA, TAM, Electronic tunability, Biquad, Filter, SIMO

1 Introduction

Over the past few decades, the current-mode approach of signal processing in the design of analogue filters has received ever increasing popularity and remarkable attention over voltage-mode approach1. Therefore, each day more and more current-mode (CM) active blocks and their applications in filter design have been proposed and examined by the number of researchers. Current conveyors and their different modified variants such as CCI, CCII, DDCCII, DVCCII, FTFN, CDBA etc., were initially proposed and studied in the literature1-12. However, the circuits based on these active elements cannot offer the electronic adjustment properties which may require in number of adjustable applications such as music synthesis, automatic control and speech synthesis to compensate for deviation due to process tolerance, parasitic, temperature, aging, etc12. So later on, few more active building blocks having the attractive feature of the electronic adjustment properties such as OTA, CCCI, CFTA, CCTA, CDTA, VDTA, CCCCTA, DDCCTA and DVCCCTA etc. were further proposed in the literature13-40. Besides it, as applications, numerous biquad filters operated in different modes also exist in the literature3-11,13,30,32,33,38-41. Among them the filter operated with voltage input and current output signal called as trans-admittance-mode (TAM) filter is worthy of research and special interest as they can be used as an interface circuit connecting voltage mode circuit to current mode circuit whose applications are found in many electronic circuits such as receiver base band block of modern radio system, D/A converter and optical receiver8. The TAM filters reported in past have been further classified as single input multi output (called SIMO) and multi input single output (called MISO) on the basis of whether they are using single input signal or multiple copies of input. The detail comparative discussions8-10,14-27 of both categories of TAM type have been summarized in Table 1. The MISO TAM filters can’t realize multi-filtering functions, simultaneously and requires multiple copies of the input signals and hence, require additional buffers (hardware) to obtain the multiple copies of the input signals. Although, they can generally provide all five filtering functions but only one at a time by appropriate selection of the input signal(s)15-17,19,27. Apart from this, they usually requires more than one matching condition(s)15-17,27, and injection of input signal from one terminal of passive element which results in using floating passive elements15-17,19,27. On the other hand, the
SIMO type TAM filter with using of single input only, can realize multiple filtering functions simultaneously which increases their adaptability in the wide variety of practical applications. A number of SIMO types TAM filters based on different active elements such as CCII, DVCC, FTFN, CCCII, OTAs, VDTA, CCCCTA can be noticed in Table 1. However, these circuits still suffer one or more following drawbacks:

(i) Consisting of more number of active and/or passive elements.
(ii) Employing floating passive components and hence, not suitable for fabrication point of view.
(iii) Unavailability of voltage input signal at high input impedance terminal.
(iv) Incompetent of realizing all five standard filtering functions.
(v) Suffering from lack of electronic tunability of filter parameters.
(vi) Consisting of more than minimum number of capacitors (two) required for realizing various filtering functions.
(vii) Not providing explicitly current outputs at high impedance output terminals.
(viii) Requiring matching conditions to realize at least two filtering functions, generally, BR and AP responses.
(ix) None of the circuit has provided chip layout and chip area.

(x) Incompatible of obtaining high quality factor ($Q_0$) value through electronic means.

In this paper, a new TAM filter circuit based on DVCCTA is proposed which is competent of simultaneously realizing all five filtering functions and does not require any scaled/inversion voltage input for realizing the filtering functions. In addition, the proposed filter employs five grounded passive elements in the form of two capacitors and three resistors which is easier to fabricate in fully integrated circuits. Besides, the proposed circuit also offers few more advantages features such as; low active and passive sensitivities, low power consumption, orthogonal electronic tunability of pole frequency and quality factor and high impedance for the input voltage signal. The validity of proposed filter is also verified by simulating it through PSPICE.

2 DVCCTA Description

The DVCCTA, a recently introduced CM active element, contains well known active element DVCC at input stage followed by OTA at output stage. After its inception, the element has been used in designing of various analog signal processing blocks such as biquad filters, oscillators, floating inductors, versatile modulator, etc. The symbolic diagram of DVCCTA is shown in Fig. 1 which has two high input impedance ports $Y_1$, $Y_2$ and one low input impedance port $X$. Beside it, $Z$ is auxiliary output port whose voltage is transferred to current at
trans-conductance type high impedance output ports (O-). The voltage and current relationship between various ports of DVCCTA can be characterized by following matrix equation:

\[
\begin{bmatrix}
I_{Y_1} \\
I_{Y_2} \\
V_X \\
I_Z \\
I_{O-}
\end{bmatrix} =
\begin{bmatrix}
0 & 0 & 0 & 0 \\
0 & 0 & 0 & 0 \\
0 & 1 & -1 & 0 \\
1 & 0 & 0 & 0 \\
0 & 0 & 0 & -g_m
\end{bmatrix}
\begin{bmatrix}
I_X \\
V_{Y_1} \\
V_{Y_2} \\
V_Z
\end{bmatrix}
\]

\[ \text{... (1)} \]

Where, \( g_m \) is the trans-conductance parameter of DVCCTA. A CMOS model of DVCCTA consisting of only twenty four transistors is also shown in Fig. 2. For the CMOS circuit of DVCCTA of Fig. 2, the dependency of \( g_m \) on biasing current of DVCCTA (\( I_B \)) can be expressed as:

\[
g_m = \sqrt{\mu C_{ox} \left( \frac{W}{L} \right)_{M14,M15}} I_B \]

\[ \text{... (2)} \]

Here \( \mu \) is the effective carrier mobility, \( C_{ox} \) is the gate oxide capacitance per unit area, and \( W \) and \( L \) are the effective channel width and length of the \( M_{14} \) and \( M_{15} \) MOS transistor.

3 Proposed TAM Filter and Analysis

The proposed TAM filter topology is shown in Fig. 3 which employs two DVCCTAs, three grounded resistors (\( R_1, R_2 \), and \( R_3 \)) which may be realized by using two NMOS transistors\(^{17} \), and two grounded capacitors (\( C_1 \) and \( C_2 \)). Routine analysis of the circuit in Fig. 3 yields three transfer functions of LP, BP and BR in trans-admittance mode across explicitly available current outputs \( I_{LP}, I_{BP}, \) and \( I_{BR} \), respectively which can be expressed mathematically as:

\[
TAM_{LP}(s) = \frac{I_{LP}}{V_{in}} = \frac{g_{m2}}{C_{1}C_{2}R_{1}R_{2}} \cdot \frac{1}{D(s)}, \quad \text{... (3)}
\]

\[
TAM_{BP}(s) = \frac{I_{BP}}{V_{in}} = \frac{s}{C_{1}R_{2}} \cdot \frac{g_{m1}}{D(s)}, \quad \text{... (4)}
\]

\[
TAM_{BR}(s) = \frac{I_{BR}}{V_{in}} = \frac{1}{R_{1}} \left( \frac{s^2 + \frac{g_{m2}}{C_{1}C_{2}R_{1}}}{D(s)} \right), \quad \text{... (5)}
\]

In addition of LP, BP and BR, the HP response can also be obtained by adding currents \( I_{LP} \) and \( I_{BR} \) together. So the trans-admittance mode HP response can be expressed as:
Similarly, AP response can also be realized simply by adding currents $I_{BP}$ and $I_{BR}$. So trans-admittance mode AP response can be expressed as:

$$TAM_{AP}(s) = \frac{I_{AP}}{V_{in}} = \frac{I_{BP} + I_{BR}}{V_{in}} = -\frac{s^2 \left( \frac{1}{R_2} \right)}{D(s)} \quad \cdots (6)$$

Similarly, AP response can also be realized simply by adding currents $I_{BP}$ and $I_{BR}$. So trans-admittance mode AP response can be expressed as:

$$TAM_{AP}(s) = \frac{I_{AP}}{V_{in}} = \frac{I_{BP} + I_{BR}}{V_{in}} = -\frac{1}{R_2} \left( s^2 - s \frac{g_{m1}}{C_1} + \frac{g_{m2}}{C_1 C_2 R_2} \right) D(s) \quad \cdots (7)$$

where, $D(s) = \left[ s^2 + s \frac{g_{m1} R_1}{C_1 R_2} + \frac{g_{m2}}{C_1 C_2 R_3} \right] \quad \cdots (8)$

It can be noted that from Eqs (3)-(7) that the proposed topology is capable of realizing trans-admittance-mode LP, BP, HP, BR and AP filtering responses. However, AP filtering response requires a matching condition $R_1 = R_2$ which can be easily satisfied. Further, the characteristic parameters of proposed filter like pole frequency ($\omega_0$), quality factor ($Q_0$), and bandwidth (BW) can be derived as:

$$\omega_0 = \sqrt{\frac{g_{m2}}{C_1 C_2 R_3}} \quad \cdots (9)$$

$$Q_0 = \frac{R_2}{g_{m1} R_1} \sqrt{\frac{g_{m2} C_1}{C_2 R_3}} \quad \cdots (10)$$

$$BW = \frac{g_{m1} R_1}{C_1 R_2} \quad \cdots (11)$$

4 Non Ideal Effects and Sensitivities Analysis

After considering the effects of non-ideal characteristics of the DVCCTA, the current and voltage relationship between various ports of DVCCTA can be rewritten as:

$$[I_Y] = \begin{bmatrix} 0 & 0 & 0 & 0 \\ I_{y2} & I_{y3} & \gamma & -\gamma \\ I_x & \alpha & 0 & 0 \\ 0 & 0 & 0 & -\beta g_m \end{bmatrix} \begin{bmatrix} I_x \\ V_{y1} \\ V_{y2} \\ V_z \end{bmatrix} \quad \cdots (12)$$

where $\alpha$, $\beta$, and $\gamma$ are the tracking errors and their values are nearly equal to one. Considering the above non ideal errors discussed in Eq. (12), we have further reanalyzed the proposed circuit of Fig. 3. On analyzing, the non-ideal filter transfer functions and its filter parameters can be derived as follow:

$$TAM_{LP}(s) = \frac{I_{LP}}{V_{in}} = \frac{\left( \frac{\alpha \alpha \gamma \gamma \beta \beta g_m}{C_1 C_2 R_2 R_3} \right)}{D(s)} \quad \cdots (13)$$
\[ \text{TAM}_{BP}(s) = \frac{I_{BP}}{V_{in}} = \frac{s \alpha \beta \gamma_1 g_{m1}}{C_1 R_2 D(s)} \quad \ldots (14) \]

\[ \text{TAM}_{BR}(s) = \frac{I_{BR}}{V_{in}} = \frac{\beta \gamma_1 (s^2 + \gamma_2 g_{m2})}{C_1 C_2 R_3 D(s)} \quad \ldots (15) \]

\[ \text{TAM}_{HP}(s) = \frac{I_{HP}}{V_{in}} = \frac{s^2 \gamma_1 R_2}{D(s)} \quad \ldots (16) \]

where,

\[ D(s) = s^2 + s \frac{\alpha \beta \gamma_1 g_{m1} R_1 + \alpha \beta \gamma_2 g_{m2}}{C_1 R_2} \quad \ldots (17) \]

\[ \omega'_0 = \sqrt{\frac{\alpha \beta \gamma_2 g_{m2}}{C_1 C_2 R_3}} \quad \ldots (18) \]

\[ \text{TAM}_{AP}(s) = \frac{I_{AP}}{V_{in}} = \frac{\alpha \gamma_1 (s^2 - s \frac{\alpha \beta \gamma_1 g_{m1}}{C_1} + \frac{\beta g_{m2}}{C_1 C_2 R_3})}{D(s)} \quad \ldots (19) \]

\[ Q'_0 = \frac{R_1}{C_1 \beta \gamma_1 g_{m1} R_1} \sqrt{\frac{\alpha \beta \gamma_2 g_{m2} C_1}{C_2 R_3}} \quad \ldots (20) \]

\[ \text{BW}' = \frac{\alpha \beta \gamma_1 g_{m1} R_1}{C_1 R_2} \quad \ldots (21) \]

It is evident from Eqs (13) - (21) that the filter parameters such as pass band gain of various filtering responses, \( \omega_0 \), \( Q_0 \), and BW of the proposed TAM filter may be slightly changed due to effect of tracking errors of DVCCTA but these deviation can be minimized by adjusting the electronic controllable trans-conductance parameters.

The active and passive sensitivities of \( \omega_0 \) and \( Q_0 \) for the proposed filter in Fig. 3 can also be derived as follow:

\[ S_{\omega_0} = \frac{1}{2}, S_{Q_0} = -\frac{1}{2} \quad \ldots (22) \]

\[ S_{\omega_0} = -\frac{1}{2}, S_{Q_0} = -\frac{1}{2}, S_{g_{m1}}, S_{\alpha_1}, S_{\beta_2}, S_{\gamma_1} = -1, S_{R_1} = 1 \quad \ldots (23) \]

From above Eqs (22) and (23), it can be noted that all the active and passive sensitivities of \( \omega_0 \) and \( Q_0 \) are low and equal or less than ‘unity’ in magnitude.

5 Non Ideal Parasitic Analysis

In this section, the effect of DVCCTA parasitics on the performance of presented TAM filter is considered. In the presence of various ports parasitic in the form of parasitic capacitors and resistors, the circuit of Fig. 3 has been changed to Fig. 4. In Fig. 4 the external resistances \( R_1, R_2, R_3 \) and parasitic resistances \( R_{Pi} \) are represented in terms of admittances as \( G_1, G_2, G_3 \) and \( G_{Pi} \) respectively, where \( G_i = 1/R_i, G_{Pi} = 1/R_{Pi} \). The parasitics can be seen as a parallel combination of resistors and capacitors at combined ports (\( Z_1, Y_1, O_1 \)) as \( C_{P1} || G_{P1} \), at port \( Z' \) as \( C_{P2} || G_{P2} \), at combined ports (\( Y_1, O_1 \)) as \( C_{P3} || G_{P3} \), and as a series parasitic impedance at port \( X \) as \( G_{P4} \), at port \( X' \) as \( G_{P5} \). The Practical value of parasitic capacitances \( C_{P} \) are found in the range of fraction of picofarads and parasitic admittances are in the range of tens of micromho. Therefore, \( \min (C_1, C_2) >> (C_{P1}, C_{P2}, C_{P3}) \) and \( \min (G_1, G_2) >> (G_{P1}, G_{P2}, G_{P3}, G_{P4}, G_{P5}) \). After reanalysing the circuit of Fig. 4, to see the effects of various parasitic impedances on the performance of
the proposed TAM filter circuit, the following transfer functions for the TAM filtering functions can be obtained as:

\[ TAM_{LP}(s) = \frac{I_{LP}}{V_{in}} = \frac{g_{m2}G_2G_1}{C_1C_2} \left(1 + \frac{sC_1}{G_1} \right) V_{in} s \quad \cdots (24) \]

\[ TAM_{BP}(s) = \frac{I_{BP}}{V_{in}} = \frac{g_{m1}G_2}{C_1} \left(1 + \frac{sC_1}{G_1} \right) G_1 \left(1 + \frac{sG_2}{sC_2} \right) \quad \cdots (25) \]

\[ TAM_{HP}(s) = \frac{I_{HP}}{V_{in}} = -\frac{G_2 \left[1 + \frac{sC_1}{G_1} \right] \left[1 + \frac{G_2}{sC_2} \right] - s g_{m1} \left[1 - \frac{C_2}{sG_2} \right] \left[1 + \frac{G_2}{sC_2} \right]}{1 + \frac{G_2}{sC_2} D(s)} \quad \cdots (26) \]

\[ TAM_{bH}(s) = \frac{I_{bH}}{V_{in}} = -\frac{G_2 \left[1 + \frac{sC_1}{G_1} \right] \left[1 + \frac{G_2}{sC_2} \right] - s g_{m1} \left[1 - \frac{C_2}{sG_2} \right] \left[1 + \frac{G_2}{sC_2} \right]}{1 + \frac{G_2}{sC_2} D(s)} \quad \cdots (27) \]

where,

\[ D(s) = \left[1 + s G_2 \left(1 + \frac{sG_2}{sC_2} \right) + s \frac{g_{m1}G_2}{C_1G_1} + \frac{g_{m2}G_2}{C_1C_2} \right] \quad \cdots (29) \]

As a result, expressions of pole frequency and quality factor have been changed to:

\[ \omega_0 = \omega_0 \sqrt{\frac{1}{1 + s \left( \frac{C_3}{G_1} \right)}} \quad \cdots (30) \]

\[ Q_0 = Q_0 \sqrt{1 + s \left( \frac{C_3}{G_1} \right)} \quad \cdots (31) \]

where \( \omega_0 \) and \( Q_0 \) are the pole frequency and quality factor of the TAM filter in ideal case. It can be clearly seen from Eqs (24) – (31) that additional first order poles and zero are yielded in the expression of transfer functions and filter parameters due to various port parasitic of DVCCTA which may deviate undesirably the pass band gain, pole frequency and quality factor of the proposed filter. However, these undesirable factors can be eliminated or minimized and hence, the proposed filter may approach towards ideal response, if we choose the operating frequency \( (\omega_0) \) in the design criterion as follows:

\[ \max \left\{ \frac{G_1}{C_1}, \frac{G_2}{C_2}, \frac{G_3}{C_3} \right\} < \omega_0 < \min \left\{ \frac{G_1}{C_3} \right\} \quad \cdots (32) \]

6 Effects of Frequency Dependent Parameter \((g_m)\) on Performance of Proposed Filter and Stability Analysis

DVCCTA is a bandwidth limited device due to frequency dependent parameter \( g_{m} \), so the stability of proposed filter may be affected due to the bandwidth limitation of \( g_{m} \). Suppose \( g_{m} \) depends only on single pole frequency \( \omega_p \) which can be expressed as:

\[ g_{m} = \frac{g_{m}}{1 + \frac{s}{\omega_p}} = \frac{g_{m}}{1 + s \omega_p} \approx g_{m} (1 - s \tau) \quad \cdots (33) \]

On using Eq. (33) and further re-analysing the proposed filter, the following transfer functions of various TAM responses and their filter parameters can be obtained as:

\[ TAM_{LP}(s) = \frac{I_{LP}}{V_{in}} = \frac{g_{m} \left(1 - s \tau \right)}{C_1C_3R_3} \quad \cdots (34) \]

\[ TAM_{BP}(s) = \frac{I_{BP}}{V_{in}} = \frac{g_{m} \left(1 - s \tau \right)}{C_1C_3} \quad \cdots (35) \]

\[ TAM_{bH}(s) = \frac{I_{bH}}{V_{in}} = \frac{g_{m} \left(1 - s \tau \right)}{C_1C_3R_3} \quad \cdots (36) \]

\[ TAM_{HP}(s) = \frac{I_{HP}}{V_{in}} = \frac{g_{m} \left(1 - s \tau \right)}{C_1C_3} \quad \cdots (37) \]
where

$$D^+(s) = \left[ s^2 \left( 1 - \frac{g_{m01} \tau_1 R_1}{C_1 R_2} \right) + s \left( \frac{g_{m02} R_2}{C_1 R_2} - \frac{g_{m02} \tau_2}{C_1 C_2 R_3} \right) + \frac{g_{m02}}{C_1 C_2 R_3} \right]$$

\cdots (39)

\begin{align*}
\omega_b' &= \sqrt{\frac{g_{m02}}{C_1 C_2 R_3} \left( 1 - \frac{g_{m01} \tau_1 R_1}{C_1 R_2} \right)} \\
Q_0^- &= \sqrt{\frac{g_{m02} R_2}{C_1 C_2 R_3} \left( 1 - \frac{g_{m02} \tau_2}{C_1 C_2 R_3} \right)}
\end{align*}
\cdots (40)

\cdots (41)

where $g_{m01}$ and $g_{m02}$ are the trans-conductance parameter of DVCCTA1 and DVCCTA2, respectively, at zero frequency. From Eq. (39), it can be observed that stability problem of proposed filter is found due to bandwidth limitation of $g_m$ of DVCCTA as pole(s) of the characteristic Eq. (39) may lie on right hand side of s-plane. However, the proposed filter can be made stable by satisfying the following conditions which can be achieved easily as:

$$\tau_1 \ll \frac{C_1 R_2}{g_{m01} R_1} \quad \text{and} \quad \tau_2 \ll \frac{g_{m01} C_2 R_1 R_3}{g_{m02} R_2}$$
\cdots (42)

### 7 Simulation Results

#### 7.1 Pre-layout simulation

In order to check the performance, the presented filter was designed using CMOS implementation of DVCCTA with calculated aspect ratio of transistor as described in Table 2 and pre-layout simulation simulations were carried out using PSPICE in ORCAD 16.5 with model of 0.18 µm CMOS process parameters. The proposed circuit was biased with power supply voltages of $V_{DD} = -V_{SS} = 1.4$ V, $V_B = -0.5$ V and designed to obtain the pole frequency of 13.0 MHz. For this designing, the active and passive components values were determined as $I_B = 137$ µA ($g_m \approx 1205$ µA/V), $R_1 = R_2 = 1.5$ kΩ, $R_3 = 0.8$ kΩ, $C_1 = C_2 = 15$ µF. The corresponding simulated as well as ideal gain responses of LP, BP, BR, and HP trans-admittance are shown in Fig. 5. It is clear from Fig. 5 that simulated results are in good agreements with the ideal results. Moreover, the simulated pole frequency was obtained 12.70 MHz which is closed to the theoretical value of 13.0 MHz. Figure 6 shows the gain and phase response of AP for the proposed TAM filter. The total power consumption of the filter was obtained as 9.21 mW.

To show the electronic tuning feature of the proposed filter, the circuit is further simulated to obtain various BP responses at different sets of $I_{B1} = I_{B2}$ ($g_{m1} = g_{m2}$) as $I_{B1} = I_{B2} = 25$ µA, $50$ µA, $100$ µA, and $200$ µA in such a way so that $g_{m1} = g_{m2} = 1/R_3$ which result in the pole frequency variation of 3.16 MHz, 5.9 MHz, 10.0 MHz, and 16.2 MHz, respectively, at constant $Q_0 = 1$. The corresponding simulated result shows the pole frequency tuning feature independent of $Q_0$ as shown in Fig. 7.

### Table 2 — Transistors aspect ratios

<table>
<thead>
<tr>
<th>Transistor</th>
<th>$W/L$</th>
<th>Transistor type</th>
</tr>
</thead>
<tbody>
<tr>
<td>M1-M8</td>
<td>4.32/0.36</td>
<td>NMOS</td>
</tr>
<tr>
<td>M10-M13</td>
<td>1.44/0.36</td>
<td>NMOS</td>
</tr>
<tr>
<td>M14-M15</td>
<td>21.6/0.36</td>
<td>NMOS</td>
</tr>
<tr>
<td>M16-M19,M9</td>
<td>21.6/0.36</td>
<td>PMOS</td>
</tr>
<tr>
<td>M20-M24</td>
<td>7.2/0.36</td>
<td>PMOS</td>
</tr>
</tbody>
</table>

![Fig. 5 — Ideal and PSPICE simulated response of LP, HP, BP, and BR TAM filter.](image1)

![Fig. 6 — Gain and phase response of AP filter.](image2)
Besides it, Fig. 8 also shows the tuning of \( Q_0 \) independent of \( \omega_0 \) by varying \( g_{m1} \), for example; 

- \( g_{m1} = 64.0 \ \mu A/V \) (\( I_{B1} = 5 \ \mu A \)), 
- \( g_{m1} = 124 \ \mu A/V \) (\( I_{B1} = 10 \ \mu A \)), 
- \( g_{m1} = 290 \ \mu A/V \) (\( I_{B1} = 25 \ \mu A \)), 
- \( g_{m1} = 538 \ \mu A/V \) (\( I_{B1} = 50 \ \mu A \)), and 
- \( g_{m1} = 1575 \ \mu A/V \) (\( I_{B1} = 200 \ \mu A \)) which obtained \( Q_0 = 18.8 \), 9.7, 4.2, 2.1, and 0.76, respectively. The simulated values were found nearly same as calculated values such as 19.2, 9.9, 4.23, 2.3, and 0.78, respectively.

Further, the transient behavior of the proposed circuit by applying the sinusoidal input of 5 MHz frequency was also investigated and corresponding simulated output results of LP filter are shown in Fig. 9, which shows the LP output in TAM with respect to applied sinusoidal input voltage signal having peak to peak amplitude of 100 mV. Next, the total harmonic distortions (THDs) of the LP response of the proposed circuit was also measured by applying a sinusoidal current input signal of varying frequency in the range of 500 kHz to 14 MHz at constant peak to peak amplitude of 100 mA. The THDs result is shown in Fig. 10 which shows that the % THD figures are adequate and not more than moderate and acceptable range\(^{37}\) of 2.8% and causes the LP TAM output not distorted significantly for an applied sinusoidal voltage input of variable frequency and constant amplitude.

To observe the effect of component mismatching on filter’s performance, Monte-Carlo analysis was performed. To measure the impact, the TAM BP output was simulated with 10% Gaussian deviation in \( C_1 = C_2 = 15 \ \text{pF} \) for 300 concurrently runs. Corresponding simulated results of BP response are shown in Fig. 11(a) and 11(b). Figure 11(a) shows the magnitude response whereas Fig. 11(b) shows the statistical results in the form of histogram where the simulated mean, median and standard deviation were obtained as 13.52 MHz, 13.50 MHz and 557.76 kHz, respectively, which conclude that with respect to the simulated pole frequency of 12.70 MHz, the proposed filter is less sensitive to the change in capacitive value and thus offers good passive sensitivity.

### 7.2 Layout designs and post-layout simulation results

In the previous section, all the simulation results were pre-layout simulation results. Now, in this section, post-layout simulations of proposed TAM biquad filter are also carried out using cadence’s virtuoso tool to see the parasitic effect which includes all the parasitic capacitances and resistor in the layout.
For this purpose, first we have designed the layout of DVCCTA which is shown in Fig. 12. Afterward, the layout of proposed TAM filter with same active and passive components value is designed and shown in Fig. 13. The layout has been verified by using design rule checks (DRC) and layout versus schematic (LVS) processes which verify the potential errors and nets mismatching between schematic and layout respectively. After these processes parasitic extraction was performed which extract the total parasitic in the design. The parasitic values as described in section 5 as $C_{P1}$, $C_{P2}$, and $C_{P3}$ were also calculated 0.057 pF, 0.0225 pF and 0.033 pF, respectively. Since parasitic capacitors $C_{P1}$ and $C_{P2}$ are parallel to large value capacitors $C_1$ and $C_2$, so these capacitors can be neglected which was also explained theoretically in section 5. The area of CMOS implemented DVCCTA layout and chip area of
biquad filter without pads are found to be 2.62 nm$^2$ and 42.20 nm$^2$, respectively. The total power consumption is calculated to be 9.21 mW. Figure 14 and Fig. 15 show the post layout simulation results of the filter in term of frequency responses of LP, BP, BR, HP, and AP responses. The post layout simulation results are almost same with pre-layout simulation results and obtained pole frequency is 12.57 MHz which is nearly same as 12.7 MHz, obtained in pre-layout simulation results.

8 Conclusions

In this paper a new DVCCTA based trans-admittance mode biquad filter topology is presented which has the ability of realising all five filtering functions such as the LP, BP, HP, and BR and AP, simultaneously and employs only two DVCCTAs as active element, two grounded capacitors and three grounded resistors for the implementation. Moreover, the presented TAM filter also enjoy the feature of low active and passive sensitivities, low power consumption, independent electronic tunability of filter parameters, input voltage applied to high input impedance terminal and no requirement of inverting type input signal etc. Beside it, the proposed filter was also analysed to consider the effect of non ideal parameter ($\alpha$, $\beta$, $\gamma$), frequency dependent parameter ($g_m$), stability condition, parasitic resistance and capacitances on the performance of the circuit. Further, both pre-layout and post layout simulation of the proposed circuit has been successively carried out which validate that the presented circuit can be made fully integrable in CMOS technology and ready for chip level fabrication. The chip area of biquad filter without pads is found to be 42.20 nm$^2$. The above distinguished features and analysis of the circuit make hope that this work will add to the body of knowledge on classical filter design.

References

24. Shankar C & Singh S V, A low voltage operable VDTA based biquad filter realizing band pass and high pass


