Multifunction Filter/Inverse Filter Configuration Employing CMOS CDBAs

Ram Bhagat, D. R. Bhaskar, Pragati Kumar

Abstract: A voltage-mode (VM) multifunction configuration for the realization of conventional active filters and inverse active filters (IAF) using two current differencing buffered amplifiers and six passive elements has been presented. The proposed structure can realize low pass filter/inverse low pass filter (LPF/ILPF), high pass filter/inverse high pass filter (HPF/IHPF), and band pass filter/Inverse band pass filter (BPF/IBPF) from the same circuit topology by appropriate choice(s) of the branch impedances(s). PSPICE simulations with CMOS current differencing buffered amplifiers implemented in 0.18µm CMOS TSMC technology have been presented to establish the workability of the proposed circuit configuration.

Keywords: Analog Electronic Filters, Inverse Filters, Analog Signal Processing, Current Differencing Buffered Amplifier

I. INTRODUCTION

Current differencing buffered amplifier (CDBA) has drawn attention of researchers working in the field of analog signal processing and signal generation circuits as it provides ideally zero input impedance at its input terminals thus, eliminating the effect of parasitic elements at the input terminals. In addition, its low output impedance (ideally zero at the voltage output terminal) makes possible the cascading of CDBA-based circuit configurations without any loading effects. Numerous applications of CDBAs [1]-[17] in analog signal processing circuits have been presented by the researchers in open literature. Since this paper deals with the applications of CDBAs in realization of analog filters/inverse analog filters, in the following we present a brief overview of the important works done on the realizati

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* Correspondence Author
Ram Bhagat, Electrical Engineering Department, Delhi Technological University, Delhi, India.
D. R. Bhaskar*, Electronics and Communication Engineering Department, Delhi Technological University, Delhi, India.
Pragati Kumar, Electrical Engineering Department, Delhi Technological University, Delhi, India.

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Table I. Comparison with earlier reported inverse filters

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Number of active devices used</th>
<th>Passive components used</th>
<th>Type of inverse filters realized</th>
<th>Whether conventional filters realized from the same circuit topology</th>
</tr>
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<tbody>
<tr>
<td></td>
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<td></td>
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<tr>
<td>[15]</td>
<td>2 CDBA</td>
<td>2-4, 2-4</td>
<td>ILPF, IHPF, IBPF, IBRF, IAPF</td>
<td>No</td>
</tr>
<tr>
<td>[16]</td>
<td>2 CDBA</td>
<td>3, 3</td>
<td>ILPF, IHPF, IBPF</td>
<td>No</td>
</tr>
<tr>
<td>[17]</td>
<td>2 CDBA</td>
<td>4/5, 2</td>
<td>IBRF, IAPF</td>
<td>No</td>
</tr>
<tr>
<td>[18]</td>
<td>1 NULLOR</td>
<td>4, 2</td>
<td>IHPF</td>
<td>No</td>
</tr>
<tr>
<td>[19]</td>
<td>1 OA</td>
<td>3/7, 2 (PCAP)</td>
<td>ILPF, IHPF, IBPF</td>
<td>No</td>
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<tr>
<td>[20]</td>
<td>3 CFOA</td>
<td>4, 2</td>
<td>ILPF, IHPF, IBPF, IBRF</td>
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<td>[21]</td>
<td>3 CFOA</td>
<td>3-5, 2</td>
<td>ILPF, IHPF, IBPF, IBRF</td>
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<tr>
<td>[22]</td>
<td>3 CFOA</td>
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<td>ILPF, IHPF, IBPF</td>
<td>No</td>
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<tr>
<td>[23]</td>
<td>3 CFOA</td>
<td>2-3, 3-4</td>
<td>ILPF, IHPF, IBPF</td>
<td>No</td>
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<td>[24]</td>
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<td>4-6, 2</td>
<td>ILPF, IHPF, IBPF, IBRF</td>
<td>No</td>
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<td>[25]</td>
<td>1 CCII</td>
<td>2, 1</td>
<td>IAPF first order</td>
<td>No</td>
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<td>[26]</td>
<td>4-6 CCII</td>
<td>3-4, 2</td>
<td>ILPF, IHPF, IBPF</td>
<td>No</td>
</tr>
<tr>
<td>[27]</td>
<td>1 FTFN</td>
<td>5, 2</td>
<td>ILPF</td>
<td>No</td>
</tr>
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<td>[28]</td>
<td>1 FTFN</td>
<td>4, 2</td>
<td>IAPF</td>
<td>No</td>
</tr>
<tr>
<td>[29]</td>
<td>1 FTFN</td>
<td>2-4, 2/3</td>
<td>ILPF, IHPF, IBPF, IBRF, IAPF</td>
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<tr>
<td>[30]</td>
<td>2 OTRA</td>
<td>4, 2/3</td>
<td>ILPF, IHPF, IBPF</td>
<td>No</td>
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<td>[31]</td>
<td>2 OTRA</td>
<td>4-5, 3-4</td>
<td>IBRF, IAPF</td>
<td>No</td>
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<td>[32]</td>
<td>3 CDTA</td>
<td>2, 2</td>
<td>IHPF</td>
<td>No</td>
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<td>[33]</td>
<td>1 CDTA</td>
<td>1, 1</td>
<td>IAPF first order</td>
<td>No</td>
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<tr>
<td>[34]</td>
<td>10/12 OTAs</td>
<td>0, 2</td>
<td>ILPF, IHPF, IBPF</td>
<td>No</td>
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<td>[35]</td>
<td>3 DDCC</td>
<td>2, 2</td>
<td>ILPF, IHPF, IBPF</td>
<td>No</td>
</tr>
<tr>
<td>[36]</td>
<td>2/3/4 VDTA</td>
<td>0, 2</td>
<td>ILPF, IHPF, IBPF, IBRF</td>
<td>No</td>
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</table>

**Proposed**

<table>
<thead>
<tr>
<th>Ref.</th>
<th>Number of active devices used</th>
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<tr>
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<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>2 CDBA</td>
<td>3, 2</td>
<td>ILPF, IHPF, IBPF</td>
<td>Yes</td>
</tr>
</tbody>
</table>

FCAP: Fractional Capacitor

From the above table, it is observed that there is no configuration(s) reported earlier in the open literature which can realize conventional/inverse filters from the same topology with suitable choice(s) of passive circuit elements.

Thus, the main aim of this paper is to present a multifunction circuit topology with two CDBAs, four resistors and two capacitors (virtually grounded) to realize second-order conventional LPF, HPF, BPF and ILPF, IHPF and IBPF utilizing the intrinsic (current differencing) property of the CDBAs.

**II. PROPOSED CIRCUIT CONFIGURATION**

The CDBA symbol is shown in Fig.1 and its terminal voltage/current relationships are given in equation (1)
The circuit for the realization of conventional LPF, HPF, BPF and ILPF, IHPF and IBPF with four branch impedances is shown in Fig. 2.

From a straightforward analysis, the transfer function (TF) for the configuration shown in Fig. 2 can be obtained as:

\[
\frac{V_o}{V_i} = \frac{Z_2Z_4}{4Z_2Z_4} \quad (2)
\]

By choosing suitable branch impedance(s), the various conventional filters and inverse filter TFs can be obtained as follows.

(A) Realization of conventional filters:

Case I: If we select

\[Z_1 = R_1, Z_2 = \left( R_2 + \frac{1}{sC_2} \right), Z_3 = R_3, \text{ and } Z_4 = \left( R_4 + \frac{1}{sC_4} \right),\]

resulting TF becomes

\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{s^2 + \frac{1}{R_1C_1} \frac{1}{R_1C_2} + \frac{1}{R_1C_3} + \frac{1}{R_1C_4}} \quad (3)
\]

which represents a LPF. The cut-off frequency \( (\omega_n) \), gain \( (H_o) \) and quality factor \( (Q) \) of this filter are given by:

\[
\omega_n = \frac{1}{\sqrt{R_1R_2C_1C_2}}, H_o = \frac{R_1R_2}{4R_1R_4}, \text{ and } Q = \frac{\sqrt{R_1R_2C_1C_2}}{R_1C_2 + R_1C_4} \quad (4)
\]

Case II: If the impedances are selected such that

\[Z_1 = \left( R_1 + \frac{1}{sC_1} \right), Z_2 = R_2, Z_3 = \left( R_3 + \frac{1}{sC_3} \right) \text{ and } Z_4 = R_4, \]

the resulting TF becomes

\[
\frac{V_o(s)}{V_i(s)} = \frac{R_1R_2}{4R_1R_3} s^2 + \frac{1}{s^2 + \frac{1}{R_1C_1} \frac{1}{R_1C_2} + \frac{1}{R_1C_3} + \frac{1}{R_1C_4}} \quad (5)
\]

which yields an HPF with \( \omega_n, H_o \) and \( Q \) given by:

\[
\omega_n = \frac{1}{\sqrt{R_1R_2C_1C_2}}, H_o = \frac{R_1R_2}{4R_1R_3} \text{ and } Q = \frac{\sqrt{R_1R_2C_1C_2}}{R_1C_2 + R_1C_4} \quad (6)
\]

Case III: (a) If we take

\[Z_1 = \left( R_1 + \frac{1}{sC_1} \right), Z_2 = R_2, Z_3 = R_3 \text{ and } Z_4 = \left( R_4 + \frac{1}{sC_4} \right),\]

then we get the transfer function of BPF given by:

\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{s^2 + \frac{1}{R_1C_1} \frac{1}{R_1C_2} + \frac{1}{R_1C_3} + \frac{1}{R_1C_4} + \frac{1}{R_2R_3C_2C_3} + \frac{1}{R_2R_4C_4C_4}} \quad (7)
\]

with \( \omega_n \), bandwidth \( (BW) \) and \( H_o \) given by:

\[
\omega_n = \frac{1}{\sqrt{R_1R_2C_1C_2}}, \quad BW = \frac{1}{R_1C_2} + \frac{1}{R_2C_2} \text{ and } H_o = \frac{R_2R_3C_2}{4R_2R_3C_2 + R_1C_2} \quad (8)
\]

(b) If we choose

\[Z_1 = R_1, Z_2 = R_2, Z_3 = \left( R_3 + \frac{1}{sC_3} \right) \text{ and } Z_4 = \left( R_4 + \frac{1}{sC_4} \right),\]

then we get the transfer function of an BPF given by:

\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{s^2 + \frac{1}{R_1C_1} \frac{1}{R_1C_2} + \frac{1}{R_1C_3} + \frac{1}{R_1C_4} + \frac{1}{R_2R_3C_2C_3} + \frac{1}{R_2R_4C_4C_4}} \quad (9)
\]

which gives \( \omega_n, BW \) and \( H_o \) as:

\[
\omega_n = \frac{1}{\sqrt{R_1R_2C_1C_2}}, \quad BW = \frac{1}{R_1C_2} + \frac{1}{R_2C_2} \text{ and } H_o = \frac{R_2R_3C_2}{4R_2R_3C_2 + R_1C_2} \quad (10)
\]

(c) If we take

\[Z_1 = \left( R_1 + \frac{1}{sC_1} \right), Z_2 = \left( R_2 + \frac{1}{sC_2} \right), Z_3 = R_3 \text{ and } Z_4 = R_4, \]

then we get the transfer function of an BPF given by:

\[
\frac{V_o(s)}{V_i(s)} = \frac{R_2}{s^2 + \frac{1}{R_1C_1} \frac{1}{R_1C_2} + \frac{1}{R_1C_3} + \frac{1}{R_1C_4} + \frac{1}{R_2R_3C_2C_3} + \frac{1}{R_2R_4C_4C_4}} \quad (11)
\]

with \( \omega_n \), bandwidth \( (BW) \) and \( H_o \) given by:

\[
\omega_n = \frac{1}{\sqrt{R_1R_2C_1C_2}}, \quad BW = \frac{1}{R_1C_2} + \frac{1}{R_2C_2} \text{ and } H_o = \frac{R_2R_3C_2}{4R_2R_3C_2 + R_1C_2} \quad (12)
\]

(d) If we select

\[Z_1 = R_1, Z_2 = \left( R_2 + \frac{1}{sC_2} \right), Z_3 = \left( R_3 + \frac{1}{sC_3} \right) \text{ and } Z_4 = R_4, \]

then we get the transfer function of an BPF given by:

\[
\frac{V_o(s)}{V_i(s)} = \frac{R_4}{s^2 + \frac{1}{R_1C_1} \frac{1}{R_1C_2} + \frac{1}{R_1C_3} + \frac{1}{R_1C_4} + \frac{1}{R_2R_3C_2C_3} + \frac{1}{R_2R_4C_4C_4}} \quad (13)
\]

which gives \( \omega_n, BW \) and \( H_o \) as:

\[
\omega_n = \frac{1}{\sqrt{R_1R_2C_1C_2}}, \quad BW = \frac{1}{R_1C_2} + \frac{1}{R_2C_2} \text{ and } H_o = \frac{R_2R_3C_2}{4R_2R_3C_2 + R_1C_2} \quad (14)
\]

(B) Realization of ILPF, IHPF and IBPF responses:
Multifunction Filter/Inverse Filter Configuration Employing CMOS CDBAs

Case I: If we select
\[ Z_1 = R_1 \frac{1}{sC_1}, \quad Z_2 = R_2, \quad Z_3 = \frac{1}{sC_3}, \quad \text{and} \quad Z_4 = R_4 \]
then transfer function becomes
\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{s^2 + \frac{1}{R_1 C_1} + \frac{1}{R_2 C_2} + \frac{1}{R_3 C_3}},
\]
which represents an ILPF with \( \omega_o, H_o, \) and \( Q \) given by:
\[
\omega_o = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}, \quad H_o = \frac{4R_1 R_2}{R_1 R_4} \quad \text{and} \quad Q = \sqrt{\frac{R_1 R_2 C_1 C_2}{R_1 C_1 + R_2 C_2}}.
\]

Case II: If the impedances are selected, such that
\[ Z_1 = R_1, \quad Z_2 = \frac{R_2 + 1}{sC_2}, \quad Z_3 = R_3, \quad \text{and} \quad Z_4 = \frac{R_4 + 1}{sC_4} \]
the transfer function becomes:
\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{s^2 + \frac{1}{R_1 C_1} + \frac{1}{R_2 C_2} + \frac{1}{R_3 C_3}},
\]
which gives an IHPF with \( \omega_o, H_o, \) and \( Q \) given by:
\[
\omega_o = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}, \quad H_o = \frac{4R_1 R_2}{R_1 R_4} \quad \text{and} \quad Q = \sqrt{\frac{R_1 R_2 C_1 C_2}{R_1 C_1 + R_2 C_2}}.
\]

Case III: (a) If the impedances are selected, such that
\[ Z_1 = R_1, \quad Z_2 = \frac{R_2 + 1}{sC_2}, \quad Z_3 = \frac{1}{sC_3}, \quad \text{and} \quad Z_4 = R_4 \]
then the transfer function realizes IBPF as
\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{s^2 + \frac{1}{R_1 C_1} + \frac{1}{R_2 C_2} + \frac{1}{R_4 C_4}},
\]
with \( \omega_o, BW, \) and \( H_o \) given by:
\[
\omega_o = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}, \quad BW = \frac{1}{R_1 C_1} + \frac{1}{R_2 C_2} \quad \text{and} \quad H_o = \frac{4R_1 R_2}{R_1 C_1 + R_2 C_2}.
\]
(b) If we take \( Z_1 = R_1, \quad Z_2 = R_2, \quad Z_3 = \frac{1}{sC_3}, \quad \text{and} \quad Z_4 = \frac{1}{sC_4} \),
then the transfer function represents the realization of IBPF
\[
\frac{V_o(s)}{V_i(s)} = \frac{1}{s^2 + \frac{1}{R_1 C_1} + \frac{1}{R_2 C_2} + \frac{1}{R_4 C_4}},
\]
which realizes an IBPF with \( \omega_o, BW, \) and \( H_o \) given by:
\[
\omega_o = \frac{1}{\sqrt{R_1 R_2 C_1 C_2}}, \quad BW = \frac{1}{R_1 C_1} + \frac{1}{R_2 C_2} \quad \text{and} \quad H_o = \frac{4R_1 R_2}{R_1 C_1 + R_2 C_2}.
\]

III. NON-IDEAL ANALYSIS
The real CDBA, in which the effects of different non-idealities associated with various terminals have been incorporated in terms of parasitic resistances and parasitic capacitances, is shown in Fig. 3.

Terminal equations of a real CDBA have been described [18] by the following relationships:
\[
V_p = V_N = 0.1 L = -\beta I_p, -\beta I_n, \quad \text{and} \quad V_W = \alpha V_Z.
\]
where $\beta_n = (1 - \varepsilon_n)$ and $\varepsilon_n |_{\text{in}} << 1$ is the current tracking error from n-terminal to z-terminal, $\beta_p = (1 - \varepsilon_p)$ and $\varepsilon_p |_{\text{p}} << 1$ is the current tracking error from p-terminal to z-terminal, and $\alpha = (1 - \varepsilon_z)$ and $\varepsilon_z |_{\text{z}} << 1$ is the voltage tracking error from z-terminal to w-terminal of the CDBA. In addition to the above, we have also considered parasitic resistance $R_p$, parasitic capacitance $C_z$ at z-terminal of the CDBA in the non-ideal analysis given below and we get the following non-ideal transfer functions of conventional filters and inverse active filters:

(A) The various non-ideal expressions of LPF, HPF and BPF are given by:

$$\frac{V_o(s)}{V_{in}(s)}_{\text{LPF}} = \frac{1}{\alpha \alpha \beta \beta \beta \beta R R R R}$$

where $A = C_1 C_2 + (1 + \beta_n)(1 + \beta_n) C_2 C_4$

$$B = \frac{C_2 z_l + C_{a_2} (1 + \beta_{a_2}) + C_{a_2} (1 + \beta_{a_2}) + C_{a_2} (1 + \beta_{a_2})}{R z_l + R_4} + \frac{C_{a_2} (1 + \beta_{a_2})}{R_2}$$

and

$$C = \frac{1}{R z_l + R_2} + \frac{(1 + \beta_{a_2})}{R_4 R_2} + \frac{(1 + \beta_{a_2})}{R_2 R_2} + \frac{(1 + \beta_{a_2})}{R_3 R_4}$$

$$\frac{V_0(s)}{V_{in}(s)}_{\text{HPF}} = \frac{1}{\alpha \alpha \beta \beta \beta \beta R R R R}$$

where $A = C_1 C_2$

$$B = \frac{C_{a_2} + C_{a_2} (1 + \beta_{a_2}) + C_{a_2} (1 + \beta_{a_2}) + C_{a_2} (1 + \beta_{a_2})}{R a_2 + R_4} + \frac{C_{a_2} (1 + \beta_{a_2})}{R_2}$$

and

$$C = \frac{1}{R z_l + R_2} + \frac{(1 + \beta_{a_2})}{R_4 R_2} + \frac{(1 + \beta_{a_2})}{R_2 R_2} + \frac{(1 + \beta_{a_2})}{R_3 R_4}$$

Since the parasitic resistance associated with the z terminal is very high (ideally infinite) and the parasitic capacitance associated with the z terminal is very small (ideally zero), we may approximate, the various filter transfer functions as:

$$\frac{V_o(s)}{V_{in}(s)}_{\text{LPF}} = \frac{1}{s^2 + \frac{1}{R C_1} + \frac{1}{R C_2} + \frac{1}{C C C R}}$$

which represents a LPF with non-ideal cut-off frequency $\omega_c$, gain $(H_i)$ and quality factor $(Q)$ given by

$$\omega_c = \frac{1}{R R C C} = \omega_c, Q = \frac{R R C C}{R C_1 + R C_2} = Q$$

$$H_i = \frac{\alpha \alpha \beta \beta \beta \beta R R R R}{(1 + \beta_n)(1 + \beta_n)} H_0$$

$$\frac{V_0(s)}{V_{in}(s)}_{\text{HPF}} = \frac{1}{s^2 + \frac{1}{R C_1} + \frac{1}{R C_2} + \frac{1}{C C C R}}$$

which represents a HPF with $\omega_c$, $H_i$ and $Q$ given by

$$\omega_c = \frac{1}{R R C C} = \omega_c, Q = \frac{R R C C}{R C_1 + R C_2} = Q$$

$$H_i = \frac{\alpha \alpha \beta \beta \beta \beta R R R R}{(1 + \beta_n)(1 + \beta_n)} H_0$$

and

$$\frac{V_0(s)}{V_{in}(s)}_{\text{BPF}} = \frac{1}{s^2 + \frac{1}{R C_1} + \frac{1}{R C_2} + \frac{1}{C C C R}}$$

which represents a BPF with $\omega_c$, $H_i$ and $Q$ given by

$$\omega_c = \frac{1}{R R C C} = \omega_c, Q = \frac{R R C C}{R C_1 + R C_2} = Q$$

From equations (32), (34) and (36) it is noted that the non-ideal values of cut-off frequency, quality factor and bandwidth of the conventional
LPF, HPF and BPF do not depend on voltage/current tracking error coefficients and parasitic elements associated with various terminals of the CDBA, however the gain of the filter depends on the tracking error parameters.

(B) Similarly, the various non-ideal transfer functions of ILPF, IHPF and IBPF are given by:

\[
\frac{V_{o}(s)}{V_{in}(s)} = \frac{1}{s^2 + \frac{\alpha_1}{\alpha_2} s + \frac{C_2}{C_3} + B_s + C}
\]

where

\[
B = \left[ \begin{array}{cc}
\frac{C_2}{R_2} & \frac{C_2}{R_4} \\
\frac{C_2}{R_2} & \frac{C_2}{R_4}
\end{array} \right] + \left[ \begin{array}{cc}
\frac{1}{R_2} & \frac{1}{R_4} \\
\frac{1}{R_2} & \frac{1}{R_4}
\end{array} \right] \frac{1}{1 + \frac{1}{R_2} + \frac{1}{R_4}}
\]

\[
C = \left[ \begin{array}{cc}
\frac{C_2}{R_2} & \frac{C_2}{R_4} \\
\frac{C_2}{R_2} & \frac{C_2}{R_4}
\end{array} \right] \left[ \begin{array}{cc}
\frac{1}{R_2} & \frac{1}{R_4} \\
\frac{1}{R_2} & \frac{1}{R_4}
\end{array} \right] \frac{1}{1 + \frac{1}{R_2} + \frac{1}{R_4}}
\]

Again, as \( R_s \) is very high (ideally infinite) and the value of \( C_2 \) is very low (ideally zero), we may approximate, the various inverse filter transfer functions as:

\[
\frac{V_{o}(s)}{V_{in}(s)} = \frac{1}{s^2 + \frac{1}{\alpha_2} s + \frac{C_2}{C_3} + B_s + C}
\]

which represents an ILPF with \( \alpha_\theta \), \( H_\theta \) and \( Q \) given by:

\[
\alpha_\theta = \frac{1}{\sqrt{\alpha_2 p_{1} p_{2} C_2 C_4 R_2}}
\]

\[
H_\theta = \frac{R_4 R_2 (1 + \beta_2) (1 + \beta_3)}{R_4 R_2}
\]

\[
Q = \sqrt{\alpha_2 p_{1} p_{2} C_2 C_4 R_2 R_4}
\]

which realizes IHPF with \( \alpha_\theta \), \( H_\theta \) and \( Q \) given by:

\[
\alpha_\theta = \frac{1}{\sqrt{\alpha_2 p_{1} p_{2} C_2 C_4 R_2}}
\]

\[
H_\theta = \frac{R_4 R_2 (1 + \beta_2) (1 + \beta_3)}{R_4 R_2}
\]

\[
Q = \sqrt{\alpha_2 p_{1} p_{2} C_2 C_4 R_2 R_4}
\]

which realizes IBPF with \( \alpha_\theta \) and \( BW \) given by:

\[
\alpha_\theta = \frac{1}{\sqrt{\alpha_2 p_{1} p_{2} C_2 C_4 R_2}}
\]

\[
BW = \frac{1}{\sqrt{\alpha_2 p_{1} p_{2} C_2 C_4 R_2}}
\]
Equations (41), (43) and (45) reveal that the cutoff frequency, gain, quality factor and bandwidth of the ILPF, HPF and IBPF are affected by voltage/current tracking errors of the CDBA terminals.

### IV. SENSITIVITY ANALYSIS

Various sensitivities (both active as well as passive) of $\omega_m$, $Q$ and $BW$ of conventional filters (LPF, HPF, BPF) and inverse active filters (ILPF, HPF, IBPF) have been determined and are presented in Table II. It may be observed that the sensitivities with respect to active and passive components are less than ±1.

<table>
<thead>
<tr>
<th>Filter</th>
<th>Sensitivity</th>
</tr>
</thead>
<tbody>
<tr>
<td>LPF</td>
<td>$s_{10}^{\omega} - s_{10}^{y} = \frac{1}{2} s_{20}^{\omega} = s_{20}^{y} = -\frac{1}{2}, s_{30}^{\omega} = s_{30}^{y} = 0$, $s_{40}^{\omega} = s_{40}^{y} = 0 \equiv s_{50}^{\omega} = s_{50}^{y} = 0$</td>
</tr>
<tr>
<td>HPF</td>
<td>$s_{10}^{\omega} - s_{10}^{y} = \frac{1}{2} s_{20}^{\omega} = s_{20}^{y} = -\frac{1}{2}, s_{30}^{\omega} = s_{30}^{y} = 0$, $s_{40}^{\omega} = s_{40}^{y} = 0 \equiv s_{50}^{\omega} = s_{50}^{y} = 0$</td>
</tr>
<tr>
<td>BPF Case(a)</td>
<td>$s_{10}^{\omega} = s_{10}^{y}$, $s_{20}^{\omega} = s_{20}^{y} = \frac{1}{2}$, $s_{30}^{\omega} = s_{30}^{y} = 0$, $s_{40}^{\omega} = s_{40}^{y} = 0 \equiv s_{50}^{\omega} = s_{50}^{y} = 0$</td>
</tr>
<tr>
<td>ILPF</td>
<td>$s_{10}^{\omega} = s_{10}^{y}$, $s_{20}^{\omega} = s_{20}^{y} = \frac{1}{2}$, $s_{30}^{\omega} = s_{30}^{y} = 0$, $s_{40}^{\omega} = s_{40}^{y} = 0 \equiv s_{50}^{\omega} = s_{50}^{y} = 0$</td>
</tr>
<tr>
<td>IHPF</td>
<td>$s_{10}^{\omega} = s_{10}^{y}$, $s_{20}^{\omega} = s_{20}^{y} = \frac{1}{2}$, $s_{30}^{\omega} = s_{30}^{y} = 0$, $s_{40}^{\omega} = s_{40}^{y} = 0 \equiv s_{50}^{\omega} = s_{50}^{y} = 0$</td>
</tr>
<tr>
<td>IBPF Case(a)</td>
<td>$s_{10}^{\omega} = s_{10}^{y}$, $s_{20}^{\omega} = s_{20}^{y} = \frac{1}{2}$, $s_{30}^{\omega} = s_{30}^{y} = 0$, $s_{40}^{\omega} = s_{40}^{y} = 0 \equiv s_{50}^{\omega} = s_{50}^{y} = 0$</td>
</tr>
</tbody>
</table>

### V. SIMULATION RESULTS

The workability of the multifunction filter configuration has been verified using PSpice simulations wherein the employed CDBA structure shown in Fig. 4 has been derived from the structure of a current differencing current conveyor [38]. The bias voltages of ±2.5V and the bias current of 40µA were used in the simulations. The aspect ratios used for implementation of CDBA are given in Table III. The parameters selected for a cutoff frequency of 1.59 MHz are as follows.

**LPF:** $C_1 = C_3 = 10pF$, $R_1 = R_3 = 5k\Omega$, $R_2 = R_4 = 10k\Omega$

**HPF:** $C_1 = C_3 = 10pF$, $R_1 = R_3 = 10k\Omega$, $R_2 = R_4 = 20k\Omega$

**BPF (case a):** $C_1 = C_4 = 10pF$, $R_1 = R_2 = R_4 = 10k\Omega$, $R_3 = 5k\Omega$

**ILPF:** $C_1 = C_3 = 10pF$, $R_1 = R_3 = 10k\Omega$, $R_2 = R_4 = 20k\Omega$

**IHPF:** $C_2 = C_4 = 10pF$, $R_1 = R_3 = 5k\Omega$, $R_2 = R_4 = 10k\Omega$

**IBPF (case a):** $C_2 = C_4 = 10pF$, $R_1 = R_3 = 10k\Omega$, $R_2 = R_4 = 20k\Omega$

![Fig. 5](image)

Fig. 5 shows the frequency responses of conventional LPF, HPF and BPF and Fig. 6 shows the frequency responses of ILPF, IHPF and IBPF. The input signal level was kept at 0.5V peak to peak. These results establish the workability of the proposed configuration.

### Table III. aspect ratio of MOSFETs used for realization of CDBA

<table>
<thead>
<tr>
<th>MOSFETs</th>
<th>W:L</th>
</tr>
</thead>
<tbody>
<tr>
<td>M_{1},M_{2},M_{3},M_{4},M_{5}</td>
<td>50 um:0.5um</td>
</tr>
<tr>
<td>M_{1},M_{2},M_{3},M_{4},M_{5}</td>
<td>100um:0.5um</td>
</tr>
<tr>
<td>M_{1},M_{2},M_{3},M_{4},M_{5}</td>
<td>3.33um:0.5um</td>
</tr>
</tbody>
</table>
Multifunction Filter/Inverse Filter Configuration Employing CMOS CDBAs

Fig. 4. CMOS realization of CDBA

Fig. 5. Simulated frequency responses for conventional filters (a) LPF, (b) HPF and (c) BPF

Fig. 6. Simulated frequency responses of inverse filters (a) ILPF, (b) IHPF and (c) IBPF

The Monte-Carlo simulations of the conventional filters and inverse active filters showing variation of cut off frequency and gain with 5 percent variation in capacitance and resistance values have been carried out and the results have been shown in Fig.7(a-f).
(a) Variation in cut-off frequency of LPF with 5% variation in resistance and capacitance value

(b) Variation in cut-off frequency of HPF with 5% variation in resistance and capacitance value

(c) Variation in centre frequency of BPF with 5% variation in resistance and capacitance value

(d) Variation in gain of ILPF with 5% variation in resistance and capacitance value

(e) Variation in cut-off frequency of IHPF with 5% variation in resistance and capacitance value

(f) Variation in centre frequency of IBPF with 5% variation in resistance and capacitance value

Fig. 7 Monte-Carlo simulation results of the (a) LPF (b) HPF (c) BPF (d) ILPF (e) IHPF and (f) IBPF

VI. CONCLUSION

A multifunction structure employing two CDBAs and six passive components has been presented. The proposed structure can realize conventional as well as inverse active filter responses by appropriate selection(s) of branch impedance(s) as resistor(s)/capacitor(s). The active and passive sensitivities of the presented filters are low. Monte-Carlo analysis has also been carried out to check the robustness of the described circuit. The workability of the proposed filter has been validated by PSPICE and MATLAB simulation employing an exemplary CMOS CDBA [38] architecture.

REFERENCES


Multifunction Filter/Inverse Filter Configuration Employing CMOS CDBAs


Authors Profile

Ram Bhagat Associate Professor in Department of Electrical Engineering, Delhi Technological University, New Delhi, India. Currently, he is pursuing Ph.D. from the Delhi Technological University. His research interests are in the area of Network Analysis and Synthesis, Microelectronics, CMOS Analog Integrated Circuits and Control System.

D. R. Bhaskar received B.Sc. degree from Agra University, B. Tech. degree from Indian Institute of Technology (IIT) Kanpur, M. Tech. from IIT Delhi and Ph.D. from University of Delhi. Prof. Bhaskar held the positions of Lecturer (1984–1990) and Senior Lecturer (1990–1995) at the Electrical Engineering Department of Delhi College of Engineering (now Delhi Technological University). He joined the Electronics and Communication Engineering Department of Jamia Millia Islamia in July 1995, as a Reader and became a Professor in January 2002. He served as the Head of the Department of ECE from 2002 to 2005. Presently, he is working in the Department of Electronics and Communication Engineering, Delhi Technological University, Delhi, India. His teaching and research interests are in the areas of Bipolar and CMOS Analog Integrated Circuits and Systems, Current Mode/Voltage Mode Signal Processing, Communication Systems, Fractional Order Filters and Electronic Instrumentation. Prof. Bhaskar has authored or co-authored 92 research papers-all in international journals of repute, 9 international conference papers and 4 book chapters. He has co-authored 3 monographs published by Springer. He has acted/has been acting as a Reviewer for several journals of IEEE, IEE and other international journals of repute.

Pragati Kumar Professor in Department of Electrical Engineering, Delhi Technological University, New Delhi, India was born in Muzaffarpur, Bihar, India. He received his Ph.D. from the University of Delhi in 2008. His teaching and research interests are in the area of Network Analysis and Synthesis, Microelectronics, CMOS Analog Integrated Circuits and Fractional Order Circuits/Systems. He has co-authored 13 research papers in various international journal/conferencesedited book volumes.