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Multifunction Filter/Inverse Filter Configuration Employing CMOS CDBAs

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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 impedance(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 realization of filters/inverse filters using CDBAs to put the proposed work in this paper in proper prospective. In [1], single CDBA-based CM notch filter has been reported with two capacitors and two resistors. Realization of CM universal filter using three CDBAs, two capacitors and two resistors is reported in [2]. In [3], a multi-mode multifunction filter structure has been presented employing one CDBA, along with two/three resistors and capacitors. A third order VM all pass filter (APF) has been proposed using four CDBAs, three capacitors and eleven resistors in [4]. CM multipurpose filter configuration has been presented in [5] using single/two CDBA(s), three/four resistors and two/three capacitors. Two CDBA-based VM universal biquad filter and quadrature oscillator structure employing two capacitors and four resistors have been presented in [6]. Two electronically controllable configurations providing VM filters and quadrature sinusoidal oscillators using two CDBAs, one multiplier element, three capacitors and five resistors have been presented in [7]. A CM multifunction filter employing two CDBAs, three/four resistors, three/four capacitors is described in [8]. A single CDBA based multifunction biquad with three/four resistors and three/four capacitors has been reported in [9]. In [10] VM single CDBA-based universal filter has been presented with four resistors and two capacitors. A multiple output biquadratic filter has been reported in [11] using three CDBAs, two/four resistors and two/five capacitors. A CM KHN-biquad has been presented in [12] employing three CDBAs, two capacitors and six resistors. In [13], a VM single CDBA based APF and notch filter with three resistors and two capacitors has been reported. Two VM universal filter configurations with two CDBAs, four resistors and two capacitors have been described in [14]. It may be noted that in [13], and [14] the intrinsic property (current differencing) of the CDBA has not been used. Inverse analog active filters are an important class of analog signal processing circuits from the view point of some applications in the areas where the distortion introduced in the signal transmission path may be corrected by making the signal pass through an inverse filter whose characteristics are the reciprocal of the original system which has introduced the distortion. Over the years, several active inverse analog filter designs employing different active building blocks (ABBs) have been reported. Table I given below summarizes the salient features of active inverse analog filters.

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Table I. Comparison with earlier reported inverse filters

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

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.

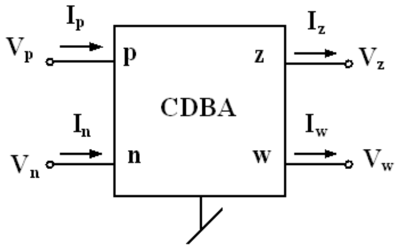

Fig. 1 Symbolic representation of CDBA

II. PROPOSED CIRCUIT CONFIGURATION

The CDBA symbol is shown in Fig.1 and its terminal voltage/current relationships are given in equation (1)

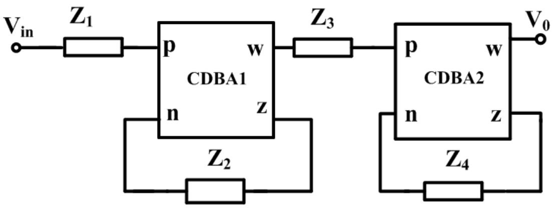

Fig. 2 The proposed circuit configuration

$$V_p = 0 = V_n,\ I_z = (I_p - I_n),\ \text{and}\ V_w = V_z \quad (1)$$

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

$$\frac{V_0}{V_{in}} = \frac{Z_2 Z_4}{4 Z_1 Z_3} \quad (2)$$

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

$Z_1 = R_1, Z_2 = \left(R_2 \| \frac{1}{sC_2}\right), Z_3 = R_3$ and $Z_4 = \left(R_4 \| \frac{1}{sC_4}\right)$, resulting TF becomes

$$\frac{V_0(s)}{V_{in}(s)} = \frac{\left(\frac{1}{4R_1R_3C_2C_4}\right)}{s^2 + \left(\frac{1}{R_4C_4} + \frac{1}{R_2C_2}\right)s + \frac{1}{R_2R_4C_2C_4}} \quad (3)$$

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

$$\omega_o = \frac{1}{\sqrt{R_2R_4C_2C_4}},\ H_o = \frac{R_2R_4}{4R_1R_3} \text{ and } Q = \frac{\sqrt{R_2R_4C_2C_4}}{R_2C_2 + R_4C_4} \quad (4)$$

Case II: If the impedances are selected such that

$Z_1 = \left(R_1 + \frac{1}{sC_1}\right), Z_2 = R_2, Z_3 = \left(R_3 + \frac{1}{sC_3}\right)$ and $Z_4 = R_4$, *the* resulting TF becomes

$$\frac{V_0(s)}{V_{in}(s)} = \frac{\left(\frac{R_2R_4}{4R_1R_3}\right)s^2}{s^2 + \left(\frac{1}{4R_1C_1} + \frac{1}{R_3C_3}\right)s + \frac{1}{R_1R_3C_1C_3}} \quad (5)$$

which yields an HPF with ω_o, H_o and Q given by:

$$\omega_o = \frac{1}{\sqrt{R_1R_3C_1C_3}},\ H_o = \frac{R_2R_4}{4R_1R_3} \text{ and } Q = \frac{\sqrt{R_1R_3C_1C_3}}{R_1C_1 + R_3C_3} \quad (6)$$

Case III: (a) If we take

$Z_1 = \left(R_1 + \frac{1}{sC_1}\right), Z_2 = R_2, Z_3 = R_3$ and $Z_4 = \left(R_4 \| \frac{1}{sC_4}\right)$, then we get the transfer function of BPF given by:

$$\frac{V_0(s)}{V_{in}(s)} = \frac{\left(\frac{R_2}{4R_1R_3C_4}\right)s}{s^2 + \left(\frac{1}{R_1C_1} + \frac{1}{R_4C_4}\right)s + \frac{1}{R_1R_4C_1C_4}} \quad (7)$$

with ω_o, bandwidth (BW) and H_o given by:

$$\omega_o = \frac{1}{\sqrt{R_1R_4C_1C_4}};\ BW = \frac{1}{R_1C_1} + \frac{1}{R_4C_4} \text{ and } H_o = \frac{R_2R_4C_1}{4R_3(R_1C_1 + R_4C_4)} \quad (8)$$

(b) If we choose

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

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

$$\frac{V_0(s)}{V_{in}(s)} = \frac{\left(\frac{R_2}{4R_3R_1C_4}\right)s}{s^2 + \left(\frac{1}{R_3C_3} + \frac{1}{R_4C_4}\right)s + \frac{1}{R_3R_4C_3C_4}} \quad (9)$$

which gives ω_o, BW and H_o as:

$$\omega_o = \frac{1}{\sqrt{R_3R_4C_3C_4}};\ BW = \frac{1}{R_3C_3} + \frac{1}{R_4C_4} \text{ and } H_o = \frac{R_2R_4C_3}{4R_1(R_3C_3 + R_4C_4)} \quad (10)$$

(c) If we take

$Z_1 = \left(R_1 + \frac{1}{sC_1}\right), Z_2 = \left(R_2 \| \frac{1}{sC_2}\right), Z_3 = R_3$ and $Z_4 = R_4$, then we get the transfer function of an BPF given by:

$$\frac{V_0(s)}{V_{in}(s)} = \frac{\left(\frac{R_4}{R_1R_3C_2}\right)s}{s^2 + \left(\frac{1}{R_1C_1} + \frac{1}{R_2C_2}\right)s + \frac{1}{R_1R_2C_1C_2}} \quad (11)$$

with ω_o, BW and H_o given by:

$$\omega_o = \frac{1}{\sqrt{R_1R_2C_1C_2}};\ BW = \frac{1}{R_1C_1} + \frac{1}{R_2C_2} \text{ and } H_o = \frac{R_2R_4C_1}{4R_3(R_1C_1 + R_2C_2)} \quad (12)$$

(d) If we select $Z_1 = R_1, Z_2 = \left(R_2 \| \frac{1}{sC_2}\right), Z_3 = \left(R_3 + \frac{1}{sC_3}\right)$ and $Z_4 = R_4$,

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

$$\frac{V_0(s)}{V_{in}(s)} = \frac{\left(\frac{R_4}{R_3R_1C_2}\right)s}{s^2 + \left(\frac{1}{R_2C_2} + \frac{1}{R_3C_3}\right)s + \frac{1}{R_2R_3C_2C_3}} \quad (13)$$

which gives ω_o, *BW* and H_o as:

$$\omega_o = \frac{1}{\sqrt{R_2R_3C_2C_3}};\ BW = \frac{1}{R_2C_2} + \frac{1}{R_3C_3} \text{ and } H_o = \frac{R_2R_4C_3}{4R_1(R_2C_2 + R_3C_3)} \quad (14)$$

(B) Realization of ILPF, IHPF and IBPF responses:

Case I: If we select

$Z_1=\left(R_1 \| \frac{1}{sC_1}\right),\ Z_2=R_2,\quad Z_3=\left(R_3 \| \frac{1}{sC_3}\right)$ and $Z_4=R_4$ then

transfer function becomes

$$\frac{V_0(s)}{V_{in}(s)}=\frac{1}{\frac{\left(\frac{4}{R_2R_4C_1C_3}\right)}{s^2+\left(\frac{1}{R_3C_3}+\frac{1}{R_1C_1}\right)s+\frac{1}{R_1R_3C_1C_3}}} \tag{15}$$

which represents an ILPF with ω_o ,H_o and Q given by:

$$\omega_o=\frac{1}{\sqrt{R_1R_3C_1C_3}},\ H_o=\frac{4R_1R_3}{R_2R_4} \text{ and } Q=\frac{\sqrt{R_1R_3C_1C_3}}{R_1C_1+R_3C_3} \tag{16}$$

Case II: If the impedances are selected, such that

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

the transfer function becomes:

$$\frac{V_0(s)}{V_{in}(s)}=\frac{1}{\frac{\left(\frac{4R_1R_3}{R_2R_4}\right)s^2}{s^2+\left(\frac{1}{R_2C_2}+\frac{1}{R_4C_4}\right)s+\frac{1}{R_2R_4C_2C_4}}} \tag{17}$$

which gives an IHPF with ω_o, H_o and Q given by:

$$\omega_o=\frac{1}{\sqrt{R_2R_4C_2C_4}},\ H_o=\frac{4R_1R_3}{R_2R_4} \text{ and } Q=\frac{\sqrt{R_2R_4C_2C_4}}{R_2C_2+R_4C_4} \tag{18}$$

Case III: (a) If the impedances are selected, such that

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

then the transfer function realizes IBPF as

$$\frac{V_0(s)}{V_{in}(s)}=\frac{1}{\frac{\left(\frac{4R_1}{R_2R_4C_3}\right)s}{s^2+\left(\frac{1}{R_2C_2}+\frac{1}{R_3C_3}\right)s+\frac{1}{R_2R_3C_2C_3}}} \tag{19}$$

with ω_o, BW and H_o given by:

$$\omega_o=\frac{1}{\sqrt{R_2R_3C_2C_3}},\ BW=\frac{1}{R_2C_2}+\frac{1}{R_3C_3} \text{ and } H_o=\frac{4R_1R_3C_2}{R_4(R_2C_2+R_3C_3)} \tag{20}$$

(b) If we take $Z_1=R_1, Z_2=R_2,\ Z_3=\left(R_3+\frac{1}{sC_3}\right)$ and $Z_4=\left(R_4 \| \frac{1}{sC_4}\right)$,

then the transfer function represents the realization of IBPF

$$\frac{V_0(s)}{V_{in}(s)}=\frac{1}{\frac{\left(\frac{4R_1}{R_2R_4C_3}\right)s}{s^2+\left(\frac{1}{R_3C_3}+\frac{1}{R_4C_4}\right)s+\frac{1}{R_3R_4C_3C_4}}} \tag{21}$$

which realizes an IBPF with ω_o, BW and H_o given by:

$$\omega_o=\frac{1}{\sqrt{R_3R_4C_3C_4}},\ BW=\frac{1}{R_3C_3}+\frac{1}{R_4C_4} \text{ and } H_o=\frac{4R_1R_3C_2}{R_4(R_2C_2+R_3C_3)} \tag{22}$$

(c) If we take $Z_1=\left(R_1 \| \frac{1}{sC_1}\right), Z_2=\left(R_2+\frac{1}{sC2}\right)\ Z_3=R_3$, and $Z_4=R_4$, then the resulting transfer function yields the realization of IBPF as

$$\frac{V_0(s)}{V_{in}(s)}=\frac{1}{\frac{\left(\frac{4R_3}{R_2R_4C_1}\right)s}{s^2+\left(\frac{1}{R_2C_2}+\frac{1}{R_1C_1}\right)s+\frac{1}{R_2R_1C_2C_1}}} \tag{23}$$

which realizes an IBPF with ω_o, BW and H_o given by:

$$\omega_o=\frac{1}{\sqrt{R_1R_2C_1C_2}},\ BW=\frac{1}{R_2C_2}+\frac{1}{R_1C_1} \text{ and } H_o=\frac{4R_1R_3C_2}{R_4(R_2C_2+R_1C_1)} \tag{24}$$

(d) If we select

$Z_1=\left(R_1 \| \frac{1}{sC_1}\right), Z_2=R_2, Z_3=R_3$ and $Z_4=\left(R_4+\frac{1}{sC_4}\right)$, then the resulting transfer function represents the realization of IBPF

$$\frac{V_0(s)}{V_{in}(s)}=\frac{1}{\frac{\left(\frac{4R_3}{R_2R_4C_1}\right)s}{s^2+\left(\frac{1}{R_1C_1}+\frac{1}{R_4C_4}\right)s+\frac{1}{R_4R_1C_4C_1}}} \tag{25}$$

with ω_o, BW and H_o given by:

$$\omega_o=\frac{1}{\sqrt{R_1R_4C_1C_4}},\ BW=\frac{1}{R_1C_1}+\frac{1}{R_4C_4} \text{ and } H_o=\frac{4R_1R_3C_4}{R_2(R_4C_4+R_1C_1)} \tag{26}$$

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:

$$V_P=V_N=0, I_Z=\beta_P I_P-\beta_n I_n \text{ and } V_W=\alpha V_Z \tag{27}$$

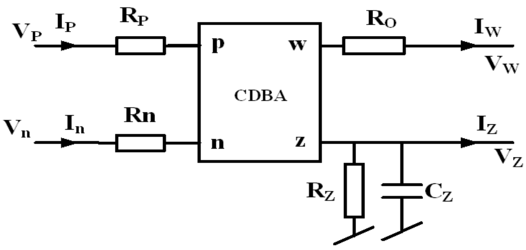

Fig. 3 Real CDBA model incorporating parasitic impedances

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where $\beta_n = (1-\varepsilon_n)$ and $\varepsilon_n(|\varepsilon_n| << 1)$ is the current tracking error from n-terminal to z-terminal, $\beta_P = (1-\varepsilon_P)$ and $\varepsilon_p(|\varepsilon_p| << 1)$ is the current tracking error from p-terminal to z-terminal, and $\alpha = (1-\varepsilon_v)$ and $\varepsilon_v(|\varepsilon_v| << 1)$ 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_z, 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:

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{LPF} = \frac{\dfrac{1}{\alpha_1\alpha_2\beta_{p_1}\beta_{p_2}R_1R_3}}{As^2+Bs+C} \qquad (28)$$

where $A = C_{z_1}C_{z_2} + (1+\beta_{n_1})(1+\beta_{n_2})C_2C_4$

$$B = \left(\frac{C_{z2}}{R_{z2}} + \frac{C_{z1}}{R_{z1}} + \frac{C_{z1}(1+\beta_{n2})}{R_4} + \frac{C_{z2}(1+\beta_{n1})}{R_2} + \left(\frac{C_2}{R_4}+\frac{C_4}{R_2}\right)(1+\beta_{n1})(1+\beta_{n2})\right)$$ and

$$C = \left(\frac{1}{R_{z_1}R_{z_2}} + \frac{(1+\beta_{n2})}{R_{z1}R_4} + \frac{(1+\beta n_1)}{R_{z_2}R_2} + \frac{(1+\beta_{n_1})(1+\beta_{n_2})}{R_2R_4}\right)$$

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{HPF} = \frac{\dfrac{1}{\alpha_1\alpha_2\beta_{p_1}\beta_{p_2}R_1R_3}s^2}{As^4+Bs^3+Cs^2+Ds+E} \qquad (29)$$

where

$A = C_{z_1}C_{z_2}$

$$B = \left(\frac{C_{z1}}{R_{z2}} + \frac{C_{z2}}{R_{z1}} + \frac{C_{z1}(1+\beta_{n2})}{R_4} + \frac{C_{z2}(1+\beta_{n1})}{R_2} + C_{z1}C_{z2}\left(\frac{1}{R_1C_1}+\frac{1}{R_3C_3}\right)\right)$$

$$C = \left(\frac{1}{R_{z1}R_{z2}} + \frac{C_{z2}(1+\beta_{n1})}{R_2} + \frac{C_{z1}(1+\beta_{n2})}{R_4} + \frac{(1+\beta_{n2})}{R_4R_{z1}} + \frac{(1+\beta_{n1})}{R_2R_{z2}} + \frac{(1+\beta_{n1})(1+\beta_{n2})}{R_2R_4} + \frac{C_{z1}}{R_{z2}}\left(\frac{1}{R_1C_1}+\frac{1}{R_3C_3}\right) + \frac{C_{z2}}{R_{z1}}\left(\frac{1}{R_1C_1}+\frac{1}{R_3C_3}\right) + \frac{C_{z1}C_{z2}}{R_1R_3C_1C_3}\right)$$

$$D = \left(\frac{1}{R_1C_1}+\frac{1}{R_3C_3}\right)\left(\frac{1}{R_{z1}R_{z2}} + \frac{(1+\beta_{n2})}{R_4R_{z1}} + \frac{(1+\beta_{n1})}{R_2R_{z2}} + \frac{(1+\beta_{n1})(1+\beta_{n2})}{R_2R_4}\right) + \frac{1}{R_1R_3C_1C_3}\left(\frac{C_{z1}}{R_{z2}} + \frac{C_{z2}}{R_{z1}} + \frac{C_{z2}(1+\beta_{n1})}{R_2} + \frac{C_{z1}(1+\beta_{n1})}{R_4}\right)$$

$$E = \frac{1}{R_1R_3C_1C_3}\left(\frac{1}{R_{z1}R_{z2}} + \frac{(1+\beta_{n2})}{R_4R_{z1}} + \frac{(1+\beta_{n1})}{R_2R_{z2}} + \frac{(1+\beta_{n1})(1+\beta_{n2})}{R_2R_4}\right)$$

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{BPF} = \frac{\dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{p}R_1R_3}s}{As^3+Bs^2+Cs+D} \qquad (30)$$

where

$A = C_{z1}C_{z2} + C_2C_{z2}(1+\beta_{n1})$

$$B = \left(\frac{C_{z1}}{R_{z2}} + \frac{C_{z2}}{R_{z1}} + \frac{C_{z1}(1+\beta_{n2})}{R_4} + \frac{C_{z2}(1+\beta_{n1})}{R_2} + \frac{C_2(1+\beta_{n1})}{R_{z2}} + \frac{(1+\beta_{n1})(1+\beta_{n2})C_2}{R_4} + \frac{C_{z1}C_{z2}}{R_1C_1} + \frac{C_2C_{z2}(1+\beta_{n1})}{R_1C_1}\right)$$

$$C = \left(\frac{1}{R_{z1}R_{z2}} + \frac{(1+\beta_{n2})}{R_4R_{z1}} + \frac{(1+\beta_{n1})}{R_2R_{z2}} + \frac{(1+\beta_{n1})(1+\beta_{n2})}{R_2R_4} + \frac{C_{z1}}{R_1C_1R_{z2}} + \frac{C_{z2}}{R_1C_1R_{z1}} + \frac{C_{z2}(1+\beta_{n1})}{C_1R_1R_2} + \frac{C_{z1}(1+\beta_{n2})}{C_1R_1R_4} + \frac{C_2(1+\beta_{n1})}{C_1R_1R_{z2}} + \frac{(1+\beta_{n1})(1+\beta_{n2})C_2}{R_2R_4C_1}\right)$$

$$D = \left(\frac{1}{R_1R_{z1}R_{z2}C_1} + \frac{(1+\beta_{n2})}{R_1R_4R_{z1}C_1} + \frac{(1+\beta_{n1})}{R_1R_2R_{z2}C_1} + \frac{(1+\beta_{n1})(1+\beta_{n2})}{R_1R_2R_4C_1}\right)$$

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:

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{LPF} \cong \frac{\dfrac{\alpha_1\alpha_2\beta_{p1}\beta_{P2}}{C_2C_4R_3R_1(1+\beta_{n1})(1+\beta_{n2})}}{s^2+\left(\dfrac{1}{R_2C_2}+\dfrac{1}{R_4C_4}\right)s+\dfrac{1}{C_2C_4R_2R_4}} \qquad (31)$$

which represents a LPF with non-ideal cut-off frequency ($\overline{\omega_0}$), gain ($\overline{H_0}$) and quality factor ($\overline{Q}$) given by

$$\overline{\omega_o} = \frac{1}{\sqrt{R_2R_4C_2C_4}} = \omega_0,\ \overline{Q} = \frac{\sqrt{R_2R_4C_2C_4}}{R_2C_2+R_4C_4} = Q$$
$$\overline{H_o} = \frac{\alpha_1\alpha_2\beta_{p1}\beta_{P2}R_2R_4}{(1+\beta_{n1})(1+\beta_{n2})R_1R_3} = \frac{4\alpha_1\alpha_2\beta_{p1}\beta_{P2}}{(1+\beta_{n1})(1+\beta_{n2})}H_0 \qquad (32)$$

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{HPF} \cong \frac{\dfrac{\alpha_1\alpha_2\beta_{p1}\beta_{P2}R_2R_4}{R_3R_1(1+\beta_{n1})(1+\beta_{n2})}s^2}{s^2+\left(\dfrac{1}{R_1C_1}+\dfrac{1}{R_3C_3}\right)s+\dfrac{1}{C_1C_3R_1R_3}} \qquad (33)$$

which represents a HPF with $\overline{\omega_0}$, $\overline{H_0}$ and $\overline{Q}$ given by

$$\overline{\omega_o} = \frac{1}{\sqrt{R_1R_3C_1C_3}} = \omega_0,$$
$$\overline{H_o} = \frac{\alpha_1\alpha_2\beta_{p1}\beta_{P2}R_2R_4}{R_3R_1(1+\beta_{n1})(1+\beta_{n2})} = \frac{4\alpha_1\alpha_2\beta_{p1}\beta_{P2}}{(1+\beta_{n1})(1+\beta_{n2})}H_0 \qquad (34)$$
$$\text{and } \overline{Q} = \frac{\sqrt{R_1R_3C_1C_3}}{R_1C_1+R_3C_3} = Q$$

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{BPF} \cong \frac{\dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{p}R_1R_3}s}{s^2+\left(\dfrac{1}{R_1C_1}+\dfrac{1}{R_2C_2}\right)s+\dfrac{1}{C_1C_2R_1R_2}} \qquad (35)$$

which represents a BPF with $\overline{\omega_0}$, $\overline{H_0}$ and $\overline{BW}$ given by

$$\overline{\omega_o} = \frac{1}{\sqrt{R_1R_2C_1C_2}} = \omega_0\ ;\ \overline{BW} = \frac{1}{R_2C_2} + \frac{1}{R_1C_1} = BW$$
$$\text{and } \overline{H_o} = \frac{4\alpha_1\alpha_2\beta_{p1}\beta_{P2}}{(1+\beta_{n1})(1+\beta_{n2})}H_0 \qquad (36)$$

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.

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

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{ILPF} = \frac{1}{\dfrac{s^2 \dfrac{C_{z1}C_{Z2}}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}C_1C_3} + Bs + C}{s^2 + \dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}}\left(\dfrac{1}{R_1C_1}+\dfrac{1}{R_3C_3}\right)s + \dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}C_1C_3R_1R_3}}} \quad (37)$$

where

$$B = \left(\frac{C_{z1}}{R_{z2}} + \frac{C_{z2}}{R_{z1}} + \frac{C_{z1}}{R_4}(1+\beta_{n2}) + \frac{C_{z2}}{R_2}(1+\beta_{n1})\right)\frac{1}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_1C_3}$$

$$C = \frac{1}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}}\left(\frac{1}{R_{z1}R_{z2}C_1C_3} + \frac{(1+\beta_{n2})}{C_1C_3R_4R_{z1}} + \frac{(1+\beta_{n1})}{C_1C_3R_2R_{z2}} + \frac{(1+\beta_{n1})(1+\beta_{n2})}{C_1C_3R_4R_2}\right)$$

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{IHPF} = \frac{1}{\dfrac{As^4 + Bs^3 + Cs^2 + Ds + E}{s^2 + \dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}}\left(\dfrac{1}{R_2C_2}+\dfrac{1}{R_4C_4}\right)s + \dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}R_2R_4C_2C_4}}} \quad (38)$$

where

$$A = \frac{C_{z1}C_{z2}R_1R_3}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}}$$

$$B = \frac{1}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}}\left(R_1R_3C_{z1}C_{z2} + \frac{C_{Z1}C_{z2}R_1R_3}{C_4R_4} + \frac{C_{Z2}R_1R_3}{R_{Z1}} + \frac{C_{Z1}R_1R_3}{R_4}(1+\beta_{n2}) + \frac{C_{Z2}R_1R_3}{R_2}(1+\beta_{n2})\right)$$

$$C = \frac{R_1R_3}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}}\left(\begin{array}{l}\dfrac{1}{R_{z1}R_{Z2}} + \dfrac{1}{C_1R_2R_Z} + \dfrac{1}{C_2R_2}\left(\dfrac{C_{z1}}{R_{z2}}+\dfrac{C_{z2}}{R_{z1}}\right) + \dfrac{1}{C_4R_4}\left(\dfrac{C_{z1}}{R_{z2}}+\dfrac{C_{z2}}{R_{z1}}\right) + \\ \dfrac{C_{z1}C_{z2}}{C_2C_4R_2R_4} + \dfrac{C_{z1}}{C_2R_2R_4}(1+\beta_{n2}) + \dfrac{C_{z2}}{C_2R_2R_4}(1+\beta_{n1}) + \\ \dfrac{1}{R_4R_{z1}}(1+\beta_{n2}) + \dfrac{1}{R_2R_{z2}}(1+\beta_{n1}) + \dfrac{1}{R_4R_2}(1+\beta_{n2})(1+\beta_{n1})\end{array}\right)$$

$$D = \frac{R_1R_3}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}}\left(\begin{array}{l}\dfrac{1}{R_{z1}R_{Z2}R_2} + \dfrac{1}{C_4R_4R_{Z1}R_{z2}} + \dfrac{1}{C_2C_4R_2R_4}\left(\dfrac{C_{z1}}{R_{z2}}+\dfrac{C_{z2}}{R_{z1}}\right) + \dfrac{1+\beta_{n2}}{C_2R_2C_4R_4} \\ + \dfrac{1+\beta_{n1}}{C_2R_2C_4R_4}\end{array}\right)$$

and $E = \dfrac{R_1R_3}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_2C_4R_2R_4R_{z1}R_{z2}}$

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{IBPF} = \frac{1}{\dfrac{As^3 + Bs^2 + Cs + D}{s^2 + \dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}}\left(\dfrac{1}{R_2C_2}+\dfrac{1}{R_3C_3}\right)s + \dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}R_2R_3C_2C_3}}} \quad (39)$$

where

$$A = \frac{C_{z1}C_{z2}R_1}{\alpha_1\alpha_2\beta_{P1}\beta_PC_3}$$

$$B = \frac{R_1}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_3}\left(\frac{C_{z1}}{R_{z2}} + \frac{C_{z2}}{R_{z1}} + \frac{C_{z1}}{R_4}(1+\beta_2) + \frac{C_{z2}}{R_2}(1+\beta_{n1}) + \frac{C_{z2}C_{z1}}{R_2C_2}\right)$$

$$C = \frac{R_1}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_3}\left(\begin{array}{l}\dfrac{1}{R_{z1}R_{Z2}} + \dfrac{1}{C_2R_2}\left(\dfrac{C_{z1}}{R_{z2}}+\dfrac{C_{z2}}{R_{z1}}\right) + \dfrac{C_{z1}}{C_2R_2R_4}(1+\beta_{n2}) + \\ \dfrac{(1+\beta_{n1})}{R_2R_{z2}} + \dfrac{(1+\beta_{n2})(1+\beta_{n1})}{R_4R_2}\end{array}\right)$$

$$D = \frac{R_1}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_3}\left(\frac{1}{R_{z1}R_{z2}R_2C_2} + \frac{1+\beta_{n2}}{C_2R_2R_4R_{z1}}\right)$$

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

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{ILPF} \cong \frac{1}{\dfrac{\dfrac{(1+\beta_{n1})(1+\beta_{n2})}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_1C_3R_4R_2}}{s^2 + \dfrac{1}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}}\left(\dfrac{1}{R_1C_1}+\dfrac{1}{R_3C_3}\right)s + \dfrac{1}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_1C_3R_1R_3}}} \quad (40)$$

which represents an ILPF with $\overline{\omega_0}$, $\overline{H_0}$ and $\overline{Q}$ given by:

$$\overline{\omega_0} = \frac{1}{\sqrt{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_1C_3R_1R_3}} = \frac{\omega_0}{\sqrt{\alpha_1\alpha_2\beta_{P1}\beta_{P2}}}$$

$$\overline{H_0} = \frac{R_1R_3(1+\beta_{n1})(1+\beta_{n2})}{R_2R_4} = \frac{(1+\beta_{n1})(1+\beta_{n2})H}{4} \quad (41)$$

$$\overline{Q} = \frac{\sqrt{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_1C_3R_1R_3}}{R_1C_1 + R_3C_3} = \sqrt{\alpha_1\alpha_2\beta_{P1}\beta_{P2}}\,Q$$

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{IHPF} \cong \frac{1}{\dfrac{\dfrac{R_1R_3(1+\beta_{n1})(1+\beta_{n2})}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}R_2R_4}s^2}{s^2 + \dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}}\left(\dfrac{1}{R_2C_2}+\dfrac{1}{R_4C_4}\right)s + \dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}C_2C_4R_2R_4}}} \quad (42)$$

which realizes IHPF with $\overline{\omega_0}$, $\overline{H_0}$ and $\overline{Q}$ given by:

$$\overline{\omega_0} = \frac{1}{\sqrt{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_2C_4R_2R_4}} = \frac{\omega_0}{\sqrt{\alpha_1\alpha_2\beta_{P1}\beta_{P2}}}$$

$$\overline{H_0} = \frac{R_1R_3(1+\beta_{n1})(1+\beta_{n2})}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}R_2R_4} = \frac{(1+\beta_{n1})(1+\beta_{n2})H}{4} \quad (43)$$

$$\overline{Q} = \frac{\sqrt{\alpha_1\alpha_2\beta_{P1}\beta_{P2}C_2C_4R_2R_4}}{R_2C_2 + R_4C_4} = \sqrt{\alpha_1\alpha_2\beta_{P1}\beta_{P2}}\,Q$$

$$\left.\frac{V_0(s)}{V_{in}(s)}\right|_{IBPF} \cong \frac{1}{\dfrac{\dfrac{R_1R_3(1+\beta_{n1})(1+\beta_{n2})}{\alpha_1\alpha_2\beta_{P1}\beta_{P2}R_2R_4}s}{s^2 + \dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}}\left(\dfrac{1}{R_2C_2}+\dfrac{1}{R_3C_3}\right)s + \dfrac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}R_2R_3C_2C_3}}} \quad (44)$$

which realizes IBPF with $\overline{\omega_0}$ and $\overline{BW}$ given by:

$$\overline{\omega_0} = \frac{1}{\sqrt{\alpha_1\alpha_2\beta_{p1}\beta_{P2}R_2R_3C_2C_3}} = \frac{\omega_0}{\sqrt{\alpha_1\alpha_2\beta_{p1}\beta_{P2}}},$$

$$\overline{BW} = \frac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}}\left(\frac{1}{R_2C_2}+\frac{1}{R_3C_3}\right) = \frac{1}{\alpha_1\alpha_2\beta_{p1}\beta_{P2}}BW \quad (45)$$

Equations (41), (43) and (45) reveal that the cutoff frequency, gain, quality factor and bandwidth of the ILPF, IHPF 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 ω_o, Q and *BW* of conventional filters (LPF, HPF, BPF) and inverse active filters (ILPF, IHPF, 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 II. Sensitivity of conventional filters/ inverse filters

Filter	Sensitivity
LPF	$S_{R_2}^{\omega O}=S_{R4}^{\omega O}=-\frac{1}{2}, S_{C2}^{\omega 0}=S_{C4}^{\omega O}=-\frac{1}{2}$, $S_{R_1}^{\omega 0}=S_{R_3}^{\omega 0}=0$, $S_{\alpha 1}^{\omega O}=S_{\alpha 2}^{\omega 0}=S_{\beta_{p1}}^{\omega O}=S_{\beta_{p2}}^{\omega O}=0=S_{\beta n_1}^{\omega 0}=S_{\beta n2}^{\omega 0}=0$ $S_{R2}^{Q}=S_{C2}^{Q}=\frac{R_4C_4}{2(C_2R_2+R_4C_4)}, S_{R4}^{Q}=S_{C4}^{Q}=\frac{R_2C_2}{2(C_2R_2+R_4C_4)}$, $S_{\alpha 1}^{\omega O}=S_{\alpha 2}^{\omega 0}=S_{\beta_{p1}}^{\omega O}=S_{\beta_{p2}}^{\omega O}=0=S_{\beta n_1}^{\omega 0}=S_{\beta n2}^{\omega 0}=0$
HPF	$S_{R_1}^{\omega O}=S_{R3}^{\omega O}=-\frac{1}{2}, S_{C1}^{\omega 0}=S_{C3}^{\omega O}=-\frac{1}{2}$, $S_{R_2}^{\omega 0}=S_{R_4}^{\omega 0}=0$ $S_{\alpha 1}^{\omega O}=S_{\alpha 2}^{\omega 0}=S_{\beta_{p1}}^{\omega O}=S_{\beta_{p2}}^{\omega O}=0$, $S_{\beta n_1}^{\omega 0}=S_{\beta n2}^{\omega 0}=0$ $S_{R1}^{Q}=S_{C1}^{Q}=\frac{R_3C_3}{2(C_1R_1+R_3C_3)}, S_{R3}^{Q}=S_{C3}^{Q}=\frac{R_1C_1}{2(C_1R_1+R_3C_3)}$, $S_{\alpha 1}^{\omega O}=S_{\alpha 2}^{\omega 0}=S_{\beta_{p1}}^{\omega O}=S_{\beta_{p2}}^{\omega O}=0=S_{\beta n_1}^{\omega 0}=S_{\beta n2}^{\omega 0}=0$
BPF Case(a)	$S_{R_1}^{\omega O}=S_{R4}^{\omega O}=-\frac{1}{2}, S_{C1}^{\omega 0}=S_{C4}^{\omega O}=-\frac{1}{2}$, $S_{R_2}^{\omega 0}=S_{R_4}^{\omega 0}=0$, $S_{\alpha 1}^{\omega O}=S_{\alpha 2}^{\omega 0}=S_{\beta_{p1}}^{\omega O}=S_{\beta_{p2}}^{\omega O}=0$, $S_{\beta n_1}^{\omega 0}=S_{\beta n2}^{\omega 0}=0$ $S_{R1}^{BW}=S_{C1}^{BW}=-\frac{R_4C_4}{C_1R_1+R_4C_4}, S_{R4}^{BW}=S_{C4}^{BW}=-\frac{R_1C_1}{C_1R_1+R_4C_4}$, $S_{\alpha 1}^{\overline{BW}}=S_{\alpha 2}^{\overline{BW}}=S_{\beta_{p1}}^{\overline{BW}}=S_{\beta_{p2}}^{\overline{BW}}=0$
ILPF	$S_{R_1}^{\omega O}=S_{R3}^{\omega O}=-\frac{1}{2}, S_{C1}^{\omega 0}=S_{C3}^{\omega O}=-\frac{1}{2}$, $S_{R_2}^{\omega 0}=S_{R_4}^{\omega 0}=0$, $S_{\alpha 1}^{\omega O}=S_{\alpha 2}^{\omega 0}=S_{\beta_{p1}}^{\omega O}=S_{\beta_{p2}}^{\omega O}=-\frac{1}{2}$, $S_{\beta n_1}^{\omega 0}=S_{\beta n2}^{\omega 0}=0$ $S_{R1}^{Q}=S_{C1}^{Q}=\frac{R_3C_3}{2(C_1R_1+R_3C_3)}, S_{R3}^{Q}=S_{C3}^{Q}=\frac{R_1C_1}{2(C_1R_1+R_3C_3)}$, $S_{\alpha 1}^{\omega O}=S_{\alpha 2}^{\omega 0}=S_{\beta_{p1}}^{\omega O}=S_{\beta_{p2}}^{\omega O}=\frac{1}{2}=S_{\beta n_1}^{\omega 0}=S_{\beta n2}^{\omega 0}=0$
IHPF	$S_{R_2}^{\omega O}=S_{R_4}^{\omega O}=S_{C4}^{\omega O}=S_{C_2}^{\omega O}=-\frac{1}{2}$, $S_{R_1}^{\omega 0}=S_{R_3}^{\omega 0}=0$, $S_{\alpha 1}^{\omega O}=S_{\alpha 2}^{\omega O}=S_{\beta_{p1}}^{\omega O}=S_{\beta p2}^{\omega O}=-\frac{1}{2}$, $S_{\beta n_1}^{\omega 0}=S_{\beta n2}^{\omega 0}=0$ $S_{R2}^{Q}=S_{C2}^{Q}=\frac{R_4C_4}{2(C_2R_2+R_4C_4)}, S_{R4}^{Q}=S_{C4}^{Q}=\frac{R_2C_2}{2(C_2R_2+R_4C_4)}$, $S_{\alpha 1}^{\omega O}=S_{\alpha 2}^{\omega 0}=S_{\beta_{p1}}^{\omega O}=S_{\beta_{p2}}^{\omega O}=\frac{1}{2}=S_{\beta n_1}^{\omega 0}=S_{\beta n2}^{\omega 0}=0$
IBPF Case(a)	$S_{R_2}^{\omega O}=S_{R_3}^{\omega O}=S_{C3}^{\omega O}=S_{C_2}^{\omega O}=-\frac{1}{2}$, $S_{R_1}^{\omega 0}=S_{R_4}^{\omega 0}=0$, $S_{\alpha 1}^{\omega O}=S_{\alpha 2}^{\omega O}=S_{\beta_{p1}}^{\omega O}=S_{\beta p2}^{\omega O}=-\frac{1}{2}$, $S_{\beta n_1}^{\omega 0}=S_{\beta n2}^{\omega 0}=0$ $S_{R2}^{BW}=S_{C2}^{BW}=-\frac{R_3C_3}{C_3R_3+R_2C_2}, S_{R3}^{BW}=S_{C3}^{BW}=-\frac{R_1C_1}{C_1R_1+R_4C_4}$, $S_{\alpha 1}^{\overline{BW}}=S_{\alpha 2}^{\overline{BW}}=S_{\beta_{p1}}^{\overline{BW}}=S_{\beta_{p2}}^{\overline{BW}}=-1$

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): $C_3 = C_4 = 10pF$, $R_1 = R_2 = R_4 = 10k\Omega$, $R_3 = 5k\Omega$

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): $C_2 = C_3 = 10pF$, $R_1 = R_2 = R_3 = 10k\Omega$, $R_4 = 20k\Omega$

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

MOSFETs	W:L
$M_1, M_2, M_{17}, M_{23}, M_{25}$	50 um:0.5um
$M_3, M_4, M_{18}, M_{24}, M_{26}$	100um:0.5um
M_5-M_{16}, M_{19}-M_{22}	3.33um:0.5um

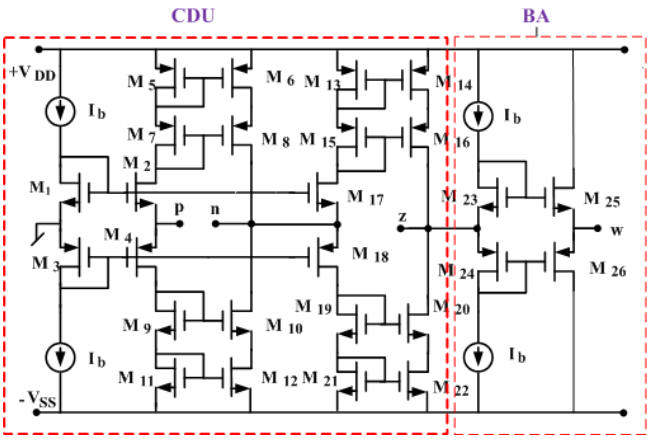
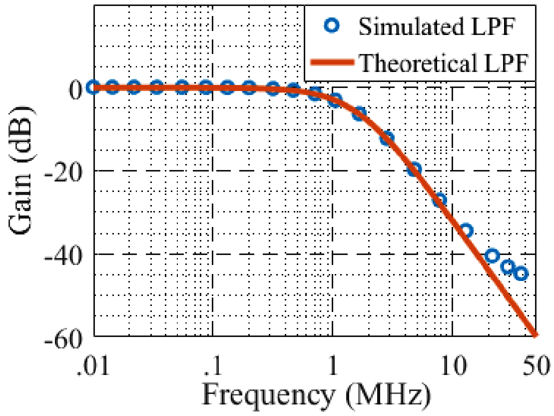
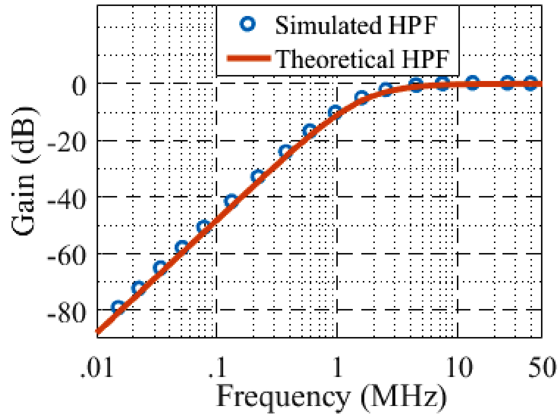


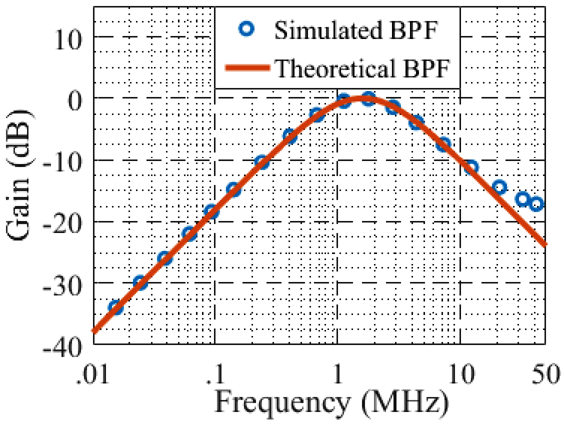
Fig. 4. CMOS realization of CDBA



(a)

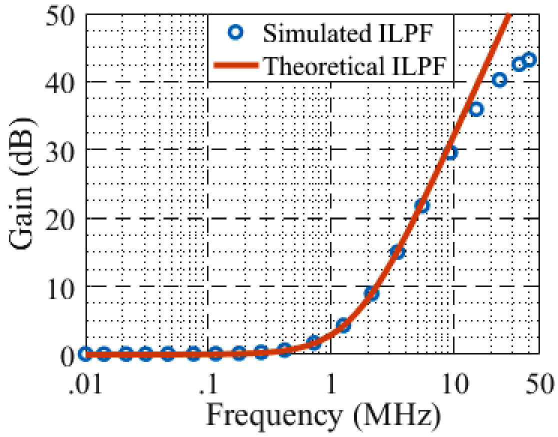


(b)

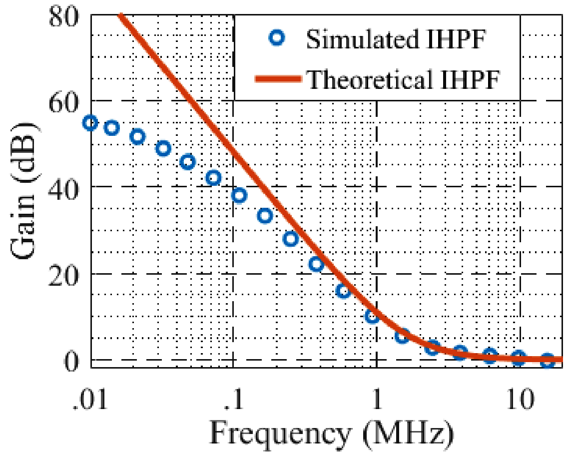


(c)

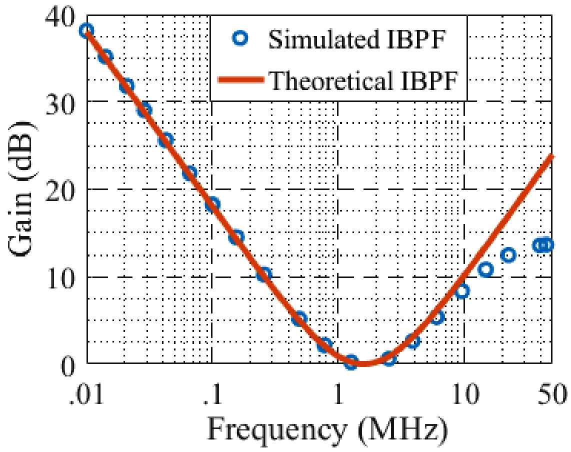
Fig. 5 Simulated frequency responses for conventional filters (a) LPF, (b) HPF and (c) BPF



(a)



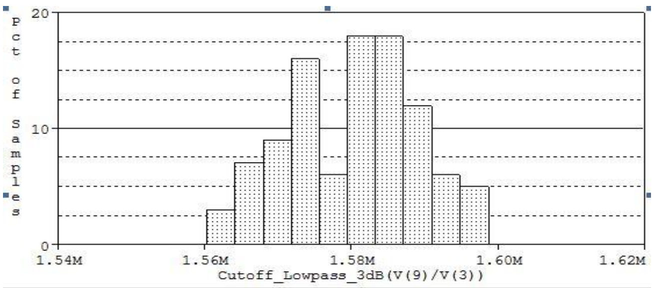
(b)



(c)

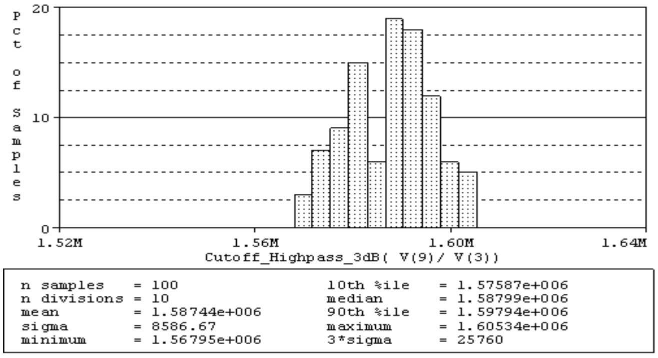
Fig. 6 Simulated frequency responses of inverse filters (a) ILPF (b) IHPF and (c) IBPF

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).

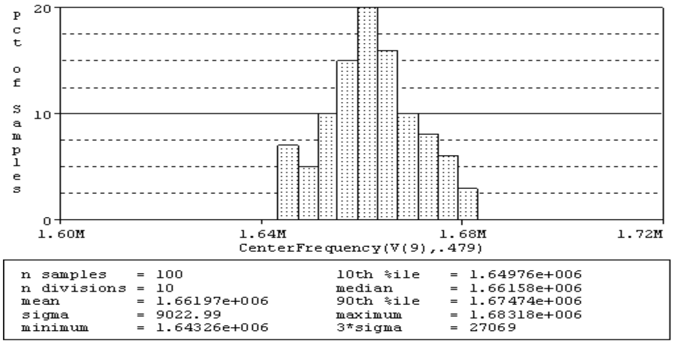



```
n samples    = 100              10th %ile   = 1.56841e+006
n divisions  = 10               median      = 1.58109e+006
mean         = 1.58032e+006     90th %ile   = 1.59103e+006
sigma        = 8763.41          maximum     = 1.59867e+006
minimum      = 1.56031e+006     3*sigma     = 26290.2
```

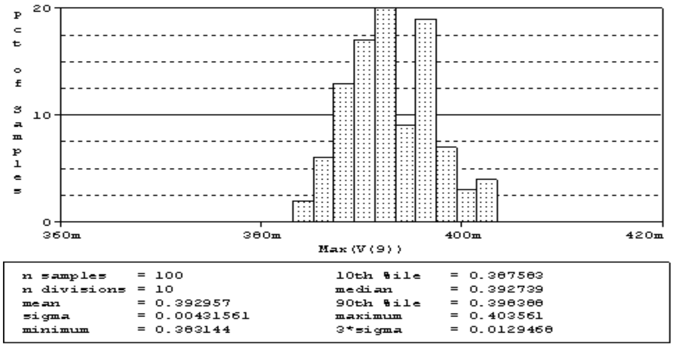
(a) Variation in cut-off frequency of LPF with 5 percent variation in resistance and capacitance value



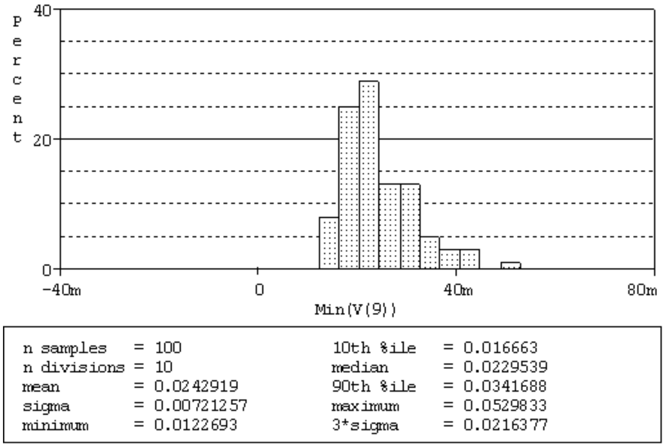
(b) Variation in cut-off frequency of HPF with 5% variation in resistance and capacitance value



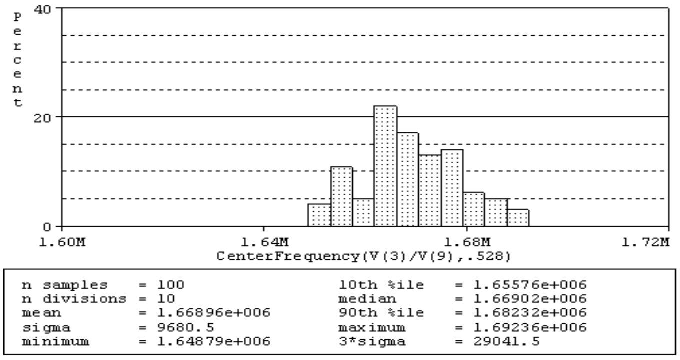
(c) Variation in centre frequency of BPF with 5% variation in resistance and capacitance value



(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.

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