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HIGHER ORDER MULTIFUNCTION FILTER USING CURRENT DIFFERENCING BUFFERED AMPLIFIER (CDBA)

SHEKHAR SUMAN BORAH[1], MOURINA GHOSH[1], ASHISH RANJAN[2]

Keywords: Current differencing buffered amplifier (CDBA), Current feedback operational amplifier (CFOA), Active multifunction filter.

This research article comes with a higher-order multifunction filter design, specifically low pass (LP), high pass (HP), and band pass (BP) filters using current differencing buffered amplifier (CDBA) as an active element. A general voltage transfer function can be observed in four admittance terms to facilitate the fifth-order filter function. The investigation of the proposed design is verified using PSPICE simulation using a CMOS-based CDBA structure as an active block and integrated with 0.5 µm CMOS technology parameter. To explore the effect of variations due to specific components on the proposed filters' performance has been examined along with the sensitivity, non-ideality analysis, and Monte-Carlo simulation. The simulation results are found in close agreement with the theoretical results. The proposed circuit achieved low power consumption and a low percentage of total harmonic distortion (%THD) which is suitable for low power VLSI design. The commercially available current-feedback operational amplifiers (CFOA based IC AD844AN is also used for experimental verification.

1. INTRODUCTION

In recent times, current-mode circuits have emerged as an advanced technique for the design of various analog signal processing over the conventional voltage-mode circuits [1,2]. The noticeable advantages of the current mode circuits offer low power dissipation, low input impedance, high output impedance, less sensitivity to switching noise, and a few more [3,4]. As a result, many current mode building blocks have been developed, contributing to the wide bandwidth and a high slew rate [5].

The beauty of the current mode circuits provides a wide range of signal processing circuits using various analog building blocks, viz. second generation current conveyor (CCCII) [2], voltage differencing transconductance amplifier (VDTA) [4], current differencing transconductance amplifier (CDTA) [6], four terminal floating nullortransconductance amplifier (FTFNTA) [7], operational transresistance amplifier (OTRA) [8], and many more. One simple active building block termed as current differencing buffered amplifier (CDBA) was introduced by Acar and Ozoguz in 1999 [3].

CDBA inherits all the advantages offered by other current modes (CM) analog building blocks (ABBs) in addition to the capability to eliminate response limitations due to parasitic [9–11]. It is a potent ABB combining voltage mode and current mode capability [12], and it can be realized by using the current feedback operational amplifier (CFOA) as ICAD844 [13]. Although the use of CDBA is found widespread, in literature, very few higher-order filters, precisely third-order, fourth-order, nth order [14–22], are available. Due to sharp cut off frequency, which is closer to the ideal response of the filter, higher-order filters have proven their popularity from the inception of filter design and widely useful for high-quality performance as hard disk drive (HDD), ultra-wide-band wireless communication (UWBWC), audio and video signal processing (AVSP), code division multiple access (CDMA) [23–26].

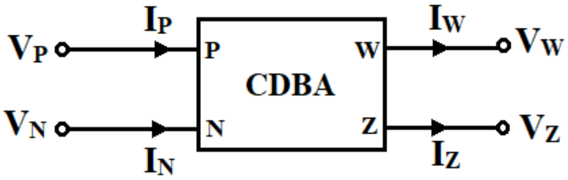
The motive of this article is to design fifth-order voltage mode (VM) low-pass (LP), high pass (HP), and band pass (BP) filters by using a single CDBA as an active element with passive components. A general model by utilizing four admittance terms (Y_P, Y_N, Y_W, Y_Z) is responsible for the filter transfer function's operation. Low sensitivities for cut-off frequency (ω_0) and quality factor (Q_0) for all filter functions are observed, which is suitable for active filter design. Moreover, performance evaluation viz. Monte-Carlo simulation and percentage of total harmonic distortion (%THD) provide a fruitful result for the proposed method. In this design, an attempt is made to design higher-order filters using a single active component and passive components. Both simulation and experimental tests verified the workability of the proposed design.

2. CIRCUIT DESCRIPTION

The ideal characteristic of CDBA in terms of current and voltage relationship can be described as:

$$\begin{aligned} &V_P = V_N = 0, \\ &I_Z = I_P - I_N, \\ &V_W = V_Z . \end{aligned} \tag{1}$$

The traditional circuit symbol and its CMOS based implementation [8] are shown in Fig. 1(a) and 1(b) respectively. A general multifunction filter (*LP*, *BP* and *HP*) based on four-admittance term and CDBA as an active element is shown in Fig. 2 [17].



(a)

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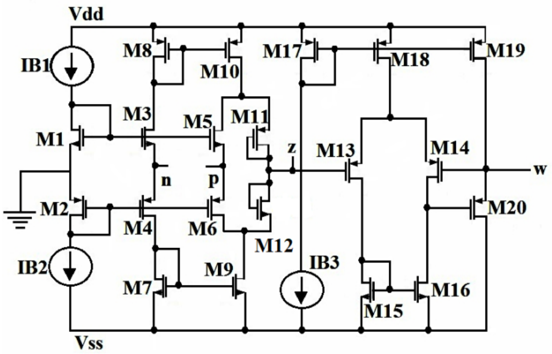
[1]Dept. of Electronics and Communication Engineering, Indian Institute of Information Technology Guwahati, Guwahati-781015, India
E-mails:borahsumanshekhar90@gmail.com, mourina_06@rediffmail.com
[2]Dept. of Electronics and Communication Engineering, National Institute of Technology Manipur, Imphal-795001, India
E-mail: ashish.ism@rediffmail.com



(b)

Fig. 1 – CDBA; a) Electrical circuit symbol; b) CMOS realization.

The traditional routine analysis gives the following transfer function as:

$$T(s)=\frac{V_{out}(s)}{V_{in}(s)}=\frac{Y_P-Y_N}{Y_Z-Y_W}=\frac{N(s)}{D(s)}. \tag{2}$$

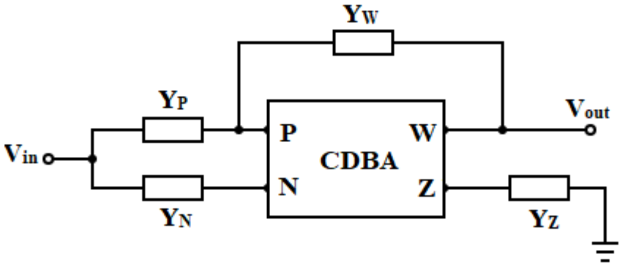
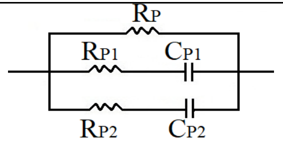
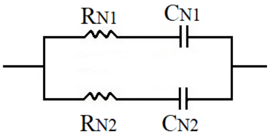
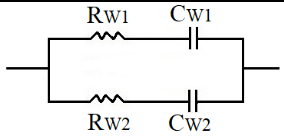
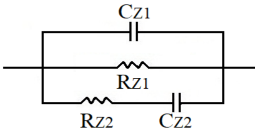
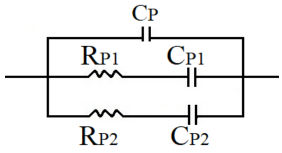
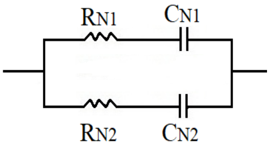
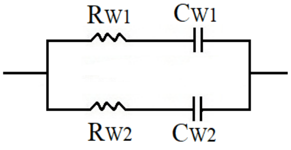
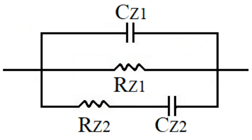
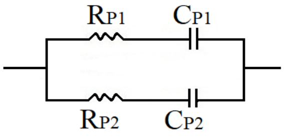
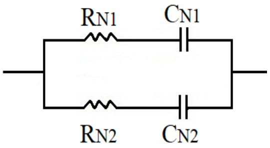
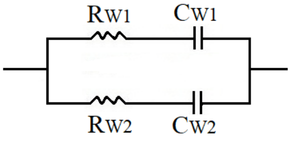
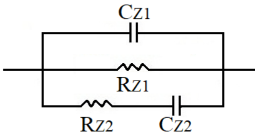


Fig. 2 – Proposed multifunction filter.

To achieve the fruitful frequency response for the multifunction filter, appropriate admittance terms have been selected which is a combination of resistors and capacitors. A complete table that designates different filter functions of different admittance terms is given in the Table 1.

Table 1

Different filter function with different admittance terms

Filter functions	Admittance Terms			
	YP	**YN**	**YW**	**YZ**
LP				
HP				
BP				

By considering the proper admittance terms, the transfer function of the fifth order *LP* Filter can be approximated by the following transfer function as:

$$T(s)\Big|_{LP}=\frac{V_{out}(s)}{V_{in}(s)}\Bigg|_{LP}=\frac{Y_P-Y_N}{Y_Z-Y_W}=\frac{N(s)}{D(s)}, \tag{3}$$

$$\begin{aligned}
&N(s)\big|_{LP}=R_{Z1}\left(1+sC_{Z2}R_{Z2}\right)\left(1+sC_{W1}R_{W1}\right)\left(1+sC_{W2}R_{W2}\right)\\
&\left[1+s^4C_{N1}C_{N2}C_{P1}R_{P1}C_{P2}R_{P2}\left\{R_{N1}R_{N2}\begin{pmatrix}R_{P1}R_{P2}+R_{P1}R_P+R_{P2}R_P\\-R_P\left(R_{N1}+R_{N2}\right)\end{pmatrix}\right\}\right]\\
&+s^3\left\{\begin{matrix}C_{P1}C_{P2}\left(R_{P1}R_{P2}+R_{P1}R_P+R_{P2}R_P\right)\\\left(C_{N1}R_{N1}+C_{N2}R_{N2}\right)-\begin{pmatrix}C_{N1}C_{N2}R_P\left(C_{P1}R_{P1}+C_{P2}R_{P2}\right)\left(R_{N1}+R_{N2}\right)\\+C_{P1}R_{P1}C_{P2}R_{P2}R_P\left(C_{N1}+C_{N2}\right)\end{pmatrix}\end{matrix}\right\}\\
&+s^2\left\{\begin{matrix}C_{P1}C_{P2}\left(R_{P1}R_{P2}+R_{P1}R_P+R_{P2}R_P\right)+C_{P1}R_{P1}+C_{P2}R_{P2}\\+C_{P1}R_P+C_{P2}R_P\left(C_{N1}R_{N1}+C_{N2}R_{N2}\right)+C_{N1}R_{N2}C_{N2}R_{N2}\\-\begin{pmatrix}C_{N1}C_{N2}R_P\left(R_{N1}+R_{N2}\right)+R_P\left(C_{P1}R_{P1}+C_{P2}R_{P2}\right)\\\left(C_{N1}+C_{N2}\right)\end{pmatrix}\end{matrix}\right\}\\
&+s\left\{C_{P2}\left(R_{P2}+R_P\right)+C_{P1}\left(R_{P1}+R_P\right)+C_{N1}R_{N1}+C_{N2}R_{N2}-R_P\left(C_{N1}+C_{N2}\right)\right\}
\end{aligned} \tag{4}$$

If the following conditions are satisfied:

$$\begin{aligned}
&i)\ C_{Z2}R_{Z2}=C_{N2}R_{N2},\ C_{W1}R_{W1}=C_{P1}R_{P1},\\
&C_{W2}R_{W2}=C_{P2}R_{P2},R_{Z1}=R_P,\\
&ii)\ R_{P1}R_{P2}+R_{P1}R_P+R_{P2}R_P=R_P\left(R_{N1}+R_{N2}\right),\\
&iii)\ C_{P1}C_{P2}\left(R_{P1}R_{P2}+R_{P1}R_P+R_{P2}R_P\right)\left(C_{N1}R_{N1}+C_{N2}R_{N2}\right),\\
&=\left\{\begin{matrix}C_{N1}C_{N2}R_P\left(C_{P1}R_{P1}+C_{P2}R_{P2}\right)\left(R_{N1}+R_{N2}\right)\\+C_{P1}R_{P1}C_{P2}R_{P2}R_P\left(C_{N1}+C_{N2}\right)\end{matrix}\right\}\\
&iv)\ C_{P1}C_{P2}\left(R_{P1}R_{P2}+R_{P1}R_P+R_{P2}R_P\right)+C_{P1}R_{P1}+C_{P2}R_{P2}\\
&+C_{P1}R_P+C_{P2}R_P\left(C_{N1}R_{N1}+C_{N2}R_{N2}\right)+C_{N1}R_{N1}C_{N2}R_{N2}\\
&=\left\{\begin{matrix}C_{N1}C_{N2}R_P\left(R_{N1}+R_{N2}\right)\\+R_P\left(C_{P1}R_{P1}+C_{P2}R_{P2}\right)\left(C_{N1}+C_{N2}\right)\end{matrix}\right\},\\
&v)\ C_{P2}\left(R_{P2}+R_P\right)+C_{P1}\left(R_{P1}+R_P\right)\\
&+C_{N1}R_{N1}+C_{N2}R_{N2}=R_P\left(C_{N1}+C_{N2}\right).
\end{aligned} \tag{5}$$

The modified *N*(*s*) of *LP* filter can be represented by considering the proper conditions given in (5) as:

$$N(s)\big|_{LP}=1. \tag{6}$$

A similar proceeding for fifth order *HP* Filter can be examined in which the transfer function becomes:

$$T(s)\Big|_{HP} = \frac{V_{out}(s)}{V_{in}(s)}\Bigg|_{HP} = \frac{Y_P - Y_N}{Y_Z - Y_W} = \frac{N(s)}{D(s)}. \tag{7}$$

Similarly, the $N(s)$ of the *HP* and *BP* filter can be represented by considering the proper conditions as:

$$N(s)\Big|_{HP} = s^5 C_P C_{N1} C_{P1} C_{N2} C_{P2} R_{N1} R_{P1} R_{N2} R_{Z1} R_{P2}, \tag{8}$$

$$\begin{aligned} &N(s)\Big|_{BP} = \\ &= s^3 \left\{ \begin{array}{l} \left(\begin{array}{l} C_{P1}C_{N1}C_{N2}R_{N1}R_{Z1}R_{N2} + C_{N1}C_{P2}C_{N2}R_{N1}R_{N2}R_{Z1} \\ +C_{P1}C_{N2}C_{P2}R_{N2}R_{Z1}R_{P2} + C_{N1}C_{P1}C_{P2}R_{N1}R_{Z1}R_{P2} \\ +C_{P1}C_{N2}C_{P2}R_{P1}R_{N2}R_{Z1} + C_{N1}C_{P1}C_{P2}R_{N1}R_{P1}R_{Z1} \end{array} \right) \\ - \left(\begin{array}{l} C_{N1}C_{P1}C_{P2}R_{P1}R_{Z1}R_{P2} + C_{P1}C_{N2}C_{P2}R_{P1}R_{Z1}R_{P2} \\ +C_{N1}C_{N2}C_{P2}R_{N2}R_{Z1}R_{P2} + C_{N1}C_{P1}C_{N2}R_{P1}R_{N2}R_{Z1} \\ +C_{N1}C_{N2}C_{Z1}R_{N1}R_{Z1}R_{P2} + C_{N1}C_{P1}C_{N2}R_{N1}R_{P1}R_{Z1} \end{array} \right) \end{array} \right\}. \end{aligned} \tag{9}$$

The D(s) of all the fifth order filters will be similar, i.e.

$$\begin{aligned} &D(s)\Big|_{LP,HP,BP} \\ &= s^5 C_{Z1}C_{W1}C_{P1}C_{W2}C_{Z2}R_{P1}R_{Z1}R_{Z2}R_{W1}R_{W2} \\ &+s^4 \left\{ \begin{array}{l} \left(\begin{array}{l} C_{Z1}C_{W1}C_{Z2}C_{W2}R_{Z1}R_{W1}R_{Z2}R_{W2} \\ +C_{Z1}C_{W1}C_{P1}C_{W2}R_{Z1}R_{W1}R_{P1}R_{W2} \\ +C_{Z1}C_{P1}C_{Z2}C_{W2}R_{Z1}R_{P1}R_{Z2}R_{W2} \\ +C_{Z1}C_{W1}C_{P1}C_{Z2}R_{Z1}R_{W1}R_{P1}R_{Z2} \\ +C_{W1}C_{P1}C_{W2}C_{Z2}R_{W1}R_{P1}R_{W2}R_{Z2} \end{array} \right) \\ - \left(\begin{array}{l} C_{W1}C_{P1}C_{W2}C_{Z2}R_{W1}R_{P1}R_{Z1}R_{Z2} \\ +C_{Z1}C_{W1}C_{P1}C_{W2}R_{Z1}R_{Z2}R_{W1}R_{W2} \end{array} \right) \end{array} \right\} \\ &+s^3 \left\{ \begin{array}{l} \left(\begin{array}{l} C_{Z1}C_{W1}C_{W2}R_{W1}R_{Z1}R_{W2} + C_{Z1}C_{W1}C_{Z2}R_{Z1}R_{W2}R_{Z2} \\ +C_{Z1}C_{W1}C_{Z2}R_{W1}R_{Z1}R_{Z2} + C_{W1}C_{W2}C_{Z2}R_{W1}R_{W2}R_{Z2} \\ +C_{W1}C_{W2}C_{Z2}R_{W1}R_{Z1}R_{W2} + C_{Z1}C_{P1}C_{W2}R_{P1}R_{Z1}R_{W2} \\ +C_{Z1}C_{W1}C_{P1}R_{W1}R_{P1}R_{Z1} + C_{Z1}C_{P1}C_{Z2}R_{P1}R_{Z1}R_{Z2} \\ +C_{W1}C_{P1}C_{W2}R_{W1}R_{P1}R_{W2} + C_{P1}C_{W2}C_{Z2}R_{P1}R_{W2}R_{Z2} \\ +C_{W1}C_{P1}C_{Z2}R_{W1}R_{P1}R_{Z2} + C_{P1}C_{W2}C_{Z2}R_{P1}R_{W2}R_{Z2} + \\ C_{W1}C_{P1}C_{Z2}R_{W1}R_{P1}R_{Z1} \end{array} \right) \\ - \left(\begin{array}{l} C_{W1}C_{P1}C_{Z2}R_{P1}R_{Z1}R_{Z2} + C_{P1}C_{W2}C_{Z2}R_{P1}R_{Z1}R_{Z2} + \\ C_{W1}C_{P1}C_{W2}R_{P1}R_{Z1}R_{W2} + C_{W1}C_{P1}C_{W2}R_{W1}R_{P1}R_{Z1} \\ +C_{W1}C_{W2}C_{Z2}R_{Z1}R_{W2}R_{Z2} + \\ C_{W1}C_{W2}C_{Z2}R_{W1}R_{Z1}R_{Z2} \end{array} \right) \end{array} \right\} \\ &+s^2 \left\{ \begin{array}{l} \left(\begin{array}{l} C_{Z1}C_{W2}R_{Z1}R_{W2} + C_{Z1}C_{W1}R_{Z1}R_{W1} + C_{Z1}C_{Z2}R_{Z1}R_{Z2} \\ +C_{Z1}C_{W2}R_{W1}R_{W2} + C_{W2}C_{Z2}R_{W2}R_{Z2} + C_{W1}C_{Z2}R_{W1}R_{Z2} \\ +C_{W2}C_{Z2}R_{Z1}R_{W2} + C_{W1}C_{Z2}R_{W1}R_{Z1} + C_{Z1}C_{P1}R_{Z1}R_{P1} \\ +C_{P1}C_{W2}R_{P1}R_{W2} + C_{W1}C_{P1}R_{W1}R_{P1} + C_{P1}C_{Z2}R_{P1}R_{Z2} + \\ C_{P1}C_{Z2}R_{P1}R_{Z1} \end{array} \right) \\ - \left(\begin{array}{l} C_{W1}C_{P1}R_{P1}R_{Z1} + C_{W1}C_{Z2}R_{Z1}R_{Z2} + C_{P1}C_{W2}R_{P1}R_{Z1} + \\ C_{W2}C_{Z2}R_{Z1}R_{Z2} + C_{W1}C_{W2}R_{Z1}R_{W2} + C_{W1}C_{W2}R_{W1}R_{Z1} \end{array} \right) \end{array} \right\} \\ &+s \left\{ \left(\begin{array}{l} C_{Z1}R_{Z1} + C_{W2}R_{W2} + C_{W1}R_{W1} + C_{Z2}R_{Z2} + \\ C_{Z2}R_{Z1} + C_{P1}R_{P1} \end{array} \right) - \left(C_{W1}R_{Z1} + C_{W2}R_{Z1} \right) \right\} \\ &+1. \end{aligned} \tag{10}$$

The modified $N(s)$ for eqs. (6), (8), (9) and $D(s)$ for eq. (10) resembles the transfer function of *LP*, *HP* and *BP* filters respectively. The pole frequency (ω_0) and quality factor (Q_0) of the proposed filter for all the three filters can be obtained as:

$$\omega_0 = \frac{1}{\sqrt[5]{R_{W1}C_{W1}C_{Z1}C_{P1}C_{W2}C_{Z2}R_{P1}R_{Z1}R_{Z2}R_{W2}}}, \tag{11}$$

$$\begin{aligned} &Q_0 = \\ &= \frac{1/\omega_0}{\left\{ \begin{array}{l} C_{Z1}R_{Z1} + C_{W2}R_{W2} + C_{W1}R_{W1} + C_{Z2}R_{Z2} \\ +C_{Z2}R_{Z1} + C_{P1}R_{P1} - C_{W1}R_{Z1} - C_{W2}R_{Z1} - 1/\omega_0 \end{array} \right\}}, \end{aligned} \tag{12}$$

It can be observed that the proper selection of R_{W1} and C_{W1} can tune the cut-off frequency, and the appropriate section of C_{W2} and R_{W2} can adjust the quality factor. The sensitivity of ω_o with respect to passive elements for fifth order filters may be expressed as:

$$\begin{aligned} &S^{\omega_0}_{C_{Z1}} = S^{\omega_0}_{R_{Z1}} = S^{\omega_0}_{C_{Z2}} = S^{\omega_0}_{R_{Z2}} = S^{\omega_0}_{C_{W1}} = S^{\omega_0}_{C_{W2}} = S^{\omega_0}_{R_{W2}} = \\ &S^{\omega_0}_{C_{N1}} = S^{\omega_0}_{R_{N1}} = -\frac{1}{5}. \end{aligned} \tag{13}$$

This analysis exhibits low value of sensitivity which is suitable for better filter frequency response.

3. NON IDEALITY ANALYSIS

In practical, the frequency response of filter deviates from ideal frequency response due to device mismatch that may arises from non-ideality [26] present in CDBA. There may exist current and voltage tracking errors. Including these errors into consideration, the terminal relationship of the CDBA (1) can be modified as:

$$\left. V_P = V_N = 0; I_Z = \beta_X I_P - \beta_Y I_N; V_W = \gamma V_Z \right\}, \tag{14}$$

where, $\beta_x = 1 - \varepsilon_x \left(|\varepsilon_x| \langle\langle 1 \right)$ and, $\beta_y = 1 - \varepsilon_y \left(|\varepsilon_y| \langle\langle 1 \right)$ are the current tracking errors from p and n terminal to z terminal, respectively. $\boxed{\gamma = 1 - \varepsilon_v \left(|\varepsilon_v| \langle\langle 1 \right)}$ is the voltage tracking error from z to w terminal of the CDBA. Including these non-idealities into the transfer function, the pole frequency and quality factors are modified as:

$$\omega'_0 = \frac{\beta_X \gamma}{\sqrt[5]{C_{Z1}C_{W1}C_{P1}C_{W2}C_{Z2}R_{P1}R_{Z1}R_{Z2}R_{W1}R_{W2}}}, \tag{15}$$

$$Q'_0 = \frac{1/\omega'_0}{\left(\begin{array}{l} C_{Z1}R_{Z1} + C_{W2}R_{W2} + C_{W1}R_{W1} + C_{Z2}R_{Z2} + \\ +C_{Z2}R_{Z1} + C_{P1}R_{P1} - C_{W1}R_{Z1} - C_{W2}R_{Z1} - 1/\omega'_0 \end{array} \right)}. \tag{16}$$

Finally, the non-ideal active sensitivities of the natural frequency (ω_0) can be obtained as:

$$S^{\omega_0}_{\beta_X} = S^{\omega_0}_{\gamma} = -\frac{1}{5}. \tag{17}$$

Active sensitivities of the proposed fifth order multifunction filter offer very low value of sensitivity.

4. SIMULATION RESULTS

In order to validate the theoretical prediction, the performance of the proposed *LPF*, *HPF* and *BPF* are evaluated with CMOS implementation of CDBA as shown in Fig. 1(b) [11] with dc power supply voltages $V_{DD} = V_{SS} = \pm 1.5$ V and bias currents $I_{B1} = I_{B2} = I_{B3} = 30$ µA. The simulations are performed using PSPICE based on 0.5 µm MOSIS (AGILENT) CMOS technology parameters. Aspect ratios used for different transistors are given in [26]. The designed values of resistances and capacitances to obtain fifth-order *LP*, *HP*, and *BP* filter output for a cut-off frequency of $f_0 = 10$ kHz are shown in Table 2.

The simulated and theoretical frequency response for the gain and phase of *LP*, *HP*, and *BP* filters are shown in Fig. 3, 4 and 5, respectively. It is observed that the theoretical values closely agree with the simulated results. In Fig. 3 it is observed that there is a deviation of simulated gain at higher frequencies for *LP* filter. To judge the quality of the output, total harmonic distortion (%THD) is obtained, shown in Fig. 6 by applying a sine wave signal with a frequency of 10 kHz. It shows that the output distortion is very low and within 5 % up to 400 mV for all the filter responses. Hence, it may be claimed that the output is good quality and the harmonic range is high.

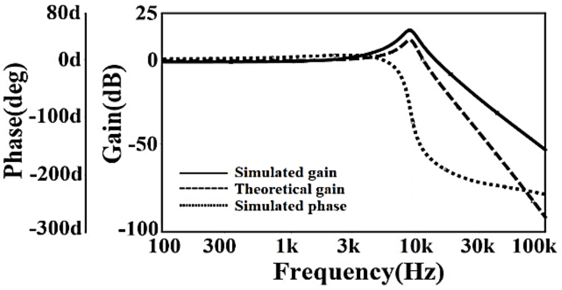


Fig. 3 – Frequency and Phase response of LP filter.

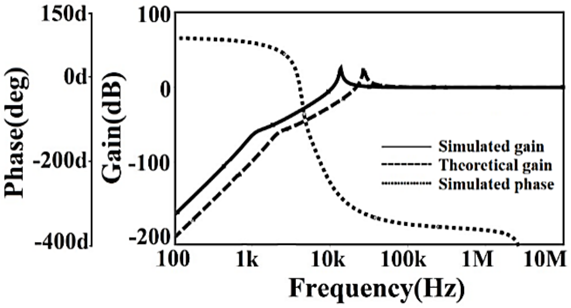


Fig. 4 – Frequency and Phase response of HP filter.

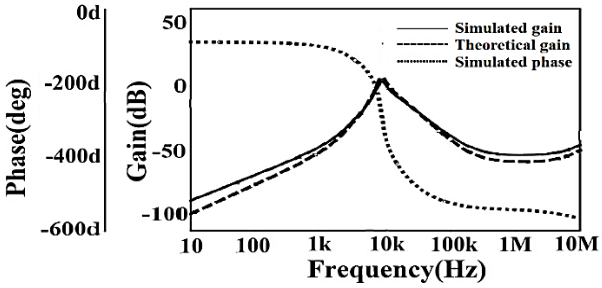


Fig. 5 – Frequency and Phase response of BP filter.

Table 2

Designed values of passive components used for higher order filters

Filter Types	Component values for 10kHz cut-off frequency
LP	$R_P= R_{P2}$=1.92 MΩ, R_{P1}=0.32 MΩ, $R_{N1}= R_{N2}$=0.48 MΩ, R_{Z1}= 1.77 MΩ, R_{Z2}= 5.72 kΩ, R_{W1}= 48.16 kΩ, R_{W2}= 4.16 kΩ, C_{P1}= 24.88 pF, C_{P2}= 2.07 pF, C_{N1}= 3.3 pF, C_{N2}= 11 pF, C_{Z1}= 199 pF, C_{Z2}= 927 pF, C_{W1}= 165 pF, C_{W2}= 956 pF
HP	C_P=199 pF, R_{P1}=480 kΩ, C_{P1}=33 pF, R_{P2}=1.968 kΩ, C_{P2}=2.695 nF, R_{N1}=10 kΩ, C_{N1}=796 pF, R_{N2}=1.872 kΩ, C_{N2}=2.1 2nF, C_{Z1}=199 pF, R_{Z1}=1.77 MΩ, C_{Z2}=927pF, R_{Z2}=5.72 kΩ, R_{W1}=48.16 kΩ, R_{W2}=4.16 kΩ, C_{W1}=165 pF, C_{W2}= 956 pF
BP	R_{P1}=480 kΩ, C_{P1}=33 pF, R_{P2}=17.76 kΩ, C_{P2}=298.35 pF, R_{N1}=40 kΩ, C_{N1}=199 pF, R_{N2}=30 kΩ, C_{N2}=132.66 pF, C_{Z1}=199pF, R_{Z1}=1.77 MΩ, C_{Z2}=927 pF, R_{Z2}=5.72 kΩ, R_{W1}=48.16 kΩ, R_{W2}=4.16 kΩ, C_{W1}=165 pF, C_{W2}=956 pF

The performance of the proposed filter topology is also evaluated through well-known Monte Carlo statistical analysis by setting the values of all the passive components in 5% tolerance. The derived histogram after 100 simulation runs for all the filters is shown in Fig. 7. The noise analysis curve for both input and output voltage is shown in the Fig. 8 for all the filters. It shows that the output voltage noise is low up-to 10 kHz for all the filters, whereas the input voltage noise is very low beyond 1 kHz. The total power consumption of the proposed circuit is 0.821 mW.

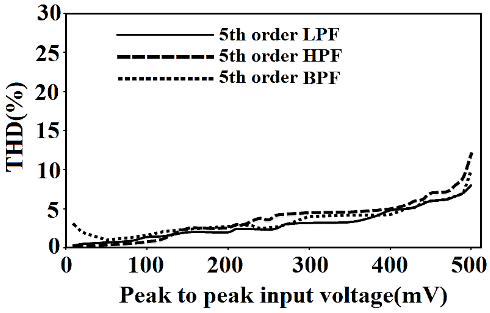


Fig. 6 – Variation of %THD with respect to input voltage amplitude.

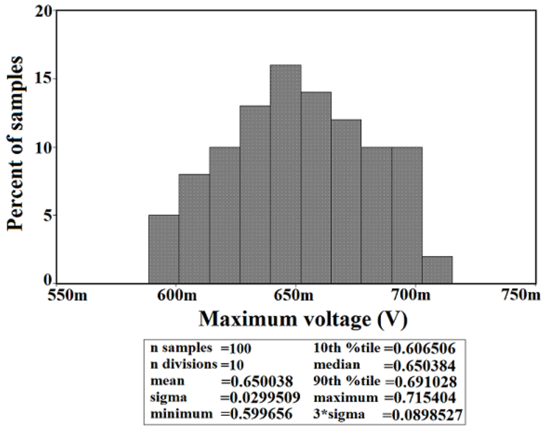


Fig. 7 – Monte-Carlo simulation.

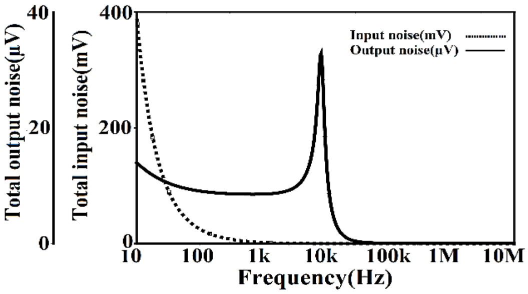


Fig.8 – Input and output noise analysis.

5. EXPERIMENTAL RESULTS

The proposed fifth order multifunction filters are also tested experimentally to verify the theory. The commercial IC AD844 is used to implement CDBA as shown in the Fig. 9 with a dc supply voltage of ±5 V.

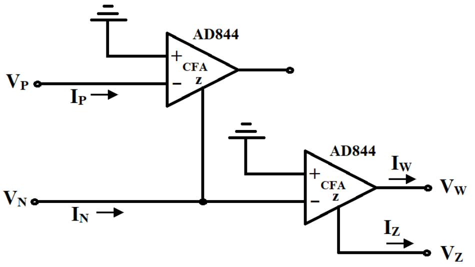
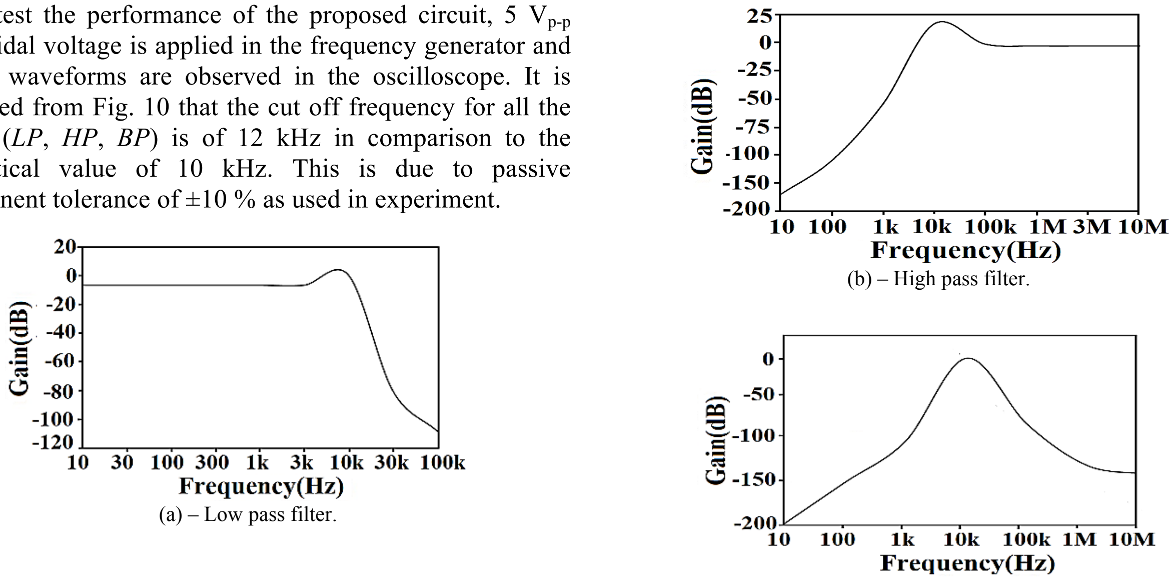


Fig.9 – AD844 based CDBA.

To test the performance of the proposed circuit, 5 $V_{p\text{-}p}$ sinusoidal voltage is applied in the frequency generator and output waveforms are observed in the oscilloscope. It is observed from Fig. 10 that the cut off frequency for all the filters (*LP*, *HP*, *BP*) is of 12 kHz in comparison to the theoretical value of 10 kHz. This is due to passive component tolerance of ±10 % as used in experiment.



(a) – Low pass filter.

(b) – High pass filter.

(c) – Band pass filter.

Fig. 10 – The experimental frequency response of the filters.

6. COMPARISON

Table 3

Comparison of the proposed work with the previously reported work

References (Figures)	Order and Standard Filter function	No. of CDBA (Active elements)	No. of Passive components R/C	Technology parameter	Power dissipation	No. of transistors	Operating Supply Voltages (V)	All passive component are grounded/virtually grounded
[4] (Fig. 4)	3 AP	4	11/3	CFA AD844 (BJT)	–	144	Not Reported	YES
[10] (Fig. 3)	2 and LP, BP, HP, BS, AP	2	4/2	AD844 (BJT)	–	72	±12V	YES
[11] (Fig. 3)	2 and LP, HP, BP, AP, Notch	1	4/2	AD844 (BJT)	–	36	±12V	YES
[12] (Fig. 2)	2 and BP	1	2/2-3	AD844 (BJT)	–	50	±2.5V	YES
[14] (Fig. 2 and Fig. 3)	2 and LP, BP, BS, HP, AP	3	2-7/2-7	CFA AD844/AD (BJT)	–	108	±12V	YES
[16] (Fig. 2 and Fig. 3)	2 and LP, BP, HP	1/2	3/2-3	AD844 (BJT)	–	36/72	±12V	YES
[18] (Fig. 2)	2 and LP, BS, HP, BP, AP	3	2-4/ 2-4	CFA AD844 (BJT)	–	108	±12V	YES
[19] (Fig. 2)	2 and LP, BP, HP, BS, AP	3	2/2	AT&T ALA 400-CBIC-R Bipolar CDBA	–	60	±1V	YES
[20] (Fig. 3)	2 and LP, BP, HP, BS, AP	1	4/4	CMOS	–	20	-	YES
[21] (Fig. 2)	2 and LP, BP, HP	1	4/2	0.18µm MOSIS (AGILENT) CMOS	–	20	±0.9V	NO
[22] (Fig. 4)	2 and LP, HP, BP, BS, AP	2	4/4	0.5µm MIETEC CMOS	–	40	±2.5V	NO
[23] (Fig. 6)	3 and LP	3	6/3	0.35µmTSMC2P4 MCMOS	–	60	±1.65V	YES
[24] (Fig. 4)	3and LP	1	5/4	3µm level-3 CMOS	–	51	±5V	YES
Proposed work	5 and LP, BP, HP	1	8-9/8-9	0.5µm MOSIS (AGILENT) CMOS	0.821mW	20	±1.5V	YES

Table 3 presents a summary of the proposed filter parameters with other existing designs. A comparative study of the proposed technique in terms of various parameters viz. order with standard filter function, a physical count of active and passive components, technology parameter, operating supply voltage, power dissipation, grounded passive elements or not, several transistors are well put with other reported articles for a fair comparison. The following comparative statements are observed: (i) The proposed fifth-order filter design use only a single CDBA block as an active element. Whereas the filters of [11,12,20,21,24] also use only one active element except that the operating supply voltage is considerably higher in those reported papers. (ii) The filter presented in [4,14,18] uses an excessive number of transistors compared to the proposed work. (iii) All the passive components are grounded/ virtually grounded, reducing the parasitic capacitances, but the filter reported in [21,22] uses floating passive components.

7. CONCLUSION

This article presents fifth-order multifunction LP, HP, and BP filter configurations using CDBA with some passive components matching criteria. Therefore, the circuits offer several advantageous features like:

(i) use of single CDBA,
(ii) Low output impedance hence suitable for cascading,
(iii) All the capacitors are grounded or virtually grounded, which can easily be fabricated for VLSI,
(iv) For all the filters, %THD is within the acceptable limit,
(v) PSPICE simulation results using CMOS and AD844 demonstrate the feasibility of the presented circuit.

Experimental results also verify the proposed work. Finally, an attempt is made for the design of higher-order filters.

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