CMOS CDBA-Based Inverse Filter Structure

Ram Bhagat, D. R. Bhaskar, Pragati Kumar

Abstract: ***This paper presents a voltage-mode(VM) tunable multifunction inverse filter configuration employing current differencing buffered amplifiers (CDBA). The presented structure utilizes two CDBAs, two/three capacitors and four/five resistors to realize inverse low pass filter (ILPF), inverse high pass filter (IHPF), inverse band pass filter (IBPF), and inverse band reject filter(IBRF) from the same circuit topology by suitable selection(s) of the branch admittances(s). PSPICE simulations have been performed with 0.18µm TSMC CMOS technology to validate the theory. Some sample experimental results have also been provided using off-the-shelf IC AD844 based CDBA.***

Keywords: Analog Filters, Inverse Active Filters, Analog Signal Processing, CDBA

I. INTRODUCTION

CDBA is an useful active building block (ABBs), which has been used widely in the field of analog signal processing and signal generation applications as it provides ideally zero input impedance at its input terminals and low output impedance(ideally zero at its output terminal).

Like filtering, inverse filtering is a frequency domain concept used in signal processing. It can be implemented in analog or in digital form. The transfer function of an analog active inverse filter is reciprocal to its conventional analog active filter. The inverse active filters are useful in removing the undesirable gain/phase alterations introduced in the signal while it is being processed by a system.

In past, several inverse active filters were reported using various active building blocks (ABBs) [1]-[11]. The notable features of these reported inverse active filters are shown in Table I. From Table I, it has been observed that there are limited number of CDBA-based inverse active filters [9]-[11]. In references [9] and [10], the intrinsic property of the CDBAs has not been fully utilized as n-terminals of both the CDBAs have been left open. In [11], conventional low pass filter, high pass filter, and band pass filter as well as ILPF, IHPF and IBPF have been reported from the same circuit topology.

This communication present a new multifunction inverse filter structure using two CDBAs, three/four resistors and two/three capacitors to realize second-order tunable ILPF, IHPF, IBPF and IBRF.

Table I An overview of inverse active filter structures

Ref.	No of ABBs	Resistors used	Capacitors used	Tunability
[1]	1 NULLOR	4	2	No
[2]	3 CFOA	4	2	No
[3]	3 CFOA	3-5	2	Yes
[4]	3 CFOA	3	3	No
[5]	3 CFOA	2-3	3-4	Yes
[6]	2 CFOA	4-6	2	No
[7]	2 OTRA	4	2/3	Yes
[8]	2 OTRA	4-5	3-4	Yes
[9]	2 CDBA	3	3	No
[10]	2 CDBA	2-4	2-4	No
[11]	2 CDBA	4	2	No
Proposed	2 CDBA	3/4	2/3	Yes

II. PRESENTED CIRCUIT TOPOLOGY

The symbolic representation of CDBA is presented in Fig.1. The terminal voltage/current relationships are given in equation (1).

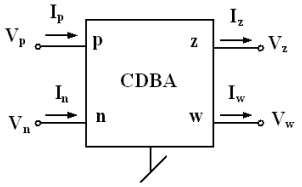

Fig. 1 CDBA symbol

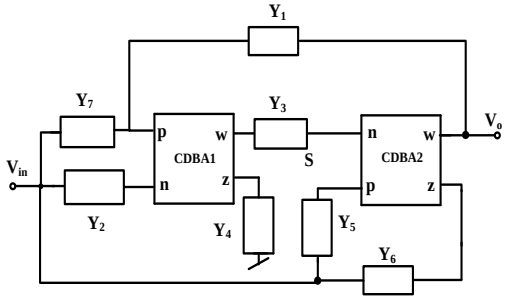

Fig. 2 The presented inverse filter topology

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

The circuit topology for the realization of ILPF, IHPF, IBPF and IBRF with seven branch admittances is shown in Fig.2

Assuming ideal CDBA, the ratio of output voltage to input voltage (TF) yields for the configuration shown in Fig. 2 can be obtained as:

$$TF = \frac{V_0}{V_{in}} = \frac{Y_4Y_6 + Y_4Y_5 + Y_7Y_3}{Y_4Y_6 + Y_1Y_3} \text{ for } Y_2 = 2Y_7 \quad (2)$$

The proper choice(s) of admittance(s) yields ILPF, IHPF, IBPF and IBRF which has been shown in Table II. Table III shows the performance parameters ω_0, BW and Q for the realized inverse active filters.

Table II Realization of various inverse filter functions from the proposed configuration

Type of filter realized	Choice of admittances							TF
	Y_1	Y_2	Y_3	Y_4	Y_5	Y_6	Y_7	
ILPF	0	$2C_1s$	$\frac{1}{R_3}+C_2s$	$\frac{1}{R_4}$	$\frac{1}{R_6}$	$\frac{1}{R_6}$	C_1s	$\frac{1}{\frac{1}{C_1C_2R_4R_6}}{s^2+\frac{1}{C_2R_3}s+\frac{2}{C_1C_2R_4R_6}}$
IHPF	0	$\frac{2}{R_2}$	$\frac{1}{R_3}$	C_1s	$\frac{1}{R_5}$	C_2s	$\frac{1}{R_2}$	$\frac{1}{\frac{s^2}{s^2+\frac{1}{C_2R_5}s+\frac{1}{C_1C_2R_2R_3}}}$
IBPF	0	$\frac{2}{R_2}$	$\frac{1}{R_3}$	C_1s	C_2s	$\frac{1}{R_6}$	$\frac{1}{R_2}$	$\frac{1}{\frac{\frac{s}{C_2R_6}}{s^2+\frac{1}{C_2R_6}s+\frac{1}{C_1C_2R_2R_3}}}$
IBRF	$\frac{1}{R_2}$	$\frac{2}{R_2}$	$\frac{1}{R_3}$	C_1s	$\frac{1}{R_5}$	C_2s	$\frac{1}{R_2}$	$\frac{1}{\frac{s^2+\frac{1}{C_1C_2R_2R_3}}{s^2+\frac{1}{C_2R_5}s+\frac{1}{C_1C_2R_2R_3}}}$

Table III Performance parameters of inverse filters of Table II

Type of Filter realized	Cut-off frequency (ω_0)	Bandwidth (BW)/Quality factor (Q)
ILPF	$\sqrt{\frac{2}{C_1C_2R_4R_6}}$	$Q = R_3\sqrt{\frac{2C_2}{C_1R_4R_6}}$
IHPF	$\frac{1}{\sqrt{C_1C_2R_2R_3}}$	$Q = R_5\sqrt{\frac{C_2}{C_1R_2R_3}}$
IBPF	$\frac{1}{\sqrt{C_1C_2R_2R_3}}$	$BW = \frac{1}{C_2R_6}$
IBRF	$\frac{1}{\sqrt{C_1C_2R_2R_3}}$	$BW = \frac{1}{C_2R_5}$

III. SENSITIVITY ANALYSIS

Using the conventional definition of sensitivity of a function F(x) with respect to a parameter of interest x i.e., $S_x^{F(x)} = \frac{x}{F(x)}\frac{\partial F(x)}{\partial x}$, the sensitivities of ω_0, Q and BW of inverse active filters have been tabulated in Table IV. It may be observed from the Table IV that the sensitivities with respect to all passive components are low.

Table IV Inverse filters sensitivity analysis

Filter	Sensitivity
ILPF	$S_{R4}^{\omega_0} = S_{R6}^{\omega_0} = -\frac{1}{2},\ S_{R3}^{\omega_0} = 0,\ S_{C1}^{\omega_0} = S_{C2}^{\omega_0} = -\frac{1}{2}$ $S_{C1}^{Q} = S_{R4}^{Q} = S_{R6}^{Q} = -\frac{1}{2},\ S_{C2}^{Q} = \frac{1}{2}, S_{R3}^{Q} = 1$
IHPF	$S_{R2}^{\omega_0} = S_{R3}^{\omega_0} = -\frac{1}{2},\ S_{R5}^{\omega_0} = 0,\ S_{C1}^{\omega_0} = S_{C2}^{\omega_0} = -\frac{1}{2}$ $S_{C1}^{Q} = S_{R3}^{Q} = S_{R2}^{Q} = -\frac{1}{2},\ S_{C2}^{Q} = \frac{1}{2}, S_{R5}^{Q} = 1$
IBPF	$S_{R2}^{\omega_0} = S_{R3}^{\omega_0} = -\frac{1}{2},\ S_{R6}^{\omega_0} = 0,\ S_{C1}^{\omega_0} = S_{C2}^{\omega_0} = -\frac{1}{2}$ $S_{C2}^{BW} = S_{R6}^{BW} = -1, S_{C1}^{BW} = S_{R2}^{BW} = S_{R3}^{BW} = 0$
IBRF	$S_{R2}^{\omega_0} = S_{R3}^{\omega_0} = -\frac{1}{2},\ S_{R5}^{\omega_0} = 0,\ S_{C1}^{\omega_0} = S_{C2}^{\omega_0} = -\frac{1}{2}$ $S_{C2}^{BW} = S_{R5}^{BW} = -1, S_{C1}^{BW} = S_{R2}^{BW} = S_{R3}^{BW} = 0$

IV. SIMULATION RESULTS

The realized inverse filters have been simulated using CMOS CDBA [12] (which is reproduced here in Fig. 3) in PSPICE employing 0.18µm technology. The various aspect ratios of the MOSFETs have been taken from [12]. The bias voltages and bias currents used are ±2.5V and 40µA respectively. The proposed inverse active filters are designed for the ω_0 of 159 kHz and Q-factor of 0.707 by appropriate selection of the passive elements as:

ILPF: $C_1 = C_2 = 100pF,\ R_4 = 1\ k\Omega,\ R_5 = R_6 = 14k\Omega,\ R_3 = 7k\Omega$

IHPF: $C_1 = C_2 = 100pF,\ R_2 = 5k\ \Omega,\ R_1 = R_3 = R_5 = R_7 = 10k\Omega$

IBPF: $C_1 = C_2 = 100pF,\ R_2 = 5k\ \Omega,\ R_1 = R_3 = R_5 = R_7 = 10k\Omega$

IBRF: $C_1 = C_2 = 100pF,\ R_2 = R_3 = R_5 = 10k\Omega$

Frequency (AC) responses of the inverse active filters are presented in Fig. 4, which establish the validity of the proposed circuit topology. The tunability for the cut-off frequency of proposed inverse active filters is shown in Fig. 5.

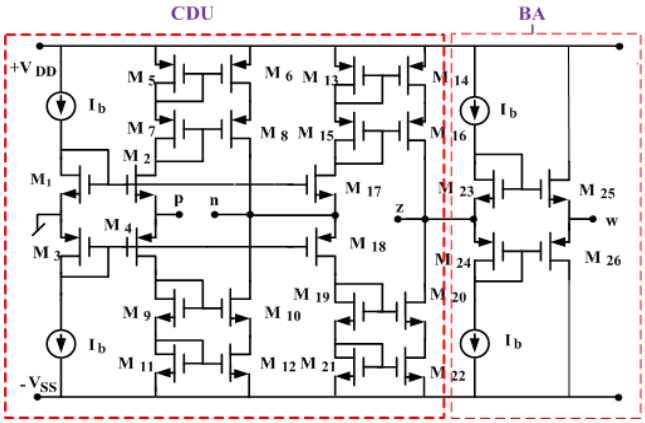
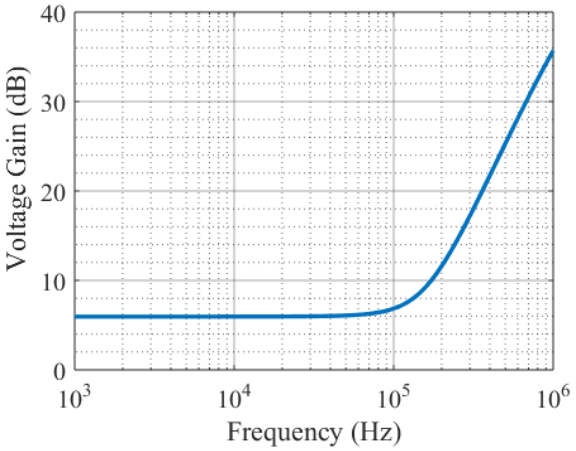
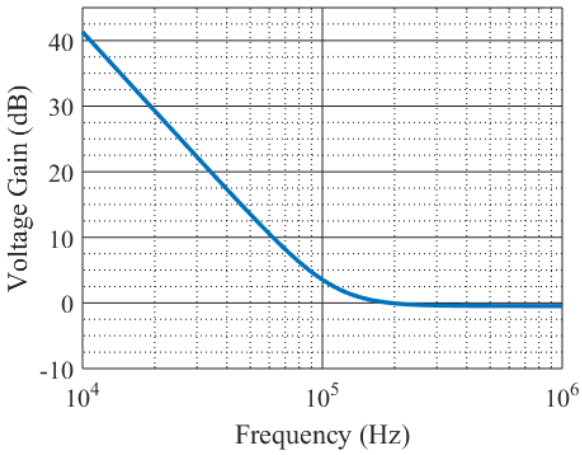


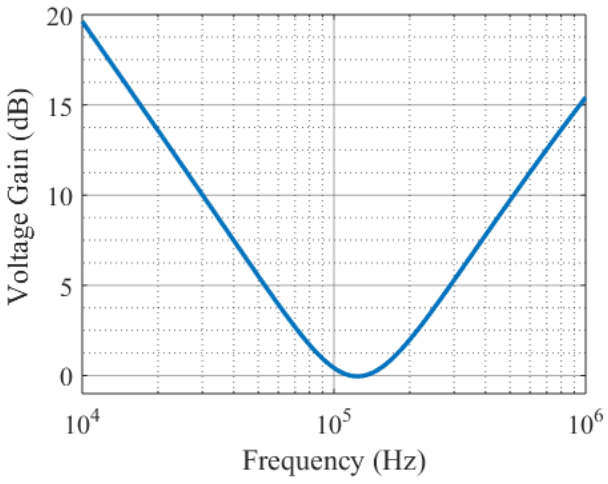
Fig. 3. CDBA realization using CMOS [12]



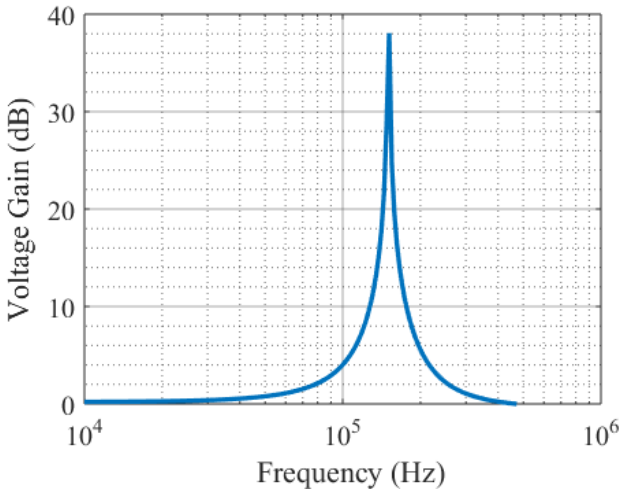
(a)



(b)

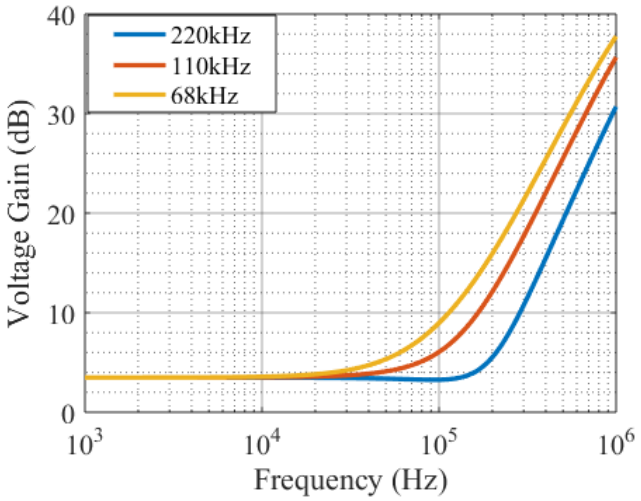


(c)

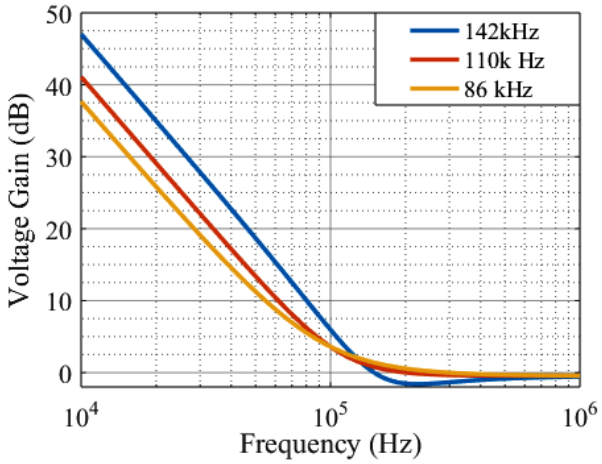


(d)

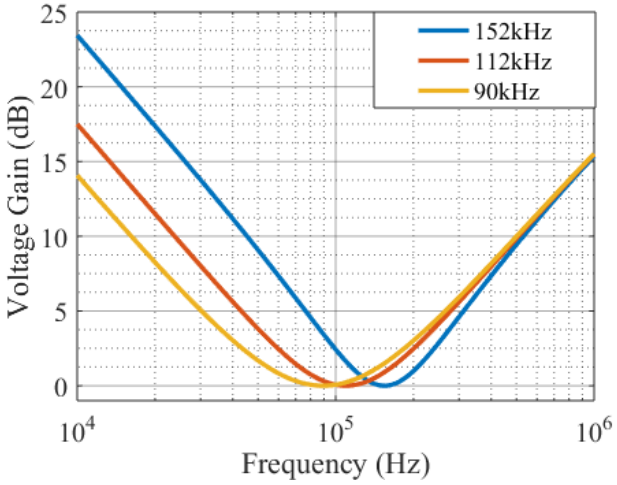
Fig 4. AC responses of (a) ILPF (b) IHPF (c) IBPF and (d) IBRF



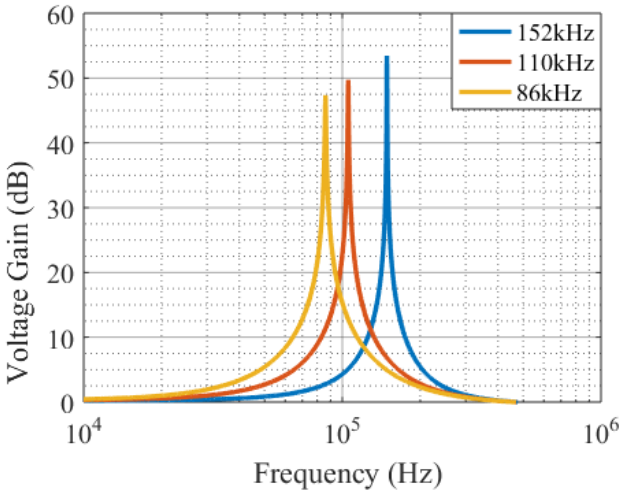
(a)



(b)



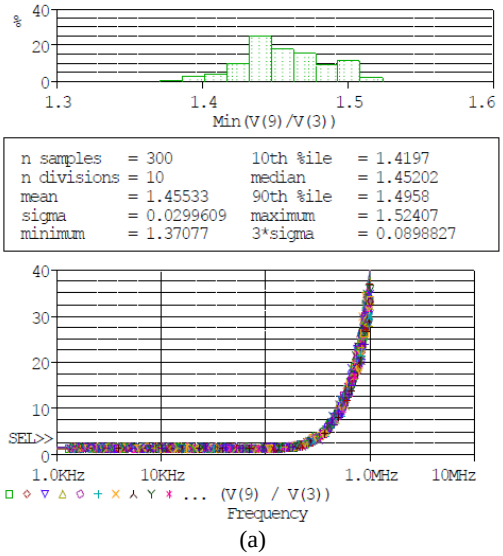
(c)



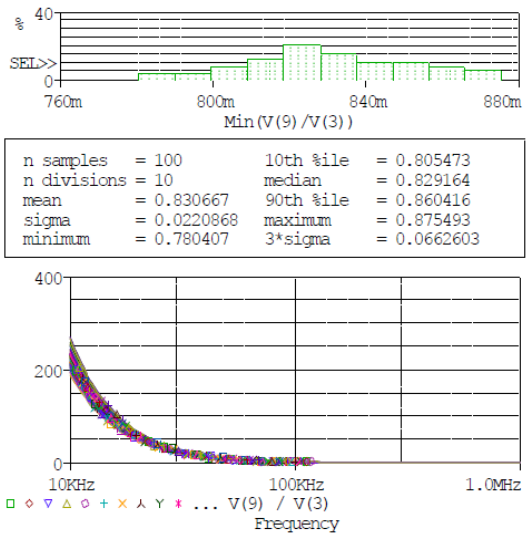
(d)

Fig. 5 Tunability of cut-off frequency (a) ILPF (b) IHPF (c) IBPF and (d) IBRF

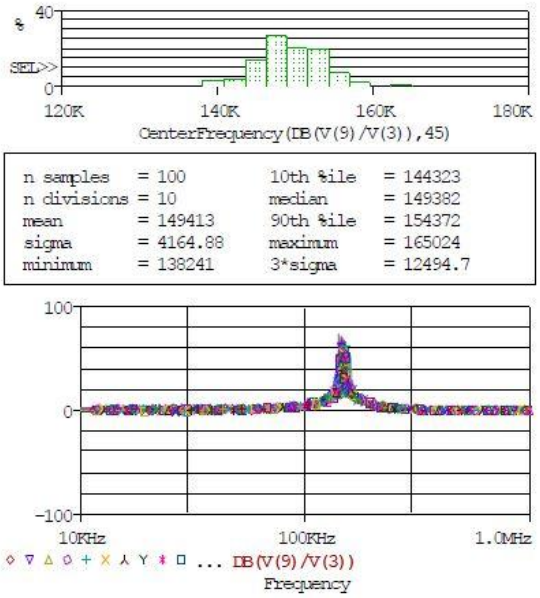
Fig. 6 presents variation in cut-off frequency and gain for the realized inverse active filters using Monte-Carlo simulations, for 5% variation in capacitor and resistor values.



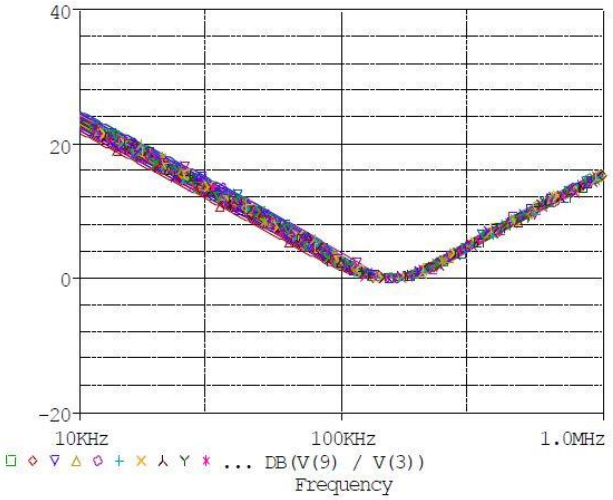
(a)



(b)



(c)



(d)

Fig. 6 Histogram and AC responses of (a) ILPF (b) IHPF (c) IBPF and (d) IBRF using Monte-Carlo simulation for 5% variation in resistor and capacitor value

Fig. 7 represents the implementation of CDBA using AD844 ff-the shelf IC. Some sample experimental results e.g. frequency response, transient response and frequency spectrum of IBRF are demonsrated in Fig 8 for 100 mV sinusoid input signal. The percentage total harmonic distortion (THD) obtained is 0.23 which is quite low.

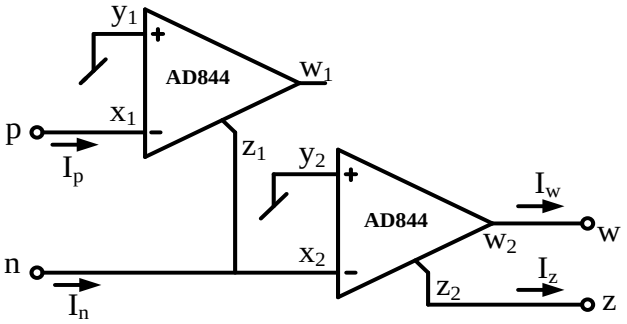
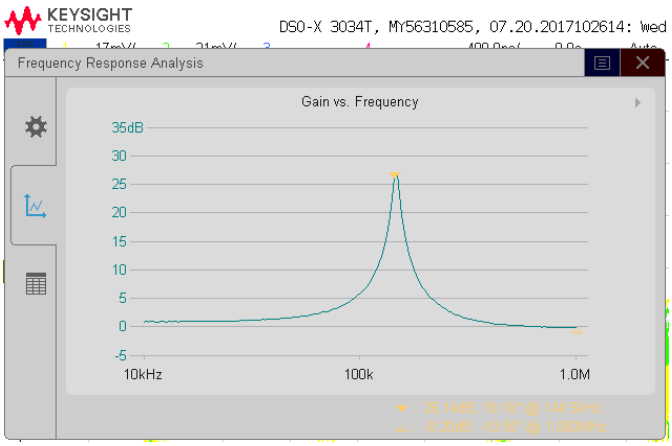
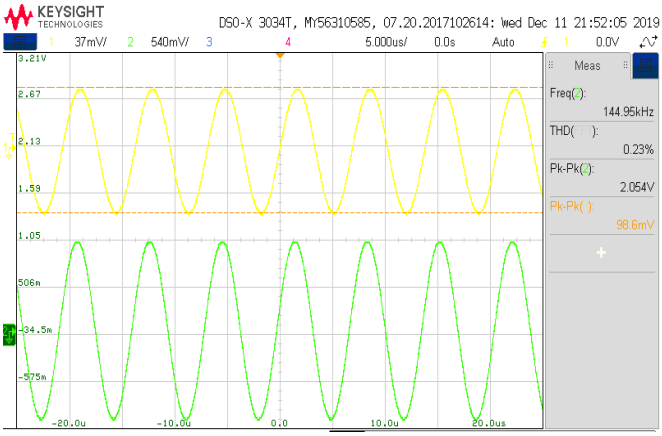


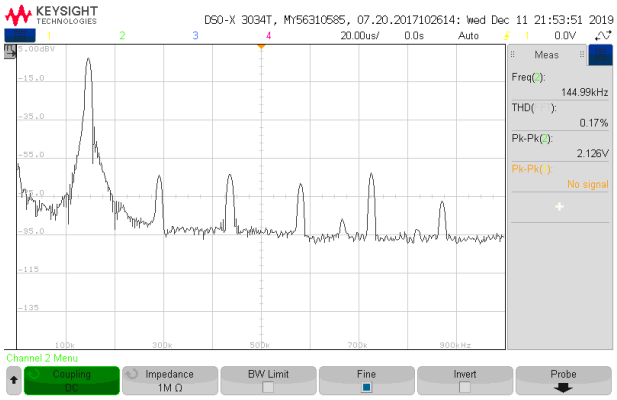
Fig. 7 AD844 based implementation of CDBA



(a) Experimental AC response of IBRF



(b) Transient response of IBRF



(c) Frequency spectrum of IBRF

Fig. 8 Experimental results of IBRF

V. CONCLUDING REMARKS

A voltage-mode tunable inverse active filter circuit utilizing two CDBAs along with six/seven passive elements has been described. The presented configuration is capable of realising ILPF, IHPF, IBPF and IBRF from the same circuit configuration by proper selection(s) of admittance(s). The sensitivities of various performance parameters of all the inverse active filters have been calculated, from where it has been observed that the passive sensitivities are low. The robustness of the inverse filters has been checked through Monte-Carlo simulations. Some sample experimental results have also been incorporated to validate the workability of the presented structure.

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