Research Article

CDBA Based Universal Inverse Filter

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Current difference buffered amplifier (CDBA) based universal inverse filter configuration is proposed. The topology can be used to synthesize inverse low-pass (ILP), inverse high-pass (IHP), inverse band-pass (IBP), inverse band-reject (IBR), and inverse all-pass filter functions with appropriate admittance choices. Workability of the proposed universal inverse filter configuration is demonstrated through PSPICE simulations for which CDBA is realized using current feedback operational amplifier (CFOA). The simulation results are found in close agreement with the theoretical results.

1. Introduction

Inverse filters are commonly used in communication [1], speech processing, audio and acoustic systems [2, 3], and instrumentation [4] to reverse the distortion of the signal incurred due to signal processing and transmission. The transfer characteristics of the system that caused the distortion should be known a priori and the inverse filter to be used should have a reciprocal transfer characteristic so as to result in an undistorted desired signal. Literature review on inverse filter suggests that numerous well-established [5] methods for digital inverse filter design do exist but analog inverse filter design remained unexplored area as is evident from the limited availability of analog inverse filter circuits/design methods [6–14] until recently. However recent research trend suggests that the area is now gaining a renewed interest.

A brief account of the complete literature on analog inverse filter is presented here. Reference [6] presents a general method for obtaining the inverse transfer function for linear dynamic systems and the inverse transfer characteristic for nonlinear resistive circuits using nullors. The realization procedures for the current-mode FTFN-based inverse filters from the voltage-mode op-amp-based RC filters are presented in [7, 8]. The procedure outlined in [7] is applicable to planar circuits only as it uses RC:CR dual transformation, whereas the method presented in [8] makes use of adjoint transformation and thus is applicable to nonplanar circuits

[12]. Single FTFN based inverse filters proposed in [9–12] present inverse filters using current feedback operational amplifier (CFOA). All the circuits presented in [10, 11] provide single inverse filter function; however [12] presents a topology which can realize inverse low-pass (ILP), inverse high-pass (IHP), and inverse band-pass (IBP) filter functions by appropriate admittance choice. In [13, 14] inverse all-pass (IAP) filters have been implemented using current difference transconductance amplifier (CDTA) and current conveyors, respectively. This study reveals that no universal inverse filter configuration has been proposed in the literature so far, to the best of the authors' knowledge. Therefore the aim of this paper is to present a current differencing buffered amplifier (CDBA) based universal inverse filter topology which realizes all five inverse filter functions, namely, ILP, IHP, IBP, IBR and IAP by appropriate admittance selection.

2. Circuit Description

Inherent wide bandwidth which is virtually independent of closed-loop gain, greater linearity, and large dynamic range are the key performance features of current mode technique [15]. The CDBA being a current processing analog building block inherits the advantages of current mode technique. In addition, it is free from parasitic capacitances [16] as its input terminals are internally grounded. Thus this active block is appropriate for high frequency operation. The circuit symbol

FIGURE 1: Block diagrammatic representation of CDBA.

FIGURE 2: Proposed inverse filter configuration.

of CDBA is shown in Figure 1, and the port characteristics are given by

$$\begin{bmatrix} I_z \\ V_w \\ V_p \\ V_n \end{bmatrix} = \begin{bmatrix} 0 & 0 & 1 & -1 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} V_z \\ I_w \\ I_p \\ I_n \end{bmatrix}. \quad (1)$$

The proposed inverse filter configuration is shown in Figure 2. Routine analysis of the circuit of Figure 2 results in the following transfer function:

$$\frac{V_o(s)}{V_i(s)} = \frac{N(s)}{D(s)} = \frac{Y_1 Y_3}{Y_2 Y_4 + Y_3 Y_6 - Y_2 Y_5}, \quad (2)$$

where

$$\begin{aligned} N(s) &= Y_1 Y_3, \\ D(s) &= Y_2 Y_4 + Y_3 Y_6 - Y_2 Y_5. \end{aligned} \quad (3)$$

With the admittance choices of $Y_1 = sC_1 + G_1$ and $Y_3 = sC_3 + G_3$, the $N(s)$ can be expressed as

$$N(s) = s^2 C_1 C_3 + s(C_1 G_3 + C_3 G_1) + G_1 G_3. \quad (4)$$

And the appropriate admittance choices for Y_2 , Y_4 , Y_5 , and Y_6 , as shown in Table 1, would result in the required denominator functions $D(s)$ and hence the required inverse filter responses.

TABLE 1

Response type	Y_2	Y_4	Y_5	Y_6
ILP	G_2	G_4	0	0
IHP	sC_2	sC_4	0	0
IBP	sC_2	G_4	0	0
IBR	G_2	G_4	sC_5	sC_6
IAP	G_2	G_4	sC_5	sC_6

Using the admittance choices given in Table 1, the ILP, IHP, and IBP response can, respectively, be expressed as

$$\begin{aligned} \frac{V_o}{V_i} &= \frac{1}{(G_2 G_4) / (s^2 C_1 C_3 + s(C_1 G_3 + C_3 G_1) + G_1 G_3)}, \\ \frac{V_o}{V_i} &= \frac{1}{(s^2 C_2 C_4) / (s^2 C_1 C_3 + s(C_1 G_3 + C_3 G_1) + G_1 G_3)}, \\ \frac{V_o}{V_i} &= \frac{1}{(s C_2 G_4) / (s^2 C_1 C_3 + s(C_1 G_3 + C_3 G_1) + G_1 G_3)}. \end{aligned} \quad (5)$$

For admittance choices suggested for IBR and IAP in Table 1, the $D(s)$ can be written as

$$D(s) = s^2 C_3 C_6 + s(C_6 G_3 - C_5 G_2) + G_2 G_5. \quad (6)$$

The resulting transfer function can be expressed as

$$\frac{V_o(s)}{V_i(s)} = \frac{1}{\frac{s^2 C_3 C_6 - s(C_5 G_2 - C_6 G_3) + G_2 G_4}{s^2 C_1 C_3 + s(C_1 G_3 + C_3 G_1) + G_1 G_3}} \quad (7)$$

which represents an IBR response if $C_5 = C_6 = C_1$ and $G_1 G_3 = G_2 G_5$. The response will be IAP if $C_5 G_2 - C_6 G_3 = C_1 G_3 + C_3 G_1$ which can be easily obtained by choosing

FIGURE 3: CDBA realization with AD844 [17].

FIGURE 4: CDBA realization with nonideal model of AD844.

a suitable value of C_5 . If $C_3 = C_6 = C_1 = C$, then $C_5 = 3C$ yields an IAP response provided $G_1 = G_2 = G_3$.

The resonant angular frequency (ω_0) and the quality factor (Q_0) are given by (8) and (9), respectively, for all the responses

$$\omega_0 = \sqrt{\left(\frac{G_1 G_3}{C_1 C_3}\right)}, \quad (8)$$

$$Q_0 = \frac{\sqrt{C_1 C_3 G_1 G_3}}{(C_1 G_3 + G_1 C_3)}, \quad (9)$$

(whereas H_{ILP} , H_{IHP} , and H_{IBP} , the gain constants for ILP, IHP, and IBP responses, respectively, are given by

$$\begin{aligned} H_{ILP} &= \frac{G_2 G_4}{G_1 G_3}, & H_{IHP} &= \frac{C_2 C_4}{C_1 C_3}, \\ H_{IBP} &= \frac{C_2 G_4}{(C_1 G_3 + C_3 G_1)}. \end{aligned} \quad (10)$$

3. Sensitivity Analysis

The passive sensitivities of ω_0 and Q_0 for the proposed configuration can be expressed as

$$\begin{aligned} S_{G_1}^{\omega_0} &= S_{G_3}^{\omega_0} = \frac{1}{2}, & S_{G_1}^{\omega_0} &= S_{C_3}^{\omega_0} = -\frac{1}{2}, \\ S_{G_1}^{Q_0} &= S_{C_3}^{Q_0} = \frac{1}{2} - \frac{C_3 G_1}{(C_1 G_3 + C_3 G_1)}, \\ S_{G_3}^{Q_0} &= S_{C_1}^{Q_0} = \frac{1}{2} - \frac{C_1 G_3}{(C_1 G_3 + C_3 G_1)}. \end{aligned} \quad (11)$$

It is clearly observed from (11) that the passive sensitivities are lower than 1/2 in magnitude and hence the proposed universal inverse filter configuration may be termed as insensitive.

FIGURE 5: (a) Inverse low-pass response. (b) Inverse high-pass response. Inverse band-pass response. (d) Inverse band reject response. (e) Inverse all-pass magnitude response. (f) Inverse all-pass phase response.

4. Realizing a CDBA and Associated Nonideality Analysis

For the proposed configuration, the CDBA was realized using AD844 CFOA IC as shown in Figure 3 [17]. Ideally the input resistance at the x terminal is zero and is infinite at the z terminal. From Figure 3 various currents can be calculated as

$$\begin{aligned} I_{z1} &= I_p, \\ I_{x2} &= I_n - I_{z1}, \\ I_{z2} &= I_{x2}. \end{aligned} \quad (12)$$

Therefore the current from z terminal I_z can be calculated as

$$I_z = -I_{z2} = (I_p - I_n). \quad (13)$$

And the output voltage V_w is given as

$$V_w = V_z. \quad (14)$$

In analysis so far, ideal characteristics of the CFOA have been considered. However, the effect of the parasitics of the CFOA needs to be taken into consideration for performing nonideality analysis [18–21]. For this, the model of AD844 [18] which includes a finite input resistance R_x in series with C_x at port- x , the z -port parasitic impedance ($R_z \parallel C_z$), and the y -port parasitic impedance ($R_y \parallel C_y$) is used. Using this nonideal model for CFOA, the CDBA structure of Figure 3

modifies to Figure 4. The nonideal transfer function of ILP from Figure 4 can be expressed as

$$\frac{V_0}{V_i} = \left(s^2 C_1 C_3 + s (C_1 G_3 + C_3 G_1) + G_1 G_3 \right) /$$

$$G_2' G_4' \left(1 + \frac{s C_{z1}}{G_2'} \right) \left(1 + \frac{s C_{z2}}{G_4'} \right)$$

$$\times \left(1 + \frac{s}{G_{x1}} ((C_{x1} + C_1) + G_1) \right)$$

$$\times \left(1 + \frac{s}{G_{x2}} ((C_{x2} + C_3) + G_3) \right), \quad (15)$$

where $G_2' = 1/(R_2 \parallel R_{z1})$ and $G_4' = 1/(R_4 \parallel R_{z2})$.

Considering $G_{x1} \gg G_2$ and $G_{x2} \gg G_5$, (15) modifies to

$$\frac{V_0}{V_i} = \left(s^2 C_1 C_3 + s (C_1 G_3 + C_3 G_1) + G_1 G_3 \right) /$$

$$G_2' G_4' \left(1 + \frac{s C_{z1}}{G_2'} \right) \left(1 + \frac{s C_{z2}}{G_4'} \right)$$

$$\times \left(1 + \frac{s (G_{x1} + C_1)}{G_{x1}} \right) \left(1 + \frac{s (G_{x2} + C_3)}{G_{x2}} \right). \quad (16)$$

It is clear from (16) that nonidealities of CFOA introduce parasitic poles in the transfer function. The deviation from the ideal behavior so caused can be kept small if all the external resistors are chosen to be much larger than R_x but much smaller than R_y and R_z . Similarly external capacitors should be chosen to be much larger than C_y and C_z . Nonideal transfer functions for IHP and IBP can also be deduced in a similar manner.

5. Simulation Results

The proposed theoretical predictions are validated through simulations using PSPICE macromodel of CFOA AD844 IC as shown in Figure 3. Supply voltages used are ± 10 V. The proposed inverse filter configuration is designed with equal value components. All the resistances of value 10 K Ω and capacitors of value 50 pF are chosen resulting in a theoretical f_0 of 318.5 KHz. Simulated frequency magnitude responses for ILP, IHP, IBP, IBR, and IAP are shown from Figure 5(a) to Figure 5(e), respectively, whereas Figure 5(f) shows the phase response for IAP. The simulated f_0 for all the responses is found to be 316.3 KHz and is in close agreement to the theoretical value.

6. Conclusion

A current difference buffered amplifier (CDBA) based universal inverse filter configuration is proposed. Appropriate admittance selections allow using the proposed topology as one of the five inverse filter configurations, namely, ILP, IHP, IBP, IBR, and IAP. Workability of the proposed universal inverse filter configuration is demonstrated through PSPICE

simulations for which CDBA is realized using current feedback operational amplifier (CFOA). The simulation results are found in close agreement with the theoretical results.

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