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A Novel Multifunction CFOA-Based Inverse Filter

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Abstract

We present a novel multifunction inverse biquad configuration based on current feedback operational amplifiers (CFOAs) and grounded passive elements. The proposed scheme can be used to realize inverse lowpass, inverse bandpass and inverse highpass filter functions. The relevant coefficients of the inverse filters are orthogonal adjustable by independent passive elements. All the passive elements in the proposed scheme are grounded to benefit easier electronic tunability. With the high input impedance and low output impedance properties, the scheme is input and output cascadable for voltage operation. The feasibility of the proposed scheme is demonstrated by HSPICE simulations.

Keywords: Multifunction, Inverse Filter, CFOA

1. Introduction

In communication, control and instrumentation systems, there are numerous situations in which an electrical signal is altered through a linear or nonlinear transformation by a processing or a transmission system. So it is necessary to recover the input signal from the available distorted output signal resulted from the signal progress. This can often be done by using a system that has an inverse transfer characteristic of the original system [1]. For digital signal processing, several methods for obtaining digital inverse filters have been established [2]. Nevertheless, for analog signal processing, only a few works are known for realizing continuous-time analog inverse filters [1,3-6].

In [1], a general approach is presented for obtaining the inverse transfer function for linear dynamic systems and the inverse transfer characteristic for non-linear resistive circuits. In [3], a procedure for deriving current-mode, four-terminal floating nullor (FTFN)-based inverse filter from the voltage-mode filter is given. It uses the method in [1] and dual transformation [7] during the procedure. Due to the use of dual transformation, this approach can only be applied to planar circuit. By the use of adjoint transformation, another easier procedure for deriving current-mode FTFN-based inverse filter from the voltage-mode filter is presented and it is applicable to nonplanar circuits [4]. All the proposed approaches in [1,3,4] are useful for obtaining single-input single-output inverse filters. Additional various inverse current-mode and voltage-mode filters are presented in [5] and [6], respectively. However, each circuit proposed in [5,6] has one inverse filter function. In this paper, we present a novel inverse filter scheme based on CFOAs and grounded passive elements. By slight modification of the passive elements of the proposed scheme, various inverse filter functions can be realized. The presented scheme possesses high input impedance and low output impedance which enables the convenience of connecting with the other stage in cascade. The workability of the proposed scheme is verified by HSPICE simulations. The simulated results confirm the theoretical prediction.

2. The Proposed Circuit

The current-feedback operational amplifier, such as AD844 from Analog Devices Inc. [8], has gained the acceptance of researchers as a building block in circuit design. The advantages of CFOAs are their constant bandwidths, independent closed-loop gains and high slew-rate capabilities [9]. The CFOA can be described using the following matrix-relations:

$$\begin{bmatrix} V_x \\ I_y \\ I_z \\ V_w \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_z \\ I_w \end{bmatrix}. \quad (1)$$

Considering the proposed scheme in **Figure 1**, three CFOAs are used to construct the circuit functions. The transfer functions can be expressed as:

$$\frac{V_{o1}}{V_{in}} = \frac{V_{o3}}{V_{in}} = \frac{y_1 y_3 + y_2 y_4}{y_0 y_4} \quad (2)$$

$$\frac{V_{o2}}{V_{in}} = \frac{y_1}{y_4} \quad (3)$$

If the admittances are $y_0 = G_0$, $y_1 = sC_1$, $y_2 = sC_2+G_2$, $y_3 = sC_3$ and $y_4 = G_4$, the functions of inverse lowpass filter and inverse integrator can be realized at V_{o1} and V_{o2}, respectively. They are given by

$$\frac{V_{o1}}{V_{in}} = \frac{V_{o3}}{V_{in}} = \frac{s^2 C_1 C_3 + sC_2 G_4 + G_2 G_4}{G_0 G_4} \quad (4)$$

$$\frac{V_{o2}}{V_{in}} = \frac{sC_1}{G_4} \quad (5)$$

From Equation (4), it is clear that the coefficients of the s^2, s^1 and s^0 terms in the numerator and the term in denominator are tunable by the values of C_1, C_2, G_2 and G_0 respectively. So the system parameters, such as the corner angular frequency ω_o and quality factor Q of the inverse filter are tunable by independent passive elements.

In Equation (2), if the admittances are $y_0 = sC_0$, $y_1 = sC_1$, $y_2 = sC_2+G_2$, $y_3 = sC_3$ and $y_4 = G_4$, the functions of inverse bandpass filter and inverse integrator can be realized at V_{o1} and V_{o2}, respectively. They can be given by

$$\frac{V_{o2}}{V_{in}} = \frac{sC_1}{G_4} \quad (6)$$

$$\frac{V_{o1}}{V_{in}} = \frac{V_{o3}}{V_{in}} = \frac{s^2 C_1 C_3 + sC_2 G_4 + G_2 G_4}{sC_0 G_4} \quad (7)$$

Similarly, if the admittances are $y_0 = sC_0$, $y_1 = G_1$, $y_2 = sC_2+G_2$, $y_3 = G_3$ and $y_4 = sC_4$, the functions of inverse highpass filter and inverse differentiator can be realized at V_{o1} and V_{o2}, respectively. They can be expressed by

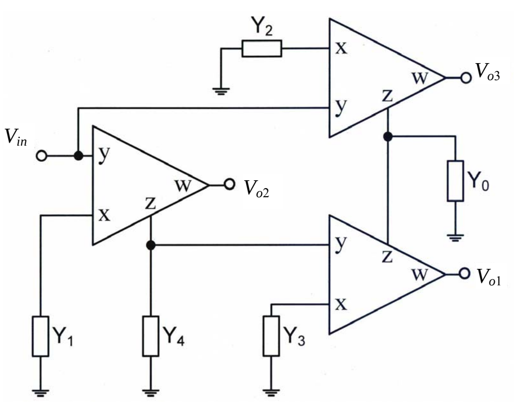


Figure 1. The proposed inverse filter scheme.

$$\frac{V_{o1}}{V_{in}} = \frac{V_{o3}}{V_{in}} = \frac{s^2 C_2 C_4 + sC_4 G_2 + G_1 G_3}{s^2 C_0 C_4} \quad (8)$$

$$\frac{V_{o2}}{V_{in}} = \frac{G_1}{sC_4} \quad (9)$$

The output of V_{o3} has the same function as V_{o1}, it provides the additional output which makes the filter application more flexible.

From (2) and (3), after the restricting ourselves only to the using of six passive elements, we can derive all the filter functions as shown in **Table 1**. It can be found that the coefficients of all terms in the numerator and denominator of the transfer functions are adjustable by independent passive elements. Furthermore, for the presented scheme in **Figure 1**, it can be observed that all the employed passive elements are grounded. The use of grounded passive elements conduces to easier electronic tunability and integrated-circuit implementation [10]. A number of realizations of tunable grounded passive elements can be found in the literature [10-13]. The passive sensitivities of corner angular frequency are equal to 0.5 for the inverse filter realizations in **Table 1**, so they can be classified as insensitive. In addition, the proposed configuration in **Figure 1** possesses the characteristics of input and output cascadability due to its high input impedance and low output impedance. So it is convenient to connecting other stages at both input and output terminals for signal processing. It must be noted that the proposed inverse lowpass and inverse bandpass filters in [6] are included in the filter realizations of **Table 1**. The presented scheme in **Figure 1** provides more flexible functions and different realization with identical configuration.

3. Simulation Results

To verify the potentialities of the proposed scheme, circuit simulations of the presented multi-function inverse filters have been carried out. The commercial current feedback amplifiers AD844 macromodel with ± 12 V voltage supply is used to realize the CFOA in **Figure 1** [12]. Using an AD844 IC to realize the CFOA, its equivalent model can be shown in **Figure 2**. It is important to understand that the low input impedance at x ter-

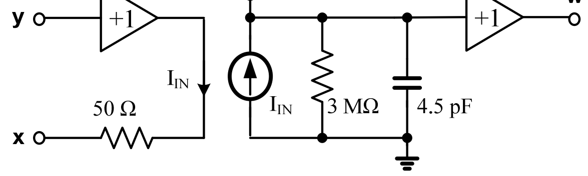


Figure 2. The realization of CFOA with an AD844 IC.

Table 1. All the inverse filter functions using six passive elements.

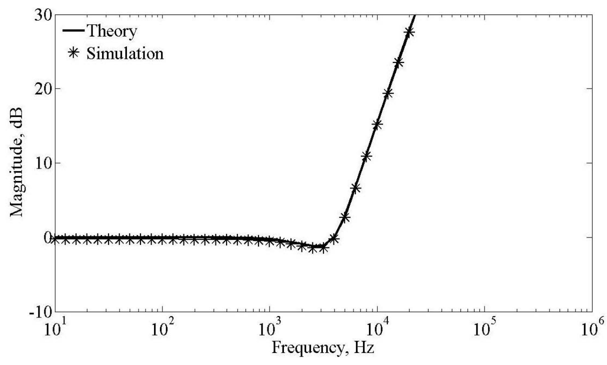
Case	Function at V_{o1}	Function at V_{o2}	y_0	y_1	y_2	y_3	y_4
1	Inverse lowpass	Differential	G_0	sC_1	sC_2+G_2	sC_3	G_4
2	Inverse lowpass	Inverse lowpass	G_0	sC_1+G_1	G_2	sC_3	G_4
3	Inverse lowpass	Differential	G_0	sC_1	G_2	sC_3+G_3	G_4
4	Inverse bandpass	Differential	sC_0	sC_1	sC_2+G_2	sC_3	G_4
5	Inverse bandpass	Inverse lowpass	sC_0	sC_1+G_1	G_2	sC_3	G_4
6	Inverse bandpass	Differential	sC_0	sC_1	G_2	sC_3+G_3	G_4
7	Inverse bandpass	Integration	G_0	G_1	sC_2+G_2	G_3	sC_4
8	Inverse bandpass	Integration	G_0	G_1	sC_2	sC_3+G_3	sC_4
9	Inverse bandpass	Inverse highpass	G_0	sC_1+G_1	sC_2	G_3	sC_4
10	Inverse highpass	Integration	sC_0	G_1	sC_2	sC_3+G_3	sC_4
11	Inverse highpass	Inverse highpass	sC_0	sC_1+G_1	sC_2	G_3	sC_4
12	Inverse highpass	Integration	sC_0	G_1	sC_2+G_2	G_3	sC_4

minl is locally generated and does not depend on feedback. This is very different from the "virtual ground" of a conventional operational amplifier used in the current summing mode which is essentially an open circuit until the loop settles [8]. In the simulation, the values of all resistors and all capacitors are 40 kΩ and 1 nF, respectively.

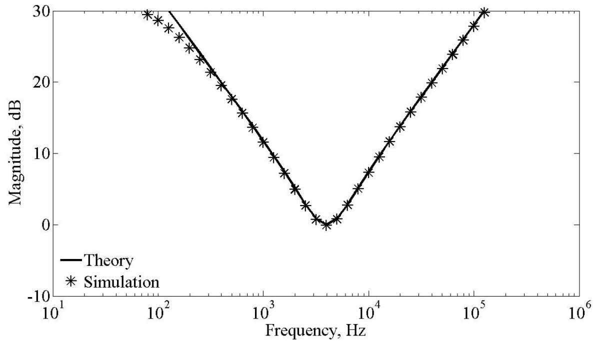
It is found that the workability of all the inverse biquids in **Table 1** is in good agreement with our theoretical prediction. The typical frequency responses of inverse lowpass (the case 1 of **Table 1**), inverse bandpass (the case 4 of **Table 1**) and inverse highpass (the case 12 of **Table 1**) are shown in **Figure 3**. The deviation to theoretical response is due to the parasitic impedance of nonideal CFOA [14].

4. Conclusions

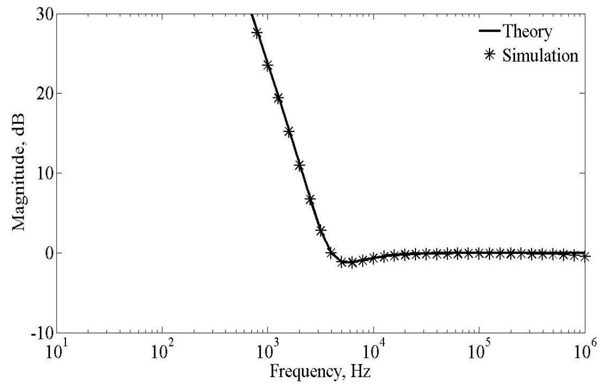
We have proposed a novel scheme for the realization of an input and output cascadable voltage-mode multifunction inverse filter. It consists of CFOAs and grounded-passive elements. Many various inverse filter functions are realized by slight modification of the passive elements of the proposed scheme. It offers more convenient



(a)



(b)



(c)

Figure 3. Typical frequency responses of inverse filters: (a) inverse lowpass; (b) inverse bandpass; (c) inverse highpass.

realizations for inverse filter functions. The feasibility of the proposed circuit is verified by simulation results.

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