On the Realization of the FDNR Simulators Using Only a Single Current Feedback Operational Amplifier

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Abstract

In this paper, two new circuits for realization frequency dependent negative resistance (FDNR) depending on the passive component selection are proposed. Also, two FDNRs using a canonical number of elements, a CFOA, two resistors and maximum two capacitor, are developed. The proposed FDNR circuits do not need critical component matching constraints. Also, simulation results using SPICE program are given for the first introduced FDNR simulator to verify the theory and to exhibit the performance of the circuit.

1. Introduction

The current conveyor as an active element offers several advantages, such as greater linearity and wider bandwidth over the voltage mode counterparts, op-amps [1–4]. Recently, the attention is focused to the use of current feedback operational amplifier (CFOA) as a true current-mode active in the current mode signal processing circuits[5]. This is due to the fact that it offers wider signal bandwidth and linearity higher than the conventional operational amplifier configuration. As a result, many implementations of CFOA based circuits have also been developed by various researchers [6-13]. Several works for realization of frequency dependent negative resistors employing different types of active elements are available in the literature [10-13]. The circuit of [10] requires four current feedback operational amplifiers (CFOA) and five passive components. The circuit of [11] uses three active elements, two second generation current conveyor (CCII) and a buffer. The circuit of [12] uses three second-generation current-controlled current conveyor and require matching component. Frequency dependent negative resistance (FDNR) circuits can be used to make an active filter based on a passive ladder filter design. In applications where an elliptical low-pass filter is required and an active filter is possible, FDNR filters can be used as an alternative to a biquad filter. Yuce [13] proposed FDNR simulator with three DO-CCIIs, three resistors and one capacitor, and the proposed circuit requires matching component.

In this paper, two circuits for the realization of synthetic frequency-dependent negative resistor (FDNR) are proposed. The proposed circuits consist of only a single CFOA as the active element and three or four passive components. The proposed circuit is superior over earlier circuits in terms of the number of active and passive components and/or functionality.

2. Proposed grounded FDNR simulators

The circuit symbol of the current feedback operational amplifier (CFOA) is shown in Fig.1, where Y and X are input, W and Z are output terminals. It is characterized with the following matrix equation

$$\begin{bmatrix} I_Y \\ I_Z \\ V_X \\ V_W \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I_X \\ V_Y \\ V_Z \end{bmatrix} \quad (1)$$

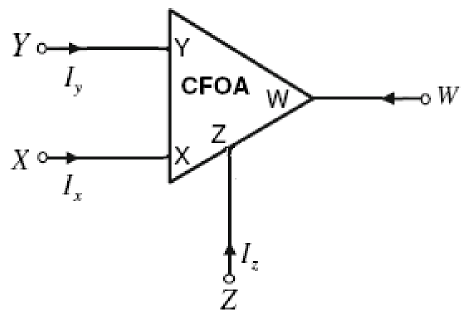

Fig. 1. Circuit symbol of the CFOA

The proposed FDNR simulators are shown in Fig.2 and Fig.3. Routine analysis of the circuit in Fig.2 and Fig.3. are characterized by the Y;

$$[Y] = s^2 D_{eq} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} \quad (2)$$

If $R_1=R_2$ as in Fig.3, the equation (3) will be same for the circuits in Fig.2 and Fig.3.

$$D_{eq} = \frac{RC_1C_2}{2} \quad (3)$$

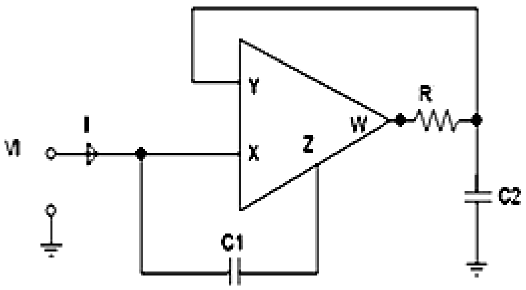

Fig. 2 The first proposed FDNR simulator

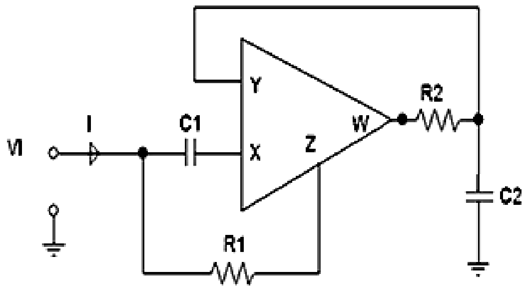

Fig. 3 The second proposed FDNR simulator

3. Simulation Results and design Example of Anti-aliasing filter

In radio frequency (RF) transceivers, filters are inevitable circuit blocks. Efficient anti-aliasing is one of the main requirements in today's RF circuits. Low-pass filter that precedes the A/D converter is called as anti-aliasing filter. Fig.4 shows the position of anti-aliasing filter in Analog Front-End (AFE) of the digital radio receivers [14].

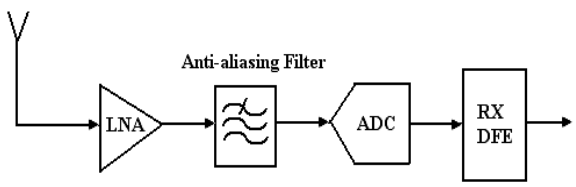

Fig.4: Schematic diagram of the anti-aliasing filter in digital radio receivers [14]

Fig.5a shows the basic anti-aliasing filter structure which is a third-order passive LC ladder filter. The transfer function of the third order passive lowpass filter in Fig.5a is given by

$$\frac{V_O}{V_I} = \frac{1}{s^3 + \frac{1}{RC_1}s^2 + \frac{C_1C_2}{LC_1C_2}s + \frac{1}{RLC_1C_2}} \quad (4)$$

If the approval of scaling s as an equivalent transfer function is obtained [15], replacing all the capacitors, resistors and inductors by FDNRs, capacitors and resistors, the filter converts to the circuit in Fig.5b. Fig.5c illustrates the realization of the filter employing the FDNR simulator given in Fig.2.

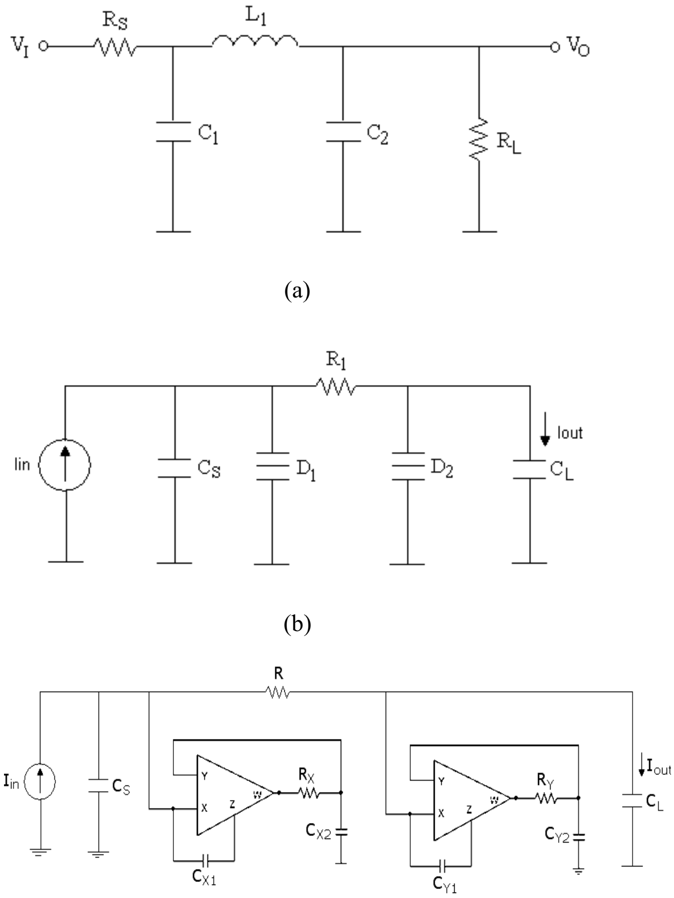

Fig. 5. (a) Third-order, Butterworth passive LPF (b) Current-Mode Equivalent circuit with FDNRs (c) Current-Mode LPF constructed with CFOA FDNRs

The frequency response of the active filter was simulated by an ideal model for the CFOAs and the macro model of the AD844 from Analog Devices. The circuit is supplied with ± 15V. The filter was designed to provide a cut-off frequency of 22.5 MHz. The values for passive LC filter elements and normalized components are specified as follows: R_S=R_L=50Ω, C_1=C_2=276.79pF, L=1.384μH and C_S=C_L=0.5nF, R_1 = 0.5kΩ, D_1 = $C_{X1}C_{X2}R_X$ where C_{X1} = C_{X2} = 0.1nF, R_X = 0.5k Ω, D_2 = $C_{Y1}C_{Y2}R_Y$ where C_{Y1} = C_{Y2} = 0.2uF, R_Y = 0.5kΩ, respectively. Results of the simulation of the filter are shown in Fig.6, which is in good agreement with the theory predicted. The differences in the frequency response of the filter from theoretical values are caused by parasites zero input resistance at X and Y terminal of the CFOA.

Time domain analysis result is given in Fig.7 for peak-to-peak 200 mV at 11.5 MHz sine wave input for third-order low-pass filter configuration for the circuit in Fig.5b. The THD results for the third-order low-pass filter for Fig.5b are given in Fig.8 which clearly shows that for an input signal lower than 200 mV, the THD remains in acceptable limits thus confirming the practical utility of the proposed circuit. Filter step response is shown in Fig. 9, where a square wave of 500kHz is applied to the input.

4. Conclusion

In this paper, two new FDNR simulators were proposed.. The circuits employing only a single CFOA and three or four passive elements. The performance of the proposed circuit is demonstrated on a design example of third order low-pass filter with the SPICE simulation program. Simulation results confirm the theoretical analysis. Since the proposed circuits do not require component matching, they are superior over earlier circuits in terms of the number of active and passive components and/or functionality. It is expected that the proposed FDNRs can be useful in analog filter designs and oscillator realizations, providing flexibility and new possibilities to the circuit designer.

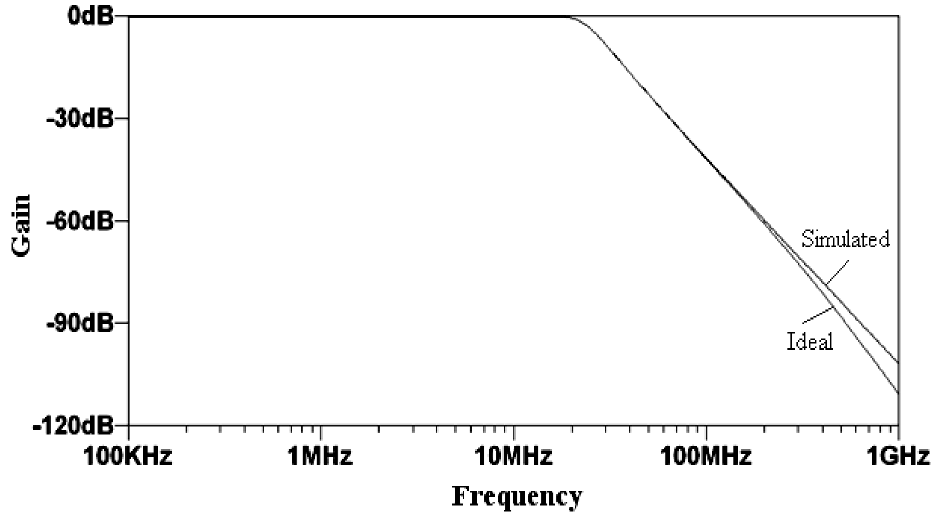

Fig.6. Frequency response of third order-ladder type low-pass filter (FDNR)

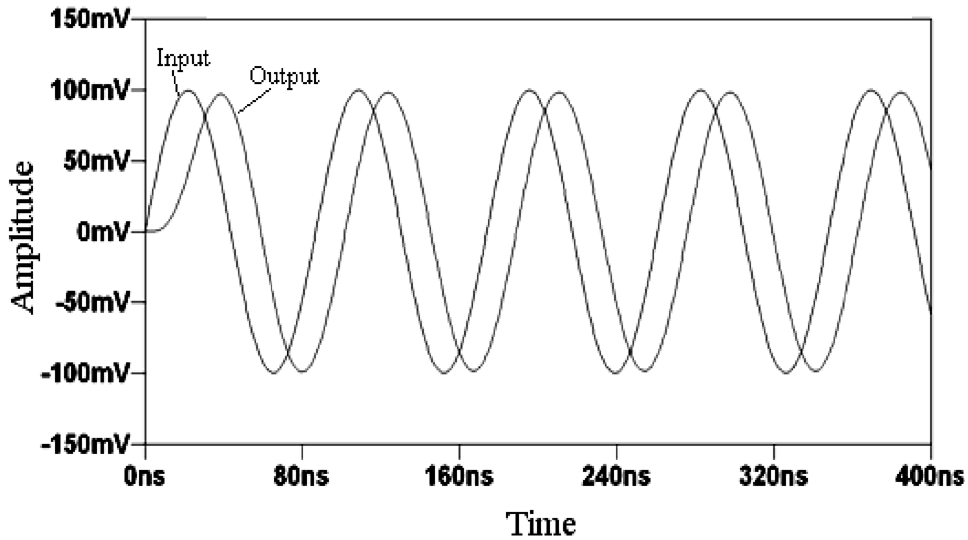

Fig.7. Time domain response of third-order low-pass filter for 0.2V peak-to-peak 11.5MHz sine wave input

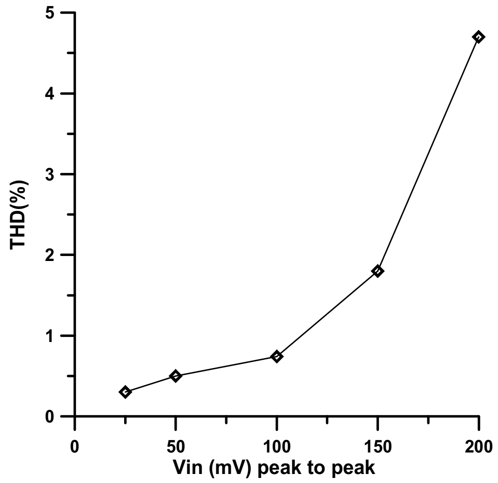

Fig.8. Total harmonic distortion (THD) of the third-order low-pass filter for an input signal of 200mV (peak to peak) amplitude at 11.5MHz.

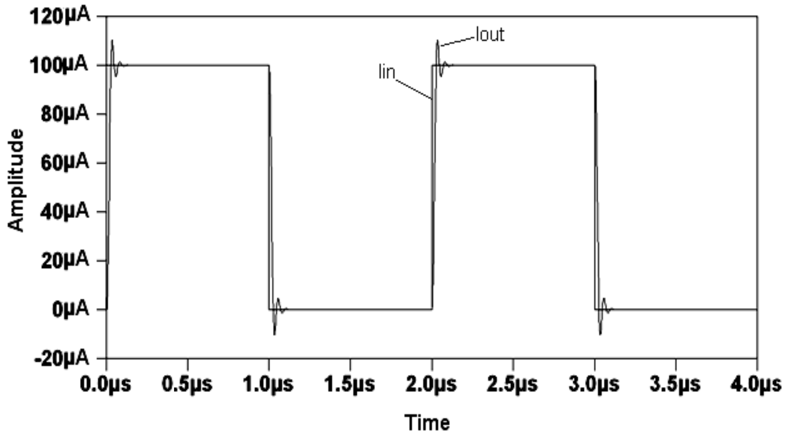

Fig.9. Step response of the filter, f = 500kHz.

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