Int. J. Electron. Commun. (AEÜ) 65 (2011) 753–762

Contents lists available at ScienceDirect

International Journal of Electronics and Communications (AEÜ)

journal homepage: www.elsevier.de/aeue

Active realization of doubly terminated LC ladder filters using current feedback operational amplifier (CFOA) via linear transformation

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ARTICLE INFO

Article history:
Received 16 September 2010
Accepted 7 December 2010

Keywords:
Doubly terminated filters
Active filters
CFOA
Two port network

ABSTRACT

A new technique for passive doubly terminated ladder filters transformation has been proposed. The proposed technique depends on current mode realization of doubly terminated LC ladder filters instead of voltage mode realizations presented by Constantinides and Dimopoulos in [1]. Different realizations of passive elements using new technique have been proposed. Design example of a 3rd order low-pass filter has been realized using the proposed technique and compared with the realization introduced by Rathore and Khot [2] using current feedback operational amplifier (CFOA) as an active building block. SPICE simulations have been carried out using 0.18 μ m TSMC CMOS technology and supply voltages of ± 0.9 V. The simulation results have been demonstrated and discussed.

1. Introduction

Analog designs have been viewed as a voltage dominated form of signal processing for a long time. However current-mode signal processing circuits have been preferred over the voltage-mode signal processing circuits due to their advantages such as higher signal bandwidth, larger dynamic range, greater linearity, lower power consumption, and simpler circuitry. Designs for active realizations of passive elements using high performance active devices are a rich area of research; Lots of active elements have been used to simulate the inductor part in doubly terminated ladder filters. A second generation (CCII) based inductance simulator is presented in [3–9]. In [10] inductor simulator based on operational transconductance amplifier (OTA) has been proposed. Current feedback operational amplifier (CFOA) based inductor simulator introduced in [11]. Other realizations using different active blocks have been presented in [12–14]. Doubly terminated LC ladder filters have been used as prototypes to derive op-amp based *RC* active filters [15,16], OTA based filters [17,18], a current differencing buffered amplifier (CDBA) based filters [19] and current feedback operational amplifier (CFOA) based filters [2].

There are several procedures for realization of active RC networks that simulate lossless ladder doubly terminated filters [20,21]. Constantinides and Dimopoulos [1] have introduced approach to the design of active RC filters that realize lossless doubly terminated ladder filters via linear transformation of port variables. They used the voltage op-amp as an active block to realize their approach. Rathore and Khot [2] presented a second systematic technique for deriving CFOA-based all-grounded-capacitor filters from current mode RLC prototype ladder. It is based on the operational simulation of node voltages and branch currents. It is extended to a voltage-mode ladder as well.

Recently CM (current mode) signal processing techniques are recognized to offer potential advantages for applications in both the continuous-time and sampled-data signal processing [22–24]. CM filters have received a wide attention due to their wide bandwidth, low-voltage operation and simple implementation of signal operations, such as addition and subtraction [25–27]. Current feedback operational amplifier (CFOA) [28–30]-based CM circuits have received considerable attention in many filtering and signal processing applications. CFOA-based circuits are attractive due to greater linearity, better dynamic range, high slew rate and bandwidth independent of the closed-loop gain of CFOA compared with voltage op-amps. Symbol diagram of the CFOA is shown in Fig. 1.

In this paper, active realization of doubly terminated ladder filter using current feedback operational amplifier (CFOA) has been presented based on linear transformation of port variable presented by Constantinides and Dimopoulos [1]. Performance comparison between this approach and Rathore and Khot [2] has been performed using a 3rd order low pass filter.

The paper is organized as follows Section 2 presents the CMOS current feedback operational amplifier, Section 3 Illustrates the linear transformation of two port network concepts and discuss

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doi:10.1016/j.aeue.2010.12.002

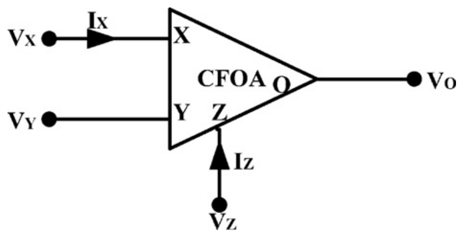

Fig. 1. CFOA building block.

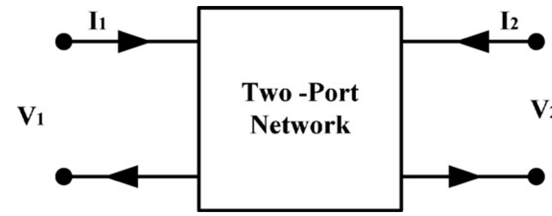

Fig. 2. Two-port network.

different circuits realization, Section 4 discuss the implementation of a 3rd order low pass filter using the proposed realization and the realization presented by Rathore and Khot [2] and finally Section 5 drawn the conclusion.

2. Current feedback operational amplifier (CFOA) [28–30]

The current feedback operational amplifier is a four port network with terminal characteristics described by the following matrix:

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

where V_X, V_Y, V_Z and V_O, I_X, I_Y, I_Z and I_o are the voltages and the currents of X-, Y-, Z- and O-terminals. The basic building block of CFOA is shown in Fig. 1.

3. Ladder filter transformations

3.1. Element transformation

Based on two-port network element by element transformation of the ladder filter component will be done regardless of the element itself but based on its connection whether it is shunt element or series element. On the other hand the one-port networks at the input and output of the ladder filter should be examined as well. Each element is transformed individually and be interconnected accordingly. The problem of interconnection arises and the question is asked how to interconnect the transformed elements this question will be answered later in this section.

Fig. 2 shows a two port network, the transmission matrix of it as shown in Eq. (2).

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} A & B \\ C & D \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad (2)$$

where both I_1, I_2 are supposed to flow into the network so any negative sign will be included in B and C signs. Using the two-port network concept; the transmission matrix of a series and shunt element can be written as shown in Eqs. (3) and (4) respectively.

$$[T] = \begin{bmatrix} 1 & -Z \\ 0 & -1 \end{bmatrix} \quad (3)$$

$$[T] = \begin{bmatrix} 1 & 0 \\ Y & -1 \end{bmatrix} \quad (4)$$

From Eqs. (3) and (4), for both matrices $A = 1$, $D = -1$ and $BC = 0$. Fig. 3 shows the interconnection between the old port variables which can be described by the interconnection matrix in Eq. (5)

$$\begin{bmatrix} V_1 \\ I_1 \end{bmatrix} = \begin{bmatrix} 1 & 0 \\ 0 & -1 \end{bmatrix} \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad (5)$$

The voltages and currents of the two-port network could be represented using new port variables as given in Eqs. (6) and (7).

$$\begin{bmatrix} X_1 \\ Y_1 \end{bmatrix} = C_1 \begin{bmatrix} V_1 \\ I_1 \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} = C_2 \begin{bmatrix} V_2 \\ I_2 \end{bmatrix} \quad (7)$$

where $C_i = \begin{bmatrix} \alpha_i & \beta_i \\ \gamma_i & \delta_i \end{bmatrix}, i = 1, 2$

From Eqs. (6) and (7) the relation between the input and the output port could be written as in Eq. (8)

$$\begin{bmatrix} X_1 \\ Y_1 \end{bmatrix} = C_1 \begin{bmatrix} A & B \\ C & D \end{bmatrix} C_2^{-1} \begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} \quad (8)$$

It can be written in the form of Eq. (9)

$$\begin{bmatrix} X_1 \\ Y_1 \end{bmatrix} = \begin{bmatrix} h & l \\ m & n \end{bmatrix} \begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} \quad (9)$$

where $\begin{bmatrix} h & l \\ m & n \end{bmatrix} = C_1 \begin{bmatrix} A & B \\ C & D \end{bmatrix} C_2^{-1}$

From Eq. (9), Y_1 and Y_2 could be written as a linear combination of X_1 and X_2.

The interconnection between the two-port doubly terminated ladders could be modeled using the new port variables as follows:

$$\begin{bmatrix} X_1 \\ Y_1 \end{bmatrix} = \begin{bmatrix} 0 & k_2 \\ k_1 & 0 \end{bmatrix} \begin{bmatrix} X_2 \\ Y_2 \end{bmatrix} \quad (10)$$

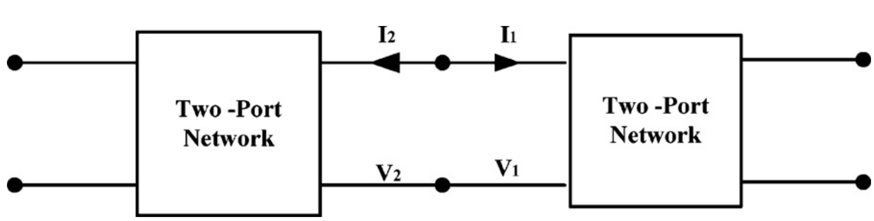

Fig. 3. Interconnection in VI domain.