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Voltage-mode first-order universal filter realizations based on subtractors

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ABSTRACT

Two new voltage-mode (VM) first-order universal filters including two subtractors as active elements as well as one resistor and one capacitor (grounded) as passive components are proposed in this paper. Each of the proposed first-order universal filters can realize low-pass response, high-pass response with a low output impedance and all-pass response with a low output impedance simultaneously. As a result, each of them can be connected to any other VM structures easily. Neither of them suffers from passive element matching conditions. They are free from non-ideal current gains which are frequency dependent. Nevertheless, each of them does not have the feature of high input impedance. A lot of simulations where 0.13 μm IBM CMOS technology parameters are used are carried out through SPICE program. The power supply voltages of the subtractors are chosen as ± 0.75 V. Each of the proposed first-order universal filters dissipates 1.77 mW. Furthermore, an experimental test is accomplished so as to show the performance of the first proposed first-order universal filter as an example.

1. Introduction

A differential difference current conveyor (DDCC) which is defined as a current-mode (CM) active device has the advantages of both of the differential difference amplifier (DDA) and second-generation current conveyor (CCII) [1]. These advantages can be given as good linearity, wide bandwidth, large dynamic range, arithmetic operation capability and high-input impedance. Moreover, a differential voltage current conveyor (DVCC) previously developed in [2], can be easily implemented from the DDCC by grounding Y_1 terminal or Y_3 terminal of the DDCC. A subtractor can be easily realized from the DVCC by removing Z terminals of the DVCC. The subtractor does not suffer from non-ideal current gains which are frequency dependent. Therefore, it can be worked at higher frequencies.

All-pass filters namely phase shifters change phases of the applied input voltage signals while keeping their gains constant are used in many areas for instance signal processing and in telecommunications [3–19]. In the related open literature, a number of first-order voltage-mode (VM) filter topologies including DVCC/DDCC/DDA/subtractor have been recently reported [3–18]. However, the filters of [3,5,7–11,13–18] can provide only all-pass responses. The filters of [3–10,12–16] suffer from non-ideal current gains which are frequency dependent. The filters of [14,15] use floating capacitor(s). Each of the filters of [5,9,12,16] has a drawback of a critical passive component matching condition. The filters of [5,9,15] have a capacitor connected in series to the X terminal of the DVCC/DDCC, which results in limitations at high frequencies [20]. On the other hand, an all-pass filter using one subtractor and one operational transconductance amplifier (OTA) [18] and CCII based first-order all-pass filters [19] have been proposed.

Two novel VM first-order universal filters are proposed in this work. Each of the proposed first-order universal filters is composed of only two subtractors, a resistor and a grounded capacitor which is advantageous in integrated circuit (IC) process [21]. Each of the proposed first-order universal filters can simultaneously realize low-pass response, high-pass response with a low output impedance and all-pass response with a low output impedance. Therefore, each of them can be connected with other VM circuits easily. Each of them does not require any critical passive component matching conditions and cancellation constraints. Each of them does not suffer from frequency dependent non-ideal current gains. Nonetheless, each of the proposed first-order universal filters does not have high input impedance. Simulations of the proposed circuits are achieved through SPICE program in which 0.13 μm IBM CMOS technology parameters [22] are used. Power consumption of each of the first-order universal filter circuits is found as 1.77mW through SPICE simulations. Moreover, an experimental test result for the first proposed first-order universal filter as an example is included to show the performance.

After Section 1, the proposed first-order universal filters are described in Section 2. Parasitic impedance effects on the performances of the proposed circuits are investigated in Section 3. Simulation results and an experimental test result are included in Sections 4 and 5, respectively. Conclusion is drawn in Section 6.

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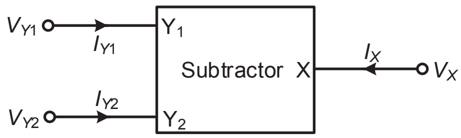

Fig. 1. Electrical symbol of the subtractor.

2. The proposed first-order universal filters

Electrical symbol of the subtractor is illustrated in Fig. 1. The subtractor is defined by the following matrix equation:

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ V_X \end{bmatrix} = \begin{bmatrix} 0 & 0 \\ 0 & 0 \\ \beta & -\eta \end{bmatrix} \begin{bmatrix} V_{Y1} \\ V_{Y2} \end{bmatrix} \tag{1}$$

Here, β and η which are ideally equal to unity are frequency dependent non-ideal voltage gains.

The first and second proposed first-order universal filters are given in Figs. 2 and 3, respectively. Straightforward analysis of the first proposed filter can provide the following transfer functions (TFs):

$$\frac{V_{LP}}{V_{in}} = \frac{1}{1 + sCR} \tag{2a}$$

$$\frac{V_{HP}}{V_{in}} = \frac{sCR}{1 + sCR} \tag{2b}$$

$$\frac{V_{AP}}{V_{in}} = \frac{1-sCR}{1 + sCR} \tag{2c}$$

Here, all the TFs have non-inverting unity gains. Also, angular pole frequency (ω_o) is found as $1/(CR)$. Routine analysis of the second proposed filter gives the same low-pass and high-pass TFs as the first one does. Also, the second proposed filter can realize the following all-pass TF:

$$\frac{V_{AP}}{V_{in}} = -\frac{1-sCR}{1 + sCR} \tag{3}$$

with an inverting unity gain. In (3), ω_o is also found as $1/(CR)$. Phase responses of the first and second proposed all-pass filters are respectively evaluated as follows:

$$\varphi(\omega) = -2Arctan(\omega CR) \tag{4a}$$

$$\varphi(\omega) = \pi - 2Arctan(\omega CR) \tag{4b}$$

In Eq. (4a), as the frequency changes from zero to infinity, phase response varies from 0° to −180°. Similarly, in Eq. (4b), phase response varies from 180° to 0°. If non-ideal gains are considered, Eq. (2a) remains the same. Also, Eqs. (2b) and (2c) respectively turn to

$$\frac{V_{HP}}{V_{in}} = \frac{sCR\beta_1 + \beta_1 - \eta_1}{1 + sCR} \tag{5a}$$

$$\frac{V_{AP}}{V_{in}} = \frac{\beta_2 + \eta_1\eta_2 - \beta_1\eta_2 - sCR\beta_1\eta_2}{1 + sCR} \tag{5b}$$

It is seen from Eq. (5) that ω_o remains the same if the non-ideal gains are considered.

If non-ideal gains for the second proposed universal filter are considered, low-pass TF does not change, high-pass TF remains the same as given in Eq. (5a). Further, Eq. (3) converts to

$$\frac{V_{AP}}{V_{in}} = -\frac{\eta_2 + \beta_2\eta_1 - \beta_1\beta_2 - sCR\beta_1\beta_2}{1 + sCR} \tag{6}$$

If non-ideal gains are considered, phase responses of the first and second proposed all-pass filters are respectively calculated as follows:

$$\varphi(\omega) = -Arctan\left(\frac{\omega CR\beta_1\eta_2}{\beta_2 + \eta_1\eta_2 - \beta_1\eta_2}\right) - Arctan(\omega CR) \tag{7a}$$

$$\varphi(\omega) = \pi - Arctan\left(\frac{\omega CR\beta_1\beta_2}{\eta_2 + \beta_2\eta_1 - \beta_1\beta_2}\right) - Arctan(\omega CR) \tag{7b}$$

The proposed all-pass filters have a zero at high frequencies; accordingly, they can be modelled as

$$H(s) = \frac{V_{AP}\left(1 + \frac{s}{\omega_Z}\right)}{V_{in}} \tag{8}$$

where ω_Z is a zero stemmed from parasitic impedances and non-ideal voltage gains. Also, in frequency domain, TF in (8) can be shown as in the following:

$$H(\omega) = |H(\omega)|e^{j\phi(\omega)} \tag{9}$$

Here, gain response, $|H(\omega)|$ and phase response, $\phi(\omega)$ are respectively evaluated as

$$|H(\omega)| = \sqrt{1 + \frac{\omega^2}{\omega_Z^2}} \tag{10a}$$

$$\phi(\omega) = Arctan\left(\frac{\omega}{\omega_Z}\right) + \varphi(\omega) \tag{10b}$$

It is seen from Eq. (10) that the proposed filters have the following constraint:

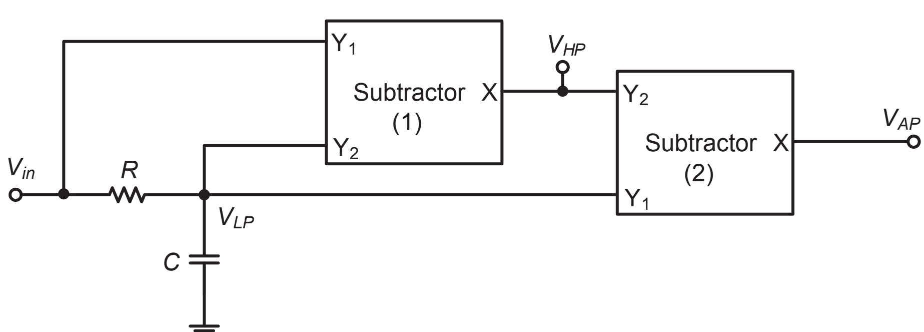

Fig. 2. The first proposed first-order universal filter.