World Academy of Science, Engineering and Technology
International Journal of Electronics and Communication Engineering
Vol:1, No:2, 2007

A New Current-mode Multifunction Filter with High Impedance Outputs Using Minimum Number of Passive Elements

Mehmet Sagbas, Kemal Fidanboylu and Mehmet C. Bayram

***Abstract*—**A new current-mode multifunction filter using minimum number of passive elements is proposed. The proposed filter has single-input and four high-impedance outputs. It uses four passive elements (two capacitors and two resistors) and four dual output second generation current conveyors. Each output provides a different filter response, namely, low-pass, high-pass, band-pass and band-reject. The sensitivity analysis is also carried out on both ideal and non-ideal filter configurations. The validity of the proposed filter is verified through PSPICE simulations.

***Keywords*—**Active filter, Universal filter, Current conveyors.

I. INTRODUCTION

RECENTLY there is a growing interest to current-mode multifunction filters employing current conveyors [1-2], which are accepted to have wider bandwidth and greater linearity compared to voltage mode operational amplifiers [3-4].

Second generation current conveyors (CCIIs) have been found very useful in filtering applications. Second-order active filters with infinite output impedance are of great interest because several cells of this kind can be directly connected in cascade to implement higher-order filters [5-6]. The circuits presented in the literature have only three outputs giving low-pass (LP), high-pass (HP) and band-pass (BP) responses [7]. Band-reject (BR) filter response is obtained indirectly by connecting the outputs in a special way.

This paper presents a multifunction filter which has four high-impedance outputs providing low-pass, high-pass, band-pass and band-reject responses simultaneously. It uses minimum number of passive elements (two capacitors and two resistors) and four dual-output second generation current conveyors (DO-CCII). The high impedance outputs enable easy cascadability without the need of any supplementary buffer circuits. In Section 2, the proposed circuit configuration and the transfer functions of the four different filter responses are presented. The sensitivity analysis considering the ideal and the non-ideal effects is presented in Section 3. Section 4 presents the simulation results of the proposed filter configuration obtained using PSPICE. Finally, concluding remarks are presented in Section 5.

II. CIRCUIT CONFIGURATION

The dual-output second generation current conveyor [8] also called four terminal active current conveyor (CFCCII) [9] which is shown in Fig. 1 is defined by the following terminal equations:

$$\begin{bmatrix} V_x \\ I_y \\ I_{z+} \\ I_{z-} \end{bmatrix} = \begin{bmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_{z+} \\ V_{z-} \end{bmatrix} \qquad (1)$$

The input impedances for the ideal DO-CCII are infinite at terminal *y* and zero at terminal *x*, respectively. The terminal *z*, which is equivalent to a current generator, possesses infinite output impedance.

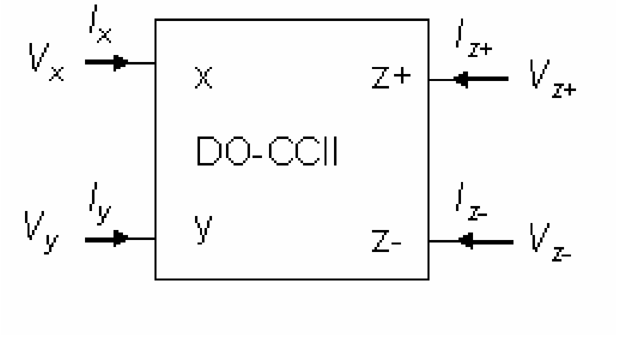

Fig. 1. Block diagram of the dual-output second generation current conveyor (DO-CCII).

This active element has been used in several applications [10-11]. Bipolar [12] and CMOS realizations [13] of the DO-CCII were presented in the literature. Fig. 2 shows a bipolar realization of a typical DO-CCII. Taking the non-idealities of the DO-CCII into account, the above terminal equations can be rewritten as

$$\begin{bmatrix} V_x \\ I_y \\ I_{z+} \\ I_{z-} \end{bmatrix} = \begin{bmatrix} 0 & \beta & 0 & 0 \\ 0 & 0 & 0 & 0 \\ \alpha & 0 & 0 & 0 \\ -\alpha & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_x \\ V_y \\ V_{z+} \\ V_{z-} \end{bmatrix} \qquad (2)$$

The authors are with the Electronics Engineering Department at Fatih University, Istanbul, Turkey (phone: +90-212-889-0810, fax: +90-212-889-0906, e-mail: kfidan@fatih.edu.tr).

where, $\beta = 1 - \varepsilon_V$ and $\alpha = 1 - \varepsilon_i$; ε_V $(|\varepsilon_V| << 1)$ and ε_i $(|\varepsilon_i| << 1)$ denote the voltage and current tracking errors, respectively.

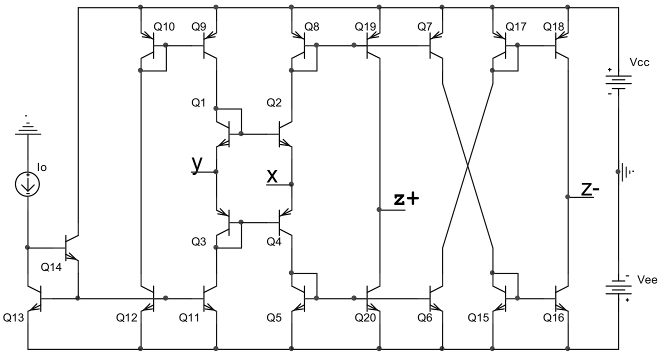

Fig. 2. Schematic implementation for DO-CCII using BJT technology.

The proposed multifunction filter is shown in Fig. 3. The transfer function of the circuit at different outputs is found as follows:

$$\frac{I_{LP}}{I_i} = \frac{1/R_1R_2C_1C_2}{s^2 + s/R_2C_2 + 1/R_1R_2C_1C_2} \tag{3}$$

$$\frac{I_{HP}}{I_i} = \frac{s^2}{s^2 + s/R_2C_2 + 1/R_1R_2C_1C_2} \tag{4}$$

$$\frac{I_{BP}}{I_i} = \frac{s/R_2C_2}{s^2 + s/R_2C_2 + 1/R_1R_2C_1C_2} \tag{5}$$

$$\frac{I_{BR}}{I_i} = -\frac{s^2 + 1/R_1R_2C_1C_2}{s^2 + s/R_2C_2 + 1/R_1R_2C_1C_2} \tag{6}$$

Equations (3), (4), (5) and (6) show that the proposed filter produces LP, HP, BP and BR responses simultaneously at its high impedance outputs.

In addition, if we connect I_{LP}, I_{HP} and $-I_{BP}$ together, then we obtain an all-pass output, I_{AP} as shown in Fig. 4. The all-pass filter output is related with the other outputs as follows:

$$I_{AP} = I_{LP} - I_{BP} + I_{HP} \tag{7}$$

The transfer function of the all-pass filter is given by

$$\frac{I_{AP}}{I_i} = \frac{s^2 - s/R_2C_2 + 1/R_1R_2C_1C_2}{s^2 + s/R_2C_2 + 1/R_1R_2C_1C_2} \tag{8}$$

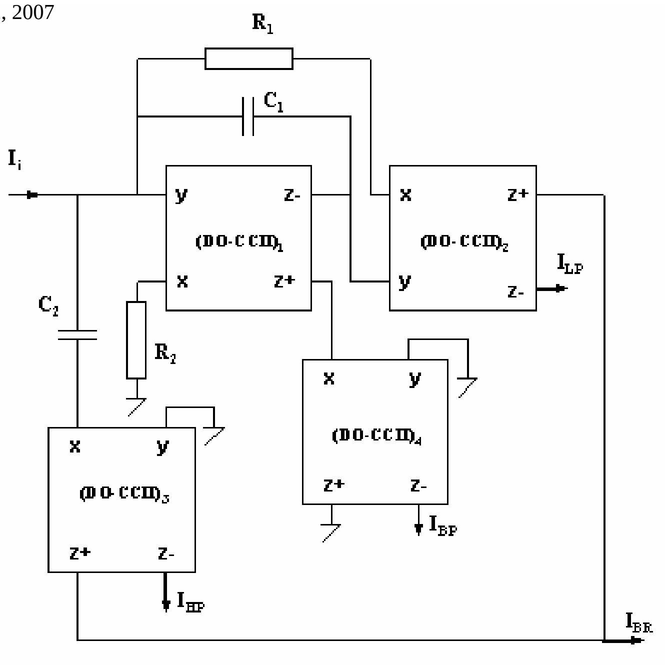

Fig. 3. Circuit diagram of the proposed filter realizing LP, HP, BP and BR responses at high impedance outputs.

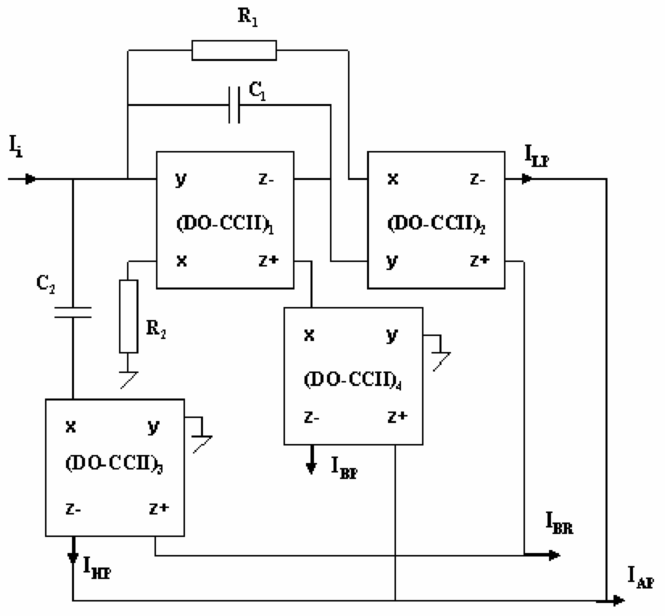

Fig. 4. Circuit diagram of the proposed filter realizing all-pass filter response (AP) at high impedance outputs.

The natural frequency and the quality factor of the proposed circuit are calculated from the denominator of the transfer functions as follows:

$$\omega_o = \frac{1}{\sqrt{R_1R_2C_1C_2}} \tag{9}$$

$$Q = \sqrt{\frac{R_2C_2}{R_1C_1}} \tag{10}$$

Taking the non-idealities of the second generation current conveyors given in equation (2) into account, the denominator polynomial of the transfer functions for the proposed filter is found as follows:

$$D(s) = s^2 + s\left[\frac{R_1\alpha_1\beta_1 + R_2(1-\beta_2)}{R_1R_2C_2}\right] + \frac{\beta_1\beta_2\alpha_1}{R_1R_2C_1C_2} \quad (11)$$

where, the subscripts of β and α refer to the number of each current conveyor shown in Fig. 3.

Using equation (11), the natural frequency and the quality factor considering the non-ideal effects become

$$\omega_o = \sqrt{\frac{\beta_1\beta_2\alpha_1}{R_1R_2C_1C_2}} \quad (12)$$

$$Q = \sqrt{\frac{R_1R_2C_2\beta_1\beta_2\alpha_1}{C_1}}\,\frac{1}{R_1\beta_1\alpha_1 + R_2(1-\beta_2)} \quad (13)$$

III. SENSITIVITY ANALYSIS

The ideal sensitivities of the natural frequency and the quality factor with respect to passive components are calculated as follows:

$$S^{\omega}_{R_1} = S^{\omega}_{R_2} = S^{\omega}_{C_1} = S^{\omega}_{C_2} = -\frac{1}{2} \quad (14)$$

$$S^{Q}_{R_1} = S^{Q}_{C_1} = -\frac{1}{2} \quad (15)$$

$$S^{Q}_{R_2} = S^{Q}_{C_2} = \frac{1}{2} \quad (16)$$

From the above calculations, it can be seen that all sensitivities are constant and smaller than 1.

From Eq. (12) and Eq. (13), the non-ideal sensitivities can be calculated as

$$S^{\omega}_{\alpha_2} = S^{\omega}_{\alpha_3} = S^{\omega}_{\alpha_4} = S^{\omega}_{\beta_3} = S^{\omega}_{\beta_4} = 0 \quad (17)$$

$$S^{Q}_{\alpha_2} = S^{Q}_{\alpha_3} = S^{Q}_{\alpha_4} = S^{Q}_{\beta_3} = S^{Q}_{\beta_4} = 0 \quad (18)$$

$$S^{\omega}_{R_1} = S^{\omega}_{R_2} = S^{\omega}_{C_1} = S^{\omega}_{C_2} = -\frac{1}{2} \quad (19)$$

$$S^{Q}_{\alpha_1} = S^{Q}_{\beta_1} = S^{Q}_{C_1} = S^{Q}_{R_1} = -\frac{1}{2} \quad (20)$$

$$S^{\omega}_{\alpha_2} = S^{\omega}_{\beta_1} = S^{\omega}_{\beta_2} = \frac{1}{2} \quad (21)$$

$$S^{Q}_{C_2} = S^{Q}_{R_2} = \frac{1}{2} \quad (22)$$

$$S^{Q}_{\beta_2} = \frac{1}{2} + \frac{R_2}{R_1} \quad (23)$$

Equations (17) through (23) were obtained by assuming that $\beta_1 = \beta_2 = \alpha_1 = \alpha_2 = 1$. Furthermore, if we choose $R_1 > 2R_2$ in Equation (23), then all the sensitivities for the non-ideal case also become less than 1.

IV. SIMULATION RESULTS

The validity of the proposed multifunction filter was verified through PSPICE. Each DO-CCII was implemented using the BJT realization shown in Fig. 2. For these simulations the passive components were chosen as, $C_1 = 0.4\,nF$, $C_2 = 0.2\,nF$ and $R_1 = R_2 = 20\,k\Omega$. The voltage supplies of DO-CCIIs were taken as $V_{cc} = 2.5\ V$ and $V_{ee} = -2.5\ V$ and the bias currents were chosen as $100\,\mu A$. Fig. 5 shows the magnitude responses of the LP, HP, BP, and BR filter outputs. Furthermore, Fig. 6 and Fig. 7 show the magnitude and phase responses of the all-pass output, respectively.

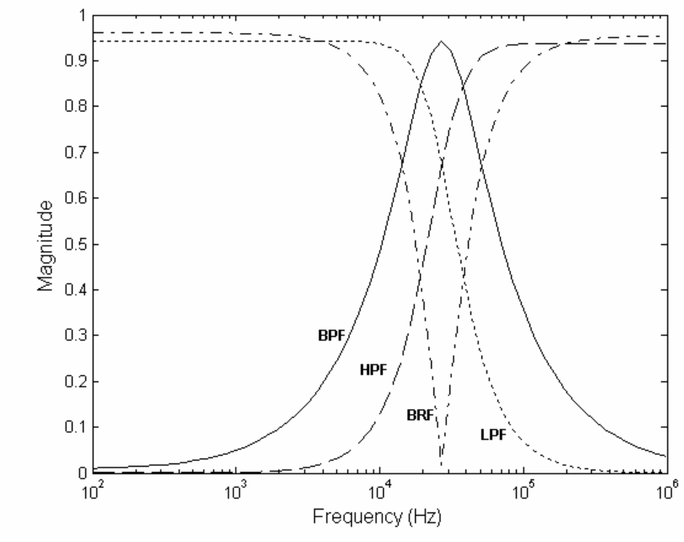

Fig. 5. PSPICE simulation results for the proposed multifunction filter showing LP, HP, BP and BR responses.

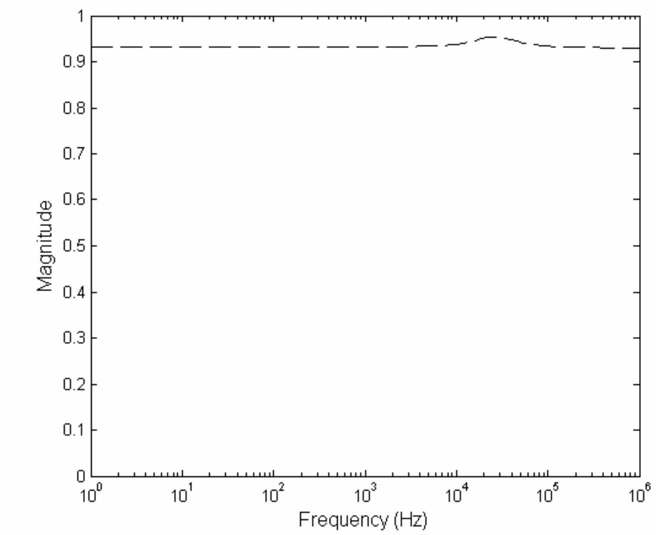

Fig. 6. PSPICE simulation results for the proposed multifunction filter showing all-pass magnitude response.

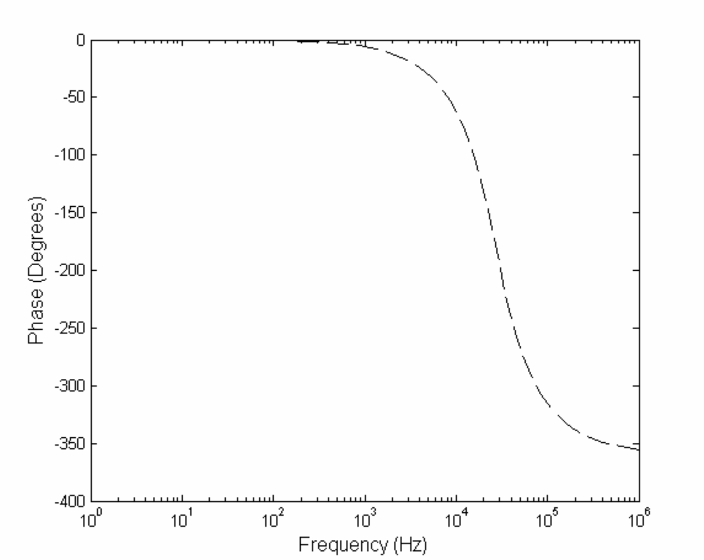

Fig. 7. PSPICE simulation results for the proposed multifunction filter showing all-pass phase response.

V. CONCLUSIONS

In this paper, we have presented a new current-mode multifunction filter with high-impedance outputs using minimum number of passive elements. The proposed filter has the following advantages: (i) Four filter responses (LP, HP, BP and BR) at different outputs; (ii) High output impedance, which enables easy cascadability without the need of any supplementary buffer circuits; (iii) Very low active and passive filter sensitivities; (iv) Use of minimum number of passive elements; (v) Possible realization of the all-pass filter response.

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