TRANSRESISTANCE MULTIFUNCTION FILTER USING CURRENT FEEDBACK AMPLIFIER

Murat AKSOY[1] Sadri ÖZCAN[2] Hakan KUNTMAN[3] Oğuzhan ÇİÇEKOĞLU[4]

aksoy@mail.cu.edu.tr sozcan@ehb.itu.edu.tr kuntman@ehb.itu.edu.tr cicekogl@boun.edu.tr

[1]Çukurova University, Electrical and Electronic Eng. Dep. 01330, Adana, TURKEY

[2,3]Istanbul Technical University, Faculty of Electrical and Electronics Eng., 80626, Maslak, İstanbul, TURKEY

[4]Boğaziçi University, Institute of Biomedical Engineering, Bebek, İstanbul, TURKEY

ABSTRACT

Active filters play important role in communication systems. They can be obtained and constructed by different methods. Recently, there is a tendency of designing current-mode circuits using unity-gain active elements such as, CFOAs, CCIIs, etc. instead of classical infinite gain operational amplifiers in active filter design. This paper presents transresistance multifunction filter realization using current-feedback operational amplifiers (CFOAs). A CFOA is similar to CCII structure except its output buffer. AD844 of AD is used as CFOA, so its unity gain buffer can be used as voltage monitoring. The need for such filters with different input and output variables rises in the application of A/D converter with current output. Such A/D converters follow by a reconstruction filter with current input and voltage output. Simulation results are included to verify theory.

I. INTRODUCTION

Several active filters have been introduced with second-generation current conveyors (CCII) and similar active elements, which are accepted to have wider bandwidth and greater linearity compared to active filters with Op-Amp [1-4]. Some translinear cells are used to implement the unity-gain voltage buffer [5,6]. For example in a current feedback op-amp, (AD844) +in and –in terminals can be used as the input and output of a unity-gain of voltage amplifier and the z terminal is used for current monitoring [7-9]. Op-Amps may be used for this purpose and in this case, the op-amp will be operated at the edge of the gain-bandwidth product limit frequency.

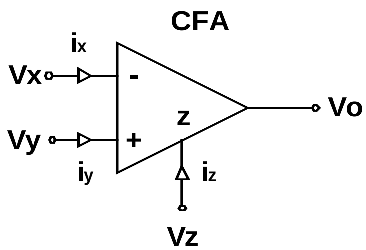

Figure 1. Circuit symbol of current feedback operational amplifier

In this work, transresistance multifunction filter with CFOA active element is proposed. Numbers of passive elements are reduced to a limiting number; only three resistors and three capacitors are used, except the gain resistors connected to the z-terminal. All capacitors and resistor values are chosen equal-valued. The resistors which are connected to the z terminals are used for transfering the voltage to the output.

II. CURRENT FEEDBACK OP-AMP

Current feedback op-amp symbol is shown in Fig.1. This element is equal to the second-generation current conveyor (CCII) except its voltage buffer. The current-voltage terminal characteristic of an ideal CFOA can be modeled as

$$\begin{pmatrix} i_y \\ v_x \\ i_z \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{pmatrix} \begin{pmatrix} v_y \\ i_x \\ v_z \end{pmatrix}$$

and (1)

$$v_0 = v_z$$

Deviations from the ideal characteristics will affect the performance of the circuits realized with CFOA. Taking the current and voltage tracking errors into account the current-voltage terminal characteristic of the non-ideal CFOA becomes,

$$\begin{pmatrix} i_y \\ v_x \\ i_z \end{pmatrix} = \begin{pmatrix} 0 & 0 & 0 \\ \beta & 0 & 0 \\ 0 & \alpha & 0 \end{pmatrix} \begin{pmatrix} v_y \\ i_x \\ v_z \end{pmatrix}$$

and (2)

$$v_0 = \gamma v_z$$

where α, β, and γ are the non-ideal voltage and current gains.

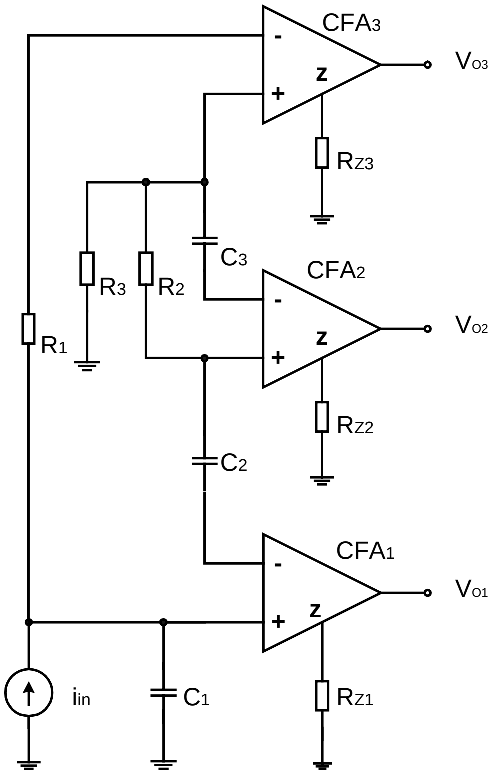

Figure 2. Proposed transresistance multifunction filter

III. CIRCUIT DESCRIPTION

The proposed circuit is shown in Fig. 2. This filter contains three active and nine passive elements. The CFOAs (AD844) are used essentially as second-generation current conveyors. The z-terminal current of each active element is converted to a voltage by the use of a resistor (R_{Z1}, R_{Z2}, R_{Z3}) and transferred to the output over a unity gain voltage buffer. For the ideal case, the transfer functions of the circuit in Fig. 2 are given as

$$\frac{v_{01}}{i_{in}} = -R_{Z1}\frac{C_2 G_2 G_3 s}{\Delta_1} \tag{3}$$

$$\frac{v_{02}}{i_{in}} = -R_{Z2}\frac{C_2 C_3 G_3 s^2}{\Delta_1} \tag{4}$$

$$\frac{v_{03}}{i_{in}} = R_{Z3}\frac{G_1 G_3 (G_2 + C_2 s)}{\Delta_1} \tag{5}$$

where

$$\Delta_1 = G_1 G_2 G_3 + G_3(C_2 G_1 + C_1 G_2)s + C_1 C_2 (G_2 + G_3)s^2 + C_1 C_2 C_3 s^3$$

For the non-ideal case, β_1, β_2, and β_3 are voltage gains of each CFOA. Inputs are V_{i1}, V_{i2}, and V_{i3} , V_{O1}, V_{O2} and V_{O3} are outputs of the amplifiers. So,
$V_{O1}= \beta_1 V_{i1}$, $V_{O2}= \beta_2 V_{i2}$, and $V_{O3} = \beta_3 V_{i3}$

$$\frac{v_{01}}{i_{in}} = -R_{Z1}\gamma_1 \frac{\alpha_1\beta_3 C_2 G_2 [\beta_2 G_3 - (1-\beta_2)C_3 s]s}{\Delta_2} \tag{6}$$

$$\frac{v_{o2}}{i_{in}} = -R_{Z2}\gamma_2 \frac{\alpha_2\beta_3 C_2 C_3 [G_2(1-\beta_2) + G_3]s^2}{\Delta_2} \tag{7}$$

$$\frac{v_{03}}{i_{in}} = R_{Z3}\gamma_3 \frac{\alpha_3 G_1 \left\{\begin{array}{l}\beta_1\beta_2\beta_3 G_2 G_3 - \beta_2 C_2 G_2 \\ [(1-\beta_3\beta_1) + (1-\beta_2)\beta_3]s \\ + \beta_1\beta_2\beta_3 C_2 G_3 s - \\ C_2 C_3 (1-\beta_1\beta_2\beta_3)s^2\end{array}\right\}}{\Delta_2}$$

(8)

where

$$\Delta_2 = \beta_1\beta_2\beta_3 G_1 G_2 G_3 - \{G_1 G_2 [\beta_2 C_2 (1-\beta_1\beta_3) - \beta_1\beta_3 C_3 (1-\beta_2)] + \beta_1\beta_2\beta_3 G_3 (C_2 G_1 + C_1 G_2)\}s - C_3\{[C_2 G_1 (1-\beta_1\beta_2\beta_3) - \beta_1\beta_3 C_1 G_2 (1-\beta_2)] + \beta_1\beta_2\beta_3 C_1 C_2 (G_2 + G_3)\}s^2 + \beta_1\beta_2\beta_3 C_1 C_3 s^3$$

When equal valued passive elements are selected then Eqns. from (3) to (5) become

$$\frac{v_{01}}{i_{in}} = R_{Z1}\frac{sCR}{(sCR)^3 + 2(sCR)^2 + 2sCR + 1} \tag{9}$$

$$\frac{v_{02}}{i_{in}} = R_{Z2}\frac{(sCR)^2}{(sCR)^3 + 2(sCR)^2 + 2sCR + 1} \tag{10}$$

$$\frac{v_{03}}{i_{in}} = R_{Z3}\frac{sCR + 1}{(sCR)^3 + 2(sCR)^2 + 2sCR + 1} \tag{11}$$

Taking G= 1Mho and C= 1F, the normalized transfer functions are

$$\frac{v_{01}}{i_{in}} = R_{Z1}\frac{s}{1 + 2s + 2s^2 + s^3} \tag{12}$$

$$\frac{v_{02}}{i_{in}} = R_{Z2}\frac{s^2}{1 + 2s + 2s^2 + s^3} \tag{13}$$

$$\frac{v_{03}}{i_{in}} = R_{Z3}\frac{s + 1}{1 + 2s + 2s^2 + s^3} \tag{14}$$

The first transfer function exhibits a non-symmetrical frequency response with a slope of 20dB/dec at low frequencies and a slope of –40dB/dec at high frequencies.

The second results in 40dB/decade before the tuning frequency and -20 dB/decade at high frequencies. The last transfer function gives a low pass filter with -40dB/dec. To shift the center frequency to the desired value, impedance and frequency scaling can easily be performed on the filter circuit. Performing RC-CR transformation on the circuit, the last normalized transfer function yields a high pass filter with 20 dB/dec. In this case, the first transfer function has a s^2 term in the numerator and exhibits a frequency response with a slope of 40dB/decade before the tuning frequency and -20 dB/decade at high frequencies. The second transfer function has a s term in the numerator and yields a frequency response with rolloff slopes 20 dB/dec and –40 dB/dec.

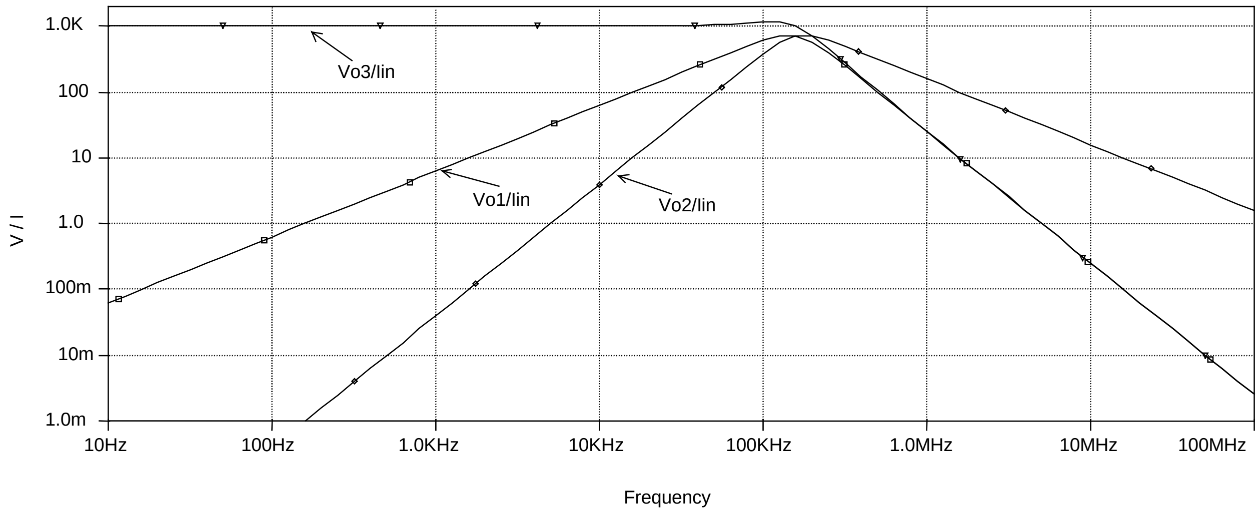

Figure 3. Frequency responses of the multifunction filter with ideal CFOA.

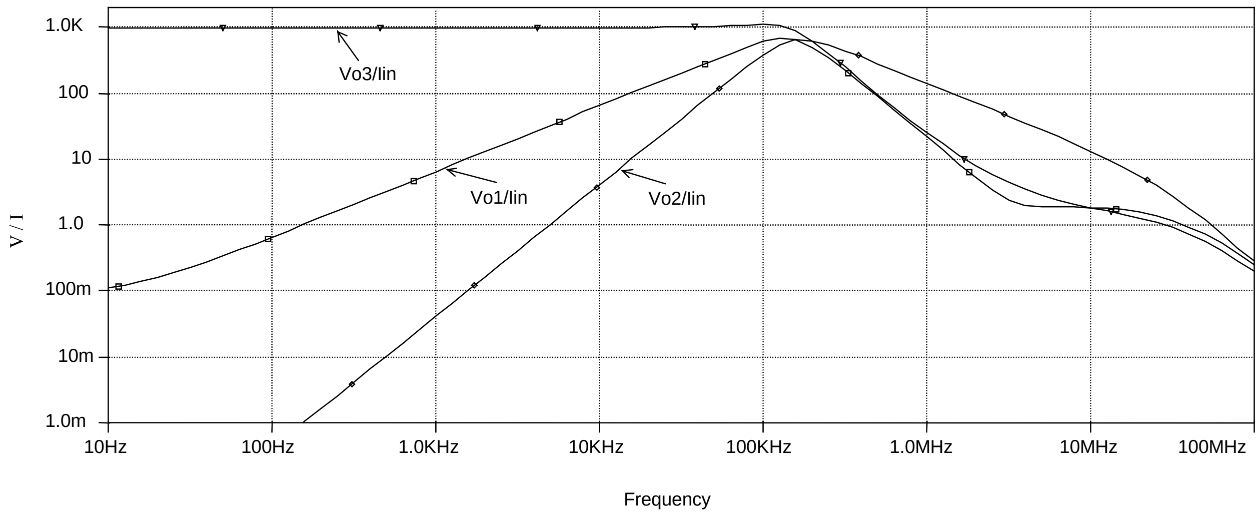

Figure 4. Frequency responses of the multifunction filter realized with AD844 of AD

IV. SIMULATION RESULTS

The analysis of the filter for ideal and non-ideal cases is demonstrated with SPICE simulations. Ideal and AD844 model are used as a CFOA and the filter circuit is analyzed with SPICE. The equal valued capacitors and resistors are chosen as C=1nF and R=1kΩ. The center frequency is 142 kHz. The supply voltage of the circuit is chosen ±10V. The resulting frequency responses obtained from SPICE simulations with ideal CFOA and non-ideal CFOA (AD844) are illustrated in Fig. 3 and Fig. 4. The deviation from theory in high frequency region is caused by the limited bandwidth of the AD844. A sinusoidal input signal with 142kHz frequency and 1mA amplitude is applied to the filter to test the large signal behavior. In Table 1 the effect of input current to the total harmonic distortion (THD) is given. The acceptable maximum peak input current for this filter is 5 mA.

V. CONCLUSION

In this work, a new transresistance multifunction filter is proposed. The circuit has minimum number of passive elements which are equal-valued, three resistors and three capacitors, except the gain resistors. The gains of the outputs are easily adjustable by the resistors connected to the z terminals. SPICE simulations are performed and the results obtained are found to be in good agreement with the theoretical results. The non-ideality case is also investigated. There are little differences between ideal and non-ideal responses at high and low frequency regions in the frequency response of this filter. These differences stems from the non-ideality case, that is to say, from the parasitics of the AD844, but they are within the acceptable limits. The proposed filter can be used in many applications. One possible application is a D/A converter with current output that can be followed by a reconstruction filter with current input and voltage output.

Table 1. The effect of input current to the total harmonic distortion (THD)

I_{in}(mA)	THD%		
	V_{O1}	V_{O2}	V_{O3}
0.3	0.64	0.68	0.78
0.7	0.63	0.61	0.64
1.2	0.63	0.63	0.58
2	0.87	1.01	0.80
4	0.63	0.77	0.59
4.5	0.64	0.77	0.60
4.7	1.32	2.44	1.79
5	2.13	6.59	4.05

REFERENCES

[1] Chang C. M., Current-Mode Lowpass Bandpass and Highpass Biquads Using Two CCIIs, ELECTRONICS LETTERS, vol. 29, pp. 2020-2021, 1993

[2] Abuelma'atti M. T., Al-Qahtani M. A., Current-Mode Universal Filters Using Unity-Gain Cells ELECTRONICS LETTERS, vol. 32, no. 12, pp. 1077-1078, 1996

[3] Acar C., Özoğuz S., High-Order Voltage Transfer Function Synthesis Using CCII+ Based Unity Gain Current Amplifiers, ELECTRONICS LETTERS, vol. 32, no. 22, pp. 2030-2031, 1996

[4] Chang C. M. , Novel Universal Current-Mode Filter with Single-Input and 3 Outputs Using Only 5 Current Conveyors, ELECTRONICS LETTERS, Vol. 29, Iss 23, pp 2005-2007, 1993

[5] Fabre A., Amrani H., Bartelemy H., A Novel Class AB First Generation Current Conveyor, IEEE TRANSACTIONSON CIRCUITS AND SYSTEMS II ANALOG AND DIGITAL SIGNAL PROCESSING, vol. 46. no. 1, pp. 96-98, 1999

[6] Fabre A., Saaid O., Wiest F., Boucheron C., High Frequency Applications Based on a New Current Controlled Conveyor, IEEE TRANSACTIONS ON CIRCUITS AND SYSTEMS I FUNDAMENTAL THEORY AND APPLICATIONS, vol.43, Iss. 2, pp. 82-91, 1996

[7] Güneş E. O., Anday F., CFA Based Fully Integrated Nth-Order Lowpass Filter, ELECTRONICS LETTERS, vol. 33, no. 7, pp. 571-573, 1997

[8] Wu D. S., Lee H. T., Hwang Y. S., Wu Y. P, CFA-Based Universal Filter Deduced From a Mason Graph, INTERNATIONAL JOURNAL OF ELECTRONICS, vol. xx, no. x, pp. 1059-1065, 1994

[9] Abuelma'atti M. T., Al-Zaher H. A., New Universal Filter with One Input and Five Outputs Using Current-Feedback Amplifiers, ANALOG INTEGRATED CIRCUITS AND SIGNAL PROCCESSING, vol. 16, no. 3, pp. 239-244, 1998