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New Universal Filter with One Input and Five Outputs Using Current-Feedback Amplifiers

MUHAMMAD TAHER ABUELMA'ATTI AND HUSSAIN ABDULLAH AL-ZAHER

King Fahd University of Petroleum and Minerals
Dhahran, Saudi Arabia

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ABSTRACT

A new universal voltage-mode second-order filter circuit is presented. The circuit uses five current-feedback operational amplifiers, two grounded capacitors, three grounded resistors and three floating resistors. The circuit can realize all the standard filter functions, lowpass, highpass, bandpass, notch and allpass, without changing the passive elements. The proposed circuit enjoys independent grounded-resistance-control of the natural frequency and the bandwidth, low output impedances, and low active and passive sensitivities.

Key Words: filters, current-feedback amplifiers

I. Introduction

At present, there is growing interest in designing active filters using current-feedback amplifiers (CFAs) (Abuelma'atti and Alshahrani, 1996; Chang *et al.*, 1994; Fabre, 1992, 1993; Liu, 1995a, 1995b; Liu and Hwang, 1994). This is attributed to the extended operating bandwidths and relatively large values of slew rates compared to the conventional realizations using voltage-feedback amplifiers. In Chang *et al.* (1994), a voltage-mode highpass and bandpass filter using two CFAs was proposed, and in Fabre (1992), a voltage-mode bandpass and highpass/lowpass filter using one CFA was proposed. Both circuits have one input and two outputs. In Fabre (1993), a voltage-mode highpass/bandpass/lowpass filter using one CFA was proposed. Realization of the different filter functions requires changes in the passive components used. The voltage-mode notch and lowpass and bandpass filters proposed by Abuelma'atti and Alshahrani (1996) uses three CFAs and five passive components, namely, three floating resistors and two grounded capacitors. The circuit has one input and three low-impedance outputs. The high input impedance universal filter proposed by Liu (1995a) uses two CFAs and six passive elements, namely, four resistors and two capacitors. The circuit has three inputs and one low impedance output and uses the same passive components for all realizations. The high input impedance filter proposed by Liu (1995a) can be configured to realize either a bandpass or a lowpass or a highpass filter function. The circuit uses five passive elements, namely, three (or two) capacitors and two (or three) resistors depending on the required filter function. The three filter functions can not be realized without changing the locations of the passive components used. The low component universal filter proposed by Liu and Hwang (1994) uses two CFAs, three resistors and two capacitors, and can realize all the five filter functions. The circuit has three inputs and one output, and enjoys independent control of the parameters ω_o and $\frac{\omega_o}{Q_o}$. Careful investigation of the above mentioned circuits shows that none of them enjoys all the following attractive features:

(1) simultaneous realization of all the filter functions, namely, lowpass, highpass, bandpass, notch and allpass;
(2) low output impedances;
(3) use of grounded capacitors;
(4) independent grounded-resistance-control of the parameters ω_o and $\frac{\omega_o}{Q_o}$.

The major intention of this paper is to present a new current-feedback-amplifier based circuit. This circuit can simultaneously realize the five filter functions, uses grounded capacitors, enjoys independent grounded-resistance-control of the parameters ω_o and $\frac{\omega_o}{Q_o}$, and has low output impedances.

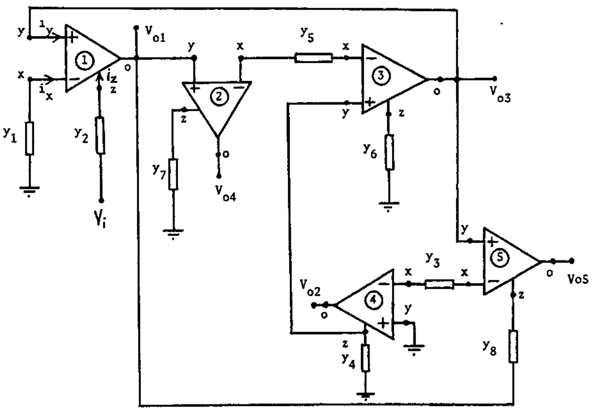

Fig. 1. Proposed universal filter structure.

II. Proposed Circuit

The proposed circuit is shown in Fig. 1. Assuming ideal current-feedback amplifiers with $i_z=i_x$, $i_y=0$, $v_x=v_y$ and $v_o=v_z$, routine analysis, using Kirchhoff's current law (KCL) at the different nodes, shows that the transfer functions of the circuit shown in Fig. 1 can be expressed as

$$\frac{V_{o1}}{V_i}=\frac{y_2y_4y_6+y_2y_3y_5}{y_2y_4y_6+y_2y_3y_5+y_1y_4y_5} \qquad (1)$$

$$\frac{V_{o2}}{V_i}=\frac{-y_2y_3y_5}{y_2y_4y_6+y_2y_3y_5+y_1y_4y_5} \qquad (2)$$

$$\frac{V_{o3}}{V_i}=\frac{-y_2y_4y_5}{y_2y_4y_6+y_2y_3y_5+y_1y_4y_5} \qquad (3)$$

$$\frac{V_{o4}}{V_i}=\frac{y_2}{y_7}\frac{y_4y_5y_6}{y_2y_4y_6+y_2y_3y_5+y_1y_4y_5} \qquad (4)$$

and

$$V_{o5}=V_{o1}+\frac{y_3}{y_8}V_{o3}. \qquad (5a)$$

Combining Eqs. (1), (3) and (5a), we have

$$\frac{V_{o5}}{V_i}=\frac{y_2y_4y_6-y_2y_4y_5\frac{y_3}{y_8}+y_2y_3y_5}{y_2y_4y_6+y_1y_4y_5+y_2y_3y_5}. \qquad (5b)$$

Now if $y_1y_8=y_2y_3$, then

$$\frac{V_{o5}}{V_i}=\frac{y_2y_4y_6-y_1y_4y_5+y_2y_3y_5}{y_2y_4y_6+y_1y_4y_5+y_2y_3y_5}. \qquad (5c)$$

Proper selection of the admittances y_i; $i=1-8$ can yield a realization of the five standard filter transfer functions, namely, lowpass, highpass, bandpass, notch and allpass. Thus, if we choose $y_1=G_1$, $y_2=G_2$, $y_3=G_3$, $y_4=sC_4$, $y_5=G_5$, $y_6=sC_6$, $y_7=G_7$, then Eqs. (1)-(4) and (5c) reduce to

$$\frac{V_{o1}}{V_i}=\frac{s^2+\frac{G_3G_5}{C_4C_6}}{D(s)} \qquad (6)$$

$$\frac{V_{o2}}{V_i}=\frac{-\frac{G_3G_5}{C_4C_6}}{D(s)} \qquad (7)$$

$$\frac{V_{o3}}{V_i}=\frac{-s\frac{G_5}{C_6}}{D(s)} \qquad (8)$$

$$\frac{V_{o4}}{V_i}=\frac{s^2\frac{G_5}{G_7}}{D(s)} \qquad (9)$$

and

$$\frac{V_{o5}}{V_i}=\frac{s^2-s\frac{G_1G_5}{G_2C_6}+\frac{G_3G_5}{C_4C_6}}{D(s)}, \qquad (10)$$

where

$$D(s)=s^2+s(\frac{\omega_o}{Q_o})+\omega_o^2=s^2+s\frac{G_1G_5}{G_2C_6}+\frac{G_3G_5}{C_4C_6}. \qquad (11)$$

From Eqs. (6)-(11), it can be seen that a notch response is obtained from V_{o1}, a lowpass response is obtained from V_{o2}, a bandpass response is obtained from V_{o3}, a highpass response is obtained from V_{o4} and an allpass response is obtained from V_{o5}. In all cases, the parameters ω_o and $\frac{\omega_o}{Q_o}$ are given by

$$\omega_o^2=\frac{G_3G_5}{C_4C_6} \qquad (12)$$

and

$$\frac{\omega_o}{Q_o}=\frac{G_1G_5}{G_2C_6}. \qquad (13)$$

Also, it can be seen that the notch gain, lowpass gain, highpass gain and bandpass gain can be given by

$$G_{notch}=G_{LP}=1 \qquad (14)$$

$$G_{HP}=\frac{G_5}{G_7} \qquad (15)$$

and

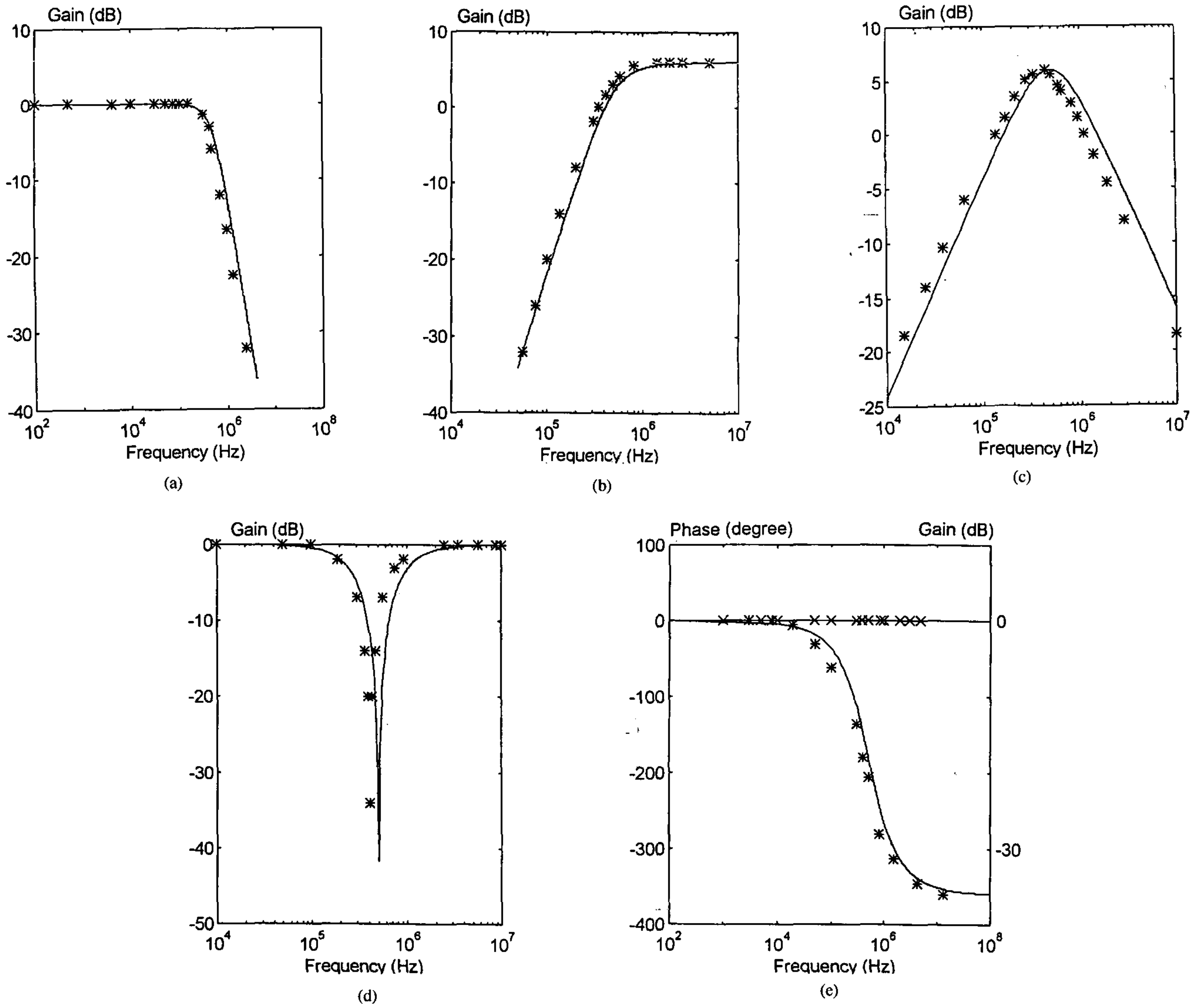

Fig. 2. Measured and Calculated results obtained from the circuit of Fig. 1. *:Measured, –: Calculated, C_4=C_6=100 pF, R_1=R_7=2 K, R_3=10 K, R_2=R_5=1 K, R_8=5 K

$$G_{BP}=\frac{G_2}{G_1}. \quad \textbf{(16)}$$

From Eqs. (12) and (13), it can be seen that, except for the allpass realization, the parameter ω_o can be controlled by adjusting the grounded resistor G_3 and/or the grounded capacitor C_4 without disturbing the parameter $\frac{\omega_o}{Q_o}$, and that the parameter $\frac{\omega_o}{Q_o}$ can be controlled by adjusting the grounded resistors G_1 and/or G_2 without disturbing the parameter ω_o. Thus, the lowpass, highpass, bandpass and notch realization of the proposed circuit enjoy independent grounded-resistance control of the parameters ω_o and $\frac{\omega_o}{Q_o}$. However, for the allpass realization, the matching condition G_1G_8=G_2G_3 does not allow independent grounded-resistance control of the parameters ω_o and $\frac{\omega_o}{Q_o}$. In this case, while the parameter ω_o can be controlled by adjusting the grounded capacitance C_4 without disturbing the parameter $\frac{\omega_o}{Q_o}$, the parameter $\frac{\omega_o}{Q_o}$ can not be controlled without disturbing the parameter ω_o. Thus, for the allpass realization, the proposed circuit enjoys orthogonal tuning. The proposed circuit is attractive for integration because the two capacitors are grounded. The circuit requires a minimum number of active components with no requirement for matched passive components except for the allpass filter realization. Because of the low output impedances, the proposed circuit can be easily cascaded to produce higher order filter realizations.

Taking into consideration the nonidealities of current-feedback amplifiers, namely, $i_z=\alpha i_x$, $\alpha=1-\psi_1$, $|\psi_1|<<1$ denoting the current tracking error, $v_x=\beta v_y$, $\beta=1-\psi_2$, $|\psi_2|<<1$ denoting the input voltage tracking error and $v_o=\gamma v_z$, $\gamma=1-\psi_3$, $|\psi_3|<<1$ denoting the output voltage tracking error, Eq. (11) becomes

$$D(s)=s^2+s\frac{\alpha_3\beta_1\beta_4\gamma_1\gamma_3G_1G_5}{G_2C_6}+\frac{\alpha_3\beta_3\beta_5\gamma_3G_3G_5}{C_4C_6}\,. \quad \textbf{(17)}$$

From Eq. (17), the parameters ω_o^2 and ω_o/Q_o can be expressed as

$$\omega_o^2=\frac{\alpha_3\beta_3\beta_5\gamma_3G_3G_5}{C_4C_6} \quad \textbf{(18)}$$

and

$$\frac{\omega_o}{Q_o}=\frac{\alpha_3\beta_1\beta_4\gamma_1\gamma_3G_1G_5}{G_2C_6}\,. \quad \textbf{(19)}$$

It is easy to show that the passive and active sensitivities of the parameters ω_o and ω_o/Q_o can be expressed as

$$S^{\omega_o}_{\alpha_3,\beta_3,\beta_5,\gamma_3,G_3,G_5}=-S^{\omega_o}_{C_4,C_6}=1/2$$

$$S^{\omega_o/Q_o}_{\alpha_3,\beta_1,\beta_4,\gamma_1,\gamma_3,G_1,G_5}=-S^{\omega_o/Q_o}_{G_2,C_6}=1/2$$

and

$$S^{\omega_o}_{\alpha_1,\alpha_2,\alpha_4,\alpha_5,\beta_1,\beta_2,\beta_4,\gamma_1,\gamma_2,\gamma_4,\gamma_5}=S^{\omega_o/Q_o}_{\alpha_1,\alpha_2,\alpha_4,\alpha_5,\beta_2,\beta_3,\beta_5,\gamma_2,\gamma_4,\gamma_5}$$

$$=0\,.$$

Thus, all the active and passive sensitivities are no more than unity.

III. Experimental Results

To verify the theoretical analysis, the proposed circuit was used to realise LP, HP, BP, notch and allpass filters using the AD844 current-feedback amplifier. The results obtained with $R_1=R_7=2$ kΩ, $R_2=R_5=1$ kΩ, $R_3=10$ kΩ, $R_8=5$ kΩ, and $C_4=C_6=100$ pF are shown in Fig. 2. The experimental results are in good agreement with the theory presented.

IV. Conclusion

A new universal filter using five current-feedback amplifiers, two grounded capacitors, three grounded resistors and three floating resistors has been presented. The new circuit can simultaneously realize the standard filter functions, lowpass, highpass, bandpass, notch and allpass, and, in comparison with available realizations, simultaneously enjoys all the following attractive features:

(1) independent grounded-resistance-control of the natural frequency and the bandwidth;
(2) low active and passive sensitivities;
(3) low output impedances;
(4) no component matching is required except for the allpass realization.

The proposed circuit is, therefore, more attractive than the realizations available in the literature.

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使用電流迴授放大器具有單一輸入與五個輸出的新型全功能濾波器

MUHAMMAD TAHER ABUELMA'ATTI AND HUSSAIN ABDULLAH AL-ZAHER

King Fahd University of Petroleum and Minerals
Dhahran, Saudi Arabia

摘 要

本文完成了一個新型全功能電壓模式的二階濾波器電路。此一電路包含了五個電流迴授運算放大器、兩個接地電容器、三個接地電阻器、以及三個浮接電阻器。它可以在不更換任何被動元件的情況下提供典型的濾波器功能，如低通、高通、帶通、帶阻（notch）、以及全通等。此一電路也具備下述諸項優點：工作頻率及頻寬可以用接地電阻單獨控制，低輸出阻抗，低靈敏度（對主動元件與被動元件皆然）。