NEW UNIVERSAL FILTER USING TWO CURRENT-FEEDBACK AMPLIFIERS

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A new universal voltage-mode second-order filter circuit is presented. The circuit has three inputs and one low-impedance output and can realize all the standard filter functions; low-pass, highpass, bandpass, notch, and allpass, without changing the passive elements. The proposed circuit uses only five passive components and enjoys independent control of the natural frequency and the bandwidth, orthogonal control of the natural frequency and the quality factor, as well as low active and passive sensitivities.

INTRODUCTION

At present there is a growing interest in designing active filters using current-feedback amplifiers (CFAs) [1–7]. This is attributed to the extended operating bandwidths and relatively large values of slew rates compared to the conventional realizations using the voltage-feedback amplifiers. In [2], a voltage-mode highpass and bandpass filter using two CFAs is proposed and in [3] a voltage-mode bandpass and highpass/lowpass filters using one CFA are proposed. Both circuits are with one input and two outputs. In [4], a voltage-mode highpass/bandpass/lowpass filter using one CFA, but with different passive components, is proposed. In [1], a voltage-mode notch, lowpass, and bandpass filter using three CFAs and five passive components; namely, three floating resistors and two grounded ca-

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capacitors, is proposed. The circuit has one input and three low-impedance outputs. In [5] and [7], two universal filters using two CFAs and six passive elements each; namely four resistors and two capacitors, are presented. Each circuit has three inputs and one low impedance output and uses the same passive components for all realizations. In [6], a high input impedance filter is presented. The circuit 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 cannot be realized without changing the locations of the passive components used.

The major intention of this paper is to present a new universal filter using CFAs. The proposed circuit enjoys the following advantages:

- a. it uses two CFAs.
- b. it uses five passive elements only; namely, two capacitors and three resistors.
- c. it can realize all the filter functions; namely, lowpass, highpass, bandpass, notch, and allpass, without changing the topology or the number of resistors and capacitors used.
- d. it enjoys independent tuning of the natural frequency, ω_o , and the bandwidth, ω_o/Q_o .
- e. it enjoys orthogonal tuning of the natural frequency, ω_o , and the quality factor, Q_o .
- f. it has one low-impedance output and can, therefore, be easily cascaded to produce higher order filters.

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 shows that the transfer function of the circuit of Fig. 1 can be expressed as

$$V_o = \frac{s^2 C_2 C_3 V_3 - s G_5 C_2 V_2 + G_1 G_5 V_1}{s^2 C_2 C_3 + s G_4 C_2 + G_1 G_5} \quad (1)$$

FIGURE 1 Proposed universal filter.

From (1), one can see that:

- (i) a second-order lowpass filter can be obtained with V_o/V_1 if $V_2 = V_3 = 0$ (grounded)
- (ii) a second-order bandpass filter can be obtained with V_o/V_2 if $V_1 = V_3 = 0$ (grounded)
- (iii) a second-order highpass filter can be obtained with V_o/V_3 if $V_1 = V_2 = 0$ (grounded)
- (iv) a second-order notch filter can be obtained with V_o/V_{input} if $V_2 = 0$ (grounded) and $V_1 = V_3 = V_{input}$
- (v) a second-order allpass filter can be obtained with V_o/V_{input} if $V_1 = V_2 = V_3 = V_{input}$ and $R_4 = R_5$.

The proposed circuit is attractive for realizing the lowpass filter function, because the two capacitors are grounded. The circuit requires the minimum number of active and passive components with no requirement for match components except for the allpass filter realization. Moreover, the impedance of the single output is very small, so the proposed circuit can be easily cascaded to produce higher order filter realizations. From (1), the parameters ω_o^2 and ω_o/Q_o can be expressed as

$$\omega_o^2 = 1/C_2C_3R_1R_5 \quad (2)$$

and

$$\frac{\omega_o}{Q_o} = 1/C_3 R_4 \quad (3)$$

From (2) and (3), one can see that the parameter ω_o can be adjusted by tuning C_2 and/or R_1 and/or R_5 without disturbing the parameter ω_o/Q_o . Also, the parameter ω_o/Q_o can be adjusted by tuning R_4 without disturbing the parameter ω_o/Q_o . Thus, the parameters ω_o and ω_o/Q_o are independently adjustable. From (2) and (3), Q_o can be expressed as

$$Q_o = R_4(C_3/C_2 R_1 R_5)^{1/2} \quad (4)$$

From (2) and (4), one can easily see that the parameters ω_o and Q_o can be orthogonally adjusted.

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

$$V_o = \frac{(\alpha_1 \alpha_2 \gamma_1) G_1 G_5 V_1 - (\alpha_2 \gamma_1) s C_2 G_5 V_2 + \alpha_2 \gamma_2 s^2 C_2 C_3 V_3}{s^2 C_2 C_3 + \alpha_2 \gamma_2 s C_2 G_4 + (\alpha_1 \alpha_2 \beta_1 \gamma_1 \gamma_2) G_1 G_5} \quad (5)$$

From (5), the parameters ω_o^2 and ω_o/Q_o can be expressed as

$$\omega_o^2 = \alpha_1 \alpha_2 \beta_1 \gamma_1 \gamma_2 / C_2 C_3 R_1 R_5 \quad (6)$$

and

$$\frac{\omega_o}{Q_o} = \alpha_2 \gamma_2 / C_3 R_4 \quad (7)$$

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

$$S_{\alpha_1, \alpha_2, \beta_1, \gamma_1, \gamma_2}^{\omega_o} = -S_{R_1, R_5, C_2, C_3}^{\omega_o} = 1/2, S_{C_3, R_4}^{\omega_o/Q_o} = -S_{\alpha_2, \gamma_2}^{\omega_o/Q_o} = -1$$

and

$$S_{\beta_2}^{\omega_o} = S_{\alpha_1, \beta_1, \beta_2, \gamma_1}^{\omega_o/Q_o} = 0$$

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

The proposed circuit was tested experimentally and the results obtained from lowpass, highpass, bandpass, and notch filter realizations using the AD844 current-feedback amplifier are shown in Fig. 2. The experimental results are in good agreement with the theory presented.

a lowpass characteristic obtained with $R_4 = R_5 = 2K$, $R_1 = 1K$, $C_2 = C_3 = 100 \text{ pF}$.

b highpass characteristic obtained with $R_4 = R_5 = 2K$, $R_1 = 1K$, $C_2 = C_3 = 100 \text{ pF}$.

FIGURE 2 Measured characteristics of the universal filter of Fig. 1 (continued).

c bandpass characteristic obtained with $R_1 = 1K$, $R_4 = 10K$, $R_5 = 2K$, $C_2 = C_3 = 100 pF$.

d Notch characteristic obtained with $R_1 = 1K$, $R_4 = 4K$, $R_5 = 2K$, $C_2 = C_3 = 100 pF$.

FIGURE 2 (continued).

CONCLUSION

A new minimum component universal filter using two current-feedback amplifiers, two capacitors, and three resistors has been presented. The new circuit uses less number of passive components and enjoys all the following attractive features: independent control of the natural frequency and the bandwidth, orthogonal control of the natural frequency and the quality factor, low active and passive sensitivities, low output impedance, and the same passive components are used to realize all the standard filter functions; lowpass, highpass, bandpass, notch, and allpass with no component matching requirement except for the allpass realization.

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