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New Voltage-Mode Multifunction Filter with One Input and Three Outputs Using Unity-gain Cells

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ABSTRACT

A new voltage-mode-multifunction filter circuit with one input and three outputs is presented. The proposed filter uses unity gain current- and voltage-followers. The filter can simultaneously realize lowpass, highpass and bandpass responses. The proposed circuit enjoys low active and passive sensitivities.

Key Words: active filters, unity-gain cells

I. Introduction

Recently, there has been growing interest in designing current-mode and voltage-mode continuous-time filters using unity gain current mirrors and/or voltage followers (Ramirez-Angulo and Sanchez-Sinencio, 1994; Tsividis and Papananos, 1994; Zele *et al.*, 1993; Celma *et al.*, 1995; Abuelma'atti and Al-Qahtani, 1996). This is attributed to their low power dissipation and high frequency operation. While (Ramirez-Angulo and Sanchez-Sinencio, 1994; Tsividis and Papananos, 1994; Zele *et al.*, 1993) reported several specific application filters, Celma *et al.*, (1995) reported two universal filter structures which can implement all the basic second-order filter functions (lowpass, highpass, bandpass, notch and allpass). These five filters, however, can not be simultaneously realized as it is necessary to change the circuit topology to achieve a specific filter function. In Abuelma'atti and Al-Qahtani (1996), two current-mode universal filters which can simultaneously realize the five basic filter functions were reported.

No attempts have been reported, so far, to present a universal voltage-mode biquad filter structure using the unity-gain voltage-follower and the unity-gain current-follower. It is the purpose of this paper to present such a realization. The proposed circuit can simultaneously realize second-order lowpass, highpass and bandpass responses. The circuit enjoys the attractive feature of independent control of its basic parameters ω_o and $\frac{\omega_0}{Q_0}$.

II. Proposed Circuit

The proposed circuit is shown in Fig. 1. Using standard notations, the current-followers $CF\pm$ can be characterized by $i_z=\pm\alpha_n i_x$, $n=1-3$, and the unity-gain voltage-follower can be characterized by $v_{output}=\beta_n v_{input}$, $n=1-3$, where $\alpha_n=1-\varepsilon_n$, $|\varepsilon_n|<<1$ represents the current tracking error of the nth current-follower, and $\beta_n=1-\delta_n$, $|\delta_n|<<1$ represents the voltage tracking error of the nth voltage-follower. Routine analysis yields the voltage transfer functions:

$$\frac{V_{HP}}{V_i}=\frac{s^2\alpha_1\beta_1\frac{R_6}{R_3}}{s^2+s\frac{\alpha_1\alpha_2\beta_1\beta_2R_6}{C_1R_1R_4}+\frac{\alpha_1\alpha_2\alpha_3\beta_1\beta_2\beta_3R_6}{C_1C_2R_1R_2R_5}} \quad (1)$$

$$\frac{V_{LP}}{V_i}=\frac{-\frac{\alpha_1\alpha_2\alpha_3\beta_1\beta_2\beta_3R_6}{C_1C_2R_1R_2R_3}}{s^2+s\frac{\alpha_1\alpha_2\beta_1\beta_2R_6}{C_1R_1R_4}+\frac{\alpha_1\alpha_2\alpha_3\beta_1\beta_2\beta_3R_6}{C_1C_2R_1R_2R_5}} \quad (2)$$

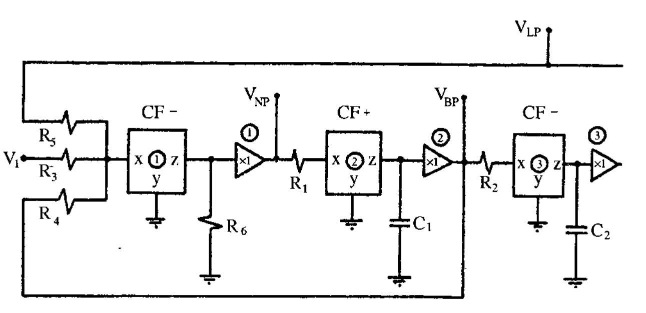

Fig. 1. Proposed voltage-mode multifunction filter.

and

$$\frac{V_{BP}}{V_i}=\frac{-s\dfrac{\alpha_1\alpha_2\beta_1\beta_2R_6}{C_1R_1R_3}}{s^2+s\dfrac{\alpha_1\alpha_2\beta_1\beta_2R_6}{C_1R_1R_4}+\dfrac{\alpha_1\alpha_2\alpha_3\beta_1\beta_2\beta_3R_6}{C_1C_2R_1R_2R_5}}. \quad (3)$$

From Eqs. (1)-(3), the parameters ω_o and $\frac{\omega_o}{Q_o}$ can be expressed as

$$\omega_0^2=\frac{\alpha_1\alpha_2\alpha_3\beta_1\beta_2\beta_3}{C_1C_2R_1R_2}\frac{R_6}{R_5} \quad (4)$$

and

$$\frac{\omega_o}{Q_o}=\frac{\alpha_1\alpha_2\beta_1\beta_2}{C_1R_1}\frac{R_6}{R_4}. \quad (5)$$

From Eqs. (1)-(3), it can be seen that the lowpass DC gain and the high frequency gain of the highpass and the bandpass gain at ω_o are approximately equal to

$$G_{LP}\cong\frac{R_5}{R_3} \quad (6)$$

$$G_{HP}=\frac{R_6}{R_3} \quad (7)$$

$$G_{BP}=\frac{R_4}{R_3}. \quad (8)$$

From Eqs. (4)-(8), it can be seen that parameter ω_o can be adjusted by controlling resistors R_2, R_5 and/or capacitor C_2 without disturbing parameter $\frac{\omega_o}{Q_o}$. Moreover, parameter $\frac{\omega_o}{Q_o}$ can be adjusted by controlling resistor R_4 without disturbing parameter ω_o. However, controlling resistances R_4 and/or R_5 will disturb the bandpass and/or the lowpass gain. A possible strategy for adjusting parameters ω_o and $\frac{\omega_o}{Q_o}$, and the lowpass, the highpass and the bandpass gains is, therefore, as follows: first, resistor R_4 is adjusted to control parameter $\frac{\omega_o}{Q_o}$; then, resistor R_3 is adjusted to control the bandpass and the highpass gains, resistor R_5 is adjusted to control the lowpass gain and resistor R_2 is adjusted to control parameter ω_o.

From Eqs. (4) and (5), it is easy to show that the active and passive sensitivities of parameters ω_o and Q_o are

$$S^{\omega_o}_{\alpha_1}=S^{\omega_o}_{\alpha_2}=S^{\omega_o}_{\alpha_3}=S^{\omega_o}_{\beta_1}=S^{\omega_o}_{\beta_2}=S^{\omega_o}_{\beta_3}=S^{\omega_o}_{R_6}=-S^{\omega_o}_{R_5}$$

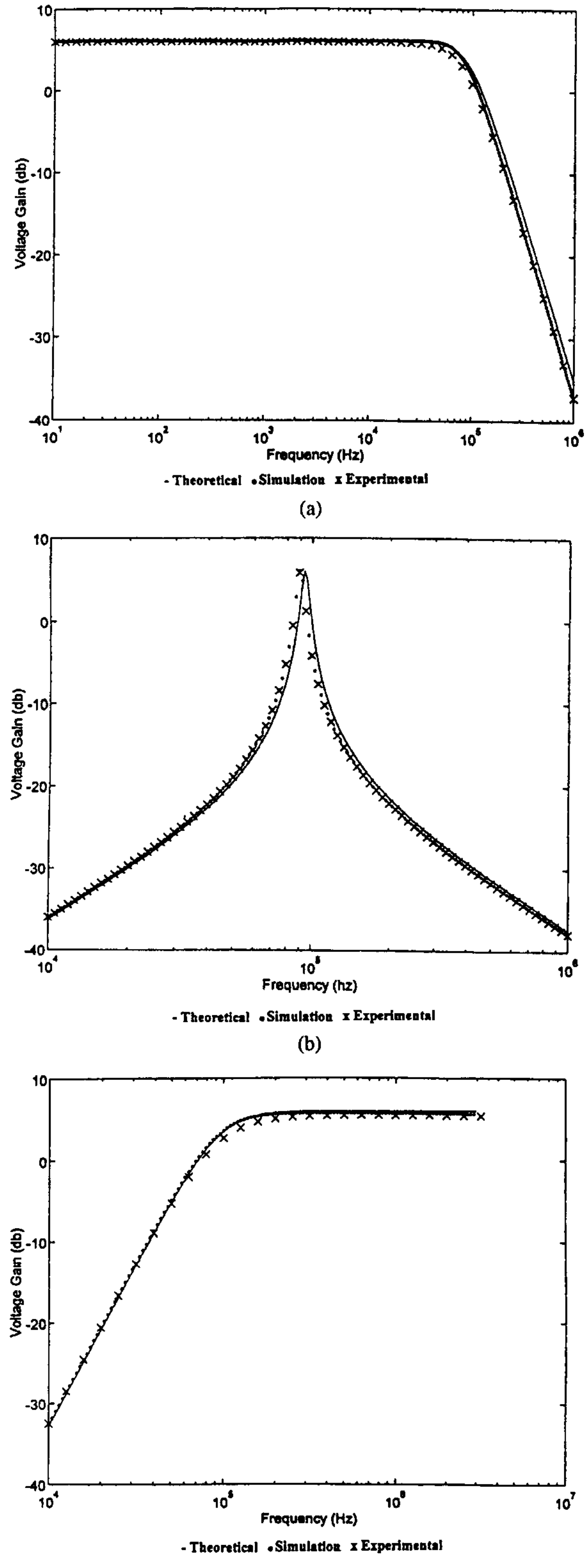

Fig. 2. (a) The lowpass response with $R_1=R_2=R_3=R_4=R_6=1$ kΩ, $R_5=2$ kΩ, $C_1=C_2=1.2$ nF. (b) The bandpass response with $R_1=R_2=R_6=1$ kΩ, $R_3=10$ kΩ, $R_4=20$ kΩ, $R_5=2$ kΩ, $C_1=C_2=1.2$ nF. (c) The highpass response with $R_2=R_3=R_4=1$ kΩ, $R_5=R_1=R_6=2$ kΩ, $C_1=C_2=1.2$ nF.

$$= -S^{\omega_o}_{C_1} = -S^{\omega_o}_{C_2} = -S^{\omega_o}_{R_1} = -S^{\omega_o}_{R_2} = \frac{1}{2}$$

$$S^{Q_o}_{\alpha_1} = S^{Q_o}_{\alpha_2} = -S^{Q_o}_{\alpha_3} = S^{Q_o}_{\beta_1} = S^{Q_o}_{\beta_2} = -S^{Q_o}_{\beta_3} = -S^{Q_o}_{C_1}$$

$$= -S^{Q_o}_{R_1} = S^{Q_o}_{C_2} = S^{Q_o}_{R_2} = S^{Q_o}_{R_5} = S^{Q_o}_{R_6} = -\frac{1}{2}$$

$$S^{Q_o}_{R_4} = 1\,,$$

all of which are small.

III. Experimental Results

The circuit of Fig. 1 was tested experimentally. Although there are several ways to implement the required current-followers and voltage-followers, the present results were obtained using the AD844 transimpedance integrated-circuit. In fact, the kernel of the work presented here is independent of the particular realization selected. The AD844 contains a second-generation current-conveyor which can be converted into a current-follower by grounding its high-impedance terminal and a unity-gain voltage follower. Thus, realization of the circuit in Fig. 1 requires only three AD844s. The experimental results obtained using the values R_1=R_2=R_3=R_4=R_6=1 kΩ, R_5=2 kΩ and C_1=C_2= 1.2 nF for the lowpass response, R_1=R_2=R_6=1 kΩ, R_3=10 kΩ, R_4=20 kΩ, R_5=2 kΩ and C_1=C_2=1.2 nF for the bandpass response, and R_1=R_5=R_6=2 kΩ, R_2=R_3=R_4=1 kΩ and C_1=C_2=1.2 nF for the highpass response are shown in Fig. 2. Also shown in Fig. 2 are the calculated responses obtained using Eqs. (1)-(3). The circuit was also simulated using Pspice. The simulation was performed using the model of the AD844 used in Svoboda (1994). The simulation results are also shown in Fig. 2. From Fig. 2, it appears that the measured, simulated and calculated results are in excellent agreement. The differences between the measured and calculated results are attributable to the AD844 parasitics, which will manifest themselves at high frequencies.

It is worth mentioning here that the experimental and simulation results reported in Fig. 2 were obtained using different values of resistance R_1, R_3, R_4 and R_6 for the lowpass, bandpass and highpass responses. Different values of resistances were selected to illustrate the ability of the circuit to provide high values of Q for the bandpass response, and flat and equal gain characteristics for the lowpass and highpass responses. However, this does not represent any restriction on simultaneous realization of the three filter functions.

IV. Conclusion

In this paper, a new multifunction voltage-mode filter with one input and three outputs has been presented. The proposed filter enjoys the following advantages:

(1) simultaneous realization of lowpass, highpass and bandpass responses;
(2) use of grounded capacitors, which paves the way for high frequency operation;
(3) independent tuning of parameters ω_o and $\frac{\omega_o}{Q_o}$;
(4) low active an passive sensitivities.

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使用單一增益單元的單端輸入三端輸出多功能電壓式濾波器

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摘 要

本文提出一個單端輸入三端輸出的新型多功能電壓式濾波器電路。此電路採用單一增益的電流與電壓隨耦器。它能同時提供低通、高通、以及帶通的響應模式，並且具備了低的主動與被動靈敏度。