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ORIGINAL PAPER

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Multi-function biquad using single CDBA

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Abstract A voltage-mode, multi-input single-ouput type multi-function biquad is proposed having the following features: (a) It uses only one current differencing buffered amplifier as the active element, (b) it contains grounded and virtually grounded capacitors, (c) using this biquad, one may realize all five filter functions (i.e., lowpass, highpass, bandpass, notch and allpass) without changing the circuit topology, (d) it can be directly cascaded without any need of impedance matching circuits, (e) its Q-factor can be independently adjusted if the natural frequency is fixed, (f) biquad offers low sensitivities, and its natural frequency is insensitive to tracking errors. Experimental results are in agreement with theory.

Keywords Multi-function biquad · CDBA · Active filters

1 Introduction

Multi-function type active filters are especially versatile, since the same topology can be used for different filter functions. Numerous multi-function voltage mode (VM) filters containing more than one active current mode (CM) element, such as current feedback amplifiers [1], current conveyors [2, 3], operational transconductance amplifiers [4], with their well known advantages of providing wide bandwidths and high slew rates are reported in literature.

In recent years, there is a growing interest in the applications of another CM element, the so called, current differencing buffered amplifier (CDBA) [5–11]. Although some CDBA-based multi-function filters are reported in literature [6–9], they all involve more than one CDBA. From the point of view of power dissipation and manufacturing cost, it is advantageous to keep the number of active elements at minimum.

In this paper, a multi-input single-output (MISO) type VM biquad, employing single CDBA as the active element is proposed, which realizes all of the five filter functions, i.e., lowpass (LPF), highpass (HPF), bandpass (BPF), notch (BSF) and allpass (APF), without changing the circuit topology.

2 Circuit description

The circuit symbol of the CDBA is shown in Fig. 1. Its defining equations are [2]:

$$V_p = V_n = 0, \quad I_z = I_p - I_n, \quad V_w = V_z \tag{1}$$

Here, the current through z-terminal follows the difference of the currents through p-terminal and n-terminal. Input terminals p and n are internally grounded. A CMOS-based CDBA is given in Fig. 2 [7].

Let Y_a be the admittance between a voltage source V_{in} and p terminal, Y_b the admittance between V_{in} and n terminal, Y_c the admittance between the z terminal and ground, and Y_d admittance connecting p and w terminals of the CDBA. Voltage transfer function of this configuration can be described by the following relationship [10]:

$$\frac{V_w}{V_{in}} = \frac{Y_a - Y_b}{Y_c - Y_d} \tag{2}$$

If $Y_a = R_a||C_a$, $Y_c = R_c||C_c$, $Z_b = (1/Y_b) = R_b + (1/sC_b)$, $Z_d = (1/Y_d) = R_d + (1/sC_d)$, and splitting Y_a, Y_b junction into three parts as shown in Fig. 3 and applying superposition of input voltages V_{in}, V_1, V_2 in the circuit yields the equation for the output voltage V_w ($= V_o$) as

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$$V_o = \frac{C_a}{C_c} \cdot \frac{s^2 V_2 + (1/(R_b C_b) + 1/(R_a C_a) - 1/(R_b C_a)) s V_{in} + 1/(R_a C_a R_b C_b) V_1}{s^2 + (1/(R_b C_b) + 1/(R_c C_c) - 1/(R_d C_c)) s + 1/(R_c C_c R_b C_b)} \quad (3)$$

In this circuit, with the condition $R_b C_b = R_d C_d$(except APF), biquad voltage transfer functions $(= V_o/V_{in})$ realize

1. LPF; if $V_1 = V_{in}$, $V_2 = 0$, $R_a = R_b$
2. HPF; if $V_2 = V_{in}$, $V_1 = 0$, $C_a = C_b$
3. BPF; if $V_1 = V_2 = 0$,
4. BSF; if $V_1 = V_2 = V_{in}$, $R_a = R_c = 2R_b$, $C_b = 2C_c = 2C_a$
5. APF; if $V_1 = V_2 = V_{in}$, $R_a = R_c = 4R_b$, $C_b = 2C_c = 4C_a$

Note that, C_a is omitted ($C_a = 0$) for the low pass configuration, R_a is omitted ($R_a = \infty$) for the high pass filter realization. On the other hand, both R_a and C_a are omitted for the band pass configuration, while R_d is omitted for the all pass case.

The natural angular frequency ω_o and the pole Q-factor of this filter are

$$\omega_o = \frac{1}{(R_b R_c C_b C_c)^{1/2}} \quad (4a)$$

$$Q = \frac{(R_b R_c C_b C_c)^{1/2}}{R_b C_b + R_c C_c - R_b R_c C_b / R_d} \quad (4b)$$

It is apparent that Q can be controlled by varying R_d without affecting ω_o.

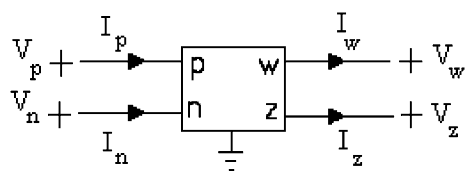


Fig. 1 Symbol for the CDBA

3 Non-ideal case

In non-ideal case, the CDBA can be characterized by

$$V_p = V_n = 0, \quad I_z = \alpha_p I_p - \alpha_n I_n, \quad V_w = \gamma V_z \quad (5)$$

where α_p, α_n and γ are current and voltage gains, respectively, and $\alpha_p = 1 - \epsilon_p$, $\alpha_n = 1 - \epsilon_n$, $\gamma = 1 - \epsilon_v$. Here, ϵ_p, ϵ_n are current tracking errors and ϵ_v is the voltage tracking error, absolute values of all last three terms being much less than unit value. Taking the effect of these tracking errors into account, the expression for V_o becomes :

$$V_o = \frac{\gamma \alpha_p C_a}{C_c} \cdot \frac{s^2 V_2 + \left(1/(R_b C_b) + 1/(R_a C_a) - \alpha_n / \left(\alpha_p R_b C_a\right)\right) s V_{in} + 1/(R_a C_a R_b C_b) V_1}{s^2 + \left(1/(R_b C_b) + 1/(R_c C_c) - \left(\gamma \alpha_p\right) / (R_d C_c)\right) s + 1/(R_c C_c R_b C_b)} \quad (6)$$

Note that the natural frequency of this biquad is not influenced by tracking errors of the CDBA, and other ω_o and Q-factor passive sensitivities are

$$S_{\gamma}^{\omega o} = S_{\alpha_p}^{\omega o} = S_{\alpha_n}^{\omega o} = S_{\alpha_n}^{Q} = S_{d}^{Q} = 0, \quad S_{R_b}^{\omega o} = S_{R_c}^{\omega o} = S_{C_b}^{\omega o} = S_{C_c}^{\omega o} = -\frac{1}{2} \quad (7a,b)$$

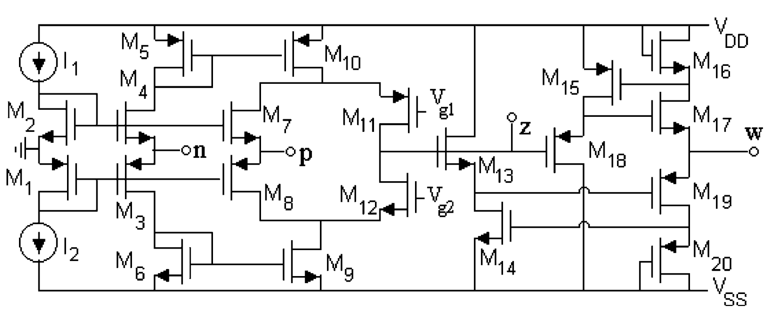
$$S_{R_c}^{Q} = -\frac{R_b C_b - R_c C_c + \gamma \alpha_p R_c R_b C_b / R_d}{2[\gamma \alpha_p R_c R_b C_b / R_d - (R_b C_b + R_c C_c)]} \quad (8a)$$

$$S_{R_b}^{Q} = S_{C_b}^{Q} = -S_{C_c}^{Q} = -\frac{R_c C_c - R_b C_b + \gamma \alpha_p R_c R_b C_b / R_d}{2[\gamma \alpha_p R_c R_b C_b / R_d - (R_b C_b + R_c C_c)]} \quad (8b)$$

$$S_{\alpha_p}^{Q} = S_{\gamma}^{Q} = \frac{\gamma \alpha_p R_c R_b C_b}{\gamma \alpha_p R_c R_b C_b - R_d (R_b C_b + R_c C_c)} \quad (8c)$$

Here, for filters with complex poles, Q-factor sensitivities (Eq. 8a, b, c) can be minimized by proper selection of component values. On the other hand, for filters having real poles, the feedback path between w–p ter-

Fig. 2 Simplified CMOS CDBA circuit



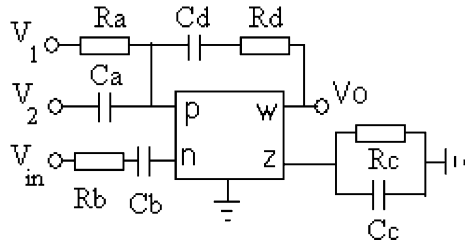


Fig. 3 Single CDBA-based voltage-mode Universal biquad

minals of the CDBA vanishes. This means that two components are reduced from the configuration, further desensitizing the Q-factor of the circuit against tracking errors.

4 Experimental results

In order to demonstrate the feasibility of the proposed multi-function biquad, SPICE circuit simulations were performed using CMOS CDBA circuit given in Fig. 2. Additionally, the circuit shown in Fig. 3 was set up in the laboratory and tested for its performance. Since the CDBA is not yet commercially available product, a current feedback amplifier (CFA) equivalent circuit of this element [5] was implemented instead, as shown in Fig. 4. AD 844 type of CFAs (Analog Devices Inc, Norwood, MA, USA) were used in these experiments, because, an external (compensation) terminal is readily provided which can be used as the z terminal for the CDBA. Component values used in the experiments are the following:

(a) LPF (Butterworth); $R_a = R_b = R_c = R_d = 10$ kΩ, $C_b = C_d = 70$ nF, $C_c = 140$ nF,
(b) HPF (Butterworth); $R_b = R_d = 14$ kΩ, $R_c = 7$ kΩ, $C_a = C_b = C_c = C_d = 100$ nF,
(c) BPF(Butterworth); $R_b = R_c = 10$ kΩ, $R_d = 20$ kΩ, $C_c = C_d = 70$ nF, $C_b = 140$ nF,
(d) BSF (Butterworth symmetric notch); $R_a = R_c = 14$ kΩ, $C_a = C_c = 70$ nF, $R_b = 7$ kΩ, $C_b = 140$ nF, $R_d = 24$ kΩ,
(e) APF; $R_a = R_c = 50$ kΩ, $C_a = C_c = 20$ nF, $R_b = 12.5$ kΩ, $C_b = 80$ nF.

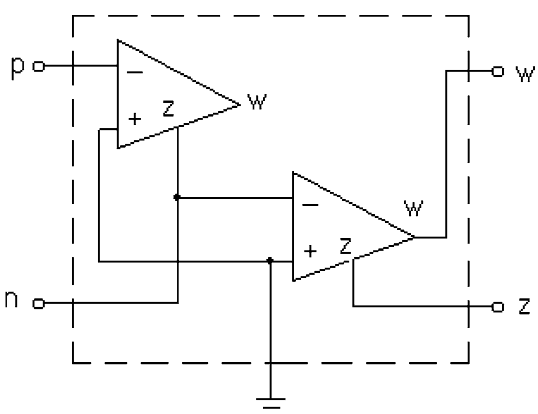


Fig. 4 CDBA equivalent circuit employing two CFAs (used in the experiments)

The natural frequency (= 159 Hz) is the same for all cases. All absolute ω_o and Q-component sensitivities at these above-given values are less than or equal to unity. The experimental results are displayed in Fig. 5.

5 Discussion and conclusion

It can be argued that the circuit requires more matched passive components than previously reported multi-function biquads. However, considering the circuit integration issues, those circuits employing more than one active element require also identical active elements, which are more difficult to manufacture than matched passive components. On the other hand, attractive features of this new VM, MISO type multi-function biquad are: (a) It employs only single active element, (b) Its ω_o has small passive sensitivities, and it is insensitive to tracking errors of the CDBA, (c) Its Q-factor can be adjusted without affecting ω_o, if parameters determining the ω_o are fixed, (d) This filter employs capacitors that are grounded or virtually grounded, which is an important aspect regarding integrated circuit implementation, (e) In addition to the fact that the proposed circuit employs only single active element, the number of passive components it requires is less than those of previously reported multi-CDBA-based VM biquads [9], (f) Moreover, the proposed filter is cascadable, since it has very low output impedance associated with it. The fact that circuit simulations and experimental results are in very good agreement with theory verifies the usefulness of this single CDBA-based biquad, which is

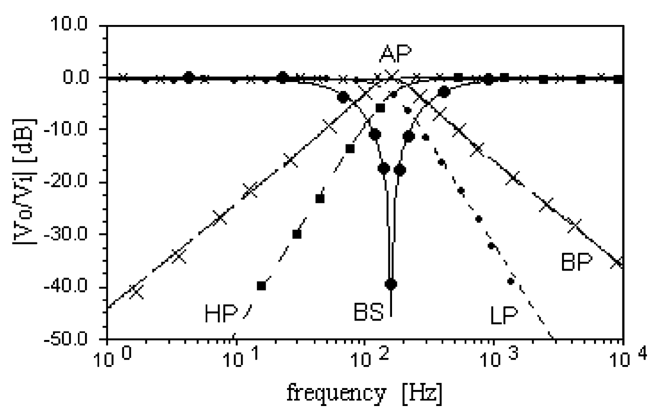


Fig. 5 Experimental and simulation results for the Bode magnitudes of five different filter functions using single CDBA-based universal biquad. Experimental values are shown by *filled small circles* (LPF), *squares* (HPF), *large crosses* (BPF), *filled larger circles* (BSF), *small crosses* (APF). ($V_{in} = 1 V_{p-p}$). Experimental data were obtained down to −40 dB of input signal amplitude

universal in the sense that it realizes low-pass, high-pass, band-pass and band-stop filters.

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