Voltage-Mode All-pass Biquads Using Current Differencing Buffered Amplifiers (CDBA)

[Sener Deniz, Ali Umit Keskin]

Abstract— **In this paper, three current differencing buffered amplifier (CDBA)-based voltage-mode (VM) biquadratic all-pass filters (APFs) are presented. These circuits contain one or two CDBAs as active elements. The circuits are analyzed theoretically, and results of their circuit simulations are presented. It is shown that the results of experiments and circuit simulations are in good agreement with theory.**

Keywords— **CDBA, biquads, second order all-pass filters, current mode circuits, continuous time filters**

I. Introduction

Biquadratic allpass filters are widely used to linearize the phase of an higher-order lowpass filter, in crossover systems, and broad class of transfer functions can be implemented as the parallel combination of two allpass filters [1-2]. Parallel sums of allpass filters have recently arisen in a variety of applications, one example being orthogonal and perfect reconstruction filter banks. This means that they are also useful for the construction of wavelets.

Conventional op-amps and universal resistor programmable switched-C filters are configurable as biquadratic all-pass filters (APFs), but most of these active elements cannot operate at bandwidths higher than 100 kHz. Current mode (CM) active elements provide wide bandwidths and higher slew rates than their voltage mode counterparts, such as op-amps. Therefore, it is advantageous to implement CM active elements in continuous time filter circuits. A new CM active element, the current differencing buffered amplifier (CDBA) has received considerable interest in recent years [3-17]. It has been proven that the CDBA is a versatile active building block particularly for current mode signal processing applications.

Some VM APF biquads using CDBAs have been reported in literature. For example, Pisitchalermpong et.al [15] introduce a multi-output biquad using 3 CDBAs and 9 passive components. This is a single input-three output (SITO) circuit which yields an APF structure if certain conditions are met.

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Gunes and Anday [2] proposed an nth-order allpass voltage transfer function synthesis procedure, using Current Feedback Amplifiers (specifically AD 844) where general nth-order allpass circuit includes n + 1 active components, n grounded capacitors and 3n + 2 resistors. This means that their method requires 3 active elements and 10 passive components to realize an APF biquad.

Koksal and Sagbas [15] introduce the realization of an nth order voltage transfer function by an active RC circuit involving CDBAs. The general transfer function can be realized using (n+1) CDBAs, and design procedure is relatively complicated. Another APF biquad (part of a multifunctional filter) proposed by Salama et.al. [13] consists of 2 CDBAs and 8 passive components.

This paper presents three CDBA-based VM biquadratic APF realizations and reports their theoretical and simulated performance results.

II. CDBA

The circuit symbol of the CDBA is shown in Fig.1. The ideal characteristic equations of this element can be given as

$$V_p = V_n = 0, \quad I_z = I_p - I_n, \qquad V_w = V_z \qquad (1)$$

Here, current through z-terminal follows the difference of the currents through p-terminal and n-terminal. Input terminals p and n are internally grounded. The difference of the input currents is converted into the output voltage V_w.
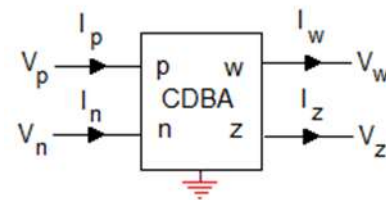

Figure 1. Current Differencing Buffered Amplifier (CDBA).

III. CDBA-based APF biquads

The general form of a biquadratic VM APF transfer function is

$$\frac{V_o}{V_i} = \frac{s^2 - bs + c}{s^2 + bs + c} \qquad (2)$$

where the last term c in both numerator and denominator has a value of the square of critical angular frequency.

An APF biquad topology based on CDBAs is shown in Fig.2. Note that this circuit employs only single active element and 3 resistors in addition to 3 capacitors.

This filter has the following voltage transfer function:

$$\frac{V_o}{V_i} = k_a \frac{A_a\, s^2 + B_a s + 1}{C_a\, s^2 + D_a s + 1} \qquad (3)$$

$$A_a = C_1 C_2 R_1 R_2 \qquad (4)$$

$$B_a = C_1 R_1 + C_2 R_2 - C_2 R_1 \qquad (5)$$

$$C_a = C_2 C_3 R_2 R_3 \qquad (6)$$

$$D_a = C_2 R_2 + C_3 R_3 \qquad (7)$$

$$k_a = \frac{R_3}{R_1} \qquad (8)$$

If $R_1 = R_3 = 4R_2$, $C_1 = C_3 = C_2/4$,

then the transfer function becomes an APF biquad.

The phase of the transfer function of this circuit varies between 360o (at low frequencies) and 0o (at high frequencies).

Example 1:

Let $R_1 = R_3 = 4R_2 = 1\Omega$, $C_1 = C_3 = C_2/4 = 1F$

$$\frac{V_o}{V_i} = \frac{s^2 - 2s + 1}{s^2 + 2s + 1} \qquad (9)$$

$$\omega_0 = \sqrt{\frac{1}{C_2 C_3\, R_2 R_3}} = 1\ rad/s \qquad (10)$$

as specified in (2).

Alternative forms of APF biquads can also be realized by cascading of two first order APF sections. Some examples of cascadable first order APF structures in voltage mode have been reported in [16] and [4]. These first order filters consist of at least 4 passive components and a CDBA. Thus, an APF type biquad using a cascaded first order sections will require at least 8 passive components in addition to 2 CDBAs.
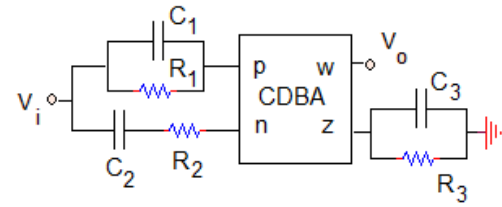

Figure 2. Type a CDBA-based biquad APF.

A typical APF biquad of this kind is given in Fig.3. This circuit has the voltage transfer function of

$$\frac{V_o}{V_i} = k_b \frac{A_b\, s^2 + B_b s + 1}{C_b\, s^2 + D_b s + 1} \qquad (11)$$

$$A_b = C_1 C_2 (R_1 - R_2)(R_4 - R_5) \qquad (12)$$

$$B_b = C_1 (R_2 - R_1) + C_2 (R_5 - R_4) \qquad (13)$$

$$C_b = C_1 C_2 R_2 R_5 \qquad (14)$$

$$D_b = C_1 R_2 + C_2 R_5 \qquad (15)$$

$$k_b = \frac{R_3 R_6}{R_1 R_4} \qquad (16)$$

If $R_1 = R_3 = R_4 = R_6 = 2R_2 = 2R_5$, $C_1 = C_2$, then the transfer function defines an APF biquad. The phase of transfer function of this circuit varies between 360° (at low frequencies) and 0° (at high frequencies).

Example 2:
Let $R_1 = R_3 = R_4 = R_6 = 2R_2 = 2R_5 = 1\Omega$
$C_1 = C_2 = 1F$,

$$\frac{V_o}{V_i} = \frac{s^2 - 4s + 4}{s^2 + 4s + 4} \qquad (17)$$

$$\omega_0 = \sqrt{\frac{1}{C_1 C_2\, R_2 R_5}} = 2\ rad/s \qquad (18)$$

as specified in (2).

The third VM APF biquad circuit topology is displayed in Fig. 4 as Type c CDBA-based APF Biquad. The voltage transfer function of this circuit is

$$\frac{V_o}{V_i} = k_c \frac{A_c\, s^2 + B_c s + 1}{C_c\, s^2 + D_c s + 1} \qquad (19)$$

$$A_c = C_1 C_3 R_1 R_3 \qquad (20)$$

$$B_c = -(C_1 R_1 + C_3 R_3) \qquad (21)$$

$$C_c = C_2 C_4 R_2 R_4 \qquad (22)$$

$$D_c = C_1 R_1 + C_3 R_3 \qquad (23)$$

$$k_c = \frac{R_2 R_4}{R_1 R_3} \qquad (24)$$

If $R_1 = R_2 = R_3 = R_4$, $C_1 = C_2 = C_3 = C_4$,
then the transfer function defines an APF biquad. The phase of transfer function of this circuit varies between 360° (at low frequencies) and 0° (at high frequencies).

Example 3:
Let $R_1 = R_2 = R_3 = R_4 = 1\Omega$, and
$C_1 = C_2 = C_3 = C_4 = 1F$,

$$\frac{V_o}{V_i} = \frac{s^2 - 2s + 1}{s^2 + 2s + 1} \qquad (25)$$

$$\omega_0 = \sqrt{\frac{1}{C_2 C_4 R_2 R_4}} = 1 \; rad/s \qquad (26)$$

as specified in (2).

IV. Circuit Simulations

In order to test the validity of theoretical results, the circuits presented here were all simulated in SPICE, using a CDBA MOSFET structure as displayed in Fig.5, and transistor parameters given in [12]. One of the simulation results (phase response) for the APF biquad circuit of Fig.2 is shown in Fig. 6.

V. Conclusion

In this paper, three CDBA-based voltage mode all-pass biquad filter circuits are studied. These structures have less component counts than their earlier presented counterparts. The first APF biquad circuit has minimum component structure with a single CDBA and only 6 passive components. Last two circuits compare to the op-amp based biquad APFs regarding their component counts. However, they have wider frequency range of operation (due to limited gain-bandwidth product parameter of an operational amplifier). It is shown that SPICE simulations verify theoretical results.
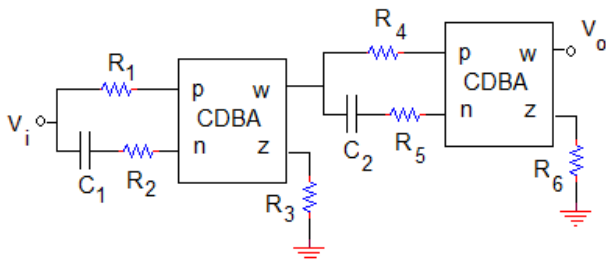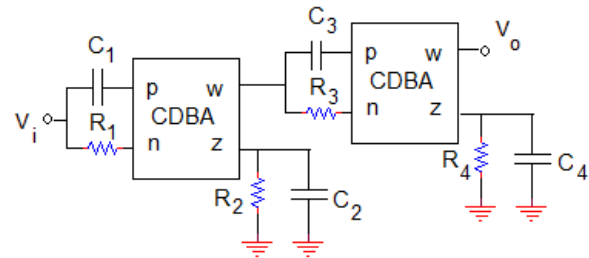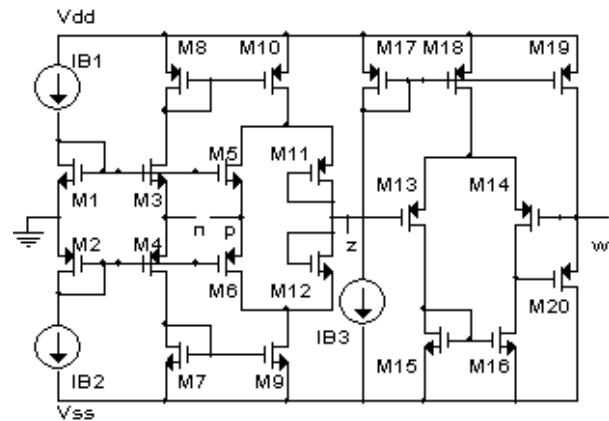

Figure 4.Type c CDBA-based APF Biquad.

Figure 5. The CMOS implementation of CDBA used in simulation studies. $I_{B1} = I_{B2} = 20\mu A$ while $I_{B3} = 25\mu A$. Vdd = -Vss = 2.5V.
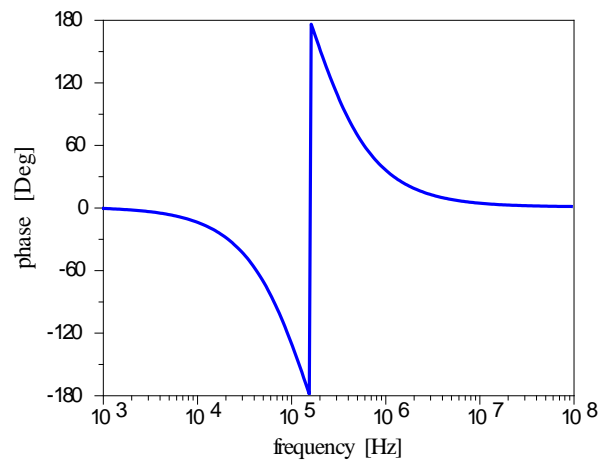

Figure 6. Phase response of APF biquad of Fig.2. Component values; $R_1 = R_3 = 4R_2 = 1k\Omega$, $C_1 = C_3 = C_2/4 = 1nF$. Critical frequency is 159 kHz, with a phase shift of 180°. Due to SPICE plotting convention, phase is shown as 0° (in place of 360°) at low frequencies, and it approaches 0° at high frequencies.

Figure 3.Type b CDBA-based APF Biquad.

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