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Voltage Mode Kerwin-Huelsman-Newcomb Circuit Using CDBAs

Ein Kerwin-Huelsman-Newcomb-Schaltkreis vom Spannungstypus mit CDBAs

Abstract
A novel fully integrated voltage mode realization of the Kerwin-Huelsman-Newcomb biquad filter using the Current Differencing Buffered Amplifier (CDBA) is presented. Independent control on the bandwidth, quality factor and gain can be achieved through control voltages. All possible combinations of polarities of the highpass, bandpass and lowpass responses can be obtained. A comparison between previously published implementations of the KHN biquad is included. Analysis of the parasitics associated with the CDBA is presented and compensation techniques are included

Übersicht
Ein neues vollständig integriertes biquadratisches Kerwin-Huelsman-Newcomb-Filter vom Spannungstypus mit CDBA (Current Differencing Buffered Amplifier) wird vorgestellt. Bandbreite, Güte und Verstärkung können unabhängig voneinander durch Steuerspannungen eingestellt werden. Alle Kombinationen der Polaritäten der Hochpaß-, Bandpaß- und Tiefpaß-Ausgänge sind möglich. Die Arbeit beinhaltet einen Vergleich mit früher veröffentlichten Vorschlägen. Die mit den CDBA verbundenen parasitären Effekte werden analysiert und Kompensationsmaßnahmen vorgeschlagen.

By Khaled N. Salama[1]
and Ahmed M. Soliman[2]

Für die Dokumentation
MOSFET-C Filter / KHN-Filter

1. Introduction

Recently, current-mode analog integrated circuits in CMOS technology have received considerable interest. Current-mode techniques can achieve considerable improvement in amplifier speed, accuracy and bandwidth. Traditionally, most analog signal processing operations have been accomplished employing the voltage as the signal variable. In order to maintain compatibility with existing voltage processing circuits, it is necessary to convert the input and output signals of a current-mode signal processor to voltage using transconductors. This has the disadvantage of increasing both the chip area and power dissipation.

In this paper the application of the Current Differencing Buffered Amplifier (CDBA) in realizing a fully integrated MOSFET-C voltage mode continuous time universal filter is introduced. Thus keeping compatibility with existing signal processing circuits and taking advantage of the CDBA current mode characteristics. The CDBA is a recently introduced active block [1-3]. Since the CDBA is not slew limited in the same fashion as op amps, it can provide amplification of high frequency signals with the ease of using standard op amps in addition to a constant bandwidth virtually independent of the gain [2].

2. Circuit description

The Current Differencing Buffered Amplifier (CDBA) which is shown symbolicaly in **Figure 1(a),** is a four terminal analog building block with a describing matrix in the form:

$$\begin{bmatrix} V_{xp} \\ V_{xn} \\ I_z \\ V_o \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 1 & -1 & 0 & 0 \\ 0 & 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} I_{xp} \\ I_{xn} \\ V_z \\ I_o \end{bmatrix}. \qquad (1)$$

Both input terminals are characterized by low impedance, thereby eliminating response limitations incurred by capacitive time constants leading to circuits that are insensitive to stray capacitances at the input terminals [4]. **Figure 1(b)** represents a CMOS realization of the CDBA, which consists of a current differencing amplifier in cascade with a voltage buffer.

The CDBA has similar transmission characteristics to the Current Feedback Operational Amplifier (CFOA), but with two low impedance input terminals, a high impedance output terminal and a low impedance output terminal. However the CDBA suffers from parasitic capacitance C_Z, and resistance R_Z, at the Z terminal in a fashion similar to the CFOA.

The main advantage of the CDBA is the ability to implement different analog circuits without the need of resistors, since it can be used to cancel both the even and odd nonlinear terms associated with MOS transistors operating in the ohmic region [5]. The conductance of each matched transistor pair is given by

$$G_i = \mu_n C_{ox} \frac{W_i}{L_i} \left(V_{ai} - V_{bi} \right). \qquad (2)$$

Positive and negative values of the conductance, G, can be achieved through appropriate choice of the gate control voltages V_a and V_b. Moreover the matched transistor pair exhibits self compensation to MOS intrinsic distributed parasitics since the input terminals of the CDBA are virutually grounded [6].

The state variable universal filter, usually referred to in classical literature as the Kerwin-Huelsman-Newcomb (KHN) biquad, is a fundamental second-order building block in many analog applications [7]. The proposed KHN biquad circuit is shown in **Figure 2**. Unlike the classical KHN biquad [7], all possible combinations of polarities of the highpass, bandpass and lowpass responses can be obtained as indicated in **Table 1**. The transfer function of the highpass, bandpass and lowpass outputs are given by:

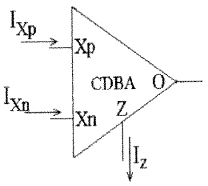

Fig. 1(a): Current Differencing Buffered Amplifier (CDBA) Symbol

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[1] Stanford University, CA, USA.
[2] Cairo University, Giza, Egypt.

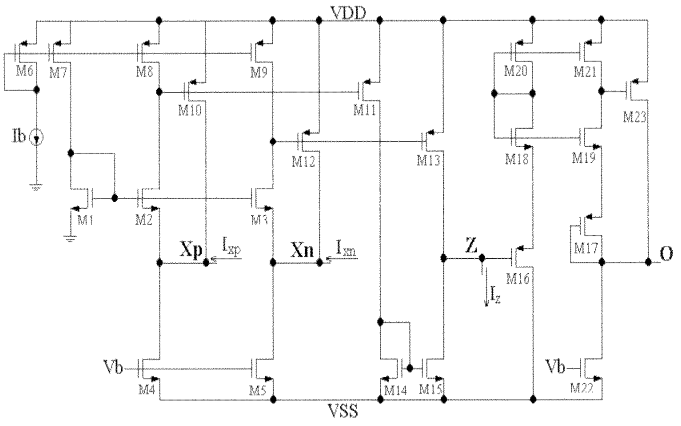

Fig. 1(b): A CMOS realization of the CDBA

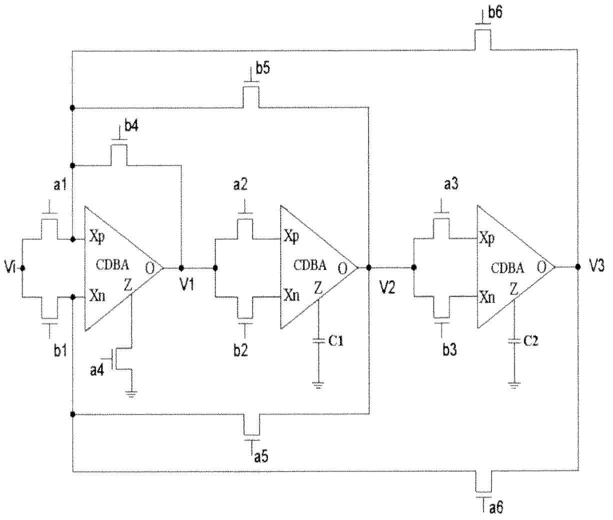

Fig. 2: KHN biquad circuit using CDBA

$$\frac{V_1}{V_i}=\frac{\frac{G_1 s^2}{G_4}}{D(s)},\ \frac{V_2}{V_i}=\frac{\frac{G_1 G_2 s}{G_4 C_1}}{D(s)}\ \text{and}\ \frac{V_3}{V_i}=\frac{\frac{G_1 G_2 G_3}{G_4 C_1 C_2}}{D(s)}, \tag{3}$$

where $D(s)$ is given by

$$D(s)=s^2+\frac{G_2 G_5}{G_4 C_1}s+\frac{G_2 G_3 G_6}{G_4 C_1 C_2}. \tag{4}$$

Thus ω_0 and Q are given by

$$\omega_o=\sqrt{\frac{G_2 G_3 G_6}{G_4 C_1 C_2}}\ \text{and}\ Q=\frac{1}{G_5}\sqrt{\frac{C_1 G_3 G_4 G_6}{C_2 G_2}}. \tag{5}$$

For a lowpass response with a specified DC gain $|T(0)|$:

$$G_1=|T(0)|G_6. \tag{6}$$

For a bandpass response with a specified center frequency gain $|T(j\omega_o)|$:

$$G_1=|T(j\omega_o)|G_5. \tag{7}$$

For a highpass response with a specified gain $|T(\infty)|$:

$$G_1=|T(\infty)|G_4. \tag{8}$$

It is clear that the quality factor Q can be independently controlled by varying G_5 without affecting ω_o. It is also seen that the conductance G_1 controls the filter gain without affecting ω_o or Q, an advantage, which does not exist in the classical KHN circuit using op amps [7]. A comparison between all previously published realizations of the KHN biquad is presented is **Table 2**.

3. The CDBA Non-idealities

The CDBA suffers from the presence of a parasitic capacitance and resistance at the Z terminal in a manner similar to the CFOA. The parasitic admittance Y_Z present at the Z terminal, is given by

Table 1: Conductance choice for all possible filter responses

Gi Polarity						Filter Response Polarity		
G1	G2	G3	G4	G5	G6	HP	BP	LP
+	+	+	+	+	+	+	+	+
+	+	-	+	+	-	+	+	-
+	-	-	+	-	+	+	-	+
+	-	+	+	-	-	+	-	-
-	-	+	+	-	-	-	+	+
-	-	-	+	-	+	-	+	-
-	+	-	+	+	-	-	-	+
-	+	+	+	+	+	-	-	-

Table 2: Comparison between different KHN biquad realizations

	KHN[7]	Ismail[8]	Sol.[9]	Sol.[10]	Sol.[11]	Sol.[12]	Ozguz[2]	Salama[13]	Proposed
Active Element	3 op amp	3 op amp	5 CCII	5 CCII	4 CCII	3-5 CFOA	(2+2*) CDBA	3 OTRA	3 CDBA
Independent ω_o	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Independent Q	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Independent gain	No	Yes	No	Yes	No	Yes	No	Yes	Yes
# of Capacitors	2	4	2	2	2	2	2	2	2
Grounded Capacitors	No	No	Yes	Yes	Yes	Yes	Yes	No	Yes
# of Polarities	2	8	2	8	4	4	4	8	8
# of MOSFETS	NA	24	NA	NA	NA	NA	10	12	12
# of Resistors	6	NA	6	6	3	6	NA	NA	NA
Mode of operation	Voltage mode	Voltage mode	Voltage mode	Voltage mode	Current mode	Voltage mode	Current mode	Voltage mode	Voltage mode

*additional CDBAs are needed to obtain single ended output

$$Y_Z = sC_Z + \frac{1}{R_Z}. \tag{9}$$

Since the CDBA is intended for high frequency filtering applications, the admittance Y_Z reduces to:

$$Y_Z \approx sC_Z. \tag{10}$$

Considering the effect of the parasitic capacitance for the compensated KHN biquad circuit shown in **Figure 3**, $D(s)$ reduces to

$$D(s) = \frac{sC_Z - Y}{G_4} s^2 + s^2 + \frac{G_2G_5}{G_4(C_1+C_Z)} s + \frac{G_2G_3G_6}{G_4(C_1+C_Z)(C_2+C_Z)} \tag{11}$$

It is clear that the frequency limitations imposed by the parasitic capacitance C_Z can be reduced and even eliminated. It is also clear that by choosing $Y = sC_Z$ (i. e. connecting a capacitor whose value is equal to C_Z, between the Xp and the O terminals) the higher order term is eliminated. Complete compensation is achieved by taking the design values of the integrating capacitors C_1 and C_2 equal to the theoretical values minus C_Z, thus achieving self-compensation without using additional elements.

To demonstrate the effectiveness of the proposed circuit. The KHN biquad was simulated using the CDBA presented in [3]. **Figure 4** represents the lowpass and highpass responses designed to give a Butterworth response where: $C_1 = C_2 = 15$ pF, $G_1 = G_2 = G_3 = G_4 = G_6 = 32.25$ µA/V and $G_5 = 50.3$ µA/V.

Figure 5 represents the positive bandpass response of the filter designed to give $Q = 10$, where: $C_1 = C_2 = 15$ pF, $G_2 = G_3 = G_4 = G_6 = 80.1$ µA/V and $G_1 = G_5 = 8.01$ µA/V.

4. Conclusions

A new realization of the KHN biquad filter is presented. The new realization achieves complete MOS nonlinearty cancellation, and is therefore suitable for MOSFET-C continuous-time fully integrated filters. It also provides independent control over all filter design aspects mainly the center frequency ω_o, quality factor Q, and gain. In addition all possible combinations of polarities of the highpass, bandpass and lowpass responses can be obtained. Spice simulations that confirm the theoretical analysis are included.

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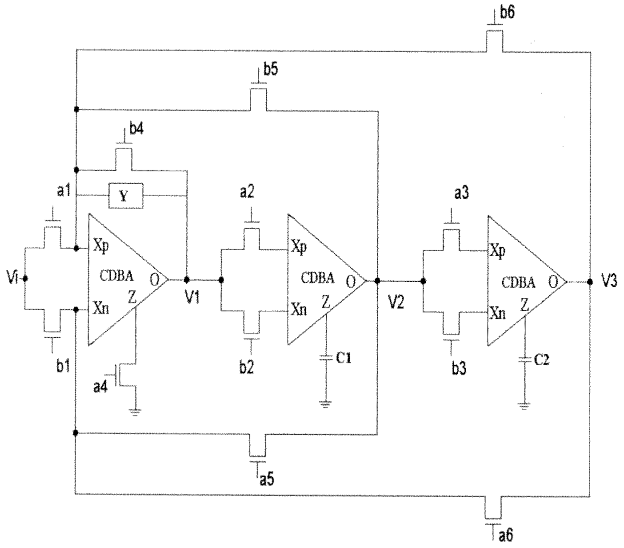

Fig. 3: Passive Compensated KHN Biquad

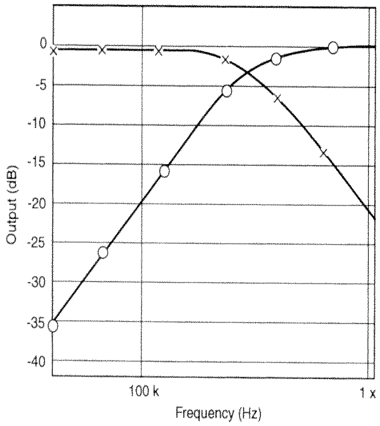

Fig. 4: Highpass and Lowpass responses of KHN biquad

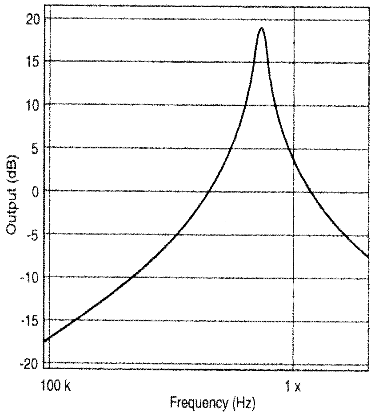

Fig. 5: Bandpass response of the KHN biquad

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K. N. Salama
Electrical Engineering Department, School of Engineering
Stanford University, CA, USA

A. M. Soliman
Electronics and Communication Engineering Department
Cairo University, Giza, Egypt
Email: asoliman@idsc1.gov.eg

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