A NEW VOLTAGE-MODE KHN-BIQUAD USING DIFFERENTIAL DIFFERENCE CURRENT CONVEYORS

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Key words: KHN-biquad, DDCC

ABSTRACT

In this paper, a new voltage-mode (VM) Kerwin-Huelsman-Newcomb (KHN) biquad is proposed. The proposed circuit employs two differential difference current conveyors (DDCCs) as active elements together with two grounded capacitors and two grounded resistors as passive elements. Thus, it employs minimum number of passive elements. The circuit simultaneously provides the three basic filter functions, namely bandpass (BP), highpass (HP) and lowpass (LP) functions. The new configuration offers very high input impedance, which enables easy cascading. SPICE simulation results are given to verify the theoretical analysis.

I. INTRODUCTION

Of the various methods of universal filter design, those based upon Current Conveyors (CC) or their variants, have received recently more attention [1-4]. On the other hand, the well known Kerwin-Huelsman-Newcomb biquad, or KHN-biquad, which is a filter circuit consists of two integrator and a summer circuits, offers several advantages such as low passive and active sensitivities, low component spread and good stability behaviour [5]. Based on the active elements used in the integrator and summer circuits, several KHN-biquads have been presented in the literature [6-10]. Some of them employ current conveyors, which do not suffer from the limited gain-bandwidth products of the op-amps. The circuits given in [5-6, 8-9] operate in voltage-mode (VM). However, these circuits use three or more active elements and/or six or more passive elements. In this work, we propose a VM KHN-biquad circuit, which employs two DDCCs [11] as active elements together with minimum number of passive elements, namely two capacitors and two resistors. All the passive elements are grounded, which is important in integrated circuit implementation point of view. The filter circuit has infinite input impedance, of which several cells can be directly connected in cascade with no need to interpose active separating stages.

II. PROPOSED CIRCUIT

The DDCC, whose electrical symbol is shown in Figure 1, is a five-terminal network with terminal characteristics described by

$$\begin{bmatrix} I_{Y1} \\ I_{Y2} \\ I_{Y3} \\ V_X \\ I_Z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & -1 & 1 & 0 & 0 \\ 0 & 0 & 0 & \pm 1 & 0 \end{bmatrix} \begin{bmatrix} V_{Y1} \\ V_{Y2} \\ V_{Y3} \\ I_X \\ I_Z \end{bmatrix} \qquad (1)$$

where the plus and minus signs indicate whether the conveyor is configured as a minus or plus type circuit, termed DDCC- or DDCC+, respectively.

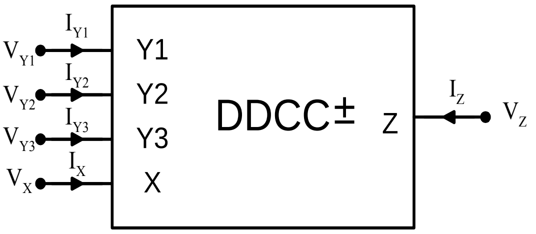


Figure 1. Electrical symbol of DDCC

The corresponding VM biquad circuit can be implemented from the basic signal processing block diagram of implementing VM KHN-biquad illustrated in Figure 2 as shown in Figure 3, from which it can be

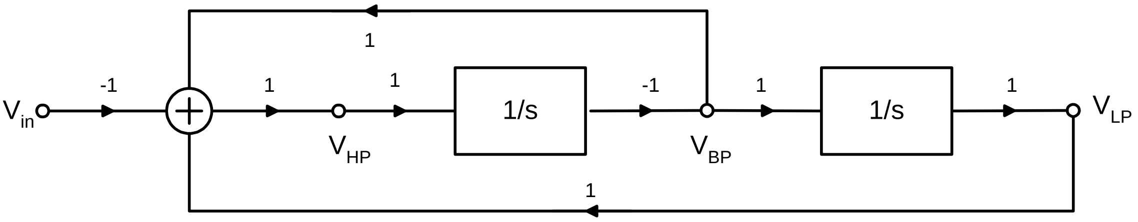


Figure 2. The basic signal processing block of implementing VM KHN-biquad

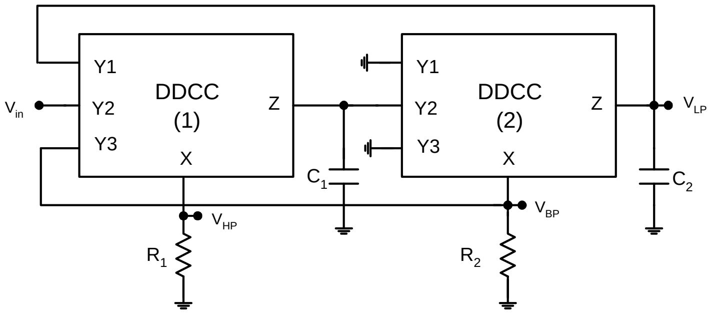


Figure 3. The proposed VM KHN-biquad based on DDCCs

observed that the first stage is the summer and the first integrator circuit stage and the second stage is the second integrator circuit stage.

The nodal analysis of the circuit shown in Figure 3 yields the following voltage transfer functions

$$\frac{V_{HP}}{V_{in}} = -\frac{s^2}{s^2 + \frac{1}{C_1R_1}s + \frac{1}{R_1R_2C_1C_2}} \tag{2a}$$

$$\frac{V_{BP}}{V_{in}} = \frac{\frac{1}{R_1C_1}s}{s^2 + \frac{1}{C_1R_1}s + \frac{1}{R_1R_2C_1C_2}} \tag{2b}$$

$$\frac{V_{LP}}{V_{in}} = \frac{\frac{1}{R_1R_2C_1C_2}}{s^2 + \frac{1}{C_1R_1}s + \frac{1}{R_1R_2C_1C_2}} \tag{2c}$$

The natural angular frequency ω_o and the quality factor Q of the filter can be expressed as

$$\omega_o = \sqrt{\frac{1}{R_1R_2C_1C_2}}, \quad Q = \sqrt{\frac{R_1C_1}{R_2C_2}} \tag{3}$$

It should be noted that ω_o and Q are orthogonally adjustable. In addition, the three basic filter functions, namely highpass (HP), bandpass (BP) and lowpass (LP) filter functions are obtained simultaneously.

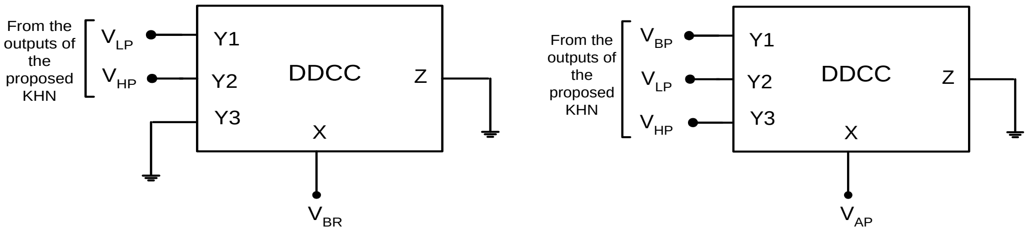
It is worth noting that using the voltage relation property of the DDCC a bandreject (BR) and/or an allpass (AP) responses can be achieved by connecting additional DDCC(s) to the proposed configuration as illustrated in Figure 4.

The corresponding transfer functions of the BR and AP filter circuits can be written as

$$\frac{V_{BR}}{V_{in}} = \frac{s^2 + \frac{1}{R_1R_2C_1C_2}}{s^2 + \frac{1}{C_1R_1}s + \frac{1}{R_1R_2C_1C_2}} \tag{4}$$

$$\frac{V_{AP}}{V_{in}} = -\frac{s^2 - \frac{1}{C_1R_1}s + \frac{1}{R_1R_2C_1C_2}}{s^2 + \frac{1}{C_1R_1}s + \frac{1}{R_1R_2C_1C_2}} \tag{5}$$

Note also that an amplification process can be achieved from the configuration shown in Figure 4 by connecting a resistor to X-terminal (say R_X) and another to the Z-terminal (say R_Z) and taking the output from Z-terminal. In this case the output signal of the BR and AP filter will be amplified by the ratio of R_Z/R_X.



(a) (b)

Figure 4. The implementation of a) BR and b) AP responses from the outputs of the proposed KHN-biquad

III. NON-IDEALITY ANALYSIS OF DDCC

Taking into consideration the DDCC+ non-idealities, the port relations in (1) can be expressed as

$$V_X = \beta_1 V_{Y1} - \beta_2 V_{Y2} + \beta_3 V_{Y3} \quad \text{and} \quad I_Z = \alpha I_X \qquad (6)$$

where $\beta_j = 1 - \varepsilon_{vj}$ and $\alpha = 1 - \varepsilon_i$ for j=1, 2, 3. Here, $\varepsilon_{vj}, \varepsilon_i$ ($|\varepsilon_{vj}|, |\varepsilon_i| \langle\langle 1$) represent voltage and current tracking errors of the DDCC, respectively. Reanalysis of the filter circuit yields the modified functions of the proposed KHN-biquad as

$$\frac{V_{HP}}{V_{in}} = -\frac{\beta_{21} s^2}{s^2 + \dfrac{\alpha_1 \beta_{22} \beta_{31}}{C_1 R_1} s + \dfrac{\alpha_1 \alpha_2 \beta_{11} \beta_{22}}{R_1 R_2 C_1 C_2}} \qquad (7a)$$

$$\frac{V_{BP}}{V_{in}} = \frac{\dfrac{\alpha_1 \beta_{21} \beta_{22}}{R_1 C_1} s}{s^2 + \dfrac{\alpha_1 \beta_{22} \beta_{31}}{C_1 R_1} s + \dfrac{\alpha_1 \alpha_2 \beta_{11} \beta_{22}}{R_1 R_2 C_1 C_2}} \qquad (7b)$$

$$\frac{V_{LP}}{V_{in}} = \frac{\dfrac{\alpha_1 \alpha_2 \beta_{21} \beta_{22}}{R_1 R_2 C_1 C_2}}{s^2 + \dfrac{\alpha_1 \beta_{22} \beta_{31}}{C_1 R_1} s + \dfrac{\alpha_1 \alpha_2 \beta_{11} \beta_{22}}{R_1 R_2 C_1 C_2}} \qquad (7c)$$

where β_{1i}, β_{2i}, β_{3i} and α_i are the mentioned parameters in (6) associated to the i-th DDCC. In this case, the natural frequency ω_o and quality factor Q of the filter can be rewritten as

$$\omega_o = \sqrt{\frac{\alpha_1 \alpha_2 \beta_{11} \beta_{22}}{R_1 R_2 C_1 C_2}} \quad \text{and} \quad Q = \frac{1}{\beta_{31}} \sqrt{\frac{\alpha_2 \beta_{11} R_1 C_1}{\alpha_1 \beta_{22} R_2 C_2}} \qquad (8)$$

The active and passive sensitivity analyses of the proposed circuits show that

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

$$S^{\omega}_{\alpha_1} = S^{\omega}_{\alpha_2} = S^{\omega}_{\beta_{11}} = S^{\omega}_{\beta_{22}} = -S^{Q}_{\alpha_1} = S^{Q}_{\alpha_2} = S^{Q}_{\beta_{11}} = -S^{Q}_{\beta_{22}} = -\frac{1}{2},$$

$$S^{Q}_{\beta_{31}} = -1$$

and the remaining sensitivities are zero. Thus, the entire sensitivities are low.

IV. SIMULATION RESULTS

The proposed KHN-biquad filter circuit has been simulated using SPICE program to verify the given theoretical analysis. The DDCCs have been simulated using the CMOS structure of Figure 5 [11]. The MOS transistors aspect ratio of the CMOS DDCC are given in Table 1. The device model parameters used for the SPICE simulations are taken from MIETEC 0.5 µm CMOS process. The supply voltages have been selected as V_{DD}=-V_{SS}=2.5 V.

Table 1. Transistor aspect ratios of the DDCC circuit given in Figure 5.

TRANSISTOR	W (µm)	L (µm)
M1-M4	0.8	0.5
M5-M6	14.4	0.5
M7-M8	4	0.5
M9-M10	10	0.5
M11-M12	45	0.5
M13-M15	9.6	0.5
M16-M18	45	0.5

Simulated gain responses of the basic filter functions (HP, BP and LP) of the proposed KHN-biquad circuit are given in Figure 6. For the simulation, equal resistance values of 10 kΩ are chosen while the capacitance values of C2=2C1=2 pF are chosen for a natural frequency of f_o≈11.25 MHz and a quality factor of Q=0.707. From Figure 6 it can be realized that the theoretical and simulation results are in good agreement.

V. CONCLUSIONS

In this work, a VM KHN-biquad circuit has been presented. The filter employs two DDCCs, two capacitors and two resistors. All the passive elements are grounded, which is important with respect to integrated circuit

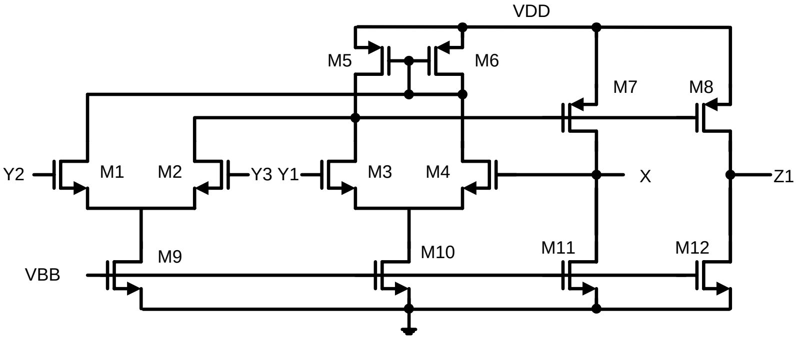


Figure 5. The CMOS structure of DDCC

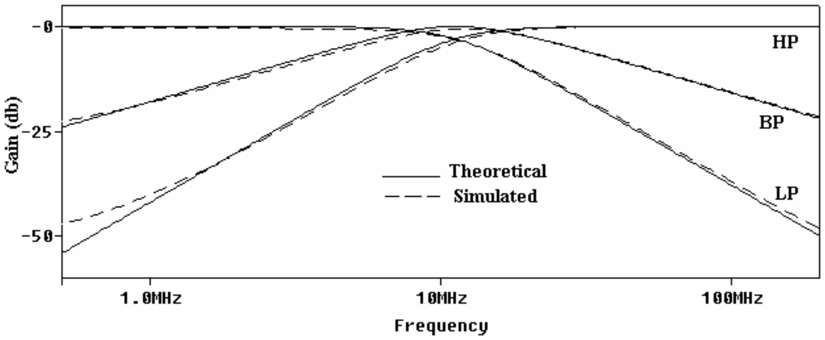


Figure 6. Simulated gain responses of the basic filter functions of the proposed VM KHN-biquad

implementation. The filter provides the basic three filter functions (BP, HP and LP) simultaneously. The bandreject and/or allpass responses can be achieved using additional DDCC(s). The filter circuit has infinite input impedance, of which several cells can be directly connected in cascade. It should be noted that the proposed filter has the main advantages of the original KHN circuit such as low passive sensitivity performance, low component spread and good stability behavior.

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