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# Voltage and Current Mode KHN Filter: A Current Feedback Amplifier Approach

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*Abstract*— ***In this paper, voltage -mode and a current-mode Kerwin-Huelsman-Newcomb (KHN) filter structure employing current feedback amplifiers (CFAs) is proposed. Both circuits perform three standard functions including low-pass, high-pass and band-pass functions. The current mode filter is multi-input and single-output (MISO) type whereas voltage mode filter is single-input and multi-output (SIMO) type. The proposed filter is capable of providing an independent control of the natural angular frequency (ωo) and quality factor (Q).***

*Index Terms*— **Current Feedback Amplifier, Active Filters, Current Conveyor, Current-Mode Circuit, Filters.**

## I. INTRODUCTION

The Current-mode active elements offer the main advantages like greater linearity, low power consumption and wider bandwidth over their voltage-mode counterparts [1-2]. Also, the design of filter circuits employing current-mode active elements may be used in phase-locked loop frequency modulation (FM), stereo demodulators, touch-tone telephone, tone decoder and cross over networks used in a three-way high fidelity loudspeaker . Current Feedback Amplifier is a versatile building block whose applications appear in the literature. In general, multi-purpose and universal filters can be classified either as multi-input and single-output (MISO) filter [3-9] or single-input and multi-output (SIMO) filter [10-12]. The MISO current-mode filters have simple structures but cannot realize multiple outputs at the same time.

In this paper we present voltage-mode and current- mode KHN filter using CFAs. The CFA based voltage-mode filter is derived from well-known KHN operational amplifier (OA) filter using OA – CFA Transformation**,** and further the current mode filter using CFA is derived from voltage-mode CFA circuit by principle of adjoint transformation. The proposed biquadratic circuits realize low pass (LP), high pass (HP), band pass (BP) and transfer functions. The circuits have the advantage of low sensitivities. Since the circuits are composed of CFAs, they are very suitable for high frequency operation and IC implementation.

## II. CURRENT FEEDBACK AMPLIFIER

The circuit symbol of a current-feedback amplifier (CFA) is shown in Fig. 1. This circuit is equivalent to a second-generation current conveyor with a voltage buffer. The model of a CFA is given by Fig. 2.

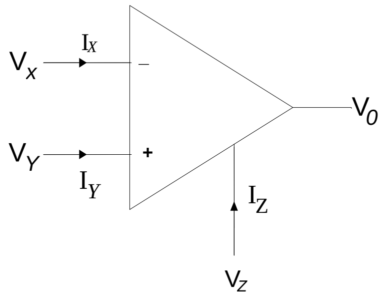


**Fig: 1. Circuit symbol of current-feedback amplifier.**

The relation between terminal voltages and currents can be described using the following matrix:

$$\begin{bmatrix} i_y \\ v_x \\ i_z \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 \\ 1 & 0 & 0 \\ 0 & 1 & 0 \end{bmatrix} \begin{bmatrix} v_y \\ i_x \\ v_z \end{bmatrix}$$

*and*

$$v_o = v_z \qquad (1)$$

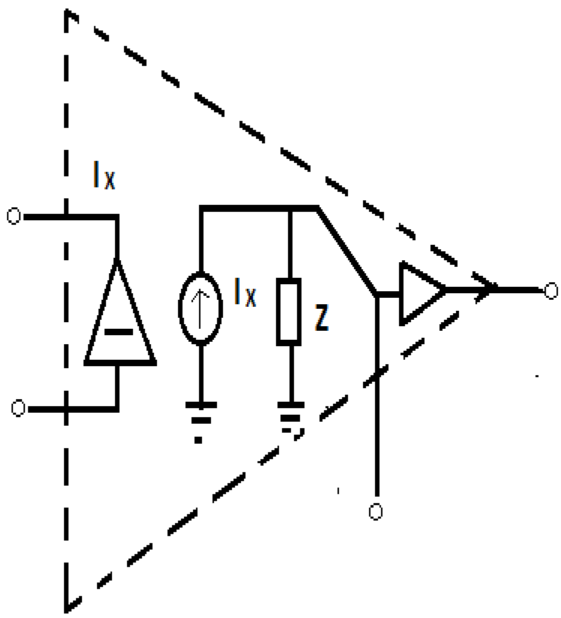


**Fig: 2. Model of current-feedback amplifier.**

An operational Amplifier in an inverting amplifier mode has been replaced by a CFA as shown in Fig.3.The admittance $Y_2$ connected in feedback loop in case of Op-Amp, is connected to Z terminal of CFA.

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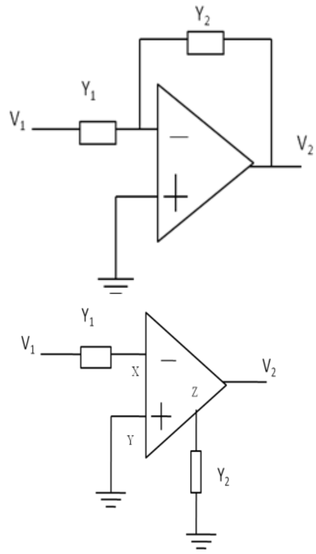


**Fig. 3: OA – CFA Transformation**

## III GENERAL STRUCTURE OF KHN BIQUAD FILTER

Kerwin, Huelsman, and Newcomb filter also known as the State variable Filter or Universal Filter provides Band Pass, High Pass and Low Pass responses in voltage mode simultaneously for a single input.

KHN is the most used active-RC filter topology to realize second order functions, mainly because the structure offers several advantages such as low passive and active sensitivity performance, low component spread, good stability behavior and possible to realize different filter functions without changing the topology. However this extraordinary design suffers from the inherent problems of the operational amplifiers (op-amps). CFAs prove to be a good alternative to operational amps.

A KHN structure consists of two integrator blocks and a summer block as shown in Fig. 4. From block diagram, the transfer functions of HP, BP and LP can be respectively expressed as follows:

$$\frac{Y_{HP}}{X_{in}} = \frac{s^2}{s^2 + s\frac{1}{\tau_1} + \frac{1}{\tau_1\tau_2}} \qquad (2)$$

$$\frac{Y_{BP}}{X_{in}} = \frac{s\frac{1}{\tau_1}}{s^2 + s\frac{1}{\tau_1} + \frac{1}{\tau_1\tau_2}} \qquad (3)$$

$$\frac{Y_{LP}}{X_{in}} = \frac{\frac{1}{\tau_1\tau_2}}{s^2 + s\frac{1}{\tau_1} + \frac{1}{\tau_1\tau_2}} \qquad (4)$$

From above Equations, the pole frequency and quality factor can be expressed as:

$$\omega_0 = \sqrt{\frac{1}{\tau_1\tau_2}} \quad and \quad Q_0 = \sqrt{\frac{\tau_1}{\tau_2}} \qquad (5)$$

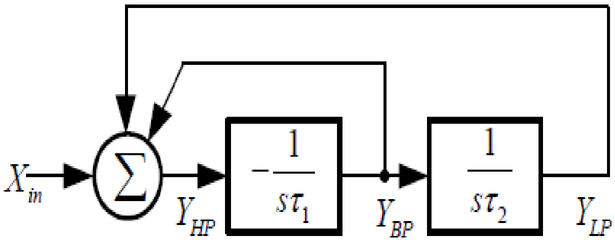


**Fig. 4: Fundamental KHN structure.**

## IV.THE PROPOSED CIRCUIT

The well-known voltage-mode 2nd-order KHN filter is shown in fig. 5. It is a preferred building block for cascade filter design as it has single-input three-output, generating three basic 2nd-order transfer functions (low-pass, band-pass, and high-pass). The classical KHN structure is transformed into voltage mode filter using current feedback amplifier (CFA) by utilizing OA – CFA Transformation as mentioned above. Fig. 6 shows a KHN filter in voltage mode using current feedback amplifier. The transfer functions are given by:

$$\frac{V_{HP}}{V_I} = \frac{-R_5}{R_3}\frac{As^2}{As^2 + Bs + 1} \qquad (6)$$

$$\frac{V_{LP}}{V_I} = \frac{-R_4}{R_3}\frac{1}{As^2 + Bs + 1} \qquad (7)$$

$$\frac{V_{BP}}{V_I} = \frac{-R_4}{R_3}\frac{R_4R_7C_2s}{As^2 + Bs + 1} \qquad (8)$$

Where

$$A = R_4R_6R_7C_1C_2/R_5$$

$$B = R_4R_7C_2(1 + \frac{R_5}{R_3} + \frac{R_5}{R_4})/(1 + \frac{R_2}{R_1})R_5$$

$$Q = \frac{\left(1 + {R_2}/{R_1}\right)\left({R_5R_6C_1}/{R_4R_7C_2}\right)^{1/2}}{1 + {R_5}/{R_3} + {R_5}/{R_4}} \qquad (9)$$

$$\omega_0 = \left(\frac{{R_5}/{R_4}}{R_6C_1R_7C_2}\right)^{1/2} \qquad (10)$$

This filter is tuned as follows: (a) adjust $R_3$ for the desired magnitude of the response, (b) adjust $R_6$ (or $R_7$) to tune $\omega_0$, (c) adjust the ratio $R_2/R_1$ to tune Q. Note that Q can be adjusted independently of $\omega_0$ by changing the value of $R_2$. As we can see that quality factor Q depends on the resistor ratio $R_2/R_1$ and therefore Q is less sensitive to resistance tolerances and temperature drift. A voltage-mode circuit can be converted into a current-mode circuit by constructing an inter-reciprocal network by using the adjoint principle. According to this principle, a network N is replaced with an adjoint network Na, the voltage excitation is interchanged to a current response, and the voltage response is interchanged

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to a current excitation. Thus, the resulting transfer functions of these two networks N and Na are identical:

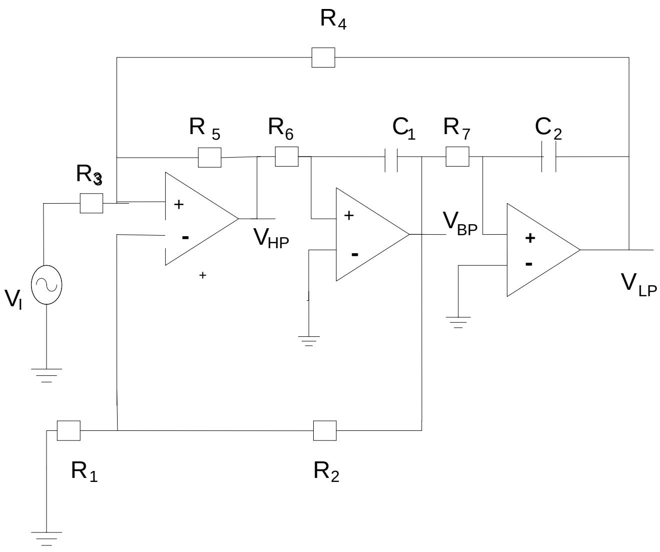


**Fig. 5: Basic KHN Filter using Operational Amplifier**

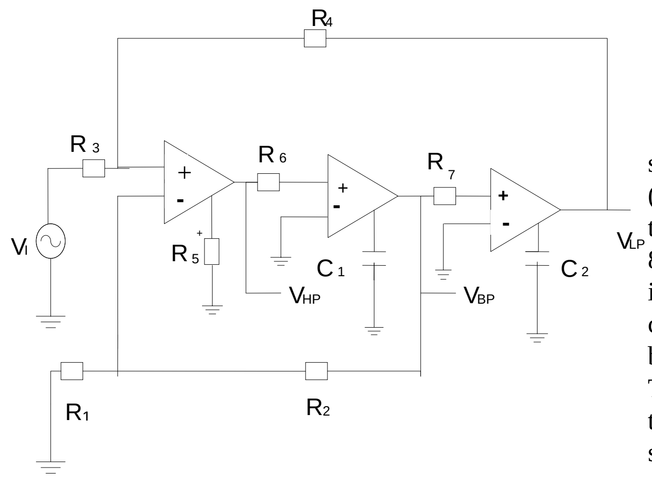


**Fig. 6: CFA based voltage mode KHN Filter**

The expression (8) and (9) is simplified to

$$\omega_0 = {}^{1}/_{RC} \tag{11}$$

$$Q = \frac{1}{3}\left(1 + {}^{R_2}/_{R_1}\right) \tag{12}$$

$$H_v(s) = \frac{V_{out}}{V_{in}} = \frac{I_{out}}{I_{in}} = H_i(s) \tag{12}$$

The networks N and Na are thus said to be inter-reciprocal to one another. In order to maintain identical transfer functions for both the original network N and the adjoint network Na the impedance levels in the corresponding nodes of both networks should be identical. Therefore, the signal flow is reversed in the adjoint network and a voltage source is converted to a current sensing element as they both behave as short circuits. Similarly, a voltage sensing element is converted to a current source.

By interchanging input and output, the resultant circuit that realizes LP and BP and HP transfer functions in current-mode as shown in fig.7. By routine analysis, the transfer functions are given by:

$$\frac{I_O}{I_{HP}} = \frac{-R_5}{R_3}\frac{As^2}{As^2 + Bs + 1} \tag{14}$$

$$\frac{I_O}{I_{LP}} = \frac{-R_4}{R_3}\frac{1}{As^2 + Bs + 1} \tag{15}$$

$$\frac{I_O}{I_{LP}} = \frac{-R_4}{R_3}\frac{R_4R_7C_2s}{As^2 + Bs + 1} \tag{16}$$

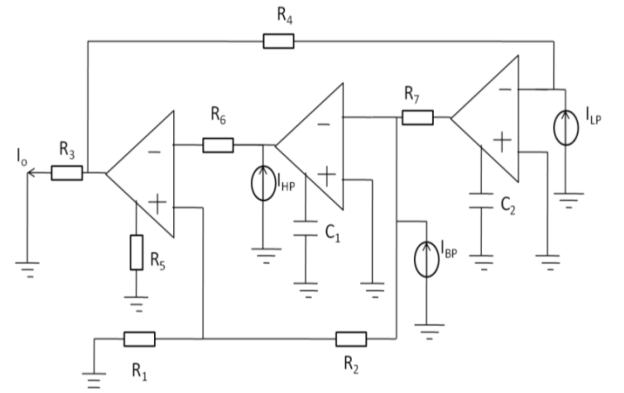


**Fig. 7: CFA based Current mode KHN Filter.**

## IV. SIMULATION RESULTS

To prove the performances of the proposed filters, PSPICE simulation was done. The circuits were realized by AD-844 (CFA) IC. The simulated response of the LP, BP and HP of the proposed voltage mode filter using CFA is shown in Fig. 8. Responses of he current mode filter using CFA are shown in Fig 9, 10, 11. It clearly shows that the voltage mode filter circuit provides simultaneously low-pass, high-pass and band-pass responses without modifying the circuit topology. The current mode filter accepts current at one terminal at a time and produces the respective response. For all simulations, DC supply voltage of +5V capacitance values were $C_1 = C_2 = 0.1$ nF, $R_6 = R_7 = 15.9$ KΩ and $R_3 = R_4 = R_5 =$ 10KΩ were chosen.

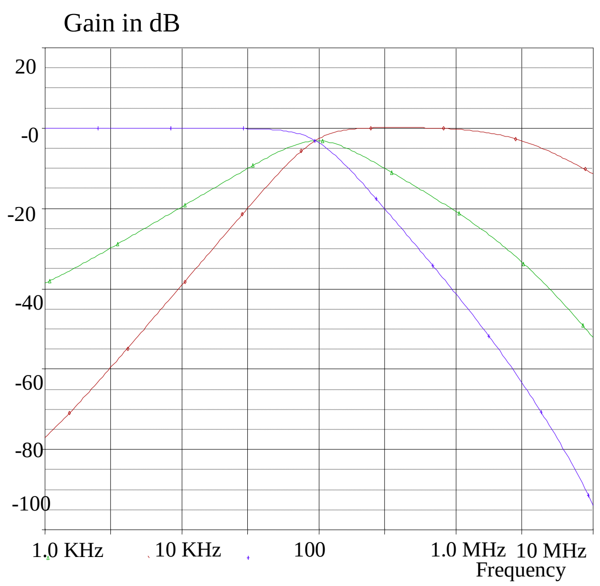


**Fig. 8: Simulated BP, LP and HP voltage mode responses.**

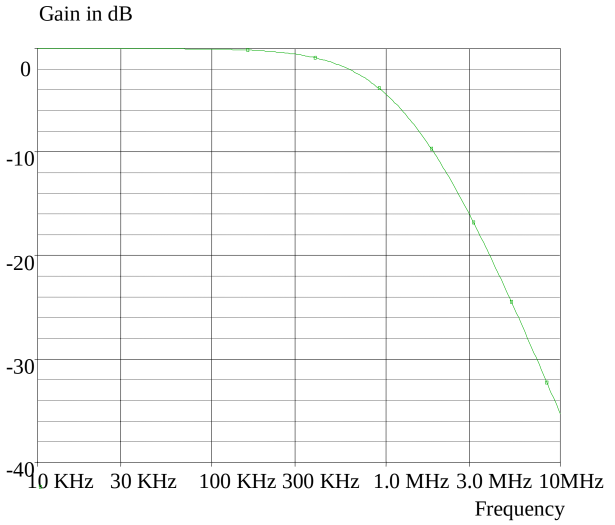


**Fig. 9: Simulated LP current mode response.**

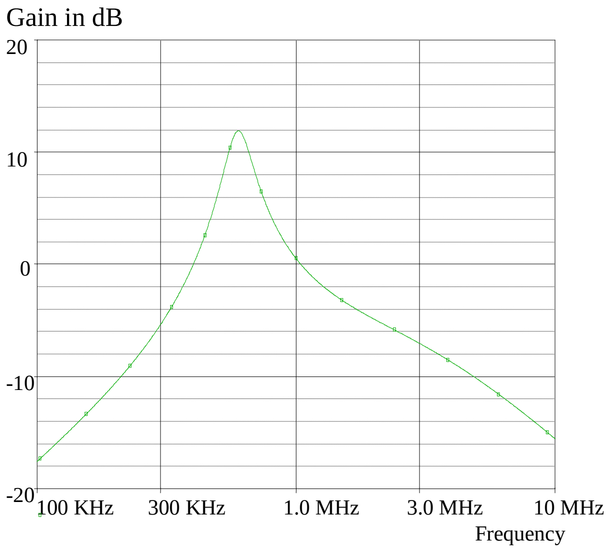


**Fig. 10: Simulated BP current mode response.**

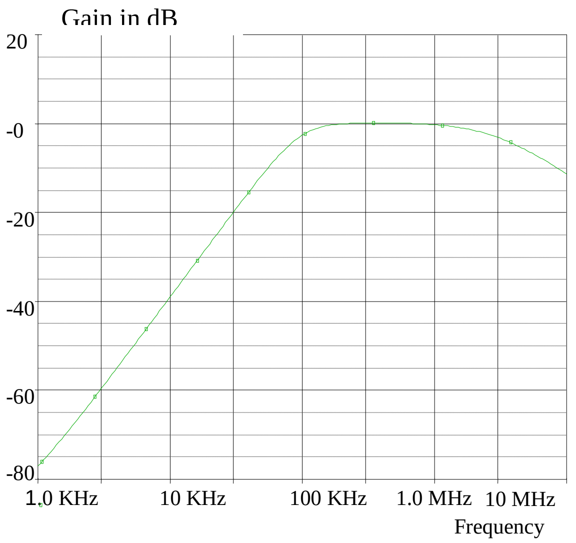


**Fig. 11: Simulated HP current mode response**

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