A 22.5MHz current-mode KHN-biquad using differential voltage current conveyor and grounded passive elements

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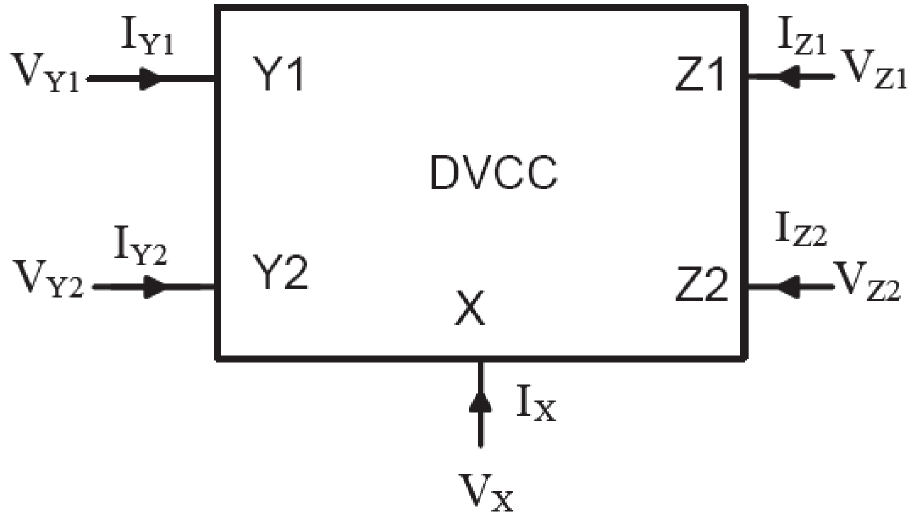
- A current-mode (CM) Kerwin–Huelsman–Newcomb (KHN) biquad
- The circuit employs three differential-voltage current conveyors (DVCCs) as active elements together with two capacitors and four resistors as passive elements, which all are grounded.
- The circuit simultaneously provides the three basic filter functions, namely bandpass (BP), highpass (HP) and lowpass (LP) functions.
- The notch and allpass (AP) functions can be obtained by connecting appropriate output currents directly without using additional active elements.
- The output signals are obtained at high output impedance ports, which is important for easy cascading in CM operation.



Electrical symbol of the DVCC.

The DVCC terminal relations are givens by

$$\begin{bmatrix} V_X \\ I_{Y1} \\ I_{Y2} \\ I_{Z1} \\ I_{Z2} \end{bmatrix} = \begin{bmatrix} 0 & 1 & -1 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 \\ 1 & 0 & 0 & 0 & 0 \\ -1 & 0 & 0 & 0 & 0 \end{bmatrix} \begin{bmatrix} I_X \\ V_{Y1} \\ V_{Y2} \\ V_{Z1} \\ V_{Z2} \end{bmatrix} .$$

- It should be noted that using a single DVCC and two grounded admittances *Y_1 and Y_2, it is easy to construct the* basic current processing block, which has the following transfer function

$$I_{\text{out}1} = \frac{Y_2}{Y_1} I_{\text{in}} = -I_{\text{out}2}.$$

- By choosing Y_1 *and* Y_2 *appropriately, various basic blocks*operating in CM can be obtained:
- (A) *Amplifier: If the admittances are* $Y_1 = 1/R_1$ *and* $Y_2 = 1/R_2$*, the current-mode amplifier can be found as*

$$\frac{I_{\text{out}1}}{I_{\text{in}}} = \frac{-I_{\text{out}2}}{I_{\text{in}}} = \frac{R_1}{R_2}.$$

- The gain of the amplifier can be adjusted by changing R_1 and/or R_2.

- (B) *Integrator: If the admittances are* $Y_1 = sC_1$ *and* $Y_2 = 1/R_2$ *the current-mode integrator can be achieved as*

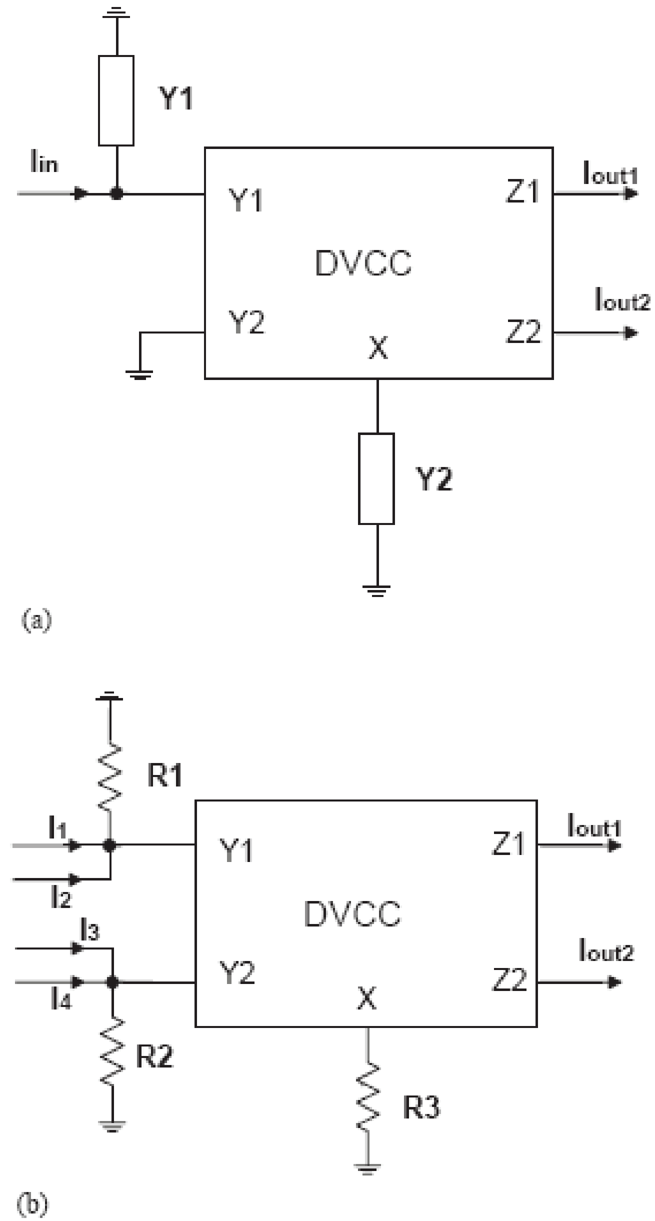
$$\frac{I_{out1}}{I_{in}} = \frac{-I_{out2}}{I_{in}} = \frac{1}{sC_1 R_2}.$$

- (C) *Differentiator: If the admittances are* $Y_1 = 1/R_1$ *and* $Y_2 = sC_2$ *the current-mode differentiator can be obtained as*

$$\frac{I_{out1}}{I_{in}} = \frac{-I_{out2}}{I_{in}} = sC_2 R_1.$$

- (D) *Summer/substructure: Differentiated input currents* converted to voltages can be applied to the *Y-terminals* of the DVCC, which results in a current-mode summer/ substructure circuit. The output currents can be found as

$$I_{out1} = -I_{out2} = \frac{R_3}{R_1}(I_1 + I_2) - \frac{R_3}{R_2}(I_3 + I_4).$$



DVCC based basic current processing block, (b) DVCC based CM summer/substructure circuit.

- **Proposed KHN-biquad**

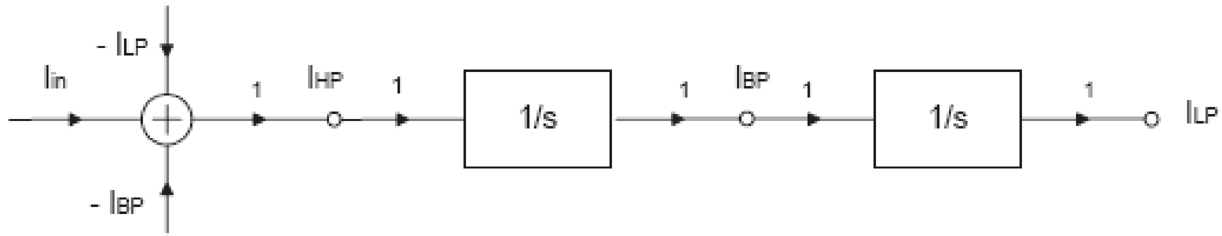
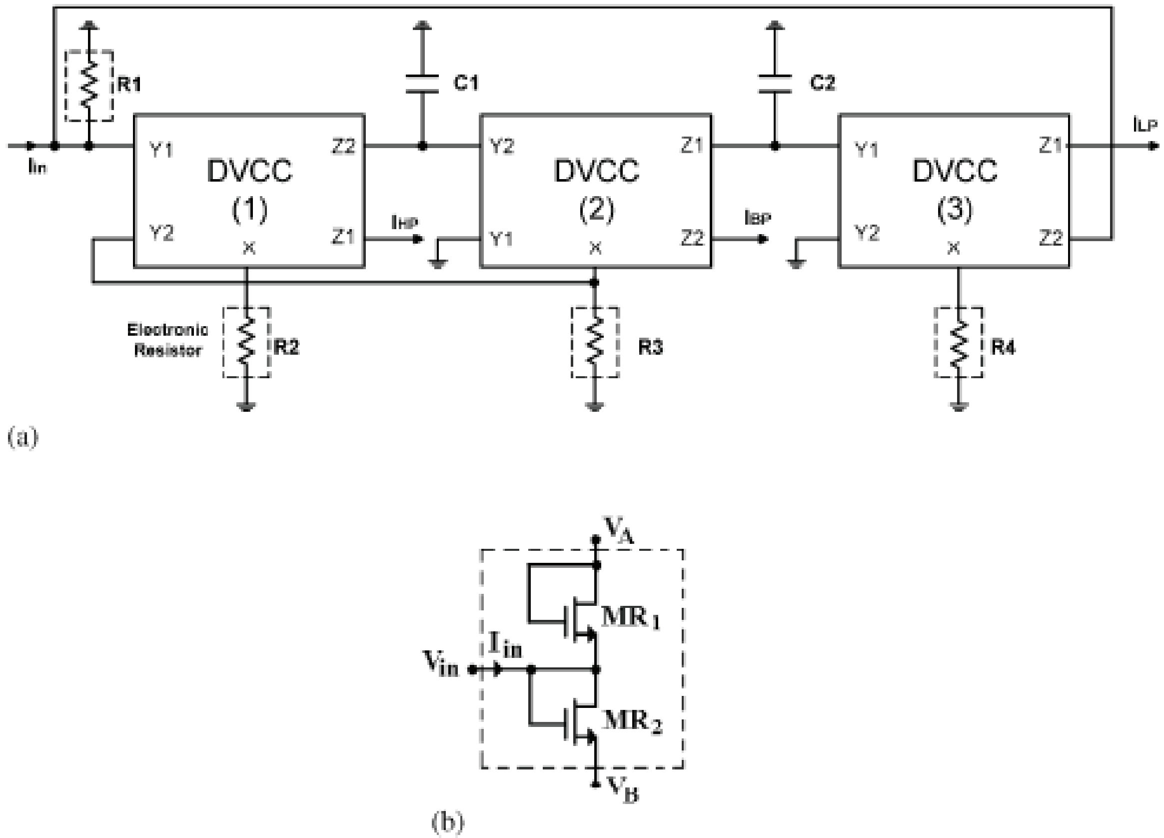


Fig. 5. The basic signal processing block of implementing CM KHN-biquad.



. (a) The proposed CM KHN-biquad based on DVCCs. (b) Electronic resistor.

- The node analysis of the circuit yields the following current transfer functions:

$$\frac{I_{HP}}{I_{in}} = \frac{(R_1/R_2)s^2}{s^2 + (1/C_1R_2)s + (R_1/R_2R_3R_4C_1C_2)},$$

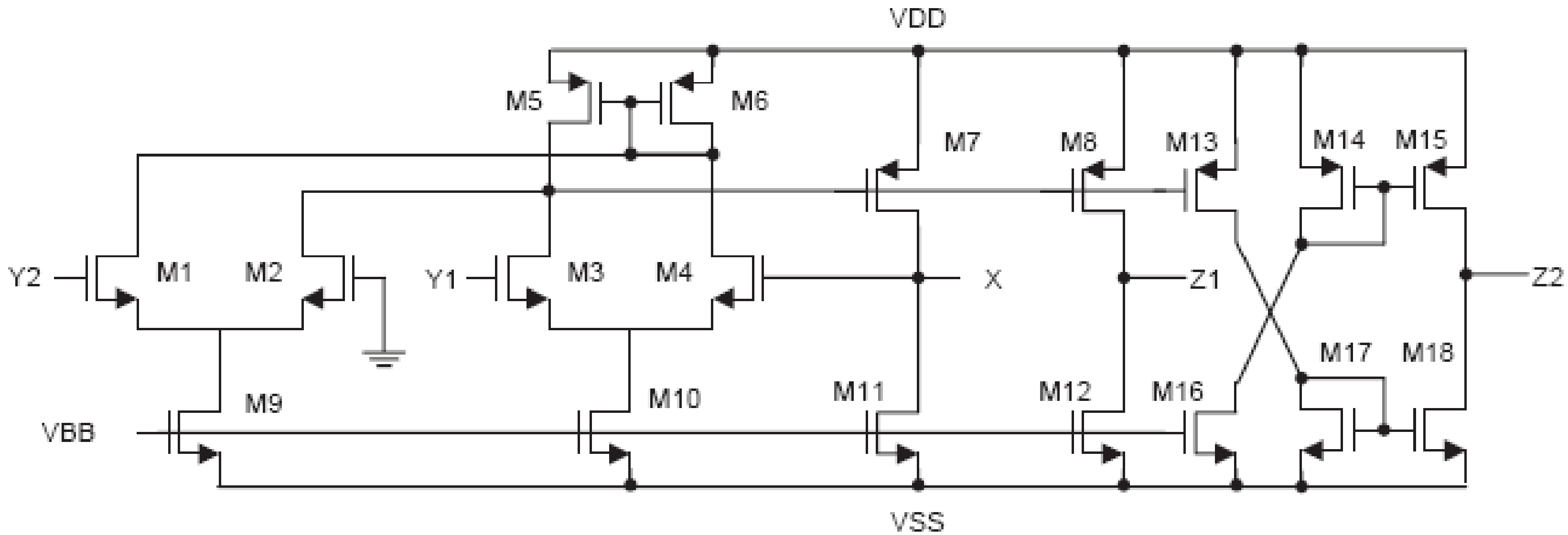
$$\frac{I_{BP}}{I_{in}} = -\frac{(R_1/R_2R_3C_1)s}{s^2 + (1/C_1R_2)s + (R_1/R_2R_3R_4C_1C_2)},$$

$$\frac{I_{LP}}{I_{in}} = \frac{(R_1/R_2R_3R_4C_1C_2)}{s^2 + (1/C_1R_2)s + (R_1/R_2R_3R_4C_1C_2)}.$$

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

$$\omega_0 = \sqrt{\frac{R_1}{R_2 R_3 R_4 C_1 C_2}}, \quad Q = \sqrt{\frac{R_1 R_2 C_1}{R_3 R_4 C_2}}.$$

- It should be noted that ω_0 and Q *are orthogonally adjustable.*
- It means that ω_0 can be adjusted without disturbing the *Q by changing R_2 and R_4 simultaneously while R_2/R_4 is* constant.
- The three basic filter functions (HP, BP and LP) are obtained simultaneously, all at high impedance outputs.



The CMOS implementation of DVCC.

Table 1. Transistor aspect ratios of the DVCC circuit

Transistor	W (μm)	L (μm)
M1, M2, M3, M4	0.8	0.5
M5, M6	4	0.5
M9, M10	14.4	0.5
M7, M8, M13, M14, M15	10	0.5
M11, M12, M16, M17, M18	45	0.5

Tracking error analysis

Taking into consideration the DVCC non-idealities, the terminal relations in (1) can be expressed as

$$V_X = \beta_1 V_{Y1} - \beta_2 V_{Y2},$$
$$I_{Z1} = \alpha_1 I_X \quad \text{and} \quad I_{Z2} = -\alpha_2 I_X,$$

where $\beta_j = 1 - \varepsilon_{vj}$ and $\alpha_j = l - \varepsilon_{ij}$ for $j = 1, 2$. Here ε_{vj} and ε_{ij} ($|\varepsilon_{vj}|, |\varepsilon_{ij}| \ll 1$) represent voltage and current tracking errors of the DVCC, respectively. Reanalysis of the filter circuit yields the modified transfer functions as follows

$$\frac{I_{\mathrm{HP}}}{I_{\mathrm{in}}} = \frac{\frac{\alpha_{21}\beta_{11}R_1}{R_2}s^2}{s^2 + \alpha_{11}\beta_{12}\beta_{21}\frac{1}{C_1R_2}s + \alpha_{11}\alpha_{12}\alpha_{23}\beta_{11}\beta_{12}\beta_{13}\frac{R_1}{R_2R_3R_4C_1C_2}}$$

$$\frac{I_{\mathrm{BP}}}{I_{\mathrm{in}}} = -\frac{\frac{\alpha_{11}\alpha_{22}\beta_{11}\beta_{12}R_1}{R_2R_3C_1}s}{s^2 + \alpha_{11}\beta_{12}\beta_{21}\frac{1}{C_1R_2}s + \alpha_{11}\alpha_{12}\alpha_{23}\beta_{11}\beta_{12}\beta_{13}\frac{R_1}{R_2R_3R_4C_1C_2}}$$

$$\frac{I_{\mathrm{LP}}}{I_{\mathrm{in}}} = \frac{\frac{\alpha_{11}\alpha_{12}\alpha_{13}\beta_{11}\beta_{12}\beta_{13}R_1}{R_2R_3R_4C_1C_2}}{s^2 + \alpha_{11}\beta_{12}\beta_{21}\frac{1}{C_1R_2}s + \alpha_{11}\alpha_{12}\alpha_{23}\beta_{11}\beta_{12}\beta_{13}\frac{R_1}{R_2R_3R_4C_1C_2}}$$

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

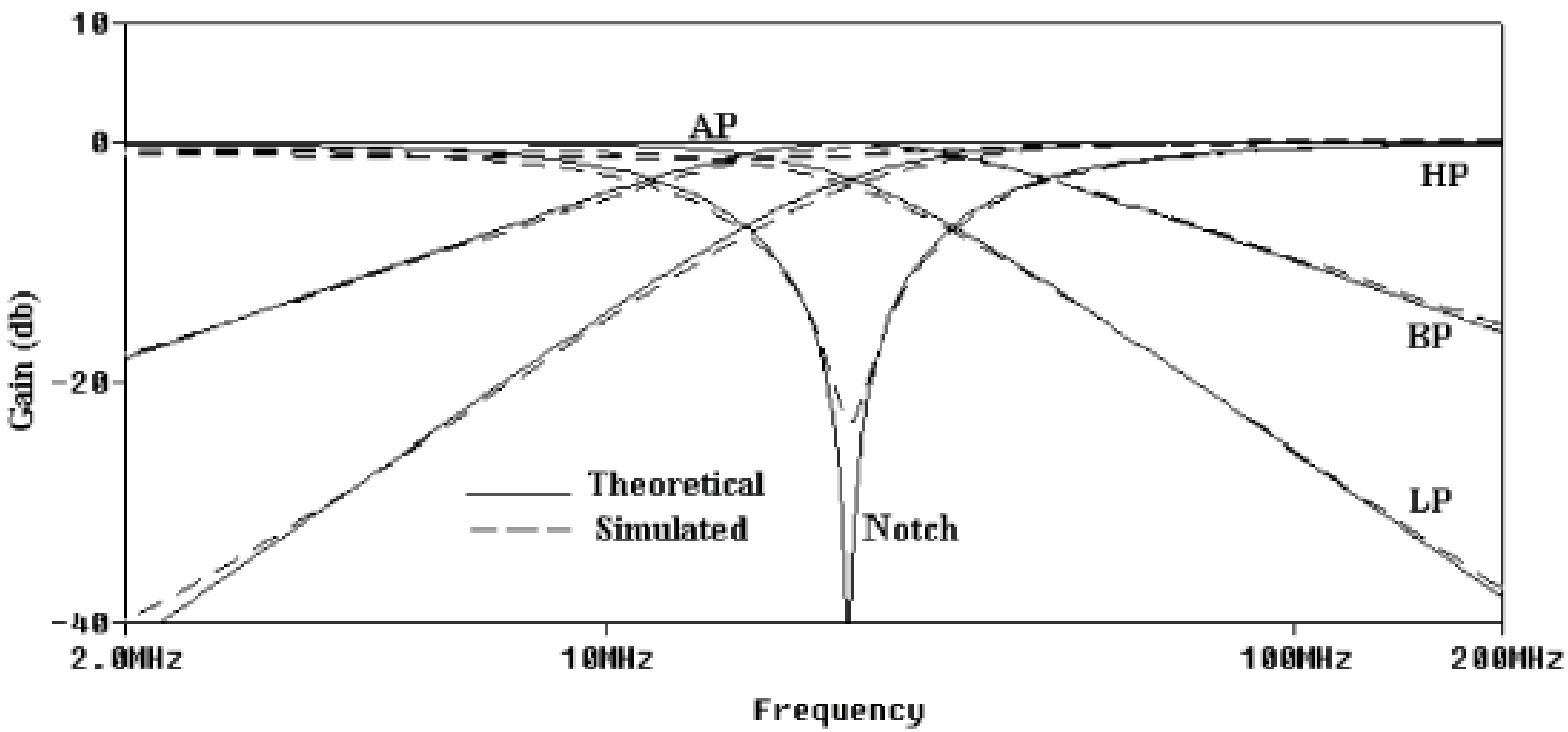
$$S_{\alpha_{21}}^{\omega_o} = S_{\alpha_{22}}^{\omega_o} = S_{\alpha_{13}}^{\omega_o} = S_{\beta_{21}}^{\omega_o} = S_{\beta_{22}}^{\omega_o} = S_{\beta_{23}}^{\omega_o} = S_{\alpha_{21}}^{Q} = S_{\alpha_{22}}^{Q} = S_{\beta_{22}}^{Q} = S_{\beta_{23}}^{Q} = 0,$$

$$S_{\alpha_{11}}^{\omega_o} = S_{\alpha_{12}}^{\omega_o} = S_{\alpha_{23}}^{\omega_o} = S_{\beta_{11}}^{\omega_o} = S_{\beta_{12}}^{\omega_o} = S_{\beta_{13}}^{\omega_o} = S_{\beta_{11}}^{Q} = S_{\beta_{13}}^{Q} = S_{\alpha_{12}}^{Q} = S_{\alpha_{23}}^{Q} = S_{R_1}^{\omega_o} = S_{R_1}^{Q} = S_{R_2}^{Q} = S_{C_1}^{Q} = \frac{1}{2},$$

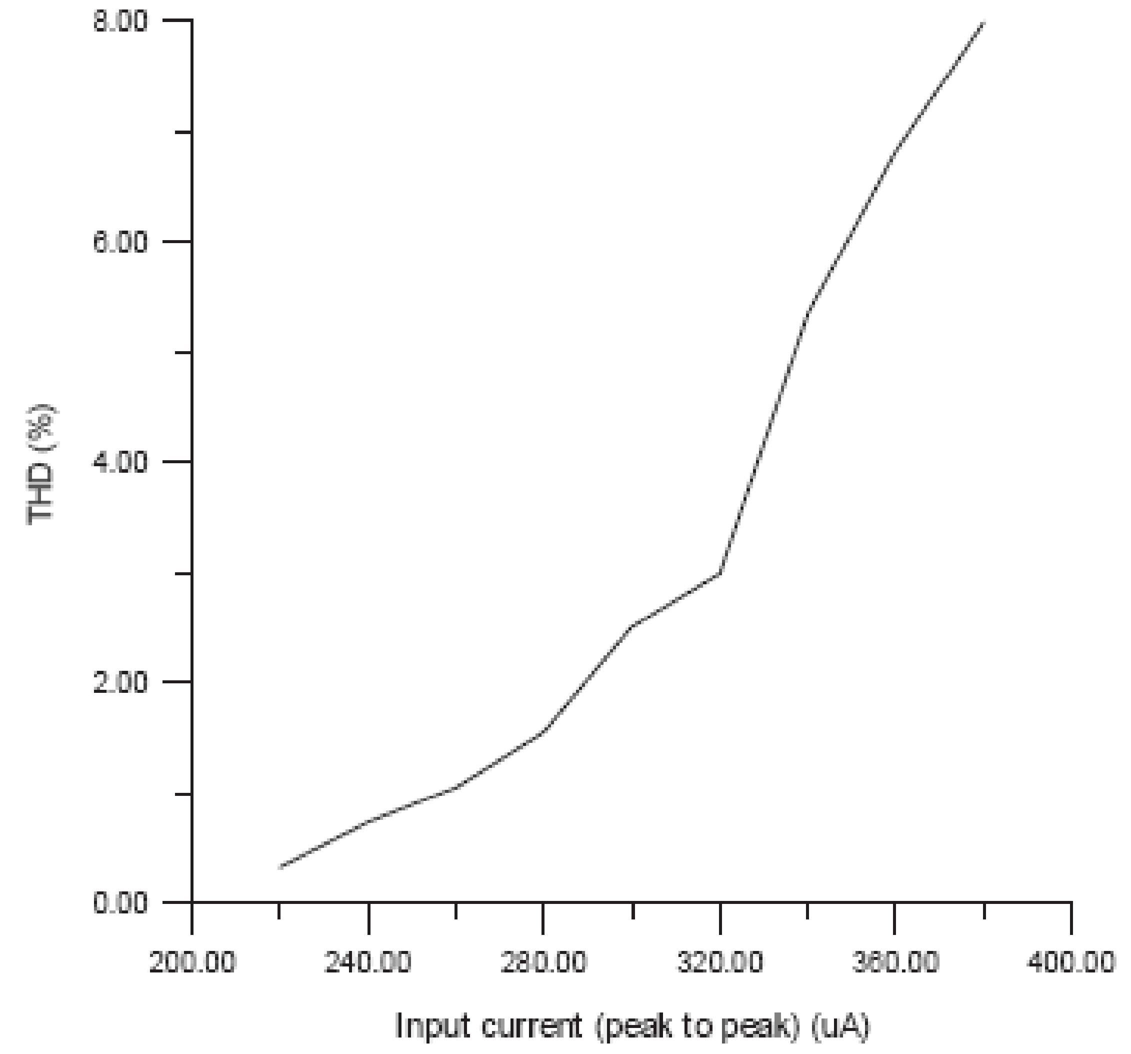
$$S_{\alpha_{11}}^{Q} = S_{\beta_{12}}^{Q} = S_{R_2}^{\omega_o} = S_{R_3}^{\omega_o} = S_{R_4}^{\omega_o} = S_{C_1}^{\omega_o} = S_{C_2}^{\omega_o} = S_{R_3}^{Q} = S_{R_4}^{Q} = S_{C_2}^{Q} = -\frac{1}{2},$$

$$S_{\beta_{21}}^{Q} = -1.$$

Thus, the all active and passive sensitivities are not more than unity in magnitude.



The frequency response of the basic filter functions (BP, HP, LP, Notch and AP) for the proposed KHN-biquad.



Dependence of the output harmonic distortion of BP filter on input current amplitude.

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