*ISSN: 2278 – 909X*
*International Journal of Advanced Research in Electronics and Communication Engineering (IJARECE)*
*Volume 4, Issue 5, May 2015*

# Single Voltage Differencing Current Conveyor Based Second-Order Filter Realization

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***Abstract*- In this paper, single voltage differencing current conveyor (VDCC) based voltage mode second order filter is proposed. The proposed circuit employs one voltage differencing current conveyor (VDCC) as active elements together with two capacitors and three resistors as passive elements. A unique application of the VDCC is used, when the terminal P and $W_P$ are connected together. Using this way a suitable building block is obtained in synthesis of several biquads. A 0.18µm TSMC CMOS technology is used as the active element to analyse the VDCC [2]. PSPICE simulation results are given to verify the theoretical analysis.**

***Index terms*– Biquad, Voltage mode, VDCC.**

## I. INTRODUCTION

It is well known that precisely tailored frequency filters can be produced with standard operational amplifiers but for audio application only. In higher frequency range it is better to use some of modern active functional blocks. Recently, various active building blocks have been introduced in [1], in which versatile and powerful building blocks are the voltage differencing current conveyor (VDCC). Continuous-time active RC filters based on the VDCC have recently found attractive considerable attention. This stems from inherent advantages of the current conveyor circuits and OTA circuits, namely low supply voltages and power, current operational mode possibility, well-developed IC topology and particularly a frequency range of the signal processing which can be higher than with circuits with the standard operational amplifiers [8]. Since their introduction, the VDCC have led to a great number of applications in signal processing circuits, especially many oscillators and filters. In case of the biquadratic (second order) filters, low-pass (LP), band-pass (BP), high-pass (HP) filters will be given in this paper. A unique systematic design procedureis presented, which is based on generalized autonomous network corresponding with suitable characteristic equations.

## II. VOLTAGE DIFFERENCING CURRENT CONVEYOR

VDCC provides electronically tunable transconductance gain in addition to transferring both current and voltage in its relevant terminals; it is very suitable for the design of various active filters or inductor simulators.The circuit symbol of the active element VDCC is shown in figure 1, where P and N are input terminals and Z, X, $W_P$ and $W_N$ are output terminals. All of the terminals exhibit high impedance, except the X terminal [2]. Ideally, the VDCC is an active block which is the combination of OTA and MO-CCII as shown in figure 2.

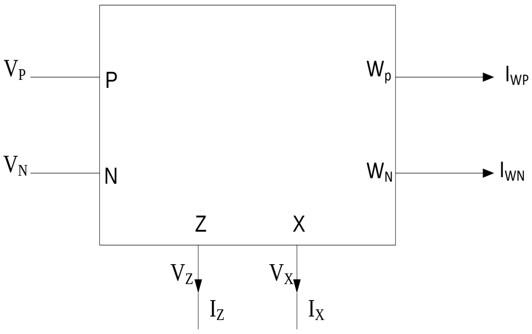

Figure 1: Block diagram of VDCC [2]

Using standard notation, the port relations of an ideal VDCC, as shown in fig. 1, can be characterized by

$$\begin{bmatrix} I_N \\ I_P \\ I_Z \\ V_X \\ I_{WP} \\ I_{WN} \end{bmatrix} = \begin{bmatrix} 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ g_m & -g_m & 0 & 0 \\ 0 & 0 & 1 & 0 \\ 0 & 0 & 0 & 1 \\ 0 & 0 & 0 & -1 \end{bmatrix} \begin{bmatrix} V_P \\ V_N \\ V_Z \\ I_X \end{bmatrix}$$

According to the above matrix equation, the first stage can be realized by a balanced transconductance amplifier to convert the difference of the input voltages ($V_P - V_N$) into the output current ($I_Z$) with transconductance gain of $g_m$ and the second stage is a current conveyor using for transferring X-terminal current to $W_P$ and $W_N$ terminals. For a balanced CMOS transconductance amplifier the parameter $g_m$ can be given as

$$g_m = \sqrt{\left(I_{B1} \mu_n C_{ox} \left(\frac{W}{L}\right)_1\right)} \quad (1)$$

Where $\mu_n$ is the mobility of the carrier for NMOS transistors, $C_{OX}$ is the gate-oxide capacitance per unit area, W is the effective channel width, L is the effective channel length and $I_{B1}$ is bias current [2].

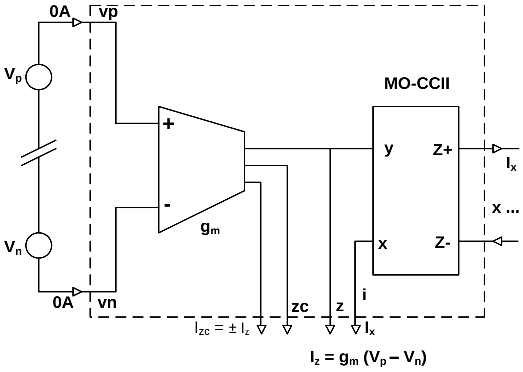

Figure 2: Internal structure of VDCC [1]

## III. SINGLE VDCC BASED $2^{ND}$ ORDER FILTER REALIZATION

Filter is an electronic circuit that performs a frequency selection function: passing signals whose frequency spectrum lies within a specified range, and stopping signals whose frequency spectrum falls outside this range. Let us consider the single VDCC biquad as given in figure 3, where the VDCC is shown connected to five passive elements. By applying routine circuit analysis, we obtain the following transfer function (assuming an ideal VDCC) –

$$\frac{V_{out}}{V_{in}} = \frac{\frac{g_m Y_1 Y_3}{Y_5}}{Y_1 Y_3 + Y_1 Y_4 + Y_2 Y_3 + Y_2 Y_4 - \frac{g_m Y_3 Y_4}{Y_5}} (2)$$

It can be seen that equation (2), expressed in terms of admittances, is able to perform various second-order voltage filtering operation, including LP, HP, BP functions.

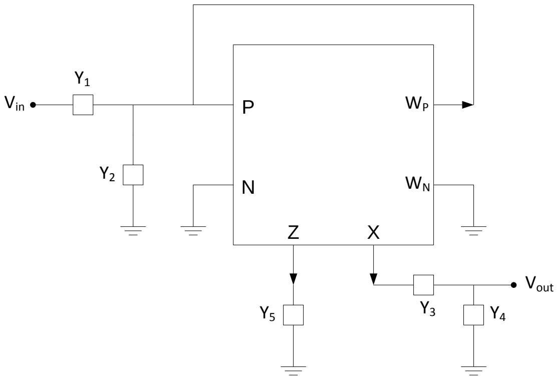

Figure 3: Configuration for the synthesis of single VDCC biquads

## IV. LOW PASS FILTER

A low pass filter is an electronic filter that passes signals with a frequency lower than a certain cutoff frequency and attenuates signals with frequencies higher than the cutoff frequency. The general form of transfer function for low pass filter is given as follow –

$$T_{lp}(s) = \frac{V_{out}}{V_i} = \frac{K\omega_0^2}{s^2 + s\frac{\omega_0}{Q} + \omega_0^2} \quad (3)$$

The value of admittances shown in fig. 3 is taken as follows –

$Y_1 = 1/R_1$, $Y_2 = sC_1$, $Y_3 = 1/R_2$, $Y_4 = sC_2$, $Y_5 = 1/R_3$ (as shown in figure 4), then the transfer function becomes

$$\frac{V_{out}}{V_{in}} = \frac{\frac{g_m R_3}{R_1 R_2 C_1 C_2}}{s^2 + s\left(\frac{1}{R_1 C_1} + \frac{1}{R_2 C_2} - \frac{g_m R_3}{R_2 C_1}\right) + \frac{1}{R_1 R_2 C_1 C_2}} (4)$$

which is the transfer function of low pass filter. Comparing equation (4) with equation (3), we can get 3dB frequency ($\omega_0$), quality factor (Q) and DC gain (K) as follows

$$\omega_0 = \sqrt{\frac{1}{R_1 R_2 C_1 C_2}}$$

$$Q = \frac{\sqrt{\frac{C_1 C_2}{R_1 R_2}}}{\frac{C_1}{R_2} + \frac{C_2}{R_1} - \frac{g_m R_3 C_2}{R_2}}$$

$$K = g_m R_3$$

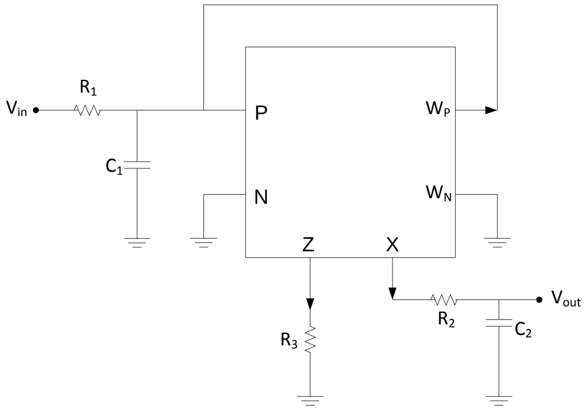

Figure 4: Circuit realization for low pass biquad filter

## V. HIGH PASS FILTER

A high pass filter is an electronic filter that passes signals with a frequency higher than a certain cutoff frequency and attenuates signals with frequencies lower than the cutoff frequency. The general form of transfer function for high pass filter is given as follow

$$T_{hp}(s) = \frac{V_{out}}{V_{in}} = \frac{Ks^2}{s^2+s\frac{\omega_0}{Q}+\omega_0^2} \quad (5)$$

The value of admittances shown in fig. 3 is taken as follows –

$Y_1 = sC_1$, $Y_2 = 1/R_1$, $Y_3 = sC_2$, $Y_4 = 1/R_2$, $Y_5 = 1/R_3$ (as shown in figure 5), then the transfer function becomes

$$\frac{V_{out}}{V_{in}} = \frac{g_m R_3 s^2}{s^2+s\left(\frac{1}{R_1C_1}+\frac{1}{R_2C_2}-\frac{g_m R_3}{R_2C_1}\right)+\frac{1}{R_1R_2C_1C_2}} \quad (6)$$

which is the transfer function of high pass filter.

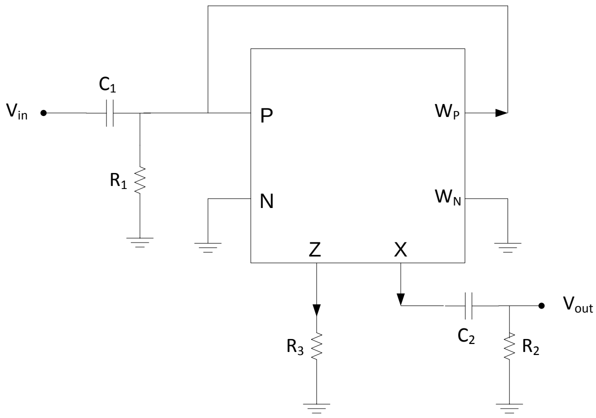

Figure 5: Circuit realization for high pass biquad filter

Comparing equation (6) with equation (5), we can get 3dB frequency ($\omega_0$), quality factor (Q) and high frequency gain (K) as follows -

$$\omega_0 = \sqrt{\frac{1}{R_1R_2C_1C_2}}$$

$$Q = \frac{\sqrt{\frac{C_1C_2}{R_1R_2}}}{\frac{C_1}{R_2}+\frac{C_2}{R_1}-\frac{g_m R_3 C_2}{R_2}}$$

$$K = g_m R_3$$

## VI. BAND PASS FILTER

A band pass filter is an electronic circuit that passes frequencies within a certain range and rejects (attenuates) frequencies outside that range. The general form of transfer function for band pass filter is given as follows –

$$T_{bp}(s) = \frac{V_{bp}}{V_i} = \frac{-K\omega_0 s}{s^2+s\frac{\omega_0}{Q}+\omega_0^2} \quad (7)$$

The value of admittances shown in fig. 3 is taken as follows –

$Y_1 = sC_1$, $Y_2 = R_1$, $Y_3 = 1/R_2$, $Y_4 = sC_2$, $Y_5 = 1/R_3$ (as shown in figure 6), then the transfer function becomes

$$\frac{V_{out}}{V_{in}} = \frac{\frac{g_m R_3 s}{R_2C_2}}{s^2+s\left(\frac{1}{R_1C_1}+\frac{1}{R_2C_2}-\frac{g_m R_3}{R_2C_1}\right)+\frac{1}{R_1R_2C_1C_2}} \quad (8)$$

which is the transfer function of band pass filter.

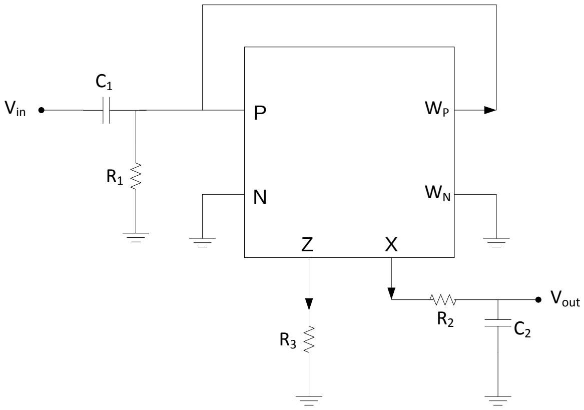

Figure 6: First circuit realization for band pass biquad filter

Similarly, if we take the value of admittances shown in figure 3 is taken as follows –

$Y_1 = 1/R_1$, $Y_2 = sC_1$, $Y_3 = sC_2$, $Y_4 = 1/R_2$, $Y_5 = 1/R_3$ (as shown in figure 7), then the transfer function becomes

$$\frac{V_{out}}{V_{in}}=\frac{\frac{g_m R_3 s}{R_1C_1}}{s^2+s\left(\frac{1}{R_1C_1}+\frac{1}{R_2C_2}-\frac{g_m R_3}{R_2C_1}\right)+\frac{1}{R_1R_2C_1C_2}} \quad (9)$$

which is also the transfer function of band pass filter.

Comparing equation (8) with equation (7), we can get center frequency ($\omega_0$), quality factor (Q) and center frequency gain (-KQ) as follows

$$\omega_0=\sqrt{\frac{1}{R_1R_2C_1C_2}}$$

$$Q=\frac{\sqrt{\frac{C_1C_2}{R_1R_2}}}{\frac{C_1}{R_2}+\frac{C_2}{R_1}-\frac{g_mR_3C_2}{R_2}}$$

$$(\text{-KQ})=\frac{\frac{g_mR_3C_1}{R_2}}{\frac{C_1}{R_2}+\frac{C_2}{R_1}-\frac{g_mR_3C_2}{R_2}}$$

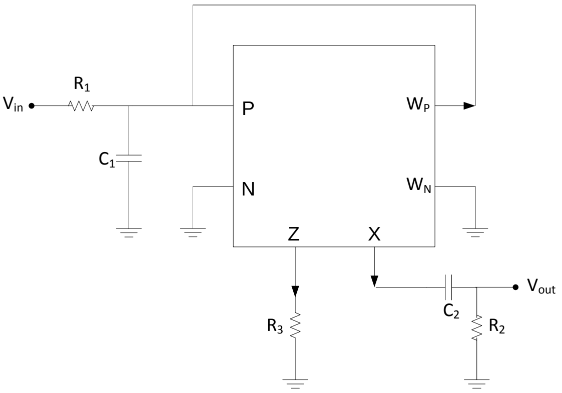

Figure 7: Second circuit realization for band pass biquad filter

## VII. SIMULATION RESULTS

Simulation was performed using a CMOS realization of VDCC given in [2]. To prove the theoretical validity of single VDCC biquad filter of figure 4, 5 and 6 for pole frequency ($f_0$) = 5MHz and Q=0.707, the filters were simulated with PSPICE program. The passive elements are selected as $R_1$ = 2.25KΩ, $R_2$ = 4.5KΩ, $R_3$ = 3.67KΩ and $C_1$ = $C_2$ = 10pF. The bias currents are selected as $I_{B1}$ = 50μA ($g_m$ = 273μA/V) and $I_{B2}$ = 100μA in [2]. The LPF, HPF and BPF frequency responses and time responses are shown in figure 8 to figure 13 respectively. The simulated center frequency of BPF was measured as 4.79MHz. 3dB (cut-off) frequency of LPF and HPF were measured as 5MHz and 4.56MHz respectively.

The sensitivity of $\omega_0$ is given as follows

$$S^{\omega_0}_{C_1,C_2,R_1,R_2}=-\frac{1}{2}$$

To test the input dynamic range of the second filters, a sinusoidal signal of $f_0$ = 5MHz with different amplitudes are applied to the input. The THD of the output signal versus amplitude of the input signal is shown in figure 14. The result shows that for input signal with amplitude lower than 300mV peak-to-peak, the THD remains below 2% which confirm the practical utility of the proposed circuit.

By PSPICE simulation, the total power dissipation of the single VDCC biquad was calculated as 0.845 mW which is acceptable to design an IC implementation.

## VIII. CONCLUSION

This paper covers the realization of single VDCC based second order filters such as low pass filter, high pass filter and band pass filter. The single VDCC based voltage mode second order filters have been proposed and simulated which verified the usability of VDCC in the analog signal processing among the novel active building blocks. The time responses and frequency responses for these filters have been shown which was simulated using PSPICE.

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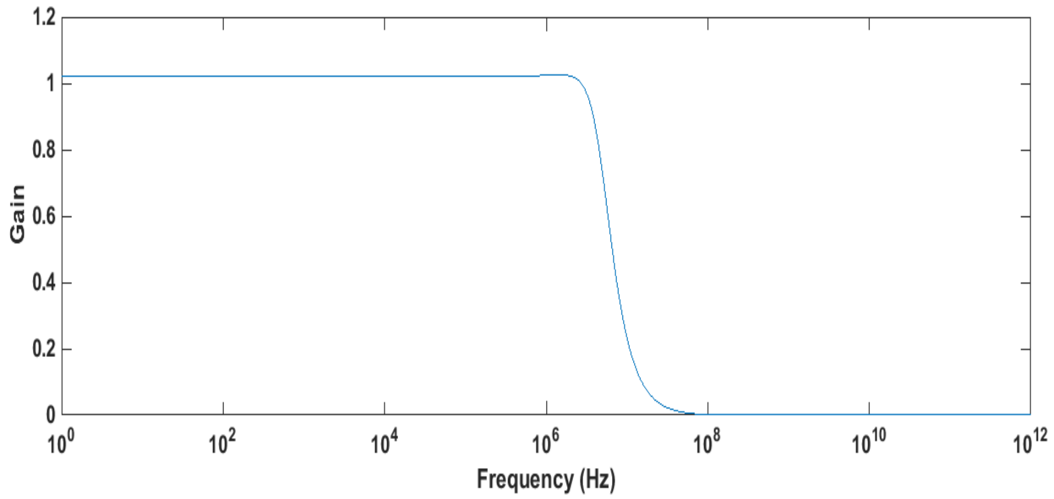

Figure 8: Frequency response of low pass filter shown in figure 4

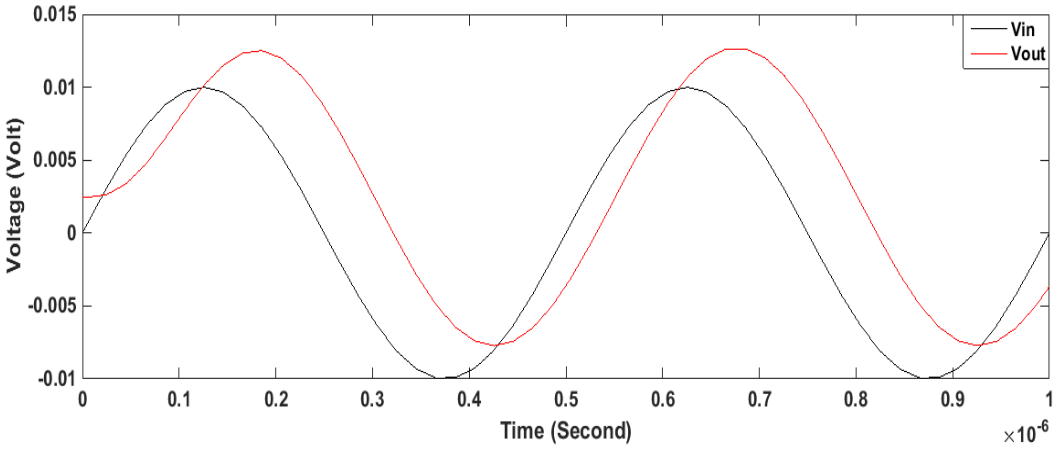

Figure 9: Time response of low pass filter shown in figure 4

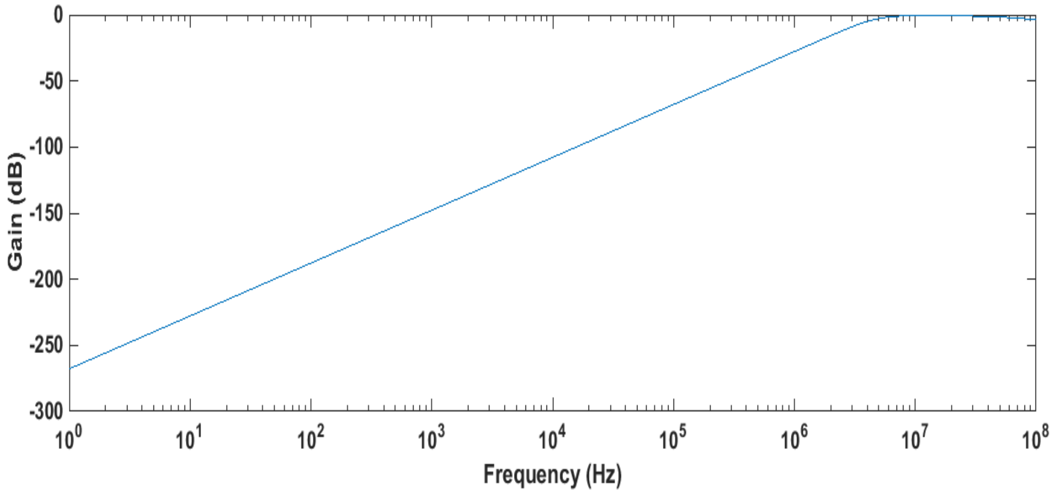

Figure 10: Frequency response of high pass filter shown in figure 5

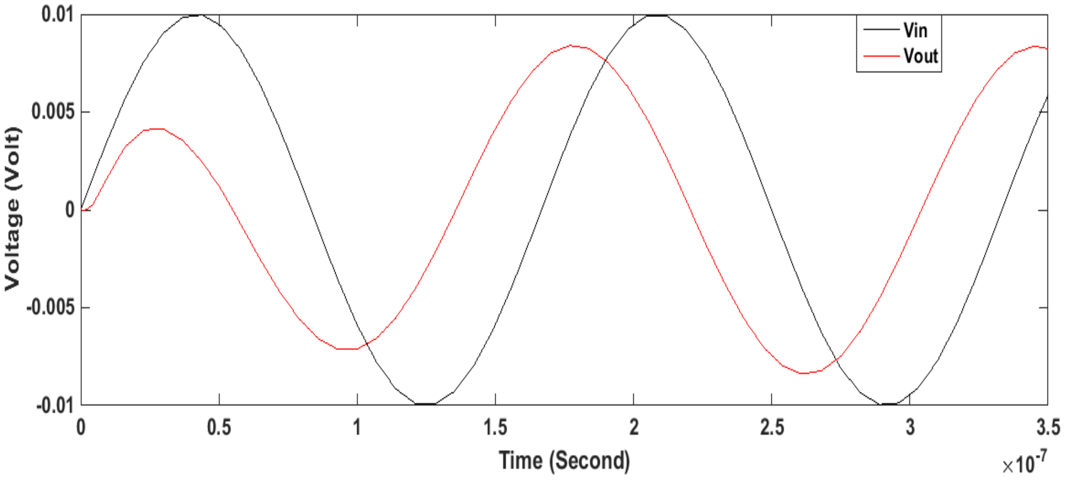

Figure 11: Time response of high pass filter shown in figure 5

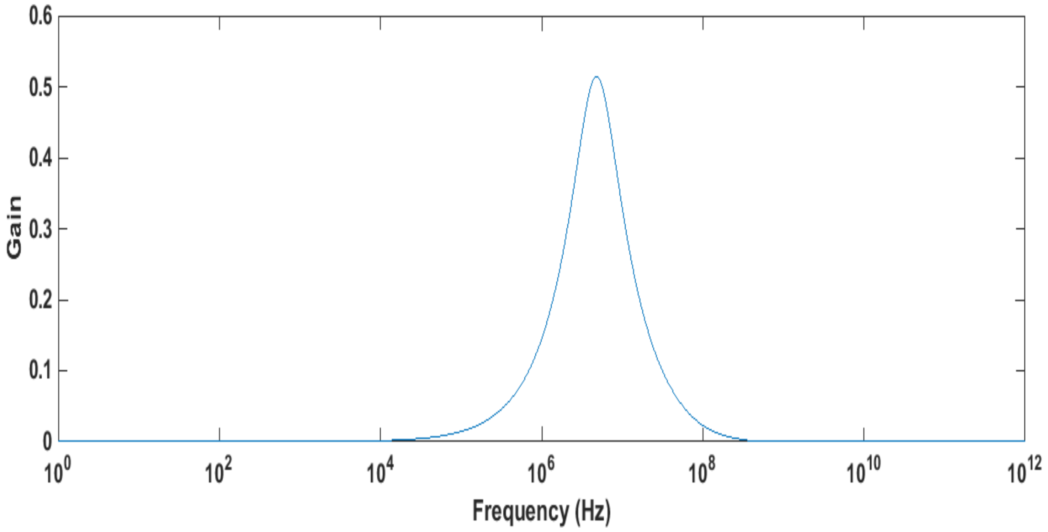

Figure 12: Frequency response of band pass filter shown in figure 6

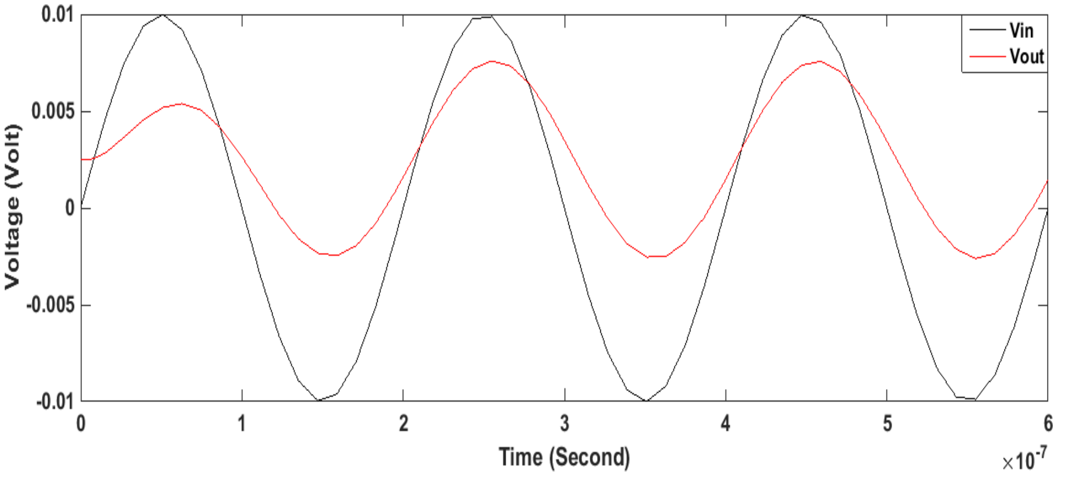

Figure 13: Time response of band pass filter shown in figure 6

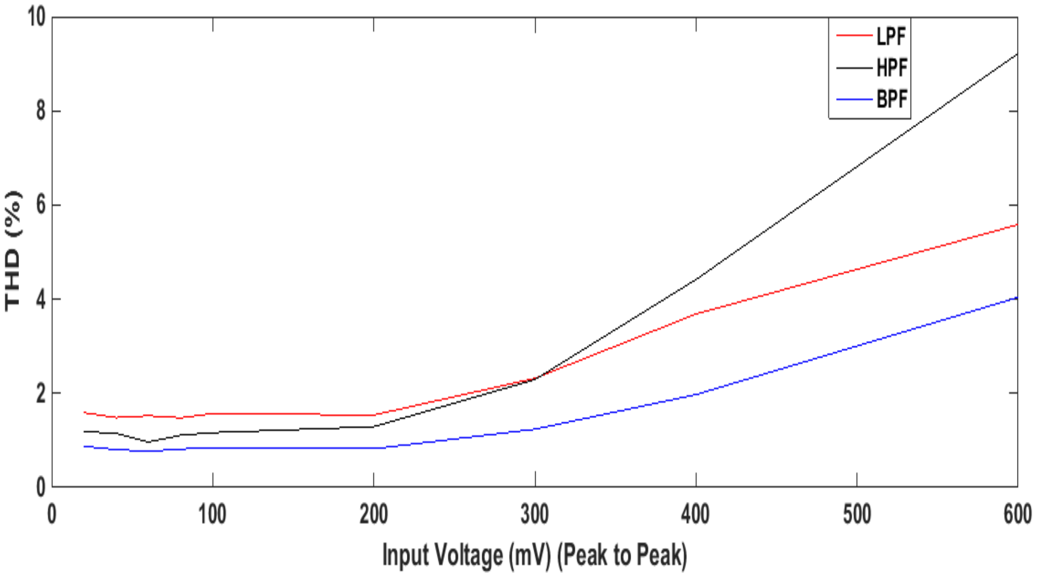

Figure 14: Dependence of output voltage harmonic distortion on input voltage amplitude of low pass, high pass and band pass filter