# Single VDTA Based Multifunction Trans-admittance mode Biquad Filter

Chandra Shankar [#1] , Sajai Vir Singh[*2]
[#]Dept. of Electronics Engineering ,
[#]JSS Academy of Technical Education Noida, 201301, INDIA
Dept. of Electronics and Communication Engineering
[*]Jaypee Institute of Information Technology, Noida, 201304, INDIA
[1]porwalchandra@gmail.com
[2]sajaivir75@gmail.com

**Abstract— This paper proposed a multifunction biquad filter topology using only single VDTA as active element. In addition, it uses one grounded resistor, two capacitors and capable of realizing trans-admittance mode low pass (LP), high pass (HP), band pass (BP), and band reject (BR) biquad filtering response, simultaneously, by the use of single voltage input signal only. Apart from this, the proposed circuit has many excellent features such as, low active and passive sensitivity, low power consumption, canonical structure and electronic tunability of pole frequency and quality factor. To justify the theoretical analysis, the proposed circuit is simulated using PSPICE in 0.18µm CMOS technology from TSMC.**

**Keyword-** Biquad, TAM ,VDTA, Filter, Analog signal processing, Electronic tunable, multifunction.

## I. INTRODUCTION

In now a days current-mode active elements are being preferably used in the designing of analog filter and other analog circuits also due to offering many advantages such as wider signal bandwidth, low power consumption, larger dynamic range, better linearity, simple circuitry and requirement of lesser on chip area [1]-[27] over voltage-mode counterpart (such as op-amp). One type of analog filter named as trans-admittance mode filer which uses voltage signal as input and provide current signal in the form of output and hence, it can act as interface filter circuits connecting voltage-mode to current-mode in number of applications such as receiver base band blocks of modern radio system where conversion of voltage signal to current signal is required [16]-[18],[25].

In available literature, the numbers of papers proposing biquad filtering topology operating in trans-admittance-mode have been found which are further classified either as multi input single output (MISO) [23]-[25] or single input multi output (SIMO) [15]-[22],[27] on the basis of number of input and output signals involved in the circuits. However, it is also noted that MISO structure offers the disadvantage over SIMO structure in the sense it requires multiple copies of the input signals which further requires additional hardware to implement multiple copies of input signals and realizes only one filtering function at a time. On the other hand, SIMO require only one input signal and realizes more than one filtering functions simultaneously. Table.1 is showing the detailed comparative study of SIMO TAM biquad filter [15]-[22],[27] which can conclude that most of the circuits realizes only three filtering functions simultaneously and except [27], uses more than one active element in the filtering functions realization. Few of them employ more number of passive elements [15]-[16] and does not provide the feature of electronic tunability of pole frequency ($\omega_0$), quality factor ($Q_0$) too [15]-[16],[18],[21].

After looking the facts from above discussion, we have proposed a new single input four output trans-admittance-mode biquad filter by the use of only single VDTA, and three passive elements (one resistor and two capacitors) and can realize LP, HP, BP, BR filtering functions, simultaneously. Moreover, $\omega_0$ can also be tuned electronically independent of $Q_0$. The circuit possesses low active and passive sensitivity. The proposed circuit has been simulated on PSPICE simulation tools (ORCAD 16.3) to justify its performance.

## II. VDTA DESCRIPTION

VDTA is relatively a new proposed active element and has been paid significant attention in current-mode analog signal processing applications due to having its silent features such as dual electronic tuning ability through two transconductance parameters, each input and output terminals in VDTA having high impedance and its flexibility to be operated in both current as well as voltage-modes [24]-[27]. VDTA was first introduced by A. Yesil, F. Kacar and H. Kuntman in 2011 [26]. The block diagram of VDTA is shown in Fig.1. The relationship of voltage and current between various input and output terminals of VDTA can be characterized by following matrix equation

$$\begin{bmatrix} I_z \\ I_{X\pm} \end{bmatrix} = \begin{bmatrix} g_{m1} & -g_{m1} & 0 \\ 0 & 0 & \pm g_{m2} \end{bmatrix} \begin{bmatrix} V_P \\ V_N \\ V_Z \end{bmatrix} \quad (1)$$

Here, $g_{m1}$ and $g_{m2}$ are transconductance parameters of first and second stage of VDTA, respectively whose value are controlled by biasing current $I_{B1}$ and $I_{B2}$ of VDTA, respectively. A CMOS transistors implementation of VDTA is also shown in Fig.2. For this realization, mathematical expression of $g_{m1}$ and $g_{m2}$ can be derived [25] as.

$$g_{m1} = \sqrt{I_{B1}\mu_n C_{ox}(\frac{W}{L})_{M1,M2}} \quad (2)$$

$$g_{m2} = \sqrt{I_{B2}\mu_n C_{ox}(\frac{W}{L})_{M5,M6}} \quad (3)$$

Where $\mu_n$ is the effective carrier mobility of MOS transistor and $C_{ox}$ is the gate-oxide capacitance per unit area. $(W/L)_{M1,\ M2}$ and $(W/L)_{M5,\ M6}$ are the aspect ratio of M1, M2 and M5, M6 NMOS transistor pairs, respectively.

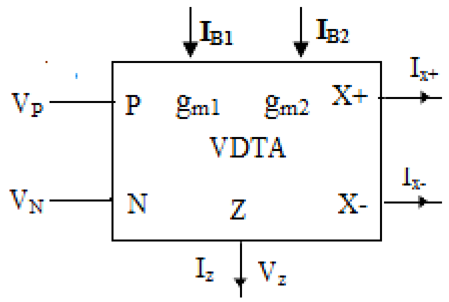


Fig. 1. Block diagram of VDTA

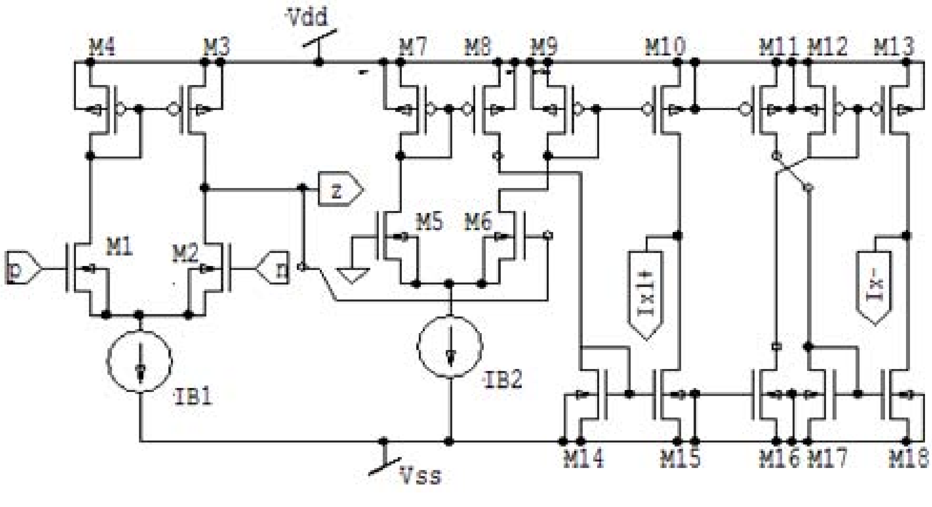


Fig. 2. Implementation of VDTA using CMOS transistors

TABLE I. A COMPARATIVE STUDY OF VARIOUS TAM BIQUAD FILTER IN SINGLE INPUT MULTIPLE OUTPUT MODE

| **References → Features ↓** | **[15]** | **[16]** | **[17]** | **[18]** | **[19]** | **[20]** | **[21]** | **[22]** | **[27]** | **Proposed** |
|---|---|---|---|---|---|---|---|---|---|---|
| **Nos & types of Active element's.** | 3-PFTFN | 3- CCII | 2-CCCCTA | 3-CCCII | 4- OTA | 4-OTA | 5-DCC-DVCC | 2-VDTA | 1-VDTA | 1-VDTA |
| **Nos. & types of Passive element's** | 3-R , 2-C | 3-R ,2-C | 3-C | 2-C | 2-C | 2-C | 2-C, 1-R | 2-C | 1-R, 2-C | 1-R, 2-C |
| **No. of Floating passive element** | 4(2-R+ 2-C) | 4 (2-R+ 2-C) | NIL | NIL | NIL | NIL | 3(2-R+ 1-C) | NIL | 1(1-R) | 1(1-C) |
| **Functions Realized** | LP, HP, BP | LP, HP BP | LP, HP BP | LP, HP BP, BR | LP, HP BP | LP, HP BP | LP, HP BP | LP, HP BP | HP ,BP | LP, HP BP, BR |
| **Electronic tunability feature** | NO | NO | YES | NO | YES | YES | NO | YES | YES | YES |

## III. PROPOSED TAM FILTER AND ITS ANALYSIS

Fig.3 shows the proposed TAM filter configuration which employs one VDTA, two capacitances ($C_1$ and $C_2$) with one of the capacitor ($C_1$) being grounded and one grounded resistor (R). The following transfer functions described in (4)–(7) can be obtained after analysing the proposed circuit in Fig.3.

$$\frac{I_{LP}}{V_{in}} = -\frac{g_{m1}g_{m2}/C_1C_2R}{D(s)} \quad (4)$$

$$\frac{I_{BP}}{V_{in}} = \frac{sg_{m1}/C_1R}{D(s)} \quad (5)$$

$$\frac{I_{HP}}{V_{in}} = \frac{s^2/R}{D(s)} \quad (6)$$

$$\frac{I_{BR}}{V_{in}} = \frac{\left(s^2 + g_{m1}g_{m2}V_{in}/C_1C_2\right)\frac{1}{R}}{D(s)} \quad (7)$$

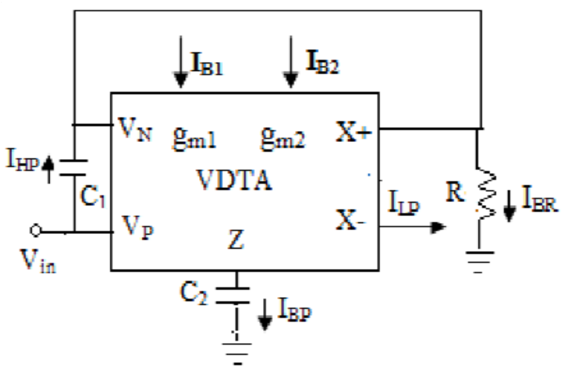


Fig. 3. Proposed TAM Biquad filter

where

$$D(s) = \left[ s^2 + \frac{s}{C_1 R} + \frac{g_{m1} g_{m2}}{C_1 C_2} \right] \tag{8}$$

It can be noted that from (4)-(7), the proposed topology as shown in Fig.3 is capable of realizing trans-admittance-mode LP, BP, HP and BR filtering responses. The characterized parameters of the proposed filter like pole frequency ($\omega_0$), quality factor ($Q_0$) and bandwidth (BW) can be derived as

$$\omega_0 = \sqrt{\frac{g_{m1} g_{m2}}{C_1 C_2}} \tag{9}$$

$$Q_0 = R \sqrt{\frac{C_1 g_{m1} g_{m2}}{C_2}} \tag{10}$$

$$BW = \frac{1}{C_1 R} \tag{11}$$

It is clear from (9)-(10) that $\omega_0$ can be tuned electronically independent of $Q_0$ by maintaining the conditions $g_{m1} = g_{m2} = 1/R$.

## IV. Non Ideal errors and Sensitivity Analysis

In this section, the effect of non-ideal errors of VDTA occurring due to mismatching in MOS transistors in CMOS implementation on the the performance of the proposed circuit is considered. By taking non-ideal errors of VDTA into consideration, the current and voltage relation between various ports of VDTA can be rewritten as:

$$\begin{bmatrix} I_z \\ I_{X\pm} \end{bmatrix} = \begin{bmatrix} \beta_1 g_{m1} & -\beta_1 g_{m1} & 0 \\ 0 & 0 & \pm \beta_2 g_{m2} \end{bmatrix} \begin{bmatrix} V_P \\ V_N \\ V_Z \end{bmatrix} \tag{12}$$

Where $\beta_1$ and $\beta_2$ are named as the tracking error for the first and second stages of VDTA. Now, by considering non-ideal errors discussed in (12), the proposed circuit of Fig.3 is further reanalyse to obtain various TAM transfer functions and characteristic parameters. The resultant expressions are derived as

$$\frac{I_{LP}}{V_{in}} = -\frac{\beta_1 \beta_2 g_{m1} g_{m2} / C_1 C_2 R}{D(s)} \tag{13}$$

$$\frac{I_{BP}}{V_{in}} = \frac{s \beta_1 g_{m1} / C_1 R}{D(s)} \tag{14}$$

$$\frac{I_{HP}}{V_{in}} = \frac{s^2 / R}{D(s)} \tag{15}$$

$$\frac{I_{BR}}{V_{in}} = \frac{\left( S^2 + \beta_1 \beta_2 g_{m1} g_{m2} V_{in} / C_1 C_2 \right) \frac{1}{R}}{D(s)} \tag{16}$$

Where

$$D(s) = \left[ s^2 + \frac{s}{C_1 R} + \frac{\beta_1 \beta_2 g_{m1} g_{m2}}{C_1 C_2} \right] \tag{17}$$

Expression of filter parameters are also changed as

$$\omega_0 = \sqrt{\frac{\beta_1\beta_2 g_{m1} g_{m2}}{C_1 C_2}} \tag{18}$$

$$Q_0 = R\sqrt{\frac{\beta_1\beta_2 C_1 g_{m1} g_{m2}}{C_2}} \tag{19}$$

$$BW = \frac{1}{C_1 R} \tag{20}$$

It can be noted that that filter parameters such as pass band gain, $\omega_0$, and $Q_0$ may deviate slightly due to effect of tracking errors of VDTAs. But the effect of these changes can be minimized by selecting proper electronic controllable trans-conductance parameters.

The active and passive sensitivities of $\omega_0$ and $Q_0$ for proposed filter in Fig.3 are also calculated and described in following set of equations.

$$S^{\omega_0}_{\beta_1,\beta_2} = \frac{1}{2}, S^{\omega_0}_{g_{m1},g_{m2}} = \frac{1}{2} \tag{21}$$

$$S^{\omega_0}_{C_1,C_2} = -\frac{1}{2} \tag{22}$$

$$S^{Q_0}_{\beta_1,\beta_2} = \frac{1}{2}, S^{Q_0}_{g_{m1},g_{m2}} = \frac{1}{2} \tag{23}$$

$$S^{Q_0}_{C_1} = \frac{1}{2}, S^{Q_0}_{C_2} = -\frac{1}{2} \tag{24}$$

$$S^{Q_0}_{R} = 1 \tag{25}$$

Above results explained that all sensitivities of $\omega_0$ and $Q_0$ are low and less than unity in magnitude.

## V. SIMULATION RESULT

In order to justify the theoretical discussion in previous sections, various PSPICE simulations of the proposed circuit were performed using CMOS realization of VDTA in 0.18µm CMOS technology from TSMC [24]. The power supply voltage and biasing currents were taken as $V_{DD} = -V_{SS} = 1.1$V and $I_{B1} = I_{B2} = 58$µA ($g_{m1} = g_{m2} \approx 495.0$µA/V). The passive component values were also selected as R = 2.05KΩ, $C_1 = C_2 = 20$pF. The aspect ratios of various transistors were determined as given in Table II. Fig.4 shows the ideal and PSPICE simulated TAM gain responses of LP, HP, BP, and BR filtering functions of the proposed biquad filter. It is clear from Fig.4 that ideal and PSPICE simulated results are almost same and the simulated value of the pole frequency was obtained as 3.94 MHz which is nearly same as the calculated value of 3.95 MHz.

An electronically tuning behaviour of the proposed circuit in term of pole frequency ($f_0$) variation independent of $Q_0$ was also shown in Fig.5 which was obtained by simulating various TAM BP filtering functions at constant $Q_0$. To see the transient behaviour of the circuit, it was further simulated for LP output by applying a sinusoidal input voltage signal having peak to peak amplitude of 50mV at frequency of 500 KHz. Fig.6 shows the simulated result of the transient response of LP output which was obtained across 2 KΩ load resistor connected across the LP filtering response. In addition, Fig.7 shows the total harmonic distortion (THD) results for LP responses which can clearly conclude that the THD values of the proposed filter for LP voltage output across resistor was found in the range of .644 to 3.06% for sinusoidal input voltage signal of constant frequency of 500 KHz and variable peak to peak amplitude of 20mV to 180mV. Furthermore, Monte-Carlo analysis was also carried out to observe the tolerance variation of passive components. The TAM BP output with 10% Gaussian deviation in $C_1 = C_2 = 20$pF has been simulated. The simulation was performed concurrently for 100 runs. Fig.8 shows the corresponding histograms. From these plots the simulated standard deviation and mean were found to be 17.80KHz and 3.98MHz respectively, which demonstrate that capacitive variation do not disturb the performance of the circuit . Lastly, the effect of noise was observed by analysing noise spectral density on BP output of proposed trans-admittance mode filter. The obtained noise spectral density is very small and its maximum value is equal to 21.19 nV/$Hz^{1/2}$, as shown in Fig.9.

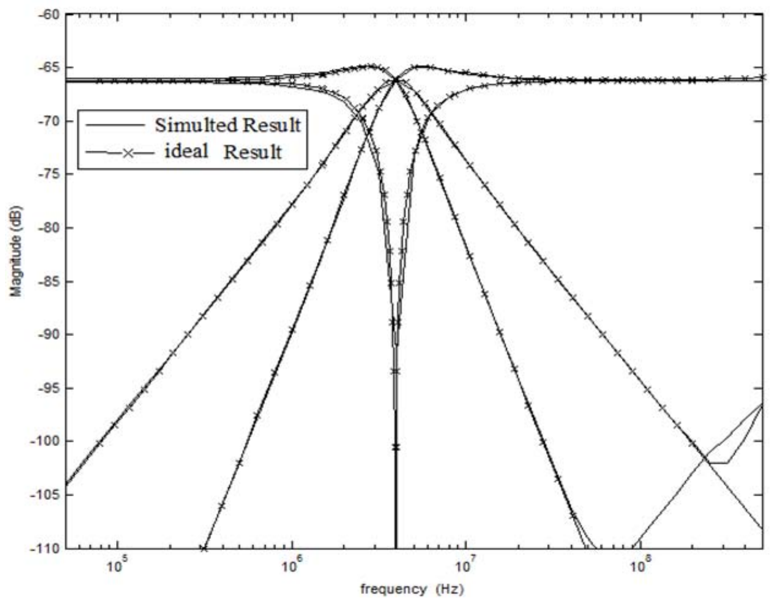


Fig. 4. Ideal and PSPICE simulated response of LP,HP,BP,BR TAM Filter

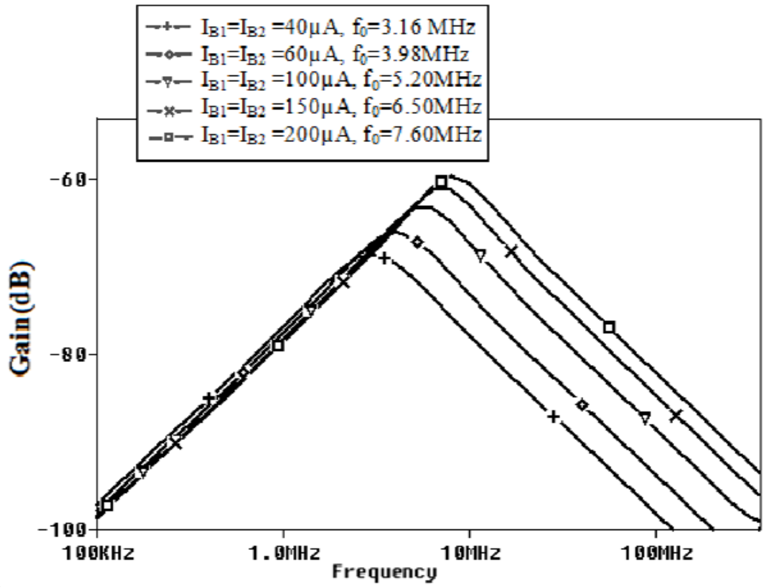


Fig. 5. Electronic tuning feature of $\omega_0$ independent of $Q_0$

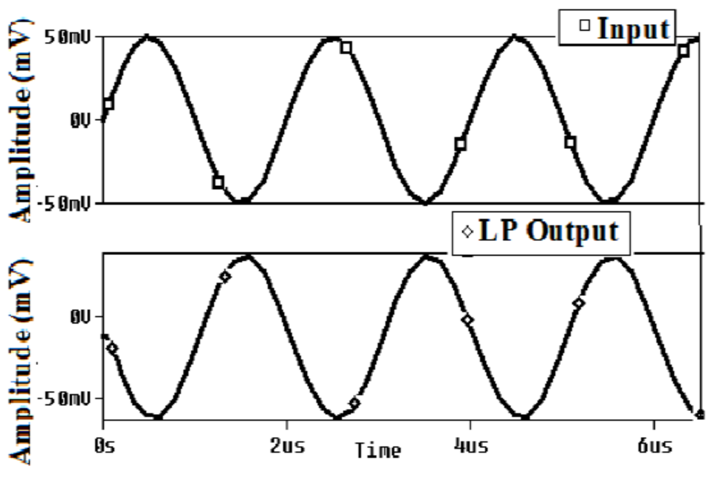


Fig. 6. Transient response of LP filter

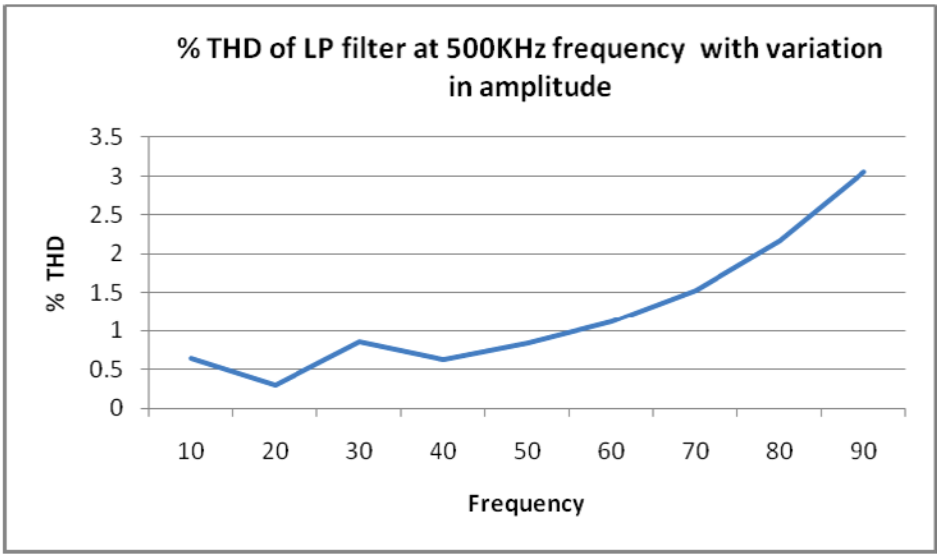


Fig. 7. % THD of LP filter

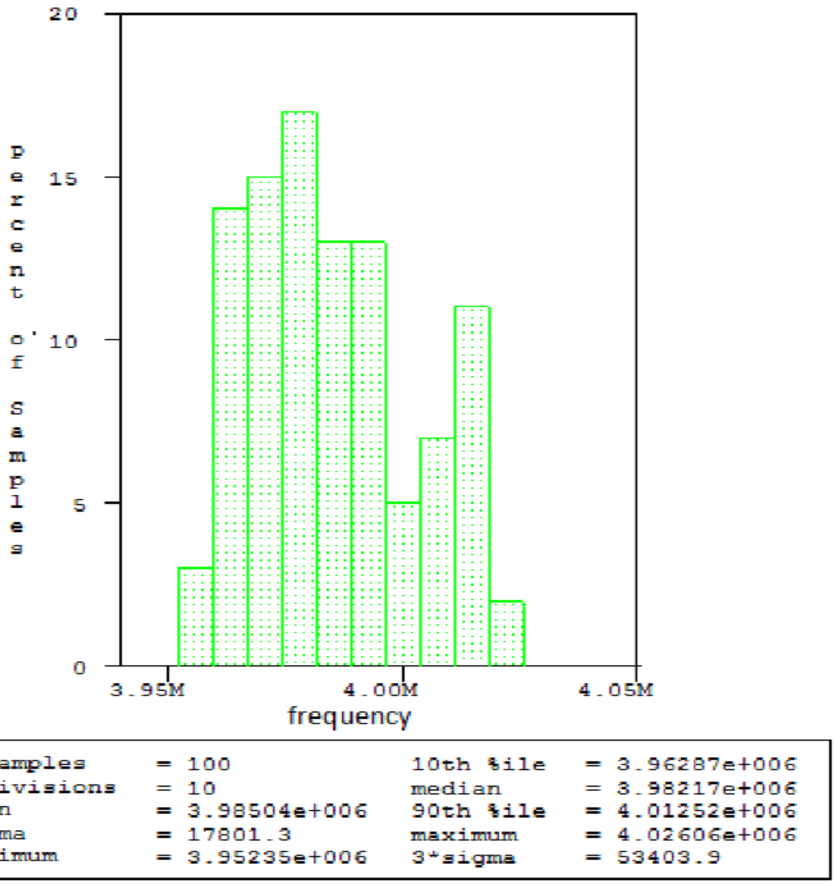


Fig. 8. Monte Carlo simulation results

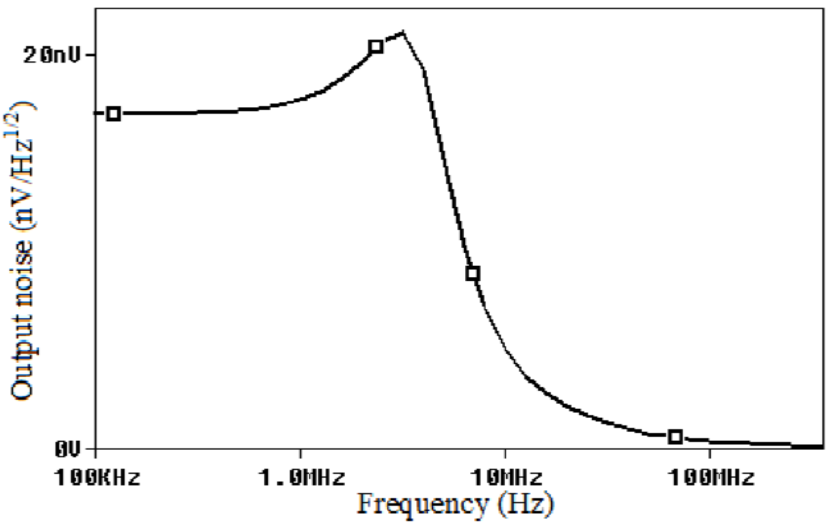


Fig. 9. Output noise density of band pass filter

TABLE II. TRANSISTORS ASPECT RATIOS OF THE CIRCUIT SHOWN IN FIG.2

| **Transistor** | **W(μm)/L(μm)** |
|---|---|
| M1,M2,M5,M6 | 8.28/.36 |
| M3,M4 | 14.4/.36 |
| M7-M13 | 4.32/.36 |
| M14-M18 | 3.6/.36 |

## VI. CONCLUSION

In this paper, a new biquad filter circuit is realized using single VDTA, one grounded resistors and two capacitors with one of the capacitor being grounded which is competent of simultaneously realizing trans-admittance-mode LP, BP, HP, and BR filtering responses by the use of single voltage input signal. Apart from these features, the proposed circuit offers the following other features also.

i. Use of minimum number of active element (only single) to realize four filtering responses simultaneously in TAM.
ii. Use of one grounded resistor only.
iii. Low active and passive sensitivities.
iv. Low power dissipation.
v. Filter parameters such as $\omega_0$ and $Q_0$ are electronically tuned.
vi. Providing canonical structure as having only two capacitors.

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## AUTHOR PROFILE

Chandra Shankar was born in Etawah, India. He received his B.Tech degree in Electronics and Communication from GLAITM, Mathura (India), M.Tech. degree from CDAC, Mohali (India) and Pursuing Ph.D from Jaypee Institute of Information Technology, Noida (India). He is working as an Asst. Professor in the Dept. of Electronics of JSS Academy of Technical Education Noida, (India). His area of interest is Analog Signal Processing and Circuit Designing.

Dr. Sajai Vir Singh was born in Agra, India. He received his B.E. degree in Electronics and Telecommunication from NIT Silchar, Assam (India), M.E. degree from MNIT Jaipur, Rajasthan (India) and Ph.D. degree) from Uttarakhand Technical University. He is currently working as Assistant Professor (Sr. Grade) in the Department of Electronics and Communication Engineering of Jaypee Institute of Information Technology, Noida (India) and has been engaged in teaching and design of courses related to the design and synthesis of Analog and Digital Electronic Circuits.