Table 1

Ref. No.	Year of Publication	Order filter	Number of Devices used		Number of		Filtering function implemented	Independent tunability of filter parameters
			Active	Passive	Input	output		
2	1980	2nd	2OA	4R	1	1	BP	yes
3	1983	2nd and VM	1	1C, 4R	1	1	LP	yes
4	1986	New Active-R filter using 2nd –order blocks for realization of higher-order filters (nth-order) is presented in this paper						
5	1991	FDNR and FDNC techniques are used for realization of higher-order filter.						
6	1992	2nd and CM	2	7R	1	1	HP	yes
7	1992	2nd and CM	1	1C, 2R	1	2	HP and BP	yes
8	1993	2nd and CM	2	5R	1	1	LP	yes
9	1993	2nd and CM	1	2R, 1C	1	3	LP, BP and HP	
10	1993	2nd and CM	1	3R, 1C	1	2	BP and LP	yes
11	1995	2nd and CM	3	11R	1	3	LP,BP, HP,BS and AP	yes
12	1996	2nd and CM	2	3MO-OTA	1	1	All filtering functions	yes
13	1997	2nd and CM	2	5OTA	3	1	All filtering functions, by choosing inputs	yes
14	2000	2nd and CM	2	3MO-OTA	1	1	All filtering functions	yes
15	2001	2nd and VM	2	5OTA	5	3	All filtering functions, by choosing inputs	yes
16	2002	2nd and CM and VM The circuit implements higher order filter and second-order filter is presented as an example						
17	2002	Ist and CM	1	2OTA	1	1	AP	
18	2002	2nd and CM	2OA	5OTA	1	4	All filtering function	No, tunability , except gain
19	2002	2nd and MM VM and CM	2 OA	15 OTA	1VM 1CM	3VM 3CM	All filtering function	yes
20	2003	3rd and VM	3OA	4R	1	3	LP, BP and HP	yes
21	2003	2nd and CM	2OA	3 CCCII	1	3	All filtering functions	yes
22	2003	Inductance simulation using 1 OA and CCCII						
23	2003	2nd and CM and VM	2OA	2 OTA for VM and 5 OTA for CM	1 1	3 for VM 4 for CM	LP, BP and HP for VM And LP BP HP and BS	No Gain of CM is independently tunable
24	2003	2nd CM and V M	3 OA	8 OTAs	1	1	All filtering functions by satisfying conditions in terms of g_m of OTA	yes
25	2003	2nd and CM	2 OA	3 OTA	1	3	All filtering functions	yes
26	2004	2nd and CM, VM	2 OA	4 OTA	4	1	All filtering functions	yes
27	2005	2nd and TIM	2 OA	4 OTA	1	3	LP, BP and HP	yes
28	2005	2nd and TAM	1 OA	2R, 1C	1	2	LP and BP	yes
29	2006	2nd and VM	2 OA	4 OTA	2	3	LP, BP and HP	yes
30	2006	2nd and CM	2 OA	2 MO-OTA	3	4	LP, BP HP and HP	no
31	2007	2nd and VM	1 OA	2R, 1C	3	1	All filtering functions	yes
32	2008	2nd and CM	2 OA	3OTA,3R	3	1	All filtering functions	no
33	2011	2nd and VM	OA	6 MO-OTA	1	5	All filtering functions	yes
34	2015	1st and CM	1 OA	2 OTA	1	1	AP	yes
35	2017	1st and CM	1 OA	2 MO-OTA	1	1	LP	yes
36	2021	2nd and 8th	2 and 8	6 R and 24R	1	1	BP	yes

FDNR stands for frequency dependent negative resistance
FDNC stands for frequency dependent negative conductance
CM stands for Current-mode
VM stands for Voltage-mode
TIM stands for Transimpedance mode
TAM stands for Transadmittance-mode
MO-OTA stands for multiple output operational transconductance amplifier
OA stands for Operational amplifier
LP lowpass, BP bandpass HP highpass BS bandstop and AP allpass

simultaneously. The pole frequency is electronically tunable through bias current of transconductance gain of VDTA. The circuit is highly suitable for integrated circuit (IC) implementation.

2 Circuit Description

Voltage Operational Amplifier or simply operational amplifier (OA) is a voltage controlled voltage source (VCVS) and is described by the port relation:

$$V_o(s) = A(s)\left[V^+(s) - V^-(s)\right] \qquad \dots (1)$$

V^+ and V^- are non-inverting and inverting terminals. A(s) is the open-loop gain of OA and is of our concern. A(s) being a function of frequency that is by increasing frequency, the gain decreases. The open-loop gain of OA which is frequency-dependent is assumed to be of the form,

$$A(s) = \frac{B_i \sum_{j=1}^{m} \omega_i}{s \prod_{j=1}^{m} (s + \omega_j)} \approx \frac{B}{s}\left(1 - \prod_{j=1}^{m} \tau_j s\right) \qquad \dots (2)$$

For first-order approximation the above equation reduces to,

$$A(s) = \frac{A_0}{1 + s\tau_1} = \frac{A_0\omega_0}{s + \omega_0} \approx \frac{B}{s} \quad \text{for } s >> \omega_0 \qquad \dots (3)$$

where A_0 is the open loop dc gain, ω_0 is the 3db-frequency of the OA and is given by $\omega_0 = \dfrac{1}{\tau_1}$ and B is the gain bandwidth product. It follows from Eq. (2) that the OA acts as an ideal integrator neglecting the effects of 3-db frequency.

VDTA has two input voltage (V_P ,V_N) which is transferred to the current at the terminal Z by the first transconductance gain, and the voltage drop at the terminal Z is transferred to the current at the terminals X^+ and X^- by second transconductance gain. The circuit symbol of VDTA is shown in Fig. 1. The port relation of VDTA is given by

$$\begin{bmatrix} I_Z \\ I_{X+} \\ I_{X-} \end{bmatrix} = \begin{bmatrix} g_{m1} & -g_{m1} & 0 \\ 0 & 0 & g_{m2} \\ 0 & 0 & -g_{m2} \end{bmatrix} \begin{bmatrix} V_p \\ V_n \\ V_z \end{bmatrix} \qquad \dots (4)$$

where $g_{mi} = \sqrt{I_{Bi}\mu_n C_{ox}\left(\frac{W}{L}\right)_i}$ i = 1 $\qquad \dots (5)$

Both transconductance gains (g_m) are electronically controllable by external bias currents I_B.

Active-only proposed filter using OA and VDTA is shown in Fig. 2. The routine analysis of the circuit using pole model of OA given by equation (3) and port relation of VDTA given by equation (4) gives the following transfer function.

$$\frac{V_{LP}}{V_{in}} = \frac{B^{g_1}/g_2}{s + B^{g_1}/g_2} \qquad \dots (6)$$

$$\frac{V_{HP}}{V_{in}} = \frac{s^{g_1}/g_2}{s + B^{g_1}/g_2} \qquad \dots (7)$$

The natural angular frequency ω_0 is given by

$$\omega_0 = B^{g_1}/g_2$$

$$H_{HP} = {g_1}/{g_2}$$

Fig. 1 — Circuit symbol of VDTA.

Fig. 2 — Proposed LP and HP filter.

It is clear that the frequency is electronically tunable through bias current of transconductance gains g_m of VDTA.

3 Non-idealities of OA

If the open-loop gain of OA is assumed to be $A(s) = \frac{B}{s}[1-s(\tau_2+\tau_3)]$ where $\tau_2 = \frac{1}{\omega_2}$ and $\tau_3 = \frac{1}{\omega_3}$ are second and third pole in the frequency range of interest, then the transfer function is given by:

$$\frac{V_{LP}}{V_{in}} = \frac{B\frac{g_1}{g_2}-\left(B\frac{g_1}{g_2}\right)s(\tau_1+\tau_2)}{s[1+\left(B\frac{g_1}{g_2}\right)(\tau_1+\tau_2)]+B\frac{g_1}{g_2}}$$

It is seen that undesirable terms appear in transfer function due to higher poles of OA. However, these effects can be minimized by satisfying the condition $g_2 >> g_1$. .

4 Simulations

In order to verify the proposed circuit, simulation were carried out by using PSPICE. VDTA was obtained by cascading two LT 1228 OTAs ($g_{mi} = 10I_i$, i = 1,2)[38] and OA LM 741 with gain bandwidth product B = 1.5 MHZ. The circuit was constructed for a pole frequency of 150 KHZ. The value of transconductance g_{m1} = 1mS and g_{m2} = 10ms. The magnitude and phase responses of the proposed circuit is shown in Figs. 3 & 4 for LP filter and in Figs. 5 & 6 for 6 HP filter. Figs. 7 & 8 shows the transit response for LP and HP filter respectively.

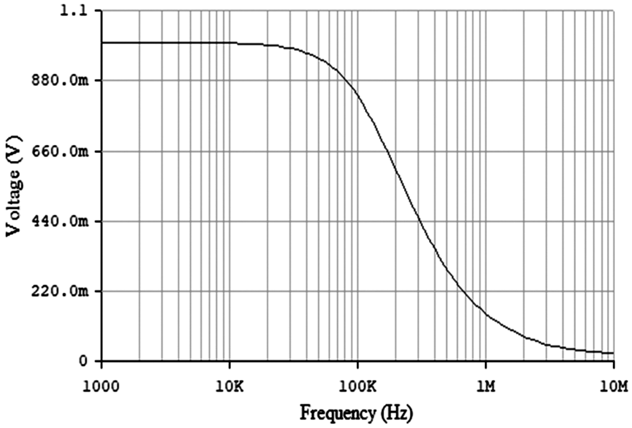

Fig. 3 — Frequency response for LP filter.

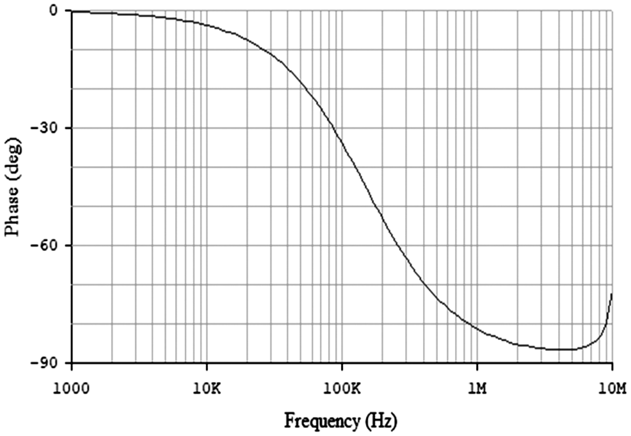

Fig. 4 — Phase response for LP filter.

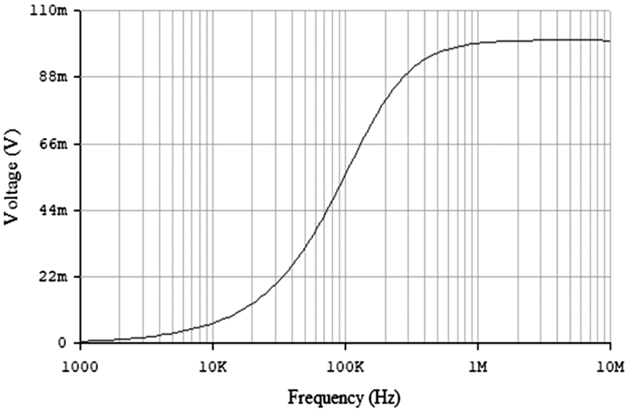

Fig. 5 — Frequency response for HP filter.

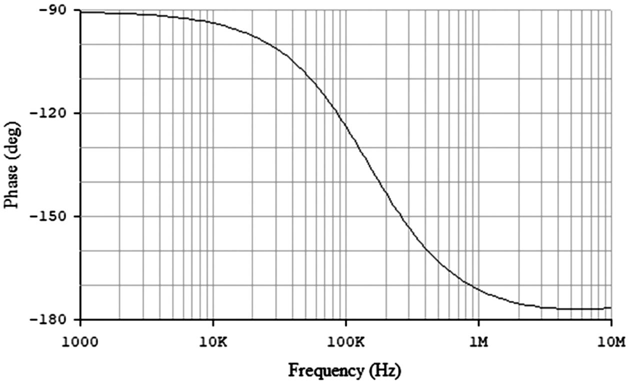

Fig. 6 — Phase response for HP filter.

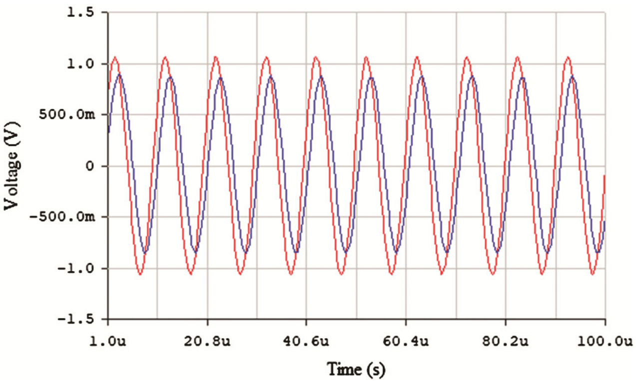

Fig. 7 — Transit response of LP filter (Red trace is input and Blue trace is output).

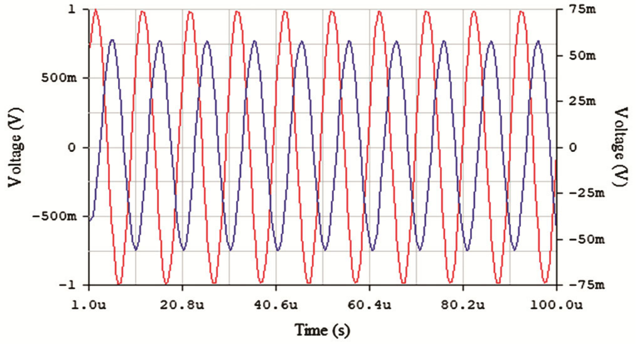

Fig. 8 — Transit response of HP filter (Red trace is input and Blue trace is output).

The input of 1V and 100 KHz sinusoidal signal was used to study the larger signal behavior of the proposed filter and the simulated response is shown in Figs. 7 & 8. The applied signal is in the pass band in LP case and stop band in HP filter.

5 Conclusion

In this paper active-only filters using OA and VDTA is presented. The circuit uses only two active devices and implements LP which is having low impedance and HP filtering function simultaneously. The circuit has an advantage of electronic tunability of the pole frequency which is highly desirable in IC technology. PSPICE simulation is used to check the proposed filter and the results are confirming workability of the proposed filter.

References

1 Brand J R & Schaumann R, *Electron Circuits Syst*, 2 (1978) 90.
2 Ananda M P V, *Electron Lett*, 16 (1980) 379.
3 Zhi-Xiao S, *Int J Electron*, 55 (1983) 479.
4 Okine M, *Electron Commun Jpn,* 69 (1986) 365.
5 Siddiqi M A & Ahmed M T, *Int J Electron*, 71 (1991) 621.
6 Higashimura M, *Int J Electron*, 73 (1992) 1279.
7 Higashimura M, *Int J Electron*, 73 (1992) 647.
8 Higashimura M, *Int J Electron*, 75 (1993) 719.
9 Higashimura M, *Microelectron J*, 24 (1993) 863.
10 Higashimura M, *Int J Electron*, 74 (1993) 945.
11 Tsukutani T, Ishidas M & Fukui Y, *Int J Electron*, 78 (1995) 1119.
12 Tsukutani T, Ishida M, Tsuiki S & Fukui Y, *Electron Lett*, 32 (1996) 197.
13 Abuelma'atti M T & Alzaher H A, *Electron Lett*, 33 (1997).
14 Tsukutani T, Higashimura M, Sumi Y & Fukui Y, *Int J Electron*, 87 (2000) 307.
15 Tsukutani T, Higashimura M, Takahashi N, Sumi Y & Fukui Y, *Int J Electron*, 88 (2001) 1093.
16 Tsukutani T, Kinugasa Y, Higashimura M, Takahashi N, Sumi Y & Fukui Y, *Int J Electron*, 89 (2002) 429.
17 Minaei S & Cicekoglu O, *ICCSC'021st IEEE Int Conf on and Sys for Comm Proc*, (2002) 70.
18 Minaei S & Cicekoglu O, *Electron Circuits Syst, 9th Int Conf*, 1 (2002) 173.
19 Tangsrirat W, Unhavanich S & Dumawipata T, *Int Symp Nonlin Theory Appl*, (2002) 727.
20 shinde G N, Patil P B & Mirkute P R, *Sadhana*, 28 (2003) 1019.
21 Shah N A & Iqbal S Z, *Int J Electron*, 90 (2003) 407.
22 Minae S, Cicekoglu O, Kuntman H & Turkoz S, *Int J Electron*, 89 (2003) 905.
23 Minae S, Cicekoglu O, Kuntman H, Dündar G & Cerid Ö, *Int J Electron Commun (AUE)*, 57 (2003) 63.
24 Tsukutani T, Kinugasa Y, Sumi Y, Higashimura M & FukuiY, *Int J Electron*, 90 (2003) 627.
25 Shah N A & S Z Iqbal, *Indian J Pure Appl Phys*, 41 (2003) 578.
26 Tsukutani T, Sumi Y, Higashimura M & Fukui Y, *Int J Electron*, 91 (2004) 525.
27 Minaei S, Topcu G & Cicekoglu O, *Int J Electron*, 92 (2005) 385.
28 Shah N A, Iqbal S Z & Parveen B, *Int J Electron Commun (AUE),* 59 (2005) 410.
29 Satansup J, Pukkalanun T, & Tangsrirat W, *21th Int Tech Conf on Circuits Systems, Comp and Commun, ITC-CSCC* (2006).
30 Prommee P, Kumngern M & Dejhan K, *IEEE Asia-Pacific Conf Circuits Syst*, (2006) 896.
31 Shah N A & S Z Iqbal, *Int J Electron*, 94 (2007) 75.
32 Prommee P, Somdunyakanok M & Dejha K, *Int Symp on Intel Signal Proc & Comm Syst,* Bangkok, Thailand (2008).
33 Singh A K, Senani R, Bhaskar D R & Sharma R, *J Circ Syst Comp*, 20 (2011) 549.
34 Jankatan A & Jaikala W, *Indian J Pure Appl Phys*, 53 (2015) 557.
35 Prommee P, Manositthichai N & Khateb F, *Turkish J Elect Eng Comp Sci*, 25 (2017) 4326.
36 Atsuwe B A, Amah A N & Igwu G A, *Int J Res Sci Innov*, 8 (2021) 1.
37 Singh G, Pasha H, Hadiman H C, *et al.*, *Wseas Trans Circ Syst,* 20 (2021) 48.
38 Pwint W M P, Suwanjan P, Jaikla W & Chaichana A, *Elektronika IR Elektrotechnika*, 27 (2021) 11.