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Electronically Tunable SIMO Mixed-mode Universal Filter using VDTAs

***Abstract**. This research paper presents a single-input multi-output (SIMO) mixed-mode universal filter based on voltage differencing transconductance amplifier (VDTA). The proposed filter can be used in both voltage and trans-admittance modes. In the voltage mode, it can serve as highpass filter (HPF), bandpass filter (BPF) and lowpass filter (LPF). In the trans-admittance mode, the proposed filter can provide HPF, BPF and LPF. Furthermore, by interconnection of significant output currents, the proposed filter can be able to work as bandreject filter (BRF) and allpass filter (APF). The proposed filter consists of 3 VDTAs and 2 grounded capacitors. This configuration allows the proposed filter to be suitable for fabricating into IC. Without effect of pole frequency, the quality factor can be electronically tuned the by adjusting DC bias current of the VDTA. The PSPICE simulation was utilized to confirm the performance of the proposed filter. The results of the simulation agree well in accordance with theoretical analysis.*

Streszczenie.** W artykule zaprezentowano uniwersalny filtr bazujący na voltage differencing tranconductance amplifier VDTA. Filtr może pracować we wszystkich trybach, jak dolnoprzepustowy, górnoprzepustowy, środkowo przepustowy i środkowo-zaporowy. Filtr składa się z 3 układów VDTA I dwóch uziemionycvh pojemności. **Elektronicznie strojony uniwersalny filtr SIMO wykorzystujący układy VDTA

Keywords: SIMO filter, Mixed-mode filter, VDTA, Grounded capacitor
Słowa kluczowe: filtr, układy VDTA.

Introduction

An universal filter is useful in analog signal processing since it can be very used in radio system, measurement system, television system and etc. [1-4]. A multi-output (SIMO) universal filter with feeding single input signal has been found to be popular in research and publication, especially those can be operated in all filter functions including lowpass (LP), highpass (HP), bandpass (BP), bandreject (BR) or bandstop or notch filter and allpass (AP). Also, most of modern active building blocks can be applied in analog signal processing that among these, the voltage differencing transconductance amplifier (VDTA). The VDTA is consisted of two transconductance gains. Both transconductance gains are electronically tuning by external DC bias currents which is suitable for circuit synthesis with electronically tunable.

Many universal filters base on VDTA have been reported in literatures [5-19]. Nevertheless, the configuration of the filters in [6-7, 11-13, 19] are needed external resistors which increase power consumption. Moreover, the filters in [5, 12, 14-15, 17, 19] employ floating capacitors that is unsuitable for developing into IC. Although, the universal filters reported in [5, 8, 9, 19] have the drawback of the dependence between their quality factor (Q_p) and pole frequency (ω_p) which is inconvenient for use.

In this paper, an electronically tunable SIMO mixed-mode universal filter is proposed and analysed. This analysis includes the standard filter functions of both voltage and trans-admittance modes in the same circuit configuration. The independence between its quality factor and pole frequency is detailed. The relative sensitivities of the active and passive elements used in the proposed filter are evaluated.

Proposed circuit description

VDTA

Voltage differencing transconductance amplifier so called VDTA has been introduced by Yesil A. and etc [5] on 2011. It employs two Arbel-Goldminz transconductances. A VDTA has the voltage input of p and n terminals and the current output of x+, x-, z+ and z- terminals. All terminals of VDTA provide high impedance. The electrical symbol of VDTA is given in Fig. 1 and the CMOS implementation of VDTA is shown in Fig.2. The relationship of the voltage and current of VDTA can be written in the following equation.

$$\begin{bmatrix} I_z \\ I_{z-} \\ I_x \\ I_{x-} \end{bmatrix} = \begin{bmatrix} g_{mF} & -g_{mF} & 0 & 0 \\ -g_{mF} & g_{mF} & 0 & 0 \\ 0 & 0 & g_{mS} & 0 \\ 0 & 0 & -g_{mS} & 0 \end{bmatrix} \begin{bmatrix} V_p \\ V_n \\ V_z \\ V_{z-} \end{bmatrix} \tag{1}$$

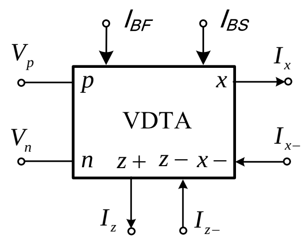

Fig. 1 The electrical symbol of VDTA

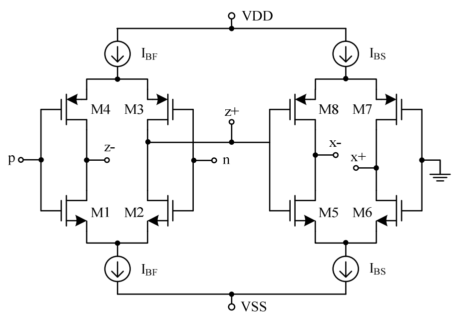

Fig. 2 CMOS implementation of VDTA [5]

From Eq. (1), the first transconductance (g_{mF}) and second transconductance (g_{mS}) of VDTA can be approximated as follow :

$$g_{mF} = \sqrt{k_1 I_{BF}} \tag{2}$$

$$g_{mS} = \sqrt{k_2 I_{BS}} \tag{3}$$

It can be noted that, the g_{mF} and g_{mS} of VDTA can be electronically adjusted with external DC bias currents I_{BF} and I_{BS}, respectively. While $k = \mu C_{OX}\left[W/L\right]$, μ is the mobility of the carrier of CMOS transistors, C_{OX} is the gate-oxide capacitance per unit area, *W/L* is the channel width per length.

Proposed SIMO universal filter

The configuration of the proposed SIMO universal filter is exhibited in Fig. 3. It employs 3 VDTAs and 2 grounded capacitors without external passive resistor that is suitable for development to fabricate in an integrated circuit [20-23]. Also, the grounded capacitors can be reduced/eliminated the stay capacities at high-impedances ports of VDTAs and node of circuits. Moreover, the proposed filter can be operated mixed-mode universal filter including voltage-mode and trans-admittance -mode. They have been explained the versatility of filter as follows.

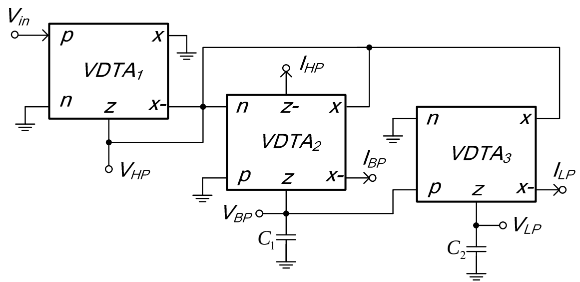

Fig. 3 Proposed filter

a) Voltage-mode SIMO universal filter

The proposed filter can be shown in Fig.3, it can be seen that, voltage-input (V_{in}) is connected at p port of VDTA1 which is properness since it has high input impedances. The voltage gain transfer function of circuit can be analyzed by using equation (1) that the standard function of filter can be expressed as

$$\frac{V_{HP}(s)}{V_{in}(s)} = \frac{g_{mF1}C_1C_2s^2}{g_{mS1}C_1C_2s^2 + g_{mF2}g_{mS2}C_2s + g_{mF2}g_{mF3}g_{mS3}} \quad (4)$$

$$\frac{V_{BP}(s)}{V_{in}(s)} = \frac{g_{mF1}g_{mF2}C_2s}{g_{mS1}C_1C_2s^2 + g_{mF2}g_{mS2}C_2s + g_{mF2}g_{mF3}g_{mS3}} \quad (5)$$

and

$$\frac{V_{LP}(s)}{V_{in}(s)} = \frac{g_{mF1}g_{mF2}g_{mF3}}{g_{mS1}C_1C_2s^2 + g_{mF2}g_{mS2}C_2s + g_{mF2}g_{mF3}g_{mS3}} \quad (6)$$

For the gain of filters are unity, $g_{mF1} = g_{mS1}$, the pole frequency (ω_p) and the quality factor (Q_p) of proposed filter can be found as

$$\omega_p = \sqrt{\frac{g_{mF2}g_{mF3}g_{mS3}}{g_{mS1}C_1C_2}} \quad (7)$$

$$Q_p = \frac{1}{g_{mS2}}\sqrt{\frac{g_{mF3}g_{mS1}g_{mS3}C_1}{g_{mF2}C_2}} \quad (8)$$

It is evident that, ω_p in equation (7) can be electronically tuned with keeps to be setting $g_{mF2} = g_{mF3}$, while Q in equation (8) can be orthogonally adjusted by remaining $g_{mS1} = g_{mS3}$. However, Q_p can be independently/electronically adjusted by g_{mS2} without effecting ω_p.

b) Trans-admittance-mode SIMO universal filter

It is interest that, the proposed filter can be operated in trans-admittance-mode without changing the circuit configuration. The terminals of current-outputs are high impedances which is connected to load or next stages without current buffers. From equation (1) the trans-admittance-mode transfer function can be realized as

$$\frac{V_{HP}(s)}{V_{in}(s)} = \frac{g_{mF1}C_1C_2s^2}{g_{mS1}C_1C_2s^2 + g_{mF2}g_{mS2}C_2s + g_{mF2}g_{mF3}g_{mS3}} \quad (9)$$

$$\frac{I_{BP}(s)}{V_{in}(s)} = \frac{g_{mF1}g_{mF2}g_{mS2}C_2s}{g_{mS1}C_1C_2s^2 + g_{mF2}g_{mS2}C_2s + g_{mF2}g_{mF3}g_{mS3}} \quad (10)$$

$$\frac{I_{LP}(s)}{V_{in}(s)} = \frac{g_{mF1}g_{mF2}g_{mF3}g_{mS3}}{g_{mS1}C_1C_2s^2 + g_{mF2}g_{mS2}C_2s + g_{mF2}g_{mF3}g_{mS3}} \quad (11)$$

The realization of bandrejected response can be accomplished by adding current-outputs of I_{HP} and I_{LP}. It can be obtained the transfer function as

$$\frac{I_{BR}(s)}{V_{in}(s)} = \frac{g_{mF1}(g_{mF2}C_1C_2s^2 + g_{mF2}g_{mF3}g_{mS3})}{g_{mS1}C_1C_2s^2 + g_{mF2}g_{mS2}C_2s + g_{mF2}g_{mF3}g_{mS3}} \quad (12)$$

As well, the transfer function of allpass response can be realized by summing the current-outputs of I_{HP}, $-I_{BP}$ and I_{LP}. The transfer function can be achieved as

(13)

$$\frac{I_{AP}(s)}{V_{in}(s)} = \frac{g_{mF1}(g_{mF2}C_1C_2s^2 - g_{mF2}g_{mS2}C_2s + g_{mF2}g_{mF3}g_{mS3})}{g_{mS1}C_1C_2s^2 + g_{mF2}g_{mS2}C_2s + g_{mF2}g_{mF3}g_{mS3}}$$

The pole frequency (ω_0) and the quality factor (Q) are same of voltage-mode as calculation in equation (7) and (8), respectively.

Non-ideal Analysis

The tracking error of voltage and current.

The non-ideal analysis of proposed filter is considered the tracking errors of voltage and current of VDTA that are the equation (1) changes to

$$\begin{bmatrix} I_z \\ I_{z-} \\ I_x \\ I_{x-} \end{bmatrix} = \begin{bmatrix} \beta_F g_{mF} & -\beta_F g_{mF} & 0 & 0 \\ -\beta_F g_{mF} & \beta_F g_{mF} & 0 & 0 \\ 0 & 0 & \beta_S g_{mS} & 0 \\ 0 & 0 & -\beta_S g_{mS} & 0 \end{bmatrix} \begin{bmatrix} V_p \\ V_n \\ V_z \\ V_{z-} \end{bmatrix} \quad (14)$$

where β_F and β_S are the tracking errors of first and second stage of VDTA, respectively. The parameters of universal filter can be re-analyzed as

$$\omega_p = \sqrt{\frac{\beta_{F2}\beta_{F3}\beta_{S3}g_{mF2}g_{mF3}g_{mS3}}{\beta_{S1}g_{mS1}C_1C_2}} \quad (15)$$

and

(16) $$Q_p = \frac{1}{\beta_{S2} g_{mS2}} \sqrt{\frac{\beta_{F3}\beta_{S1}\beta_{S3} g_{mF3} g_{mS1} g_{mS3} C_1}{\beta_{F2} g_{mF2} C_2}}$$

From equations (15) – (16), ω_p and Q_p are slightly effected of tracking errors of VDTA. These effects can be reduced by suitably adjusting the transconductance gain of VDTAs.

The relation of sensitivity

The relative sensitivity of ω_p and Q_p with passive and active elements of filter are analyzed as follows,

(17) $$S^{\omega_p}_{\beta_{F1},B_{S2}} = S^{\omega_p}_{g_{mF1},g_{mS2}} = S^{Q_p}_{\beta_{F1}} = S^{Q_p}_{g_{mF1}} = 0$$

(18) $$S^{\omega_p}_{\beta_{F2},\beta_{F3},\beta_{S3}} = S^{\omega_p}_{g_{mF1},g_{mF3},g_{mS3}} = S^{Q_p}_{g_{mF3},g_{mS1},g_{mS3}} = \frac{1}{2}$$

(19) $$S^{\omega_p}_{\beta_{S1}} = S^{\omega_p}_{g_{mS1}} = S^{Q_p}_{\beta_{F2}} = S^{Q_p}_{g_{mF2}} = -\frac{1}{2}$$

(20) $$S^{Q_p}_{\beta_{S2}} = S^{Q_p}_{g_{mS2}} = -1$$

(21) $$S^{\omega_p}_{C_1,C_1} = S^{Q_p}_{C_2} = -\frac{1}{2} \quad \text{and} \quad S^{Q_p}_{C_1} = \frac{1}{2}$$

It can be seen that, the sensitivities of ω_p and Q_p are low and they are not more than unity.

The parasitic element effects

The parasitic element effects on any port of proposed filter is considered

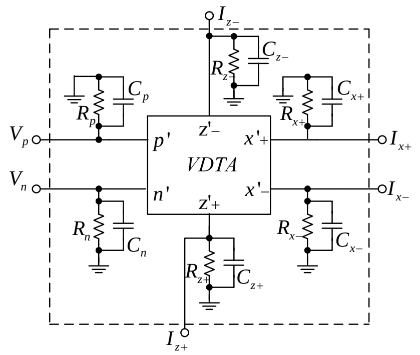

Fig. 4 The parasitic element of VDTA

The parameter of universal filter can be re-analyzed as:

Where $C_1^{'} = C_1 + C_{z2}$; $C_2^{'} = C_2 + C_{z3}$

(22 $$\omega_p = \sqrt{\frac{g_{mF2} g_{mF3} g_{ms3}}{g_{ms1}\left[\left((\frac{1}{R_{z2}+R_{p3}}) + (C_1^{'}//C_{p3})\right)(\frac{1}{R_{z3}} + C_2^{'})\right]}}$$

(23) $$Q_p = \frac{1}{g_{ms2}} \sqrt{\frac{g_{mF3} g_{ms1} g_{ms3}\left((\frac{1}{R_{z2}+R_{p3}}) + (C_1^{'}//C_{p3})\right)}{g_{mF2}(\frac{1}{R_{z3}} + C_2^{'})}}$$

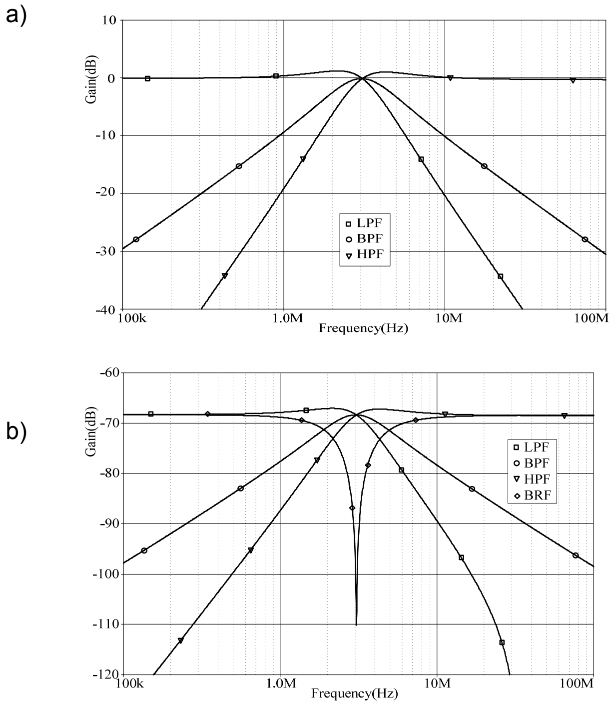

Fig. 4 Frequency response of proposed filter (a) voltage-mode (b) trans-admittance-mode

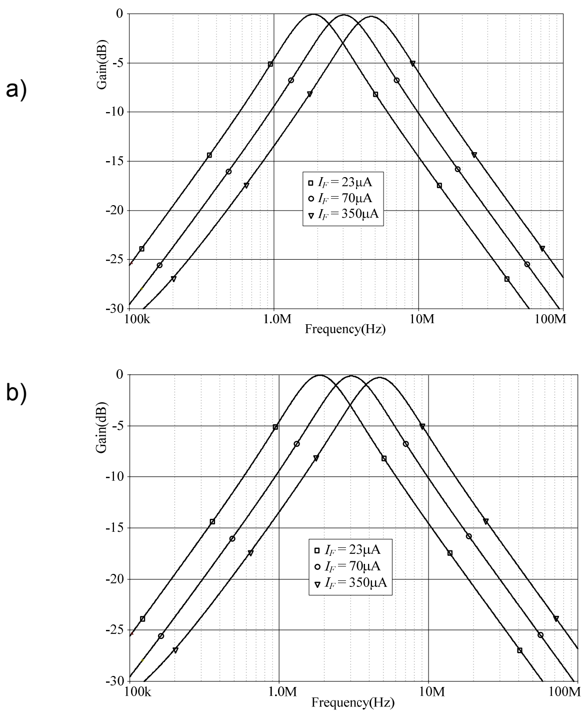

Fig. 6 Simulated of frequency response of BP filter when adjusting I_F (a) voltage-mode (b) trans-admittance-mode

Computer simulation

To confirm the performance of proposed SIMO filter, the Pspice program was used. The simulation of proposed filter using instruction of VDTA in Fig. 2 based-on $0.25\mu m$ TMSC parameters. The aspect ratio of PMOS and NMOS are $W/L = 8\mu m / 0.25\mu m$ and $W/L = 5\mu m / 0.25\mu m$, respectively. The VDTAs of proposed filter are biased with $\pm 1.25V$ and $I_{BF1} = I_{BF2} = I_{BF3} = I_{BS1} = I_{BS2} = I_{BS3} = 70\mu A$. The grounded capacitors are chosen as $C_1 = C_2 = 20pF$. The first results in Fig. 4 (a) are exhibited the frequency response of LP, BP and HP. There are the frequency responses in voltage-mode. Also, the freuqency responses of trans-admittance-mode are presented in Fig. 4 (b), which is LP, BP, HP and BR. The AP response of trans-admittance-mode is shown in Fig. 5. These simulation are yielded about $f_p = 3.04MHz$ and $Q_p = 1$.

a)

b)

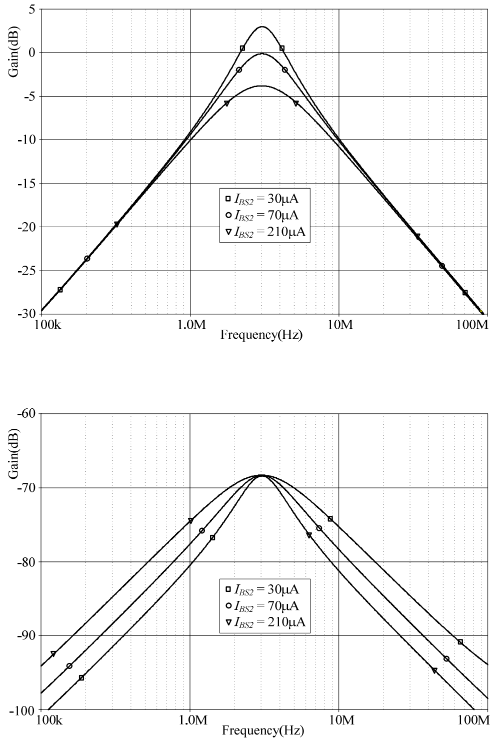

Fig. 7 Simulated of frequency response of BP filter with varying Q (a) voltage-mode (b) trans-admittance-mode

a)

b)

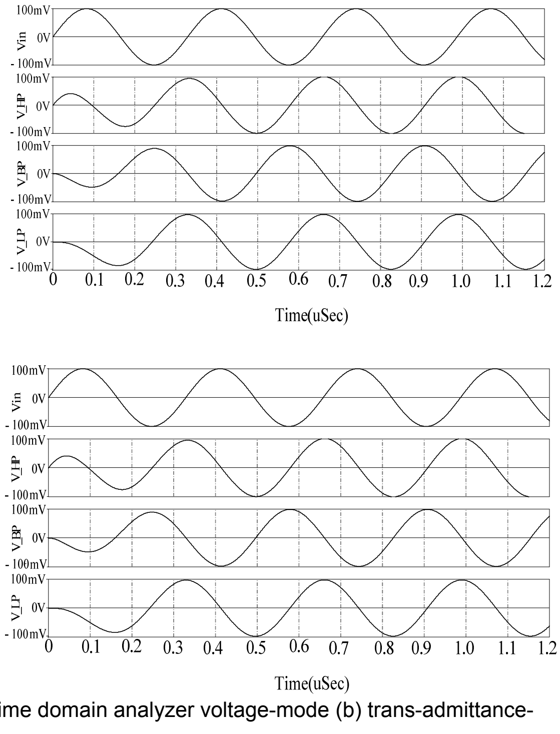

Fig. 8 Time domain analyzer voltage-mode (b) trans-admittance-mode

The demonstration of electronic tuning of pole frequency by tuning $I_{BF2} = I_{BF3} = I_F$ = 23μA, 70μA and 350μA, respectively. In this case, the simulation results of BP response are displayed in Fig. 6 (a) and (b) which is the pole frequency are varied to 1.87MHz, 3.04MHz and 5.62MHz, respectively

Moreover, an electronic adjusting of Q without influencing of ω_p by g_{mS2} can be demonstrated in Fig. 7. While, the g_{mS2} is varied with I_{BS2} that is I_{BS2} = 30μA, 70μA and 210μA. The Q is changed to 3, 1 and 0.4, respectively.

The time domain behavior of BP output to show the stability of the propose filter were to analyzed can be demonstrated in Fig. 8. The purpose filter circuit was simulated by applying sinusoidal input voltage signal of 100mV at frequency of 3.04MHz ,the simulation result showing time domain response of Fig. 8(a) voltage mode and (b) was result of BP trans-admittance mode output.

The total harmonic distortion(THD) of the purpose filter of BP response is show in Fig.9 which was found in the range of 0.039% to 0.648% in voltage-mode and of 0.257% to 4.567% in voltage-mode depence on sinusoudal input voltage of amplitude variabled in 10mV to 200mV of range.

a)

b)

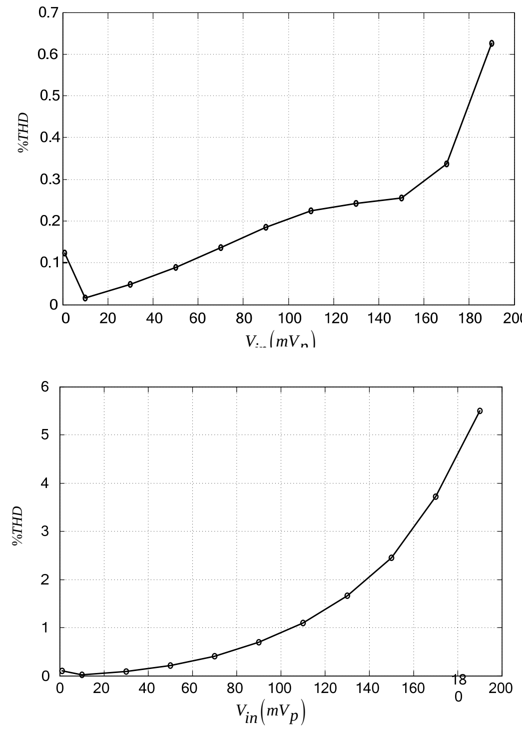

Fig. 9 The THD (a) voltage-mode (b) trans-admittance-mode

Conclusion

The SIMO mixed-mode universal filter is presented in this paper. It can be operated as voltage and trans-admittance modes. The filter standard functions in the voltage mode are LP, BP and HP. While, the trans-admittance mode can be functioned as LP, BP and HP. With summing of significant output currents, the trans-admittance mode can also be set as BR and AP functions. The proposed filter is made from three VDTAs and two grounded capacitors which is appropriate for fabricating into integrated circuit. The impedance of the voltage inputs and the current outputs of filter is high which is convenient for interconnection to next stages. The quality factor of the filter can be independently tuned via DC bias currents of the

VDTA without the effect of its pole frequency. The PSPICE program was used to simulate the functions of the proposed filter. According to the simulation results, the proposed filter functions are found to be in the agreement with theoretical analysis.

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