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MISO-Type Voltage-Mode Universal Biquadratic Filter Using Single Universal Voltage Conveyor

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Abstract

A universal biquadratic filter using single universal voltage conveyor (UVC), two resistors and two capacitors is presented in this paper. The proposed structure has three inputs and one output and can realize all the five standard biquadratic filters: low-pass (LP), high-pass (HP), band-pass (BP), band-reject (BR) and all-pass (AP) from the same circuit configuration. The presented universal filter offers low active and passive sensitivities. SPICE (Version 16.5) simulation results using 0.18 μm TSMC technology have been included.

Keywords

Universal Voltage Conveyor, Voltage-Mode, Filter, Analog Circuit Design

1. Introduction

There is a growing interest in the design of single-input multi-output (SIMO) or multi-input single-output (MISO) voltage-mode (VM) or current-mode (CM) universal filter configurations, due to their flexibility and versatility for practical applications [1]. In literature [2]-[8], filter configurations employing different active building blocks/devices (such as current differencing transconductance amplifier (CDTA), current differencing buffered amplifier (CDBA), modified current feedback operational amplifier (MCFOA), current feedback operational amplifier (CFOA) and voltage differencing voltage transconductance amplifier (VDVTA)) have been presented over the past few years. Multifunction filter structures have been presented in [9], where structures employing three UVCs could realize only three basic filters (*i.e.* LP, HP, and BP). In [10], authors have proposed three multi-function filter structures employing: i) Three UVCs which can realize three basic filters *i.e.* LP, HP, and BP. ii) Two UVCs which can realize four basic filters *i.e.* LP, HP, BP and, AP. iii) Single UVC which can realize four basic filters *i.e.* LP, HP, BP and, AP.

Filter structures presented in references [9] [10] are unable to realize all the basic biquadratic filter functions from single topology (*i.e.* LP, HP, BP, BR and AP). Therefore, the purpose of this paper is to propose a new universal VM biquad with three inputs and one output, which can realize all basic standard second order filter functions, namely: LP, HP, BP, BR and AP without changing the circuit topology. Workability of the proposed filter has been established by SPICE (Version 16.5) simulations using 0.18 μm TSMC technology.

2. Proposed Filter Configuration

The symbolic representation and equivalent circuit model of the UVC are shown in Figure 1(a) and Figure 1(b) respectively. The UVC is a 6-port active element with one voltage input x, two difference current inputs (y^+, y^-), two mutually inverse voltage outputs (z^+, z^-), and one auxiliary port w. Using standard notations, the relationship between port currents and voltages of a six port UVC is given by the following equations.

$$I_x = I_{y^+} - I_{y^-}, V_w = V_{y^+} = V_{y^-}, V_{z^+} = V_x, V_{z^-} = -V_x, I_w = 0 \quad (1)$$

A routine circuit analysis (assuming ideal UVC) of Figure 2 gives the follow-

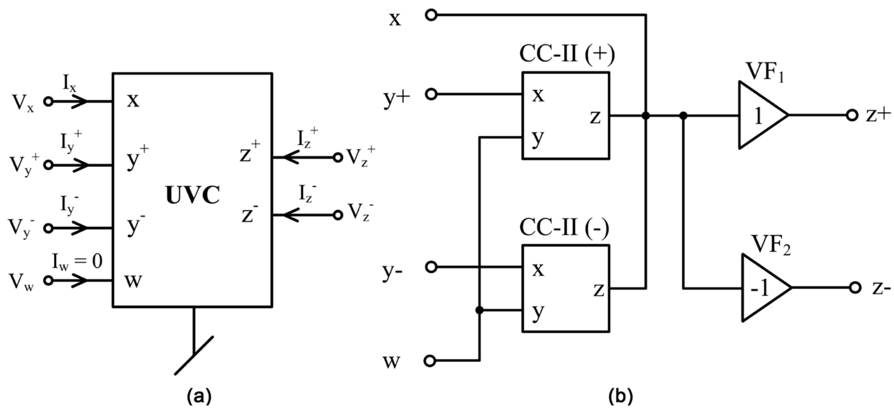

Figure 1. (a) Symbolic representation of UVC; (b) Equivalent circuit model of UVC [11].

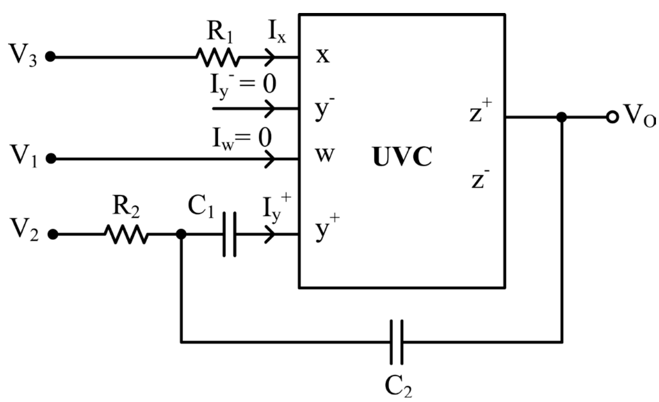

Figure 2. The proposed voltage-mode universal biquadratic filter.

ing expression for the output voltage in terms of input voltages:

$$V_o = \frac{V_1\left\{s^2 + s\left(\frac{1}{C_2R_2}\right)\right\} - V_2 s\left(\frac{1}{C_2R_2}\right) + V_3\left\{\frac{1}{R_1}\left(s\left(\frac{1}{C_1}+\frac{1}{C_2}\right)+\frac{1}{C_1C_2R_2}\right)\right\}}{s^2 + s\left\{\frac{1}{R_1}\left(\frac{1}{C_1}+\frac{1}{C_2}\right)\right\} + \frac{1}{R_1R_2C_1C_2}} \quad (2)$$

From Equation (2), all standard filter functions (LP, HP, BP, BR and AP) can be realized (for $R_1 = R_2 = R$ and $C_1 = C_2 = C$):

1) If $V_3 = V_{in}$, $V_2 = 2V_{in}$ and $V_1 = 0$ (grounded), then low pass filter can be realized.

$$T(s)\big|_{LP} = \frac{\frac{1}{R^2C^2}}{D(s)}$$

2) If $V_1 = V_2 = V_{in}$ and $V_3 = 0$ (grounded), then high pass filter can be realized

$$T(s)\big|_{HP} = \frac{s^2}{D(s)}$$

3) If $V_2 = V_{in}$ and $V_1 = V_3 = 0$ (grounded), then band pass filter can be realized.

$$T(s)\big|_{BP} = \frac{-s\left(\frac{1}{RC}\right)}{D(s)}$$

4) If $V_3 = V_1 = V_{in}$ and $V_2 = 3V_{in}$, then band reject filter can be realized.

$$T(s)\big|_{BR} = \frac{s^2 + \frac{1}{R^2C^2}}{D(s)}$$

5) If $V_3 = V_1 = V_{in}$ and $V_2 = 5V_{in}$, then all pass filter can be realized.

$$T(s)\big|_{AP} = \frac{s^2 - s\left(\frac{2}{RC}\right) + \frac{1}{R^2C^2}}{D(s)}$$

where: $D(s) = s^2 + s\left(\frac{2}{RC}\right) + \frac{1}{R^2C^2}$

The expressions for natural frequency (ω_0), quality factor (Q_0) and bandwidth (BW) are given by:

$$\omega_0 = \sqrt{\frac{1}{R_1R_2C_1C_2}},\ Q_0 = \frac{\sqrt{\frac{R_1C_1C_2}{R_2}}}{C_1 + C_2},\ BW = \frac{1}{R_1}\left(\frac{1}{C_1}+\frac{1}{C_2}\right) \quad (3)$$

From Equation (3), it can be observed that after adjusting BW by R_1, ω_0 can independently be controlled through R_2. Furthermore, it is seen that no inversion of the input signal(s) is required in any of the five filter realizations.

In the ideal case, the various sensitivities of ω_0 and BW with respect to R_1, R_2,

C_1, and C_2 are found to be:

$$S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = S_{R_1}^{\omega_0} = S_{R_2}^{\omega_0} = -\frac{1}{2} \tag{4}$$

$$S_{C_1}^{BW} = -\left(\frac{1}{1+\frac{C_1}{C_2}}\right), S_{C_2}^{BW} = -\left(\frac{1}{1+\frac{C_2}{C_1}}\right), S_{R_1}^{BW} = -1, S_{R_2}^{BW} = 0 \tag{5}$$

3. Non-Ideal Analysis and Sensitivity Performance

Model of UVC including parasitic elements is shown in the Figure 3 [12].

Taking into account, the non-idealities of UVC, the relationship of the terminal voltages and currents in Equation (1) can be rewritten as:

$$I_x = \alpha_1 I_{y^+} - \alpha_2 I_{y^-}, V_{y^+} = \delta_1 V_w, V_{y^-} = \delta_2 V_w, V_{z^+} = \gamma_1 V_x, V_{z^-} = \gamma_2 V_x, I_w = 0 \tag{6}$$

where $\alpha_j = 1-\varepsilon_{ij}$ and $\delta_j = 1-\varepsilon_{v1j}$, $\gamma_j = 1-\varepsilon_{v2j}$ for $j = 1,2$. Here $\varepsilon_{ij}\left(\left|\varepsilon_{ij}\right| \ll 1\right)$ and ε_{v1j}, ε_{v2j} $\varepsilon_{ij}\left(\left|\varepsilon_{v1j}\right|,\left|\varepsilon_{v2j}\right| \ll 1\right)$ represent the current and voltage tracking errors of the UVC, respectively. The parasitic present on the low impedance ports (y^+, y^-, z^+, z^-) is quite low as compared to the resistances on the other ports (w and x) [13]. After considering the parasitic of UVC in the proposed structure, shown in Figure 4, the expression for output voltage in terms of input voltages is given as follows:

$$V_0 = \frac{\alpha_1\delta_1\gamma_1 V_1\left(s^2 C_1 C_2 + s\frac{C_1}{R_2}\right) - \alpha_1\gamma_1 V_2\left(s\frac{C_1}{R_2}\right) + \gamma_1 V_3\left(s\left(\frac{C_1+C_2}{R_1}\right) + \frac{1}{R_1 R_2}\right)}{s^2\left(\alpha_1\gamma_1 C_1 C_2 + C_1 C_x + C_2 C_x\right) + s\left(\frac{C_1+C_2}{R_1} + \frac{C_1+C_2}{R_x} + \frac{C_x}{R_2}\right) + \frac{1}{R_2}\left(\frac{1}{R_1} + \frac{1}{R_x}\right)} \tag{7}$$

$$\omega_0 = \sqrt{\frac{R_1 + R_x}{R_1 R_2 R_x\left(\alpha_1\gamma_1 C_1 C_2 + C_1 C_x + C_2 C_x\right)}} \tag{8}$$

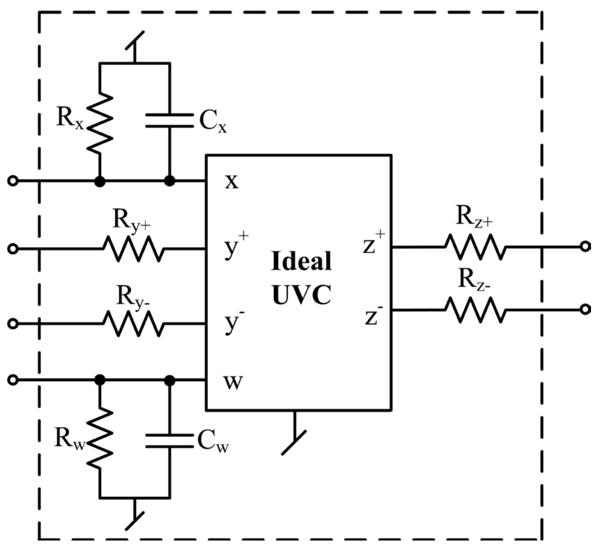

Figure 3. Non-ideal model of UVC.

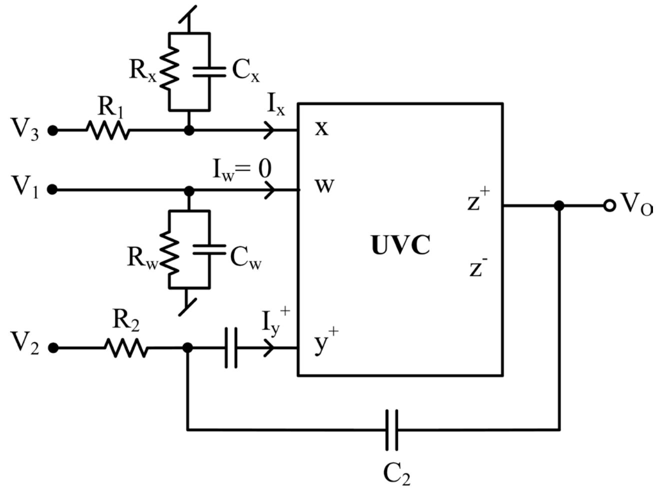

Figure 4. The proposed biquadratic filter considering the parasitic.

$$BW = \frac{\left(C_1 + C_2\right)\left(\frac{1}{R_x} + \frac{1}{R_1}\right) + \frac{C_x}{R_2}}{\alpha_1\gamma_1 C_1 C_2 + C_1 C_x + C_2 C_x} \tag{9}$$

Its active and passive sensitivities can be found as:

$$S_{C_1}^{\omega_0} = -\frac{1}{2}\left(\frac{1}{1 + \frac{C_2 C_x}{\alpha_1\gamma_1 C_1 C_2 + C_1 C_x}}\right), S_{C_2}^{\omega_0} = -\frac{1}{2}\left(\frac{1}{1 + \frac{C_1 C_x}{\alpha_1\gamma_1 C_1 C_2 + C_2 C_x}}\right) \tag{10}$$

$$S_{C_x}^{\omega_0} = -\frac{1}{2}\left(\frac{1}{1 + \frac{\alpha_1\gamma_1 C_1 C_2}{C_2 C_x + C_1 C_x}}\right), S_{R_1}^{\omega_0} = -\frac{1}{2}\left(\frac{1}{1 + \frac{R_1}{R_x}}\right), S_{R_2}^{\omega_0} = -\frac{1}{2}, S_{R_x}^{\omega_0} = -\frac{1}{2}\left(\frac{1}{1 + \frac{R_x}{R_1}}\right) \tag{11}$$

$$S_{C_1}^{BW} = -\frac{C_1\left(\left(\alpha_1\gamma_1 C_2^2\right)\left(\frac{1}{R_x} + \frac{1}{R_1}\right) + \frac{\alpha_1\gamma_1 C_2 C_x}{R_2} + \frac{C_x^2}{R_2}\right)}{\left(\left(C_1 + C_2\right)\left(\frac{1}{R_x} + \frac{1}{R_1}\right) + \frac{C_x}{R_2}\right)\left(\alpha_1\gamma_1 C_1 C_2 + C_1 C_x + C_2 C_x\right)} \tag{12}$$

$$S_{C_2}^{BW} = -\frac{C_2\left(\left(\alpha_1\gamma_1 C_1^2\right)\left(\frac{1}{R_x} + \frac{1}{R_1}\right) + \frac{\alpha_1\gamma_1 C_1 C_x}{R_2} + \frac{C_x^2}{R_2}\right)}{\left(\left(C_1 + C_2\right)\left(\frac{1}{R_x} + \frac{1}{R_1}\right) + \frac{C_x}{R_2}\right)\left(\alpha_1\gamma_1 C_1 C_2 + C_1 C_x + C_2 C_x\right)} \tag{13}$$

$$S_{C_x}^{BW} = -\frac{C_x^2\left(\frac{C_1 C_x}{R_2} + \frac{\alpha_1\gamma_1 C_1 C_2}{R_2} - C_2\left(C_1 + C_2\right)\left(\frac{1}{R_x} + \frac{1}{R_1}\right)\right)}{\left(\left(C_1 + C_2\right)\left(\frac{1}{R_x} + \frac{1}{R_1}\right) + \frac{C_x}{R_2}\right)\left(\alpha_1\gamma_1 C_1 C_2 + C_1 C_x + C_2 C_x\right)} \tag{14}$$

$$S_{R_1}^{BW} = \frac{-1}{1 + \frac{\left(\left(C_1 + C_2\right)R_2 + C_x R_x\right)R_1}{\left(C_1 + C_2\right)R_2 R_x}}, S_{R_2}^{BW} = \frac{-1}{1 + \frac{\left(C_1 + C_2\right)\left(R_x + R_1\right)R_2}{C_x R_1 R_x}} \tag{15}$$

$$S_{R_x}^{BW} = \frac{-1}{1+\frac{\left(\left(C_1+C_2\right)R_2+C_xR_1\right)R_x}{\left(C_1+C_2\right)R_2R_1}} \tag{16}$$

Considering the typical values of various parasitic capacitance $C_x = 17.41\ \text{pF}$ and parasitic resistance $R_x = 378.73\ \text{k}\Omega$, $\alpha_1 = \alpha_2 = \delta_1 = \delta_2 = \gamma_1 = -\gamma_2 = 1$ [14] along with $C_1 = C_2 = 100\ \text{pF}$, $R_1 = R_2 = 100\ \text{k}\Omega$, the various sensitivities are found to be $S_{C_1}^{\omega_0} = S_{C_2}^{\omega_0} = -0.4365$, $S_{C_x}^{\omega_0} = -0.497$, $S_{R_1}^{\omega_0} = -0.375$, $S_{R_2}^{\omega_0} = -0.5$, $S_{R_x}^{\omega_0} = -0.125$ which are all quite low.

4. Simulation Results

To validate its theoretical analysis, the presented biquadratic filter is verified by SPICE simulations. The voltage and current selected for CMOS implementation of UVC are ±1.9 V and 100 μA, respectively. CMOS implementation of universal voltage conveyor shown in Figure 5 and the aspect ratios of MOSFETs used in Figure 5 are given in Table 1 [15]. The passive elements are chosen as $C_1 = C_2 = 100\ \text{pF}$, $R_1 = R_2 = 100\ \text{k}\Omega$. The natural frequency (ω_0) and bandwidth (BW) of the proposed filter for the selected passive elements are 15.99 kHz and 31.8 kHz respectively. Figure 6 shows the magnitude response of the proposed biquadratic filter. Figure 7 and Figure 8 show the magnitude and phase responses of all pass filter respectively. A comparison with other previously known MISO-type biquads using different active building blocks has been given

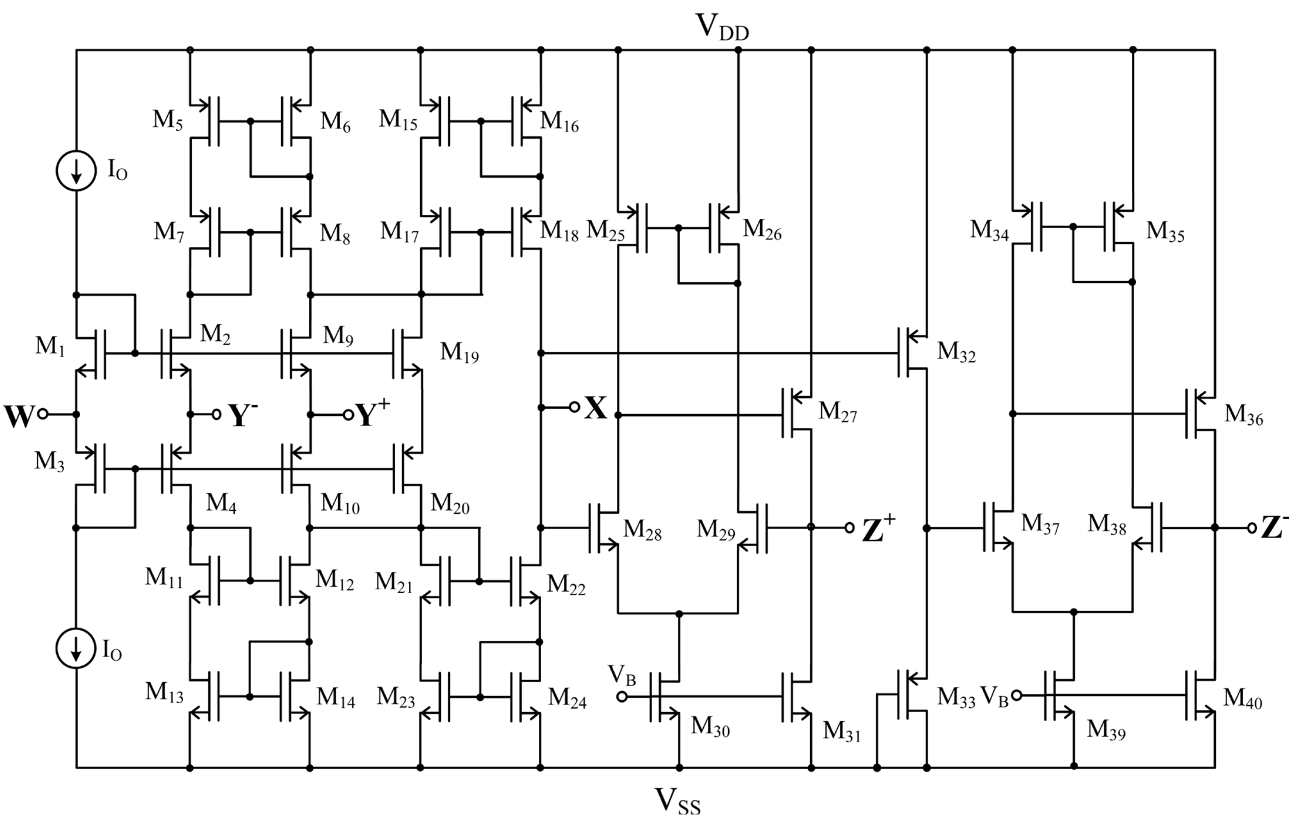

Figure 5. CMOS implementation of UVC, $V_{DD} = -V_{SS} = 1.9\text{V}$, $I_o = 100\ \mu\text{A}$.

Table 1. The aspect ratios (W/L) of MOSFETs used in **Figure 5**.

PMOS transistors	W(μm)/L(μm)
M5 - M8, M10, M15 - M18, M20	14.0/0.7
M3, M4	28/0.7
M25, M26, M34, M35	4.0/0.5
M27, M36	10.0/0.5
M32, M33	2.1/1.0
NMOS transistors MI, M2	**W(μm)/L(μm)**
M1, M2	14.0/0.7
M9, M11 - M14, M19, M21 - M24	28/0.7
M28, M29, M37, M38	0.8/05
M30, M31, M39, M40	10/0.5

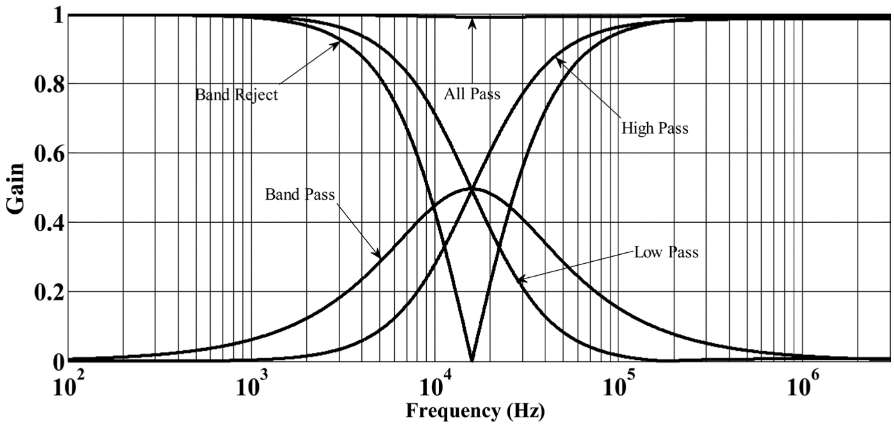

Figure 6. Frequency response of the proposed biquad filter.

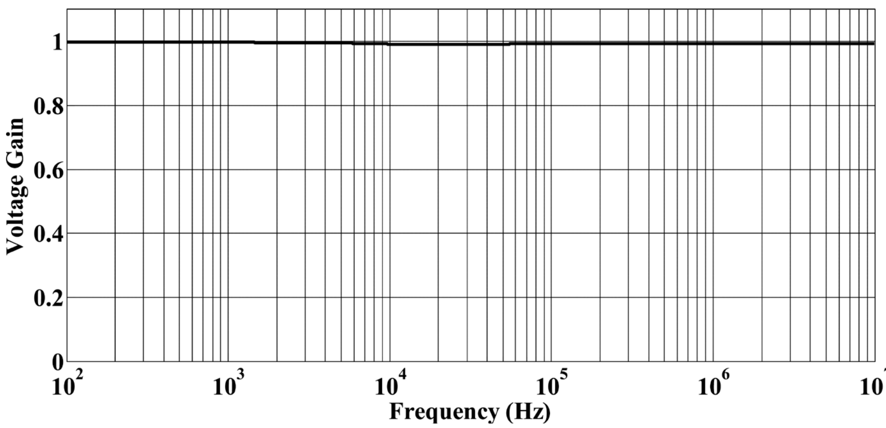

Figure 7. Frequency response of all-pass filter.

in **Table 2**. CMOS UVC was implemented using 0.18 μm TSMC CMOS model parameters [16].

5. Conclusion

A New voltage-mode MISO-type universal biquadratic filter configuration is

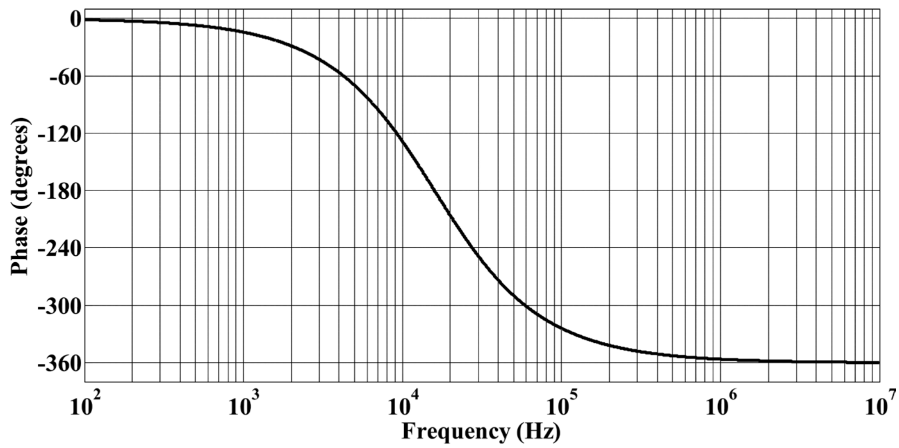

Figure 8. Phase response of all-pass filter.

Table 2. A comparison with other previously known MISO-type biquads using different active building blocks.

Reference	No. of active components	No. of passive components		Requirement of matching condition(s)	Number of standard filters realized
		Capacitors	Resistors		
[2]	1 (CDTA)	2	3	Yes	Five
[3]	1 (CDBA)	4	4	Yes	Five
[4]	1 (CDBA)	2	4	Yes	Five
[5]	1 (MCFOA)	2	3	Yes	Five
[6]	1 (CFA)	2	2	Yes	Five
[7]	1 (CFA)	2	3	Yes	Five
[8]	1(VDVTA)	1	2	No	Four
[9]	3 (UVC)	2	5	No	Three (LP, HP, BP)
	3 (UVC)	2	5	No	Three (LP, HP, BP)
[10]	2 (UVC)	2	3	No	Four (LP, HP, BP, AP)
	1 (UVC)	2	2	No	Four (LP, HP, BP, AP)
Proposed	**1 (UVC)**	**2**	**2**	**YES**	**Five**

proposed. The presented filter circuit employs single UVC with a minimum number of passive components, two capacitors, and two resistors. By proper selection of input voltages, all the basic second order filters can be realized, which are LP, HP, BP, BR, and AP without altering the circuit structure. Simulation results using 0.18 μm TSMC CMOS technology have been presented to confirm the workability of the proposed new universal biquadratic filter. Limitations of the proposed structure are: i) matching of passive components and ii) reduced gain of band pass filter. For future scope matching conditions could be removed, further unity gain of the band pass filter can be achieved.

References

[1] Pushkar, K.L., Bhaskar, D.R. and Prasad, D. (2013) Voltage-Mode New Universal Biquad Filter Configuration Using a Single VDIBA. *Circuits, Systems, and Signal Processing*, **33**, 275-285. https://doi.org/10.1007/s00034-013-9625-0

[2] Prasad, D., Bhaskar, D.R. and Singh, A.K. (2009) Multi-Function Biquad Using Single Current Differencing Transconductance Amplifier. *Analog Integrated Circuits and Signal Processing*, **61**, 309-313. https://doi.org/10.1007/s10470-009-9310-1

[3] Keskin, A.U. (2006) Multi-Function Biquad Using Single CDBA. *Electrical Engineering*, **88**, 353-356. https://doi.org/10.1007/s00202-004-0289-4

[4] Bashir, S.A. and Shah, N.A. (2012) Voltage Mode Universal Filter Using Current Differencing Buffered Amplifier as an Active Device. *Circuits and Systems*, **3**, 1-4. https://doi.org/10.4236/cs.2012.33038

[5] Herencsar, N., Koton, J., Vrba, K. and Cicekoglu, O. (2009) Single UCC-N1B 0520 Device as a Modified CFOA and Its Application to Voltage- and Current-Mode Universal Filters. *Applied Electronics*, *Pilsen*, **9**, 127-130.

[6] Shah, N.A., Rather, M.F. and Iqbal, S.Z. (2005) A Novel Voltage-Mode Universal Filter Using A Single CFA. *Active and Passive Electronic Devices*, **1**, 183-188.

[7] Horng, J.W., Chang, C.K. and Chu, J.M. (2002) Voltage-Mode Universal Biquadratic Filter Using Single Current-Feedback Amplifier. *IEICE Transactions on Fundamentals*, **85**, 1970-1973.

[8] Singh, G., Prasad, D. and Bhaskar, D. (2015) Single VDVTA-Based Voltage-Mode Biquad Filter. *Circuits and Systems,* **6**, 55-59. https://doi.org/10.4236/cs.2015.63006

[9] Herencsar, N., Koton, J. and Vrba, K. (2011) KHN-Equivalent Voltage-Mode Filters Using Universal Voltage Conveyors. *AEU—International Journal of Electronics and Communications*, **65**, 154-160. https://doi.org/10.1016/j.aeue.2010.02.005

[10] Minarcik, M. and Vrba, K. (2007) Continuous-Time Multifunctional Filters with Wide Bandwidth Using Universal Voltage Conveyors. *Proceedings of the Sixth International Conference on Networking,* Washington, DC, 22-28 April 2007. https://doi.org/10.1109/ICN.2007.32

[11] Minarcik, M. and Vrba, K. (2006) Low-Output and High-Input Impedance Frequency Filters Using Universal Voltage Conveyor for High-Speed Data Communication Systems. *International Conference on Networking*, *International Conference on Systems and International Conference on Mobile Communications and Learning Technologies*, 23-29 April 2006, 155.

[12] Herencsar, N., Koton, J., Jerabek. J., Vrba, K. and Cicekoglu, O. (2011) Voltage-Mode All Pass Filter Using Universal Voltage Conveyor and MOSFET-Based Electronic Resistors. *Radioengineering*, **20**, 10-18.

[13] Herencsar, N., Koton, J. and Vrba, K. (2009) A New Electronically Tunable Voltage-Mode Active-C Phase Shifter Using UVC and OTA. *IEICE Electronics Express*, **6**, 1212-1218. https://doi.org/10.1587/elex.6.1212

[14] Sponar, R. and Vrba, K. (2006) Measurements and Behavioral Modeling of Modern Conveyors. *International Journal of Computer Science and Network Security*, **6**, 57-65.

[15] Herencsar, N., Koton, J., Vrba, K. and Minaei, S. (2011) Electronically Tunable MOSFET-C Voltage-Mode All Pass Filter Based on Universal Voltage Conveyor.

Communication Software and Networks, 442-445.
https://doi.org/10.1109/ICCSN.2011.6014931

[16] Minaei, S. and Yuce, E. (2010) Novel Voltage-Mode All-Pass Filter Based on Using DVCCs. *Circuits System and Signal Processing*, **29**, 391-402.
https://doi.org/10.1007/s00034-010-9150-3