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VDTA-C based voltage mode Tow-Thomas Biquad filter

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Abstract **-** This paper presents a new voltage mode Tow-Thomas biquad circuit. The proposed circuit employs three voltage differencing transconductance amplifier(VDTA) as active element together with two capacitors only as passive elements. This configuration provides independent tunability of centre frequency(w), quality factor(Q) and gain by properly setting the transconductance values of the VDTAs. The synthesis of the filter has been done using gpdk 180nm technology in Cadence virtuoso environment.

Keywords**:** VDTA, Current Conveyors, OTA, Biquad fiters, Tow-Thomas,Transconductance

1. Introduction

The TT biquad, known as the Tow-Tomas biquad, is a widely used filter implementation topology that has gained significant popularity [1]. Various active elements, including operational transconductance amplifiers (OTAs), current conveyors (CCs), and differential voltage current conveyors (DVCCs), have been employed in different realizations of this structure [1]. A recent development in this area involves the implementation of a new circuit using voltage differencing current conveyors (VDCCs) [2]. The field of microelectronics has witnessed notable advancements, leading to the introduction of novel circuit principles for active building blocks, aiming to enhance the performance of existing elements such as OTAs and CCs in fast analog signal processing. One of these recent advancements is the voltage differencing transconductance amplifier (VDTA) [3].

The VDTA consists of a current source controlled by the voltage difference between two input voltages and a multiple-output transconductance amplifier. It offers electronic tuning capabilities through its transconductance gains. In the VDTA, the differential input voltage (Vp, Vn) is converted to current at terminal Z by the first transconductance gain. The voltage drop at terminal Z is then converted to current at terminals X+ and X- (negative of X+) by the second transconductance gain. Both transconductance gains can be electronically controlled using external bias currents [5].

In this study, a voltage mode TT biquad filter is designed using VDTAs, incorporating an optimal number of active and passive elements. This circuit configuration enables high cut-off frequency and independent tunability.

2. Voltage Differencing Transconductance Amplifier (VDTA)

The circuit symbol for VDTA is depicted in Figure 1, illustrating input terminals labeled as p and n, and output terminals labeled as Z, X+, and X-. It is important to note that all these terminals demonstrate a high impedance characteristic.

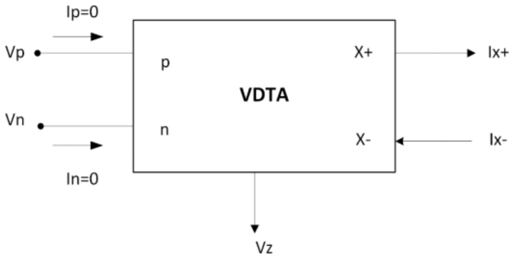

Fig. 1: VDTA block diagram

Considering ideal VDTA, the terminal relations can be characterized by the following matrix:

$$\begin{bmatrix} I_z \\ I_{x+} \\ I_{x-} \end{bmatrix} = \begin{bmatrix} g_{mf} & -g_{mf} & 0 \\ 0 & 0 & g_{ms} \\ 0 & 0 & -g_{ms} \end{bmatrix} \begin{bmatrix} V_p \\ V_n \\ V_z \end{bmatrix} \tag{1}$$

In the given matrix, the parameters g_mf and g_ms represent the tunable transconductance gains of the first and second stage respectively, and they are influenced by external currents supplied to the VDTA. The output current (Iz) is produced by converting the difference between the input voltages (Vp –Vn) using the transconductance gain g_mf. Different methods have been utilized for the realization of VDTA. Figure 2 [5] depicts the implementation of the VDTA.

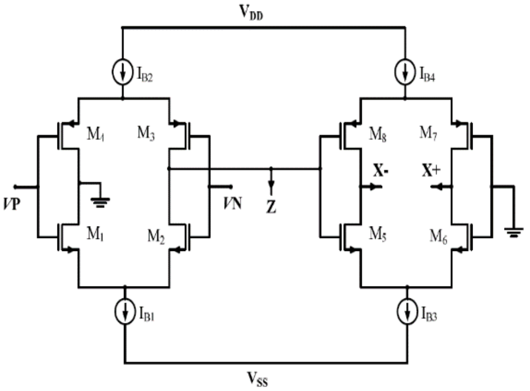

Fig. 2: VDTA Internal Architecture

The transconductance parameters derived through this structure are shown as:

$$g_{mf} = \left(\frac{g_1 g_2}{g_1+g_2}\right) + \left(\frac{g_3 g_4}{g_3+g_4}\right) \tag{2}$$

$$g_{ms} = \left(\frac{g_5 g_6}{g_5+g_6}\right) + \left(\frac{g_7 g_8}{g_7+g_8}\right) \tag{3}$$

where

$g_i = \sqrt{\frac{\mu C_{ox} W_i I_{Bi}}{L_i}}$ is the transconductance value.

In the equation above, I_Bi represents the bias current, μ denotes the effective carrier mobility, Cox corresponds to the gate-oxide capacitance, and W_i/L_i represents the effective channel length ratio of the i-th MOS transistor (where i = 1, 2, ..., 8).

2.1. VDTA-C Tow Thomas Biquad Filter

The figure provided in Fig. 3 illustrates the suggested arrangement of the multifunction voltage mode VDTA-C TT biquad filter. It enables the acquisition of both band-pass and low-pass filter responses concurrently. It may be noted that no resistors have been used in this configuration and the capacitors are grounded.

The analysis of the proposed circuit configuration yields the following output transfer function for band-pass filter:

$$T_{BP}\,(s) = \frac{V_{BP}}{V_{in}} = \frac{-\left(\frac{g_{mf1}}{C_1}\right)s}{s^2+s\left(\frac{g_{ms1}}{C_1}\right)+\left(\frac{g_{mf3}\,g_{mf2}}{C_1C_2}\right)} \tag{4}$$

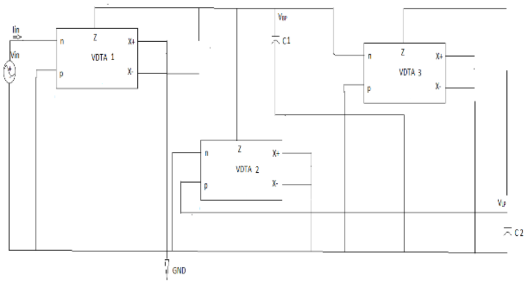

Fig. 3: VDTA-C based voltage mode Tow – Thomas biquad filter

Similarly, the transfer function of a low-pass filter can be derived as follows:

$$T_{LP}\,(s) = \frac{V_{LP}}{V_{in}} = \frac{\left(\frac{g_{mf1}\,g_{mf3}}{C_1C_2}\right)}{s^2+s\left(\frac{g_{ms1}}{C_1}\right)+\left(\frac{g_{mf3}\,g_{mf2}}{C_1C_2}\right)} \tag{5}$$

The filter parameters namely the pole frequency (ω0), Bandwidth (BW) and quality factor (Q), can be mathematically expressed as follows:

$$\omega_0 = \sqrt{\frac{g_{mf3}\,g_{mf2}}{C_1C_2}} \tag{6}$$

$$BW = \frac{g_{ms1}}{C_1} \tag{7}$$

$$Q = \sqrt{\frac{C_1\;g_{mf2}}{C_2 g_{mf3}}} \tag{8}$$

The DC gain for low pass response is given by:

$$H_{LP} = \frac{g_{mf1}}{g_{mf2}} \tag{9}$$

where g_mf1 and g_ms1 are first and second stage transconductance gain of VDTA1 and g_mf2 〖,g〗_mf3 are first stage transconductance gains of VDTA2 and VDTA3 block respectively.

In the case of a low-pass filter, it is possible to adjust the pole frequency and DC gain independently without any mutual interference, as demonstrated by equations (6), (7), and (9). Similarly, for a band-pass filter, we have observed the ability to independently tune the pole frequency and center frequency gain.

3. Simulation Results

The proposed circuit is simulated using gpdk 180 nm CMOS process in the Cadence virtuoso environment. The implementation of VDTA is done using given MOS transistor aspect ratio in Table 1. The supplied value of biasing is 150μA and at the supply voltage Vdd = +0.9V and Vss =-0.9V. The cutoff frequency is obtained as 10MHz using capacitor values as, C1 = C2 = 15pF. A sinusoidal

waveform of amplitude 1V and 100 KHZ is applied to the given circuit. The ideal Simulation results show that this choice yields transconductance values of VDTA as g_mf = g_ms= = 636.3 μA/V and the parasitic capacitance at the Z terminal is specified as Cp = 0.15 pF. The DC transfer characteristic is shown in the Fig. 4.

Table 1

MOS- Transistor Aspect Ratios (W/L) of VDTA

S.No	**Transistors**	**L (μm)**	**W (μm)**
1	M_1 - M_2 - M_5 - M_6	0.36	3.6
2	M_3 - M_4 - M_7 - M_8	0.36	16.64

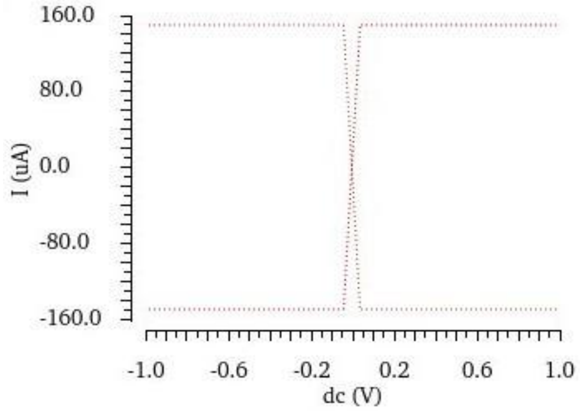

Fig. 4: DC characteristics of VDTA

The frequency response of band-pass and low pass filter is shown in Fig. 5. The phase response of band-pass filter is also obtained and can be seen in Fig. 6. The transient response of the filter is also obtained as shown in Fig. 7.

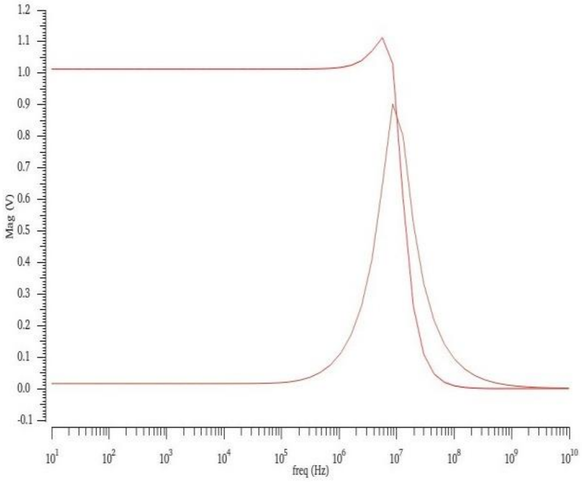

Fig. 5: Frequency response of TT Biquad filter

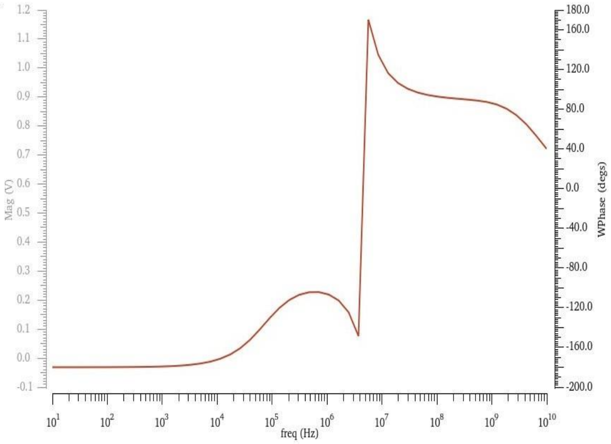

Fig. 6: Phase response of Band Pass Filter

Since the inverse configuration is obtained, we are aving 180 dergree phase change as we can see from the phase response and also from the transient response as seen in fig 8.

Table 2 - Comparision of TT biquad circuit based on number of components used

Active elements	**No. of blocks**	**Resistors**	**Capacitor**	**Gain Control**
OTA	3	6	2	Yes
OTRA	2	4	2	Yes
CCII	3	4	2	Yes
DVCC	3	3	2	No
VDCC	2	5	2	Yes
VDTA (Proposed)	3	0	2	Yes

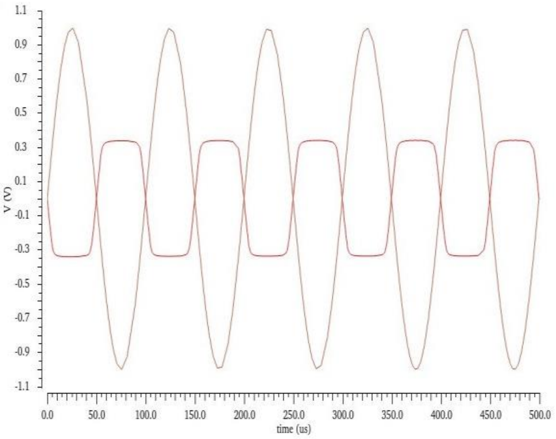

Fig. 7: Transient response of Band Pass Filter

4. Conclusion

The VDTA-C Tow-Thomas biquad presented in this paper makes use of an optimal combination of active and passive elements. Table 2 presents a comparison of various voltage mode TT biquad filter configurations, considering different numbers of active building blocks and passive elements.Noted point is that resistor is not used in this proposed configuration. The independent tunability is also demonstrated and the high frequency performance is required which can be seen in simulation results obtained from Cadence Virtuoso environment.

References

[1] Ahmed M. Soliman, "History and progress of the Tow-Thomas biquadratic filter part II: OTRA, CClI, and DVCC realizations", World Scientific, Journal of circuits, systems, and computers, Vol. 17, No.5, 2008.

[2] Dalibor Biolek, Raj Senani, Viera Biolkova, Zdenek Kolka,"Active elements for analog signal processing Classification, Review and New Proposals" Radioengineering, Vol.17, No.4, December 2008.

[3] Adel S. Sedra, Kenneth C. Smith, "Microelectronics circuits - theory and applications", Oxford University Press, 2013.

[4] Dinesh Prasad, Javed Ahmad, "New electronically-controllable lossless synthetic floating inductance circuit using single VDCC", Scientific Research, Circuits and Systems, 2014, 5, 13-17, January 2014.

[5] A. Yesil, F. Kacar, H. Kuntman, New simple CMOS realization of voltage differencing transconductance amplifier and its RF filter application. Radioengineering 20(3), 632–637 (2011)

[6] M. Srivastava, D. Prasad, Laxya and A. K. Sharma, "Novel Active Circuit for Realizing Variable Grounded Passive Elements," 2016 International Conference on Micro-Electronics and Telecommunication Engineering (ICMETE), 2016, pp. 559-563, doi: 10.1109/ICMETE.2016.110.

[7] D. Prasad et al., "Novel active PID controller employing VDTA," 2016 IEEE International Symposium on Signal Processing and Information Technology (ISSPIT), 2016, pp. 286-289, doi: 10.1109/ISSPIT.2016.7886050.

[9] K. Roja, M. Sarada and A. Srinivasulu, "A Voltage Mode All Pass Filter Employing Voltage Difference Transconductance Amplifier," 2018 10th International Conference on Electronics, Computers and Artificial Intelligence (ECAI), 2018, pp. 1-4, doi: 10.1109/ECAI.2018.8679013.

[10] O. Channumsin and W. Tangsrirat, "Electronically Controllable SITO Multifunction Filter with Single VDTA," 2018 International Conference on Engineering, Applied Sciences, and Technology (ICEAST), 2018, pp. 1-4, doi: 10.1109/ICEAST.2018.8434433.

[11] P. Moonmuang, S. Unhavanich and W. Tangsrirat, "Simple Current-Controlled VDTA-R Schmitt Trigger Circuit," 2019 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST), 2019, pp. 1-4, doi: 10.1109/ICEAST.2019.8802589.

[12] M. Faseehuddin, J. Sampe, S. Shireen and S. H. M. Ali, "Lossy and lossless inductance simulators and universal filters employing a new versatile active block", Informacije MIDEM, vol. 48, no. 2, pp. 97-113, 2018.

[13] "Grounded and Floating Inductance Simulation Circuits Using VDTA written by Dinesh Prasad, D. R. Bhaskar published by Circuits and Systems, Vol.3 No.4, 2012S,

[14] Tiwari and T. Singh Arora, "Dual-Mode Sinusoidal Oscillator Employing Single-Active Element and Grounded Capacitors," 2021 IEEE International Conference on Technology, Research, and Innovation for Betterment of Society (TRIBES), 2021, pp. 1-5, doi: 10.1109/TRIBES52498.2021.9751652.

[15] T. Pukkalanun, P. Moonmuang and W. Tangsrirat, "Grounded Series/Parallel RL/RC Immittance Simulations with a Single VDTA," 2022 19th International Conference on Electrical Engineering/Electronics, Computer Telecommunications and Information Technology (ECTI-CON), 2022, pp. 1-4, doi: 10.1109/ECTI-CON54298.2022.9795367.