An MOS-C Multifunction Filter Employing DXCCTA for High-Frequency Operation

Karam Bharat Singh, Manoj Joshi, and Ashish Ranjan

Abstract This article introduces a biquad multifunction filter using an advanced current-mode building block termed as "Dual X Current Conveyor Transconductance Amplifier (DXCCTA)" which is a combination of dual X second generation Current Conveyor (DXCCII) followed by Operational Transconductance Amplifier (OTA). Single Input Multiple Output (SIMO) characteristics of the multifunction filter produce the filter responses and come with a single DXCCTA block with few grounded capacitors along with MOS-based resistors. All high-frequency responses of biquad multifunction filters are verified using CMOS model of DXCCTA as well as experimental verification using off the shelf ICs AD844 as "Current Feedback Operational Amplifier" and CA3080 as "Operational Transconductance Amplifier".

Keywords DXCCTA · Multifunction filter · CFOA/ICAD844 · OTA/CA3080 · Frequency response

1 Introduction

An advance active block dominance in the current scenario is now considered as an important active device in microelectronics engineering which gives a suitable platform for the generation of signal processing circuits viz. active filters [1–13], oscillators [14–16], Schmitt trigger [17, 18], chaotic circuits [19, 20], active inductor design [21] and many more. Initially, voltage-mode op-amp has the major contribution for almost every electronic circuits but after the emergence of current-mode circuits [22] became a new trend for the design of active mode circuitry with low power dissipation, greater linearity, inbuilt tunability, wide bandwidth, higher frequency of

K. B. Singh (✉) · M. Joshi · A. Ranjan
National Institute of Technology Manipur, Imphal, India
e-mail: karambharatsingh@gmail.com

M. Joshi
e-mail: manojjoshi1506@gmail.com

A. Ranjan
e-mail: ashish.ism@rediffmail.com

P. K. Mallick et al. (eds.), *Electronic Systems and Intelligent Computing*, Lecture Notes in Electrical Engineering 686, https://doi.org/10.1007/978-981-15-7031-5_13

operation and few others [23]. Some very popular advance active blocks are CCII [1, 4], CCCII [10], OTRA [24], FTFN [7, 13], CDTA [8], VDCC [9], DVCC [3, 12], CCTA [5], DDCCTA [25], DVCCTA [26], DXCCTA [27], FTFNTA [28] and few other. A wide array of second-order filters is available and can be treated as the fundamental filter circuitry in the analog domain. Moreover, literature is also enriched with different input–output combination filter as with SIMO [1–3], MISO [4–9] and MIMO [10–12]. In the case of multifunction filter, SIMO operation plays a significant role due to single input source which causes attractive design procedure without the selection of various input sources as in the case of MIMO and MISO. An intensive study of literature [1–28] have the following characteristics:

1. Excess number of active block elements [1, 2, 5, 6, 11]
2. More input signal to realize output filter [7–9]
3. Absence of electronic tenability [1, 24]
4. Low cut off frequency response [1, 4, 8, 24]
5. Component mismatch and circuit topology to get different responses [1, 5–9]
6. Necessary to use external passive components for measurement of different filter responses in current-mode topology [27].

This research paper brings a SIMO filter topology for the multifunction filter responses viz. Low pass (LP), Band Pass (BP) and High Pass (HP) filter by utilizing active MOS resistors and grounded capacitors with single active block DXCCTA. The proposed design is suitable for a very high-frequency operation up to 200 MHz. The examination of the frequency test of the multifunction filter is well executed through PSPICE simulation. An experimental test of the filter is also examined by using the ICAD844 and CA3080 to construct the DXCCTA for filter operation.

2 Circuit Description

A DXCCTA active block comprises a combination of DXCCII and an OTA. The schematic of DXCCTA and its internal MOS-based design is shown in Fig. 1, where the port characteristics can be mathematically defined as:

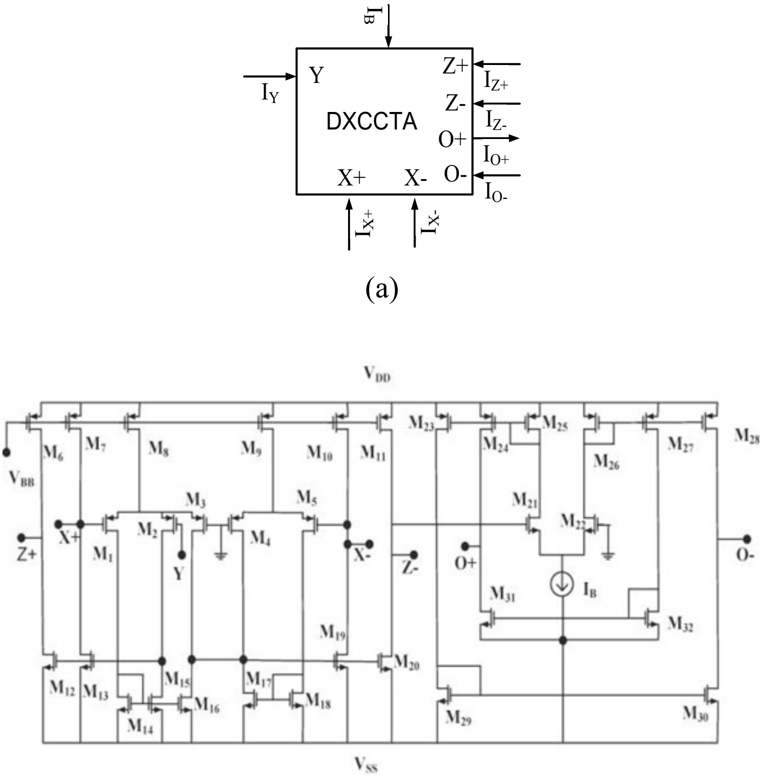
$$I_Y = 0, I_{X\pm} = I_{Z\pm}, V_{X\pm} = \pm V_Y, I_{O\pm} = \pm g_m V_{Z^-} \quad (1)$$

where g_m corresponds transconductance of DXCCTA and expressed as:

$$g_m = \sqrt{\mu_n C_{OX} \frac{W}{L} I_{\mathrm{B}}} \quad (2)$$

The term $\mu_{n,}$ C_{OX} and W/L are the conventional parameters of a MOSFET and I_{B} be the input bias current.

A simple filter of the proposed SIMO filter is shown in Fig. 2. Where Z_1, Z_2 and



(a)

(b)

Fig. 1 DXCCTA **a** Schematic symbol, **b** internal CMOS circuit

Z_3 represent the impedance term. Z_1 and Z_3 be the parallel combination of the active MOS resistor and capacitor and Z_2 be an active MOS resistor.

$$\left.\begin{aligned} Z_1 &= R_{\text{MOS1}} \left\| \frac{1}{sC_1} \right. = \frac{R_{\text{MOS1}}}{1 + sC_1 R_{\text{MOS1}}} \\ Z_2 &= R_{\text{MOS2}} \\ Z_3 &= R_{\text{MOS3}} \left\| \frac{1}{sC_3} \right. = \frac{R_{\text{MOS3}}}{1 + sC_3 R_{\text{MOS3}}} \end{aligned}\right\} \tag{3}$$

The MOS resistor exhibits a numerical resistance value in the saturation region as:

$$R_{\text{MOS}} = \frac{1}{2\mu_n C_{OX}\left(\frac{W}{L}\right)(V_{\text{GS}} - V_{\text{Th}})} \tag{4}$$

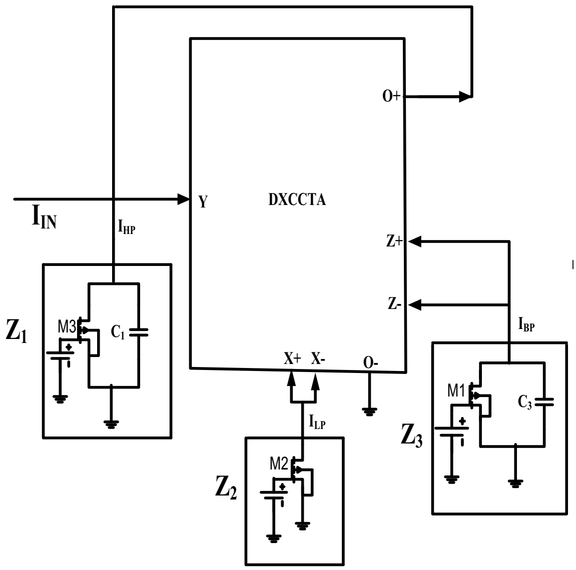


Fig. 2 Proposed MOS-C current-mode multifunction filter

A simple routine analysis gives the transfer functions for LP, BP and HP as:

$$T_{\mathrm{LP}}(s) = \frac{I_{\mathrm{LP}}}{I_{\mathrm{IN}}} = \frac{\frac{g_m}{R_{\mathrm{MOS1}} R_{\mathrm{MOS2}} R_{\mathrm{MOS3}} C_1 C_3}}{s^2 + \frac{g_m}{R_{\mathrm{MOS2}} C_3} s + \frac{g_m}{R_{\mathrm{MOS1}} R_{\mathrm{MOS2}} R_{\mathrm{MOS3}} C_1 C_3}} \tag{5}$$

$$T_{\mathrm{BP}}(s) = \frac{I_{\mathrm{BP}}}{I_{\mathrm{IN}}} = \frac{\frac{g_m}{R_{\mathrm{MOS2}} C_3} s}{s^2 + \frac{g_m}{R_{\mathrm{MOS2}} C_3} s + \frac{g_m}{R_{\mathrm{MOS1}} R_{\mathrm{MOS2}} R_{\mathrm{MOS3}} C_1 C_3}} \tag{6}$$

$$T_{\mathrm{HP}}(s) = \frac{I_{\mathrm{HP}}}{I_{\mathrm{IN}}} = \frac{s^2}{s^2 + \frac{g_m}{R_{\mathrm{MOS2}} C_3} s + \frac{g_m}{R_{\mathrm{MOS1}} R_{\mathrm{MOS2}} R_{\mathrm{MOS3}} C_1 C_3}} \tag{7}$$

The above equations of the filter function give the pole frequency (ω_0) and quality factor (Q_0) as:

$$\omega_0 = \sqrt{\frac{g_m}{R_{\mathrm{MOS1}} R_{\mathrm{MOS2}} R_{\mathrm{MOS3}} C_1 C_3}} \tag{8}$$

$$Q_0 = \sqrt{\frac{R_{\mathrm{MOS2}} C_3}{g_m R_{\mathrm{MOS1}} R_{\mathrm{MOS3}} C_1}} \tag{9}$$

Here, the performance of (ω_0) and (Q_0) can be electronically tunable with a bias current that tune g_m and bias voltage for MOS resistors.

3 Non-Ideal Study

To study the non-ideal analysis, we have examined the transfer function using non-ideal characteristic of DXCCTA. In non-ideal characteristic condition, DXCCTA port relation is express as [27]

$$I_Y = 0,\ I_{X\pm} = \alpha I_{Z\pm},\ V_X = \pm\beta V_Y,\ I_{O\pm} = \pm\gamma g_m V_{Z^-}; \tag{10}$$

where (α, β and γ) be the current transfer gain, non-ideal voltage-transfer gains and transconductance inaccuracies present in the DXCCTA, respectively. By using non-ideal parameters (α, β and γ), the current-mode LP, BP and HP transfer function of the multifunction filters are observed as:

$$T_{\mathrm{LP}}(s)|_{\alpha,\beta,\gamma} = \left.\frac{I_{\mathrm{LP}}}{I_{\mathrm{IN}}}\right|_{\alpha,\beta,\gamma} = \frac{\frac{\alpha\beta\gamma g_m}{R_{\mathrm{MOS1}}R_{\mathrm{MOS2}}R_{\mathrm{MOS3}}C_1C_3}}{s^2 + \frac{\gamma g_m}{R_{\mathrm{MOS2}}C_3}s + \frac{\alpha\beta\gamma g_m}{R_{\mathrm{MOS1}}R_{\mathrm{MOS2}}R_{\mathrm{MOS3}}C_1C_3}} \tag{11}$$

$$T_{\mathrm{BP}}(s)|_{\alpha,\beta,\gamma} = \left.\frac{I_{\mathrm{BP}}}{I_{\mathrm{IN}}}\right|_{\alpha,\beta,\gamma} = \frac{\frac{\alpha\gamma g_m}{R_{\mathrm{MOS2}}C_3}s}{s^2 + \frac{\gamma g_m}{R_{\mathrm{MOS2}}C_3}s + \frac{\alpha\beta\gamma g_m}{R_{\mathrm{MOS1}}R_{\mathrm{MOS2}}R_{\mathrm{MOS3}}C_1C_3}} \tag{12}$$

$$T_{\mathrm{HP}}(s)|_{\alpha,\beta,\gamma} = \left.\frac{I_{\mathrm{HP}}}{I_{\mathrm{IN}}}\right|_{\alpha,\beta,\gamma} = \frac{\alpha s^2}{s^2 + \frac{\gamma g_m}{R_{\mathrm{MOS2}}C_3}s + \frac{\alpha\beta\gamma g_m}{R_{\mathrm{MOS1}}R_{\mathrm{MOS2}}R_{\mathrm{MOS3}}C_1C_3}} \tag{13}$$

In this case, (ω_0) and (Q_0) becomes

$$\omega_0|_{\alpha,\beta,\gamma} = \sqrt{\frac{\alpha\beta\gamma g_m}{R_{\mathrm{MOS1}}R_{\mathrm{MOS2}}R_{\mathrm{MOS3}}C_1C_3}} \tag{14}$$

$$Q_0|_{\alpha,\beta,\gamma} = \sqrt{\frac{\alpha\beta\gamma R_{\mathrm{MOS2}}C_3}{\gamma g_m R_{\mathrm{MOS1}}R_{\mathrm{MOS3}}C_1}} \tag{15}$$

The influence of non-ideal parameter is reflected in (ω_0) and (Q_0). Moreover, the active and passive sensitivity of (ω_0) and (Q_0) are observed as:

$$\left.\begin{array}{l} S^{\omega_0}_{\alpha,\beta,\gamma,g_m} = \frac{1}{2},\ S^{\omega_0}_{R_{\mathrm{MOS1}},R_{\mathrm{MOS2}},R_{\mathrm{MOS3}},C_1,C_3} = -\frac{1}{2} \\ S^{Q_0}_{\alpha,\beta,R_{\mathrm{MOS2}},C_3} = \frac{1}{2},\ S^{Q_0}_{g_m,R_{\mathrm{MOS1}},R_{\mathrm{MOS3}},C_1} = -\frac{1}{2},\ S^{Q_0}_{\gamma} = 0 \end{array}\right\} \tag{16}$$

The sensitivity analysis (16) shows a low value that corresponds to good performances for filter design.

4 Simulation Results

To confirm the theoretical analysis, both simulation and experimental tests are performed for a multifunction filter. The first section of validation is done through PSPICE simulation in which DXCCTA is integrated with 0.18 μm CMOS TSMC parameters with supply voltage ±1.25 V and bias voltage 0.43 V.

Multifunction filter frequency response for LP, BP and HP is observed for a very high frequency in the range of 100 MHz. The active resistor have 1 KΩ reactance value and traditional capacitance with 1 pF exhibits ω_0 of 177 MHz with a response in Fig. 3. The filter frequency response of BP filter is below 0 dB which can be improved by varying the bias current I_B values which gives freedom for independent gain control behaviour. The gain variation with different I_B values is well observed in Fig. 4 for the BP filter. Also, an experimental test for DXCCTA blocks is realized with CFOA (ICAD844) and OTA (CA3080) as shown in Fig. 5.

A time-domain verification for filter is performed for ω_0 100 MHz by selecting the components values for the LP filter as $R_{MOS1} = R_{MOS2} = R_{MOS3} = 2$ KΩ and $C_1 = C_2 = 1$ pF. As we have designed for 100 MHz cut off frequency, the filter output can pass the input signal which is less than 100 MHz frequency in LP filter. Figure 6 shows the experimental result of a LP transient response for 50 MHz input supply. For LP filter the input and output waveform will be in phase as shown in Fig. 6.

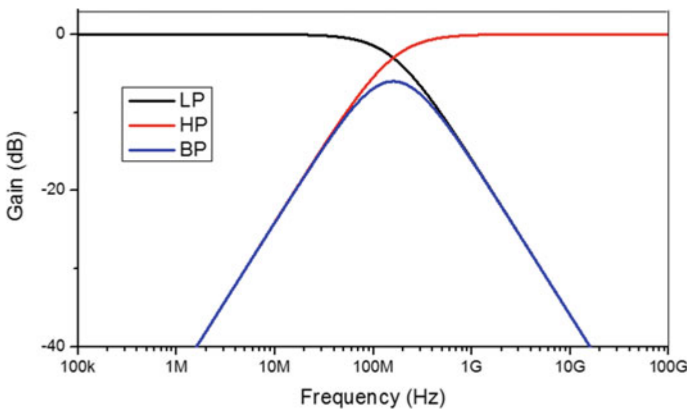


Fig. 3 Proposed CM-MF frequency response

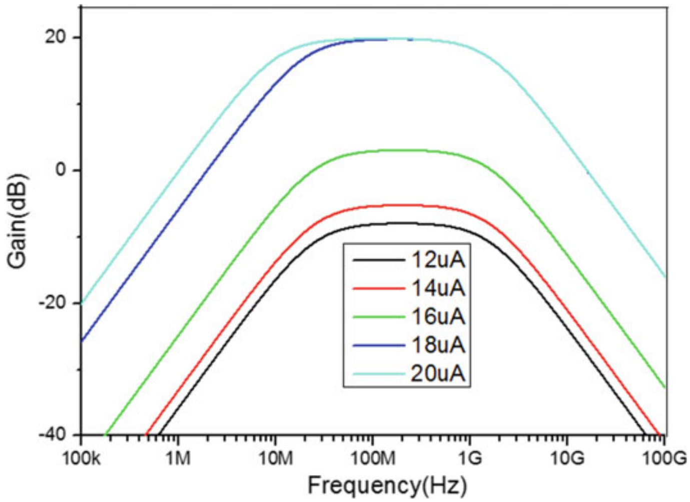
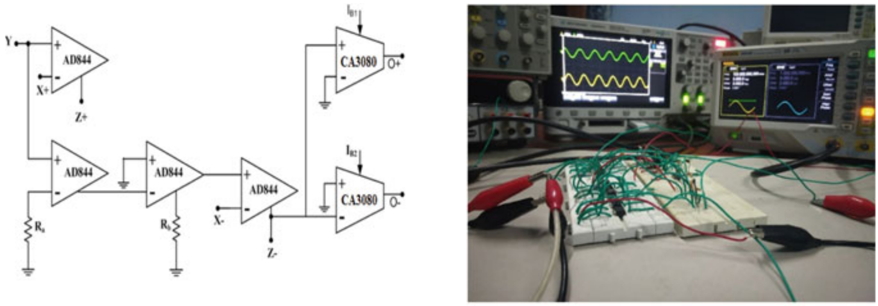


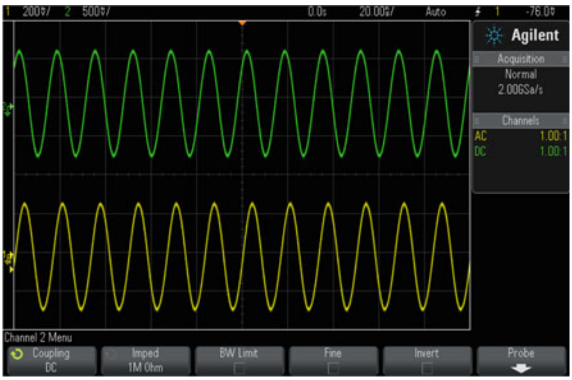
Fig. 4 Gain variation in BP with different bias current I_O



(a) (b)

Fig. 5 DXCCTA using ICAD844 and CA3080 for experimental test. **a** Circuit diagram, **b** physical experiment set up

Fig. 6 Experimental LP transient response for 50 MHz input



5 Conclusion

This article brings a high-frequency second-order filter using MOS resistors and capacitors. The behaviour of the proposed design is simulated with the PSPICE simulation by utilizing TSMC 0.18 μm technology and experimentally performed using off the shelf ICs. The influence of non-ideal behaviour is also observed. The results follow a close agreement with the theoretical prediction. Some useful characteristics of the proposed filter are as follows:

1. Use of single DXCCTA.
2. With less passive components.
3. High-frequency response in 100 MHz.
4. Provides electronic tunability by using bias current.
5. No need to disturb the input signal for different output responses.
6. Suitable for LP, BP and HP filters.

Acknowledgements This work is supported by the Third Phase of Technical Education Quality Improvement Program (TEQIP-III) under the Collaborative Research Scheme (CRS ID: 1-5728068886), National Project Implementation Unit (NPIU), a unit of Ministry of Human Resource Development (MHRD), Government of India for implementation of World Bank assisted projects in technical education.

References

1. Cicekoglu O (1999) Multifunction filters using three current conveyors. Microelectron J 30:15–18
2. Chen HP (2014) Voltage-mode multifunction biquadratic filter with one input and six outputs using two ICCIIs. Sci World J (2014)
3. Abaci A, Yuce E (2016) Second-order voltage-mode universal filters using two DVCCs, two grounded capacitors and four resistors. J Circ Syst Comput 25(12)
4. Ozcan S, Kuntman H, Cicekoglu O (2000) A novel multi-input single-output filter with reduced number of passive elements using single current conveyor. In: Proceedings of the 43rd IEEE midwest symposium on circuits and systems, vol 3, pp 1030–1032
5. Tomar RS, Singh SV, Chauhan DS (2013) Current processing current tunable universal biquad filter employing two CCTAs and two grounded capacitors. Circ Syst 4:443–450
6. Ranjan A, Paul SK (2011) Voltage mode universal biquad using CCCII. Active Passive Electron Compon
7. Ranjan A, Perumalla S, Kumar R, John V, Yumnam S (2019) Second order universal filter using four terminal floating nullor (FTFN). J Circ Syst Comput 28
8. Shah NA, Quadri M, Iqbal SZ (2007) CDTA based universal transadmittance filter. Analog Integr Circ Signal Process 52:65–69
9. Uttaphut P (2018) Single VDCC-based electronically tunable voltage-mode second order universal filter. Przeglad Elektrotechniczny 1(4):24–27
10. Tangsrirat W (2007) Current-tunable current-mode multifunction filter based on dual-output current-controlled conveyors. AEU-Int J Electron Commun 61:528–533
11. Abaci A, Yuce E (2017) A new DVCC+ based second-order current-mode universal filter consisting of only grounded capacitors. J Circ Sys Comput 26

12. Horng JW, Jhao ZY (2013) Voltage-mode universal biquadratic filter using single DVCC. Hindawi Publishing Corporation, ISRN Electronics, London
13. Abuelmaatti AT (2000) Universal current-mode filter using single four-terminal floating nullor. Microelectron J 31(2):123–127
14. Joshi M, Bhatt V, Ranjan A, Benjwal P (2017) Realization of Colpitts oscillator using second generation current controlled current conveyor. In: The second international conference on research in intelligent and computing in engineering, pp 49–52
15. Kumari A, Ranjan A (2018) Realization of extra-X current controlled current conveyor based resistorless quadrature sinusoidal oscillator. Int J Appl Eng Res 13:80–84
16. Ghosh M, Bhattacharya S, Ranjan A, Paul SK (2011) CMOS sinusoidal oscillator using current conveyor. In: Proceedings of international colloquiums on computer electronics, electrical, mechanical and civil, Kerala, India
17. Ranjan A, Pamu H, Tarunkumar H (2018) A novel Schmitt trigger and its application using a single FTFN. Analog Integr Circ Signal Process 1–13
18. Pamu H, Ranjan A, Tarunkumar H (2018) Realization of schmitt trigger using IC AD844 based differential voltage current conveyor transconductance amplifier. In: Proceedings of international conference on innovations in electrical, electronics, power, smart grids and advanced computing technologies, 9–10 Mar 2018
19. Joshi M, Ranjan A (2019) An autonomous chaotic and hyperchaotic oscillator using OTRA. Analog Integr Circ Sig Process 101:401–413
20. Joshi M, Ranjan A (2018) Realization of multi scroll 2D chaotic oscillator using DVCC. In: Lecture notes in electrical engineering, vol 553, pp 1093–1101
21. Kumar N, Vista J, Ranjan A (2019) A tuneable active inductor employing DXCCTA: grounded and floating operation. Microelectron J 90:1–11
22. Sedra A, Smith KC (1970) A second-generation current conveyor and its applications. IEEE Trans Circ Theory 17:132–134
23. Toumazou C, Lidgey FJ, Haigh DG (1993) Analogue IC design: the current-mode approach. In: IEEE circuit and system series, vol 2. Peter Peregrinus Ltd., London, UK, pp 1–666
24. Bhatt V, Benjwal P, Joshi M (2017) OTRA based second order universal filter and its optimization like Butterworth, Chebyshev and Bessel. In: Second International conference on research in intelligent and computing in engineering, vol 10, pp 143–150
25. Pandey N, Paul SK (2011) Differential difference current conveyor transconductance amplifier: a new analog building block for signal processing. J Electr Comput Eng
26. Pandey N, Paul SK (2011) VM and CM universal filters based on single DVCCTA. Active Passive Electron Compon
27. Chaturvedi B, Kumar A (2016) DXCCTA: a new active element. In: 1st IEEE international conference on power electronics. intelligent control and energy systems
28. Tarunkumar H, Singh YS, Ranjan A (2019) An active inductor employing a new four terminal floating nullor transconductance amplifier (FTFNTA). Int J Electron

Karam Bharat Singh was born in 1994. He received his Bachelor of Technology in 2017 from the Department of Electronics and Communication Engineering, North Eastern Regional Institute of Science and Technology (NERIST), Nirjuli, India. His research interests include Current-Mode Analog circuit and filter design, Mixed-signal IC design, low power VLSI design, etc. At present, He is pursuing Master of Technology in VLSI and Embedded System from the Department of Electronics and Communication Engineering, National Institute of Technology Manipur, Imphal, India.

Manoj Joshi was born in 1989. He received his B.Tech. degree in 2011 from the Department of Electronics and Instrumentation Engineering, DIT University, Dehradun, India, and M.Tech. degree in 2014 from BTKIT, Dwarahat (Uttarakhand Technical University, Dehradun). His research interests include current-mode analog circuits and study of Chaos Theory, Chaotic and Hyperchaotic oscillator, Fractional-Order Devices, Mixed-signal IC design, filter designs. At present, He is pursuing a Ph.D. in VLSI in Electronics and Communication Engineering Department, National Institute of Technology Manipur, Imphal, India.

Ashish Ranjan was born in 1986. He received his Doctor of Philosophy (Ph.D.) degree in 2013 from the Department of Electronics Engineering, Indian Institute of Technology (Indian School of Mines), Dhanbad, India. His research interests include current-mode analog circuits, the study of fractional-order circuit, chaotic oscillators, filter designs, etc. At present, he is Assistant Professor in Electronics and Communication Engineering Department, National Institute of Technology Manipur, Imphal, India.