A New Class of Bilateral SISO-(Single Input Single Output) Active Filters Targeted for Health-Care Applications

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***Abstract*—Filter circuits from the very beginning have played a vital role in the broader areas of signal processing and communications systems. In the paper, a new paradigm of bilateral filtering has been presented. The scheme presents a new class of filters that have the ability to work on the either side of the device. The working of the presented circuits in this study commensurates to the working of the transceivers. The initial verification of the circuits was done using nodal analysis and then put for simulation verifications. The Active device used to realise the proposed circuits is the translinear circuit scheme of second generation current conveyor-CCCII. Basic filter signals like low-pass, high-pass, band-pass and band-stop responses were perceived and authenticate the theory proposed. The simulation work was done on Hspice tool using the 45nm PTM CMOS technology node. The detailed analysis of the proposed circuits is open for the readers in this study. The power consumption of the proposed circuits is in the range of 100-200μW with $\pm$1 V rail to rail voltages. The Proposed circuit is expected to get applicable as the major analog front-end circuit in numerous biomedical devices.**

***Index Terms*—Bilateral Active Filter circuits, Current Controlled Current Conveyor, Low Power Circuits, Transceiver Circuits**

Acronym Used;

CCCII—Current Controlled Current Conveyor.
SISO—Single Input Single Output.
TISO—Three Input Single Output.
SITO—Single Input Three Output.
WL—width and length.
RMS—Root mean square.
PTM—Predictive Modelling Technology

I. Introduction

In the past years, the researches are concerned in designing the compact and low complex front-end circuits for the biomedical circuits and systems.The machine human interaction has been very interesting from the very beginning by the debut study of Mead and Convey[1]. In the recent years the advancement in technology has grown so high, that printed integrated chips are put on the skin and monitored remotely[2-3]. A vast and wide classification of the trending integrated chips is presented and cited over these years[4-5]. Inaddition to, bulk of literature concerning the filter circuits is available in the literature with applications posed to signal processing, communication and biomedical devices. The circuits reported in the past with the name SISO-single input single output filters are available in good quality, but the term bilateral is seen very less literature. Likely in this study, the authors have presented a new paradigm and a new class of circuits, that have the ability to work on the either side of the device or the nodes. In literature, all the circuits presented have fixed input and one output nodes, however, the proposed circuits have the bilateral characteristics or in simpler terms, the nodes are interchangeable. Circuits proposed in this work are expected to work as the analog front-end circuits for biomedical devices and since mostly the resemblance of the bilateral SISO filters commensurates to the transceivers, therefore a targeted application that is expected from the proposed circuits is the expected application in ultrasound machine transponders as shown in Fig.1 below. The authors also notify in the public interest of all the readers and researchers, that these designs are at the initial stages of verifications and investigations subjected to the applicability in biomedical devices. However, the simulation results are interestingly and fare enough to upgrade to next level of the interdisciplinary research in these proposed designs.

In the past the researchers have tried best to utilise the filter circuits for multiple electronic applications. Several circuit schemes with the keywords SISO, SITO TISO are available. But the bilateral circuit scheme is missing in all these reported circuits.

In this work, the authors have tried to portray and present the concept of inverse filtering quite differently. The introspection of the scheme is projected at the changing of the function of the signal inverted (for instance, inverse of band-pass

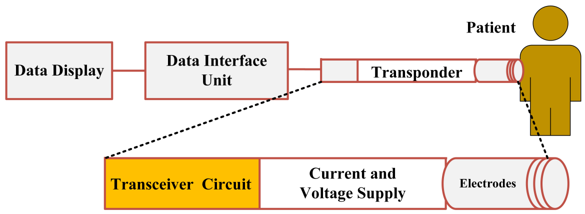

Fig. 1. Functional Block Diagram of the Proposed Projected Application

filter response has been considered as band-stop response and vice versa. Similar cases are also considered for low-pass and high-lass filter responses). Buffer filter response means the same stand of the response as initially observed (for example, a low-pass behavior on the either port of the circuit is taken as buffer response). Pertinently, it may be strongly noted down that the approach of inverse and buffer filtering in image processing applications is quite different from the circuit analysis study. The state of the art comparison with the already available literature is summarised in Fig.2. The

Literature	Active Element	Technology Node	Supply Voltage	Electronic Tunability	Result
[6]	VDGA	0.25µm CMOS	--	--	SITO
[7]	FB-VDBA	0.25µm CMOS	--	--	TISO
[8]	COA	0.18µm CMOS	±0.9V	Yes	SISO
[9]	CCCDCC/OTA	0.25µm CMOS	±3V	Yes	SISO
[10]	OTRA/3	0.35µm CMOS	±2.5V	Yes	SISO
[11]	VDBA/4	0.18µm CMOS	--	No	SISO
[12]	COA/8	0.35µm CMOS	±1.25	No	SISO
[13]	CCCII: 1 Design	45nmPTM/ 40nm SMIC	±1 V	Yes	Bilateral SISO
This Work	CCIII: 3 Designs	45nm PTM/Hspice	±1 V	Yes	Bilateral SISO

Fig. 2. State of the art comparison of the Previous reported related work

acronyms for various active devices mentioned in the Fig.2 are viz; variable gain distributed amplifier-VGDA,Current Operational Amplifier-COA, Operational transresistance amplifier-OTRA, Operational transconductance amplifier-OTA, Current Controlled Current Differencing Current Conveyor-CCCDCC and Voltage differencing buffered amplifier-VDBA.

II. Proposed Circuit Scheme: Design Considerations

The bilateral circuit scheme proposed in this study is implemented and verified using the active device second generation translinear current conveyor-CCCII. In the past years, tremendous literature has been published under the name current conveyor-CC, because of its outstanding features like, no need of analog to digital conversion, availability of full bandwidth, lesser delays etc.

The concept of the bilateral application of the circuits is to make the choice to the designers for the input and the output ports in a device. In broader terms, the nodes of the proposed circuits can work either as input or output depending on the need of the designer. The scheme we adopted in this work involves the theoretical verification of the proposed scheme in the form of a linear transfer function obtained by the nodal analysis of the circuits. Further, this study involves the paramount level of simulation analysis to prove the theory proposed. The legitimate bilateral behaviour was authenticated and analysed via the output filter responses. The two typical inverse and buffer filter responses are seen in all the designs proposed in this study and hence are suggested to support the theory of bilateral behaviour.

The overall designs suggested in this paper are analysed using the transistor level modelling. The translinear circuit scheme used to implement the suggested designs is the CCCII+ shown in Fig.4. Pertinently, it is worth to mention, current conveyor is a current mode device, that has the abstraction of three terminals. All the three nodes or terminals of the current conveyor have the characteristics of conveying the current and voltage across its terminals. For the case of second generation current conveyor; $I_y = 0$ $V_x = V_y + I_x.R_x$ $I_Z^+ = +I_x$ $I_Z^- = -I_x$ where I_x,V_x, I_z,V_z and I_y,V_z are the currents and voltages at the respective ports X, Y and Z.

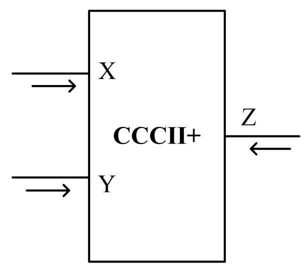

Fig. 3. Basic Block Diagram of the Second generation Current Conveyor

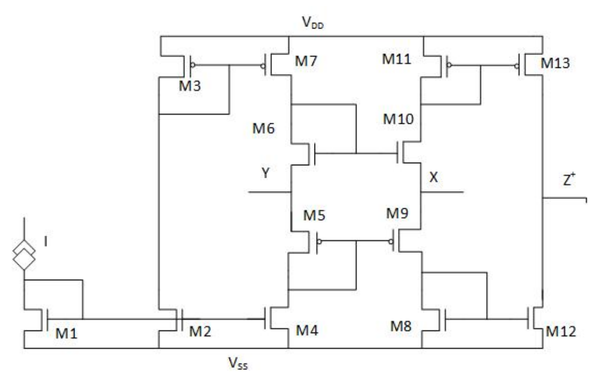

Fig. 4. Translinear Circuit Structure of the Second generation Current Conveyor[14]

The authors suggest the study commensurating to the working of the front-end designs of the traditional transceiver designs. The figures depicting the traditional and the suggested working scheme of the working of the transceivers is shown in the Fig.3 and Fig. 4 of the study.

A. Proposed Bilateral Circuits: Analysis and Discussion

This study presents three bilateral filter circuits, that are verified at the theoretical level and then put for simulation

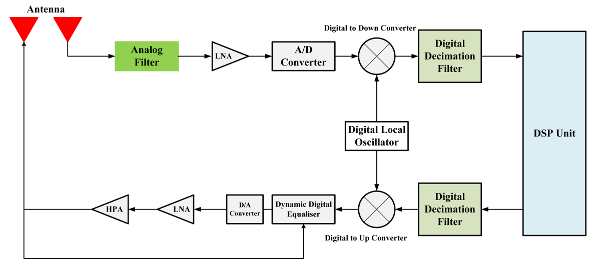

Fig. 5. Traditional Transceiver Design

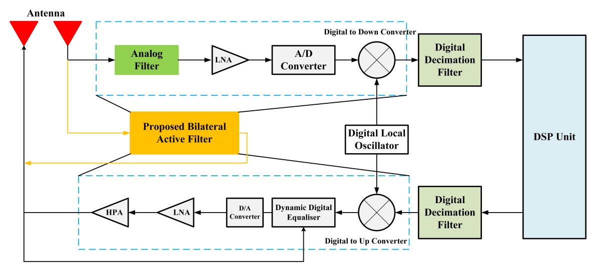

Fig. 6. Suggested Transceiver Design

purposes. The nodal analysis of the proposed designs leads to the final transfer function that helps to authentic the consistency of the circuits to a greater extent. Moreover, the parasitic components used in the designs have been minimised to the extreme lower values. All the designs were simulation in Hspice tool using the 45nm predictive modelling technology node. The nominal voltage supply in all the designs is set to $\pm$1V. The nodal analysis of the circuits is open for the readers, so as to enhance the publicity of the designs for the extended applications in the health-care systems. In the circuit shown in Fig.5, the nodal is excited by assuming the V_1 and V_2 as the two nodes of the design. In addition to, an assumption of the intrinsic resistances R_1 and R_2 for the two blocks of CCCII+ is made respectively.

$$\frac{V_1}{R_1} + (V_1 + V_2)SC_1 = 0 \tag{1}$$

$$V_1 + ((V_1 + V_3)SC_1.R_1) = 0 \tag{2}$$

$$V_1.((1 + SC_1.R_1) = V_3.SC_1R_1 \tag{3}$$

$$(V_3 - V_1)SC_1 + 2\frac{V_3 - V_2}{R_2} + \frac{V_1}{R_1} + (V_3 - V_2)SC_2 = 0 \tag{4}$$

$$V_3(SC_1.R_1.R_2 + 2(V_3 - V_2)R_1 + V_1.R_2 + (V_3 - V_2)SCR_1R_2 = 0 \tag{5}$$

$$V_3(SC_1.R_1.R_2 + SC_2R_1.R_2 + 2R_1) - V_1(SC_1R_1R_2 - R_2) - V_2(2R_1 + SCR_1R_2) = 0 \tag{6}$$

$$[SC_1R_1R_2 + SC_2R_1R_2 + 2R_1].V_1[\frac{1 + sC_1R_1}{SC_1R_1}] - V_1(SC_1R_1R_2 - R_2) = V_2(2R_1 + SC_2.R_1.R_2) \tag{7}$$

$$[SC_1R_1R_2 + SC_2R_1R_2 + 2R_1].V_1(1 + sC_1R_1) - V_1(SC_1R_1R_2 - R_2) = V_2(2R_1 + SC_2.R_1.R_2).SC_1R_1 \tag{8}$$

$$V_1[SC_1R_1R_2 + SC_2R_1R_2 + 2R_1].(1 + sC_1R_1) - V_1(S^2{C_1}^2{R_1}^2 R_2 - R_2) = V_2(2R_1 + SC_2.R_1.R_2).SC_1R_1 \tag{9}$$

The final transfer function obtained from analysing further is finalised as viz;

$$\frac{V_1}{V_2} = \frac{S^2.C_1.R_1.R_2 + 2SC_1R_1R_2 + SC_2R_2 + 2SC_1R_1}{S^2C_12R_1R_2} \tag{10}$$

where ”S” is the laplace factor.

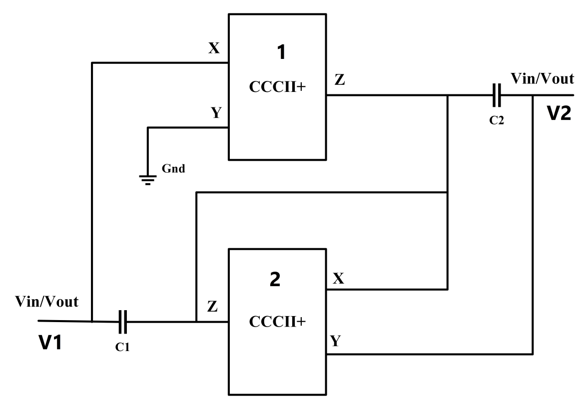

Fig. 7. Proposed Bilateral Filter circuit using CCCII+

We simulated the circuit shown in Fig.5 with the fixed width and length of MOS transistors. The circuit was comprehensively by keeping the input port V_1 and V_2 in two different individual cases. At the time V_1 was kept input, V_2 was analysed for the output reponses/results. The results perceived in the Fig.6 and Fig.7 are from the output ports V_2 and V_1. These responses clearly depict the inverse and buffer behaviour as already discussed above. Further, upon proper analysis, the 3db-bandwidth of all the filter responses lies in the range of several megahertz.

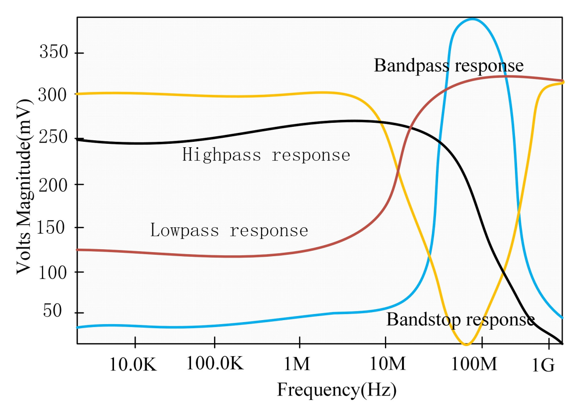

Fig. 8. Simulation results of the circuit shown in Fig.5, where V_2 is delivering the output results

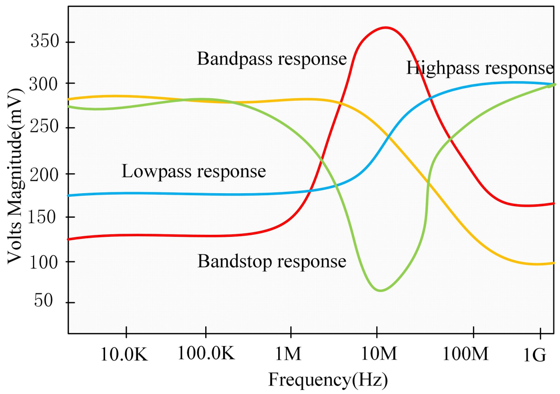

Fig. 9. Simulation results of the circuit shown in Fig.5, where V_1 is delivering the output results

B. Extended Bilateral Filter Circuits

Apart from the circuit shown in Fig.5, we did an extensive study to verify and investigate the results using the single CCCII+. Somehow, a success is seen at the cost of the resistor. The proposed design shown in Fig.8 is showing fully bilateral behaviour with two capacitors C_1, C_2 and one resistor R_1. The transfer function obtained during the nodal analysis of the proposed circuit is shown in equation 11.

$$\frac{V_1}{V_2} = \frac{S^2.C_1C_2 + S(C_1R_1 + C_2R_2 + 2C_2R_2 + R_1R_2}{S^2C_1C_2 + S(C_1R_1 + C_2R_2 - C_1R_2 + R_1R_2} \tag{11}$$

The uniformity of the results in either of the ports of the Fig.8

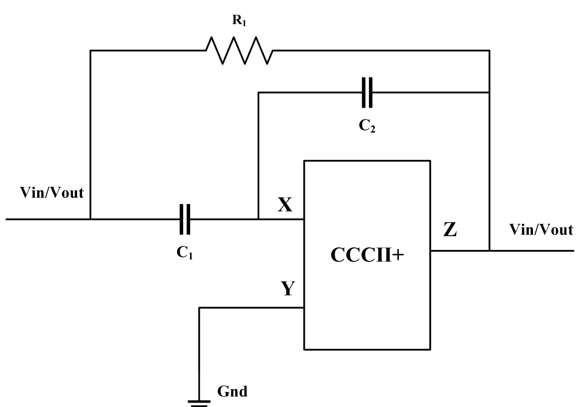

Fig. 10. Proposed Bilateral Filter circuit using CCCII+

makes it eligible for the bilateral-SISO filtering applications. Moreover the bandwidth of the output responses crosses the range of several megahertz, thereby making it eligible and sound for the biomedical applications. The results percieved in the Fig.9 and Fig.10 depict the bilateral behaviour of the proposed circuit clearly.

One more circuit shown in Fig.11 completely adopts the bilateral behaviour. The complete circuit implementation involves, one CCCII+, one resistor-R_1 and two capacitors, C_1 and C_2. The circuit also reflects a linear transfer function

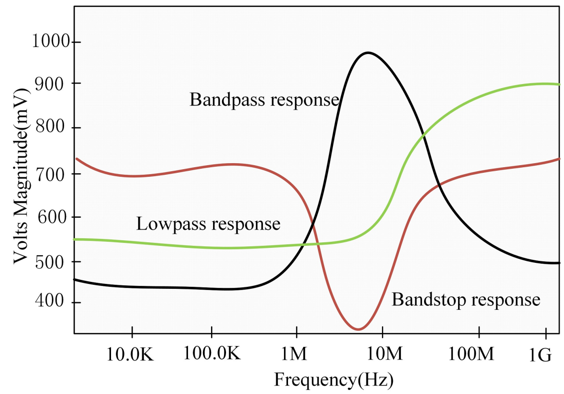

Fig. 11. Simulation results of the circuit shown in Fig.8, where V_2 is delivering the output results

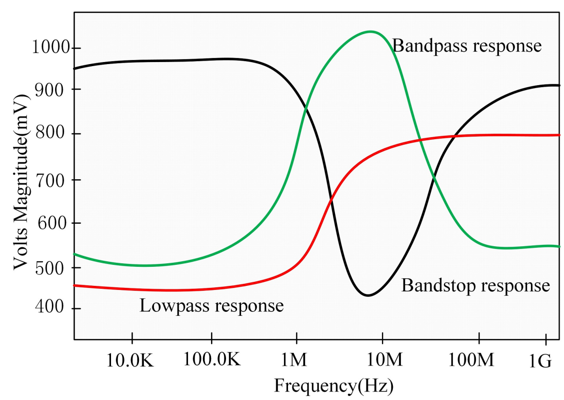

Fig. 12. Simulation results of the circuit shown in Fig.8, where V_1 is delivering the output results

and the bilateral behaviour via simulation analysis also. The circuits proposed in this section are also simulated in Hspice using 45nm PTM technology node with$\pm$1V rail to rail voltages. The simulation results also exploit the consistency of the circuit through bilateral-inverse and bilateral-buffer filter responses. A clear justification of the bilateral filtering can be seen in the Fig.8, Fig.9, Fig.12 and Fig.13. The filter respones in these figures are either inverse or buffer to each other. Inverse responses in this study have been set for the transformation of the response lowpass to highpass, bandpass to bandstop and viceversa. Further the bilateral buffer are meant for the same filter response perceived from the all nodes of the designs.

III. Conclusion

This study reports the bilateral active filters that have the tendency to deliver the outputs on the either side of the device. The proposed circuits are presented with complete verification by nodal analysis and supported by the simulation results. The authenticity of the bilateral behaviour is investigated through the bilateral-inverse and bilateral buffer filtering in this study. This work presents a unique kind of study, that is seen very less often in the reported literature before. The concept of flexility

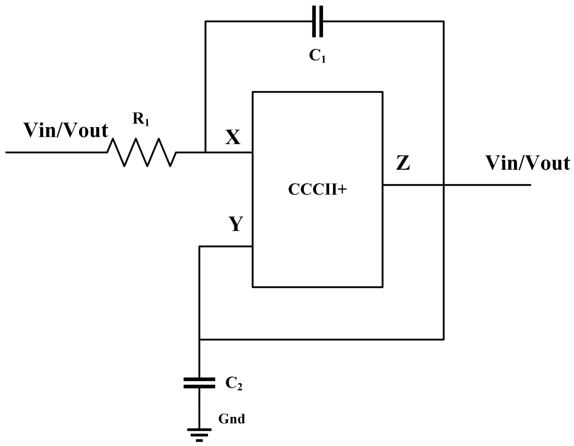

Fig. 13. Proposed Bilateral Filter circuit using CCCII+

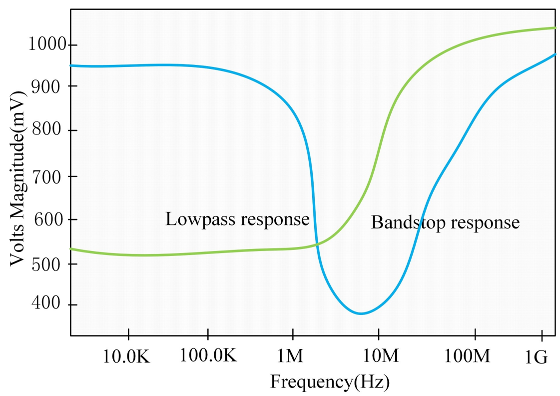

Fig. 14. Simulation results of the circuit shown in Fig.11, where V_2 is delivering the output results

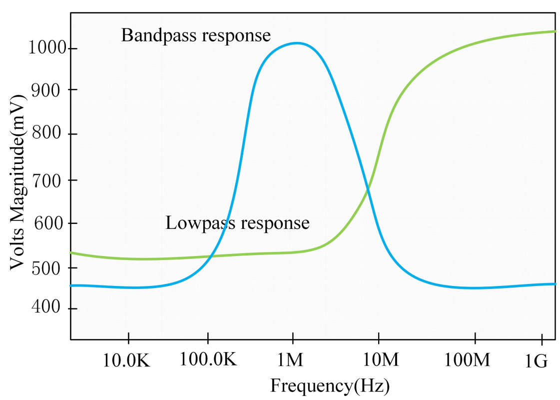

Fig. 15. Simulation results of the circuit shown in Fig.11, where V_1 is delivering the output results

of the ports/nodes in one device is merely available in the past research. All the proposed circuits reported in this study were simulated in Hspice tool using the 45nm predictive modelling technology node with ±1V rail to rail voltages. From the simulation results, the bandwidth of all the presented circuits crosses upto several megahertz. Concluding, these circuits are expected as suitable candidates for the targeted biomedical application.

References

[1] Mead, Carver, and Lynn Conway. "Introduction to VLSI systems." (1980).
[2] Hosseini, Ensieh S., et al. "Biodegradable materials for sustainable health monitoring devices." ACS Applied Bio Materials 4.1 (2020): 163-194.
[3] Iqbal, S.M.A., Mahgoub, I., Du, E. et al. Advances in healthcare wearable devices. npj Flex Electron 5, 9 (2021).
[4] U. Mohammad, M. A. Awan, A. Bermak and F. Tang, "State-of-the-Art Light to Digital Converter Circuits Applicable in Non-Invasive Health Monitoring Devices to Combat COVID-19 and Other Respiratory Illnesses: A Review," in IEEE Sensors Journal, vol. 22, no. 10, pp. 9189-9197, 15 May15, 2022, doi: 10.1109/JSEN.2022.3164148.
[5] Butt, Muhammad A., Nikolay L. Kazanskiy, and Svetlana N. Khonina. "Revolution in Flexible Wearable Electronics for Temperature and Pressure Monitoring—A Review." Electronics 11.5 (2022): 716.
[6] O. Channumsin and W. Tangsrirat. SITO-Type High-Input Impedance Voltage-Mode Multifunction Filter Using Single Active Element[C]. In 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST), 2015.
[7] N. Roongmuanpha, T. Dumawipata and W. Tangsrirat. Triple-Input Single Output Electronically Controlled Voltage-Mode Biquadratic Filter[C]. In 5th International Conference on Engineering, Applied Sciences and Technology (ICEAST), 2019.
[8] C. Hasan and A. Gokcen. A new MOS-C multifunction filter and its third-order oscillator application[J]. Journal of Molecular Structure, 2020, 12(20): 128655.
[9] S. Li, J. Jiang, X. Zhou, et al. A novel current-mode versatile filter employing CCCDCC and MO-OTA[C]. IEEE 10th International Conference on ASIC-ASICON, 2013.
[10] A. Gokcen, S. Kılınc and U. Cam. Fully integrated universal biquads using operational transresistance amplifiers with MOS-C realization[J]. Turkish Journal of Electrical Engineering Computing Sciences, 2011,19(3).
[11] P. Gupta and R. Pandey, Single VDBA based multifunction filter[J]. International Journal of Control Theory and Applications, 2017, 10(6).
[12] H. Cicekli and A. Gokcen. Design of voltage-mode multifunction filter using single current operational amplifier(C). IEEE 22nd Signal Processing and Communications Applications Conference, 2014: 381-384.
[13] Mohammad, Umar, et al. "A New Tunable SISO Filter Designed in 40 nm CMOS for Bilateral Inverse and Buffer Filtering Applications." Journal of Circuits, Systems and Computers 30.13 (2021): 2150240.
[14] Yasin, Mohd Yusuf, and Bal Gopal. "High frequency oscillator design using a single 45 nm CMOS current controlled current conveyor (CCCII+) with minimum passive components." Circuits and systems 2.02 (2011): 53.