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Research paper

First Order and Second Order Universal Filter Using Four Terminal Floating Nullor

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Abstract

A new lower order voltage mode namely first order and second order filter employing a Four terminal floating nullor (FTFN) is reported using a single schematic structure. The proposed filter uses two FTFN block along with passive components for the realization of first order filter as well as second order filter. The frequency response of proposed filter depends on the voltage input and switches present in it. Realization of both first order and second order filter have advantage features incorporating no component adjustment, absence of non-ideal behaviour and low sensitivity. PSPICE simulations are well performed using 0.35 µm CMOS process provided by Austrian Micro Systems (AMS) BSIM3v3 technology and commercial IC AD844 followed by theoretical observation. Finally, experimental verification of the proposed filter is examined for the justification of our work with the help of commercially available IC AD844.

Keywords: *Commercial IC AD844; Four terminal floating nullor (FTFN); Lower order filter; PSPICE..*

1. Introduction

In recent time, a number of research papers are available in the field of current mode circuits that associates a variety of analog signal processing circuits. One of the most important analog signal processing circuit in analog circuit is current mode filters, due to its regular use in communication systems, audio video applications, anti-aliasing filter and much more, that possess high performance parameters like wide dynamic domain, low power dissipation, wide bandwidth, uses less area for chip design, linear in nature and many more in comparison to traditional voltage mode circuits [1,2]. Literature survey reveals that a variety of paper associated with first order and second order filter are well described in [3–21]. These filter structures utilizes advance current mode analog blocks for filter design namely second generation current conveyor (CCII) [3–6] that give first order all pass filter in [3] and multifunction filter in [4-6], second generation current controlled current conveyor (CCCII) based second order universal filter [7–10], differential voltage current conveyor (DVCC) based first order filter [11] and second order voltage mode universal filter [12], Operational Transresistance Amplifier (OTRA) transimpedance type first order all pass filter [13], current controlled current conveyor transconductance amplifier (CCCCTA) [14] that presents an electronically tunable current mode first order all pass filter and [15] presents a current tunable multifunction filter, current differencing buffered amplifier (CDBA) based cascadable multipurpose filter [16] and voltage differencing-differential input buffered amplifier (VD-DIBA) first order filter [17], differential difference current conveyor (DDCC) first order all pass filter [18], current mode first order all pass filter using current operational amplifier (COA) [19], active MOS transistor based universal second order filter [20], third generation current conveyor (CCIII) based transadmittance type first order all pass filter [21] and many others. However, one of the simple analog block that may be used for filter design is the four terminal floating nullor (FTFN), due to very simple structure [22–26] and one can easily examine the practical behaviour of the circuit that utilizes FTFN by using commercially available current feedback operational amplifier (CFOA) namely IC AD844 after simulation of the signal processing circuits. It exhibits several advantage over conventional voltage mode operational amplifier and current conveyor based circuit design [22,27]. Some of the analog filter designs based on FTFN are well reported in [28–34] where [28,29,32] present second order universal filter, [30,31] comes with single input multi output (SIMO) second order filter function and [33,34] brings all pass section only. As per the author knowledge not a single paper is reported that generates both first order and second order filter using a single schematic which is free from non-ideal effects.

The main objective of this paper is to establish a single filter structure that gives both first order and second order filter responses. After extensive study, the proposed topology is obtained by the modification of [35]. The schematic of the filter realize all traditional filter function with the help of selection of inputs and some switches where the filter structure have physical components like the FTFN active block with two capacitors and two resistors each. Moreover, the circuit topology does not require any component matching constraints to realize the filter responses and free from non-ideal effects. The performance of the proposed filter is verified by PSPICE simulation using 0.35 µm AMS BSIM3v3 CMOS process parameters [36] for the design of CMOS based FTFN. Also simulation based on IC AD844 with ideal theoretical prediction are well plotted in the frequency response. Experimental verification of the proposed filter using two commercially available current feedback operational amplifier (CFOA) IC AD844 [23] is performed for the justification of computer simulations. Finally, a brief comparative analysis of the proposed filter is discussed with other reported filter topologies in terms of performance parameters and physical component count.

2. Circuit Descriptions

The circuit representation of four terminal floating nullor (FTFN) and its CMOS based implementation [36] are illustrated in Fig. 1. The port relationship of the FTFN analog device can be characterized by the following set of equations:

$$V_x=V_y;\ I_z=I_w;\ I_x=I_y=0 \tag{1}$$

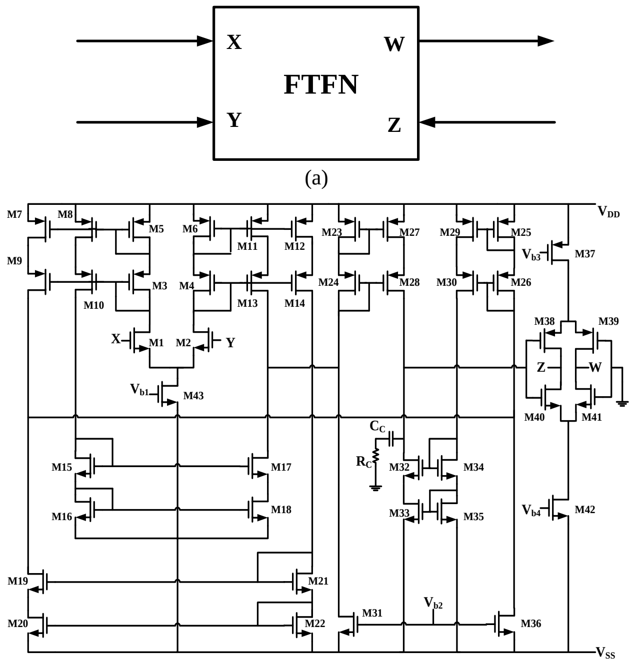


Fig.1: Circuit representation of FTFN (a) Circuit Symbol (b) CMOS based FTFN1

As per the investigation of the earlier paper [35], we can get the first order and second order filter with slight modification in the circuit. The core of the circuit of [35] may be useful for the application of higher order filter also. The proposed voltage-mode filter structure with switch is shown in Fig. 2 that responds all filter response for both first order and second order filter. It uses two FTFN, two resistors, two capacitors and two switches (S_1 and S_2) where the switches provide necessary isolation between first order and second order filter.

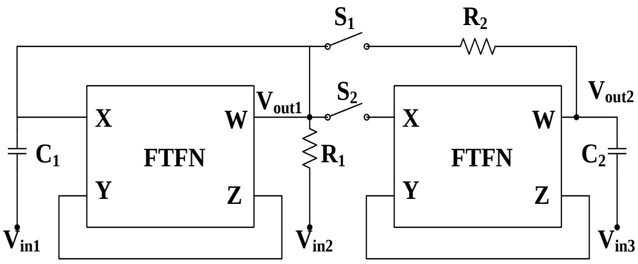


Fig. 2: Proposed voltage-mode filter structure

Routine analysis of the filter circuit in Fig. 2 with switch S_1 and S_2 open yields the output voltage function V_{out1} as:

$$V_{out1}=\frac{sC_1R_1\ V_{in1}+V_{in2}}{sC_1R_1+1} \tag{2}$$

It contributes low pass filter (LPF), high pass filter (HPF) and all pass filter (APF) responses at output terminal Vout1 where only two input section Vin1 and Vin2 are responsible for the first order filter response. The first order filter function is characterized by its cut-off frequency and its passive sensitivity as

$$\omega_{O(1st\ order)}=\frac{1}{R_1C_1} \tag{3}$$

$$S^{\omega_0}_{R_1,C_1}=-1 \tag{4}$$

When the switches S_1 and S_2 are closed, then the circuit in Fig. 2 behave as a second order universal filter and the output voltage function (Vout2) can be characterized by the following equations:

$$V_{out2}=\frac{sC_1R_1\ V_{in1}+V_{in2}+(s^2C_1C_2R_1R_2+sC_2R_2+sC_2R_1)V_{in3}}{s^2C_1C_2R_1R_2+s(C_1R_1+C_2R_2+C_2R_1)+1} \tag{5}$$

Here, all three input terminals produces the universal filter response at output terminal V_{out2}. If $R_1=R_2=R$ and $C_1=C_2=C$, then equation (5) can be modified as

$$V_{out2}=\frac{sCRV_{in1}+V_{in2}+\left(s^2C^2R^2+2sCR\right)V_{in3}}{s^2C^2R^2+3sCR+1} \tag{6}$$

Finally, the proper selection of input generates the frequency response for both filter order. Here, Table 1 and Table 2 exhibit the selection of inputs for the realization of first order filter and second order filter respectively.

Table 1: Selection of inputs for first order filter frequency response

First Order Filter Responses	Inputs	
V_{out1}	V_{in1}	V_{in2}
LPF	0	1
HPF	1	0
APF	1	-1

Table 2: Selection of inputs for second order filter frequency response

Second Order Filter Responses	Inputs		
V_{out2}	V_{in1}	V_{in2}	V_{in3}
LPF	0	1	0
HPF	-2	0	1
BPF	1	0	0
NF	-2	1	1
APF	-5	1	1

The transfer function for the second order filter is characterized by its cut-off frequency and quality factor.

$$\omega_{O(2nd\ order)}=\frac{1}{\sqrt{C_1R_1C_2R_2}} \tag{7}$$

$$Q_{(2nd\ order)}=\frac{\sqrt{C_1R_1C_2R_2}}{C_1R_1+C_2R_1+C_2R_2} \tag{8}$$

The passive sensitivity values for the proposed second order filter are obtained as:

$$S^{\omega_0}_{R_1,R_2,C_1,C_2}=\frac{-1}{2},\ S^{Q}_{R_1,C_2}=\frac{1}{6},\ S^{Q}_{R_2,C_1}=\frac{1}{3} \tag{9}$$

Here, the obtained sensitivities values are less than unity that signifies a better sign for filter design.

3. Non-Ideal Analysis

One of the most important observation for the performance of current mode circuit is non-ideal analysis. In practice, the frequency response of the filter deviates from the ideal behaviour due to non-ideal characteristics of the device. The non-ideal nature of the FTFN can be expressed as:

$$V_X=\beta\ V_Y\ ,\ I_Z=\alpha I_W\ ,\ I_X=I_Y=0 \tag{10}$$

Where, the terms (α, β) represents the current and voltage transfers gain with numerical values ($1-\varepsilon_i$) and ($1-\varepsilon_v$) respectively. The symbols ε_i and ε_v corresponds to current and voltage tracking errors respectively. In our design, Y and Z terminals of the FTFN are short circuited, which causes $I_Z = 0$, hence it eliminates the α and β terms. However, if we go for the routine analysis using non-ideal characteristics of FTFN, the obtained output voltage function for the first order and second order filters are exactly same as that of equation (2) and (5) respectively. Hence, the proposed design is free from non-ideal behaviour of the FTFN device.

4. Simulation and Experimental Results

The viability of the proposed filter circuit is verified using PSPICE simulation in which active FTFN block has been implemented using 0.35 µm AMS BSIM3v3 technology parameter [36] with supply voltages ±1.65 V. Each frequency response of the filter includes the simulated as well as theoretical response in which the simulation results consist of both CMOS based FTFN realization along with IC AD844 based FTFN realization. Also, the FTFN can be constructed with two current feedback operational amplifier (CFOA) IC AD844 as shown in Fig. 3 for the simulation as well as experimental verification of FTFN based filter circuit on IC AD844. Design frequency for both the filter order is evaluated for 1 MHz by keeping the passive component values as $R_1=R_2=1$ kΩ and $C_1=C_2=159$ pF. The filter frequency response for first order and second order filter may be achieved by using proper inputs as per Table 1 and Table 2 respectively. When the switches S1 and S2 are open, then the filter schematic produces multifunction filter as LPF, HPF and APF. The filter frequency response of the first order filter is shown in Fig. 4.

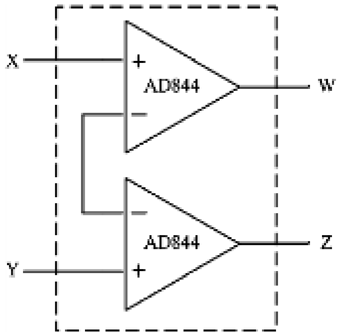
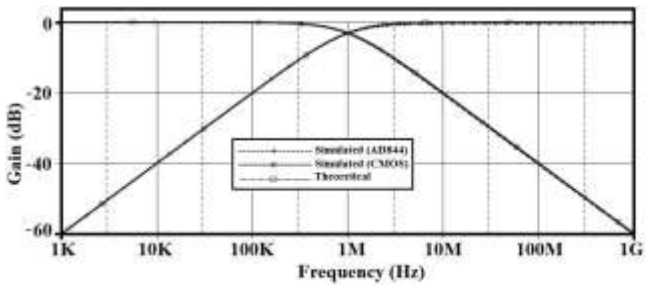
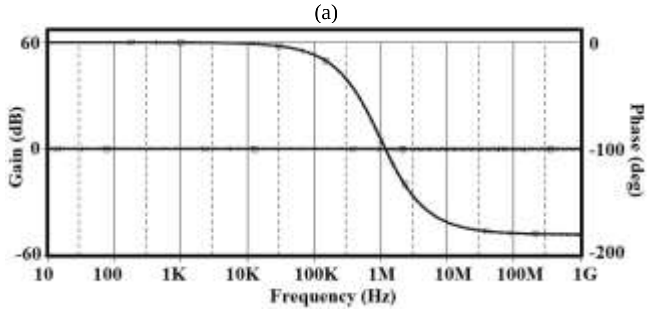


Fig. 3: FTFN based on IC AD844



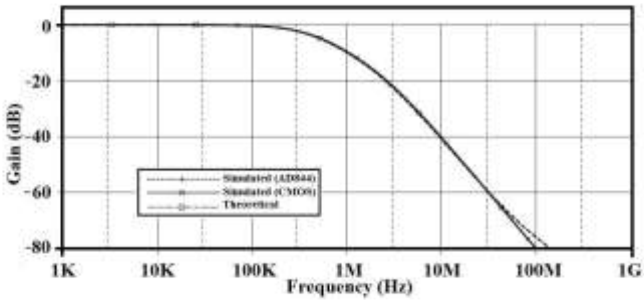
(a)



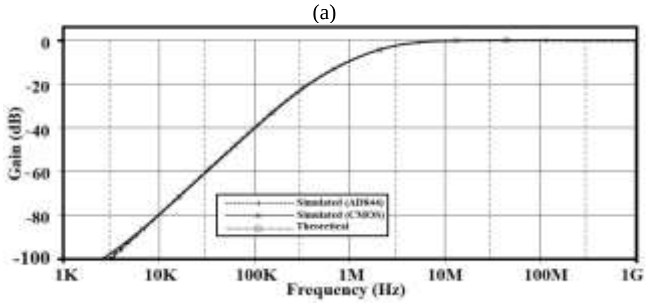
(b)

Fig. 4: Proposed First order Filter Frequency responses (a) Low pass and High pass (b) All pass magnitude and phase

However, when the switches S_1 and S_2 are closed then, it generates second order universal filter that comes with all necessary filter frequency responses. Fig. 5 illustrates all the five frequency responses of the second order universal filter along with the phase of all pass filter. The workability of the filter is well observed through simulation results that follows the general theoretical prediction, by plotting the mathematical transfer function. Our design comes with a power consumption of 6.33 mW for first order filter and 18.2 mW for second order filter.



(a)



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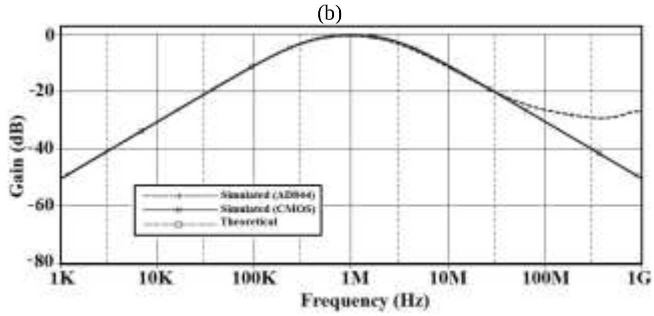

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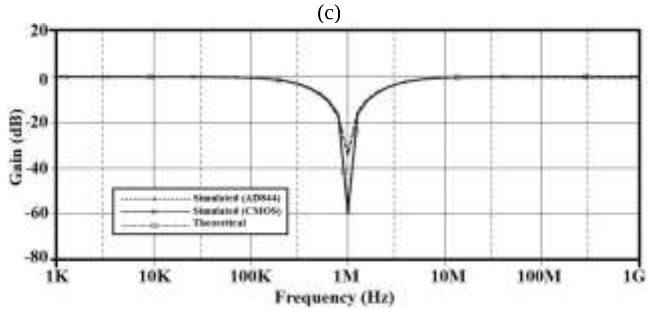
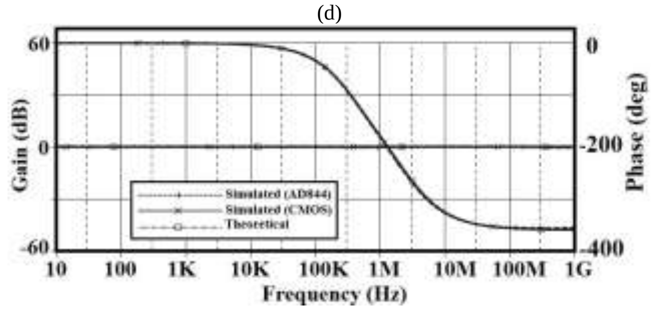


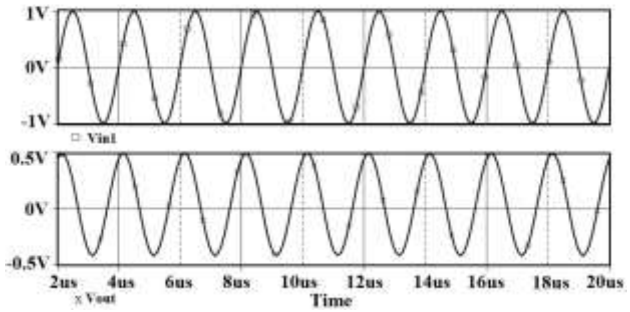
(d)



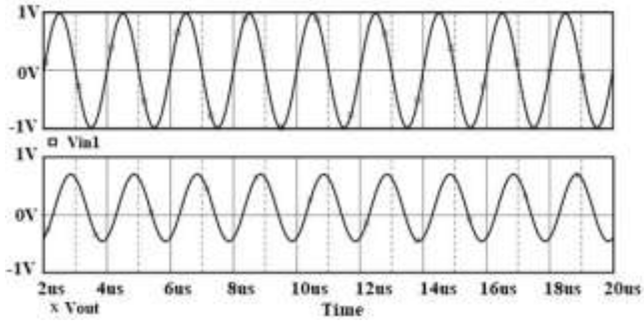
(e)

Fig. 5: Proposed Second order Filter Frequency responses (a) Low pass (b) High pass (c) Band pass (d) Notch (e) All pass magnitude and phase

The transient analysis of the proposed filter is also investigated for both first order and second order low pass filter that incorporate both simulation as well as experimental verification using commercially available IC AD844 for FTFN device. The simulated input and output waveforms of the transient analysis is given in Fig. 6 for both filter order.



(a)



(b)

Fig. 6: Simulated transient response (a) First order low pass filter (b) Second order low pass filter

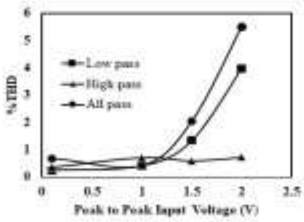
Moreover, an experimental verification of transient response, standard passive components with resistor values of 1 kΩ and capacitor value of 159 pF are used. For first order low pass filter, two inputs are required as per Table 1 and three inputs are required for second order low pass filter as per Table 2. The experimental time domain output response of the proposed LPF for both order are shown in Fig. 7.

(a)

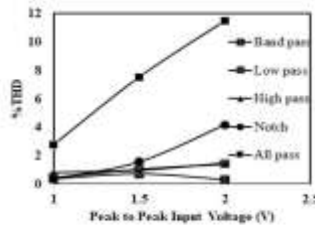
(b)

Fig.7: Time domain experimental response of LPF (a) First order (b) Second order

Further, the percentage total harmonic distortion (%THD) is evaluated for the proposed first order and second order filter with respect to the input voltage at 1 MHz. Fig. 8 shows the %THD variation for both filter order and it incorporates an acceptable limit of 2% as per reference [37].



(a)



(b)

Fig. 8: THD variation of versus input voltage at 1 MHz (a) first order (b) second order filter

Finally, a comparative analysis of the lower order filters with the other designs available in the literature is given in Table 3 and 4. From the careful study of the literature, the following conclusions have been made:

1) [3, 13, 21] uses more number of passive components than the proposed first order filter.
2) The proposed first order filter can realize low pass, high pass and all pass filter whereas [3, 13, 14, 18, 19, 21] can only realize all pass response.
3) The proposed second order filter uses less number of active blocks than [4, 15, 28, 30, 31].
4) [4, 5, 12, 28, 31] require more number of passive components for filter realization than the proposed second order filter.
5) [4, 5] can implement only second order low pass, high pass and band pass functions whereas the proposed second order filter is a universal filter. [12] requires component matching conditions to implement the universal filter function.
6) The proposed second order filter has less power consumption in comparison to [4, 5, 30].
7) Both the proposed first and second order filters are free from non-ideal effects and component matching.
8) The proposed filter topology does not provide electronic tunability and require additional circuitry for input voltage selection.
9) Our topology produces both first order and second order filter function using a single schematic with the adjustment of switch connection.

Table 3: Comparative analysis of the proposed first order filter with other existing filters

Free from non-ideal effects	N	N	N	N	N	N	N	N	Y	*Yes: Y, No: N

Ref	Filter Functions	Number of active blocks	Number of Passive components R	Number of Passive components C	Configuration	Technology used	Applied Voltage (V)	Filter Pole Frequency (Hz)	Electronic Tuning	Low Input Impedance
[3]	APF	CCII-, 1	2	1	SISO	AD844	±1.25	1 K	N	N
[6]	LPF, HPF, APF	DX-MOCCII, 1	1	1	SIMO	0.25 µm TSMC	±1.25	7.962 M	Y	N
[11]	LPF, HPF, APF	DVCC, 1	1	1	MISO	0.18 µm TSMC	±0.9	1.59 M	N	Y
[13]	APF	OTRA, 1	2	1	SISO	1.2 µm MIETEC	±5	159 K	N	Y
[14]	APF	CCCCTA, 1	1	1	SISO	0.25 µm TSMC	±1.25	1.66 M	N	Y
[18]	APF	DDCC, 1	1	1	SISO	0.5 µm MIETEC	±2.5	1.59 M	N	Y
[19]	APF	COA, 1	1	1	SISO	1.2 µm AMI	±2.5	150 K	N	Y
[21]	APF	CCIII, 1	3	1	SISO	0.5 µm MIETEC	±2.5	159.2 K	N	Y
Proposed	LPF, HPF, APF	FTFN, 1	1	1	MISO	0.35 µm AMS	±1.65	1 M	N	Y

Table 4: Comparative analysis of the proposed second order filter with other existing filters

Electronic Tuning	Free from non-ideal effects
Y	N
N	N
N	N
N	N
Y	N
Y	N
N	N
Y	N
Y	N
N	Y

*Yes: Y, No: N

Ref	Type	Number of active blocks	Number of Passive components R	Number of Passive components C	Configuration	Component Matching	Technology used	Applied Voltage (V)	Requirement of additional circuits for input voltage selection	Power Dissipation (W)
[4]	LPF, HPF, BPF	CCII, 3	2-4	2-4	SITO	N	AD844	±12	N	0.478
[5]	LPF, HPF, BPF	CCII, 1	3	2	MISO	N	AD844	±12	N	0.159
[7]	UF	CCCII, 2	0	2	MISO	N	0.5 µm AMS	±2.5	Y	17.1 m
[12]	UF	DVCC, 2	4	2	SIMO	Y	0.13 µm IBM	±0.75	N	1.26 m
[15]	UF	DOCCCII, 4	0	2	MIMO	N	ALA400	±3	N	NA
[20]	UF	MOSFET, 7+1	2	2	MISO	N	0.35 µm AMS	±1.65	N	208.25 µ
[28]	UF	FTFN, 6	4	2	SIFO	N	AD844	±12	N	NA
[30]	UF	FTFN, 4	2	2	SITO	N	AD844	±12	N	0.781
[31]	UF	FTFN, 3	3	2	SITO	N	AD844	±12	N	NA
Proposed	UF	FTFN, 2	2	2	MISO	N	0.35 µm AMS	±1.65	Y	18.2 m

5. Conclusion

A voltage mode based first order and second order universal filter employing two four terminal floating nullor (FTFN) with minimum number of passive components is designed. The proposed filter structure is free from non-ideal effects and component matching. All standard filter frequency responses are obtained through proper selection of input as well as switch selection. The sensitivities of the circuit is found to be less than unity in magnitude that gives a good sign for filter design. The workability of the proposed filter circuit is well verified using PSPICE simulation as well as experimentally. Also, a brief comparative study of proposed filter with other reported articles offers a brief summary in terms of physical component count and performance parameters.

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