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RESEARCH ARTICLE

A Powerline Filter Circuit Design for Biomedical Applications

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A new approach to the design of active comb filter to remove the unwanted harmonic interference contaminating the biomedical signal (ECG, EEG and EMG) has been presented. The filter consists of '*n*' number of band pass filters. The centre frequency of each band pass filter is the unwanted frequency characterized by powerline interference. The workability of the circuit is tested using the ECG signal with powerline interference of 60 and 180 Hz. The circuit is based on 0.5 μm CMOS technology based Operational Trans-conductance Amplifier (OTA) and grounded capacitor only. The implemented filter shows the notch depth of −38 to −58 with a THD of better than −82 dB; hence it is principally suitable for biomedical system. The results have clearly indicated that the proposed technique is very much effective for elimination of power line signal and its harmonics.

Keywords: Linear Operational Trans-Conductance Amplifiers (OTA), Electrocardiogram (E.C.G.), Comb Filter, Frequency and Q-Factor Tuning.

1. INTRODUCTION

Currently, there has been a lot of developments in the various fields of biomedical circuits.[1–28] The low frequency filter has a wide range of applications, such as hearing aid,[5] photoplethysmogram,[6] ECG,[7] wearable breathing detector[8] and neural spike detection.[9]

Nowadays, long-term monitoring of the heart activity has a lot of importance. The long time monitoring needs a patient-friendly ECG, EEG and EMG recording. For this cause the development of a low noise and patient-friendly integrated circuit is the key challenge for designers. A Comb filter is found to be very useful analog signal processing circuit for biomedical instrumentation and devices. An important application is the removal of power line odd harmonics from various devices. It is well known that biomedical signals sensed by various devices and biomedical instruments operated by powerline are corrupted by powerline interference.[29,30] There are basically two sources in power line interferences namely Electric field interference and Magnetic field interference. Electric field interference generates spike at 50/60 Hz power supply frequency, whereas magnetic field interference is caused due to the generation of magnetic field from the transformer of the power supply. This interference generates harmonic frequencies of the fundamental frequency. As an example, the source of these interferences is present in every diagnostic centre, where a number of biomedical instruments are run on AC power line. Hence, physiological signal (like E C G) gets corrupted by power line frequency and its harmonics. This interference may be removed by both digital and analog technique, which are called comb filters. However, active analog filters without the use of inductors are less costly and more suitable for real time processing than digital filters. Already, a number of analog and digital filters are available to remove the undesired fundamental and harmonic of the power line from the actual response of the instrument/diagnostic machines[1–28] using traditional op-amp based voltage approach as well as current mode analog building blocks approach. Current mode filters are found to have advantages over its voltage mode counterpart, especially in terms of bandwidth, dynamic range and slew rate, which motivates the analog designer to design various filters using current mode building blocks.[18,20–23,27]

The proposed circuit is a new analog comb filter, which is developed based on band pass filters. The proposed comb filter uses CMOS operational Transconductance Amplifier (OTA) and grounded capacitors. This filter is found suitable for filtering of corrupted biomedical signals. The parameters of the filter can easily be tuned electronically by bias current of OTA.

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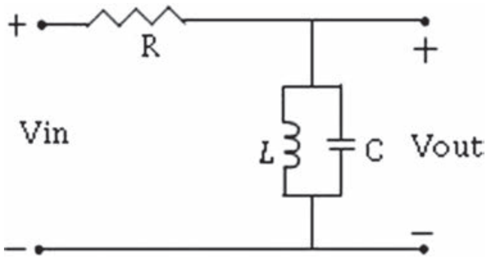

Fig. 1. Band pass filter using a basic RLC circuit.

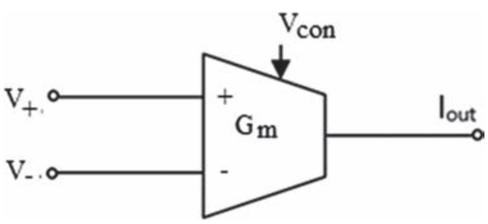

Fig. 2. Symbol of OTA.

2. CIRCUIT DESCRIPTION AND ANALYSIS

2.1. Band Pass Filter

A basic passive circuit of second order band pass filter is shown in Figure 1.

The voltage transfer function $H(s)$ using routine analysis is obtained as

$$H(s) = \frac{sL}{s^2LCR + sL + R} \tag{1}$$

The parameters of band pass filters are found to be as follows.

$$\omega_0 = \frac{1}{\sqrt{LC}} \tag{2}$$

$$Q_0 = R\sqrt{\frac{C}{L}} \tag{3}$$

$$\Delta f = \frac{1}{RC} \tag{4}$$

The active building block used for the implementation of band pass filter of Figure 1 is an operational transconductance amplifier (OTA). An electronic circuit based on inductor is no longer encouraged in integrated circuit environment of the present day because of well known disadvantages of their realization. Hence, designers prefer to implement active circuits using R–C combination.

The OTA is an active current mode building block similar to a voltage mode operational amplifier. It is nowadays widely used block in integrated circuit technique and suitable for various applications. It is totally based on a number of current mirrors. The input of OTA is applied

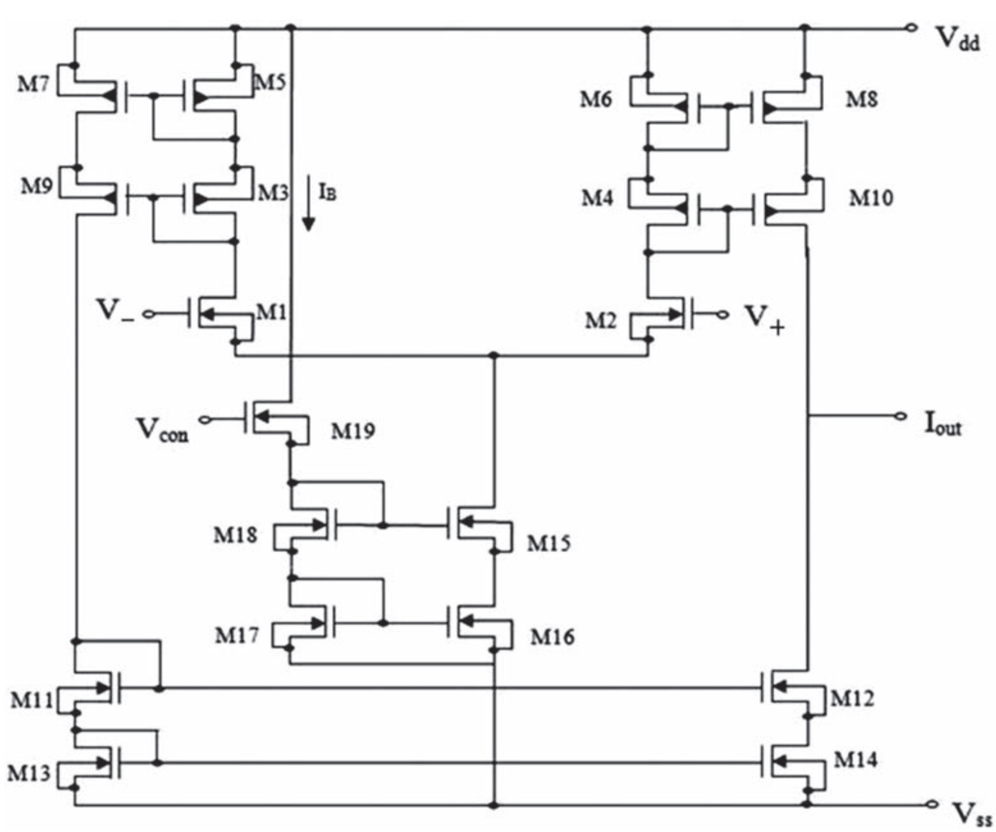

Fig. 3. CMOS based internal structure of OTA.

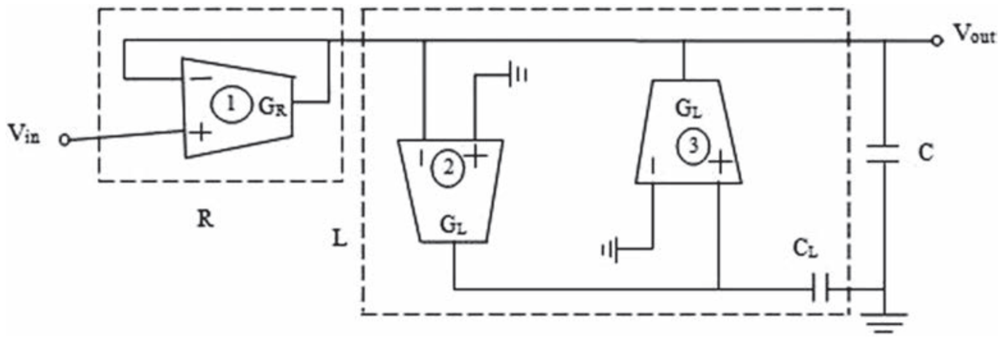

Fig. 4. Band pass filter using OTA.

at differential voltage input pair. The output of OTA is current, which is proportional to the differential input. The proportionality constant is called trans-conductance gain (G_m) of OTA, which may be controlled electronically by a control voltage (V_{con}) over a wide range. An OTA is symbolically represented in Figure 2 and the corresponding CMOS based internal structure given in Figure 3.[31] The output current of the OTA is expressed as $I_{out} = G_m(V_+ - V-)$, where, the trans-conductance gain

$$G_m = K\sqrt{2\mu C_{ox}\left(\frac{W}{L}\right)I_B} \qquad (5)$$

Here, K is constant, μ is the electron mobility of carrier, C_{ox} is oxide thickness, I_B is biasing current generated by V_{con}, W is channel width, L is the channel length of the transistor.

The proposed active band pass filter using only OTA and capacitors is shown in Figure 4. The grounded inductor is realized using two identical OTAs and a capacitor (C_L). The value of inductance may be expressed as:

$$L = \frac{C_L}{G_L^2} \qquad (6)$$

The resistance R is implemented using OTA1 and is expressed as:

$$R = \frac{1}{G_R} \qquad (7)$$

It is clear from (5), (6) and (7) that the value of inductance (L) and resistance (R) may be controlled using bias current (I_B) of OTAs. Hence ω_0 and Q_0 may be electronically controlled with bias currents of OTAs. It is also evident that Q_0 can be tuned independent of ω_0 by bias current of OTA1.

2.2. Proposed Comb Filter

A new proposed technique to realize a comb filter, which allows selective attenuation of frequencies over a range, is shown in the block diagram in Figure 5. Here f_1, f_2, $f_3, \ldots, f_n$ are the center frequency of band pass filters. In this technique the output of all the band pass filters is summed and then subtracted from the input signal to obtain a series of notches as per the centre frequencies of band pass filters. The band pass filters, which are used in comb filter, are implemented using the OTA and grounded capacitor as shown in Figure 4. The Figure 6 shows the proposed comb filter implemented using OTAs and grounded capacitors only. Here G_{Rn} are transconductance

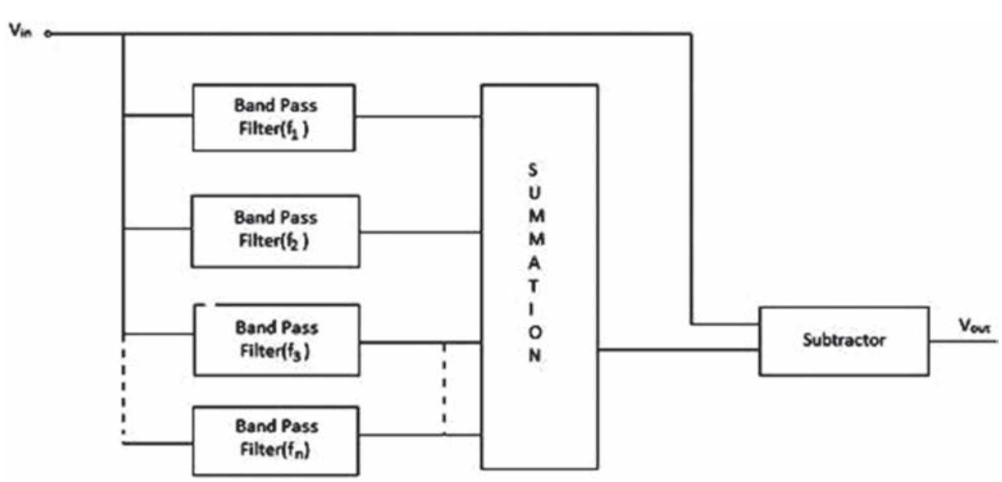

Fig. 5. Block diagram of comb filter.

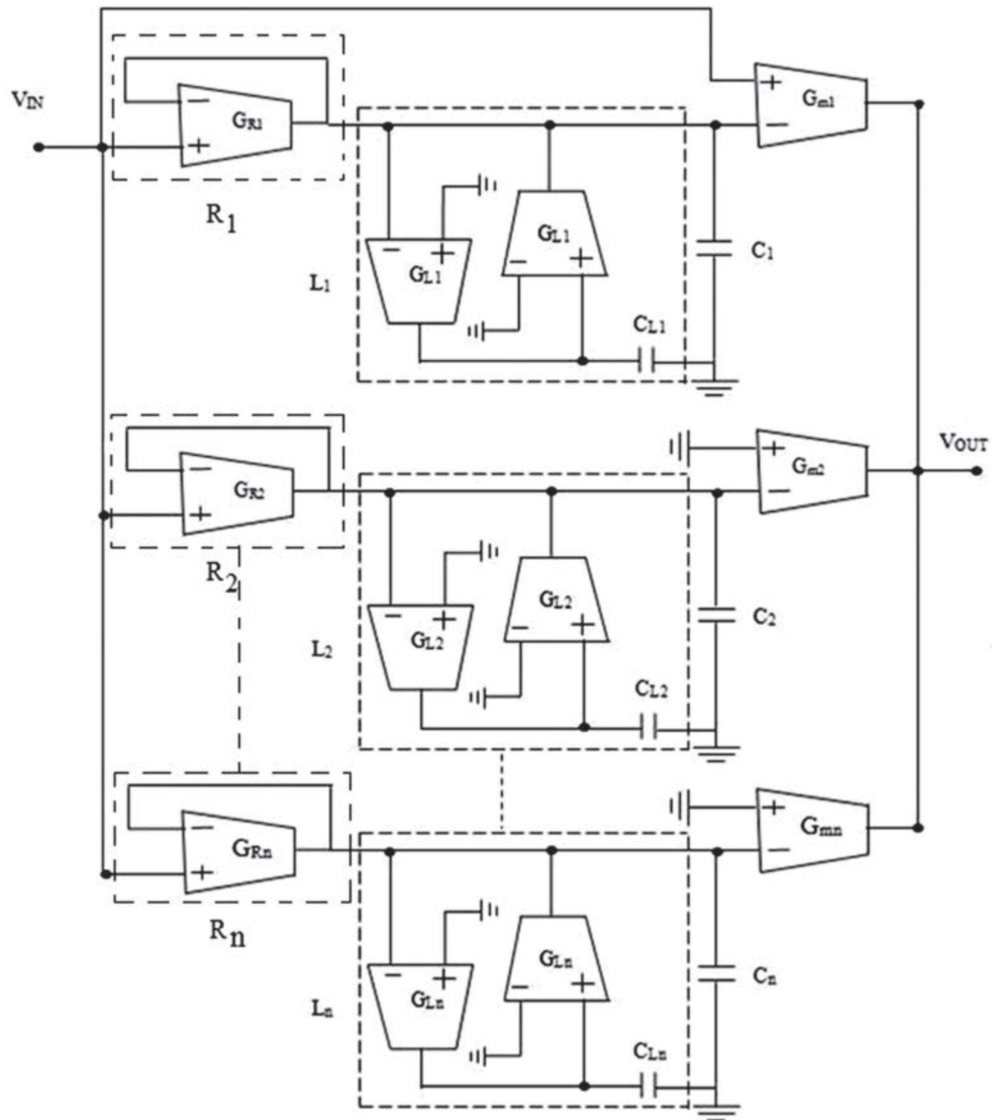

Fig. 6. Comb filter using OTA.

of OTAs to implement resistance R_n. Similarly, C_{Ln} and G_{Ln} are corresponding capacitance and trans-conductance of OTAs respectively to implement L_n for different band pass filters. The OTAs is having trans-conductance gain of G_{mn} are used to implement both summation and subtraction functions of the comb filter scheme of Figure 5.

The routine analysis results, the transfer function of the circuit of the comb filter as

$$H(s) = \frac{V_{\text{out }(S)}}{V_{\text{in }(S)}}$$

$$= 1 - \sum_n \frac{SL_n}{S^2 L_n C_n R_n + SL_n + R_n}$$

$$= 1 - \frac{SL_1}{S^2 L_1 C_1 R_1 + SL_1 + R_1} - \frac{SL_2}{S^2 L_2 C_2 R_2 + SL_2 + R_2}$$

$$- \frac{SL_3}{S^2 L_3 C_3 R_3 + SL_3 + R_3} \cdots - \frac{SL_n}{S^2 L_n C_n R_n + SL_n + R_n}$$

$$= 1 - \sum_{i=1}^{n} \frac{SL_i}{S^2 L_i C_i R + SL_i + R}$$

where $L_n = C_{Ln}/G_{Ln}^2$ and $R_n = 1/G_{Rn}$ and $n = 1, 2, 3 \ldots$.

It is evident froms (2) and (3) that the center frequency of each band pass filter can be set by C_{Ln} and G_{Ln} and quality factor by C_n, C_{Ln}, G_{Ln} and G_{Rn}.

Table I. Dimensions of MOS transistor.

	Dimensions of MOS transistors		
Sr. no.	MOS	W (μm)	L (μm)
1	M_1, M_2, M_{11}, M_{12} M_{13}, M_{14}, M_{15}, M_{16}, M_{17}, M_{18}, M_{19}	5	3
2	M_3, M_4, M_5, M_6, M_7, M_8, M_9, M_{10}	10	3

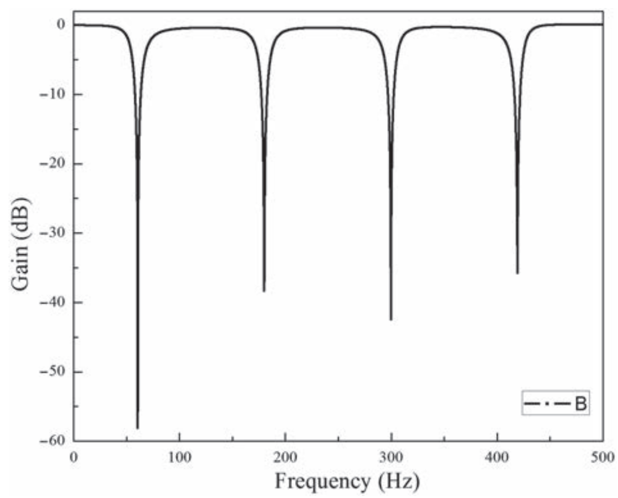

Fig. 7. Frequency response of the comb filter.

3. SIMULATION RESULTS

To test the workability of the proposed comb filter, a physiological signal (like ECG signal) corrupted with power line frequency and its harmonics are considered. As an example, the proposed comb filter is designed for $n = 4$ to show its performance to remove undesired power line signals of fundamental frequency of 60 Hz and its odd harmonics 180, 300 and 420 Hz. As it is a low frequency operation, hence a low noise and low distortion OTA as given in Figure 3 is used.[31] The circuit has been simulated using PSPICE in 0.5 μm CMOS Technology. The dimensions of the MOS are given in the Table I. The values of the components used to design comb filter are $C_{L1} = 567.80$ nF, $C_{L2} = 62.99$ nF, $C_{L3} = 22.66$ nF,

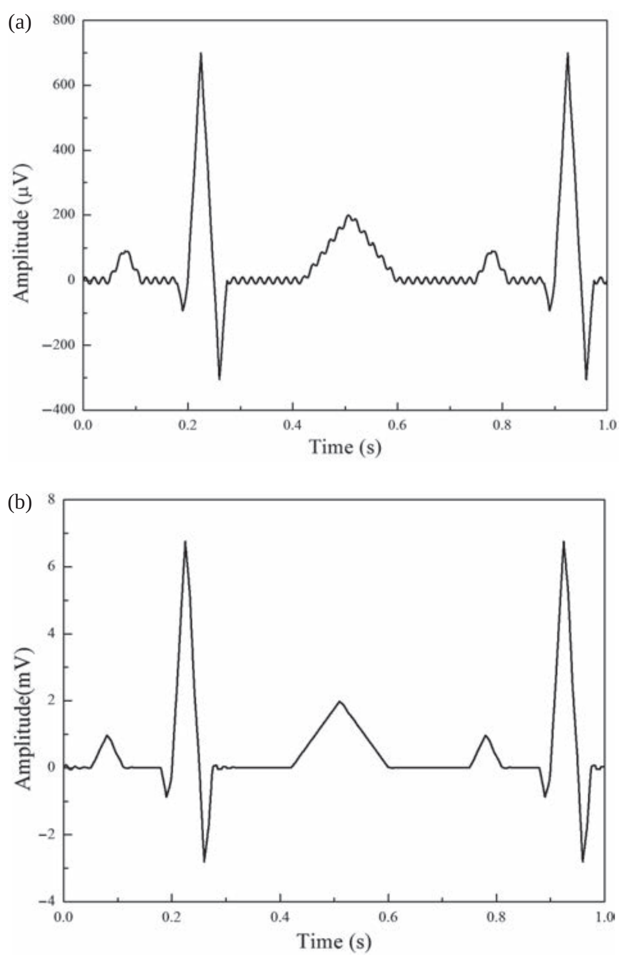

Fig. 8. (a) Input signal with noise at 60 Hz; (b) Output signal.

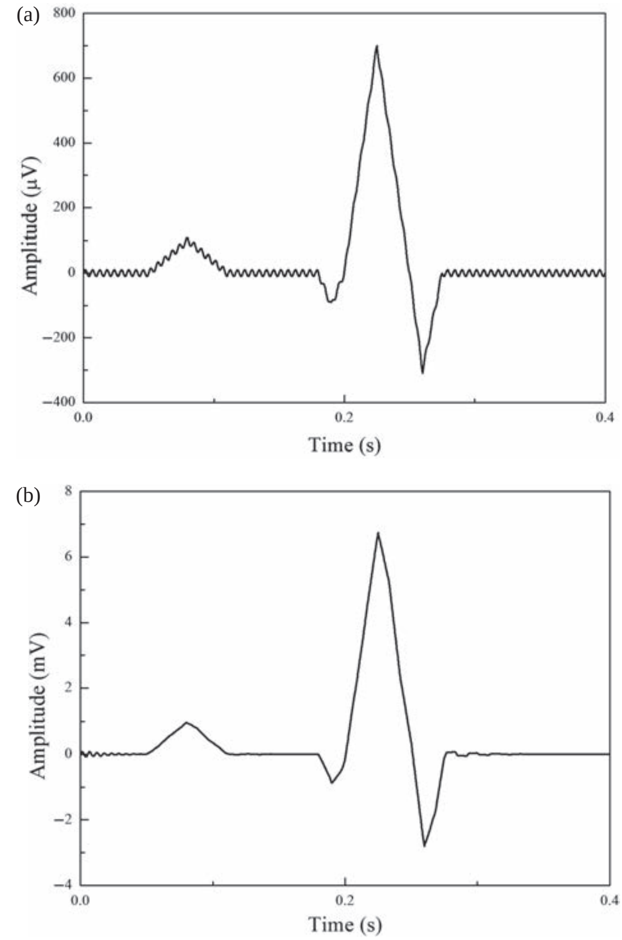

Fig. 9. (a) Input signal with noise at 180 Hz; (b) Output signal.

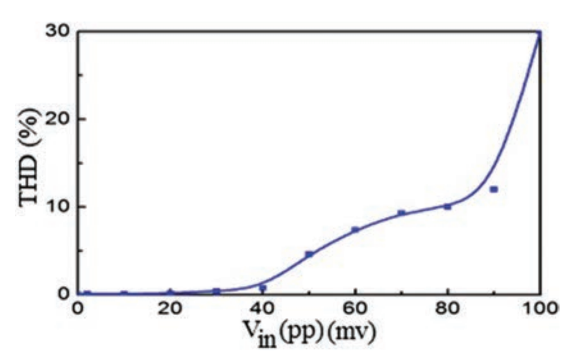

Fig. 10. %THD of comb filter.

Table II. Performance comparison.

Ref., year	Techn.	Active building block	Appln	Notch depth (dB)	Results	Centre freq. (Hz)	THD (dB)	No. of harmonics	Bandwidth adjustable
17, 1994	BJT	Op-amp	ECG	–	Sim	60, 180, 300, 420	–	4	–
19, 1998	BJT	Op-amp	ECG	–	Sim + Exp	60, 180, 300, 420	–	*n*	–
24, 1999	BJT	Op-amp	ECG	−60	–	60	–	1	–
25, 2003	BJT	Op-amp	ECG	–	Sim + Exp	60	–	1	–
26, 2006	BJT	–	ECG	–	Exp	50	–	–	–
23, 2007	CMOS 0.5 μm	OTA	EEG ECG EMG	−41	Exp	–	−45	1	Yes
21, 2008	CMOS 0.6 μm	OTA	EEG	−58	Sim	30–67	–	1	–
22, 2009	CMOS 90 nm	OTA	EEG ECG EMG	−41	Sim	50–60	–	1	Yes
27, 2011	CMOS 0.35 μm	CCII	ECG	–	Sim	60	–	1	–
28, 2011	CMOS 0.18 μm	Op-amp	ECG	−55.4	Sim	50	–	1	–
20, 2014	CMOS 0.35 μm	CCII	EEG ECG	–	Sim	–	–	1	–
18, 2014	CMOS 0.5 μm	OTA	ECG	–	Sim	60, 180, 300, 420	−40	*n*	–
Proposed circuit	CMOS 0.5 μm	OTA	EEG ECG EMG	−38 to 58	Sim	60, 180, 300, 420	−82	*n*	Yes

$C_{L4} = 11.59$ nF, $C_1 = C_2 = C_3 = C_4 = 100$ nF. The values of transconductances of OTAs are adjusted by biasing current of corresponding OTAs to $G_{Rn} = 4.27$ μA/V and $G_{Ln} = G_{mn} = 89.80$ μA/V. The frequency response of the comb filter as obtained across a grounded load resistance using OTA is shown in Figure 7. It verifies that the simulated response matches perfectly with the theoretical concepts. The time responses of the ECG signal mixed with powerline noise frequencies of 60 and 180 Hz and their corresponding inputs and outputs are shown in Figures 8 and 9 respectively. It shows the effectiveness of the proposed filter to practically eliminate the selected harmonic/frequency at the output. To study the quality of the output of the comb filter at frequencies other than notch frequencies, the total harmonic distortion (%THD) of the output of a 100 Hz signal is obtained as shown in Figure 10. It reveals that the %THD is very low (−82 dB) at low signal and well within acceptable limit.

4. COMPARISON

The performance of the proposed work is compared with the available literature in Table II. The %THD and noise depth of the proposed CMOS based implementation are found to be fairly good. It is also found that the bandwidth (BW) of the comb filter can be changed via internal resistance. The quality factor of the circuit may also be changed without disturbing the notch frequency. As the biomedical signal for EEG, ECG and EMG are normally of low amplitude, hence the proposed circuit can be useful for all the three cases. The proposed circuit is equally useful for 60 Hz and higher frequencies, such as 180, 300, 420 Hz etc.

5. CONCLUSION

In this paper a new active comb filter has been proposed using OTA for filtering of undesired power line signal and its harmonics from biomedical signal. The verification of theory has been performed by using PSPICE in 0.5 μm CMOS based OTA. All the capacitances are grounded in the proposed circuit, which is suitable for integrated circuit implementation. The parameters of the proposed filters can be tuned electronically by bias current of OTAs. The implemented filter shows the notch depth of −38 to −58 with a %THD of better than −82 dB. It is principally suitable for biomedical system.[23]

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