Design of Low Power Tunable OTA-C Filter for Biomedical Applications

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ABSTRACT

A novel CMOS continuous time integrated mixed notch and low pass filter is designed for multi standard biomedical applications like ECG, EMG, EEG etc. i.e a single device can be used to monitor multiple biomedical signals. In biomedical signal processing the power line signal (50Hz/60Hz) has to be suppressed with notch filter and remaining low pass band has to be allowed through low pass filter. In this work both notch filter and low pass filter is combined in one schematic. In order to get power line notch filter of 50 Hz and low pass filter of cutoff frequency less than 1 kHz, A Novel Bulk driven Operational Trans Conduction Amplifier (OTA) is used with 0.5V supply in CMOS 130 nm Technology. The transconductance value of proposed OTA is less than 1 nS. In this paper the notch filter of sixth order attained notch depth of 75 dB with 280 nW power consumption and low pass filter of fourth order consumes around 200 nW power.

Keywords— ECG signal, EMG, Notch filter, Operational Trans Conductance Amplifier (OTA), Biomedical

I. INTRODUCTION

Now a day’s scope of biomedical circuits is increasing tremendously. Basically any biomedical system consists of following building blocks like electrodes, pre-amplifiers, biomedical filters followed by ADC [1]. Basically the biomedical signals ECG (electrocardiogram), EEG (Electroencephalography), EMG (Electromyography) etc., are all having very small amplitude around few millivolts and very low frequency below 1 KHz.

Fig. 1 shows the biomedical processing system. It is clear that all bio medical signals consist of very low amplitude with very low frequencies up to 1 kHz [3]. Hence in order to avoid different individual biomedical signal filtering, one can design a simple multi standard biomedical filter for all signals like ECG, EEG or EMG etc. This paper presents a novel multi standard biomedical filter with ultra low power. A notch filter (50/60Hz) [4], [5] has to be needed to avoid power line interface with information signal as it is easily pick up by electrodes.

In this paper a cascaded notch and low pass filters are designed with in a schematic to avoid more area and to avoid extra components and power supply. The designing of ultra low frequency filters is not a simple task because time constant of such filters is around 0.01 s to 1 s range [6], [7]. The time constant of any filter is proportional to RC product but for lower technologies capacitance is limited to 1 pF to 10 pF. In this case capacitance has to be constant so required resistance value should be very high which indicates the effective transconductance (Gm) value should be very low around 1 nS [8], [9]. The Gm value can be reduced by choosing bulk driven in place of gate driven inputs because the transconductance of bulk driven MOS transistors are less than that of gate driven MOS transistors. The effective transconductance can be further reduced by using proposed Operational Trans Conductance Amplifier (OTA) [10], [11]. In this paper Section I describes about introduction. Section II describes about conventional Operational transconductance amplifier design and proposed OTA design. Section III describes about notch filter design and low pass filter design and mathematical analysis of these filters.[12],[13],[14].Section IV describes about simulated results and finally section V describes about conclusion.
II. Operational Transconductance Amplifier Design

In this paper to implement different low pass and notch filters a OTA is used which is designed for ultra low power and low frequency (around 100 Hz) applications. Hence the transconductance value $G_m$ should be very low. In order to get low $G_m$ value, bulk driven OTA schematic is used as shown in Fig. 4. All the transistors used in this OTA are operated in weak inversion (sub threshold) region of operation and while tuning those can be used in saturation region also. Because of wide tuning range and weak inversion region we can attain very low power consumption and bulk driven is chosen to give low $G_m$ value of the order of 50 nS. M1 and M2 transistors are two PMOS transistors to which inputs are given to the bulk terminals. M3 and M4 are NMOS transistors and biased to dc voltage of $V_b2$ to act as constant current source. Whereas PMOS transistors M6 and M7 are used as negative resistance to improve the gain of the output response. Finally the transistor M5 and resistors R1 and R2 are act as local common mode feedback of OTA. In this paper 0.5 V supply is used hence the input common mode and output common mode voltages have to be adjusted to half of supply voltage i.e 0.25V. Common mode voltages at outputs can be adjusted by $R_1$ and $R_2$. However by using OTA shown in Fig. 4 can be used to tune from 50 nS to 100 nS. Means the minimum value of $G_m$ value with this OTA is only 50 nS. But in order to get 50 Hz notch $G_m$ value should be very small. Hence in order to reduce $G_m$ value further a proposed transconductor is designed.

A. Proposed Operational Transconductance Amplifier

The bulk driven OTA shown in the Fig. 4 can be tuned only from $G_m$ value of 50 nS to 100 nS. In order to reduce $G_m$ value below 1 nS a bulk driven current deviation OTA with local common mode feedback is proposed in this paper which is shown in the Fig. 3. By using this approach $G_m$ value can be scale down to 10 to 20 times of original $G_m$ value. In this proposed OTA, except $M_{13}$, $M_{14}$ transistors all other transistors are operating in weak inversion region to consume low power. The input is given to PMOS transistors $M_1$, $M_2$, $M_4$ where (W/L) of $M_1$ is less than that of $M_3$ similarly $M_2$ is less than that of $M_4$. For local common mode feedback PMOS transistors $M_{13}$, $M_{14}$ are operated in triode region to give a tunable resistance. NMOS transistors $M_5$, $M_7$ and $M_{6}$, $M_{8}$ pairs act as constant current mirror. The minimum $G_m$ value by this proposed OTA is around 0.1 nS.

B. Capacitor Multiplier

The capacitor multiplier working is based on the principle of scaling the impedance or admittance from the required port. As capacitance increases, impedance across the capacitor reduces and for particular voltage it will pass more current [5]. This is the basic idea of capacitor multiplier. Here more current is produced for same voltage, that leads to decrease in impedance and thereby large capacitance is achieved. Capacitor multiplier allows considerable reduction in the area but at the expense of more power. The basic idea of capacitor multiplier using current amplifier is as shown in the fig2.

III. Mixed Notch - Low Pass Filter Design

A. Low pass filter design

In this paper low pass filter and notch filter can be design with similar schematic with a change of input supply positions. With a single ended supply and with two $G_m$ cells a second order low pass filter can be designed as shown in Fig. 4 and with added extra supply a second order notch filter can be designed with the same schematic as Shown in Fig. 3. The response is given by the following equations.

$$V_o(s) = \frac{G_m G_m}{s^2 C_1 C_2 + s C_1 G_m + G_m G_m}$$

(1)

$$V_o(s) = \frac{G_m^2}{s^2 C_1 C_2 + s C_1 G_m + G_m^2}$$

(2)

$$\omega_c = \frac{G_m}{\sqrt{C_1 C_2}}$$

(3)

$$Q = \frac{C_2}{\sqrt{C_1}}$$

(4)

Equation 1 represents the transfer function of second order low pass filter which is shown in the Fig. 3. Since both the $G_m$ cells are identical $G_{m1} = G_{m2}$ (1) can be reduced to (2) which is in the form of standard second order low pass filter. From the standard second order transfer function (2), the Cutoff frequency can be written as in (3) similarly the Quality Factor of second order low pass filter is given by (4).
B. Notch filter design

As described in the above subsection Fig. 5 shows the schematic of second order notch filter. The equations for the Transfer function, Cutoff frequency (Notch frequency) and Quality Factor are as shown below.

\[
\frac{V_o(s)}{V_{in}(s)} = \frac{s^2C_3C_4 + G_m^2}{s^2C_3C_4 + sC_3G_m + G_m^2}
\]  
(5)

\[
\omega = \frac{G_m}{\sqrt{C_3C_4}}
\]
(6)

\[
Q = \sqrt{\frac{C_4}{C_3}}
\]
(7)

Equation 5 represents the transfer cell function of second order notch filter similarly (6) gives notch frequency and (7) gives Quality factor of notch filter.

C. Mixed Notch-Low pass filter design

Since for any biomedical signal from the electrode can be interference with the power line (50/60 Hz) signal, so attenuation of (50/60 Hz) is necessary for all biomedical applications. By using second order notch filter the depth of notch is only around 20 dB - 30 dB. Since this much attenuation is not sufficient for biomedical processing, a sixth order notch filter is designed by cascading three second order notch filters shown in Fig. 6. Similarly a fourth order butter worth low pass filter is designed by cascading two similar second orders LPF. This mixed filter (sixth order notch and fourth order low pass) is designed by using just ten Gm cells. The Q factors of notch filter and low pass filter has to be same as it is connected in cascade. So in order to give resultant Q factor of 0.707 (butter worth) the capacitance values of C1, C2, C3 and C4 are adjusted without exceeding 10 pF.

IV. RESULTS

In this paper with using proposed OTA a sixth order notch filter and fourth order low pass filter are designed and cascaded to give combined notch low pass response. The different performance plots are shown in the following figures. In this paper single ended Gm cell are used to design low pass and notch filters. The Gm value for notch filter is fixed to 0.8 nS and the Gm value of low pass filter is variable because of this paper is designed for multi standard biomedical applications like ECG, EEG, and EMG etc. As described earlier the low pass filter of fourth order is designed with using just four Gm cells which will save the power. The fourth order low pass filters can be tuned by using different bias current values. The variable magnitude response low pass filter of different Gm values is shown in the fig. 7. The magnitude response of sixth order Gm-C notch filter is shown in the Fig. 8. The depth of notch at 50Hz is about -75dB which is more than sufficient for filtering desired signal from power line signal. The phase response of sixth order notch filter is shown in the Fig. 9. The combined frequency response of notch and low pass (cascaded notch and low pass filter) is shown in the Fig. 10. The phase
response of this mixed notch and low pass is shown in the Fig. 11. In order to compare this paper results with the literature survey, two different comparison tables are given individually i.e Table II for notch filter comparison and Table III for low pass filter comparison with the existing technologies.

Table I.

**Comparison Table for Notch Filter with Literature Survey**

<table>
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<tr>
<td>Vdd(V)</td>
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<td>1</td>
<td>1.8</td>
<td>1.5</td>
<td>0.5</td>
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<tr>
<td>Tech. (nm)</td>
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<td>180</td>
<td>180</td>
<td>180</td>
<td>130</td>
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<tr>
<td>Zero freq(Hz)</td>
<td>250</td>
<td>50-250</td>
<td>29-71</td>
<td>40-80</td>
<td>50-60</td>
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<tr>
<td>Notch dep.d</td>
<td>-</td>
<td>50</td>
<td>55</td>
<td>78</td>
<td>75</td>
</tr>
<tr>
<td>Order</td>
<td>5</td>
<td>5</td>
<td>5</td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>Structure</td>
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<td>Gm-C</td>
<td>opamp</td>
<td>opamp</td>
<td>OTA-C</td>
</tr>
<tr>
<td>Power (nW)</td>
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<td>458</td>
<td>25000</td>
<td>300</td>
<td>280</td>
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<tr>
<td>THD(dB)</td>
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<td>-48</td>
<td>-53</td>
<td>-65</td>
<td>-68</td>
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<tr>
<td>App</td>
<td>ECG</td>
<td>ECG</td>
<td>ECG,EEG</td>
<td>ECG,EMG</td>
<td>ECG,EEG,EMG</td>
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Table II.

**Summary and Comparisons of Low Pass Filter from the Literature Survey**

<table>
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<td>1.25</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
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<tr>
<td>Tech.(nm)</td>
<td>180</td>
<td>800</td>
<td>180</td>
<td>80</td>
<td>130</td>
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<tr>
<td>----------</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
<td>-----</td>
</tr>
<tr>
<td>Bandwidth(Hz)</td>
<td>2.4</td>
<td>2000</td>
<td>1M</td>
<td>100</td>
<td>100-1000 (tunable)</td>
</tr>
<tr>
<td>Order</td>
<td>6</td>
<td>6</td>
<td>4</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>Structure</td>
<td>Gm-C</td>
<td>Gm-C</td>
<td>Gm-C</td>
<td>Gm-C</td>
<td>OTA-C</td>
</tr>
<tr>
<td>Power</td>
<td>10µW</td>
<td>2.5µW</td>
<td>36uW</td>
<td>225mW</td>
<td>200mW</td>
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<tr>
<td>THD(dB)</td>
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<td>-40</td>
<td>-58</td>
<td>-60</td>
<td>-62</td>
</tr>
<tr>
<td>DR(dB)</td>
<td>60</td>
<td>70</td>
<td>54</td>
<td>75</td>
<td>73</td>
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</table>

V. CONCLUSION

This work presents a novel design of OTA for implementing power line notch filter (50Hz/60Hz) and variable low pass filter with minimum cut-off frequency of 100 Hz and maximum cut-off frequency of 1 kHz for bio potential acquisition systems. After a lot of literature survey this paper has lead to a new approach avoiding demerits of other works with improved characteristics. In this paper a novel bulk driven current sharing Operational Trans conductance Amplifier with local common mode feedback is designed for ultra low power and frequency applications. The total power consumption of the two filters (notch and low pass) is around 480 nW with 0.5 V supply. The Dynamic Range of fourth order low pass filter is 73 dB. Experimental results show significant improvement in power, linearity and total harmonic distortion

REFERENCES