An Ultra-Low Power OTA-C Bandpass Filter Design for ECG Application

C. L. Hsiao and R. B. Huang

***Abstract*—An ultra-low power OTA-C bandpass filter is presented in this paper. An 1-150 Hz 4-th order OTC-C bandpass filter is design which is suitable for ECG application. A subthreshold region OTA is designed with current cancellation technology to achieve a very small transconductance. The OTA-C filter is design with TSMC 0.18µm CMOS process. The MIM capacitor is used in this design. The supply of the proposed circuit is 1V. The total power consumption is only 245nW.**

***Index Terms*—OTA-C filter, ECG, low power, bioelectronics.**

I. Introduction

The development of portable heart monitoring system is not only useful in long-term healthcare, but also demanded in an increasing number of researches in the biomedical file [1]. Filters is continually a critical block of biopotential acquisition systems for enhancing the signal quality [2]. However, for low frequency biomedical applications, realizing filter circuits with large time constant under an acceptable capacitor's value isn't an easy task [3].

Switching-capacitor circuit is a popular technique used in implementing filter circuit. Due to the leakage problem of the advanced process, the sample-hold circuits of the switch-based topologies are not suitable for applications requiring large time constant. Compared with the switching-capacitor filters, continuous-time OTA-C filter has their benefits of lower power consumption and freeing the system from switching noise. The cut-off frequency is proportional to the transconductance (g_m) of the OTA; this allows a low-power implementation for low frequency biopotential signals. In OTA-based circuits, OTA will dominate the performance of the filter circuit, while the ratio of the capacitor to the small transconductance determines the time constant of OTA-C integrators. Thus, an OTA in which the transistors are operated in the subthreshold region is needed to save more power and realize a very low transconductance.

A 4-order Butterworth bandpass is presented in this paper. The bandwidth of this filter is 1-150Hz. A subthreshold OTA is used to achieve the 1Hz cut-off frequency. The transconductance is below 1nA/V.

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II. The Low G_M OTA Design

The performance of the OTA is based on the behavior of MOS devices operating in the subthreshold region. The channel current of subthreshold region is:[3]

$$I_D = \left(\frac{W}{L}\right) I_0 \exp\left(\frac{V_{gs}}{nV_T}\right)\left[1 - \exp\left(\frac{-V_{ds}}{V_T}\right)\right] \tag{1}$$

where I_0 is the specific current, W and L are the channel width and length of the MOSFET, n is a weak function of gate voltage and can be considered approximately constant in weak inversion and V_T is the thermal voltage.

When the $|V_{ds}|>4V_T$, the channel current and V_{ds} is almost independence. This is called weak inversion saturation region. The transconductance of the weak inversion saturation cad be expressed as:

$$g_m = \frac{\partial I_D}{\partial V_{gs}} = \frac{I_D}{nV_T} \tag{2}$$

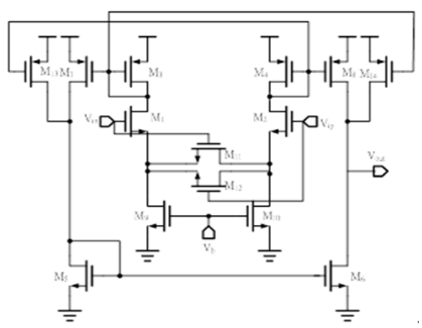

Fig. 1. The proposed low g_m OTA design.

The proposed low g_m OTA is sown in Fig. 1. M_1~M_4 are the input stage of the OTA. M_7, M_8, M_{13} and M_{14} are current cancellation technology to achieve lower transconductance. If M_3 and M_4, M_7 and M_8, $M_{13}$and M_{14} are matched respectively, and the (W/L) of the them is

$$\left(\frac{W}{L}\right)_3 : \left(\frac{W}{L}\right)_7 : \left(\frac{W}{L}\right)_{13} = 1 : M : N \tag{3}$$

The output current of the OTA can be written as:

$$i_{out} = 2(N-M)i_3 \tag{4}$$

The overall transconductance of the OTA can be driven as:

$$GM_{total} = \frac{\partial i_{out}}{\partial v} = 2(N-M)\frac{\partial i_3}{\partial v} = 2(N-M)GM_3 \tag{5}$$

If N is very close to M, then the overall transconductance can be reducing to a very small value.

M_{11} and M_{12} is the source degeneration transistor to improve the linearity performance of the OTA design. The supply voltage of the OTA is only 1V. V_b is the biasing voltage of the input stage. The total power consumption is only 30nW. The overall transconductance is only 780 pA/V.

III. The Proposed OTA-C Bandpass Filter Design

In order to precisely diagnose the heart disease, the detection circuits must be capable of attenuating the out-of band interference and the noise before analog to digital converter to avoid the aliasing. Ladder type is superior topology for high-order filter because they are inherently insensitive to component variations, especially in their passband. Hence, with the help of filter handbook, a forth-order passive ladder-type bandpass filter is deduced as shown in Fig. 2. The passband of this circuit is 1-150 Hz. The OTA-C bandpass filter is shown in Fig. 3 which is replaced the resistor and inductor in Fig. 2 by OTA-C circuit.

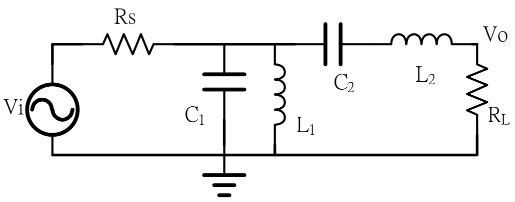

Fig. 2. 4-order bandpass filter topology.

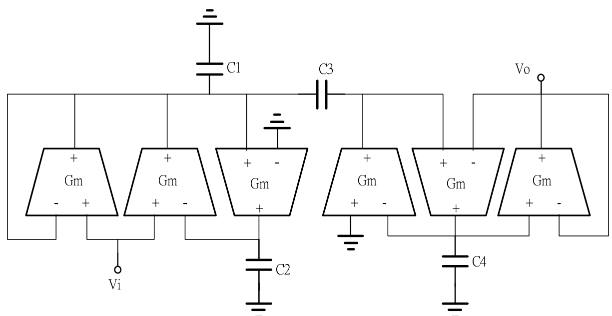

Fig. 3. The OTA-C bandpass filter topology

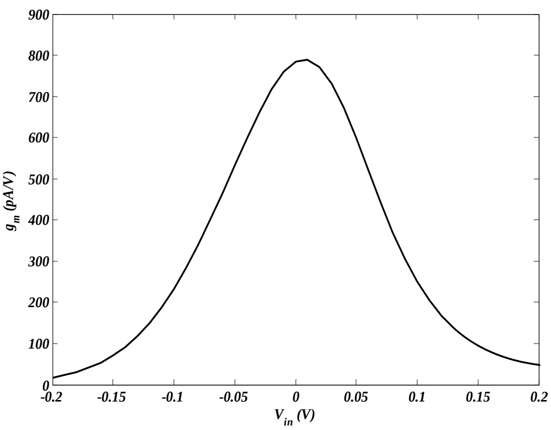

Fig. 4. The transconductance of the OTA.

IV. The Simulation Results

The proposed OTA-C bandpass filter is designed with TSMC 0.18μm CMOS process. The transconductance of the OTA is shown in Fig. 4 and the maximum g_m of the OTA is 780pA/V. The frequency response of the OTA-C bandpass filter is shown in Fig. 5 and the passband is about 1-150Hz. Fig. 6 shows the time response of the OTA-C filter with ECG signal. The supply voltage of the proposed OTA-C bandpass filter is only 1V. The total power consumption of the filter is 245nW. Fig. 7 is the layout of the proposed OTA-C bandpass filter and the core area is 670μm×280μm.

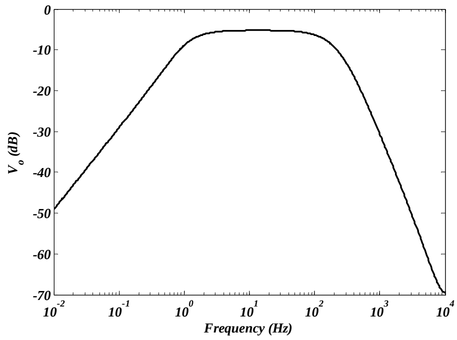

Fig. 5. The frequency response of the proposed OTA-C bandpass filter.

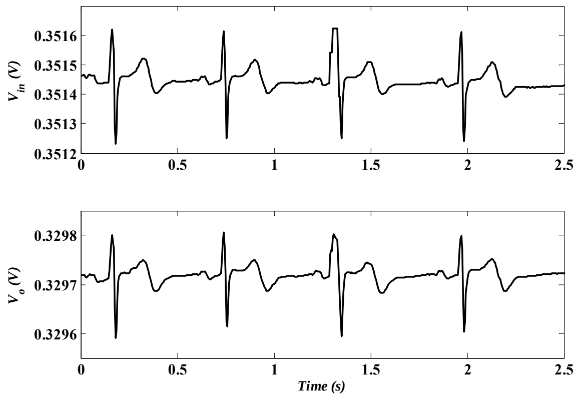

Fig. 6. The time response of the OTA-C filter.

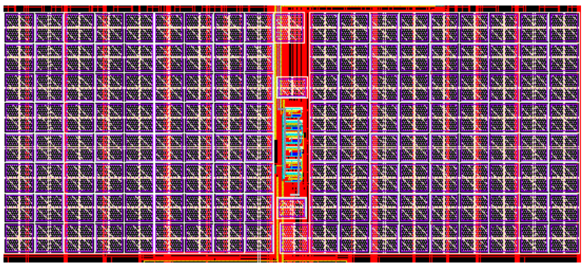

Fig. 7. The layout of the OTA-C filter.

V. Summary

An ultra low power OTA-C filter for ECG application is presented in this paper. A subthreshold region OTA is design with current cancellation technology to achieve a very small transconductance. A 4-order Butterworth OTA-C bandpass filter is design for ECG application. The performance summary is shown in Table I. The simulation results show this filter is suitable for ECG application.

TABLE I: Summary of the Proposed OTA-C Filter

Supply voltage (V)	1
Power consumption (nW)	245
Passband (Hz)	1-150
Chip area (μm^2)	670x280

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