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CMOS Based Low Pass Filter for Biomedical Applications

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ABSTRACT

Ultra low power with biomedical frequency low-pass filters has many applications in biomedical signal processing units. Biomedical signals are usually in the 10-mHz to 100-Hz frequency range and hence require subhertz frequency filters to condition the signal before processing. The performance of passive filters degrades at high frequencies and the required values of resistances and inductances are very difficult to meet from the market. To find a solution to this problem is to study   Active Filters using Operational Transconductance Amplifier (OTA). The aim of this work is to determine values of the design parameters that optimize an objective feature whereas satisfying specifications or constraints. This fourth order filter is implemented in a 0.18-μm technology In terms of power consumption and cutoff frequency this filter performs better than previous filters from the literature. This circuit is used with low frequency signal and low power portable medical equipment.

Keywords - Active filters, OTA, Subhertz frequency filter, Ultra low power.

I. Introduction

Low-frequency filters are important building blocks for biomedical systems, wherein analog pre-processing blocks, such as low noise pre-amplifiers and filters for the acquisition of bioelectric signals are employed. These circuits should not introduce any form of distortion that can destroy the information contained. For this reason, the analog pre-processing blocks must present high performance over the frequency of interest. The tolerance scheme specifies the pass-band and stop-band bandwidths of the filter and the acceptable ripple in these bands. Because a very steep cut-off filter is needed, filters of higher orders must be examined. The higher the filter order the steeper the cut-off slope is, but proportional to the order it results in a more complex circuit. This trade-off must be kept in view. In this circuit, power consumption is a critical factor thus the complexity of the filter and the steepness must be kept at an optimal value. The filters employed in biomedical systems are used for sensing bioelectrical signals which, typically, are in the range of 10mHz–100Hz At the input, a low-pass filter is usually employed in order to limit the frequency band. The design of very low-frequency filters (10 Hz) is not straightforward, especially for integrated circuit implementation.

However, despite their utility, creating large time constant low-pass filters on-chip is a challenging problem. To implement large time constants, switched-capacitor-based topologies require large capacitor ratios [9], and a sufficiently high power supply must be used to achieve an acceptably low switch on-resistance.

Switched-capacitor filter has been successfully applied to many voice band applications. It has good accuracy of time constants and good temperature characteristics; whereas the problem of clock feed-through is difficult to be solved and it also needs continuous-time filters as anti-aliasing filters. Another alternative is to use gm-c filters which do not have the aliasing problem of sampled-data systems. Due to the dependence of the cut-off frequency of the filter on the absolute values of monolithic components such as capacitors and transistor transconductances, which are both process and temperature dependent, feedback and cancellation techniques are required to control the cut-off frequency of this type of filters. And it also needs a small transconductance in order to avoid using large area capacitors at low frequency. This work describes a low cut-off frequency CMOS low pass filter which utilizes a cross-coupled input structure to cancel the deviation of the cut-off frequency under the influence of different temperature and produce an appropriate transconductance with four auxiliary amplifiers to keep the gain. It is a monolithic filter with low power consumption and   low-voltage.

1.1   OTA Based Low-pass filters

The conventional operational amplifier (op-amp) is used as the active device in the vast majority of the active filter literature operational amplifier limitations preclude the use of these filters at high frequencies, attempts to integrate these filters have been unsuccessful. In this, basic first, second and higher-order structures using the transconductance

amplifier are discussed. These structures offer improvements in design simplicity and programmability when compared to op-amp based structures as well as reduced component count. Many of the basic ota based structures use only otas and capacitors and, hence, are attractive for integration and called as gm-c filter techniques[6]. A gm-c filter is a kind of the continuous-time filter which needs the operational transconductance amplifier (ota) to be a basic building block. The cut-off frequency of a gm-c filter is directly proportional to the gain of trans-conductance and inversely proportional to the capacitance.

The major limitation of existing otas is the restricted differential input voltage swing required to maintain linearity. Since the transconductance gain of the OTA is assumed proportional to an external dc bias current, external control of the filter parameters via the bias current can be obtained.
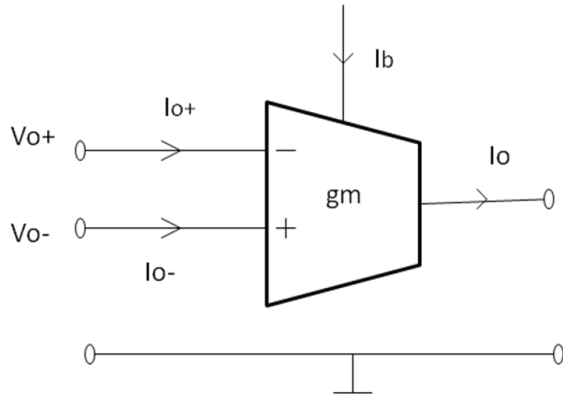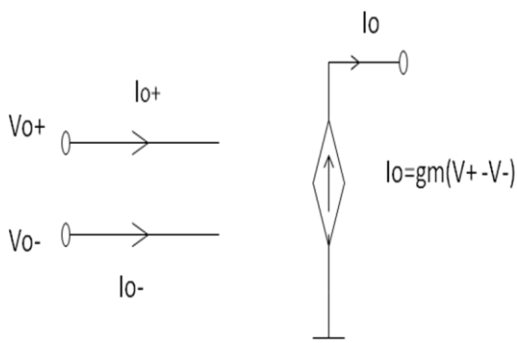

Fig 1 : Circuit symbol of OTA

Fig 2: Ideal small signal equivalent of OTA

First order low-pass filter OTA is replaced with simple differential OTA. Gm-C filtering has been used for this structure instead of switched capacitor because the problem of clock feed through is difficult to be solved and it also needs continuous-time filters as anti-aliasing filters. In Gm-C filtering due to the dependence of the cut-off frequency of the filter on the absolute values of monolithic components such as capacitors and transistor transconductances, which are both process and

temperature dependent, feedback and cancellation techniques are required to control the cut-off frequency of this type of filters[6]. And it also needs a small transconductance in order to avoid using large area capacitors at low frequency. Here, a clocked transconductor is used to form the reduced transconductance *gm* element in a *gm/C* filter. The duty cycle of the clock then determines the effective transconductance and allows easy digital control of the filter cut-off frequency.
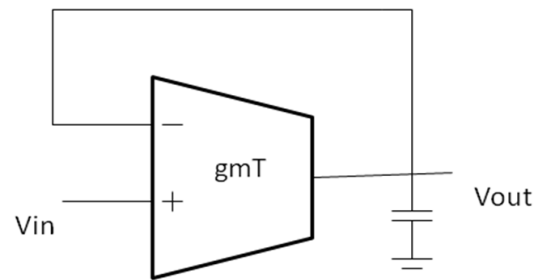

Fig3.First order low-pass filter[2]

II. Basic Operation

The basic principle of operation of proposed low-pass filter is based on clocking of the output of a transconductor element. A transconductor is placed in a feedback loop with a capacitor forming a first-order *gm/C* low-pass filter, and a switch is then added between the output of the transconductor and the capacitor. This switch allows the output of the transconductor to be connected to and disconnected from the capacitor and the feedback loop.

When the switch is closed, the output current from the transconductor I1, flows only though the capacitor, so that the average current that flows into the capacitor, I2 is reduced.
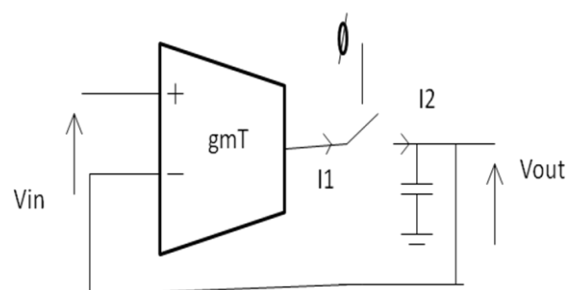

Fig4: Principle of operation of the proposed low-pass filter

When the switch is open, the output current of transconductor has no path to flow. This would cause the output of the transconductor to saturate at

the supply rails as no output current could be provided. To overcome this, two buffer cells are introduced, as shown in Fig. The first buffer is placed between the capacitor and the output node Vout to isolate the capacitor node from the load. The second buffer is then placed between the output of the filter transconductor $gm1$ and the capacitor via a second switch in opposite phase to the main switch. This second buffer thus provides a path for the output current of $gm1$ when the φ switch is open.
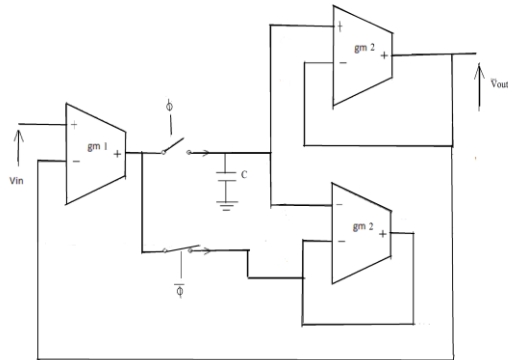

Fig5:The block diagram of low-pass filter with two buffers for ultra low power application

III. Implementation

In order to control the input-stage transconductance more precisely, and combined with the characteristics of the small value, the transistors in cross-coupled differential pair are biased in the sub-threshold area. The transconductance and the bias current have a linear relationship in a wide range.
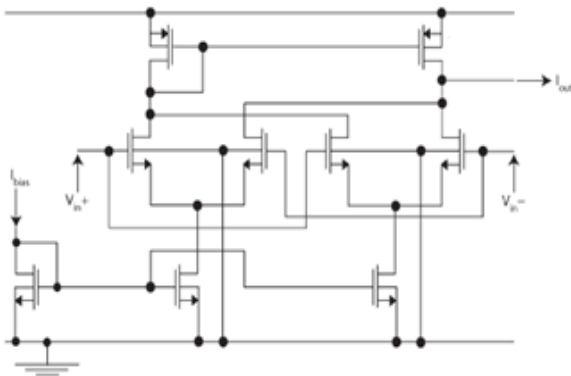

Fig6:Filter having transconductance $gm1$ schematic implemented in CMOS

The $gm2$ transconductors are buffers, as shown in Fig. It consists of basic differential pairs with their outputs connected to the negative inputs for unity voltage gain. The bias current is set at 1 nA, and since these buffers operate well below their bandwidth, their inputs are approximately equal and

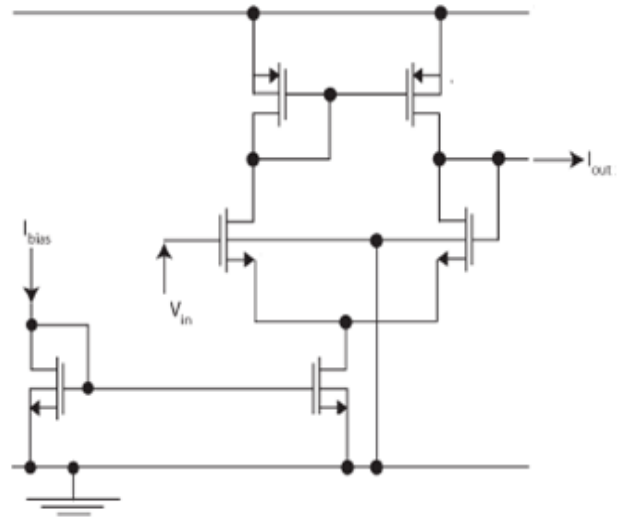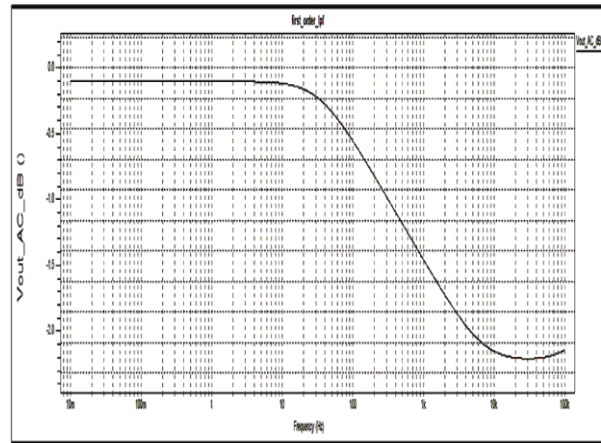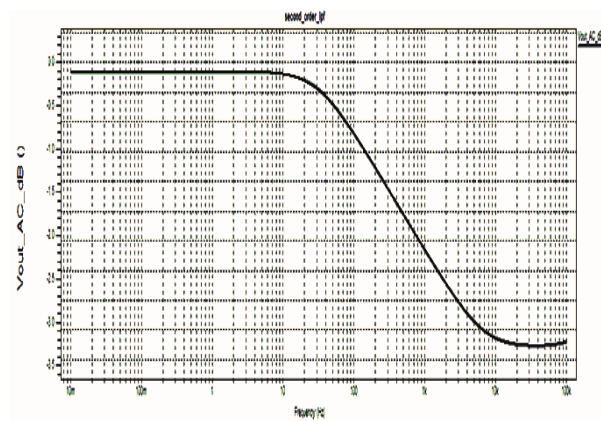they contribute very little to distortion in the overall filter.

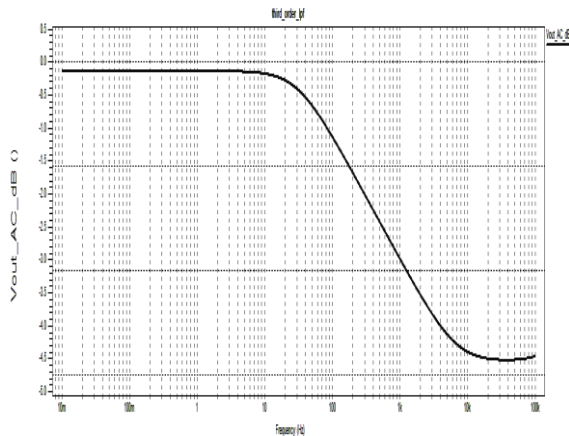Fig7: Buffer Filter having transconductance $gm2$ schematic implemented in CMOS

IV. Simulation Result

(a)

(b)

(c)

Fig 10 :ICMR measurement of proposed fourth order filter
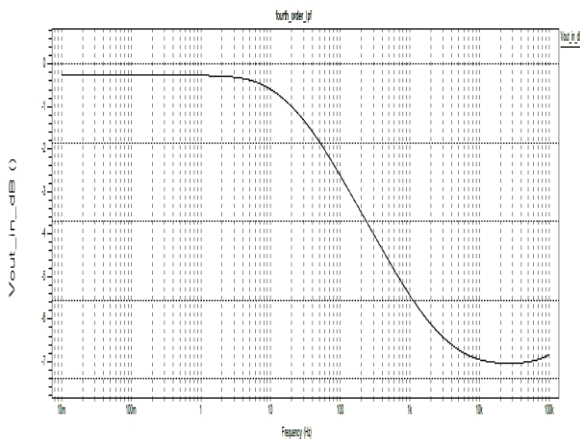
(d)

Fig8: Gain characteristic of proposed low-pass filter
(a) first order **(b)** second order
(c) third order **(d)** fourth order

The OTA is characterized by various performances like open-loop voltage gain, unity-gain bandwidth, slew rate, ICMR, PSRR and so on. These performances measures are fixed by the design parameters, e.g., transistor sizing, bias currents, and other component values.

For the measurement of PSRR, op-amp is connected in unity gain feedback, a DC bias is connected to input and AC signal at VDD terminal for PSRR measurement.

For ICMR measurement apply variable DC voltage at input of amplifier in unity gain configuration.

From the above result it is observed that we are getting gain equals to 0db and 3 db cut-off frequency below 10Hz with a bias voltage of 1V.The perfomanace parameter values PSRR = 0.022 ICMR(max)=0.937 and ICMR(min)=0.217. Which fulfill our aim of obtaining the design parameters which satisfies the biomedical equipment design specification.

V. Analysis Part

Some of the basic OTA building blocks are introduced in this section. A brief discussion about these circuits follows. Voltage amplifiers using OTAs are going to be discussed in this. The basic inverting and non-inverting configurations of OTA is shown in Fig
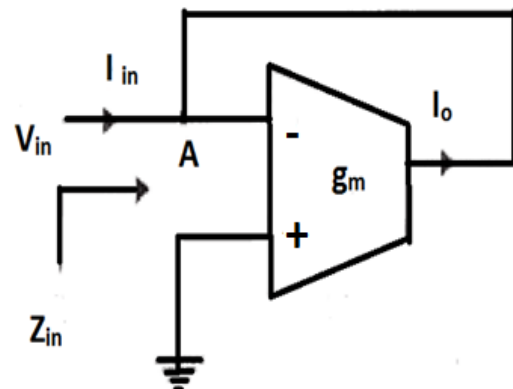

Fig 9 :PSRR Measurement of proposed fourth order filter

Fig11. Inverting feedback amplifier

Applying KCL at Node A gives us

Iin + I0 = 0 (1.1)

Where I0 = Vm x gm

Substituting the value of *I0* in equation (1.1) we have,

Zin = 1/ gm (1.2)

Fig 12. represents non inverting amplifier. In this, the voltage gain directly proportional to *gm*, which makes current (voltage) control of the gain via *Ib* straightforward. Furthermore, observe that a differential amplifier can be easily obtained by using both input terminals of the OTA in Fig.11 or Fig 12. The major limitation of these circuits is the relatively high output impedance.

Applying KCL at node A, we have

I0 = gm Vm (1.3)

Substituting equation (1.2) in equation (1.3) we have,
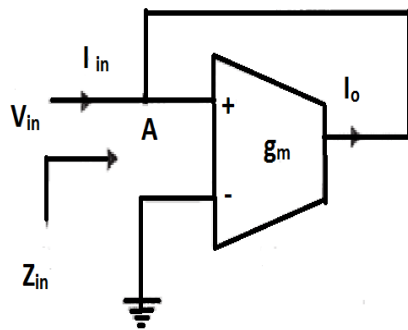
Zin = 1/ gin (1.4)

Fig 12. Non inverting feedback amplifier

VI. CONCLUSION

There is a great demand of low frequency low pass filter in biomedical and sensor technology at the same time low power consumption is great challenge. Through OTA, filter design become simple hence in this design technique OTA as a basic active element has been discussed.

The device designed collects cardiac data and monitors heart and circulation activity. It is built into the human body. The device is therefore must be realized as an integrated circuit. A very low frequency low-pass filter for power ranges of nW has been designed .This design shows excellent characteristics when compared with results in the literature. Operation is based on using a switch at the output of a transconductor in a *gm/C* filter to decrease the value of the transconductance and to increase the output resistance. This allows very low transconductance values to be achieved, and the clock signal facilitates easy digital tuning .In comparison to previous low-pass filters from the literature, the proposed topology provides the lowest power consumption, in addition to a very wide tuning range. In this, the proposed filter circuit has been designed at 0.18μm Technology.

Through low frequency demands, large capacitors must be used, which is very difficult to achieve on silicon wafer. MIM capacitor of such high valued capacitors is used.

VII. Future Scope

This work can be extended to designing of low pass filter with low frequency and low power in the future. However, the basic need in order to design low pass filter for low power is to minimize the power of OTA. The proposed clocked transconductor topology is thus highly suitable for use in low power, low-voltage sensor interfaces and in portable medical instrumentation. This can further be used for lower cut-off frequency and power. And since it is 1st order filter so for improved performances higher order filters for few nW power can be designed using this topology.

VIII. ACKNOWLEDGMENT

Table II

Parameter	Target value	First order	Second order	Third order	Fourth order
Technology	TSMC 180nm	TSMC 180nm	TSMC 180nm	TSMC 180nm	TSMC 180nm
Supply voltage	100mv-3v	1.8V	1.8V	3V	3V
Gain	0 db	~0db	~0db	~0db	~0db
Cut –off frequency	10mHz-100Hz	4Hz	3.76Hz	2.82Hz	1.67Hz

Load capacitance	2pF	0.5μ	0.5μ	2μ	2μ
-3db frequency	Below 10mHz	Below 10mHz	Below 10mHz	Below 10mHz	Below 10mHz
PSRR	0.41	-	-	-	0.222
ICMR	0.031-0.9	-	-	-	0.217-0.937

References

[1] J. Casson *"An Ultralow-Power CMOS Transconductor Design with Wide Input Linear Range for Biomedical Applications"* Yen-Ting Liu1, DonaldY.C.Lie1,2,WeibHu1 and Tam Nguyen1,2 *IEEE Circuits And Systems, 2012*

[2] Esther Rodriguez Villegas, Alexander and Phil Corbishley, *"A Subhertz Nano power Low-Pass Filter,"* IEEE *Circuits And Systems, vol .58, no.6, June 2011*

[3] Prashant K. Mahapatra, Manjeet Singh , Neelesh Kumar , *"Realization of active filters using operational transconductance amplifier (OTA)", Journal of the Instrument Society of India, pp 1-9.*

[4] Chun-Lung Hsu, Mean-Hom Ho, Yu-Kuan Wu and Ting-Hsuan Chen*, "Design of Low-Frequency Low-Pass Filters for Biomedical Applications,"* IEEE, Circuits and Systems, pp. 690-695 ,December2006

[5] Randall L. Geiger , Edgar Sánchez- Sinencio *"Active Filter Design Using Operational Transconductance Amplifiers:* A Tutorial," IEEE *Circuits and Devices Magazine*, vol. 1, pp.20-32, March 1985.

[6] Haidong Liu, Xiaohong Peng and Wuchen Wu, *"Design of a Gm-C Low Pass Filter with Low Cutoff frequency."* IEEE *Microelectronics & Electronics* , pp. 125-128 , January 2009.

[7] Andras Timar and Marta Rencz , *"Design issues of a low frequency low-pass filter for medical applications using CMOS technology,"*

[8] E.S .Sinencio and J.S. Martinez, *"CMOS transconductance amplifiers, architectures and active filters: a tutorial"*, IEEE *Proc.-Circuits Devices System*, vol. 147, no. 1, February 2000

[9] W. M. C. Sansen and P. M. Van Peteghem, *"An area-efficient approach to the design of very-large time constants in switched-capacitor integrators ,"*IEEE, *Solid-State Circuits,* vol. SSC-19, no. 5, pp. 772–780, Oct. 1984.