A Review on Low Voltage Low Power Gm-C and OTA-C Low Pass Filter for Biomedical Application

Gaurav Kumar Soni, Gouri Shankar Sharma

Abstract— **Low power low-pass filters for biomedical frequency range has many applications in sensor interfaces and biomedical signal processing units. In this paper various techniques to design Gm-C and OTA-C based low pass filter for very low cut-off frequency has been studied. The aim of this paper is to study valuable and important work from previous design for biomedical application especially for ECG and EEG.**

Index Terms **— CMOS, Operational Transconductance Amplifier (OTA), Biomedical Signal, Low Frequency, Low Pass Filter (LPF), electrocardiograph (ECG), electroencephalograph (EEG).**

I. INTRODUCTION

Biomedical Application such as ECG, EEG requires very low power designs because biomedical portable sensors are generally battery operated. ECG and EEG are two most mapping instrument, these instruments are used to monitor functioning of two most important part of the human body heart and brain.

To obtain the activity of heart and brain analog processing cells are required. These cells are connected to skin via electrode to record the activity of heart and brain. In order to record the activity directly various IC's has been designed, in these IC's one of the most important part is the low pass filter. The cutoff frequency in low pass filter in ECG and EEG are 250Hz and 200Hz respectively [1]. The filter implementations have many techniques such as Gm-c, Active RC, OTA-C, switched capacitor, the choice of the filter can be done as per the frequency requirement.

The implementation of low frequency filters are not easy to design, since the requirement of Gm value comes into nA/V range and the capacitor value reaches grater then the 100pF. Many foundries aren't able to provide capacitor value more than 50pF, also due to the large implementation area capacitor of large value can't be easily implemented. Another problem with low transconductance value in nA/V range gets deteriorated due to noise, distortion and non-idealities.

II. BIOMEDICAL SIGNAL PROCESSING SYSTEM

A typical general purpose biomedical signal processing system is shown in the fig 1. The most important part of the biomedical system is the analog processing block in which bock consists of the preamplifier and filter. The most common filter in the biomedical signal processing which is used is the low pass filter because the biomedical signal system is work on the very low frequency.

A preamplifier must amplify the input signal to a higher level with low noise and low distortion. For example in electrocardiograph application where the magnitude of the preamplifier signals has to be processed around hundred mili volt by a low pass filter. The high performance of very low frequency filter can be efficiently implemented in CMOS technology [4].

TABLE I: Most Commonly Used Biomedical Signals

Signal	Frequency
ECG	250Hz
EEG	200Hz
ERG	100Hz

Electroencephalograph (EEG) is known as the electrical recording of brain activity. It has numerous diagnostic and research application in the study of the brain. Electroencephalograph can be recorded from the human brain by the placement electrodes on the surface of the scalp but the signal picked up are very small (on the order of a few microvolt) to be recorded or digitized (for example by an A/D converter) [2].

Electrocardiograph (ECG) is an electrical recording of the heart activity.

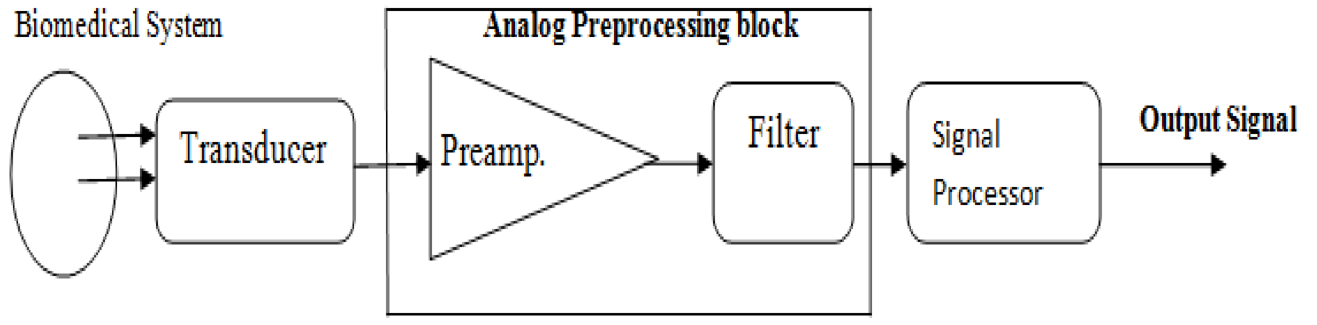

Figure 1: Block diagram of general purpose biomedical system [4]

III. DIFFERENT TECHNIQUES TO REALIZED LOW TRANSCONDUCTANCE FILTER

A. CURRENT DIVISION TECHNIQUE:

There are many salutations to the problem of large capacitor and very low transconductance has been given in the previous literature. In [4], 2.4Hz low pass filter achieve a 60dB dynamic range with linearity 2nA/V transconductance OTA and 5pF capacitor can be used. In [4] dynamic range of the filter was 60dB which is very high and it is achieve by keeping the $V_{DSAT} > 2V_{DMAX}$, where V_{DSAT} is the saturation voltage of the input transistor and $V_{DMAX}$is the maximum differential input voltage. In order to avoid noise in the system current division technique is applied. The OTA circuit used in [4] is shown in the fig 2.

The transconductance of OTA in [4] is given by

$$G_m = \frac{i_o}{v_1 - v_2} = \frac{N-1}{M+N+1} g_{oMR} \quad \text{——— (1)}$$

Where g_{oMR} is small signal source to drain conductance of transistor M R, given by

$$g_{oMR} = \mu_p C_{ox} \frac{W_{MR}}{L_{MR}} (V_{SDMR} - V_T) \quad \text{—— (2)}$$

The value of M (in eqn.1) is defined as the ratio of transconductance between MM and M1 while N is the value of ratio of transconductance between MN and N1.
In OTA-C filters frequency is given by

$$f_o = \frac{G_m}{2\pi C_L} \quad \text{——— (3)}$$

The filter constructed by this G_m circuit is 6th order 2.4Hz low pass filter with ±1.5V power supply and power consumption below 10µW and area is $1mm^2$.

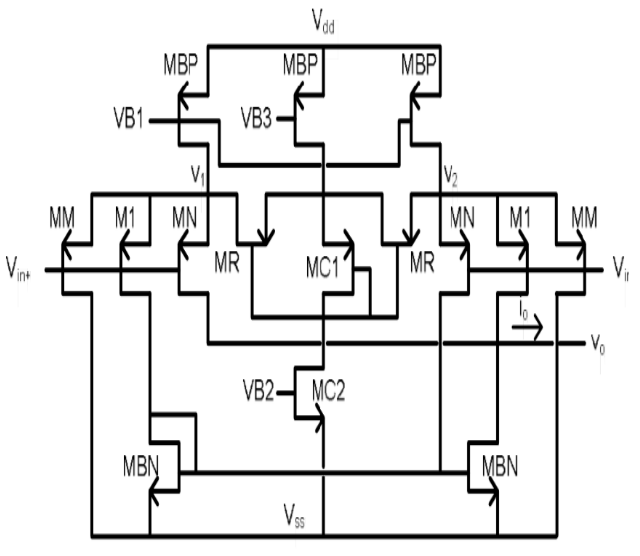

Figure 2: Single ended OTA for low frequency operation [4, 12]

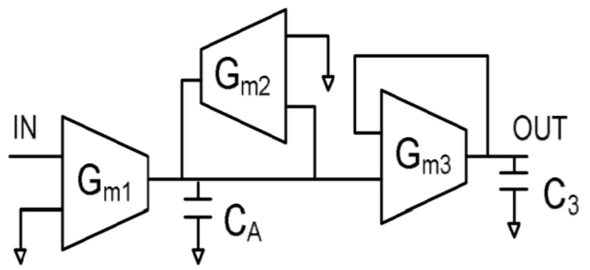

Figure 3: 2nd order Gm-C Low Pass Filter [12, 4]

B. SERIES PARALLEL CURRENT MIRROR CURRENT DIVISION TECHNIQUE:

In traditional OTA input differential pair converts voltage into current and the current mirror employed in the circuit just copy the current to the output. In this type of circuit bias current are maintained to very low level so that the low transconductance can be achieved but in this Many techniques has been introduced to achieve a better linearity by mixing two or more techniques such as by changing the design of traditional input differential pair or by using floating gate and bulk driven MOS transistor. In [7], NMOS current mirror are stacked in parallel and series to achieve effective transconductance of the circuit is given by

$$G_m = \frac{g_{m1}}{N^2} \quad \text{——— (4)}$$

Where,

N units of series transistors are stacked to generate current g_{m1} is the gate transconductance of the differential input pair.

In this [7] another technique active linearization transistor is also used to feather enhance the overall linearity of the circuit. Stacking of series parallel transistor of current mirror provides better matching and area efficiency.
To implement series parallel current mirror ACM MOSFET model is used to efficiently model the series parallel current mirror. In series parallel current mirror division technique the threshold voltage and current factor of each MOS circuit is small or large group of matched transistor will not be exactly same.

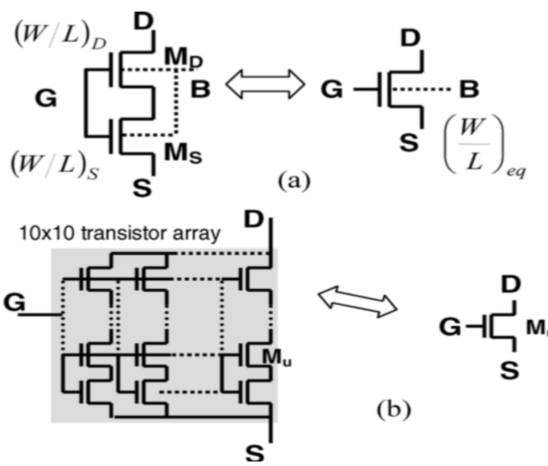

Figure 4: (a) two series-connected transistor and their equivalent. (b) A single Mu transistor is equivalent to a 10 x 10 Mu array [7]

In fig 4(a) transistor $M_{S(D)}$ are series connected then the equivalent aspect ratio can be given as

$$\left(\frac{W}{L}\right)_{eq} = \frac{\left(\frac{W}{L}\right)_D \cdot \left(\frac{W}{L}\right)_D}{\left(\frac{W}{L}\right)_S + \left(\frac{W}{L}\right)_D} \qquad (5)$$

Above equation can be used to model any transistor with equivalent geometry. The copy factor M in this current mirror is calculated as ratio between M_A and M_B (fig 5). Using equation 5 the mirror in Figure 5.

$$\frac{I_{in}}{I_{out}} = \frac{S.P}{R.Q} = M \qquad (6)$$

By using series parallel current mirror in transconductor [7] achieve a transconductance of 89nS with ±500mV linear range. From this transconductor and an integrator that means a low pass filter is designed which obtained a 3.3sec of time constant with 50pF capacitance. The 3dB frequency of this filter is 0.302Hz.

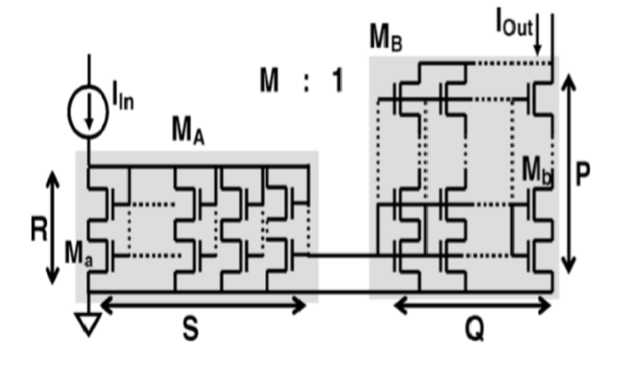

Figure 5: Generic SP current mirror. P x Q unit transistors MB and R x S unit transistor MA, are series parallel connected at the output and input branch respectively [7]

C. LOW TRANSCONDUCTANCE REALIZATION BY CASCADING TRANSCONDUCTANCE AND INVERSE TRANSCONDUCTANCE CELL:

In this [5] work a very simple technique to obtain very small transconductance based on cascading on transconductance cell. The benefit of this approach is that by adjusting theintegrating capacitor and the biasing current ratio will be very low.

In this work all the transistor are operated in week inversion so that low voltage low power assumption can be achieved. The differential pair is used in this technique is a long tailed pair that is cascaded with $g_m - g_m^{-1}$.

The circuit biasing current ratio is adjusted in such a way, so that transconductance obtained is very low. The total small signal transconductance is used in this approach is

$$g_{mT} = \frac{I_{out}}{V_{in}} = g_m\left(\frac{I_{ss3}\,.I_{ss5}}{I_{ss2}+I_{ouss\,4t}}\right) \qquad (7)$$

Where,

$I_{SS,n}$(n is the number of stage) are the tail current of the transconductance stage n.

G_{m1} is small signal transconductance of the first order transconductor which can be given by

$$g_{m1} = \frac{I_{ss1}}{2n_N V_T} \qquad (8)$$

Where,

I_{SS1} is the tail current of the first stage transconductor
n_N is the sub threshold slope factor of NMOS
V_T is the thermal voltage.

In fig 6 the transistor M1-M4, M9-M12, M17-M28 forms of g_m blocks while M5-M8 and M13-M16 forms g_m^{-1} blocks. Forms this blocks M17-M28 are high output voltage swing with regulated cascade output to obtained very high small signal output resistance.

The biasing current used in this transconductor range from 0.5-1.4 nA and also all the transistor are operate in the weak inversion region.

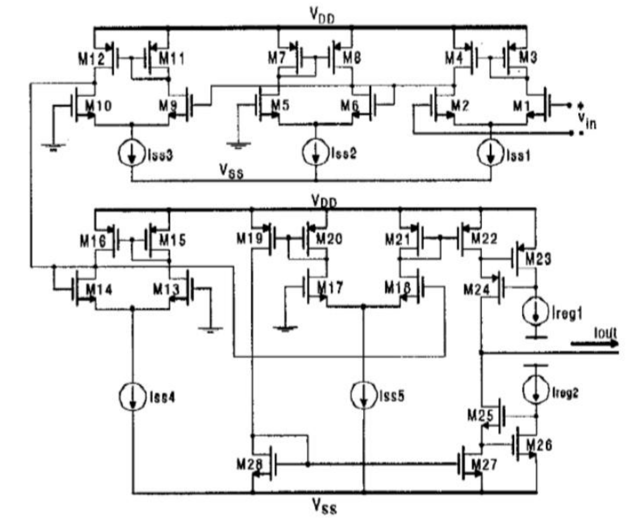

Figure 6: cascading of gm – gm-1 technique for low transconductance [5]

This transconductor is used to design first order low pass filter with 1pF integrating capacitor shown in figure 7.

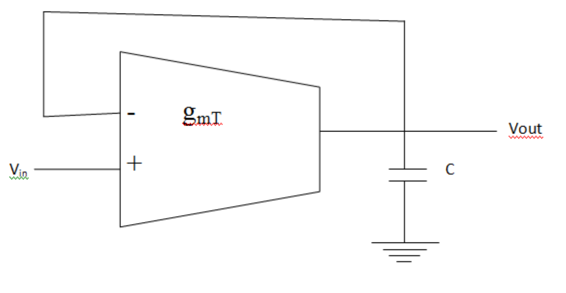

Figure 7: First Order Low Pass Filter [5]

TABLE II: Comparison of the performance of different low-frequency low-pass filters

Ref. No.	[3]	[4]	[6]	[8]	[9]	[10]	[11]	[12]
CMOS Process	0.35um	0.8 um	0.35um	0.8 um	0.35 um	0.18 um	0.35 um	0.35 um
Cut off frequency	2.4 Hz	2.4Hz	3.8 Hz	0.5-200Hz	15Hz	240Hz	0.002Hz	18 Hz
Filter order	8	6	--	2	2	5	1	5
Power Consumption	0.36nW	10uW	96.5nW	Below 2uW	--	453nW	5nW	1.23mW
Supply Voltage	3V	3V	1.5V	1.5V	3.3V	1V	1V	3V
Area	--	$1mm^2$	$0.6076 mm^2$	$0.09 mm^2$	$0.336 mm^2$	$0.13 mm^2$	$0.07 mm^2$	$0.94 mm^2$
Integrating Capacitance	20pF	5pF	--	---	35pF	--	40pF	--
Dynamic Range	85dB	60dB	--	70dB	60dB	50dB	64dB	78dB

IV. CONCLUSION

The design of low frequency filter whether OTA-C or Gm-C required very low transconductance value and very high capacitor values but capacitor value grater then 100pF in CMOS technology not easy and cost effective to fabricate. So in order to keep capacitor value low the literature survey shown various techniques to keep the transconductance and capacitor value to be low. Among all techniques discuss above, any of them is mixed with other to increase efficiency for an accurate filter design.

The frequency mentioned in the paper from previous work can be used to optimize the design of low voltage, low power, low transconductance OTA-C and Gm-C based filter. Such a filter which is to be designed is used for biomedical application like ECG, EEG, ERG, EMG etc…

REFERENCES

[1] J. D. Bronzino, The Biomedical Engineering Handbook: IEEE and CRC Press, 1995.

[2] AshwinK .Whitchurch, Jose K . Abraham, MeghanaA .Lonkar and Vijay K .Varadan, " Design of a Compact Amplifier and Signal Conditioning Module for Wireless EEG Monitoring " , IEEE 2007.

[3] Tan-Tan Zhang, Pui-In Mak, Mang-I Vai, Peng-Un Mak, Feng Wan, R. P. Martins, "An Ultra-Low-Power Filtering Technique for Biomedical Applications" IEEE, EMBS pp- 1859-1862, August 30-September 3, 2011.

[4] S S-Bustos, J S Martinez , F Maloberti and E Sanchez-Sinencio, "A 60-dB Dynamic-Range CMOS Sixth-Order 2.4-Hz Low-Pass Filter for Medical Applications", IEEE Transactions On *Circuits And Systems*, vol. 47, pp. 1391-1398, no.12, December 2000.

[5] U. Yodprasit and J.Ngarmnil, "Micro power Transconductor for Very-Low Frequency Filters", IEEE, *Circuits and Systems*, pp. 5-8, Nov.1998.

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

[7] A. Arnaud, R. Fiorelli, and C. Galup-Montoro, "Nanowatt, sub-nS OTAs, with sub-10-mV input offset, using series-parallel current mirrors," *IEEE J. Solid-StateCircuits*, vol. 41, no. 9, pp. 2009–2018, Sep. 2006.

[8] A. El Mourabit, G.-N. Lu, and P. Pittet, "A low-frequency, sub 1.5-V micropowerGm-C filter based on subthreshold MIFG MOS transistors," in Proc. IEEE ESSCIRC, Grenoble, France, Sep. 2005, pp. 331–334.

[9] P. Bruschi, N. Nizza, F. Pieri, M. Schipani, and D. Cardisciani, "A fully integrated single-ended 1.5–15-H low-pass filter with linear tuning law," IEEE, *Solid-StateCircuits*, vol. 42, no. 7, pp. 1522–1528, Jul. 2007.

[10] Shuenn-Yuh Lee, Member, IEEE, and Chih-Jen Cheng," Systematic Design and Modeling of a OTA-C Filter for Portable ECG Detection", IEEE TRANSACTIONS ON BIOMEDICAL CIRCUITS AND SYSTEMS, VOL. 3, NO. 1, FEBRUARY 2009.

[11] Esther Rodriguez Villegas, Alexander J. Casson and Phil Corbishley, "A SubhertzNanopower Low-Pass Filter, " IEEE *Circuits And Systems*,vol .58, no.6, June 2011.

[12] Alex Wong, kong-pang pun, yuan-Ting Zhang and Chiu-Sing Choy," An ECG measurement IC using driven right leg circuit", IEEE 2006.

[13] Dong Han, Yuanjinzheng, and Minkyu Je, " A 0.18µm Front End for ECG/EEG/Neural Sensor Interface", IEEE 2012.

Mr. Gaurav Kumar Soni is a M.Tech Student of Department of Electronics & Telecommunication with specialization in VLSI and Embedded System Design from Disha Institute of Management &Technology,Raipur. He has done B.Tech in Electronic &Communication from Jaipur Engineering College, Jaipur.

Email : gauravsoni2709@gmail.com

Mr. Gouri Shankar Sharma is an Asst. Professor at Disha Institute of Management & Technology in Department of Electronics & Telecommunication Raipur. He is MTech in Electronics & Communication from Indian School of Mines Dhanbad (Jharkhand). He has done BE in Electronics & Communication from Guru GhasidasUniversity,Bilaspur (CG). He has also achieved certification in Embedded System Design from University of Pune.

Publications:-

Rajendra Kumar Patel, Gouri Shankar Sharma, Rajul Jain , **"Simulation of Organic Light Emitting Devices",** INTERNATIONAL JOURNAL OF SCIENTIFIC PROGRESS AND RESEARCH (IJSPR) Volume-08, Number-01, 2015.

Ankit Singh, Gourishankar Sharma, **"Microcontroller Based Real Time Distance Measurement System"** IJREAT International Journal of Research in Engineering & Advanced Technology, Volume 3, Issue 5, Oct -Nov, 2015.

Email : gourishankar2007@gmail.com