Low Power Operational Transconductance Amplifier for Biomedical Application Using CMOS 90nm Technology

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Abstract: In this paper, a low power low transconductance operational transconductance amplifier (OTA) is designed for biomedical application such as the EEG and ECG. To achieve a very low transconductance with low power the OTA should operate in sub threshold region. For better linearity of the OTA, the multi-tanh doublet linearization technique is used. In this design 90nm CMOS technology is used with ±0.35V supply voltage. The linear range of the OTA is 200mV and the power dissipation is below 6nW. The transconductance value of the OTA is 50nS for biomedical EEG Application and 62.68mS for biomedical ECG Application, Which can be tuned by varying in control voltage V_C. The 3-db cutoff frequency required for ECG and EEG is 250Hz and 200Hz respectively.

Key words: CMOS, OTA, Biomedical frequency, ECG, EEG, Sub threshold.

I. INTRODUCTION

In this paper we design an operational transconductance amplifier for biomedical application ECG and EEG. The OTA is required design for low pass filter circuit which is a part of the portable biomedical signal processing system for monitoring and electrical recording of the heart activity (ECG) and brain activity (EEG).

The operational transconductance amplifier (OTA) is a widely used analog processing block. In recent years, the development of integrated OTA with very low conductivity and improved linearity has been mainly used in biomedical applications. Many OTA topologies have been developed to achieve very low steepness in several nA / V with a good linear range [1]. The demand for tools for biomedical applications is growing worldwide. Low voltage and low power consumption is the need for biomedical devices to achieve long battery life. [2].

Due to the rapid and numerous development of microelectronics in recent years, a multitude of applications require an extremely low amplitude signal measurement module, for example, implantable devices in biomedical applications. Monitoring of various biomedical signals of the human body is a very interesting topic, because it helps to obtain vital information about the health of the human body based on the data obtained. These data are used by doctors to diagnose diseases. Biomedical signals, such as electrocardiogram (ECG), electromyogram (EMG), electroencephalogram (EEG), are characterized by their voltage and frequency characteristics [3].

The main objective of the OTA is to convert the input voltage signal into the current signal for the next stage of the processed signal [4].

The low transconductance operational transconductance amplifier (OTAs) is important in the design of low frequency or biomedical frequency filters which is used in the biomedical signal processing system. The OTA is designed using various topologies for low power and low transconductance. In this paper we design low transconductance OTA circuit with low power dissipation which operates in sub threshold region is carried out. To increase the linearity of the OTA scheme, linearization technology with several taps is used.

Most biomedical devices monitor patients throughout the day, and therefore these devices should be low power dissipation. A typical low power biomedical device may consist of a complementary metal oxide semiconductor circuits (CMOS) operating in the sub threshold region (weak inversion) [5].

II. MOS GILBERT CELL DOUBLET IN SUBTHRESHOLD

In a weak inversion or sub threshold region, the main charge carriers are replaced from the channel region, so we have a very low density of minority carriers. Typically, the sidewall current is approximately in the range from 10-9 to 10-7 A. When the MOSFET is operating in the side-lobe range, the current is determined by [6]:

$$I_{DS} = I_M \left(\frac{W}{L}\right) \exp\left(\frac{V_{GS} - V_M}{n\emptyset_t}\right) \left[1 - \exp\ \frac{-V_{DS}}{\emptyset_t}\right] \_\_\_\_\_ (1)$$

Where, I_M is the characteristic current of order 10^{-15} to 10^{-12} amperes. [refer Anantha-P chandrakasan]

V_M is upper limit of weak inversion or sub threshold in term of V_{GS} (consider with thermal voltage) for a fixed V_{BS} (in this design -0.35V).

$\emptyset_t$ is thermal voltage and n is sub threshold slope factor,

$$n = \frac{C_{ox} + C_{Dep}}{C_{ox}} = \frac{1}{K} \qquad \_\_\_\_\_ (2)$$

C_{ox} is oxide capacitance and C_{DEP} is depletion capacitance. From eq. (1), here I_{DS} is independent of V_{DS} when $V_{DS} > 3\emptyset_t$, with less than 5% error.

So, we can approximate the eq. (1) as,

$$I_{DS} = I_{Do} \left(\frac{W}{L}\right) \exp\left(\frac{V_{GS}}{n\emptyset_t}\right) \qquad \_\_\_\_\_ (3)$$

Where,

$$I_{Do} = I_M \exp\left(\frac{-V_M}{n\emptyset_t}\right) \qquad \_\_\_\_\_ (4)$$

A. SINGLE STAGE AMPLIFIER IN SUBTHRESHOLD REGION OR WEAK INVERSION

The basic is diagram of the single stage amplifier is shown in the fig 1. We operate this single stage amplifier in sub threshold region and the output current of this single stage amplifier in sub threshold region is given by:

$$I_{out} = I_B \tanh\left[\frac{V_{in}}{2n\emptyset_t}\right] \qquad \_\_\_\_\_ (5)$$

Where,
n is the sub threshold slope factor, which value is shown in eq. (2)
$I_B = i_+ + i_-$

And V_{in} is the input voltage $V_{in} = V_+ + V_-$

$$G_m = \frac{\partial I_{out}}{\partial V_{in}} = \left.\frac{k\,I_B}{2\emptyset_t}\right|_{V_{in}=0} = \frac{I_B}{\left(\frac{2\emptyset_t}{k}\right)} \qquad \_\_\_\_\_ (6)$$

$$V_L = \frac{2\emptyset_t}{k}$$

So,

$$G_m = \frac{I_B}{V_L} \qquad \_\_\_\_\_ (7)$$

G_m is the small signal transconductance g_m of M_3 and M_4 (input transistors).
If we apply ($+V_{in}$ / 2) and ($-V_{in}$ / 2), hence the output current is

$$I_{out} = g_m V_{in} \qquad \_\_\_\_\_ (8)$$

V_L (Linear Voltage Range) can be obtained by extrapolating the G_m slope at origin until the saturation current I_B is reached.
Let, k = 0.7, $\emptyset_t$ = 26mV, then

$V_L = (2\ \emptyset_t / k) = 75$mV is very less.

If we operate this circuit in saturation can yield more large result but power consumption increases as well as we lose common mode dc operating range.
So, it is required to design a low power transconductance capable of having value of V_L (Linear Voltage Range) is more in sub threshold operation without losing signification amount of common mode dc operating range.

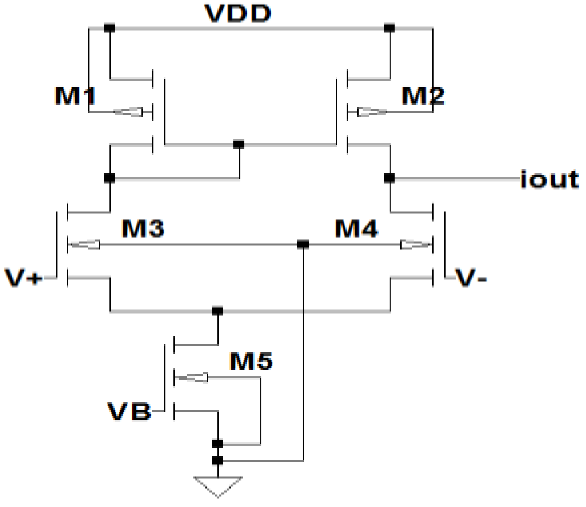

Figure 1 : single stage amplifier in subthreshold region or weak inversion

To add more linearization we add a technique called "multi-tanh linearization".

B. MULTI-tanh DOUBLET TECHNIQUE

Gilbert Multiplier cell is used as OTA which is previously used in saturation region as a multiplier, but in sub threshold region its transconductance is defined by tanh trigonometric identity.
To increase the linear range of the circuit, the multi-tanh doublet technique is used.

In the fig. 2, the differential pair represented by sets M1 – M2 & M3 – M4 shown a voltage offset with the same absolute value but in opposite direction of transfer characteristics. I_1, I_2, I_3 and I_4 are the current of transistors M_1, M_2, M_3 and M_4 respectively.

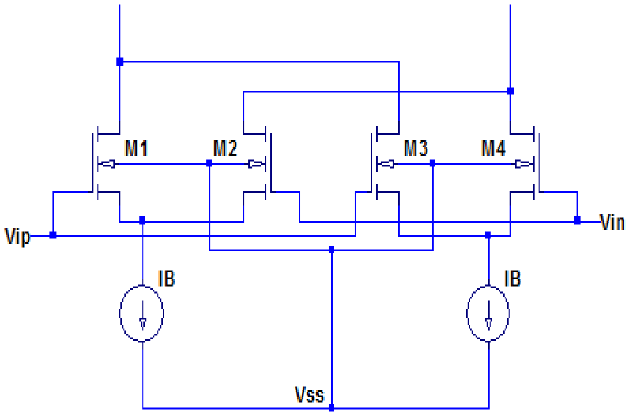

Figure 2 : Multi tanh doublet linearity technique

$$I_1 - I_2 = I_B \tanh\left[\frac{V_{in} + V_{OS}}{2n\emptyset_t}\right] \qquad \_\_\_\_\_ (9)$$

And

$$I_3 - I_4 = I_B \tanh\left[\frac{V_{in} - V_{OS}}{2n\emptyset_t}\right] \qquad \_\_\_\_\_ (10)$$

The output current of this circuit is given by:

$$I_{out} = (I_1 - I_2) + (I_3 - I_4) \qquad \_\_\_\_\_ (11)$$

Now, from using the eq. (9) and eq. (10) the final output current of the circuit is

$$I_{out} = I_B\{\tanh\left[\frac{V_{in} + V_{OS}}{2n\emptyset_t}\right] + \tanh\left[\frac{V_{in} - V_{OS}}{2n\emptyset_t}\right]\} \qquad \_\_\_\_\_ (12)$$

Using this technique we increase the linearity of the circuit and also the power consumption of the circuit is very low using this technique.

III. Proposed Transconductor :

Using the Multi-tanh doublet technique design the required low power low transconductance OTA which operates in subthreshold region. The proposed design of OTA is shown in the figure 3. In this OTA M1-M2 and M3-M4 are the two input differential pair of the OTA connected in parallel. In which we apply the positive input voltage at M1 and M4 and negative input voltage at M3 and M4. Using multi-tanh doublet we increase the linearity of the circuit and also power consumption of circuit is very low and we also operate this circuit in subthreshold at very low supply voltage. The output current of each input transistor is shown in figure 4.

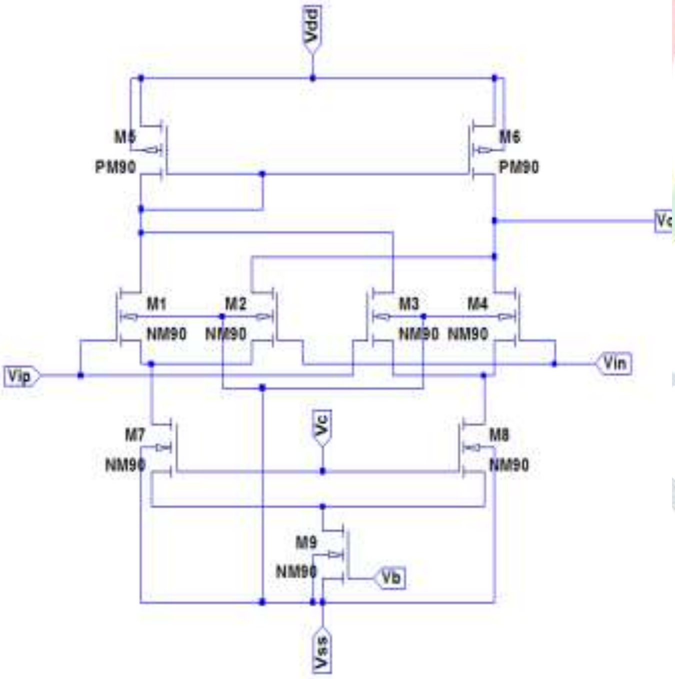

Figure 3 : Proposed OTA design

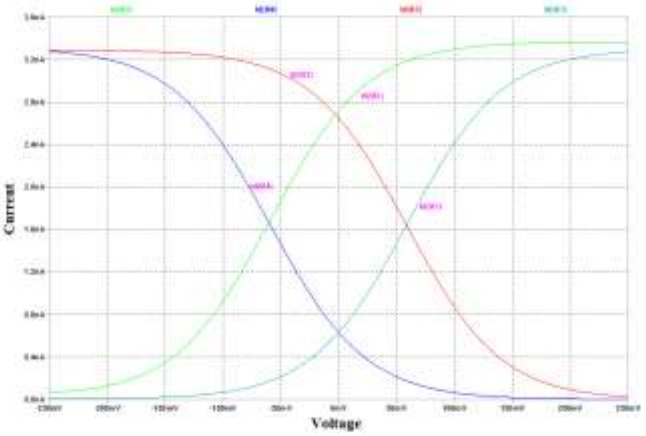

Figure 4: Output Current of Each Input transistor for EEG Application

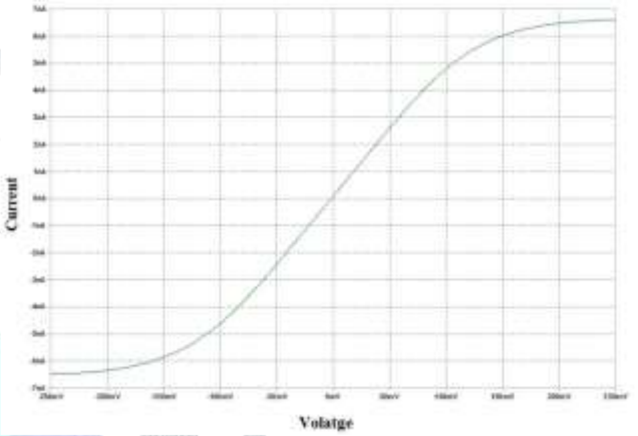

Figure 5 : Overall output current of OTA for EEG Application

The overall current in the OTA is -6.50nA to 6.60nA, thus the total current requirement of OTA is 13nA. The OTA output current for EEG Application is shown in the fig 5. The transconductance of the each input differential pair is 25nS and the overall transconductance of the designed OTA is 50nS for EEG Application.

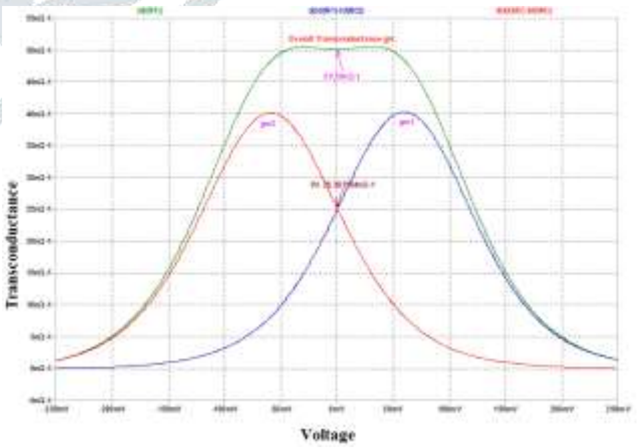

Figure 6 : Transconductance of the each input differential pair and overall transconductance of the OTA for EEG Application

The control voltage (V_c) is used in the OTA to control or vary the transconductance of OTA with different value of the control voltage. Using the control voltage the transconductance of the OTA is varied and can also the frequency. The variation in the transconductance by varying control voltage is shown in figure7.

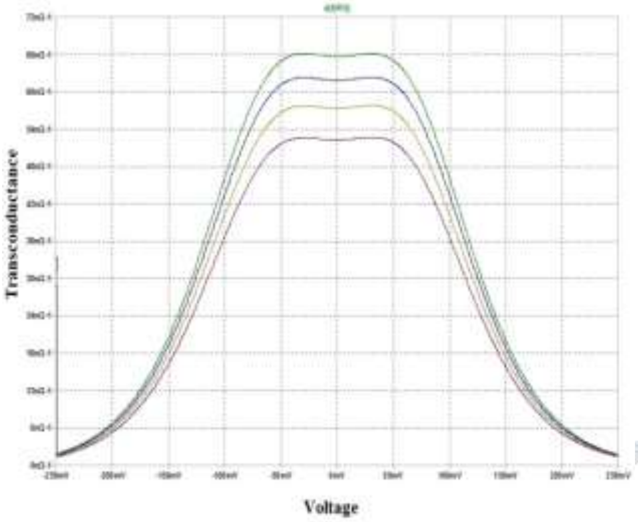

Figure 7 : Variation of the Overall Transconductance by Varying Control Voltage (V_c)

The overall transconductance of OTA is 50nS without varying the control voltage (i.e. keeping V_C fixed at -0.134V) for biomedical EEG Application. The transconductance of the OTA for biomedical EEG Application is shown in the figure 8.

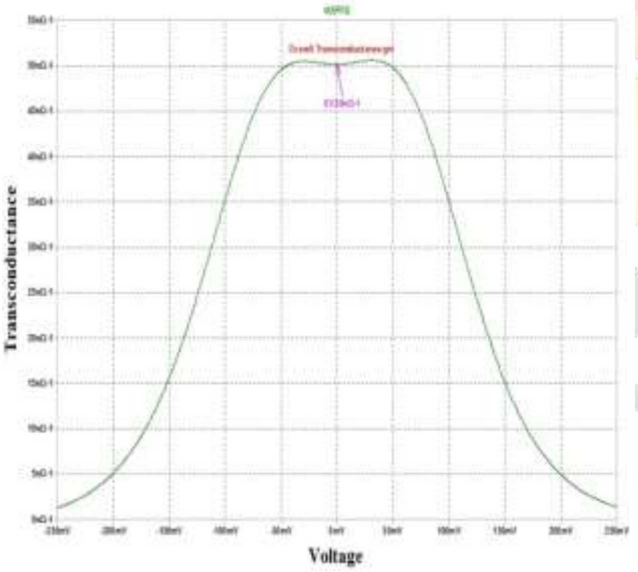

Figure 8 : Overall transconductance of OTA for biomedical EEG Application

The AC response shown in figure 9 is obtained by adding a 1pF load capacitor at the output terminal of the OTA.

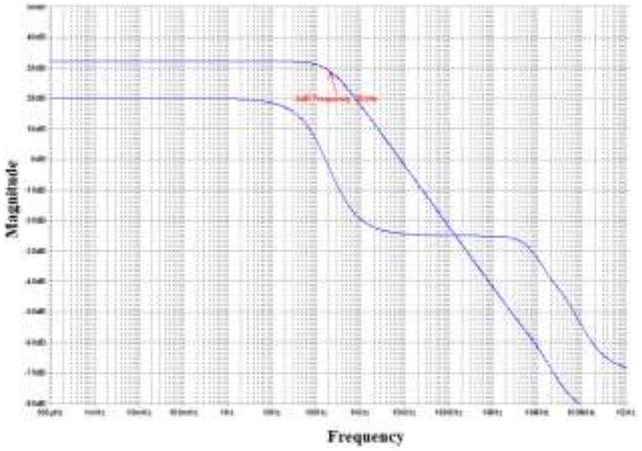

Figure 9 : Frequency response of OTA

Table 1: Transistor Demission of the Proposed OTA Design

Transistor No.	W/L (μm / μm)	Aspect Ratio
M1 , M4	0.09 / 0.09	1
M2 , M3	0.35 / 0.09	4
M5 , M6	0.12 / 0.30	0.4
M7 , M8 , M9	1.5 / 1	1.5

Table 2: Summary of OTA results for biomedical EEG Application

Parameters	Value
CMOS Technology	90nm
Supply Voltage	±0.35V
Power Consumption	4.7nW
Overall Current	13.2nA
Transconductance	50nS
Control Voltage (V_C)	-0.134 V
Transconductance Tuning Method	By varying Control Voltage (V_C)

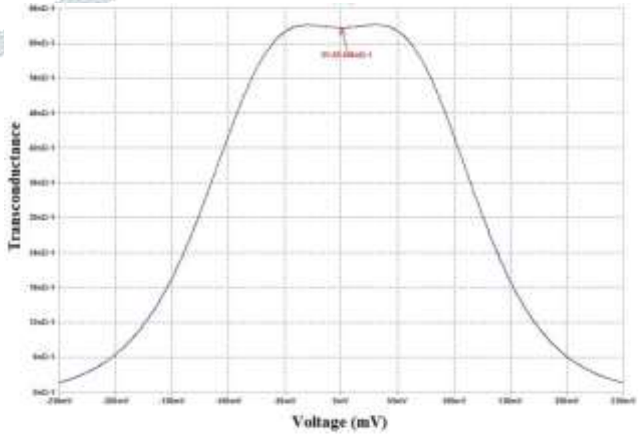

Figure 10 : Overall Transconductance of OTA for Biomedical ECG Application

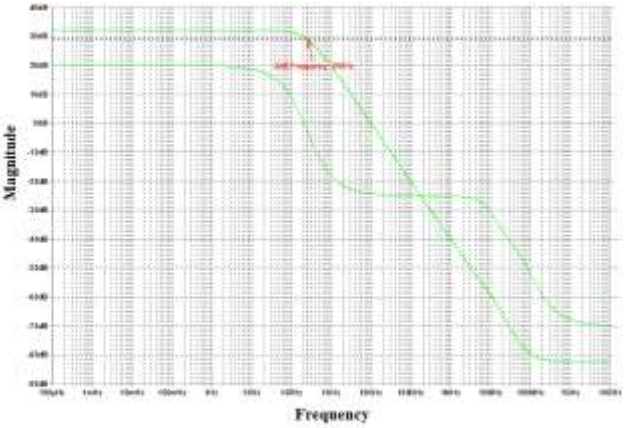

Figure 11 : Frequency Response of OTA for Biomedical ECG Application

IV. CONCLUTATION

In this paper, the low power low transconductance OTA is designed for biomedical application such as EEG and ECG. This OTA is operated in sub threshold region and it is designed using multi-tanh linearization technique. In this design 90nm CMOS technology is used with ±0.35V supply voltage. The transconductance of the OTA is 50nS for biomedical EEG Application and 62nS for Biomedical ECG Application which is varying using the control voltage V_C the value of control voltage is -0.134V and -0.108V for biomedical frequency EEG and ECG respectively. The power consumption of the OTA is 4.7nW for biomedical EEG application and 5.95nW for biomedical ECG application.

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