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CMOS-Based Operational Transconductance Amplifiers for Biomedical Application

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ABSTRACT

The field of biomedical devices is rapidly evolving with new advancements and technologies. Modern biomedical devices are designed to be highly accurate, compact, and user-friendly. However, power consumption remains a major challenge, especially in portable biomedical devices, as it directly affects battery life. Operational Transconductance Amplifiers (OTAs) are widely used in analog signal processing for biomedical applications. In recent years, the focus has been on developing OTAs with low power consumption, low voltage operation, and improved linearity to enhance their performance in biomedical systems. This paper presents a novel CMOS-based OTA designed specifically for biomedical Electromyography (EMG) applications. The proposed OTA operates at a frequency of 150Hz and is implemented using a 90nm CMOS process. The simulation is conducted with a power supply of VDD = 0.35V and VSS = -0.35V, ensuring low power consumption and efficient performance for biomedical use.

Keywords: CMOS, Operational Transconductance Amplifier (OTA), Biomedical Signal, Low Frequency, Power Consumption, Biomedical Applications.

1. INTRODUCTION

The field of biomedical electronics is rapidly advancing with new technologies and innovations, leading to highly functional, accurate, and compact devices [1], [2]. However, power consumption remains a challenge, especially for portable biomedical sensors that rely on battery life. Efficient operation with low noise is essential, as biomedical signals like ECG, EMG, and EEG are weak and sensitive to interference [3]. These signals provide crucial health insights, aiding in medical diagnoses [4], [5].

Low-frequency circuit design faces challenges due to the need for very low transconductance (Gm) and large capacitors, which are often limited by semiconductor fabrication constraints [6]. CMOS Operational Transconductance Amplifiers (OTAs) play a key role in analog signal processing by converting input voltage differences into output currents, controlled by the MOSFET transconductance (gm) [7], [8]. The tunability of OTAs allows them to adapt to different applications by adjusting their biasing current, making them highly flexible [9], [10].

CMOS OTAs offer differential operation, reducing noise and improving linearity, which is crucial for biomedical applications where precise signal amplification is needed [11]. Their ability to perform filtering, amplification, and modulation enhances the efficiency of biomedical systems, making them fundamental components in modern medical devices.

2. Biomedical Signal Processing System

The analog processing unit, including a preamplifier and filter, is a key component of biomedical systems. Operational Transconductance Amplifier (OTA)-based filters are commonly used for biomedical signals due to their low-frequency operation. The preamplifier enhances weak signals while minimizing noise and distortion. In ECG applications, it amplifies signals to around 100 mV using a low-pass filter. CMOS technology enables the design of high-performance, ultra-low-frequency filters [1]. Biomedical signals are crucial for monitoring physiological activities. ECG (250 Hz) monitors heart activity, EEG (200 Hz) records brain activity, EMG (150 Hz) measures muscle activity, and ERG (100 Hz) assesses retinal function. These signals help in diagnosing various medical conditions and improving biomedical device efficiency [12].

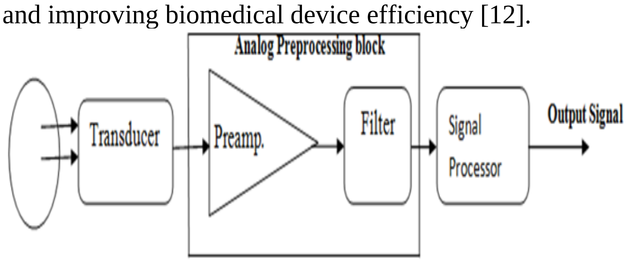

Figure 1: General Purpose Biomedical System Block Diagram

TABLE I: Most Commonly Used Biomedical Signals [12]

Signal	Frequency
ECG (Electrocardiography)	250 Hz
EEG (Electroencephalography)	200 Hz
EMG (Electromyography)	150 Hz
ERG (Electroretinography)	100 Hz

3. Proposed OTA Design

An Operational Transconductance Amplifier (OTA) is a voltage-controlled current source where the differential input voltage produces an output current. It has a high input impedance and can be used with negative feedback, similar to a standard op-amp The Gilbert Multiplier cell, traditionally used in the saturation region, functions as an OTA. In the subthreshold region, its transconductance follows a tanh trigonometric identity. This design operates the OTA in the subthreshold region for improved performance.

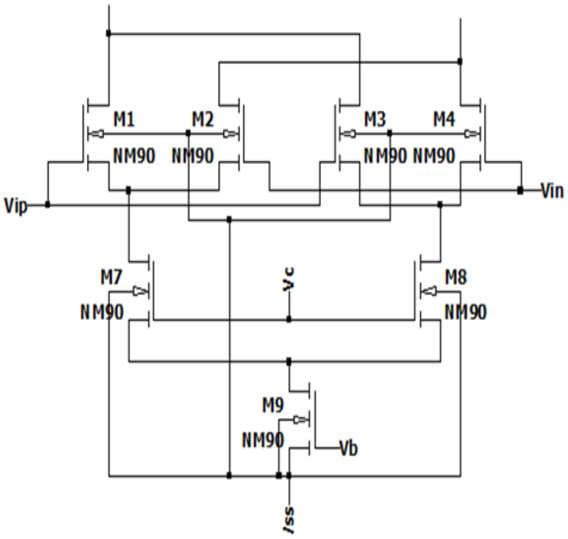

Figure 2: Multi-tanh Doublet Linearity Technique

To increase the linear range of the circuit, the multi-tanh doublet technique is used.

In the figure 3, 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. I1, I2, I3 and I4 are the current of transistors M1, M2, M3 and M4 respectively.

$$I_1 - I_2 = I_B \tanh\left[\frac{V_{in} + V_{OS}}{2n\emptyset_t}\right] \quad (1)$$

And

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

The output current of this circuit is given by:

$$I_{out} = (I_1 - I_2) + (I_3 - I_4) \quad (3)$$

Now, from using the eq. (1) and eq. (2) the final output current of the circuit is

$$I_{out} = I_B\{\tanh\left[\frac{V_{in} + V_{OS}}{2n\emptyset_t}\right] + \tanh\left[\frac{V_{in} - V_{OS}}{2n\emptyset_t}\right]\} \quad (4)$$

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

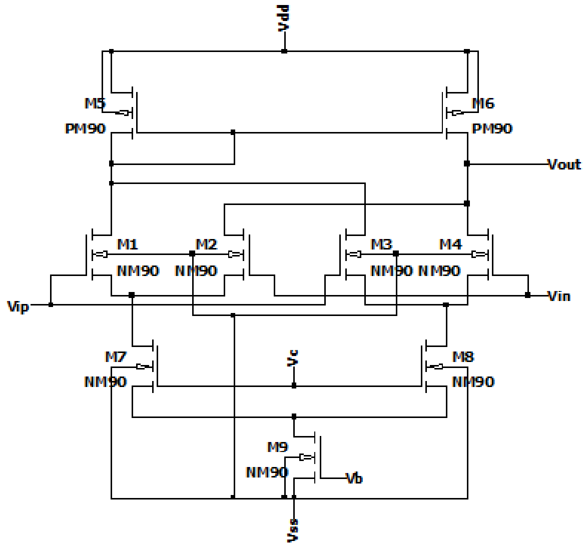

Figure 3: Proposed OTA design for EMG application

4. Results and Discussion

Figure 4 illustrates the output current generated by each input transistor (M1, M2, M3, and M4) of the Operational Transconductance Amplifier (OTA) used for the Electromyography (EMG) application. This figure helps in analyzing how each transistor contributes to the overall current flow within the OTA circuit. Similarly, Figure 5 presents the total output current of the proposed OTA for the EMG application. This overall output current is the combined effect of the individual currents from the input transistors, demonstrating the final current response of the OTA circuit when processing EMG signals.

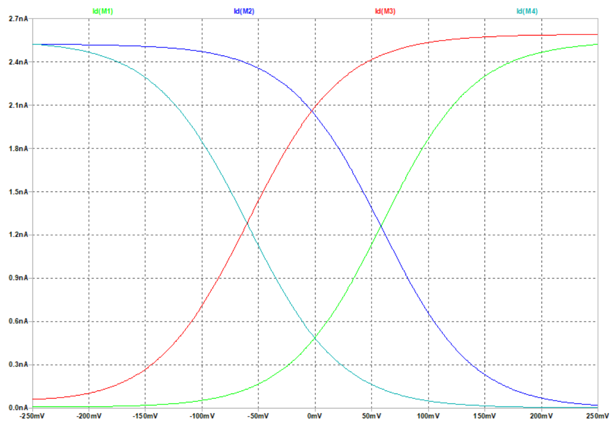

Figure 4: Output Current of Each Input Transistor in Proposed OTA for EMG Application

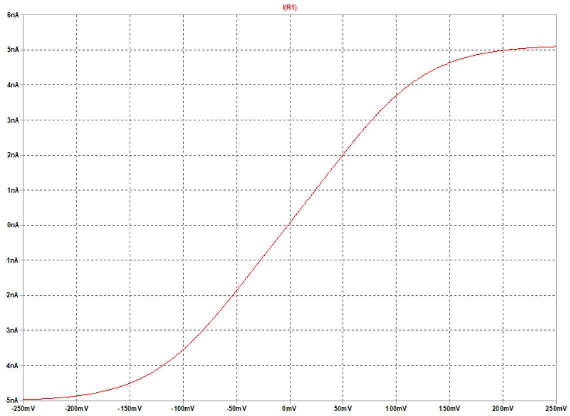

Figure 5: Overall Output Current of OTA for Electromyography (EMG) Application

The overall transconductance response of the proposed OTA is shown in the Figure 6. The overall transconductance for the EMG application is obtained 38.64 nS. The frequency response of the proposed OTA with control voltage Vc = -0.155V is obtained 150Hz that is used for the biomedical EMG application. The frequency response of proposed OTA for EMG application is shown in the Figure 7. The power consumption of the OTA for EMG application is obtained 4.15nW.

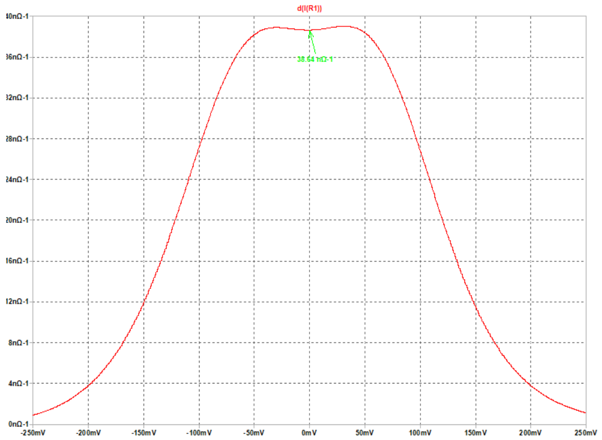

Figure 6: Overall Transconductance of OTA for EMG Application

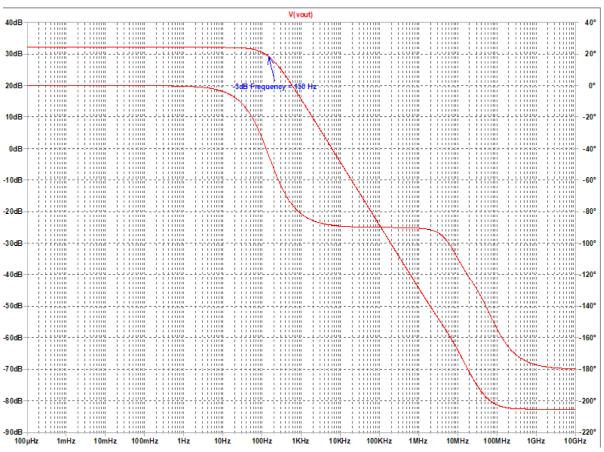

Figure 7: Frequency Response of OTA for Biomedical EMG Application

The complete summary of the proposed OTA design for biomedical EMG application is shown in the table 2.

Table 2: Summary of OTA Design for Biomedical EMG Application

Parameters	Value
CMOS Environment	90nm
Voltage Supply	±0.35V
Consumption of Power	4.15 nW
Total Current	9.98 nA
Gm	38.64 nS
Vc	-0.155 V
Application	EMG
Tuning Method	By varying Vc

5. Conclusion

This paper presents a CMOS-based Operational Transconductance Amplifier (OTA) designed for biomedical applications, specifically for Electromyography (EMG) signal processing. The proposed OTA operates at a frequency of 150 Hz, making it suitable for EMG applications. The design is implemented using a 90nm CMOS technology environment with a power supply of VDD = 0.35V and VSS = -0.35V. To optimize its performance, a control voltage of Vc = -0.155V is applied. The key performance metrics of the proposed OTA include a transconductance (gm) of 38.64 nS, an operating frequency of 150 Hz, and a low power consumption of 4.15 nW. These results demonstrate that the designed OTA is highly efficient, making it a promising candidate for low-power biomedical applications.

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