Design and Analysis of CMOS Low Power OTA for Biomedical Applications

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***Abstract* —This proposed work contributes to the design of Operational Transconductance Amplifier (OTA) which is used in Cardiac Implantable Medical Devices (IMD) for monitoring heart activities. Nowadays there is a big need in designing a low power and low noise OTA to extend the life time of primary battery. This work proposes the design of amplifier for cardiac Implantable Device, which is used for monitoring the heart pulses with high gain, low noise and low power consumption the designing of low power OTA benefits from voltage to current conversion to achieve a very low power, low noise and high gain for IMD. The proposed OTA is designed in a 45nm CMOS process, the simulation shows that the frequency of the OTA is adjustable in the range of 20KHz and it has the capability of measuring the gain in 51dB, while consuming only 11.9µW power from 1-V single power supply and an input referred noise of 1.22µVrms, The proposed OTA's performance has satisfied the required parameters and layout has been designed which is highly suitable for Cardiac IMD.**

***Keywords*— Operational Transconductance Amplifier, Complementary Metal Oxide Semiconductor, Implantable Medical Device.**

I. INTRODUCTION

Remote Health Monitoring is the method to examine patients outside of clinical surroundings such as in the workstation, home etc. Portable Medical Instruments are used for the purpose of diagnosis of respiratory problem, cardiac disease etc. They are convenient and handy medical diagnostics instruments which monitors paralytic patients and bed ridden patients. Hence, to achieve considering durability and portability, power consumption and the area of those devices should be reduced as much as possible to extend their battery lifetime. Remote Health monitoring devices helps patients to manage and understand their own health conditions. There are two types of biomedical devices, Wearable and Implantable Medical Devices [17]. The rapid growth in the field of technology towards the miniaturization of electronic devices is enabling to design more adaptable, reliable and wearable contributing for a worldwide change in the health monitoring systems. A wearable device is non-invasive, self-sufficient and that performs a specific medical function such as therapeutic or diagnostic. This decade has seen an incredible development in the use of wearable medical aid devices. For instance, to provide long-term support to patients with permanent or temporary disabilities, wearable devices are designed. Several vital signs such as blood pressure, respiration, EEG (Electroencephalography),EMG (Electromyography), ECG(Electrocardiography), temperature, body kinematics, etc. can constantly be diagnosed and medical aid can be provided immediately when any signal is abnormal. Due to rapid development of electronics in the current years, biomedical applications require a low amplitude signal measurement component, like implantable devices. A Medical Device is said to be Implantable whether it is either partly or totally introduced in patients body through surgically or medically and is intended to be there after the treatment. Implantable Cardiac Defibrillators (ICD) and Cardiac pacemakers (battery powered) are the most commonly used implantable devices is used to monitor and control the heartbeat. [14]The corresponding sensor predicts the heart pulses, by means of electrical pulses and sends the collected information through a wireless mode [8]. The major shortcoming is that the patient's health and personal data can be transmitted easily through wireless mode [9]. Powering up the battery has become another major issue present in these devices. The primary batteries could support the device for a maximum period of 10-15 years from the date of fitting, this limited shelf life of the battery compels the patient to undergo an additional microsurgery for the sake of replacing the battery

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[11][16]. The device has to be placed by means of a fully invasive method which leads the patient to suffer physically, mentally and financially as well [2][11][12]. Our objective is to design a two stage OTA with differential stage, consumes minimum power and gives a high gain used in biosensor for biomedical application. The proposed OTA identifies a very simple and different topology which gives electrical parameter like DC gain, linearity. Op-amp can also be used to avoid closed loop instability, frequency compensation but OTAs are widely used to meet the required performances.

This paper is organized as follows; Section II covers the Problem Formulation involved in IMD. Section III deals with proposed architecture. Section IV deal with results and discussion about IMD. Section V is the conclusion of the paper.

II. PROBLEM FORMULATION

Design and fabrication of nano-scale implantable devices lead to remarkable progress in integration density and dynamic power dissipation. However, current biomedical technologies as yet confronting difficulties like lower reliability, comparatively high stand-by power consumption, large area and power dissipation. The Electrode array demands additional power during the enhancement of biological signals. Thus probably increasing the thermal energy dissipated inside the implant electronic device. The recovery of the patient and long-term reliability of the device is crucial due to high cost. The inherent device and its degradation by-products could result in inflammations that successively contribute to implant degradation. The existing problems in wearable devices are increased area, fast discharge of batteries which leads to frequent change. The proposed system has been designed to achieve reduced area and increased battery span. It provides efficient performance and avoids frequent change of batteries.

III. PROPOSED ARCHITECTURE

There is an essential increase in the power consumption of ICs due to the increasing speed and complexity of medical device designs The Cardiac OTA schematic has been implemented using the CMOS 45nm in Cadence Virtuoso environment. In order to design a low power amplifier with high speed 45nm CMOS is highly preferable [13][15]. Time reduction is very low in CMOS 45nm when compare to other CMOS technology. The Cardiac OTA schematic has been implemented using the Cadence Virtuoso environment. Totally 7 CMOS transistors of 45nm processing technology are used for designing this OTA. Among 7 transistors, 3 are PMOS and rests of them are NMOS. The designed OTA consist of 2 stages. Fig. 1 has a stack of 4 transistors (2 PMOS, 2 NMOS). Using 4 transistors at ultralow voltage supply and assuming that all the devices are working in saturation (VDSsat ≥ 0.1V), produce an extremely reduced output swing. Hence, to increase the output swing and have relatively higher gains, 3 transistors are stacked. Nevertheless, an extra stage is needed to obtain better output swing [6]. In the input side, a differential PMOS pair is used. To increase the inversion level and to reduce the VTH, bulk terminal of the transistors are tied to VDD (forward biased) [7]. The input differential pairs have been operated in sub-threshold region [8] because of low power, low circuit speed and low transconductance.

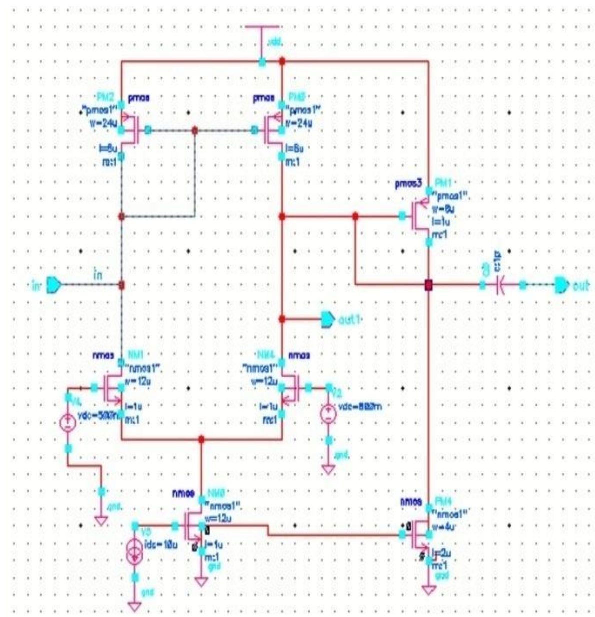

Fig. 1 Circuit diagram of proposed OTA

The second stage is cascaded with the first stage and it is used to achieve higher gain, while maximizing the output swing. The PMOS transistors PM0, PM1, PM2 work in linear region while NMOS transistors NM1, NM2, NM3, NM4 work in the sub threshold region for low power operation. The transconductance is kept low with acceptable linearity because the linearity of proposed OTA depends on it [9].In the first stage, M1 transistor and M2 transistor are connected back to back. Vin+ and Vin- are given as input to transistor M3 and M4 and these act as a differential amplifier. Bias current of 10μA is given as an input to transistor M5. The input voltage applied to cardiac OTA is 1μV. The cardiac OTA consists of two stages. The width, length of the transistors is specified in Table 1. The transistors M6 and M7 at the second stage provide further amplification of the supply voltage and drive them to the output. The first stage is connected to the second stage. A capacitor at the output terminal reduces the effect caused by connecting VDD directly to the output and provides an enormous effect in the DC shifting process. The output voltage obtained is 4.5μV across M6 and M7 transistors. The input to the cardiac OTA is in the range of 1μV because they are directly obtained from the Human Biological signals. The corresponding width, length and stage of the transistor are given below.

The current equation is

$$I_D = \mu_N C_{ox}\left(\frac{W}{L}\right)\left[(V_{GS}-V_T)V_{DS}-\frac{{V_{DS}}^2}{2}\right] \text{ -------- (1)}$$

where,

I_D – drain current

μ_N – mobility of NMOS

C_{ox} – capacitance of the oxide layer

$\left(\frac{W}{L}\right)$ - width to length ratio of the transistors

V_{GS} – gate to source voltage

V_T – threshold voltage

V_{DS} – drain to source voltage

From (1), the width to length ratios (W/L) for each transistor can be calculated.

Table1: Specifications of CMOS Transistor

Transistor	Label	Width/Length
PMOS	PM0	24/8
PMOS	PM1	6/2
PMOS	PM2	24/8
NMOS	NM1	12/8
NMOS	NM2	12/8
NMOS	NM3	12/8
NMOS	NM4	4/2

Table 2: Tools used for OTA design

Design Tasks	Tools used
Circuit design	Cadence Virtuoso ADE Product Suite
Circuit simulation	Cadence Spectre Circuit Simulator
Custom layout	Cadence Virtuoso Layout Suite
DRC	Cadence Physical Verification System

The layout of proposed OTA is done using Cadence Virtuoso Layout Suite. The assembled layout is then verified using Cadence Physical Verification System with dedicated scenarios for Design Rule Checking (DRC).

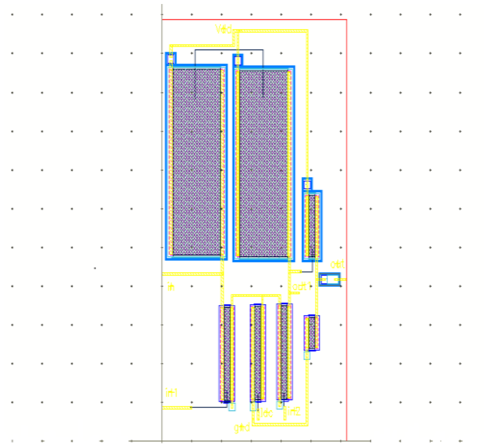

Fig. 2 Layout of proposed OTA

IV. Summary of Design Results

The CMOS OTA is simulated using 45nm technology in Cadence Virtuoso Analog Design Environment tool. The details of the circuit design are shown in Table 2. The different parameters like power, gain, noise and transconductance have been obtained. One of our main aim is to achieve low power consumption, low transconductance and high gain. After designing the proposed circuit, the obtained results have been attached below.

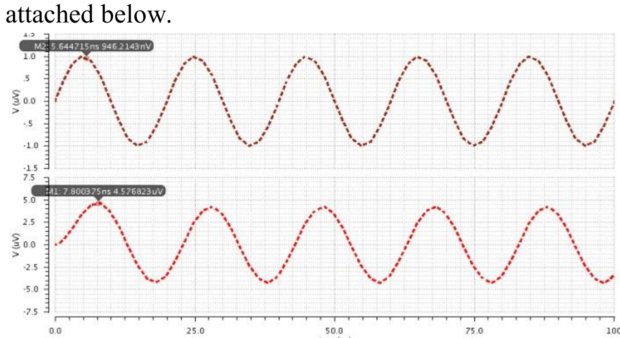

Fig. 3 Transient response of OTA

Transient analysis shows the circuit's response against the function of time. The Fig. 3 shows the amplified output of an operational transconductance amplifier (OTA). This can be obtained by keeping the differential input voltage at 1µV and observes amplified voltage as 4.5µV.

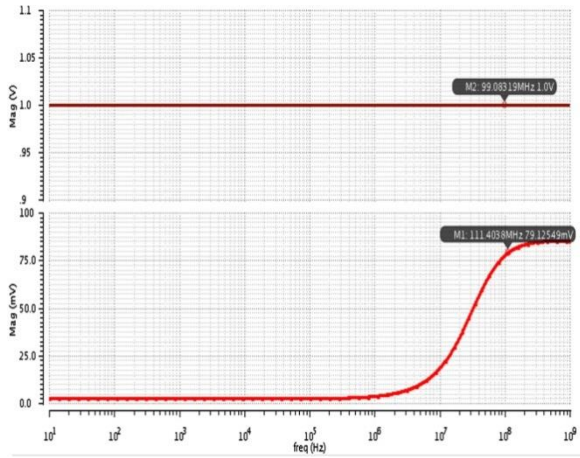

Fig. 4 AC analysis of OTA

To calculate the frequency response of a circuit, AC analysis is obtained in Fig 4. In this analysis, the quiescent point is first obtained to achieve small-signal models and linearity for all nonlinear components. Then, the corresponding circuit is analyzed from a start to a stop frequency. The obtained result of this analysis is displayed in frequency versus gain and phase versus frequency.

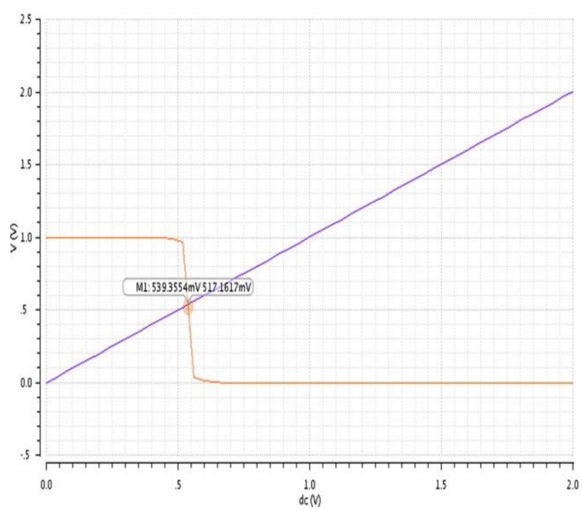

Fig. 5 DC analysis of OTA

DC Analysis calculates the performance of a circuit as shown in Fig 5 when a DC current or voltage is applied to it. The result of this analysis is normally referred as the quiescent point, Q-point or bias point.

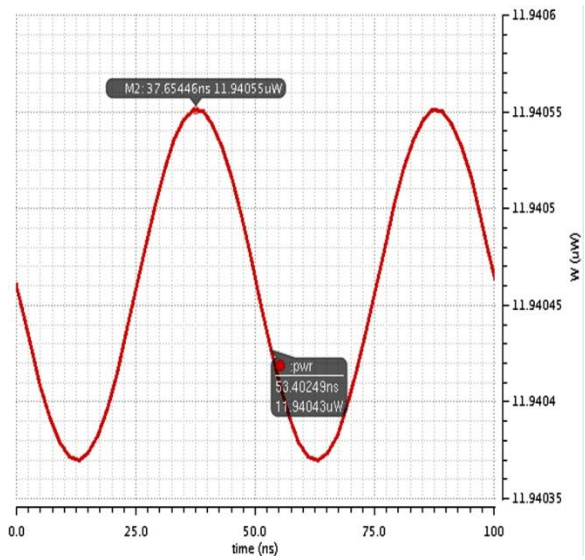

Fig. 6 Power consumption of OTA

Obtaining low power consumption in an OTA is the most challenging parameter. The proposed system aims at reducing the power in the range of µW shown in Fig. 6, thereby improving the performance of the low power Implantable Biomedical devices.

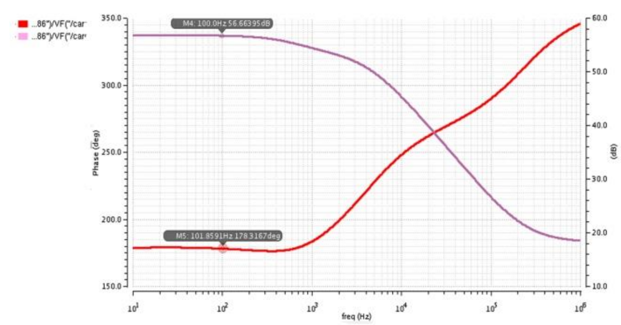

Fig.7 Gain of OTA

In the second stage of CMOS OTA, gain can be calculated. As shown in the Fig.7, the gain of the amplifier is 56.6 dB.

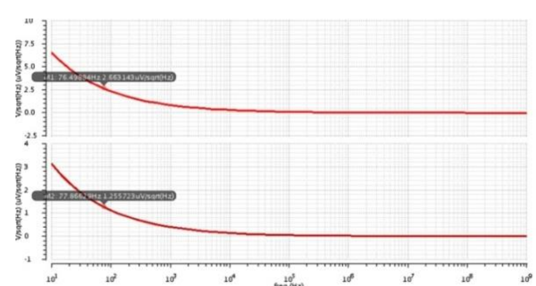

Fig. 8 Noise

Noise contribution of each component is calculated at the output node of the circuit through the specified frequency range. As shown in Fig. 8 the noise voltage over the CMOS OTA observed is 1.22µV_{rms}.

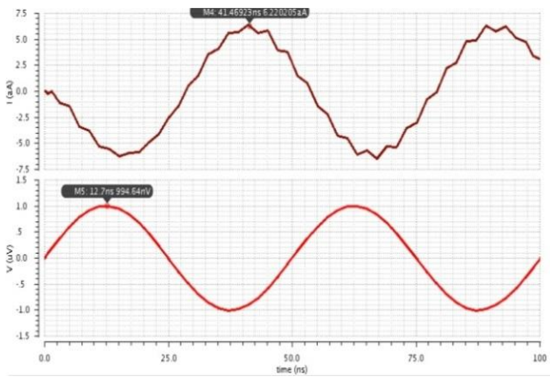

Fig. 9 Transconductance of OTA

Transconductance is the electrical characteristic relating the output current to the input voltage of a device. The transconductance of proposed OTA is 6.22aA as shown in Fig. 9

The performance parameter comparison of the proposed OTA with previously designed OTA for Cardiac and ECG applications is given below.

Table 3: Comparison of the proposed work with other recent works on OTA

Ref	Application	Tech	Gain	Supply	Power consumption (µW)	Noise µVrms
This work	ECG	45nm	56.6dB	1V	11.9	1.22
[1]	Cardiac pacemakers	180nm	39dB	1V	1.55	<0.7
[4]	Biomedical portable devices	180nm	NA	1V	NA	9
[6]	Large scale implantable neural recording system, EEG amplifier applications	1.5um	26-53dB	NA	NA	2.2
[7]	Low power heart rhythm Analysis	180nm	NA	2.2-3.2V	13	2.2
[8]	Portable ECG detection system	250nm	59dB	0.8V	40	2
[10]	Electro-cardiogram measurement	350nm	NA	1-1.8V	7.1	1.4

From the above result Table 3 it shows that the proposed CMOS OTA in 45nm technology achieves high gain, low power consumption, low noise when compare to other nm CMOS base OTA.

V. Conclusion

This paper demonstrates the design of transconductance amplifier has a low power consumption of 11.9µW which is implemented by 45nm CMOS technology with reduced number of transistors. The OTA is used in sensing signals in which it attains a high gain of 56.6dB and noise is 1.22µV_{rms} analyzed from simulation results. The proposed biosensor has features of high speed, high gain, low noise and low frequency which are most applicable for designing low power implantable medical devices. The proposed CMOS amplifier circuit for Cardiac Implantable devices arrays that simultaneously provides good performance and bandwidth while achieving very low power supply, low input current and small circuit size. Circuit characterization results show that circuit achieves a low supply voltage of 1V in frequencies at 20Hz over 1µA bidirectional input current range while having reduced number of transistors. Thus by reducing number of transistor the size of the amplifier became miniature. The significant power reduction, noise reduction in the proposed OTA is due to its Differential amplifier structure (where the least possible number of transistors is used) which is suitable for the applications in the field of cardiac Implantable Medical Devices.

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