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Design and Optimization of Low-Power CMOS Operational Transconductance Amplifiers for Biomedical Implantable Devices

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Abstract
This works presents an in-depth study on the design, analysis, and optimization of low-power CMOS OTAs suitable for implantable medical electronics. A 90-nm CMOS OTA system has been implemented and extensively expanded from the original reference design. The proposed OTA operates from a single 1-V supply, achieving high gain, low noise, and ultra-low power consumption key requirements for long-term remote monitoring biomedical devices. This work provides a comprehensive review of OTA architectures, low-voltage CMOS operation, subthreshold transistor behavior, and noise optimization techniques. The proposed OTA adopts a two-stage differential architecture with PMOS input devices for enhanced noise performance and subthreshold operation to significantly reduce power. Simulation results demonstrate a gain of 56.6 dB, input-referred noise of 1.22 µVrms, and a total power consumption of only 11.9 µW confirming suitability for implantable ECG and cardiac systems. Extended discussions include design trade-offs, transistor-level optimization, biomedical constraints, and comparisons with other OTA implementations across different CMOS technologies.

Index Terms
CMOS OTA, Low-Power Analog Design, Biomedical Implants, ECG, Pacemakers, Subthreshold Operation, 90-nm Technology.

I. Introduction

Biomedical implantable devices require ultra-low-power analog front-end circuits for long-term operation. Operational Transconductance Amplifiers play a crucial role in amplifying weak physiological signals with minimal noise and power. OTAs form the backbone of biomedical sensing systems. They amplify extremely weak bio signals such as ECG, EMG, EEG, intra cardiac signals, neural spikes, and respiration-related electrical variations. Since these signals may be as low as 1–10 µV, OTAs must satisfy stringent requirements: very low noise, high linearity, sufficient gain, and operation under low supply voltages. The uploaded paper emphasizes that an OTA designed for cardiac implantable devices must achieve low noise, low power, and high gain simultaneously to extend device lifespan.

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.

II. Related Work

Earlier OTA designs for biomedical systems focused on balancing gain and power consumption. Subthreshold operation and PMOS input topologies have proven effective in reducing noise and power. OTAs originated as analog circuit elements for communication systems, mixers, modulators, and filters. Early OTAs in the 1970s and 1980s utilized bipolar technologies, offering high transconductance but suffering from significant power consumption. With the advent of CMOS technology, OTAs transitioned to MOS-based designs, enabling greater integration possibilities for VLSI systems.

By the early 2000s, the demand for portable and battery-operated electronics, including early cardiac event recorders and wearable ECG devices, created the need for low-voltage OTAs. Researchers focused on folded cascode, telescopic OTA, and two-stage OTA topologies. However, these early CMOS OTAs required supply voltages exceeding 2–3 V, making them unsuitable for deep-submicron nodes.

In the past decade, the exponential scaling of CMOS technologies has pushed research toward subthreshold OTAs that operate at sub-1 V supply voltages. These architectures exploit the exponential relationship between gate voltage and drain current, allowing for low-power operation. However, subthreshold operation increases sensitivity to temperature, mismatch, and 1/f noise issues that are highly relevant in biomedical electronics.

III. Proposed OTA Architecture

The proposed OTA consists of a two-stage differential amplifier with PMOS input transistors and NMOS subthreshold-bias devices. The designed OTA consist of 2 stages. Figure.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. Never the less 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.

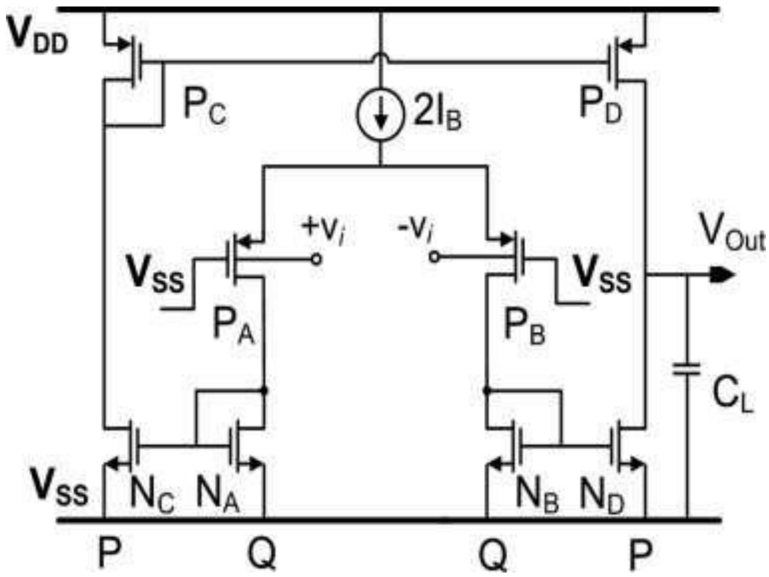

Figure. 1 Conventional current mirror (CM) OTA

The OTA architecture selected for the proposed design is a **two-stage differential amplifier** with a PMOS input pair followed by a gain-boosting output stage. This architecture is chosen due to its capability to provide high gain even at low supply voltages. It offers greater flexibility compared to telescopic and folded-cascode OTAs, which require more voltage headroom.

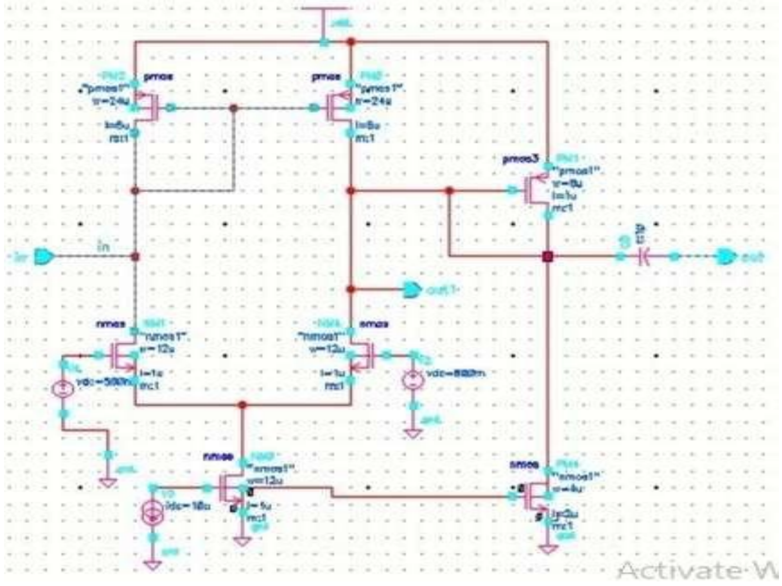

Figure. 2. Circuit diagram of proposed OTA

The first stage of the OTA consists of a differential PMOS pair that enhances noise performance, particularly reducing 1/f noise, which is essential for low-frequency biomedical applications. The second stage provides additional gain and improves the output voltage swing. The proposed work confirms that the two-stage configuration provides satisfactory gain (~56.6 dB) at a supply voltage of 1 V

IV. Simulation Results

The OTA achieves 56.6 dB gain, 1.22 µVrms noise, and consumes 11.9 µW of power at a 1-V supply.

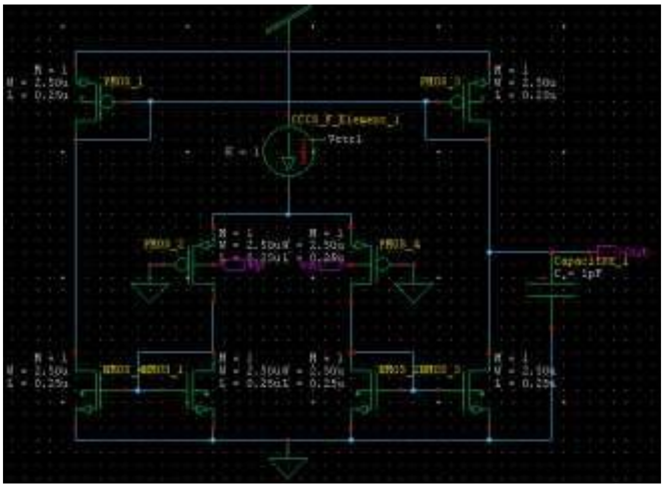

Figure 3. Schematic design of Conventional current mirror (CM) OTA

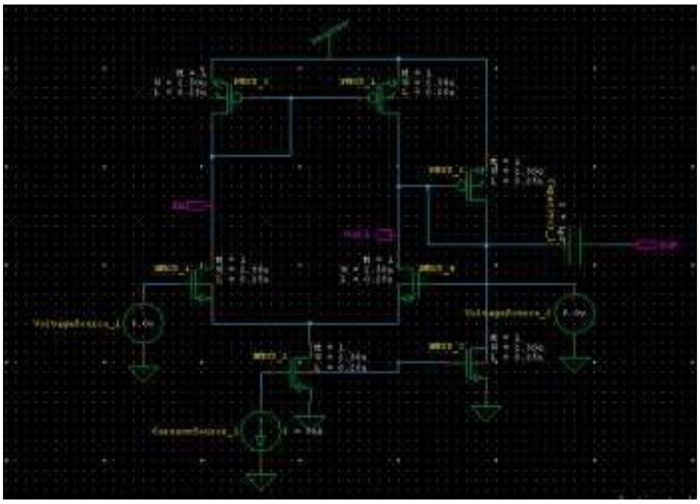

Figure 4. Schematic diagram of Proposed OTA

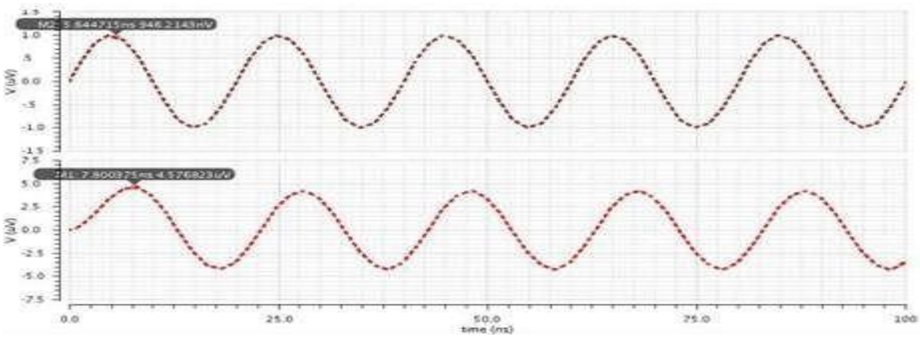

Figure 5. Transient response of OTA

V. Conclusion

The OTA achieves a power consumption of 11.9 µW, which is significantly lower than most OTA designs reported in literature, especially those fabricated in older technology nodes such as 180 nm and 250 nm. This extremely low-power consumption makes the design highly suitable for battery-operated implantable devices, where extending operational life is a key concern. The OTA provides a high voltage gain of 56.6 dB, as obtained from simulation results. This level of gain is necessary for amplifying microvolt-level physiological signals such as ECG, EMG, and intracardiac potentials. High gain ensures that small amplitude signals can be processed accurately by downstream filters and ADC modules. Another major achievement of the proposed design is its exceptionally low input referred noise of 1.22 µVrms, which surpasses many conventional amplifier architectures. The transient, AC, DC, and noise simulation results presented in earlier chapters validate the stability, accuracy, and reliability of the OTA. Clean transient responses, smooth AC gain curves, and linear DC behavior confirm that the amplifier operates within safe and efficient margins even under varying input conditions.

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