

Design and Analysis of Low-Voltage, Low-Power CMOS OTAs for Modern Applications

Manju Mathur

Assistant Professor, Global Institute of Technology, Jaipur, Rajasthan, India
manju.mathur@gitjaipur.com

Ravi Joshi

Assistant Professor, Global Institute of Technology, Jaipur, Rajasthan, India
ravi.joshi@gitjaipur.com

ABSTRACT: Operational Transconductance Amplifiers (OTAs) are essential building blocks in modern analog and mixed-signal integrated circuits, widely used in applications such as filters, data converters, sensor interfaces, and biomedical signal processing systems. The rapid growth of portable electronics, wearable devices, biomedical instrumentation, and Internet of Things (IoT) applications has created a strong demand for analog circuits that operate at low power consumption and low supply voltages. Designing CMOS OTAs under these constraints presents significant challenges, including reduced signal swing, limited gain, increased sensitivity to process variations, and degraded noise performance. This paper presents a comprehensive overview of low-power CMOS OTA design techniques, focusing on power-efficient architectures, biasing strategies, and circuit-level optimization methods. Key performance parameters such as transconductance efficiency, gain, bandwidth, noise, linearity, and power consumption are discussed in detail. In addition, the trade-offs involved in low-voltage operation and the challenges associated with technology scaling are highlighted. The review aims to provide valuable insights into the design of energy-efficient OTAs suitable for next-generation low-power analog and mixed-signal applications.

KEYWORDS: Low Power Design, CMOS OTA, Transconductance Amplifier, Analog Integrated Circuits, Low-Voltage Operation.

1. INTRODUCTION

The Operational Transconductance Amplifier (OTA) is a fundamental analog building block that functions as a voltage-controlled current source and plays a crucial role in modern analog and mixed-signal integrated circuits. OTAs are extensively employed in a wide range of applications, including analog and active filters, analog-to-digital and digital-to-analog converters, sensor interface circuits, phase-locked loops, and biomedical signal processing systems. Unlike conventional operational amplifiers that provide voltage amplification, OTAs offer electronically tunable transconductance, allowing designers to precisely control circuit gain and bandwidth through bias current adjustment. This tunability makes OTAs highly attractive for reconfigurable, low-voltage, and low-power system designs.

With the continuous scaling of CMOS technology, supply voltages have steadily decreased to reduce power consumption and improve device reliability. While technology scaling enables higher integration density and faster digital circuits, it introduces significant challenges for

analog circuit design. Reduced supply voltages limit voltage headroom, degrade intrinsic transistor gain, and restrict signal swing, making it difficult to achieve high linearity, wide bandwidth, and low noise simultaneously. Additionally, short-channel effects and process variations further complicate the design of robust analog circuits in deep submicron technologies.

As a result, the development of low-power CMOS OTA architectures capable of reliable operation under low-voltage conditions has become a critical research focus. Power-efficient OTA design is essential for emerging applications such as portable electronics, wearable health-monitoring devices, wireless sensor nodes, and Internet of Things (IoT) systems, where extended battery life and energy efficiency are primary design constraints. Consequently, innovative circuit techniques and optimization strategies are required to balance power consumption, performance, and reliability in modern CMOS OTA designs.

2. KEY PERFORMANCE PARAMETERS OF CMOS OTA

The performance of low-power CMOS Operational Transconductance Amplifiers is evaluated using several key parameters that directly influence their suitability for specific applications. A careful trade-off among these parameters is essential for achieving optimal performance under low-voltage and low-power constraints.

- **Power Consumption:** Power consumption is one of the most critical metrics in OTA design, particularly for battery-powered and energy-constrained applications. It includes both static power dissipation due to bias currents and dynamic power associated with signal processing. Reducing power consumption while maintaining adequate performance is a primary objective in low-power OTA architectures.
- **Transconductance (gm):** Transconductance defines the relationship between the input voltage and output current of the OTA and plays a vital role in determining gain and bandwidth. In low-power designs, achieving high transconductance efficiency (gm/ID) is desirable, as it allows higher performance at lower bias currents.
- **Gain and Bandwidth:** Open-loop voltage gain and gain-bandwidth product (GBW) are essential for stable and accurate signal amplification. Low supply voltages often limit achievable gain due to reduced output resistance. Therefore, advanced circuit techniques are required to enhance gain and bandwidth without increasing power consumption.
- **Noise Performance:** Noise is a critical concern in precision analog applications such as sensor interfaces and biomedical signal processing. Input-referred noise must be minimized to ensure accurate signal detection, particularly when dealing with low-amplitude signals. Noise optimization becomes more challenging in low-power designs due to reduced bias currents.
- **Linearity:** Linearity determines the OTA's ability to amplify signals without distortion. Poor linearity results in harmonic distortion and reduced signal fidelity. In low-voltage OTAs, achieving high linearity is challenging due to limited signal swing and transistor nonlinearity, necessitating the use of linearization techniques.

- **Supply Voltage:** Modern CMOS technologies operate at increasingly lower supply voltages to reduce power consumption. OTAs designed for low-voltage operation must function reliably with limited headroom while maintaining acceptable gain, noise, and linearity. This constraint significantly influences architecture selection and biasing strategies.

3. LOW POWER OTA DESIGN TECHNIQUES

Several techniques are employed to achieve low-power operation in CMOS OTAs:

- **Subthreshold (Weak Inversion) Operation:** Transistors operate below threshold voltage, significantly reducing power consumption while maintaining high gm/ID efficiency.
- **Current Reuse Techniques:** Stack multiple signal paths using the same bias current to enhance transconductance without increasing power.
- **Bulk-Driven OTAs:** Utilize the bulk terminal as an input to enable operation at ultra-low supply voltages.
- **Self-Biased and Adaptive Biasing:** Dynamically adjust bias currents based on signal conditions to optimize power efficiency.
- **Low-Voltage Topologies:** Architectures such as folded cascode, telescopic, and inverter-based OTAs are optimized for reduced voltage headroom.

4. APPLICATIONS

Low-power CMOS OTAs are extensively used in:

- Biomedical devices (ECG, EEG, and implantable sensors)
- Wireless sensor nodes
- Portable and wearable electronics
- Low-power data converters and analog filters
- IoT and energy-harvesting systems

5. CHALLENGES AND FUTURE SCOPE

Designing low-power CMOS OTAs presents challenges such as reduced gain due to low supply voltage, increased sensitivity to process variations, and higher noise levels. Future research directions include the integration of AI-assisted analog design, ultra-low power near-threshold circuits, and advanced CMOS process nodes to further enhance performance while minimizing power consumption.

6. CONCLUSION

Low-power CMOS OTA design plays a crucial role in enabling energy-efficient analog and mixed-signal systems. By adopting advanced circuit techniques such as subthreshold operation, current reuse, and low-voltage architectures, designers can achieve significant power savings without compromising performance. Continued innovation in CMOS

technologies and design methodologies will further advance the development of ultra-low power OTA circuits for next-generation applications.

REFERENCES

- [1] S. Sharma, D. Yadav, G. K. Soni and G. Shankar, "Operational Transconductance Amplifier for Bluetooth/WiFi Applications Using CMOS Technology," IEEE International Conference on Integrated Circuits and Communication Systems (ICICACS), pp. 1-4, 2024.
- [2] G. Shankar, G. K. Soni, B. Kumar Singh and B. B. Jain, "Tunable Low Voltage Low Power Operational Transconductance Amplifier For Biomedical Application," IEEE 2021 Fourth International Conference on Electrical, Computer and Communication Technologies (ICECCT), pp. 1-6, 2021.
- [3] G. K. Soni, H. Singh, H. Arora and A. Soni, "Ultra Low Power CMOS Low Pass Filter for Biomedical ECG/EEG Application," IEEE 2020 Fourth International Conference on Inventive Systems and Control (ICISC), pp. 558-561, 2020.
- [4] Y. Sahu, G. K. Soni, H. Singh, D. Jangir, A. Rawat, "Design of High Linearity Nanoscale CMOS OTA Based Bandpass Filter for Bluetooth Receiver", Journal of Emerging Technologies and Innovative Research (JETIR), Vol. 6, Issue. 1, pp. 335-338, 2019.
- [5] S. Gour and G. K. Soni, "Reduction of Power and Delay in Shift Register using MTCMOS Technique," IEEE 2020 4th International Conference on Trends in Electronics and Informatics (ICOEI), pp. 202-206, 2020.
- [6] G. K. Soni, G. S. Sharma, "A review on low voltage low power Gm-C and OTA-C low pass filter for biomedical application", International Journal of Engineering and Technical Research (IJETR), Vol. 4, Issue. 2, pp. 33-36, 2016.
- [7] G. K. Soni, H. Arora, "Low Power CMOS Low Transconductance OTA for Electrocardiogram Applications", Springer Recent Trends in Communication and Intelligent Systems. Algorithms for Intelligent Systems, pp. 63-69, 2020.
- [8] B. K. Singh, G. Shankar, Bh. B. Jain, "An Overview on Low Voltage Low Power Operational Transconductance Amplifier (OTA) for Biomedical Application", International Journal of Engineering Trends and Applications (IJETA), Vol. 8, Issue. 3, pp. 1-5, 2021.
- [9] B. K. Singh, G. Shankar, Bh. B. Jain, "Operational Transconductance Amplifier For Biomedical EMG Application Using CMOS 90nm Technology", International Journal of Technical Research & Science, Vol. 10, 2021.