Optimization of a Low Power Operational Transconductance Amplifier (OTA) for High Gain in Miniature Devices for Low Frequency Applications

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Abstract

Operational Transconductance Amplifiers (OTA) have been optimized for wireless and medical applications, in addition to other low-frequency and low-voltage applications. Even though its supply voltages differ from those employed by operational amplifiers (OPAMPs), they are similar. Since differential input pairs and bias current could potentially be employed to alter an OTA's characteristics, it has been shown advantageous for amplifiers and filters. OTA designs consider several factors, including output swing, power, speed, and gain. We compare the telescopic cascade OTAs via balanced operational OTAs; the former offers low output impedance resulting in inadequate gain. Transistors can be employed in cascades to improve impedance; a common emitter stage is loaded by the emitter of a common base stage. OTAs produce substantial variations in output current from small variations in the input voltage due to their feature of high gain.

Keywords: Operational Transconductance Amplifier (OTA), Low Voltage, Low Frequency, Medical Applications, Analog Integrated Circuits.

1. Introduction

Significant effects of Very Large-Scale Integration (VLSI) technology advancements include the growing importance of the relationship between transistor size and power usage. The design of electronic circuits is faced with an important challenge because of an apparent increase in power consumption with transistor size. The Operational Transconductance Amplifier (OTA) is a crucial component in analog circuit design. It has similarities with the more commonly referred to as Operational Amplifier (OPAMP) in that both employ differential inputs. While both OTA and OPAMP share the foundation of differential inputs, they serve distinct functions. An OPAMP functions as a voltage-controlled voltage source (VCVS), whereas an OTA operates as a voltage-controlled current source (VCCS). The adjustability of an OTA's transconductance through bias current and differential input pairs renders it a versatile tool in the creation of amplifiers and filters, offering tunability by manipulating bias currents.

In the process of designing an OTA, practical considerations include input signal amplitude, parasitic input capacitance, and parasitic output capacitances. These factors play a pivotal role in shaping the overall performance of the OTA, influencing parameters such as gain, output swing, speed, and power consumption.

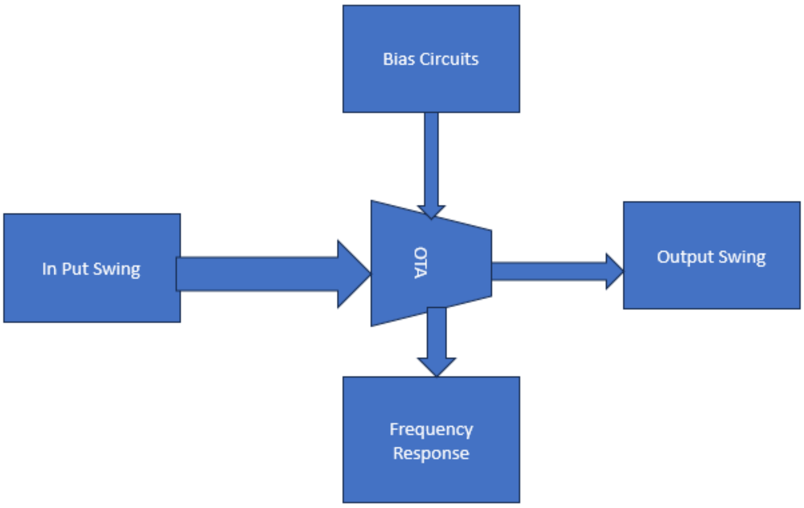

Fig1: OTA Design Flow

This paper focuses on the design and comparison of two specific OTA configurations: the telescopic cascade OTA and the balanced operational OTA. The single-stage OTA often exhibits lower gain due to its inherently low output impedance. To overcome this limitation, a strategy involving the addition of transistors at the output side, utilizing an active load, is employed. This approach, involving parasitic capacitances and the stacking of transistors, specifically in cascades, is explored to enhance the output impedance and, consequently, augment the overall gain of the OTA.

Through an in-depth investigation into these design considerations and practical implementations, this paper aims to shed light on the nuanced intricacies of OTA design, offering insights into techniques that enhance performance and address challenges associated with power consumption and transistor sizing in modern VLSI applications.

2. OTA Design flow:

The design flow of an Operational Transconductance Amplifier (OTA) involves several stages shows in Fig2, each crucial in shaping the performance characteristics of the amplifier. The design process begins with a clear understanding of the application requirements and specifications. This involves determining key parameters such as gain, bandwidth, input and output impedance, power consumption, and noise figures[1][2].

Topology Selection: Choose an appropriate OTA topology based on the specifications and requirements. Common OTA topologies include telescopic, folded-cascode, and two-stage CMOS amplifiers. The choice of topology depends on factors such as gain, power consumption, and frequency response. And followed by transistor sizing, its Determine the sizes of the transistors in the amplifier circuit. This involves selecting appropriate W/L (width/length) ratios for transistors to meet the desired specifications. Transistor sizing affects the gain, bandwidth, and power consumption of the OTA[3].

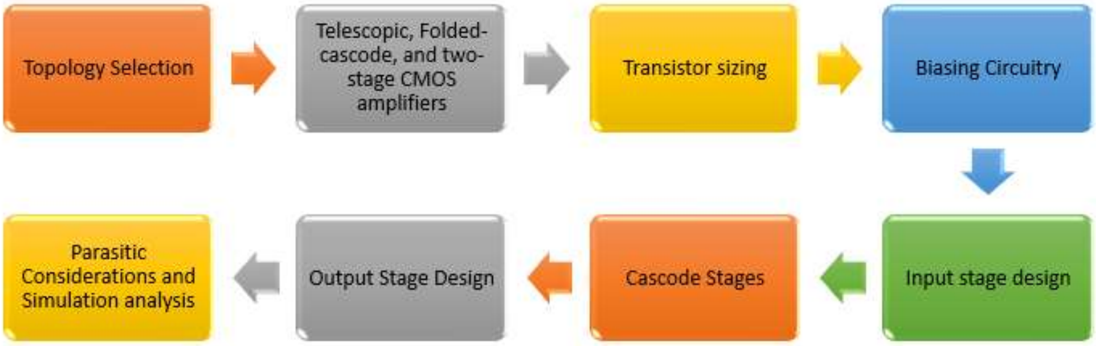

Fig2: Design Flow of an OTA

Biasing Circuitry and Input stage design: Design the biasing circuitry to establish the DC operating points of the transistors. This includes generating bias currents and voltages to ensure the transistors operate in the desired region (e.g., saturation or triode) for optimal performance. Focus on the input stage, which typically consists of a differential pair. Design this stage to provide the desired transconductance and input impedance. Common considerations include the use of current mirrors and the tail current source.

Cascode Stages: If applicable to the chosen topology, design cascode stages to enhance gain and bandwidth. Cascode stages improve output impedance and help mitigate the Miller effect, reducing the impact of parasitic capacitances. Also, the Address compensation techniques to stabilize the amplifier. Compensation is essential to prevent oscillations and achieve the desired phase margin. Common methods include the use of compensation capacitors and pole-zero analysis[4].

Output Stage Design: Design the output stage to provide the required output swing and impedance. The choice of an active load, such as a current mirror or a resistive load, impacts the overall performance of the OTA.

Parasitic Considerations and analysis:

Account for parasitic elements, such as parasitic capacitances and resistances, which can affect the high-frequency performance and stability of the OTA. Strategies to minimize the impact of parasitics may be employed. Utilize simulation tools to verify the performance of the OTA design. Perform transient, AC, and DC analyses to ensure that the amplifier meets the specified requirements. Iterative adjustments may be necessary.

2.1 Characteristics of an OTA:

An Operational Transconductance Amplifier (OTA) is a crucial component in various applications due to its characteristics. These include transconductance, gain, bandwidth, sweep rate, input and output impedance, power consumption, common-mode rejection ratio (CMRR), noise, distortion, dynamic range, and phase margin. Transconductance represents the relationship between output current and input voltage, while gain measures the amplification provided by the OTA. Bandwidth defines the range of frequencies over which the amplifier can effectively amplify signals, influenced by internal capacitances and resistances of transistors within the OTA circuit[5]. Skew rate measures the rate at which the output voltage can change in response to a step input, crucial in applications requiring fast-changing signals without distortion.

Input and output impedance refer to the resistance seen by the input signal source and the load, and matching these impedances with the surrounding circuitry is essential for optimal signal transfer and power delivery. Power consumption is a critical consideration, particularly in battery-powered or low-power applications. Common-Mode Rejection Ratio (CMRR) measures the OTA's ability to reject common-mode signals, with a high CMRR being essential for minimizing common-mode noise. Noise performance, including input-referred noise and output noise, is crucial in applications where signal fidelity is paramount. Low noise figures are especially important in sensitive applications like medical devices and communication systems. Distortions measures the degree to which the OTA introduces unwanted changes to the input signal, with low distortion being essential for applications requiring signal integrity. Dynamic range is the range between the smallest and largest detectable signals that an OTA can handle without significant distortion.

Phase margin measures the stability of the OTA, indicating the amount by which the phase shift of the amplifier exceeds 180 degrees at the unity gain frequency. Understanding and optimizing these characteristics are vital for tailoring OTAs to specific applications and meeting performance requirements.

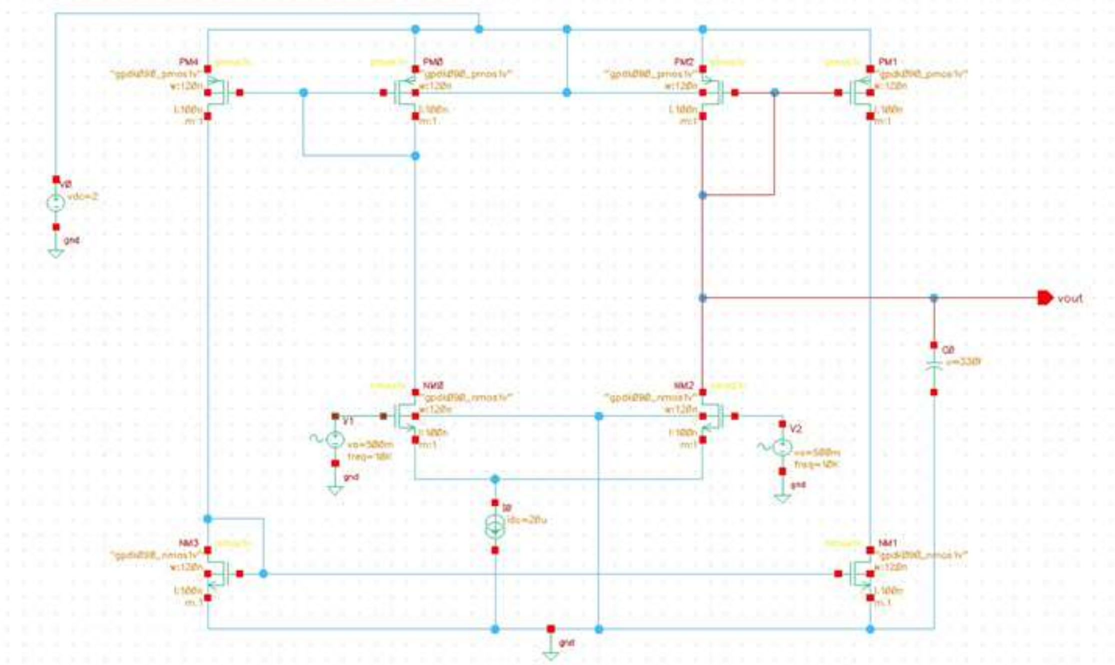

Fig3: Circuit simulation of OTA

3. Results and Discussion:

The OTA, obtained from CADENCE software, utilizes a cascode arrangement to amplify input voltages, resulting in a balanced operation with varying specifications such as gain, phase margin, and unity gain BW.

Parameters for consideration

Differential Inputs: An OTA typically incorporates two input terminals, namely the inverting and non-inverting inputs. These terminals accept differential voltage signals, and the disparity between these voltages dictates the resulting output current[1] [2].

Output Current: The primary output of an OTA manifests as a current directly proportional to the discrepancy between the voltages at its input terminals. This current, often denoted as Iout, finds diverse applications in electronic circuits.

High Gain: OTAs are engineered to furnish a substantial voltage-to-current gain. This implies that minute alterations in the input voltage yield relatively significant changes in the output current.

Linear Operation: OTAs are predominantly utilized within their linear range, where the connection between input voltage and output current approaches linearity. This linear operational characteristic renders them well-suited for applications demanding precision control and signal amplification.

Frequency Response: OTAs exhibit operational capabilities across a broad spectrum of frequencies, rendering them apt for both Direct Current (DC) and Alternating Current (AC) applications. This extensive bandwidth facilitates diverse signal processing tasks.

Adjustable Parameters: Certain OTAs feature adjustable parameters such as transconductance, bandwidth, and gain, allowing for fine-tuning to meet specific application requirements. The utilization of Cadence software guides the design process, with Fig 2 outlining the sequential steps for designing the transconductance amplifier. These steps involve considerations such as power, gain, speed, and output swing, influencing the selection of OTA topology in each phase.

Table 1: Number of receptors in each container

Parameters	Simulation Results – Telescopic Ota	Simulation Results - Balanced OTA
GAIN	*75 dB*	*65dB*
PHASE MARGIN	*55 degrees*	*63.04 degree*
UNITY GAIN BW	*60MHz*	*55.11MHz*

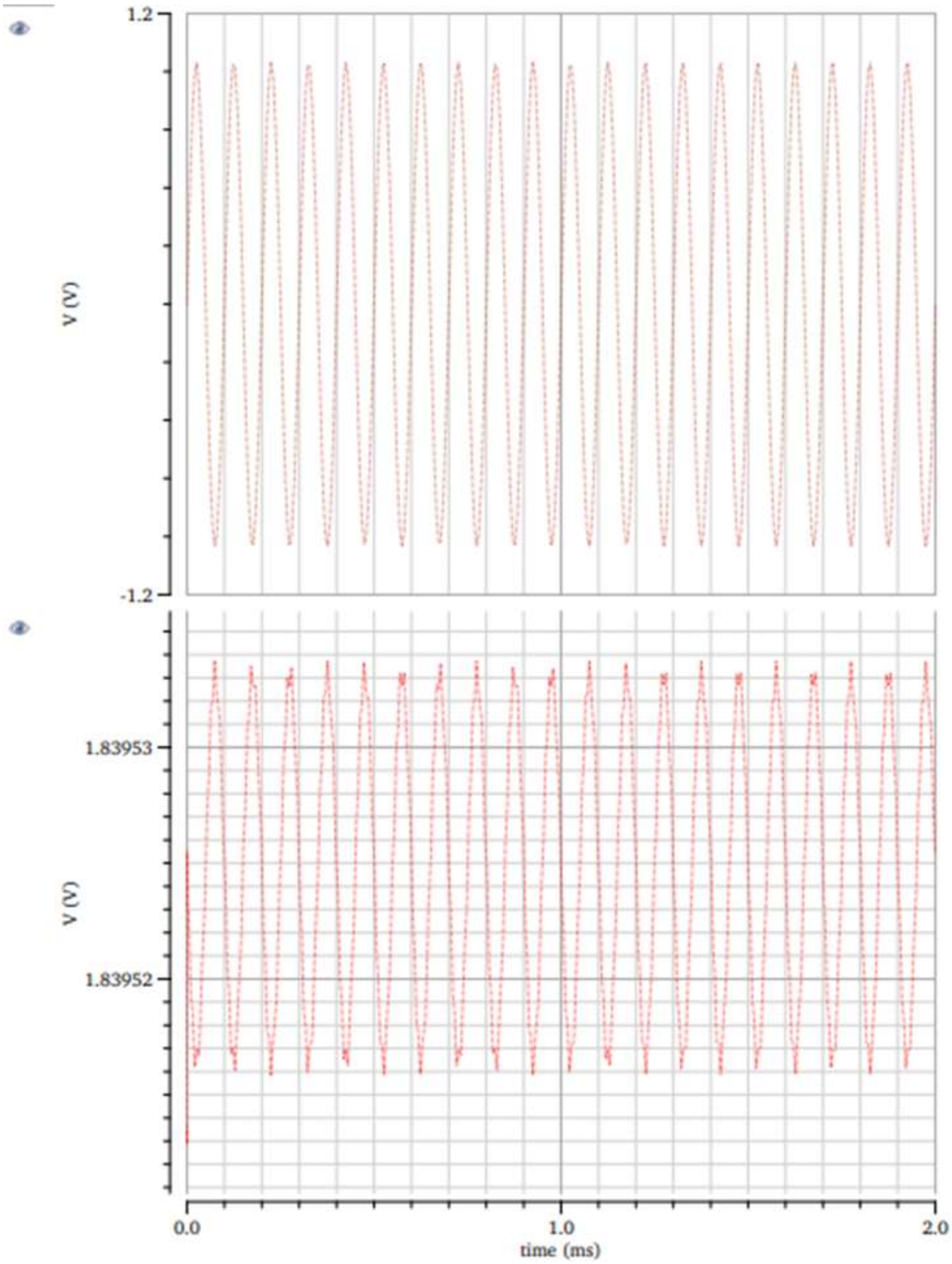

Fig4: Output Graph of OTA and Phase Margin

4. Conclusions

Operational Transconductance Amplifiers (OTAs) are essential components in various electronic systems due to their high gain capabilities. Telescopic OTAs, particularly telescopic OTAs, are particularly crucial in the development of integrated continuous-time filters and analog portable devices. Their high gain surpasses that of a Balanced OTA by 60dB, making them ideal for low-frequency applications. Integrated continuous-time filters rely on telescopic OTAs' high gain capabilities to effectively process signals in the analog domain. Telescopic OTAs also offer an optimal solution for analog portable devices, where power efficiency and compact design are critical considerations. Their substantial gain ensures enhanced sensitivity and precision, making them ideal for applications like audio amplification in portable gadgets.

In summary, OTAs, particularly telescopic OTAs, are essential components in electronic systems requiring amplification for low-frequency applications. Their unique characteristics contribute significantly to the functionality and performance of diverse electronic systems, making them indispensable components in the design of continuous-time filters and integrated into analog portable devices.

References

1. G. Ahlbom, L. Egnell, and C. Wickman et al, “Digital demodulator for optical FSK signals,” Electron. Lett., vol. 26, no. 5, pp. 290–292,published on Mar.1990.
2. KushGulati , Hae-Seung Lee et al, “A High-Swing, High-Performance CMOS Telescopic Operational Amplifier”, IEEE Journal Of Solid-State Circuits, Vol. 33, No. 12,published on Dec 1998
3. K. N. Leung , P. K. T. Mok et al, “Nested Miller compensation in lowpower CMOS design,” IEEE Trans. Circuits Syst. I, Fundam. Theory Appl., vol. 48, no. 4, pp. 388–394, published on Apr. 2001.
4. H. Lee , P. K. T. Mok et al, “Active-feedback frequency-compensation technique low-power multistage for amplifiers,” IEEE J. Solid-State Circuits, vol. 38, no. 3, pp. 511–520,published on Mar. 2003.
5. X. Peng , W. Sansen et al, “AC boosting compensation scheme for lowpower multistage amplifiers,” IEEE J. Solid-State Circuits, vol. 39, no.11, pp. 2074–2077,published on Nov. 2004.
6. Bai, C.; Zhao, H.; Qiao, D. A Wide-Band Feedback Amplifier based on a New Operational Current Amplifier in 130 nm CMOS. In Proceedings of the 2019 IEEE International Conference on Electron Devices and Solid-State Circuits (EDSSC), Xi’an, China, 12–14 June 2019.
7. Amina, M.; Bisis, P.; Ullah, A.; Chowdhury, I.B. Analysis of common-mode rejection ratio of a CMOS differential amplifier considering all the non-idealities. In

Proceedings of the 2015 2nd International Conference on Electrical Information and Communication Technologies (EICT), Khulna, Bangladesh, 10–12 December 2015.

8. Zhang, S.H.; Feng, Y.C.; Shiau, M.S.; Wan, Q.M.; Liu, D.G. A high-slew rate rail-to-rail operational amplifier by flipped voltage followers. In Proceedings of the 2015 IEEE 11th International Conference on ASIC (ASICON), Chengdu, China, 3–6 November 2015.
9. Jose, B.; Jose, L.; Kiruba, R.S.; Ekka, P.M.; Priya, S.S.S. Two Stage Class AB Op-Amp for Video Applications. In Proceedings of the 2019 3rd International Conference on Trends in Electronics and Informatics (ICOEI), Tirunelveli, India, 23–25 April 2019
10. Pandey, S.C.; Mishra, P.; Roy, R.; Pandit, A.K. Design of Two-Stage CMOS Operational Amplifier for Sigma-Delta ADC. In Proceedings of the International Conference on Computational Intelligence & Communication Networks, Tehri, India, 23–25 December 2016.
11. Zhang, G.Y. Research on Low-Power Multi-Stage Operational Amplifier for TFT-LCD Integrated Chips. Ph.D. Thesis, Tianjin University, Tianjin, China, 2016.