Contents

1 EXPERIMENT

Analysis, and design of fully differential telescopic OP-AMP circuits.

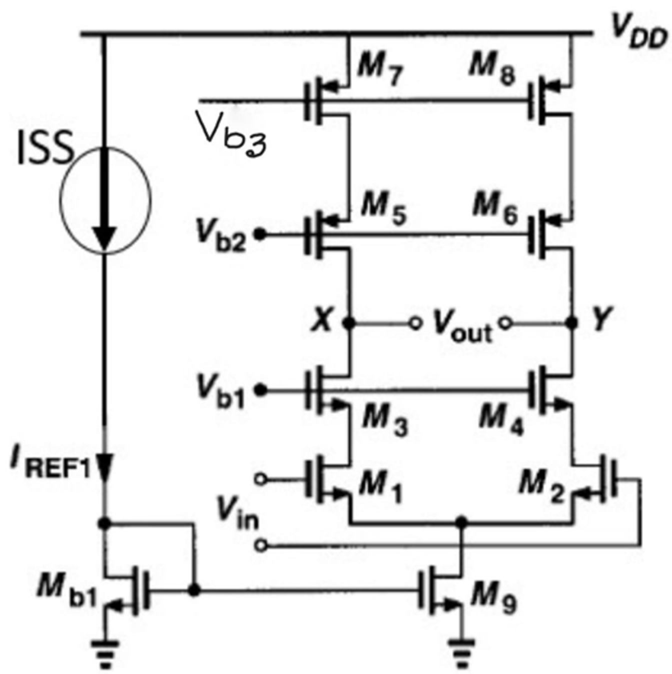
2 DESIGN SPECIFICATIONS

- **Process Technology:** 0.18µm CMOS
- **Power Supply:**
  - $V_{DD} = 1.8V$
  - $V_{SS} = 0V$
- **Load Capacitance:** 1pF
- **Phase Margin:** $\geq 60°$
- **DC Gain:** $\geq$ 1000 V/V (60 dB)
- **Common Mode Gain:** $\leq$ 0.1 V/V (-20 dB)
- **Unity Gain Frequency:** $>$ 100 MHz
- **Slew Rate:** $\geq$ 20 V/µs
- **Output Voltage Swing (Differential Peak-to-Peak):** $\geq 600\,\mathrm{mV_{pp}}$
- **Power Consumption:** less than 5mW

2.1 PROVIDED

- The source voltage is equal to 1.8 V.

3 THEORY



Introduction

- A telescopic operational amplifier (op-amp) is a high-performance analog circuit widely used in integrated circuits for applications requiring high gain, wide bandwidth, and low power consumption.
- The telescopic op-amp is an extension of the cascode amplifier topology, where multiple transistors are stacked to improve performance.
- The name "telescopic" comes from the stacked structure of the transistors, resembling a telescope.
- The telescopic op-amp is particularly popular in high-speed analog-to-

digital converters (ADCs), low-power amplifiers, and RF circuits due to its excellent gain-bandwidth product and power efficiency.

Basic Structure of a Telescopic Op-Amp

- The telescopic op-amp consists of a telescopic cascode amplifier as its core gain stage, followed by additional circuitry for biasing, compensation, and output buffering.
- **Key Components:**
  - **Input Differential Pair:**
    - The input stage typically consists of a differential pair of transistors (e.g., NMOS or PMOS) that converts the differential input voltage into a differential current.
    - This stage provides the initial gain and sets the input common-mode range.
  - **Telescopic Cascode Stage:**
    - The telescopic cascode stage is the heart of the op-amp. It consists of stacked transistors in a cascode configuration (common-source followed by common-gate stages).
    - The stacking of transistors increases the output impedance, which enhances the overall gain of the op-amp.
    - The telescopic structure also reduces the Miller effect, improving bandwidth.
  - **Load Circuit:**
    - The load is typically implemented using active loads (e.g., PMOS or NMOS transistors in saturation) or resistive loads.
    - The load circuit converts the amplified differential current into a single-ended or differential output voltage.
  - **Bias Circuitry:**
    - Proper biasing is critical to ensure that all transistors operate in the saturation region.
    - Bias circuits generate the required voltages and currents for the input pair, cascode transistors, and load.

- **Compensation Network:**
  * A compensation capacitor (e.g., Miller capacitor) is often added to ensure stability by controlling the dominant pole of the op-amp.

Key Features of Telescopic Op-Amps

- **High Gain:**
  - The telescopic cascode structure provides very high output impedance, resulting in a high voltage gain.
  - The gain is typically much higher than that of a simple two-stage op-amp.
- **Wide Bandwidth:**
  - The telescopic structure minimizes the Miller effect, which allows for a wider bandwidth compared to other op-amp topologies.
  - The reduced parasitic capacitance at the high-impedance nodes also contributes to the wide bandwidth.
- **Low Power Consumption:**
  - The telescopic op-amp operates with a single current path, making it more power-efficient than other topologies like the folded cascode or two-stage op-amps.
- **Improved Linearity:**
  - The cascode structure reduces nonlinearities in the input stage, improving the overall linearity of the op-amp.
- **Low Noise:**
  - The telescopic op-amp can achieve low noise performance due to the reduced number of noise-contributing devices in the signal path.

Advantages of Telescopic Op-Amps

- **High Gain-Bandwidth Product:**
  - The combination of high gain and wide bandwidth makes telescopic op-amps suitable for high-speed applications.
- **Power Efficiency:**
  - The single current path and reduced number of transistors result in lower power consumption compared to other op-amp topologies.
- **Compact Design:**
  - The telescopic structure is compact and requires fewer transistors than folded cascode or two-stage op-amps.
- **Low Noise and High Linearity:**
  - The telescopic op-amp is well-suited for low-noise and high-linearity applications, such as in ADCs and RF circuits.

Disadvantages of Telescopic Op-Amps

- **Limited Output Swing:**
  - The stacking of transistors reduces the available output voltage swing, which can be a limitation in low-voltage designs.
- **Complex Biasing:**
  - The telescopic structure requires precise biasing to ensure all transistors operate in the saturation region.
- **Sensitivity to Process Variations:**
  - The performance of telescopic op-amps can be sensitive to process variations, requiring robust design techniques.
- **Limited Common-Mode Input Range:**
  - The input common-mode range is limited due to the stacked structure, which can restrict its use in certain applications.

Design Considerations

- **Output Swing:**
  - The limited output swing is a key challenge in telescopic op-amps. Techniques such as gain boosting or folded cascode can be used to improve the output swing.
- **Stability:**
  - The high gain and wide bandwidth can lead to stability issues. A compensation capacitor (e.g., Miller capacitor) is often used to ensure stability.
- **Noise Performance:**
  - Careful design of the input differential pair and bias circuitry is required to minimize noise.
- **Power Supply Rejection Ratio (PSRR):**
  - The telescopic op-amp may have limited PSRR due to the stacked structure. Additional circuitry may be needed to improve PSRR.
- **Process Variations:**
  - Robust biasing and layout techniques are required to mitigate the effects of process variations.

Applications of Telescopic Op-Amps

- **High-Speed ADCs:**
  - Telescopic op-amps are commonly used in pipeline ADCs and successive approximation register (SAR) ADCs due to their high gain and wide bandwidth.
- **Low-Power Amplifiers:**
  - The low power consumption makes telescopic op-amps ideal for portable and battery-powered devices.
- **RF Circuits:**

  - The wide bandwidth and low noise make telescopic op-amps suitable for RF applications, such as low-noise amplifiers (LNAs) and mixers.

- **Analog Filters:**

  - Telescopic op-amps are used in active filters where high gain and wide bandwidth are required.

Conclusion

- The telescopic op-amp is a high-performance analog circuit that offers an excellent balance of high gain, wide bandwidth, and low power consumption.

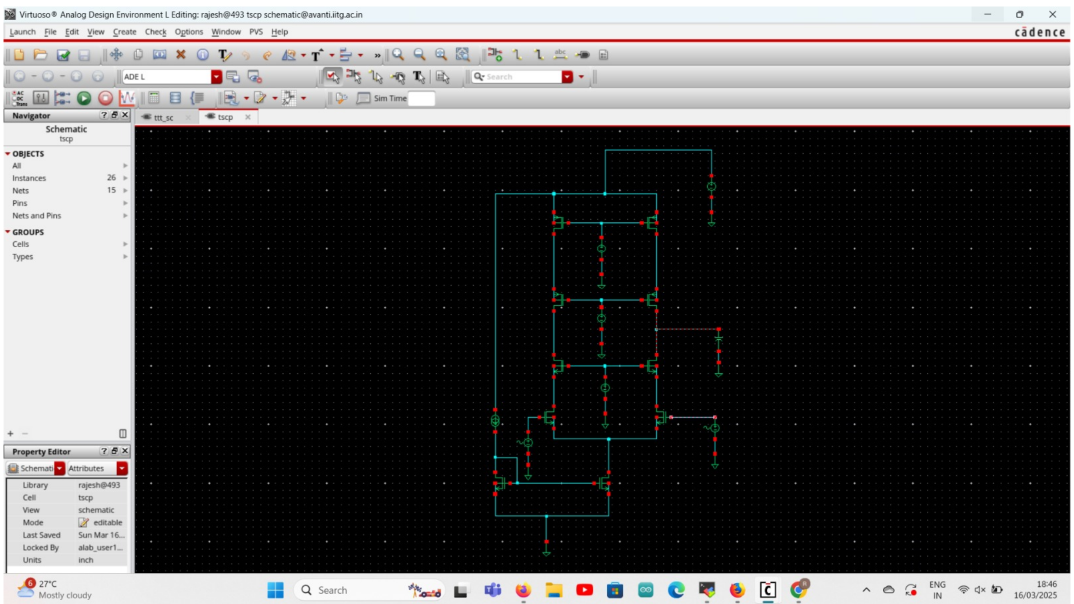
- Its compact design and efficiency make it a popular choice for high-speed and low-power applications, such as ADCs, RF circuits, and portable devices.

- However, designers must carefully address challenges such as limited output swing, biasing complexity, and sensitivity to process variations to fully leverage the benefits of telescopic op-amps.

- With proper design techniques, telescopic op-amps can achieve state-of-the-art performance in modern analog and mixed-signal systems.

4 TELESCOPIC OPAMP

4.1 Schematic

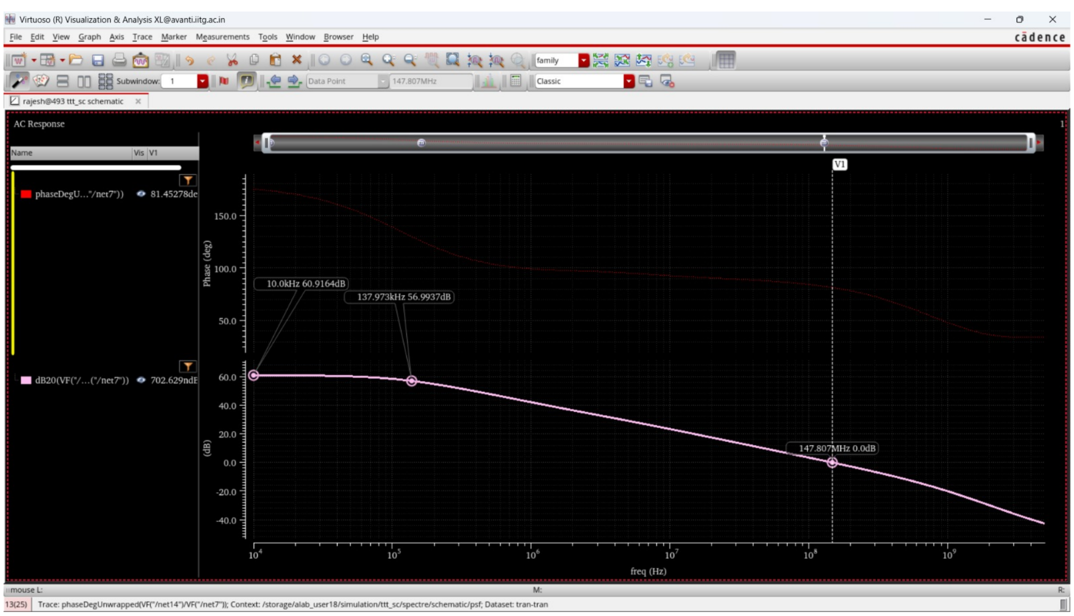


- The MOSFETs M1 and M2 have a bias voltage of vg is 0.914v.
- The MOSFETs M3 and M4 have a bias voltage of vg is 1.034v.
- The MOSFETs M5 and M6 have a bias voltage of vg is 0.924v
- The MOSFETs M7 and M8 have a bias voltage of vg is 1.156v

Transistor	Width	Length
M1	10.5 um	720 nm
M2	10.5 um	720 nm
M3	22.22 um	720 nm
M4	22.22 um	720 nm
M5	18.33 um	720 nm
M6	18.33 um	720 nm
M7	28.33 um	720 nm
M8	28.33 um	720 nm
M9	1200 nm	180 nm
Mb1	400 nm	180 nm

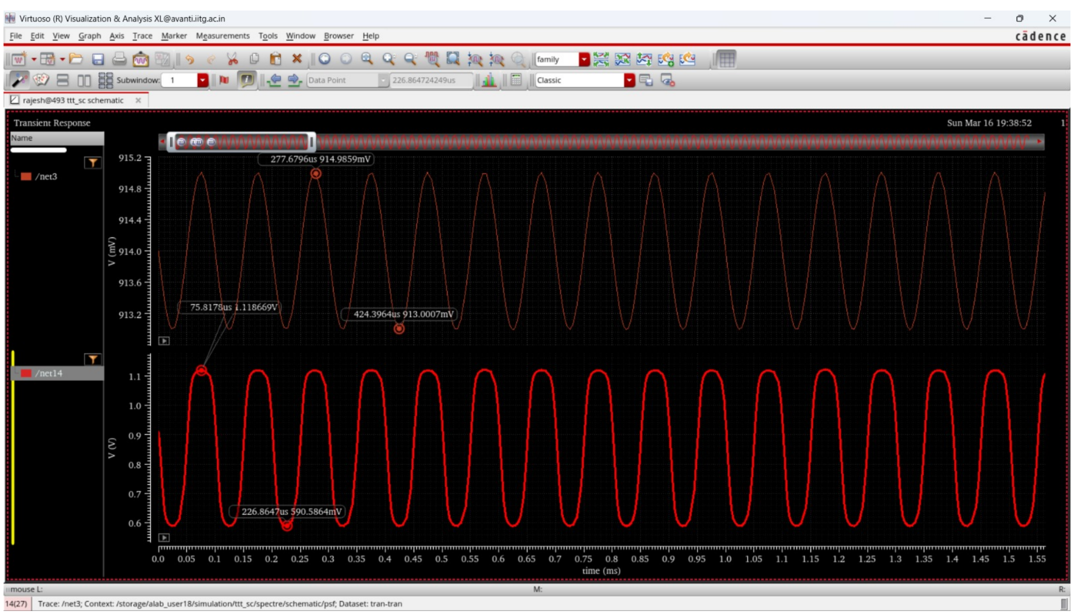
Table 1: (W/L) of all transistors

4.2 Gain VS Frequency Plot



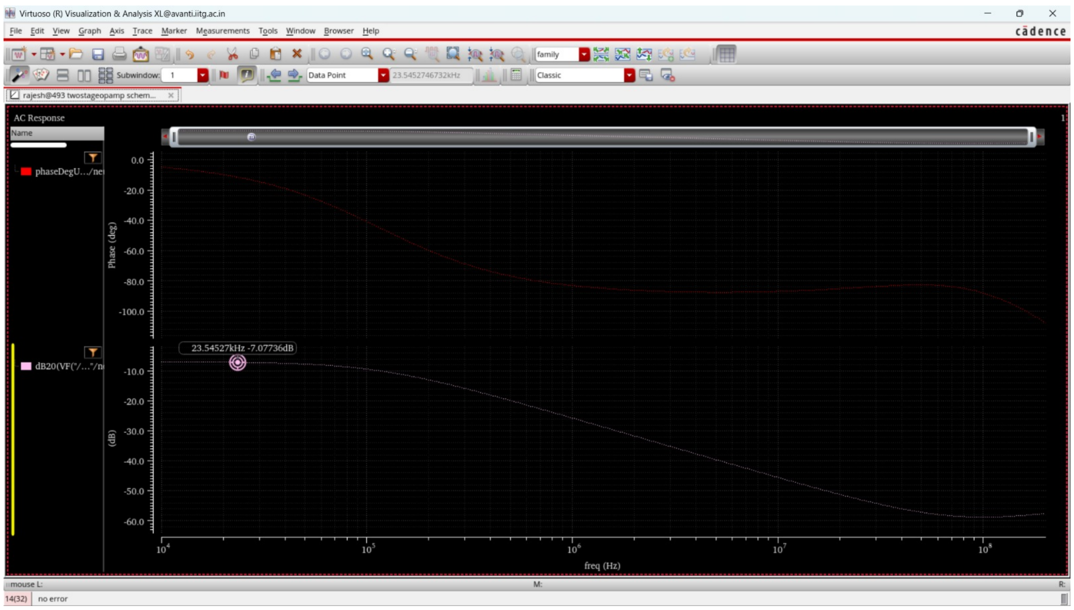
- The gain vs. frequency graph is plotted by varying the frequency from 10 kHz to 500 MHz.
- **Intrinsic Gain:** 60 dB (The constant or maximum gain in the graph).
- **Cut-off or 3dB Frequency:** 140.57 kHz (The frequency where the gain is 0.707 times of its maximum value).
- **Unity Gain Frequency:** 150.419 MHz (The frequency up to which the MOSFET acts as an amplifier).
- we obtained the phase margin as 86.92 degrees.

4.3 input and Output Swing



- The ac input is given 10mv
- we obtained a output swing between 0.59v to 1.25v.

4.4 Common Mode Gain vs frequency



Common Mode Gain (A_{cm}) is the amplification factor of an amplifier when **both inputs** receive the **same signal** (i.e., a common-mode signal).

Mathematically, it is given by:

$$A_{cm} = \frac{V_{\text{out,cm}}}{V_{\text{in,cm}}} \tag{1}$$

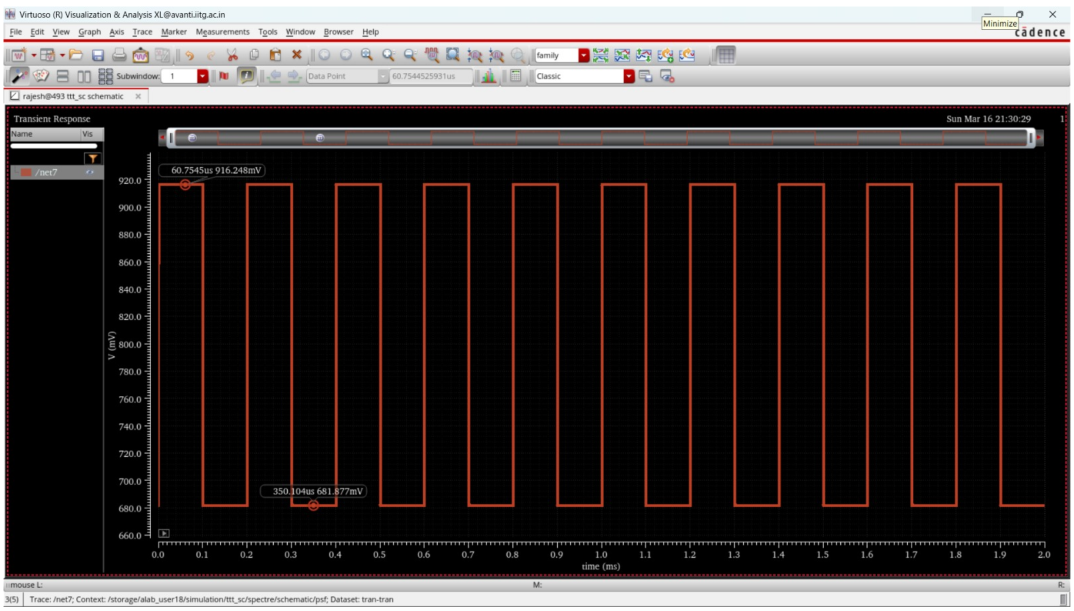
where:

- $V_{\text{out,cm}}$ is the common-mode output voltage.
- $V_{\text{in,cm}}$ is the common-mode input voltage.

An **ideal differential amplifier** should reject common-mode signals, meaning A_{cm} should be as **low as possible** (ideally zero). However, practical amplifiers exhibit some finite common-mode gain, which affects the **Common-Mode Rejection Ratio (CMRR)**.

- we obtained the common mode gain as -7.5db.

4.5 Slew Rate



- we obtained a slew rate of 67.62 volts per microsecond.
- power consupmption is 0.24975 milliwatts.

5 CALCULATIONS

- **M1 and M2:** The source voltage of M1 is equivalent to the drain voltage of M9, which is 0.3V. The overdrive voltage is given as 0.12V.
  - $V_{OD1} = 0.12V$
  - $V_{GS1} - V_{th1} = 0.12V$

- $V_{G1} - V_{S1} - V_{th1} = 0.12V$
- $V_{G1} - 0.3 - 0.494 = 0.12V$
- Hence, $V_{G1} = V_{G2} = 0.914V$.

- **M3 and M4:** The drain voltage of M1, which is 0.42V, serves as the source voltage of M3. The overdrive voltage is specified as 0.12V.
  - $V_{OD3} = 0.12V$
  - $V_{GS3} - V_{th3} = 0.12V$
  - $V_{G3} - V_{S3} - V_{th3} = 0.12V$
  - $V_{G3} - 0.42 - 0.494 = 0.12V$
  - Thus, $V_{G3} = V_{G4} = 1.034V$.

- **M7 and M8:** The source voltage of M7 corresponds to the supply voltage V_{DD}, which is 1.8V. The overdrive voltage is given as 0.18V.
  - $V_{OD7} = 0.18V$
  - $V_{SG7} - V_{th7} = 0.18V$
  - $V_{S7} - V_{G7} - V_{th7} = 0.18V$
  - $1.8 - V_{G7} - 0.464 = 0.18V$
  - Therefore, $V_{G7} = V_{G8} = 1.156V$.

- **M5 and M6:** The source voltage of M5 is equal to the drain voltage of M7, which is 1.62V. The overdrive voltage is considered as 0.12V.
  - $V_{OD5} = 0.18V$
  - $V_{SG5} - V_{th5} = 0.18V$
  - $V_{S5} - V_{G5} - V_{th5} = 0.18V$
  - $1.6 - V_{G5} - 0.464 = 0.18V$
  - As a result, $V_{G5} = V_{G6} = 0.924V$.

6 CONCLUSION AND COMPARISION OF RESULTS

- The design and implementation of telescopic opamp have been completed.
- All the results obtained theoretically and practically matched.

parameter	**Theoretical Results**	**Practical Results**
$\|A_v\|$	$60db$	$60.94db$
GBW	100 MHz	150.41 MHz
$phasemargin$	$\geq$ 60 deg	86.92 deg
$slewrate$	$\geq$ 20 v/us	67.62 v/us

Table 2: Comparison of Theoretical and Practical Results