

Differential Telescopic Cascode Amplifier in UMC 180nm CMOS using Potential Distribution Method (PDM)

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Introduction:

High-performance operational amplifiers are fundamental building blocks in a vast array of analog and mixed-signal integrated circuits. Among the various architectures, the fully differential telescopic cascode amplifier is highly regarded for its ability to achieve high DC gain, high-speed operation, and good power supply rejection, making it suitable for applications such as high-precision data converters and filters.

This report presents the complete design, analysis, and simulation of a fully differential Telescopic Cascode Amplifier. The objective of this case study is to systematically design the amplifier circuit to meet a set of rigorous performance specifications using the UMC 180nm CMOS technology.

Potential Distribution Method (PDM) was chosen for the design process. This method is particularly effective for stacked structures like the telescopic cascode amplifier, as it focuses on the strategic allocation of DC voltage levels to ensure every transistor operates robustly in the saturation region. By carefully assigning the overdrive voltages, PDM helps in achieving the required performance while maximizing the output voltage swing. The amplifier is designed to meet the following target specifications:

- **DC Voltage Gain (Av):** 1000 V/V
- **Power Consumption:** Less than 5 mW
- **Output Swing:** 1.8 V
- **Load Capacitance (CL):** 5 pF

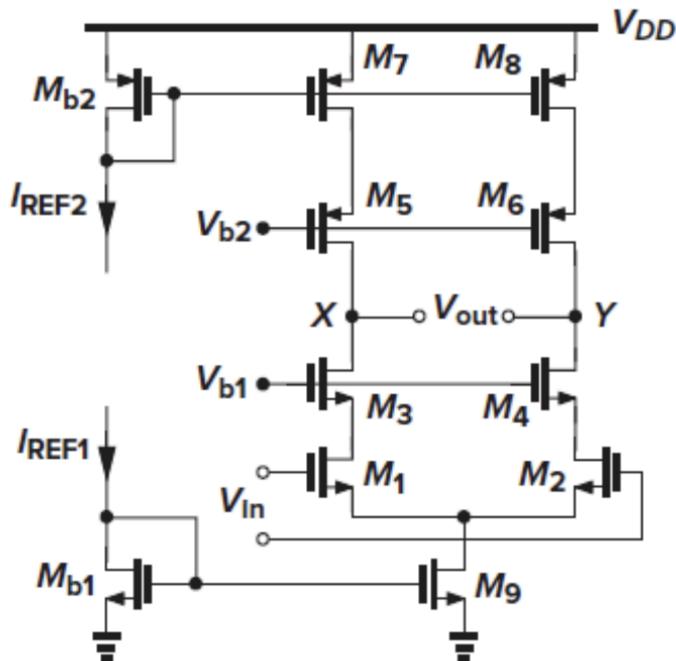


Fig. 1: Circuit Diagram

Design Procedure:

Method Chosen: Potential Distribution Method

Power consumption value choose is: 4.5mW

Calculations:

In the branch 1 as given in fig: of the circuit which contains transistor M8, M6, M4, M2, M9 the sizing is done according to the calculations given below

$$P = V \times I$$

Since the Power 4.5mW and Voltage is 1.8V

$$I = 2.5\text{mA}$$

The current though branch 1 = 1 mA

The current though branch 2 = 1 mA

The current though branch 3 = 0.5 mA

$$\text{Therefore } I_{REF1} = 0.25\text{mA} \text{ and } I_{REF2} = 0.25\text{mA}$$

For M9

$$V_{OV} = V_{GS} - V_{TH}$$

$$0.3 = V_G - 0 - 0.45$$

$$V_G = 0.75V$$

For M2

$$V_{OV} = V_{GS} - V_{TH}$$

$$0.15 = V_G - 0.3 - 0.45$$

$$V_G = 0.9V$$

For M4

$$V_{OV} = V_{GS} - V_{TH}$$

$$0.15 = V_G - 0.6 - 0.45$$

$$V_G = 1.2V$$

For M6

$$|V_{DS}| = |V_{GS}| - |V_{TH}|$$

$$0.45 = |V_G - 1.35| - 0.45$$

$$|V_G| = 0.45V$$

For M8

$$V_{OV} = V_{SG} - |V_{TH}|$$

$$0.15 = 1.8 - V_G - 0.45$$

$$|V_G| = 1.2V$$

The values that are calculated are according the parameters as given the fig:2

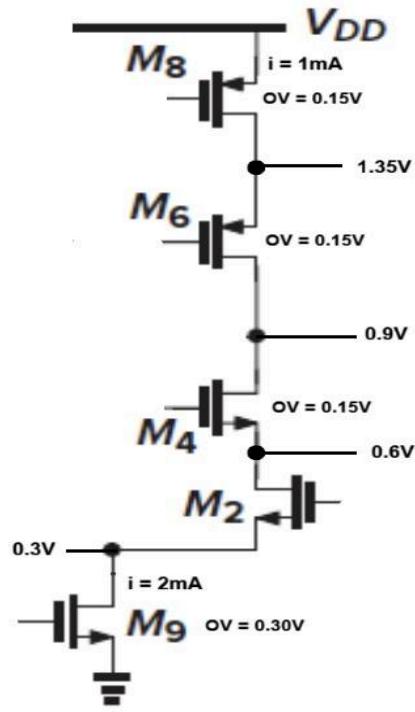


Fig. 2: Branch 1

Using the values of transistors **M8, M6, M4, and M2**, the corresponding dimensions for **M7, M5, M3, and M1** were determined, respectively. Subsequently, after obtaining the widths of **M8 and M9**, the current mirror equations were applied to calculate the widths of **Mb2 and Mb1**, based on the branch current of **0.25 mA**.

- $W_{b2} = \frac{\frac{I_{REF2}}{I_{M8}}}{\frac{W_{M8}}{W_{M9}}} = \frac{1043u}{4} = 260.755u$
 - $W_{b1} = \frac{\frac{I_{REF1}}{I_{M9}}}{\frac{W_{M8}}{W_{M9}}} = \frac{78.03u}{8} = 9.75u$

Schematic Diagram:

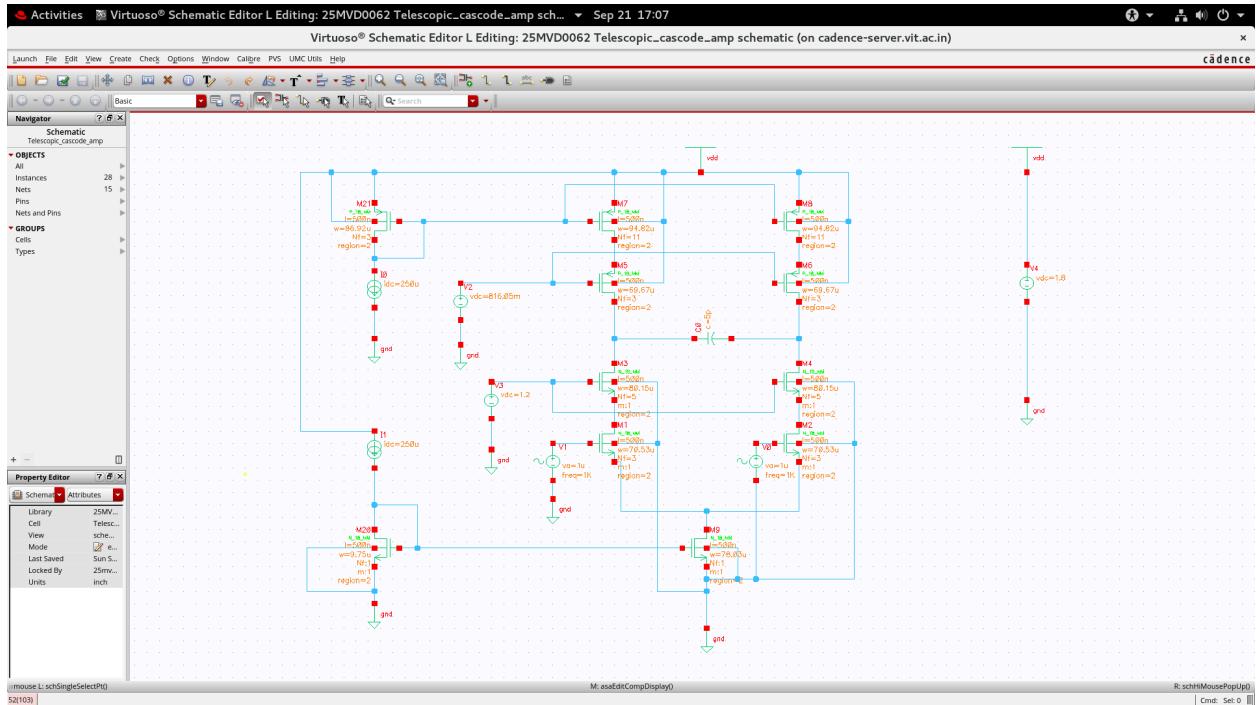


Fig. 3: Differential Telescopic Cascode Amplifier

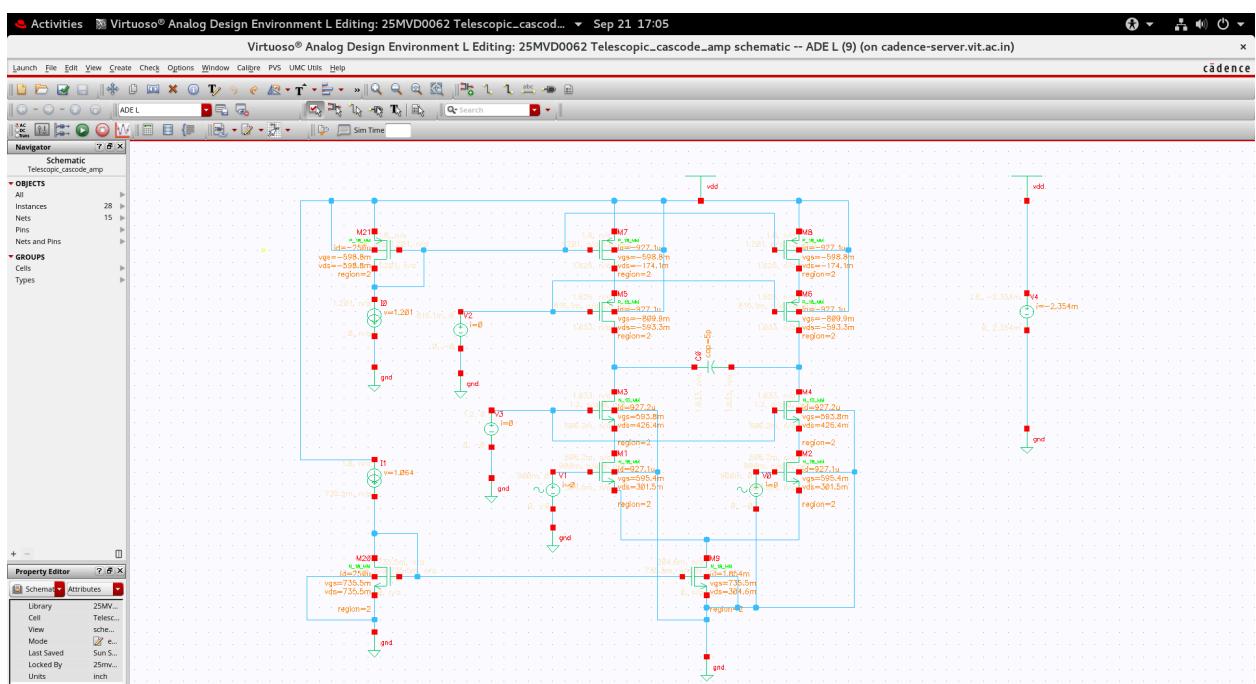


Fig. 4: Differential Telescopic Cascode Amplifier with DC Operating Points

Observations:

M8

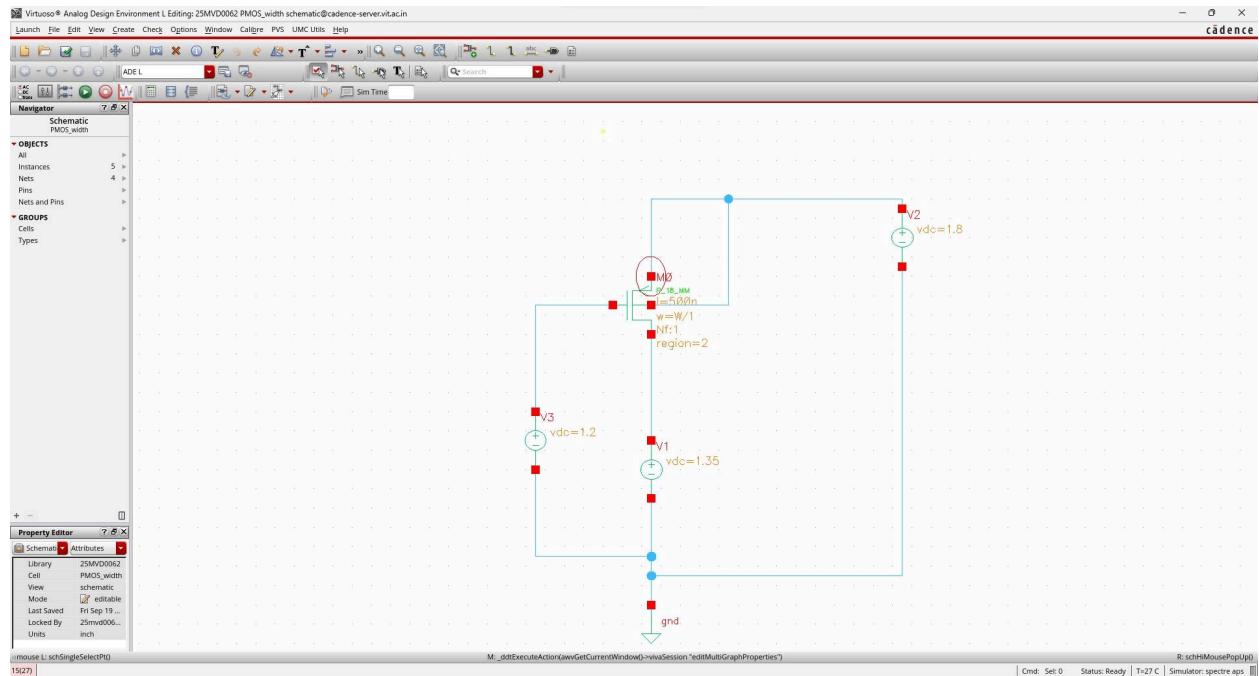


Fig. 5: M8 Circuit Diagram

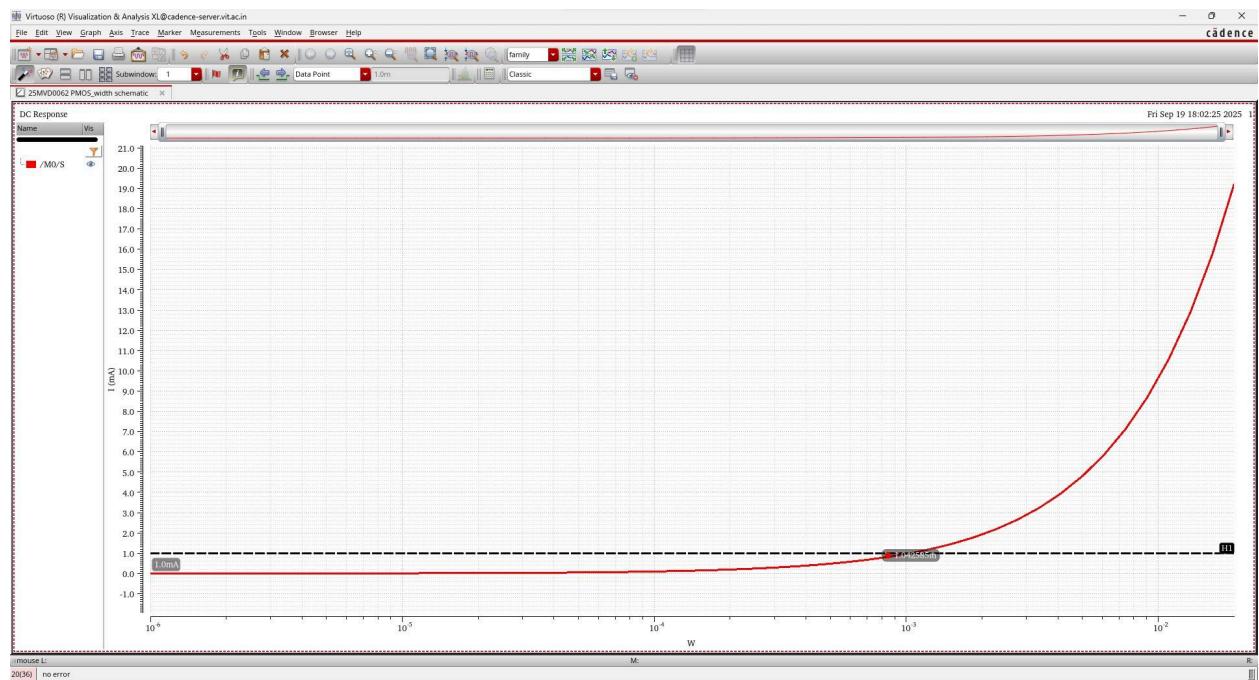


Fig. 6: I_D/W plot of M8

- Width is observed as: 1.042mm [$w = 94.82\mu m$, $N_f = 11$]

M6

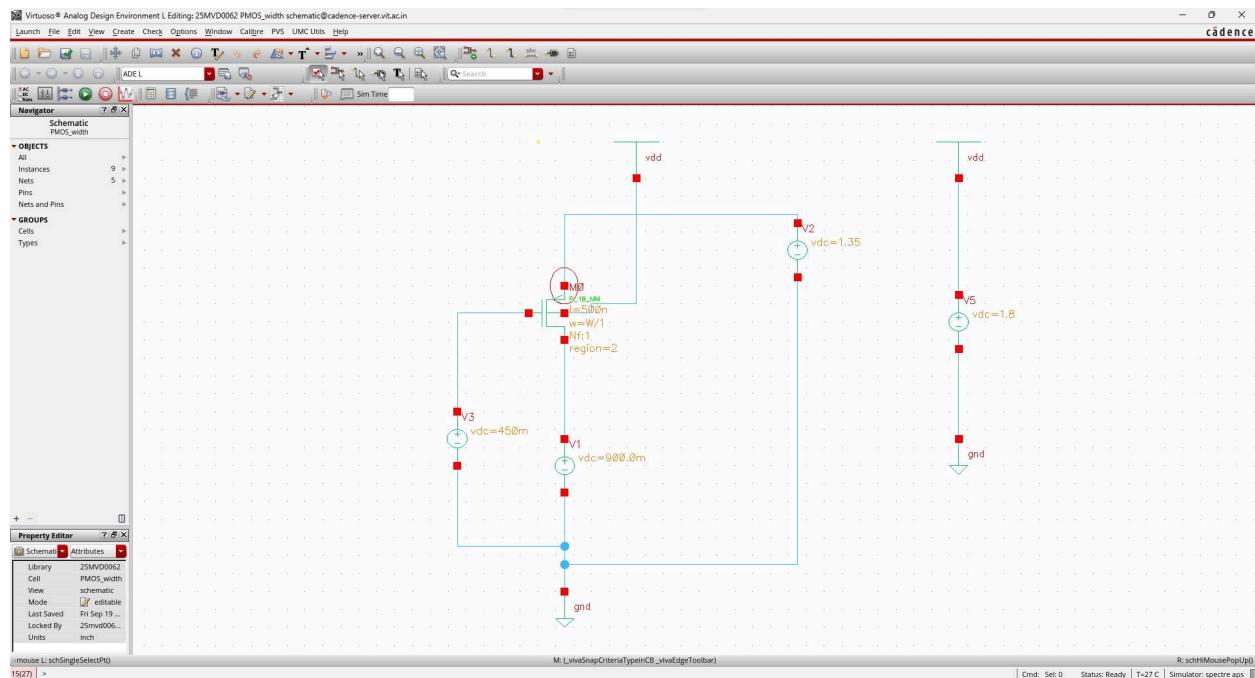


Fig. 7: M6 Circuit Diagram

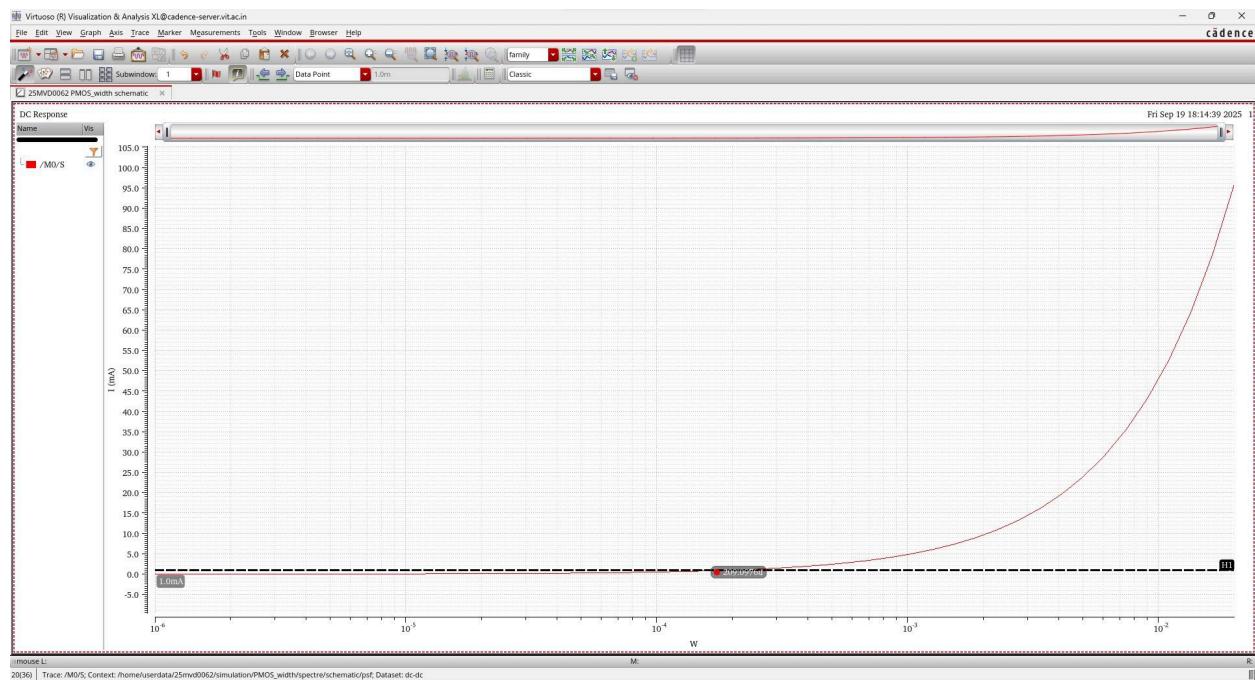


Fig. 8: I_D/W plot of M6

- Width is observed as: 209.097 um [w = 69.67um , Nf = 3]

M4

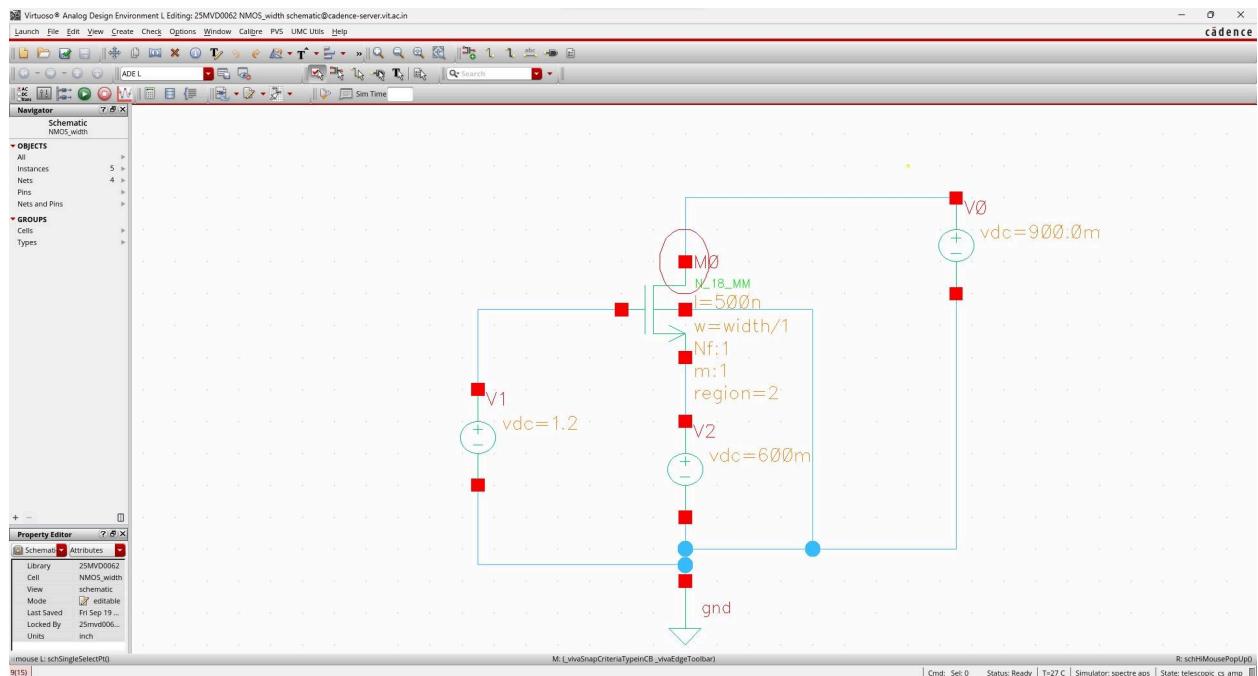


Fig. 9: M4 Circuit Diagram

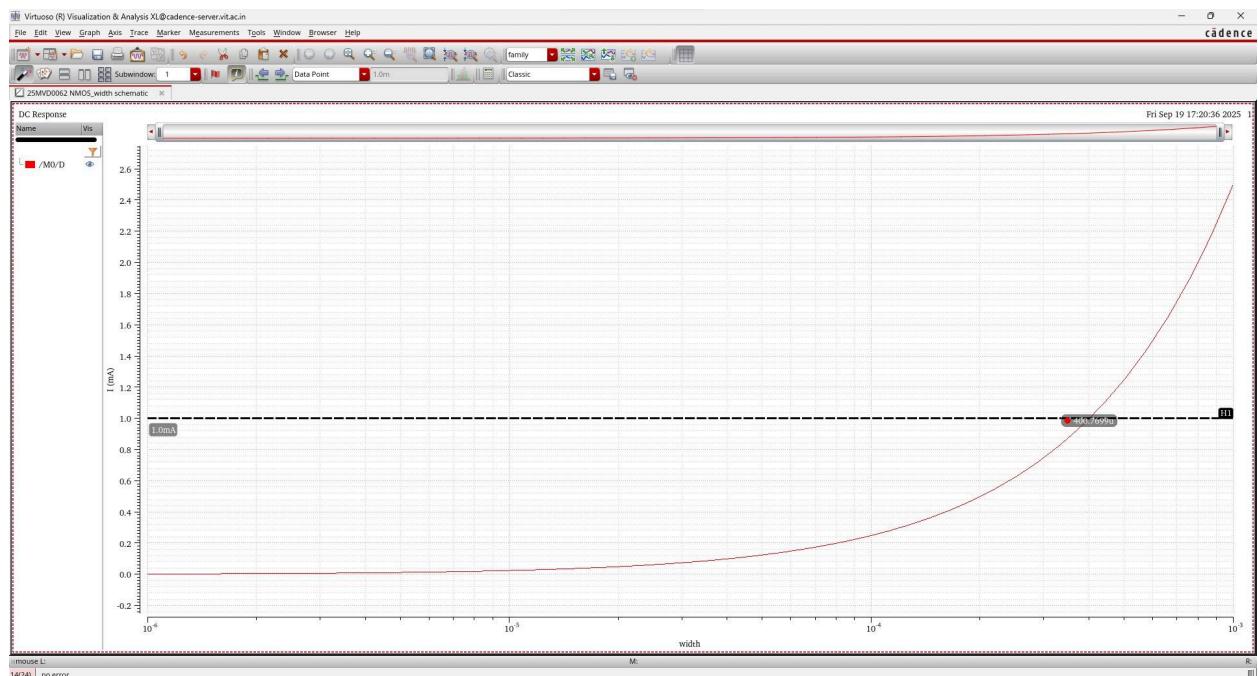


Fig. 10: I_D/W plot of M4

- Width is observed as: 400.769 μm

M2

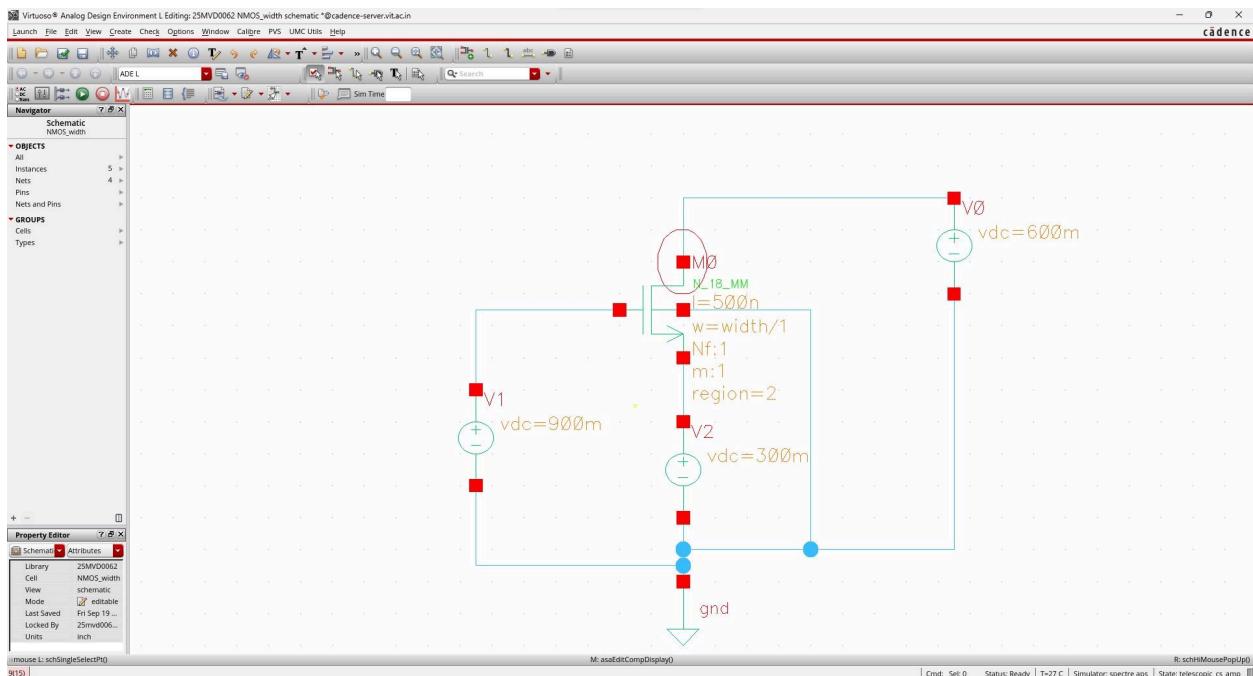


Fig. 11: M2 Circuit Diagram

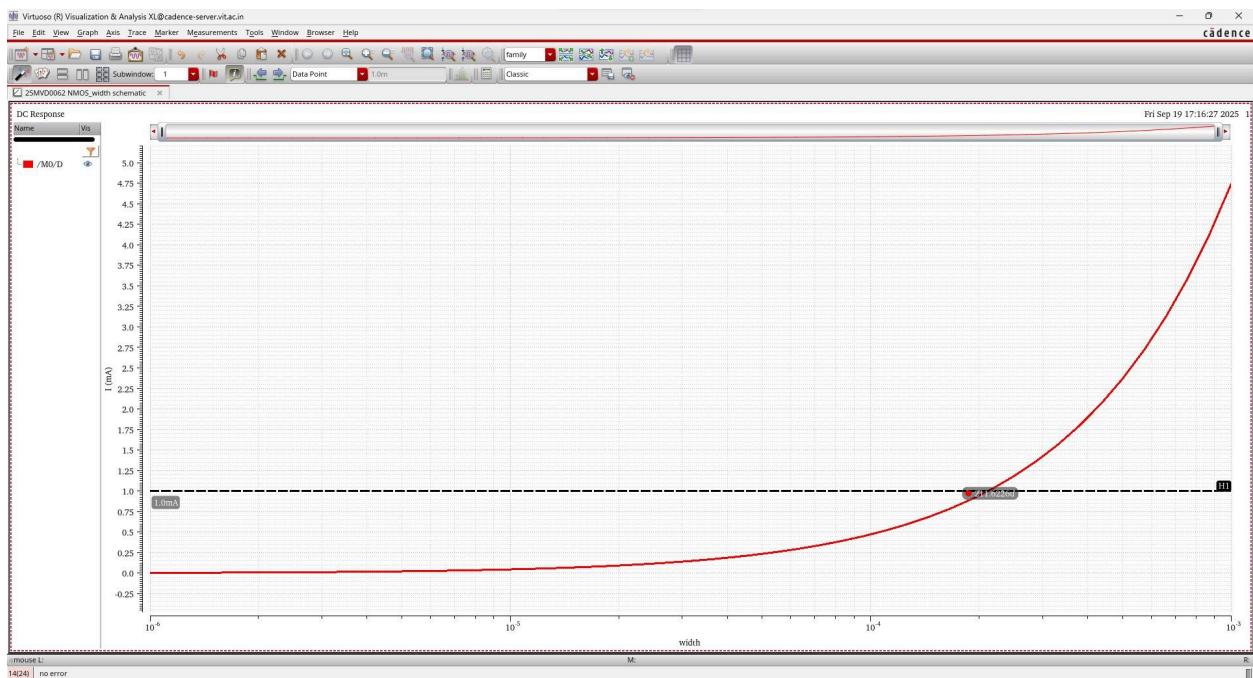


Fig. 12: I_D/W plot of M2

- Width is observed as: 211.622 μm

M9

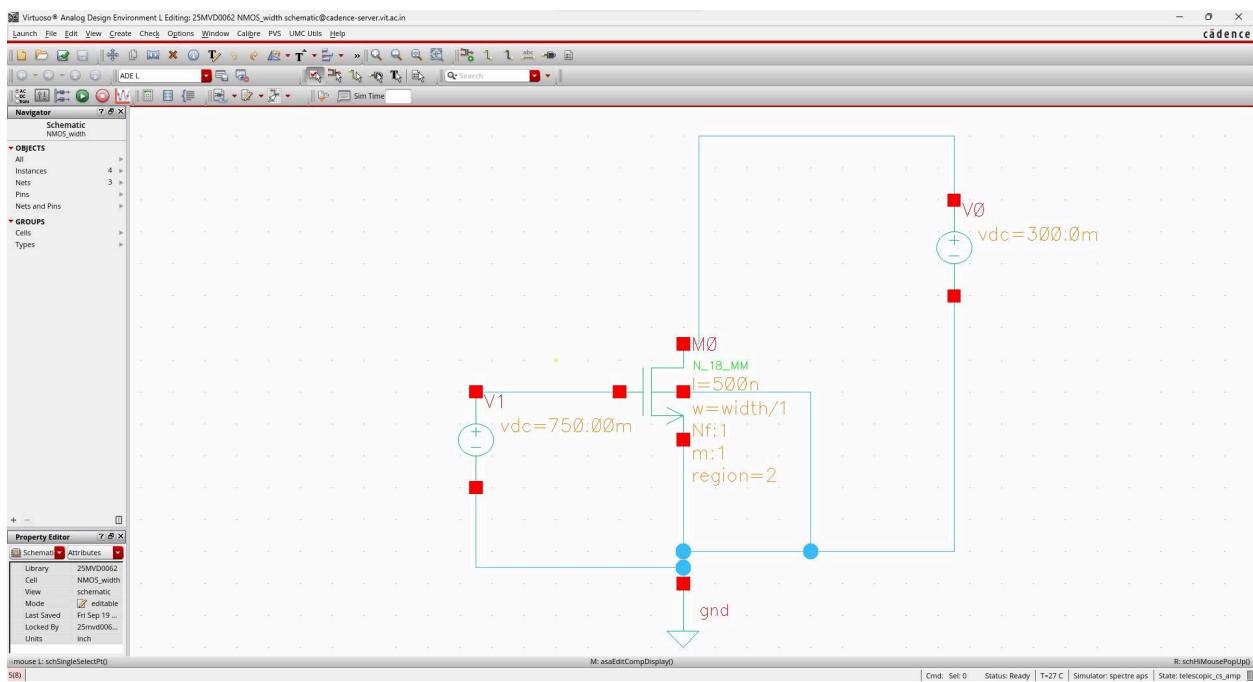


Fig. 13: M9 Circuit Diagram

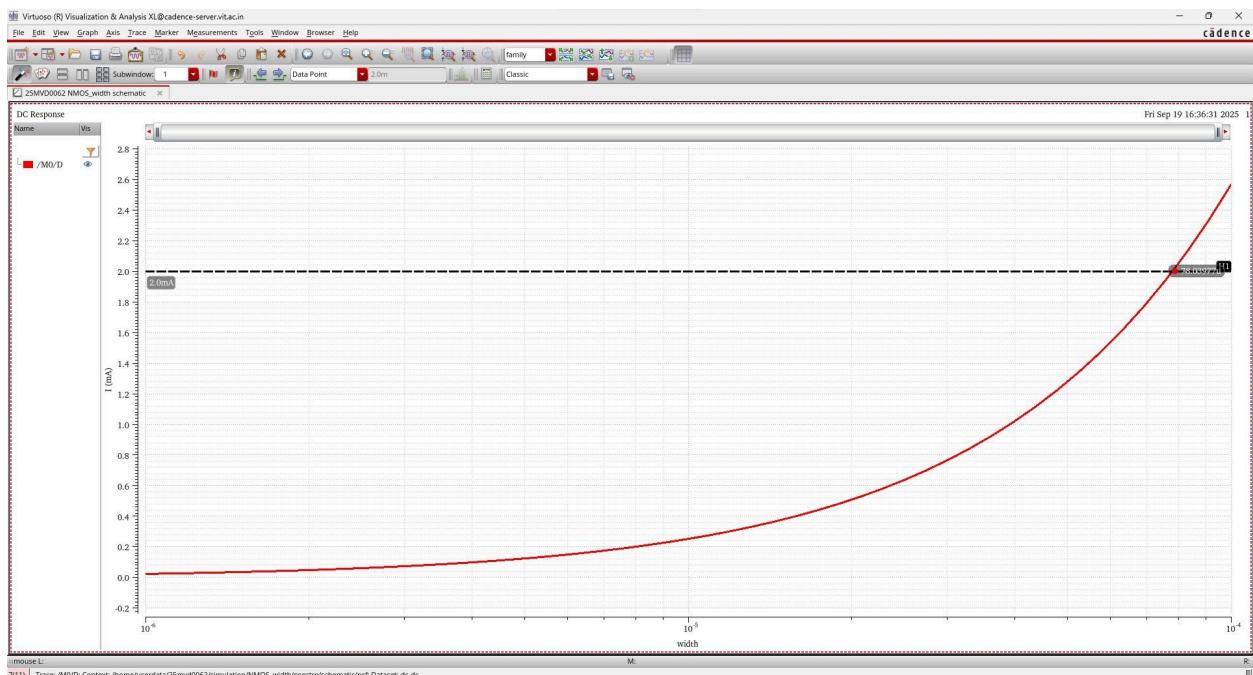


Fig. 14: I_D/W plot of M9

- Width is observed as: 211.622 μm

Observations:



Fig. 15: AC gain and Phase

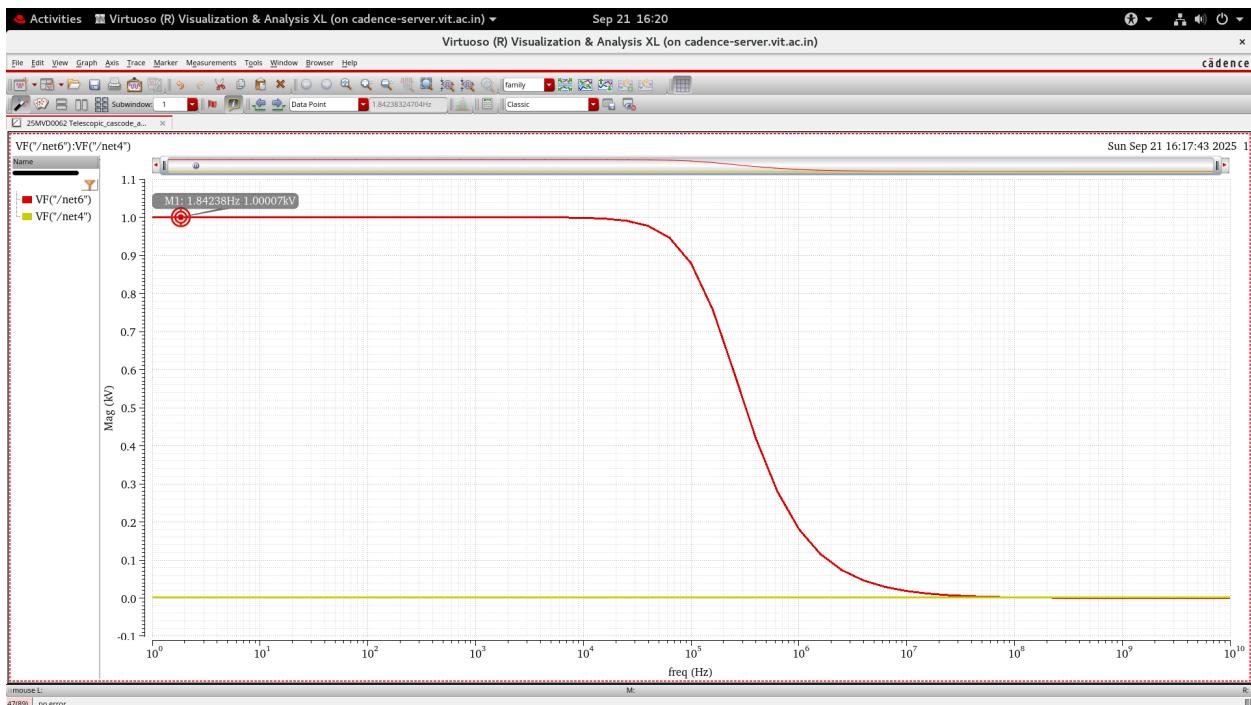


Fig. 16: AC Magnitude plot

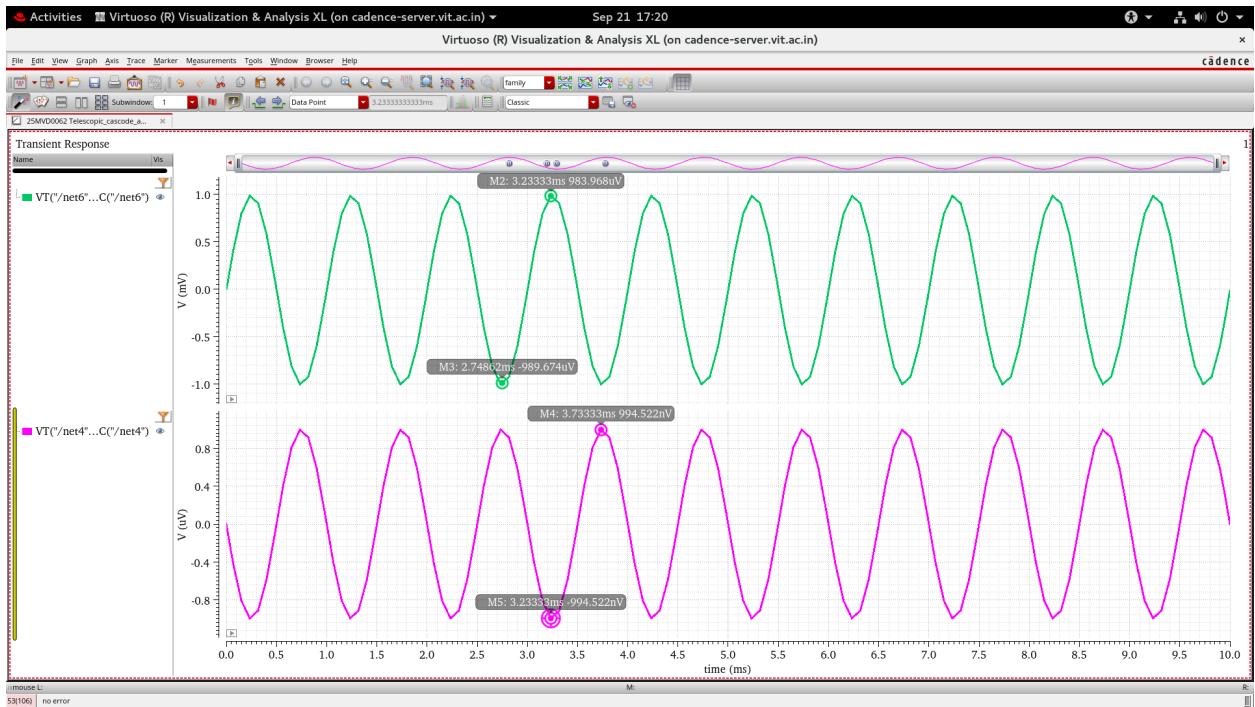


Fig. 17: Transient Analysis



Fig. 20: Transient Analysis with peak values

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Activities /home/userdata/25mv0062/simulation/Telescopic_cascade_amp/spectre/sche... Sep 21 12:48
/home/userdata/25mv0062/simulation/Telescopic_cascade_amp/spectre/schematic/psf/spectre.out (on cadence-server.vit.ac.in)
File Edit View Help CADENCE
ac freq = 0.31 MHz (88 s), step = 232.0 MHz (2 %)
ac freq = 1 GHz (90 s), step = 369 MHz (2 %)
ac freq = 1.585 GHz (92 s), step = 584.5 MHz (2 %)
ac freq = 2.329 GHz (94 s), step = 800 MHz (2 %)
ac freq = 3.981 GHz (96 s), step = 1.469 GHz (2 %)
ac freq = 6.31 GHz (98 s), step = 2.329 GHz (2 %)
ac freq = 10.00 GHz (100 s), step = 3.69 GHz (2 %)
Accumulated DC solution time = 0.1 s.
Intrinsic ac analysis time = 0.1 s.
Total time required for "analysis ac": CPU = 1.455 ms, elapsed = 1.58906 ms, util. = 91.6%.
Time accumulated: CPU = 154.42 ms, elapsed = 2.09516 s.
Peak resident memory used = 160 Mbytes.

*****
PZ Analysis pz
*****
Warning from spectre during PZ analysis "pz".
WARNING: BSIM3v3 MOS Transistor - frequency dependent components are present in the circuit, approximated as AC equivalents at 1.00000e+00Hz for pz analysis.

DC simulation time: CPU = 88 us, elapsed = 92.9832 us.
    Poles (Hz)
      Real           Imaginary          Qfactor
1 -1.84287e-05   0.00000e+00   5.00000e-01
2 -6.67760e-08   0.00000e+00   5.00000e-01
3 -1.77828e-09   0.00000e+00   5.00000e-01
      Zeros (Hz)
      at V{in1,net3}/V1
      Real           Imaginary          Qfactor
1 -6.66557e-08   0.00000e+00   5.00000e-01
2 2.28772e-10   0.00000e+00   -5.00000e-01
3 9.71445e-11   0.00000e+00   -5.00000e-01
Constant factor = 1.48172e-05
DC gain = 1.00000e+03

Accumulated DC solution time = 4.01072 s.
Intrinsic pz analysis time = -6.01993 s.
Total time required for "analysis pz": CPU = 2.464 ms, elapsed = 2.58708 ms, util. = 95.2%.
Time accumulated: CPU = 157.051 ms, elapsed = 2.09798 s.
Peak resident memory used = 164 Mbytes.

*****
Transient Analysis "tran": time = (0 s -> 10 ms)
*****
DC simulation time: CPU = 239 us, elapsed = 257.969 us.

Opening the PSF file ..//psf/tran.tran.tran ...
Important parameter values:
  tr = 10 s
  outputstart = 0 s
  stop = 10 ms
  start = 0 us
  maxstep = 200 us
  ic = no
  userpcic = no
  skipdc = no
  retol = 1e-03
  abstol(V) = 1 uV

```

Fig. 21: Pole-Zero Analysis

Bode Plot of the Transfer Function

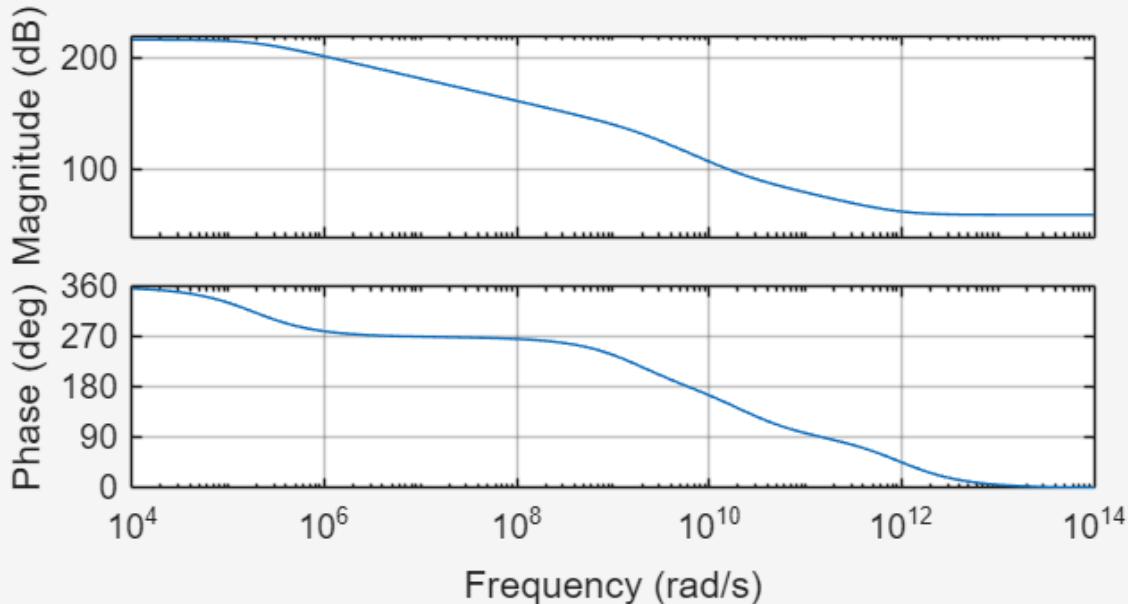


Fig. 21: Bode Plot of the Transfer Function

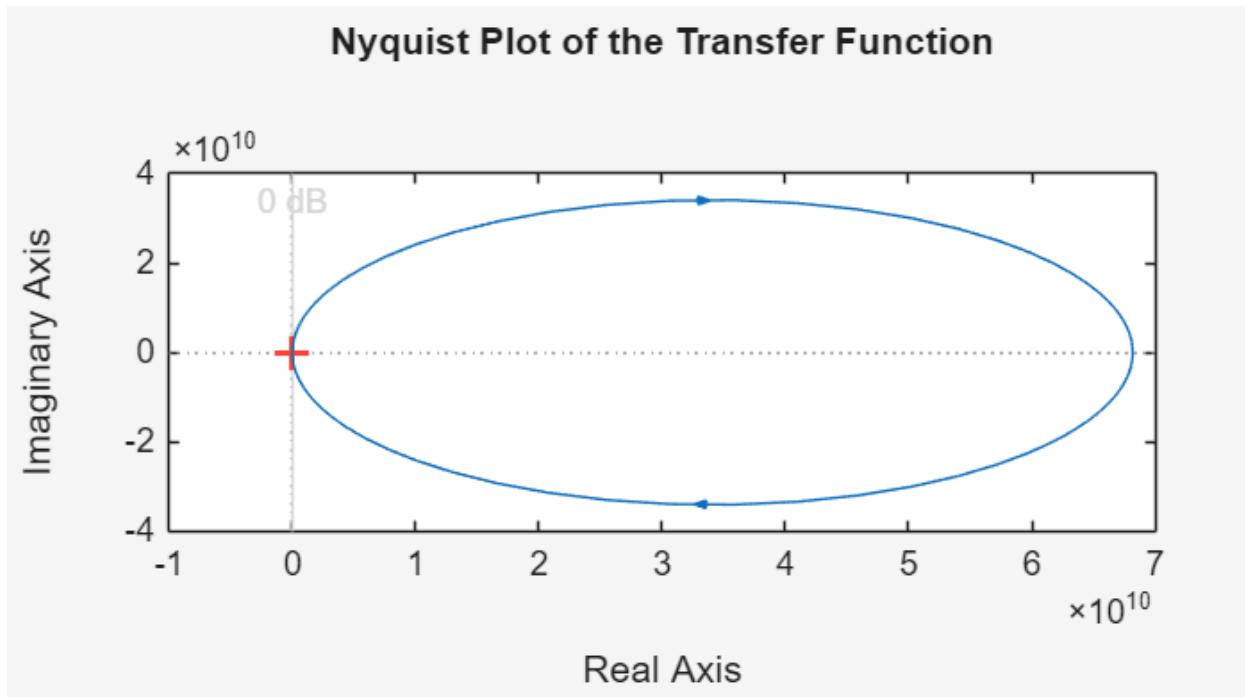


Fig. 22: Nyquist Plot of the Transfer Function

Observation-Based Calculations:

$$\text{Phase}_{0\text{dB}} = 360 + (83.585) = 443.585^\circ$$

$$\text{Phase Margin} = 180^\circ - \text{Phase}_{0\text{dB}} = 180 - 443.585 = -263.585^\circ$$

Zeros (roots):

- $Z_1 = -6.66375 \times 10^8$ (LHP)
- $Z_2 = +2.28172 \times 10^{10}$ (RHP)
- $Z_3 = +9.71445 \times 10^{11}$ (RHP)

Poles (roots):

- $P_1 = -1.84287 \times 10^5$
- $P_2 = -6.67760 \times 10^8$
- $P_3 = -1.77828 \times 10^9$

Transfer function

- $H(s) = K * \frac{(s-z_1) * (s-z_2) * (s-z_3)}{(s-p_1) * (s-p_2) * (s-p_3)}$
- $H(s) = 1000.8 * \frac{(s+6.66375 \times 10^8) * (s-2.28172 \times 10^{10}) * (s-9.71445 \times 10^{11})}{(s+1.84287 \times 10^5) * (s+6.67760 \times 10^8) * (s+1.77828 \times 10^9)}$

Results:

- Designed and simulated the Differential Telescopic Amplifier in UMC 180nm CMOS using Potential Distribution Method.
- The peak-to-peak value of the input is 2uV.
- The peak-to-peak value of the output is observed to be 1.9736mV.
- Maximum gain, $A_v \approx 60$ dB
- Phase Margin $\approx -263.5^0$
- $f_{0dB} = 187.73$ MHz
- $f_{3dB} = 184.12$ MHz
- DC gain (K) = 1000.8

$$H(s) = 1000.8 * \frac{(s+6.66260 \times 10^8) * (s-2.28180 \times 10^{10}) * (s-9.83932 \times 10^{11})}{(s+1.84530 \times 10^5) * (s+6.67669 \times 10^8) * (s+1.77841 \times 10^9)}$$

Inference:

- The designed differential telescopic amplifier achieves a high DC gain of about **60 dB** (≈ 1000), consistent with both the simulated output/input ratio and extracted gain value.
- The amplifier shows a **-3 dB bandwidth of ~184 MHz**, indicating suitability for high-speed analog applications.