AMPLIFIER:
SINGLE STAGE & DIFFERENTIAL

INDEX

AMPLIFIER: THEORY & SPECS

1. Common Source Amplifier with Resistive load:

A **common source (CS) amplifier** with a resistive load is a basic configuration in analog design used for voltage amplification. It consists of a Metal-Oxide-Semiconductor Field-Effect Transistor (MOSFET) operating in the saturation region, with a resistor connected to its drain terminal as the load. The gate of the MOSFET is the input terminal, and the amplified output voltage is obtained from the drain terminal.

Key Characteristics:

- **Voltage Gain**: The small-signal voltage gain of a CS amplifier is given by: $\mathbf{Av=-g_m*R_D}$ where, gm is the trans-conductance of the MOSFET, and R_D is the drain resistor.
- **Input Impedance**: High, as the gate is insulated.
- **Output Impedance**: Approximately equal to R_D, which may limit driving capabilities.
- **Applications**: Used in low-frequency amplification stages, active filters, and analog signal processing.

Design Considerations:

- The MOSFET must operate in the saturation region for proper amplification.
- The biasing network ensures a stable operating point.
- R_D should be selected to balance gain and output swing.

2. Common Source Amplifier with Diode Connected load:

A **common source (CS) amplifier with a diode-connected load** uses a MOSFET configured as a diode (gate and drain shorted) instead of a resistive load. This configuration is widely used in integrated circuits due to its compactness, better matching, and temperature stability compared to a resistive load.

Key Characteristics:

- **Voltage Gain**: The voltage gain is given by: $\mathbf{Av=-g_{m1}/g_{m2}}$

  where g_{m1} is the trans-conductance of the amplifying MOSFET, and g_{m2} is the trans-conductance of the MOSFET used as a diode-connected load.

  The trans-conductance ratio ensures that the gain is independent of variations in the absolute values of process parameters and temperature. This is because both g_{m1} and g_{m2} are similarly affected by temperature, resulting in a ratio that remains stable.

- **Temperature Stability**: Unlike a resistive load, whose resistance can vary significantly with temperature, a diode-connected load relies on MOSFET parameters that scale together with temperature. This makes the gain less sensitive to temperature fluctuations.
- **Input Impedance**: High, due to the gate's insulation.
- **Output Impedance**: Determined by the small-signal output resistance of the diode-connected MOSFET.

Advantages:

- **Temperature Independence**: The gain stability with respect to temperature variations is a critical advantage in applications requiring precision.
- **Compact Design**: Eliminates the need for large resistors, making it highly suitable for integrated circuits.
- **Linearity**: The diode-connected load offers improved linearity compared to resistive loads.

Applications:

- Used in CMOS analog integrated circuits where precise and temperature-independent gain is essential, such as in amplifiers, active filters, and signal conditioning circuits.

Design Considerations:

- Ensure that both the amplifying transistor and the diode-connected transistor operate in the saturation region for proper gain.
- Transistor matching is critical for achieving the desired gain and minimizing offsets.

3. Differential Amplifier (5-Transistor):

A **differential amplifier** is a fundamental building block in analog design. The configuration with 5 transistors typically consists of:

1. Two input transistors forming the differential pair.
2. A current mirror for biasing the differential pair.
3. A tail current source for biasing.

Operation:

- The differential amplifier amplifies the difference between two input signals while rejecting common-mode signals.
- The output is taken either as a single-ended signal or as a differential signal.

Key Characteristics:

- **Differential Gain**: The voltage gain is given by: $\mathbf{Av_{diff} = g_m * R_{out}}$ where g_m is the trans-conductance of the input transistors, and R_{out} is the effective output resistance.
- **Common-Mode Rejection Ratio (CMRR)**: A measure of the ability to suppress common-mode signals.

- **Input Impedance**: High, due to the MOSFET gates.
- **Output Impedance**: Determined by the load and output stage configuration.

Applications:

- Widely used in operational amplifiers, comparators, and as input stages in various analog circuits.

Advantages:

- High gain and excellent noise rejection.
- Symmetry improves common-mode rejection.

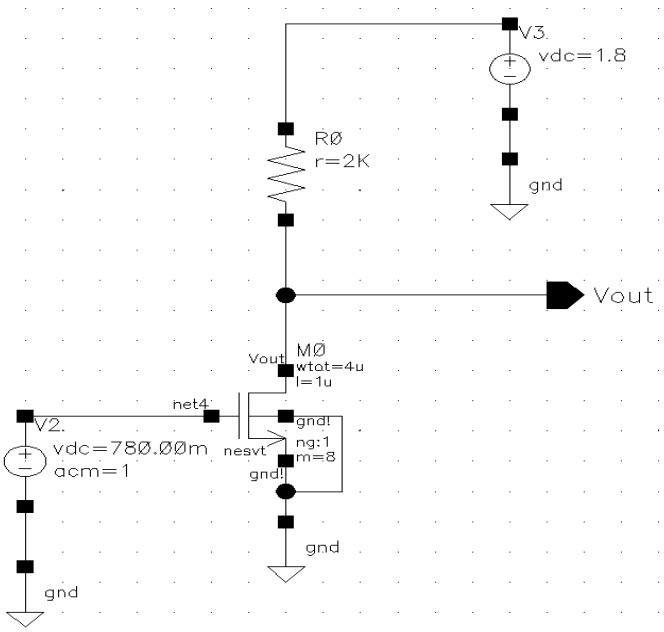
Design Considerations:

1. **Matching of Transistors**: For accurate differential operation, the input transistors should be well-matched in terms of threshold voltage and trans-conductance.
2. **Biasing Stability**: The tail current source ensures a constant current supply, improving linearity.
3. **Load Selection**: The load can be resistive, diode-connected, or an active load for enhanced performance.

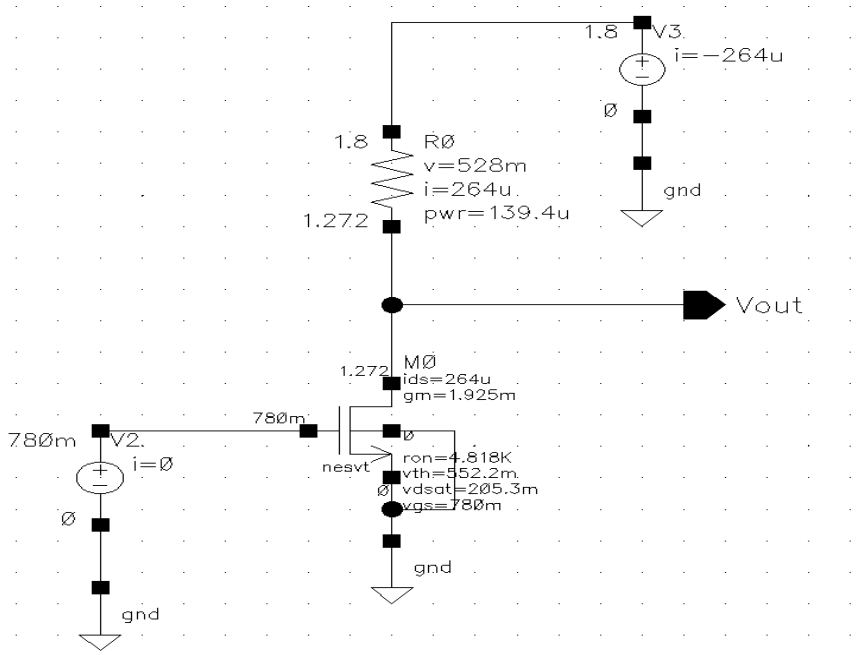
SIMULATION, SETUP & RESULTS

1. Common Source Amplifier with Resistive load:

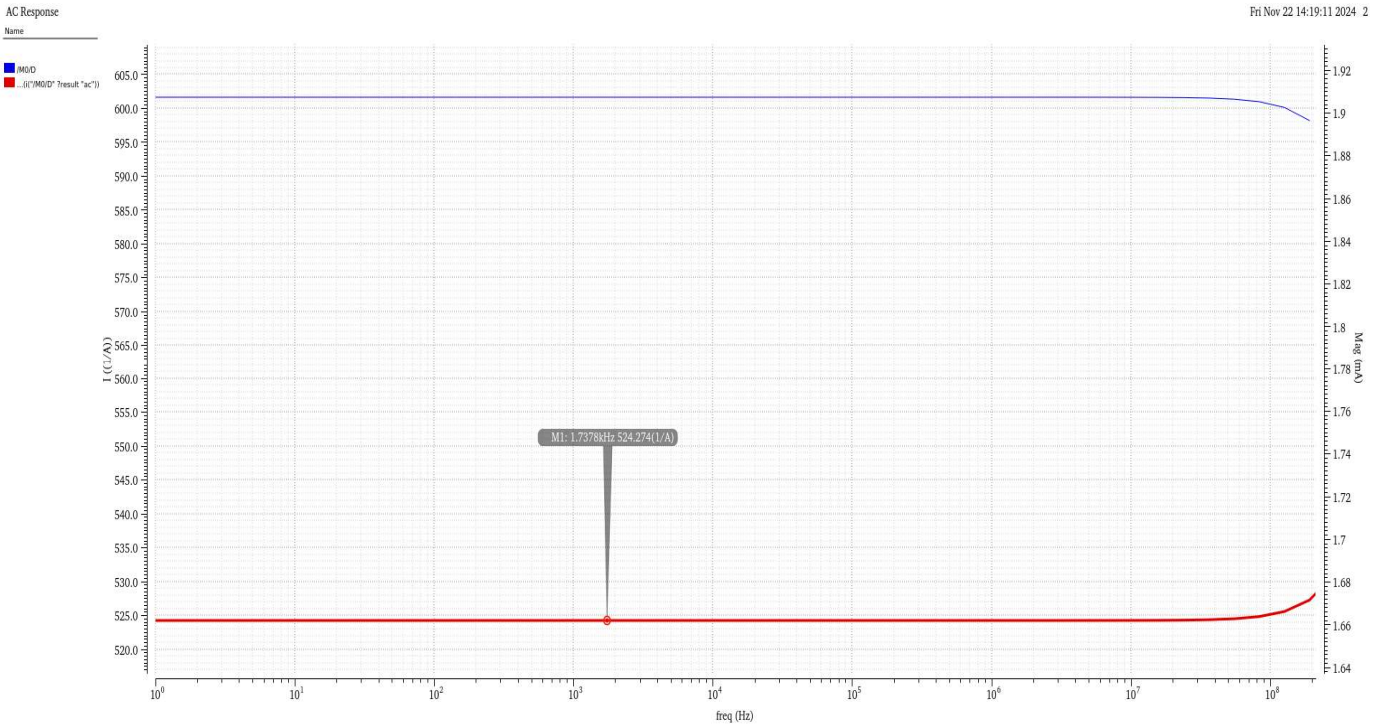
Schematic:



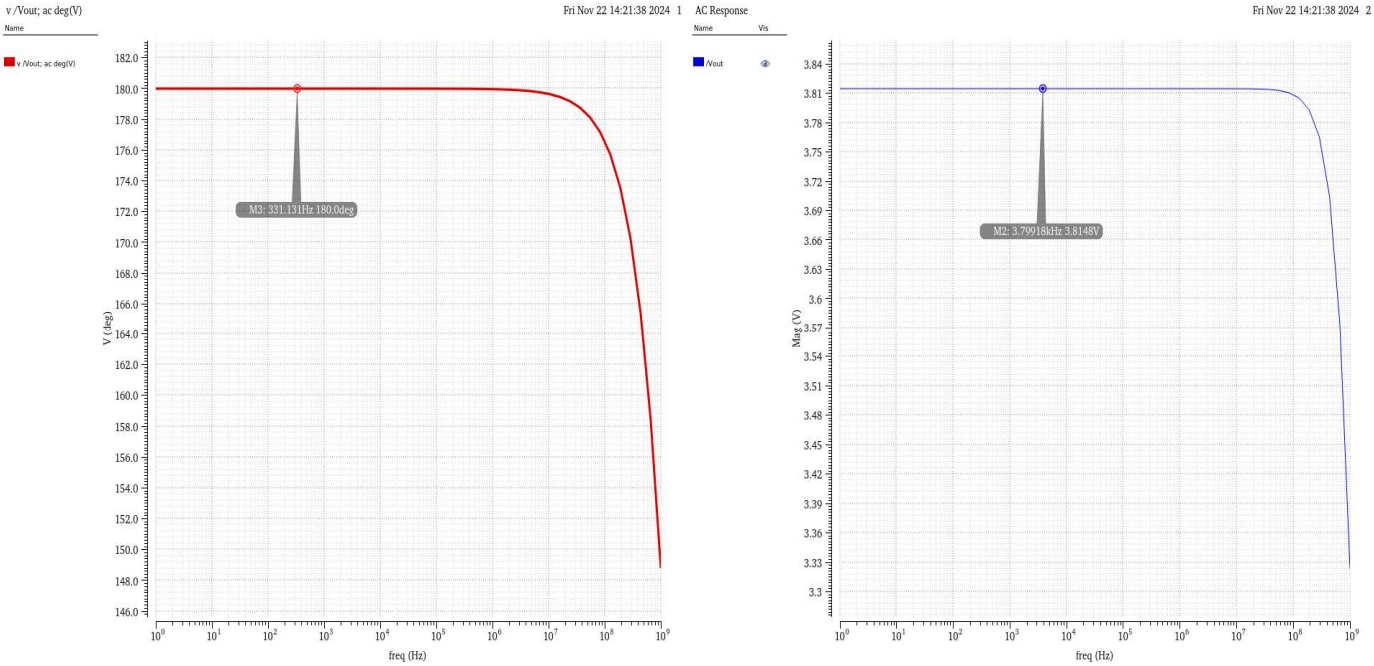
Schematic with DC operating point:



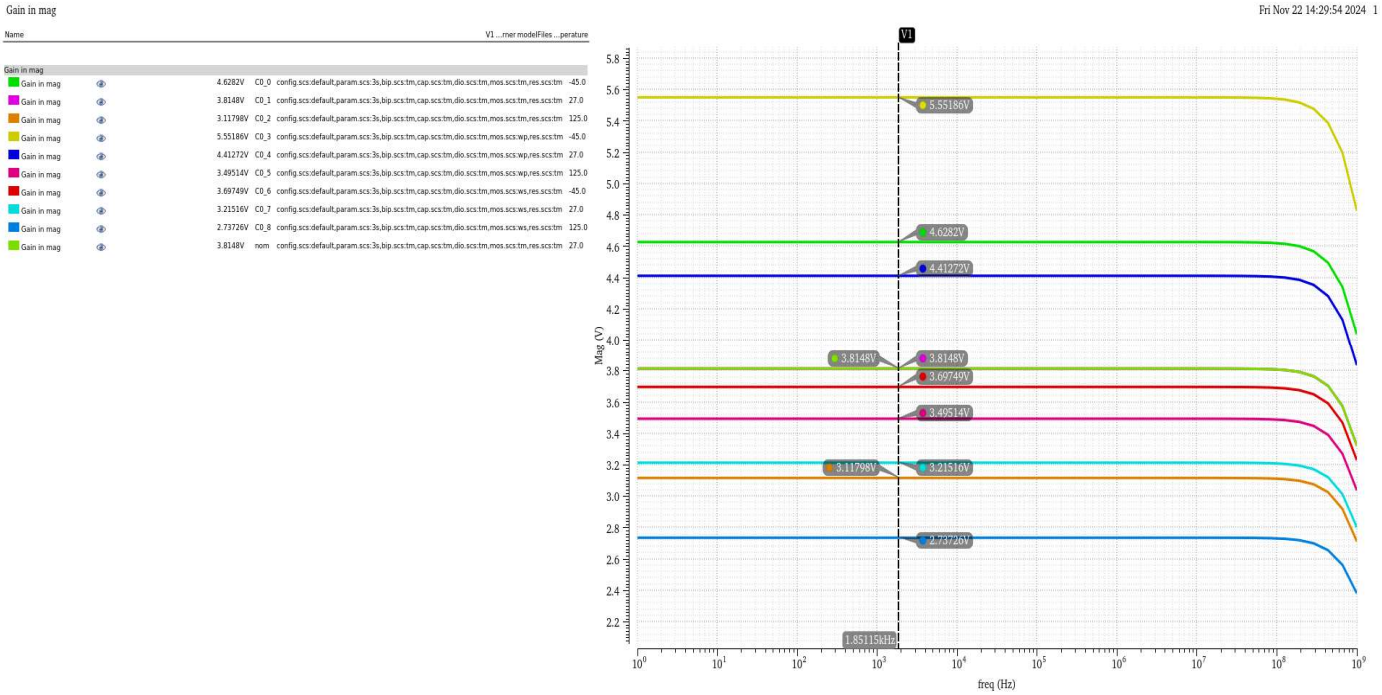
Simulation (Calculating Rout): $R_{out} = (\mathbf{R_o} \parallel \mathbf{r_o}) \sim \mathbf{R_o}$, where R_o is the drain resistance and r_o is the output resistance of MOSFET.



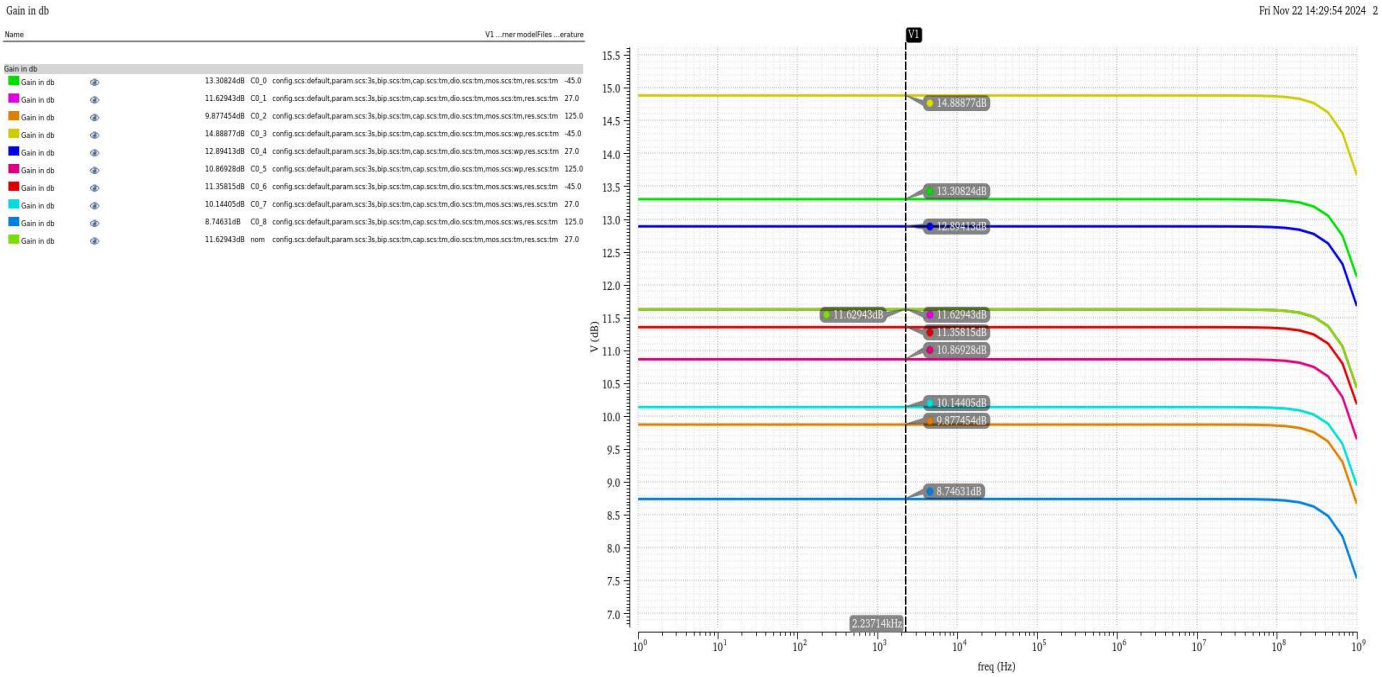
Voltage Gain & Phase: $A_v = g_m * R_D$ and $Ø = 180º$



PVT Corner analysis (Gain):



PVT Corner analysis (Gain in dB):



Observations:

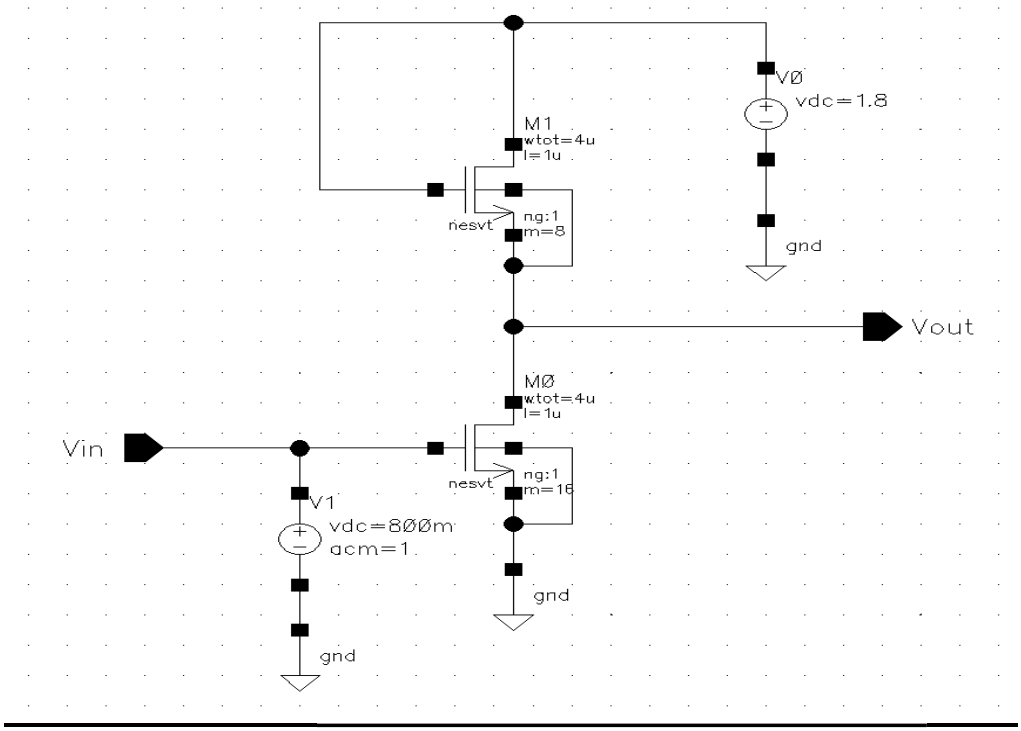
R_{out}	0.52 kΩ
Gain	3.81
Phase (Ø)	180º

During **Process, Voltage, and Temperature (PVT) corner analysis** of a common source amplifier with a resistive load, the amplifier's gain was observed to vary significantly across different conditions.

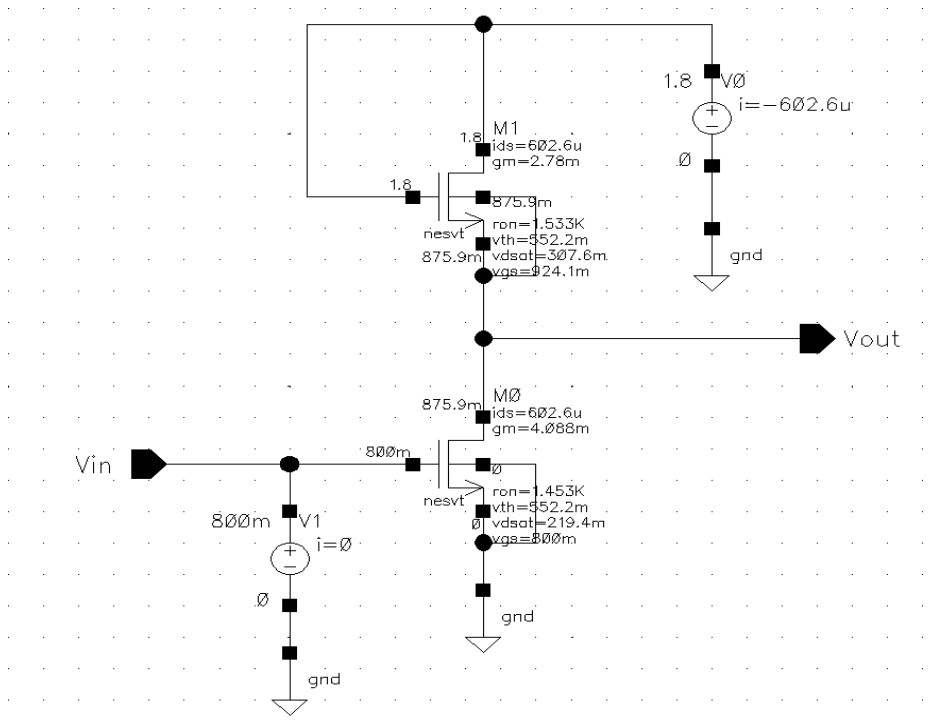
- **Highest Gain (14.8 dB)**: Occurs in the **Worst Power (wp)** condition at **-45°C**. This is due to the increased mobility of charge carriers and reduced thermal noise at lower temperatures, resulting in higher trans-conductance (g_m) of the MOSFET. The higher gm, coupled with the unchanged load resistance (R_D), maximizes the gain ($A_v = -g_m * R_D$).
- **Lowest Gain (8.8 dB)**: Occurs in the **Worst Speed (ws)** condition at **125°C**. At high temperatures, mobility decreases due to increased lattice scattering, reducing g_m. The reduction in trans-conductance, combined with potential variations in R_D due to temperature, results in a significant drop in gain.

2. Common Source Amplifier with Diode Connected load:

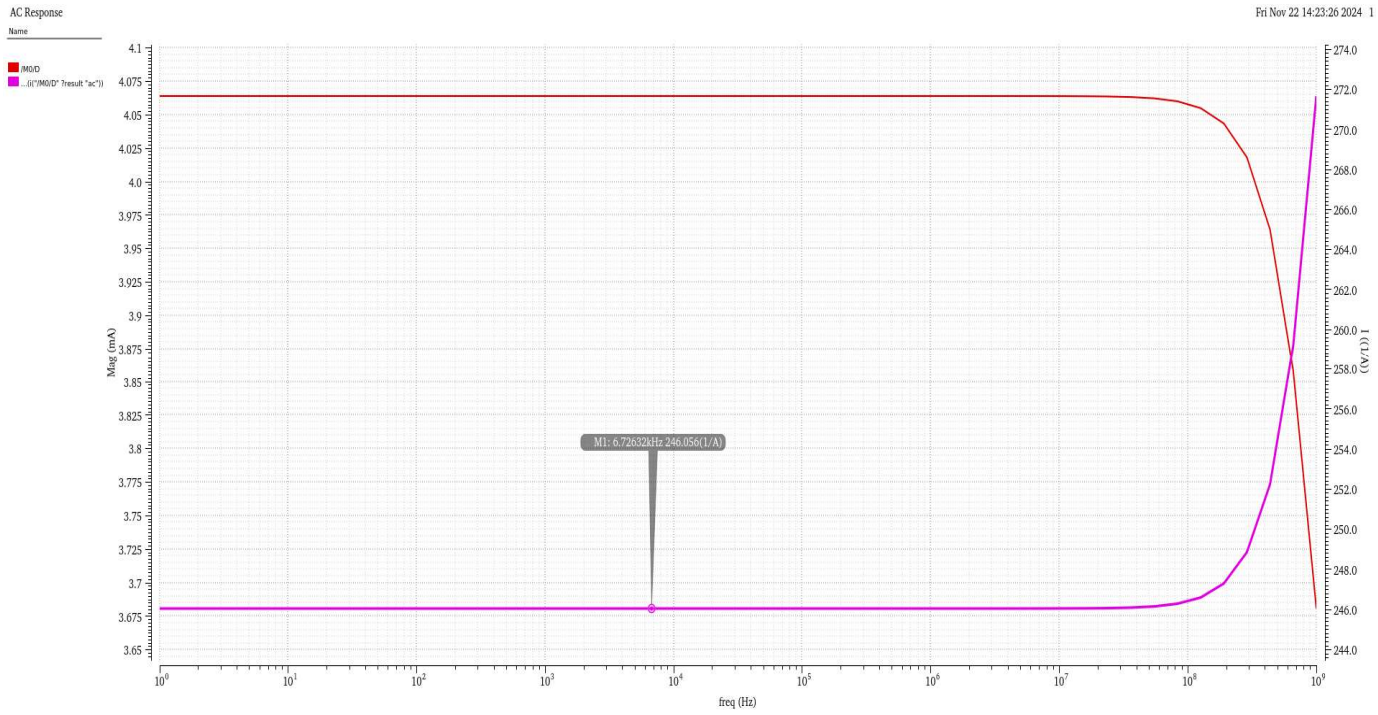
Schematic:



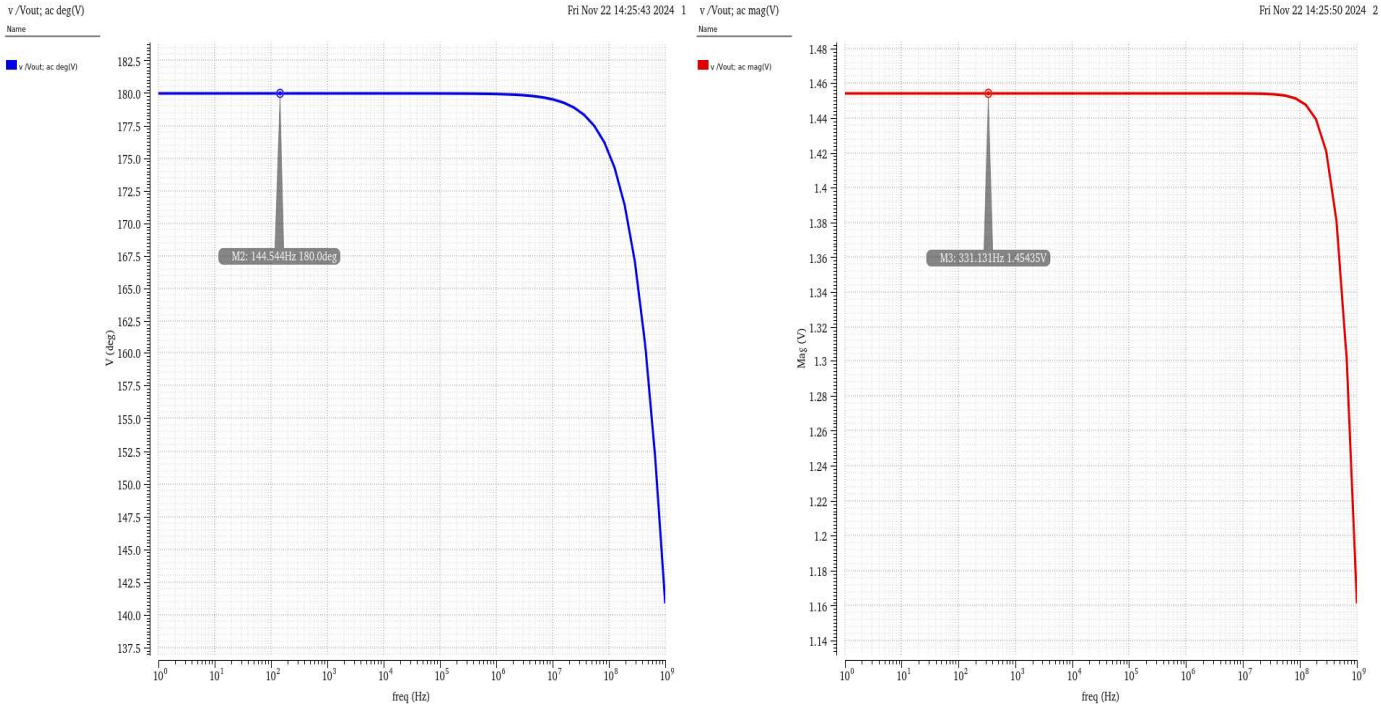
Schematic with DC Operating point:



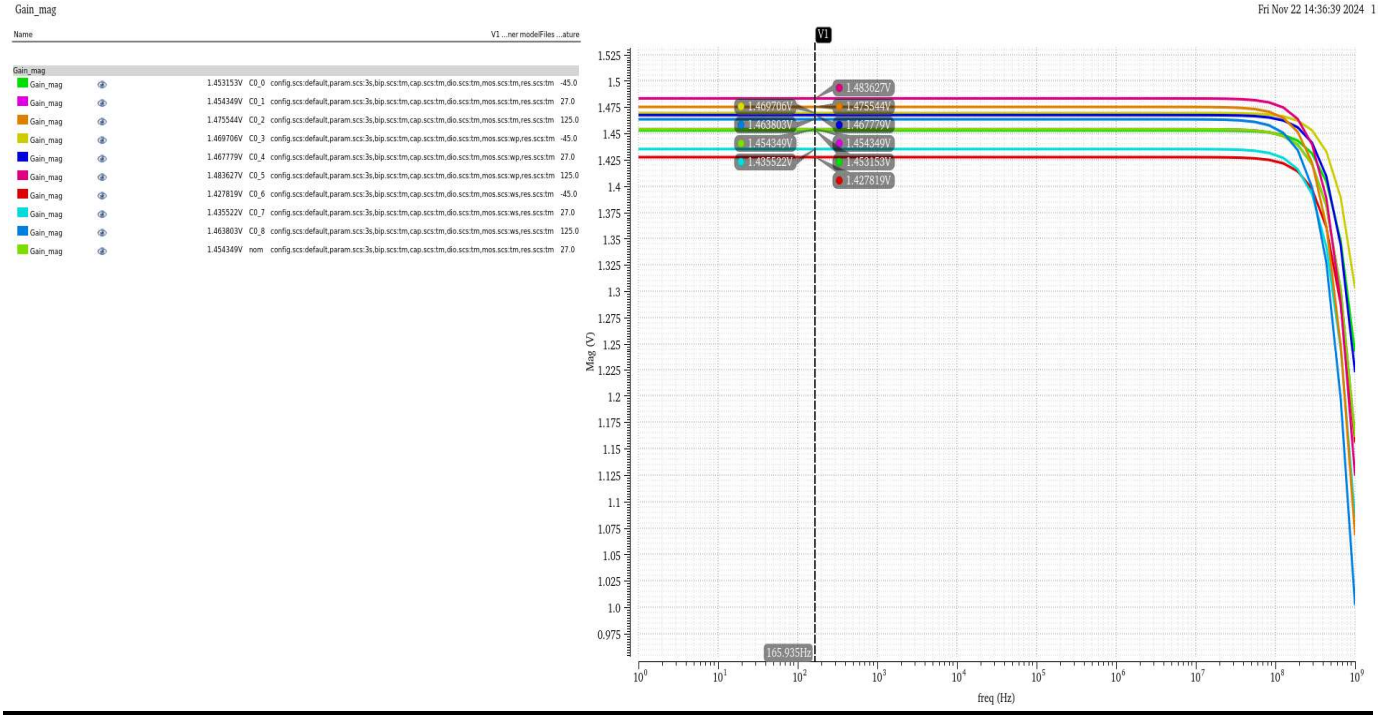
Simulation (Calculating Rout): Rout = $(r_o \parallel 1/g_{m1}) \sim 1/g_{m1}$ where, gm1 is the trans-conductance of transistor M1



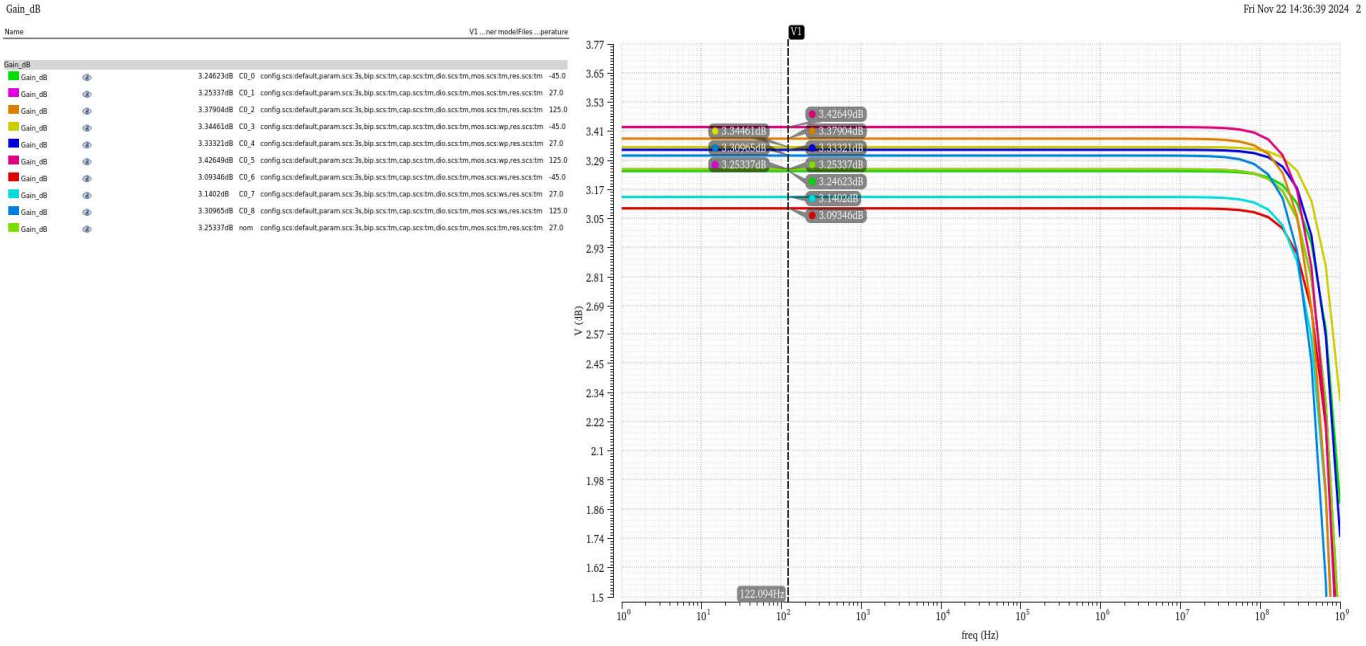
Voltage Gain & Phase: $A_v = g_{mo}/g_{m1}$ and Ø = 180º



PVT Corner Analysis (Gain):



PVT Corner Analysis (Gain in dB):



Observations:

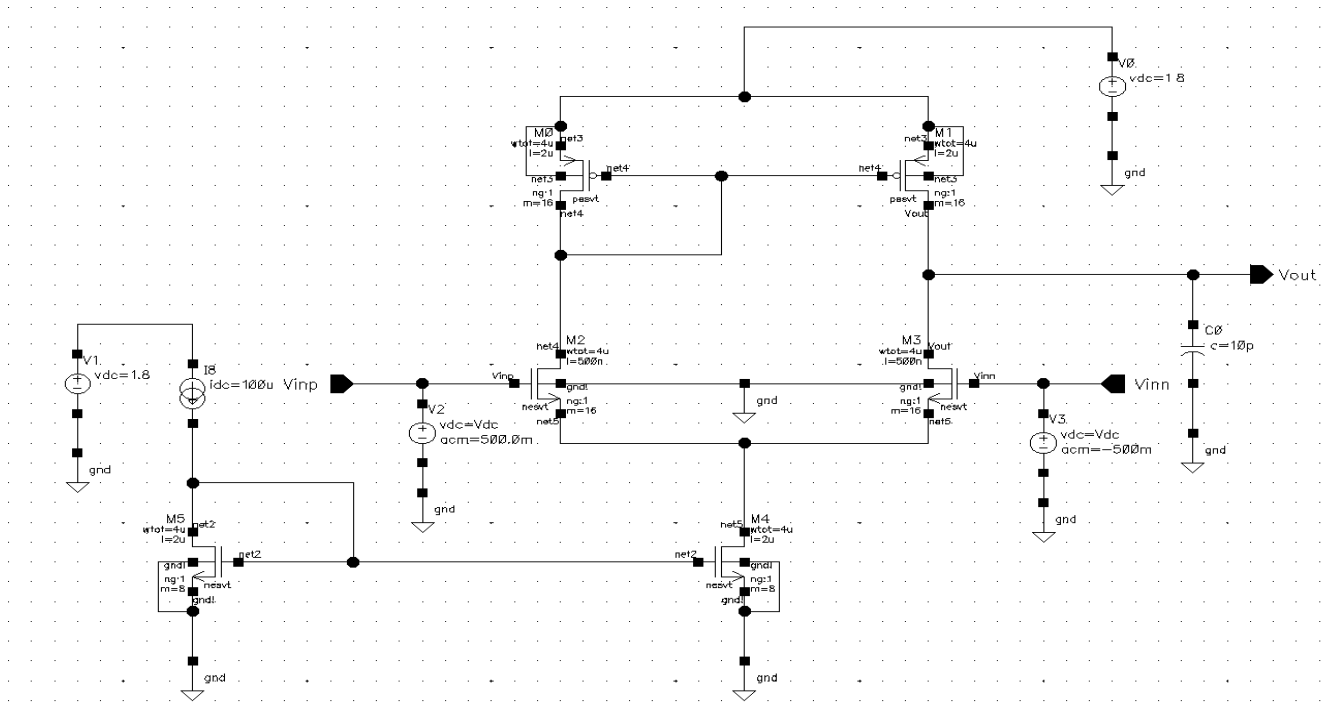
R_{out}	0.25 kΩ
Gain	1.45
Phase (Ø)	180º

- During the PVT corner analysis of the common source amplifier with a diode-connected load, the gain trends mirrored those observed with the resistive load**: highest gain (3.43 dB)** in **Worst Power (WP) at -45°C** and **lowest gain (3.1 dB)** in **Worst Speed (WS) at 125°C**.

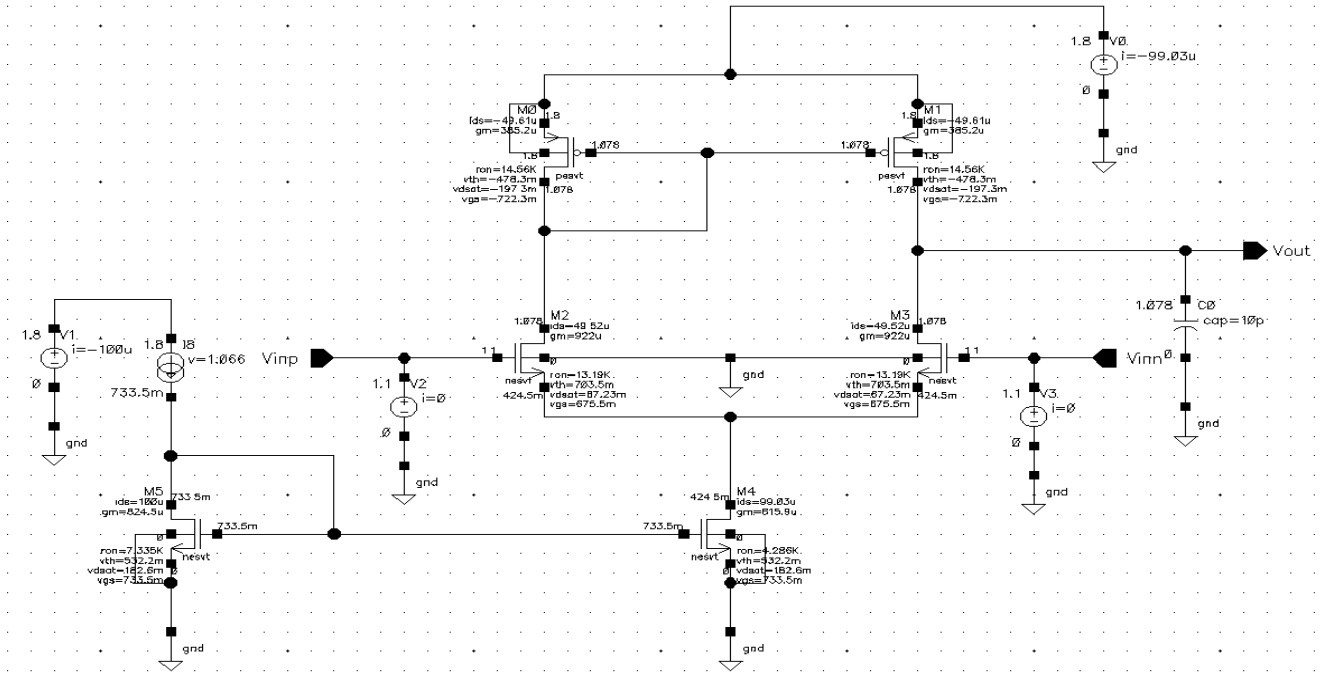
- However, the variation in gain with temperature and process was significantly smaller, due to the inherent stability provided by the diode-connected load's dependence on matched MOSFET parameters, ensuring more consistent performance across corners.

3. Differential Amplifier (5-Transistor):

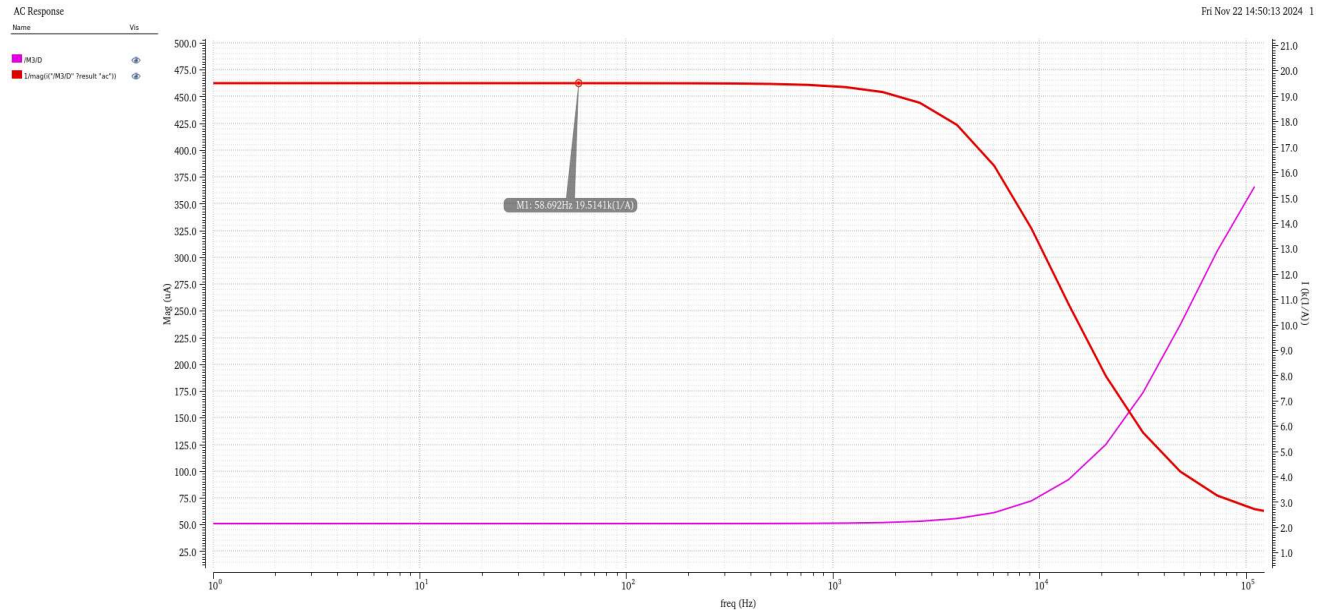
Schematic:



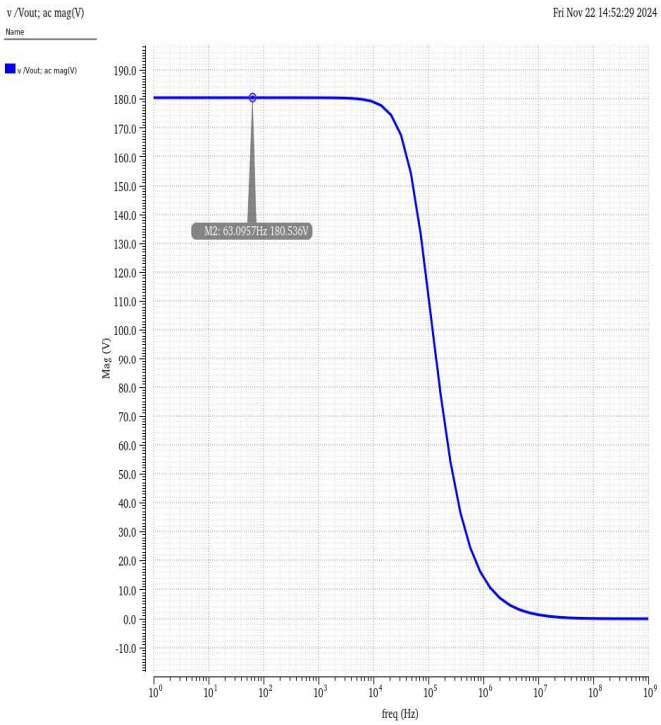
Schematic with DC Operating point:

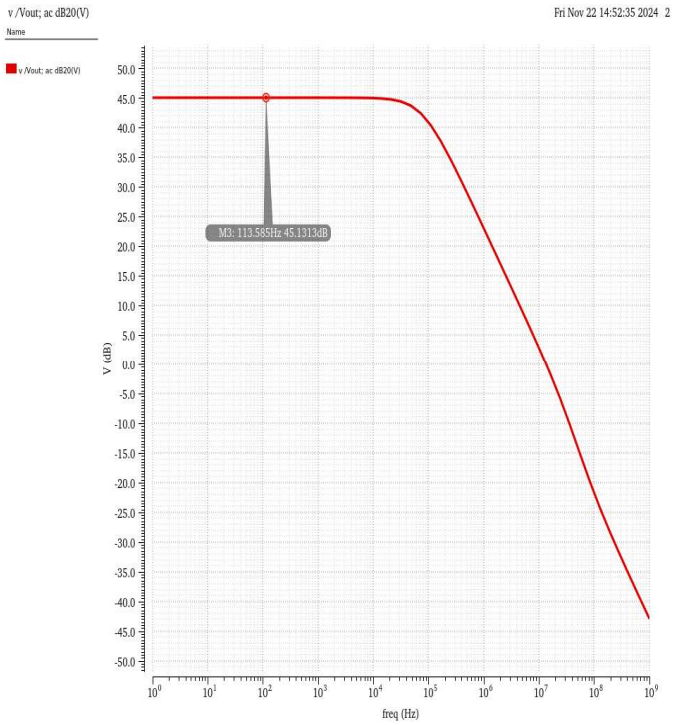


Simulation (Calculating Rout): Rout = $r_{o1} \parallel r_{o3}$ where r_{o1} and r_{o3} are the drain to source resistances of transistors M1 and M3.

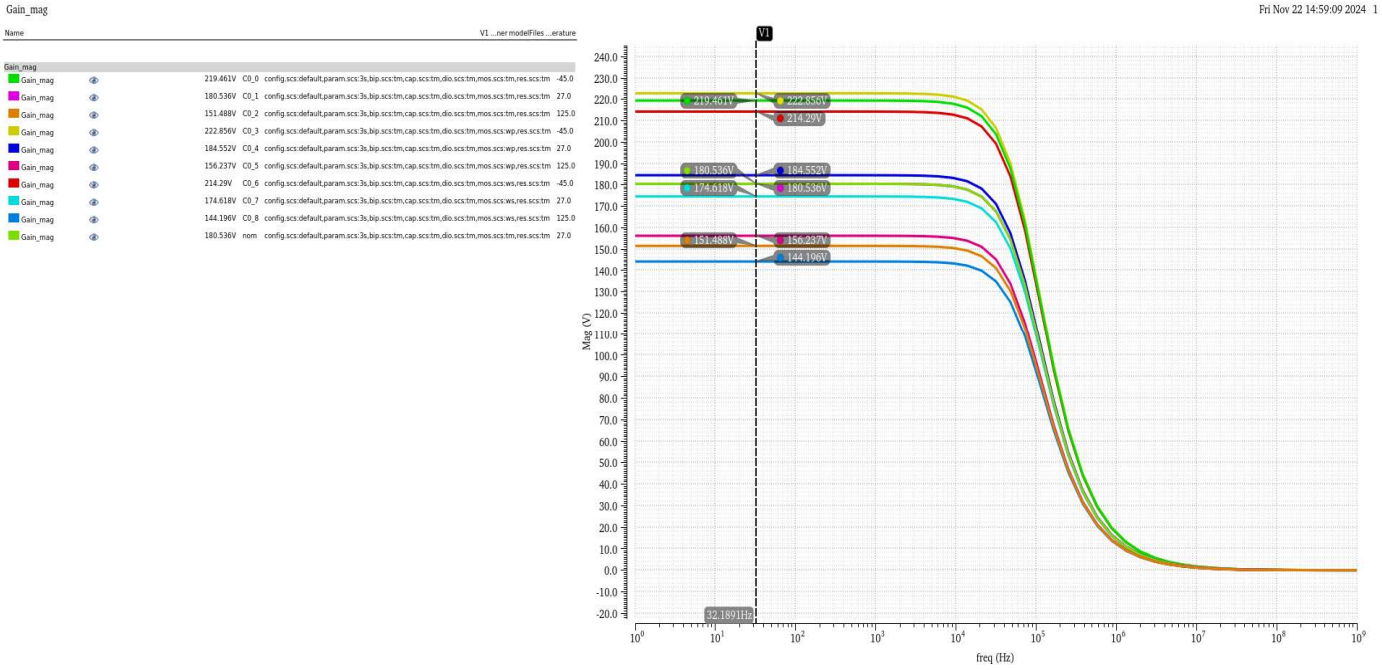


Voltage gain (In V/V and dB): $A_v = g_{m2}*(ro_1 \parallel ro_3)$; $Av_{(dB)} = 20*\log(A_v)$

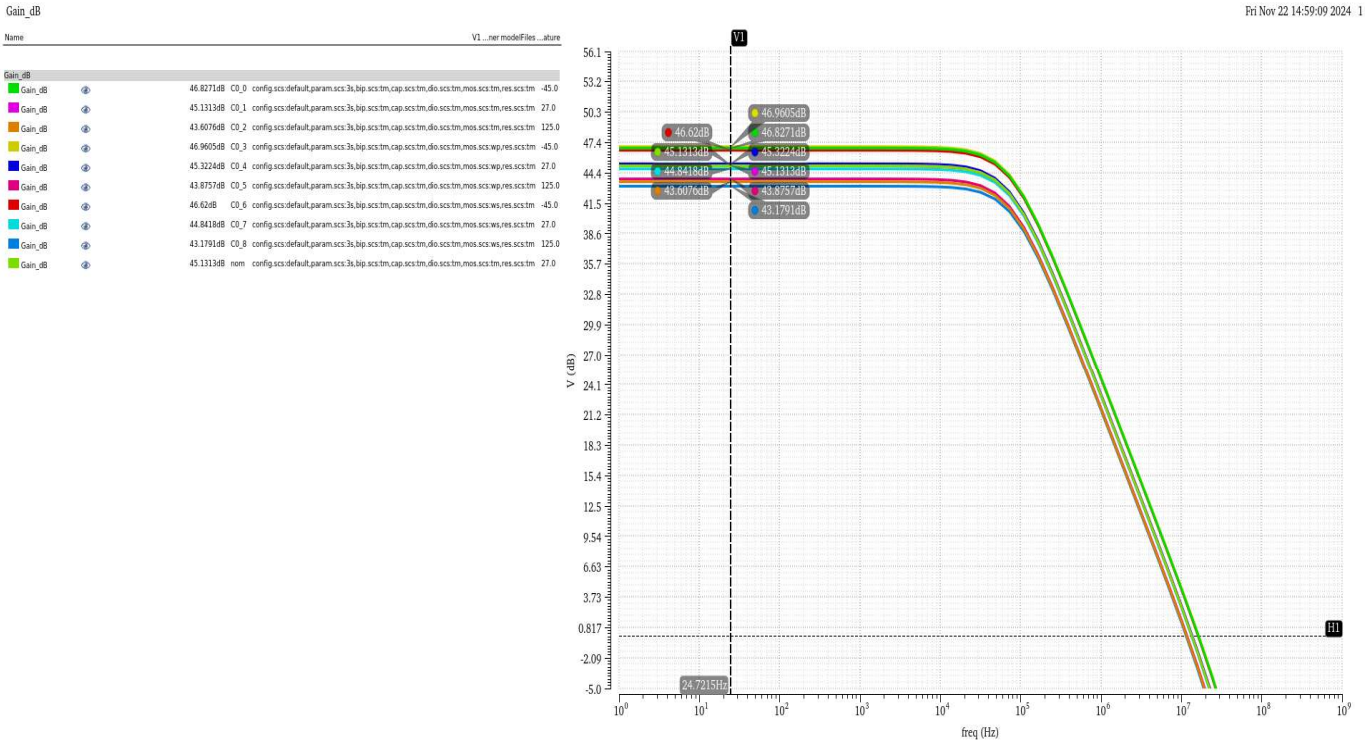




PVT Corner Analysis (Gain in mag):



PVT Corner Analysis (Gain in dB):



Observations:

R_{out}	19.5 kΩ
Gain	180 V/V
Gain in dB	45 dB

The gain of the differential amplifier was observed to be **highest (47 dB)** in the **Worst Power (WP)** condition at **-45°C**, and **lowest (43.2 dB)** in the **Worst Speed (WS)** condition at **125°C**. This variation reflects the dependence of gain on temperature and process, with better performance at lower temperatures and slower process corners.