EE537 Circuit Simulation Lab
Experiment 6

Name: <PRIKSHAT SHARMA>
ID Number: <2023EEM1023> September 27, 2024

Aim: Design and characterization of differential amplifier.

1 DIFFERENTIAL AMPLIFIER

A differential amplifier with NMOS input transistors and resistive load is shown in Fig. 1. IREF = 10 μ A, Vincm = 900 mV, (W/L)M1 = (W/L)M2 = 20 $\mu/1\mu$, (W/L)M3 = (W/L)M4 = 2 $\mu/1\mu$, RD = 100 KOhm. Derive the expressions for: 1) the small signal differential voltage gain(Av,dm), 2) the small signal common-mode voltage gain(Av,cmcm)

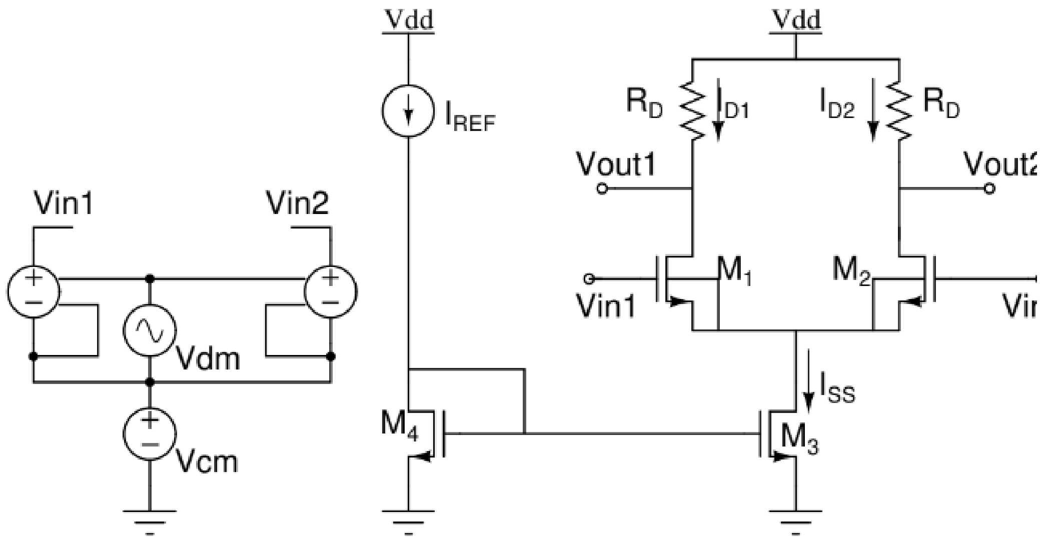

Figure 1: Differential amplifier with NMOS input transistors

Small signal differential gain(Av_{dm}),
Using Thevenin's equivalent method.
So, we have to find

$$\frac{Vx}{Vin1}$$

with Vin2 tends to 0(1)

$$\frac{Vy}{Vin1}$$

with Vin2 tends to 0(2)
Now we can say
$V_x - V_y = f(V_{in1})$
Similarly $V_x - V_y = f(v_{in2})$
to find the Av_{dm}

$$Avdm = \frac{Vx - Vy}{Vin1 - Vin2} \tag{3}$$

Considering matched transistors

$$\frac{Vx}{Vin1}$$

with Vin2 = 0(4)

$$\frac{V_x}{V_{in1}} = \frac{-RD1}{\frac{1}{g_m} + RS} = \frac{-RD1}{\frac{1}{gm1} + \frac{1}{gm2}} \tag{5}$$

$$\frac{Vin1}{\frac{1}{gm1} + \frac{1}{gm2}} = \frac{Vy}{RD1} \tag{6}$$

from 5 and 6

$$\frac{Vx - Vy}{Vin1} = \frac{-2RD1}{\frac{1}{gm1} + \frac{1}{gm2}} \tag{7}$$

Assuming gm1 = gm2 = gm and RD1 = RD2 = RD

$$\frac{Vx - Vy}{Vin1} = -gm * RD \tag{8}$$

Similarly;

$$V_x - V_y = gm * R_D * V_{in2}$$
$$V_x - V_y = -gm * R_D * V_{in1} + gm * R_D * V_{in2}$$
$$V_x - V_y = -gm * R_D(V_{in1} - V_{in2})$$

Using superposition

$$Avdm = \frac{V_x - V_y}{V_{in1} - V_{in2}} = -gm * R_D \tag{9}$$

Small signal common-mode voltage gain Av,cm,cm

Again assuming that the circuit is symmetric , and the current source has finite output impedance. let it be Rss Rd1= Rd2 = Rd and transistors are matched. the common mode gain is given by

$$Avcm = \frac{Vout}{Vin, cm} \tag{10}$$

$$Vgs = Vincm - Vs \tag{11}$$

$$Vs = 2gm(Vin, cm - Vs)Rss \tag{12}$$

$$Vs = \frac{2gmRss}{1 + 2gmRss} * Vincm \tag{13}$$

Kcl at Output terminal and using intution

$$\frac{Vout}{\frac{Rd}{2}} + 2gm(Vin, cm - Vs) = 0 \tag{14}$$

$$\frac{Vout}{\frac{Rd}{2}} = -2gm(Vin, cm - Vs) \tag{15}$$

$$\frac{Vout}{\frac{Rd}{2}} = -2gm(Vin, cm - \frac{2gmRssVin, cm}{1 + 2gmRss}) \tag{16}$$

or

$$\frac{Vout}{Vin, cm} = \frac{-gmRd}{1 + 2gmRss} \tag{17}$$

2 Plot Vout1, Vout2, Vp, ID1, ID2 vs common mode input voltage. Sweep the common mode input voltage from 0 to Vdd.

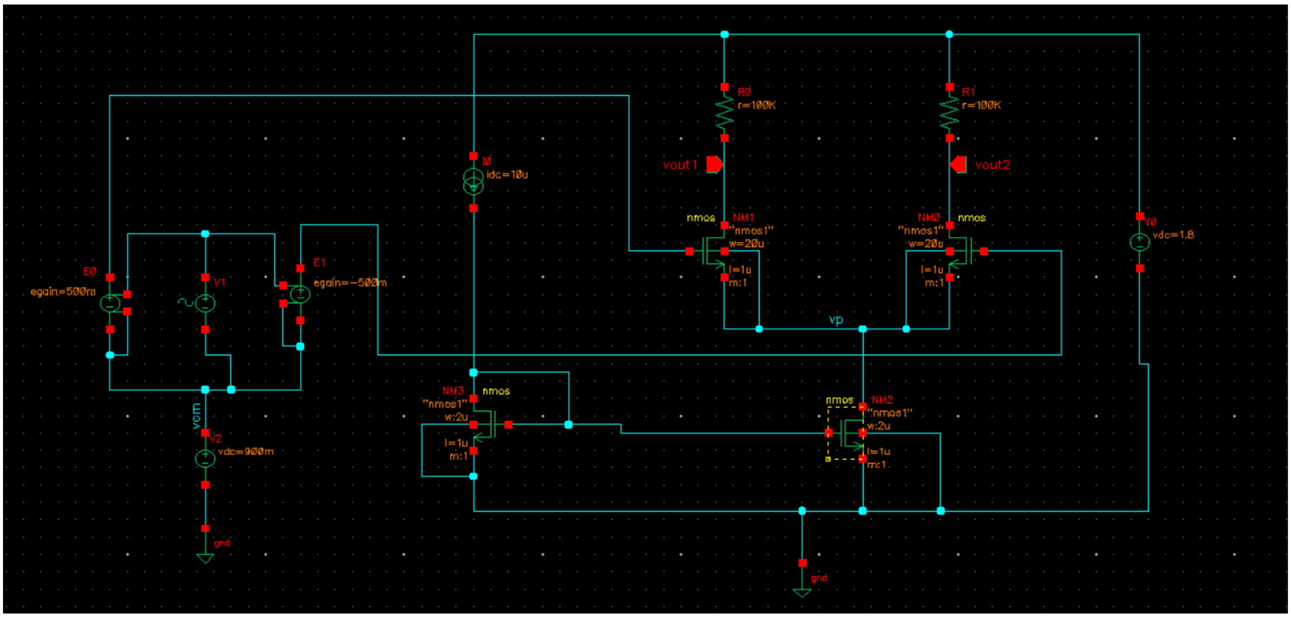

Figure 2: Ckt diagram for plotting the above variables

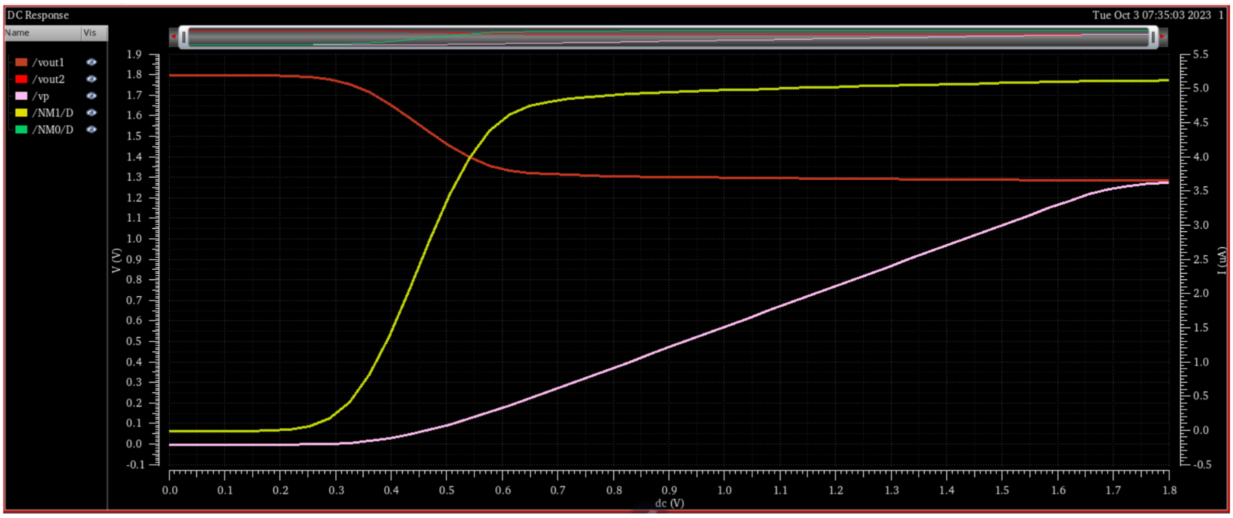

Figure 3: Vout1, Vout2, Vp, Iout1, Iout2 wrt Vcm

3 Plot Vout1, Vout1, Vout2 - Vout2, Vp, ID1, ID2 vs differential input voltage for a common mode input voltage of 0.9 V. Sweep the differential input voltage from -400mV to 400mV.

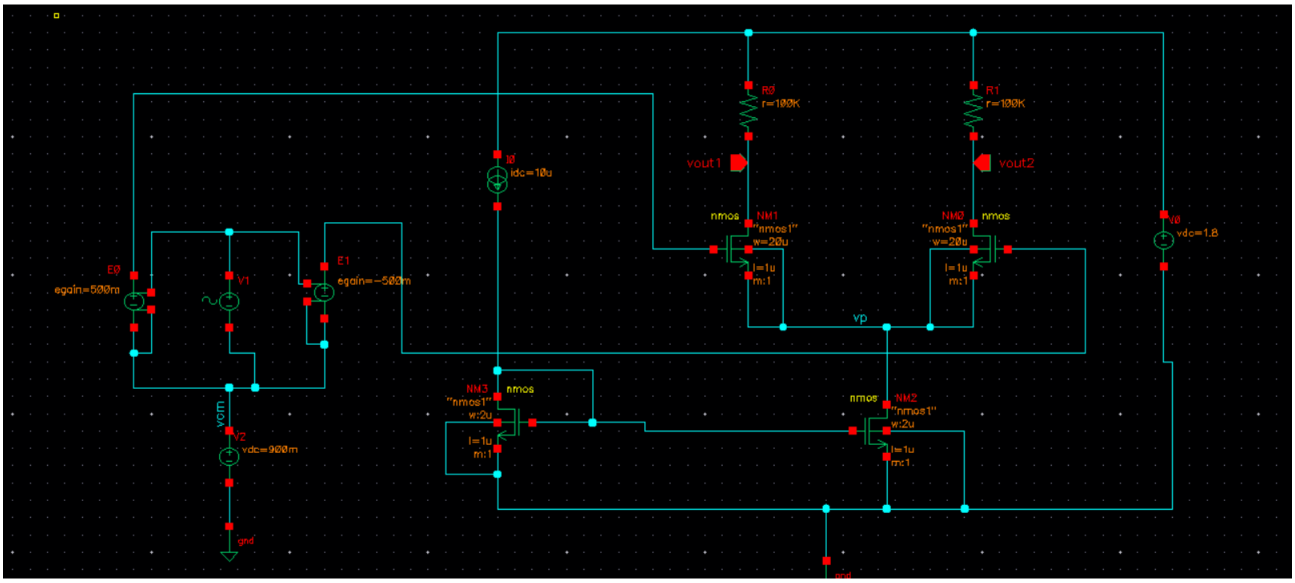

Figure 4: Ckt diagram for plotting the above variables

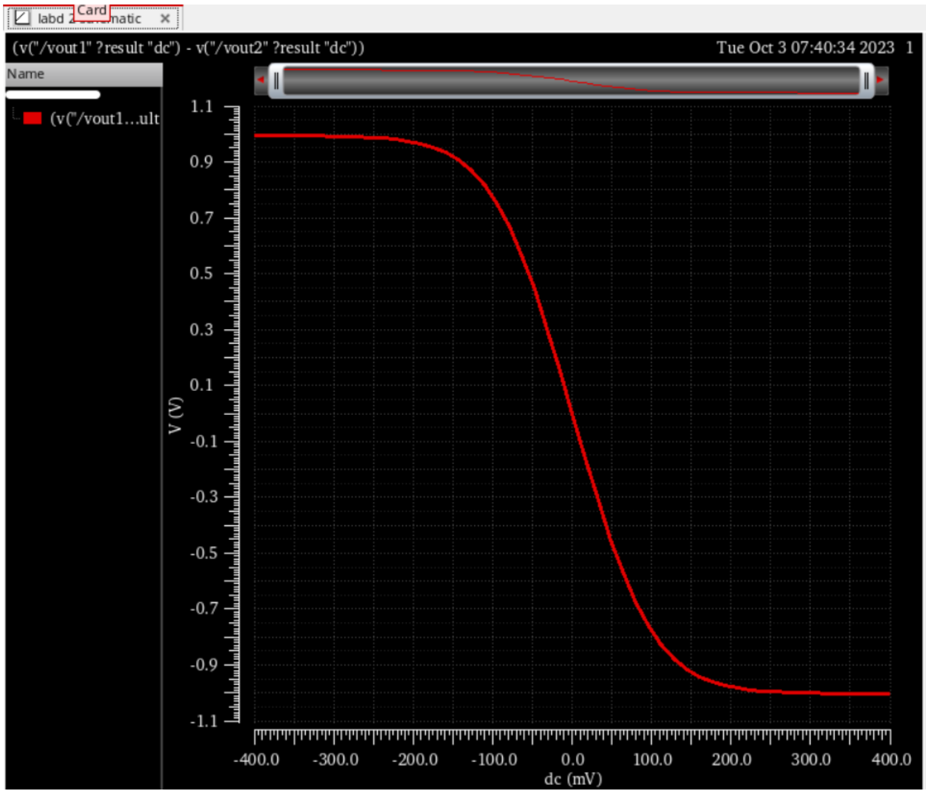

Figure 5: Vout2-Vout1 wrt Vdm

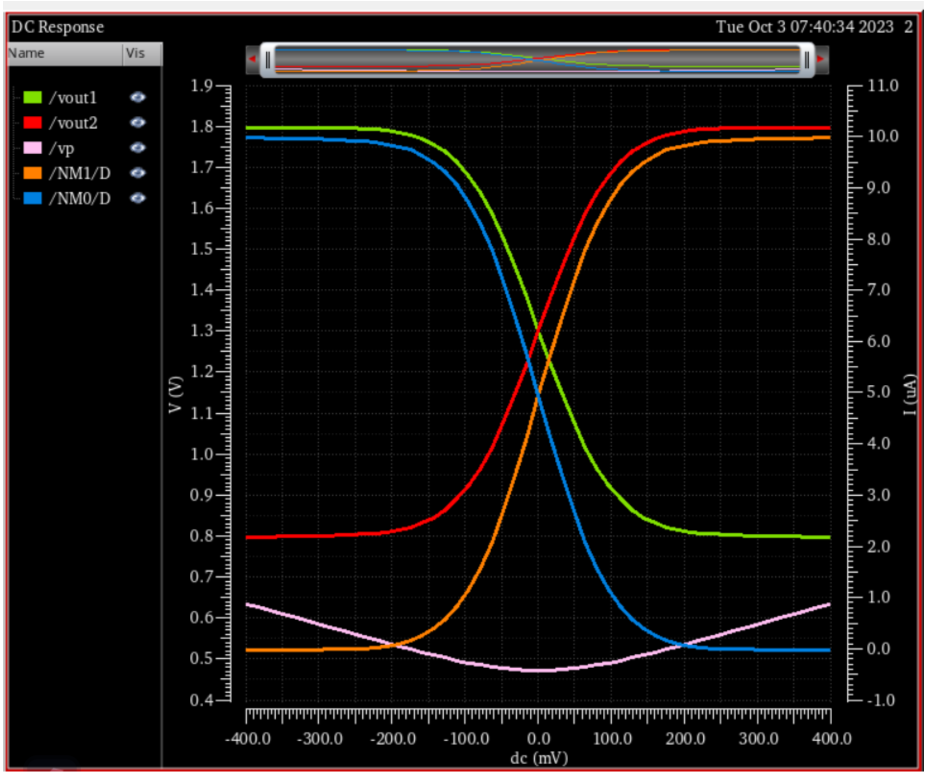

Figure 6: Vout1, Vout2, Vp, Iout1, Iout2 wrt Vdm

4 Plot differential mode gain(Av,dm) with common mode input voltage sweep from 0 to Vdd. What is the observed input common mode range(ICMR)?

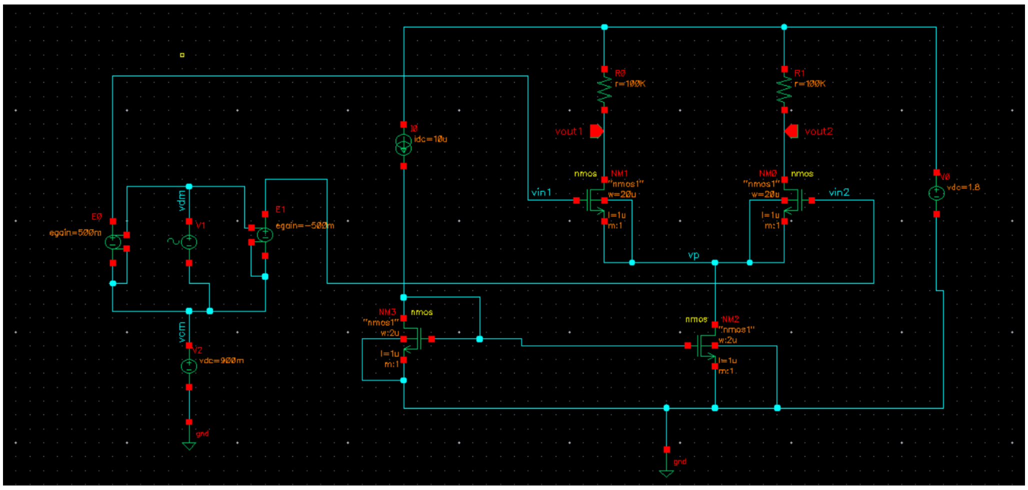

Figure 7: ckt diagram Differential mode gain wrt Vcm

The calculation for ICMR We know that

$$Vgs1 + (Vgs3 - Vth3) < Vin, cm < min([Vdd - \frac{RdId}{2} + Vth], Vdd \tag{18}$$

So ICMR is

$$580mV < Vin, cm < 1.8V \tag{19}$$

Hence the range is 1220mV. The observed value of ICMR is 1.536V-597.197mV = 939mV

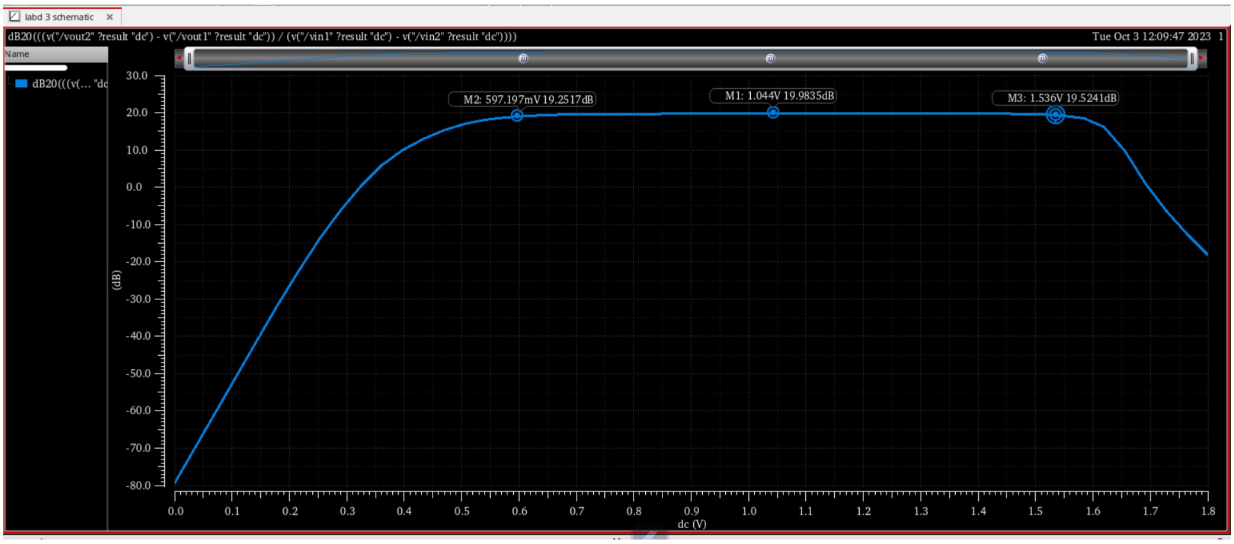

Figure 8: Differential mode gain wrt Vcm

5 Plot the differential mode gain(Av,dm), common mode to differential mode gain (Av,cmdm), common mode to common mode gain (Av,cmcm) vs. frequency. Verify the low frequency values from calculations and simulations.

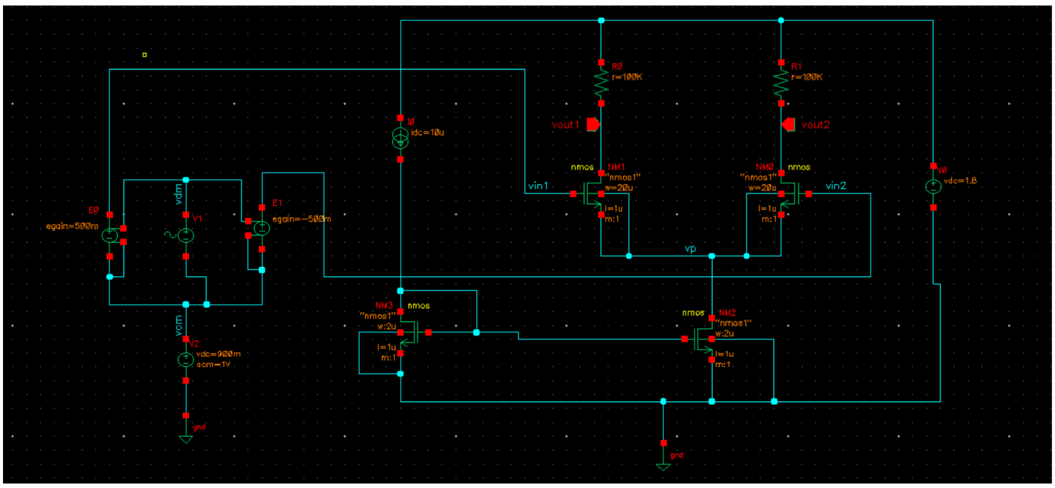

Figure 9: Ckt diagram Differential mode gain

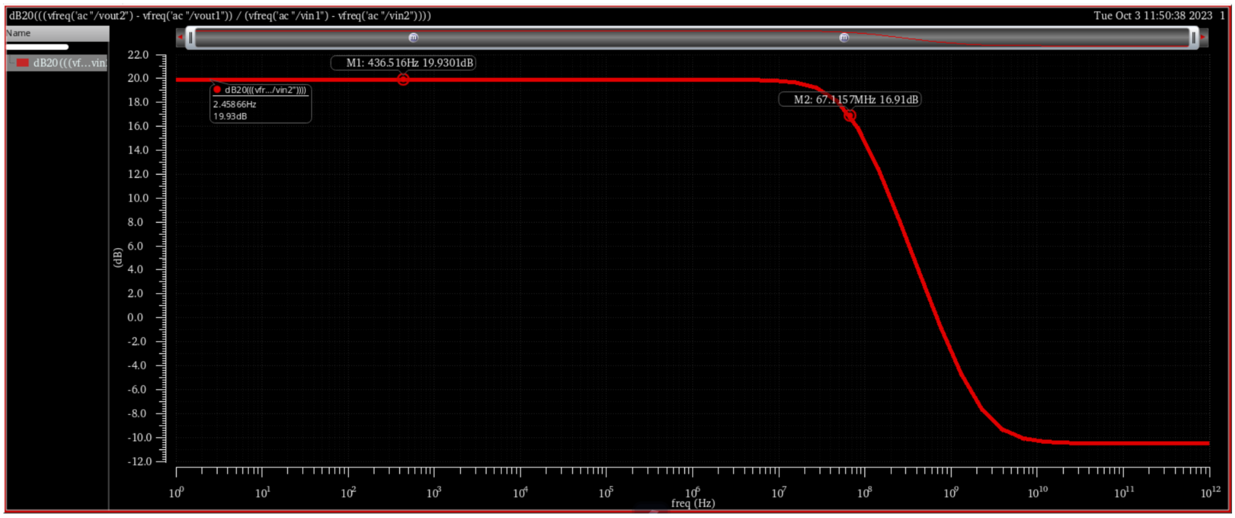

Figure 10: Differential mode gain wrt freq

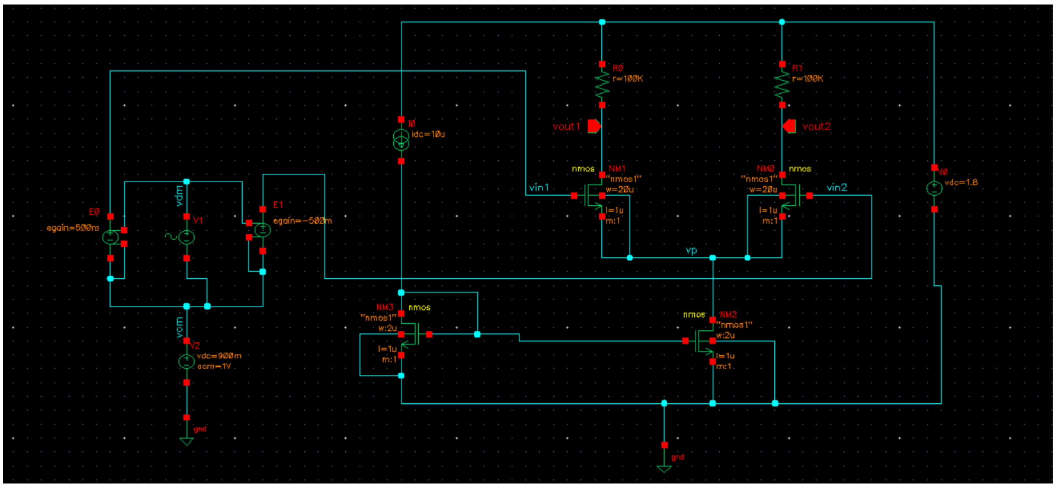

Figure 11: ckt diagram common mode to differential mode gain

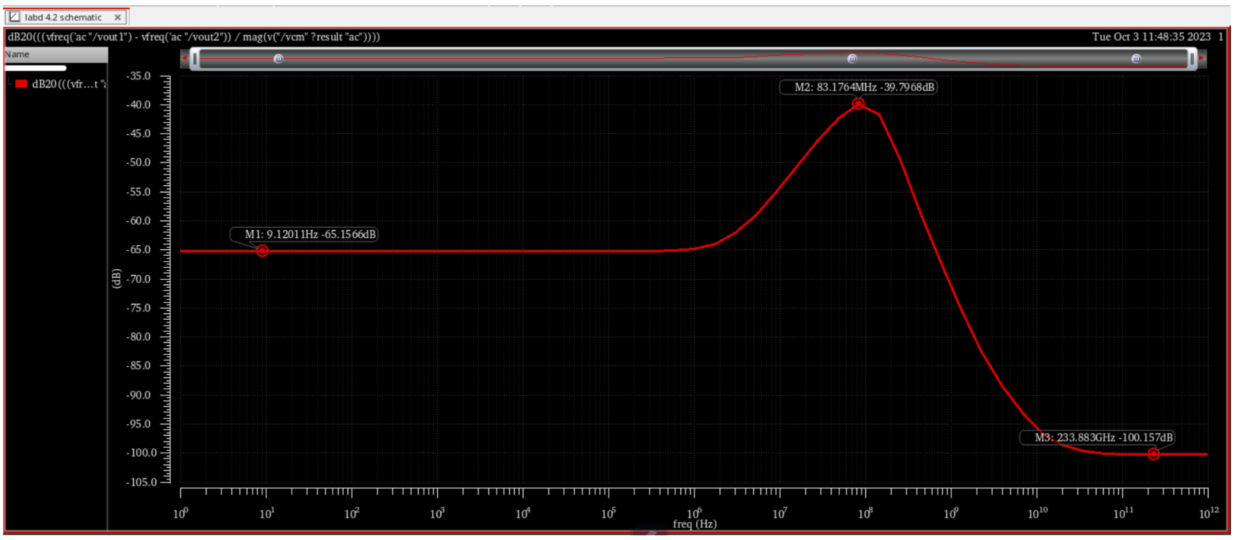

Figure 12: common mode to differential mode gain wrt freq

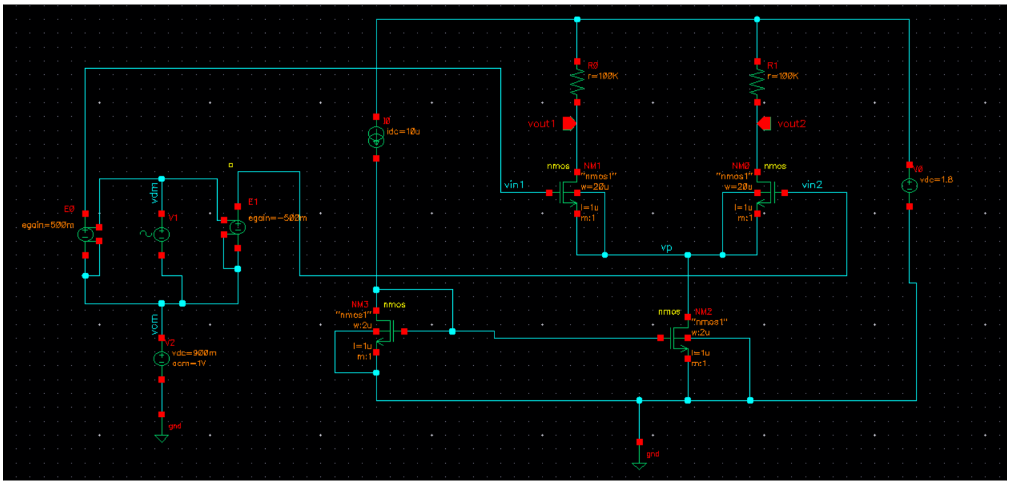

Figure 13: Ckt diagram for common mode to common mode gain

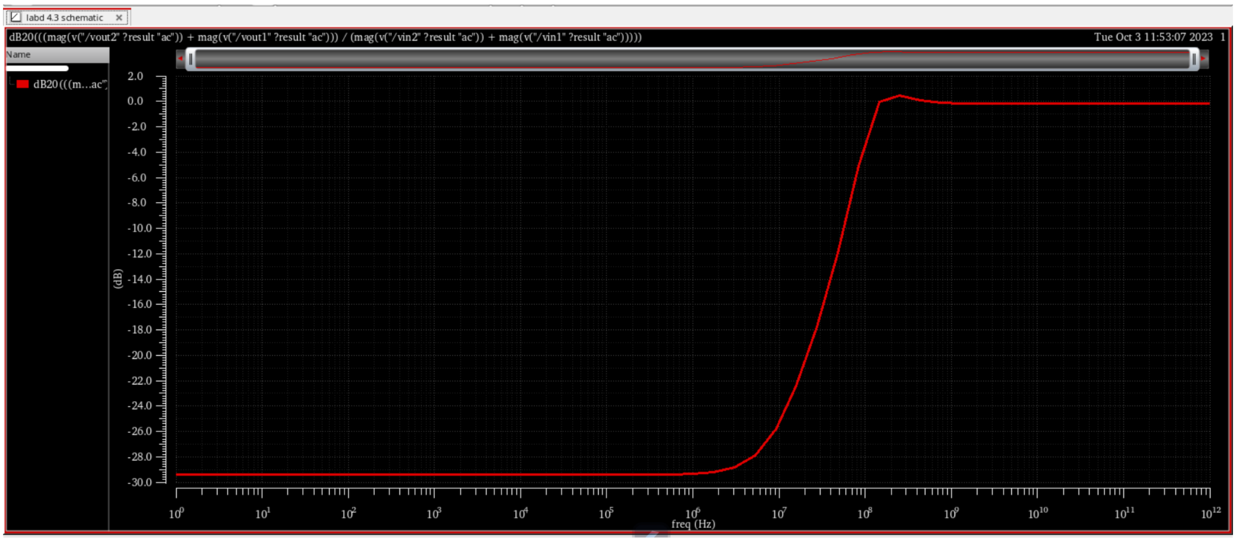

Figure 14: common mode to common mode gain wrt freq

Hand Calculations

$$Av, dm = -gmRd \tag{20}$$

$$Av = -104.09u * 100k \tag{21}$$

$$Av = -10.409 \tag{22}$$

In dB

$$|Av|dB = 20log(|-10.409|) = 20.34dB \tag{23}$$

For Av cm,dm

$$Avcm, dm = \frac{-dgmRd}{(gm1 + gm2)Rss + 1} \tag{24}$$

$$dgm = gm1 - gm2 = 104.09u - 102.21u = 2uA \tag{25}$$

$$gm1 + gm2 = 104.09 + 102.21 = 206.3uA \tag{26}$$

$$Rss = rout3 = 1.457Mohm \tag{27}$$

$$|Avcm, dm| = \frac{2u * 100k}{(206u * 1.457M) + 1} \tag{28}$$

$$|Avcm, dm|dB = 20log(|Avcm, dm|) = -63.5dB \tag{29}$$

$$Avcm, cm = \frac{\frac{-Rd}{2}}{\frac{1}{2gm} + Rss} \tag{30}$$

Rss is resistance of the current source

$$|Avcm, cm| = \frac{\frac{100k}{2}}{\frac{1}{2*104u} + 1.457M} = .034 \tag{31}$$

$$|Avcm, cm| = 20log(0.034) = -29.31dB \tag{32}$$

6 Plot the differential mode gain(Av,dm), common mode to differential mode gain (Av,cmdm), common mode to common mode gain (Av,cm-cm) and CMRR vs. frequency with 10% mismatch in Rd.

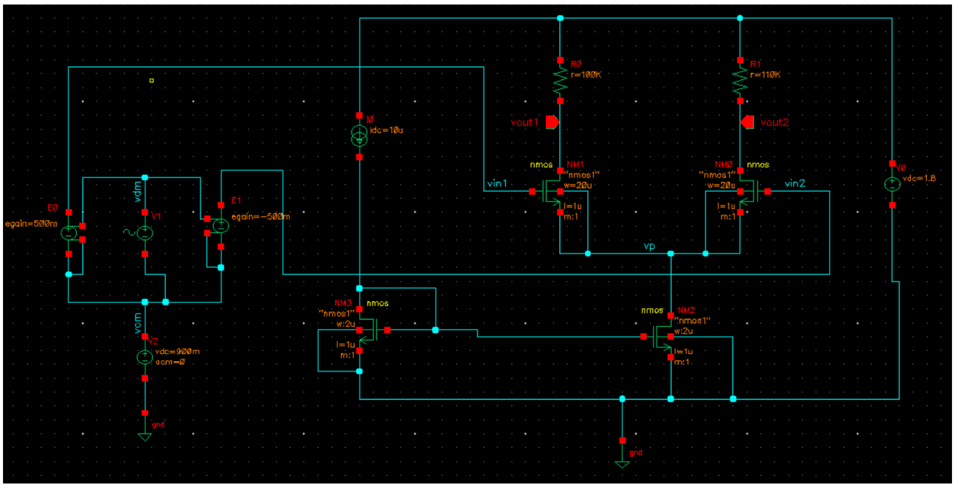

Figure 15: Differential mode gain wrt freq with 10% mismatch ckt diagram

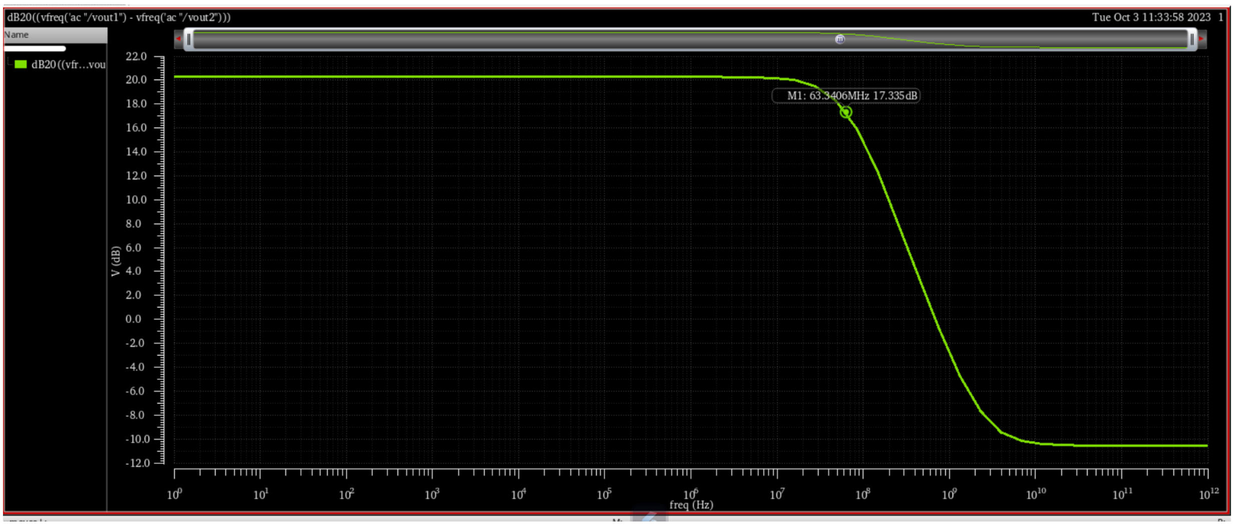

Figure 16: Differential mode gain wrt freq with 10% mismatch vs freq

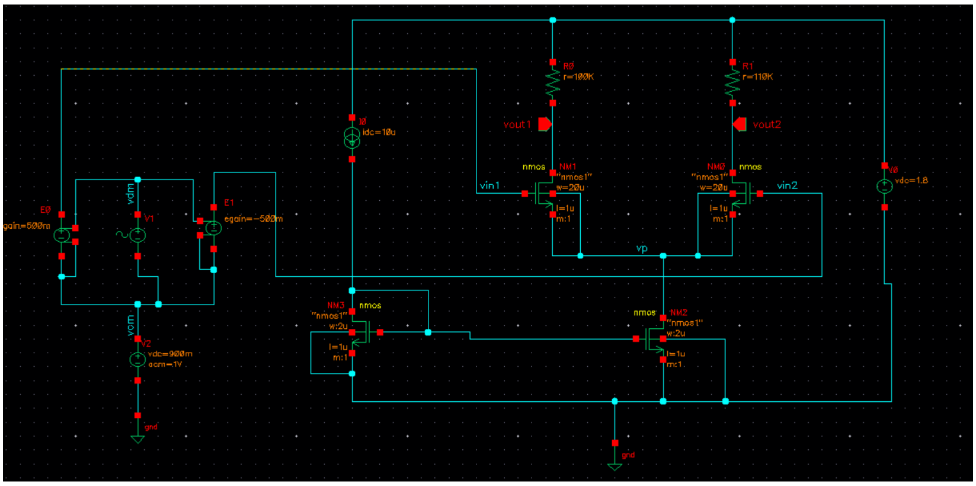

Figure 17: common mode to differential mode gain wrt freq with 10% mismatch ckt diagram

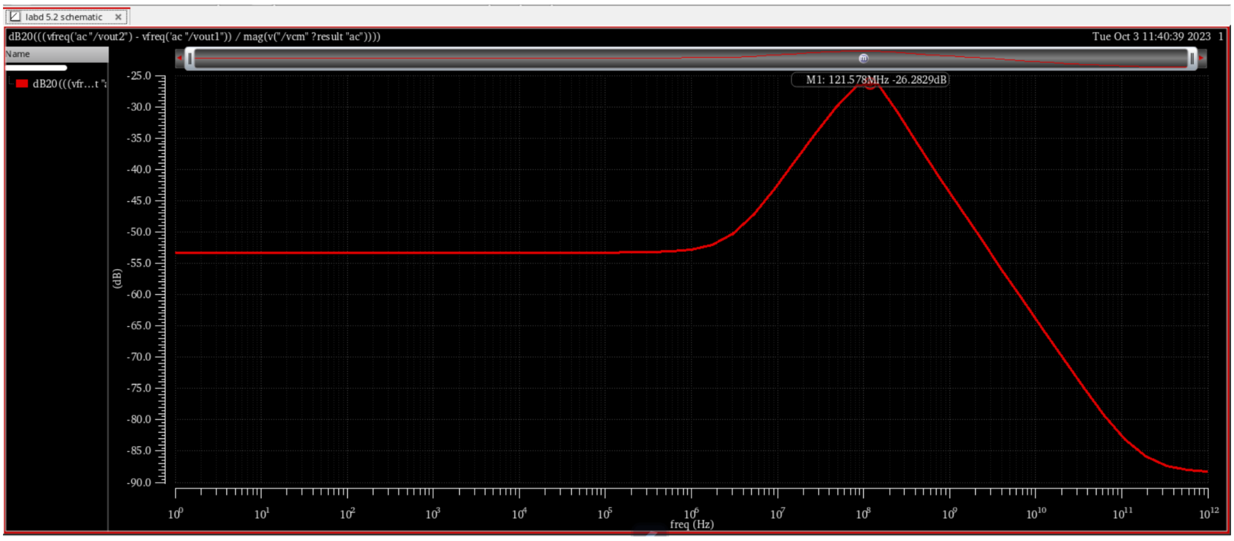

Figure 18: common mode to differential mode gain wrt freq with 10% mismatch vs freq

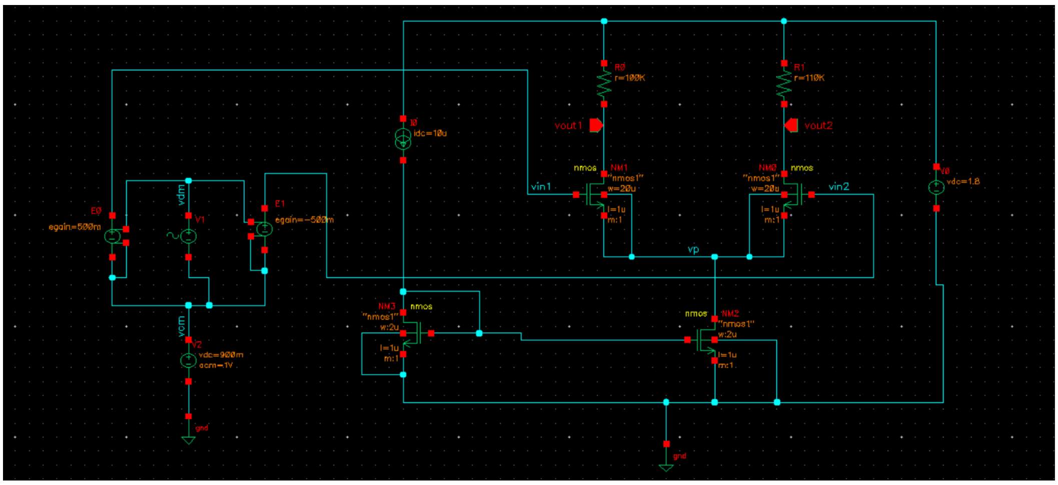

Figure 19: common mode to common mode gain wrt freq with 10% mismatch vs freq ckt diagram

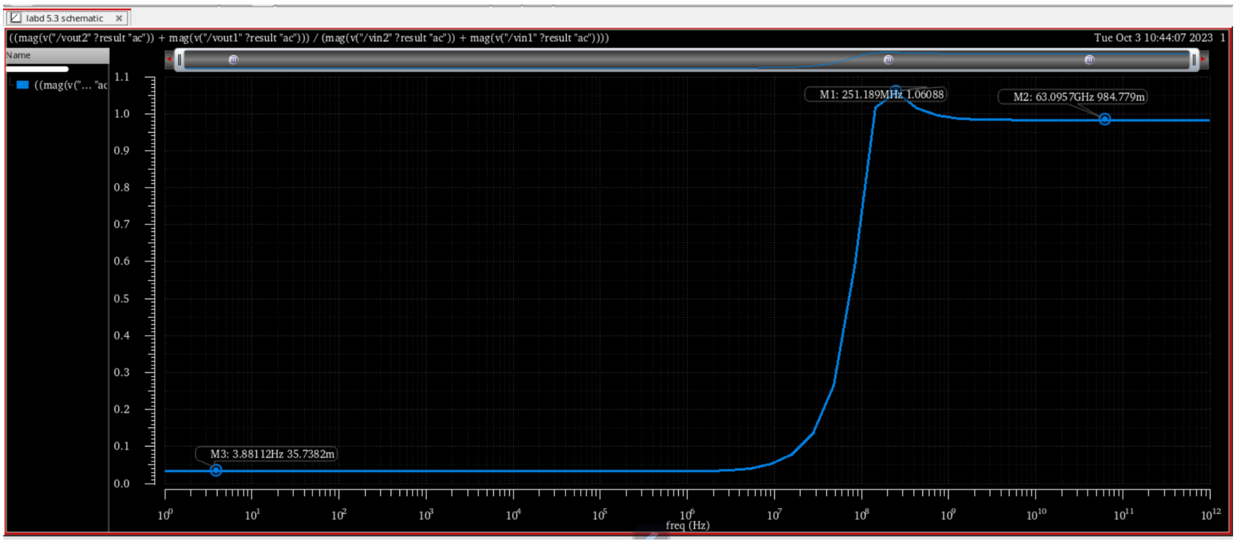

Figure 20: common mode to common mode gain wrt freq with 10% mismatch vs freq

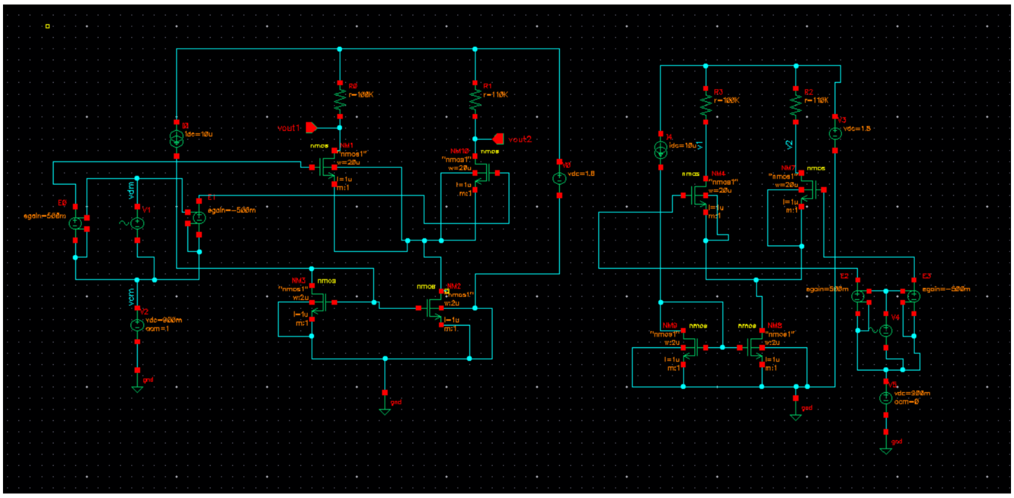

Figure 21: Ckt diagram to calculate the CMRR

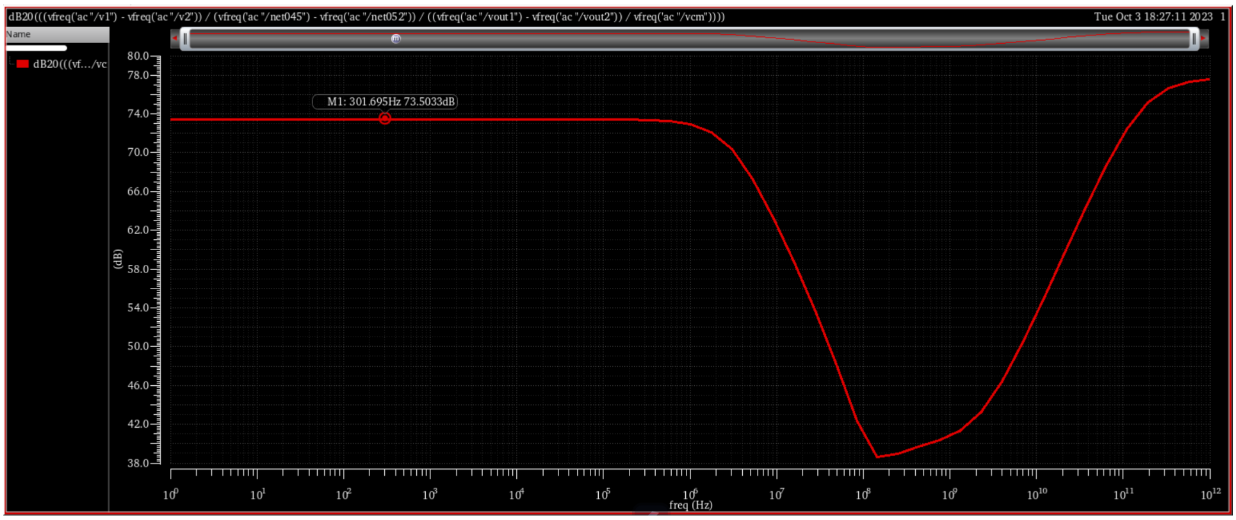

Figure 22: CMRR vs Frequency

7 Plot the power spectral density of input referred noise and output noise. Also present the integrated noise summary. The integration bandwidth is from 1 Hz to $\frac{\pi}{2}$ f3,db.

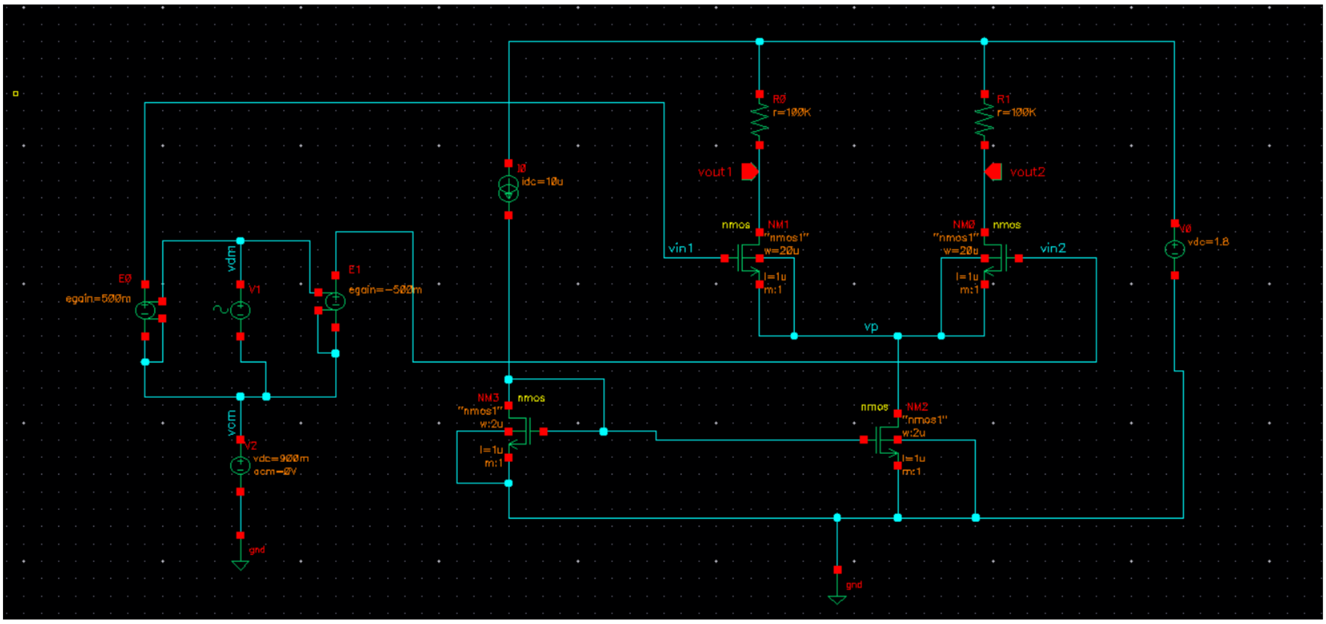

Figure 23: Ckt for plotting PSD

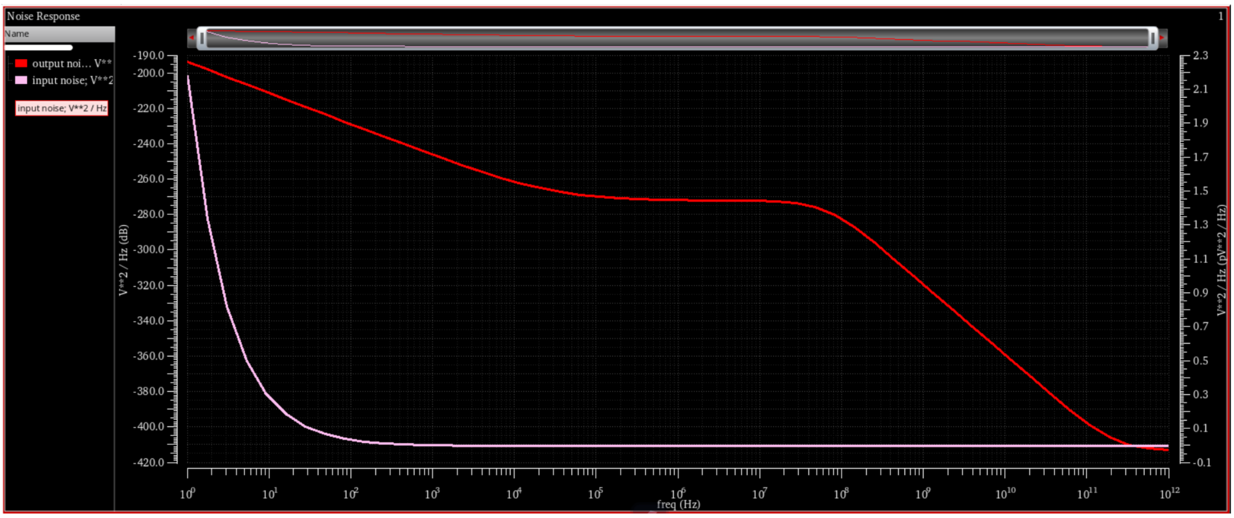

Figure 24: Power spectral density of input referred noise and out- put noise

```
Device     Param     Noise Contribution     % Of Total

/NM0       id        7.73733e-07            44.07
/NM1       id        7.59546e-07            43.27
/R0        rn        1.04638e-07            5.96
/R1        rn        1.03792e-07            5.91
/NM0       fn        6.75705e-09            0.38

Integrated Noise Summary (in V^2) Sorted By Noise Contributors
Total Summarized Noise = 1.7555e-06
Total Input Referred Noise = 2.7529e-08
The above noise summary info is for noise data


Device     Param     Noise Contribution     % Of Total
/NM0       id        7.73733e-07            44.07
/NM1       id        7.59546e-07            43.27
/R0        rn        1.04638e-07            5.96
/R1        rn        1.03792e-07            5.91
/NM0       fn        6.75705e-09            0.38

Integrated Noise Summary (in V^2) Sorted By Noise Contributors
Total Summarized Noise = 1.7555e-06
Total Input Referred Noise = 2.7529e-08
The above noise summary info is for noise data
```

Figure 25: Integration bandwidth is from 1 Hz to $\frac{\pi}{2}$*f3,db