EE537 Circuit Simulation Lab
Experiment 4

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

Aim: Design of basic gain stages using MOS transistors.
In this simulation experiment, we will be using gpdk 0.18 μ m and VDD= 1.8 V. Following are the tasks to be done and in all the questions include your hand calculations which you have used to arrive at the initial transistor sizing.

1 Design a Common-Source (CS) amplifier stage

Design the following configurations of CS amplifier with total current consumption of 100 μ A, output voltage swing of 500 mV, CL = 5 pF, fugb > 40 MHz and maximize the voltage gain. Show the DC operating point simulation and annotate Id, gm, region and overdrive(vdsat). Show the results using transient and AC analysis.

1.1 With resistive load

Considering a CS stage with resistive load,

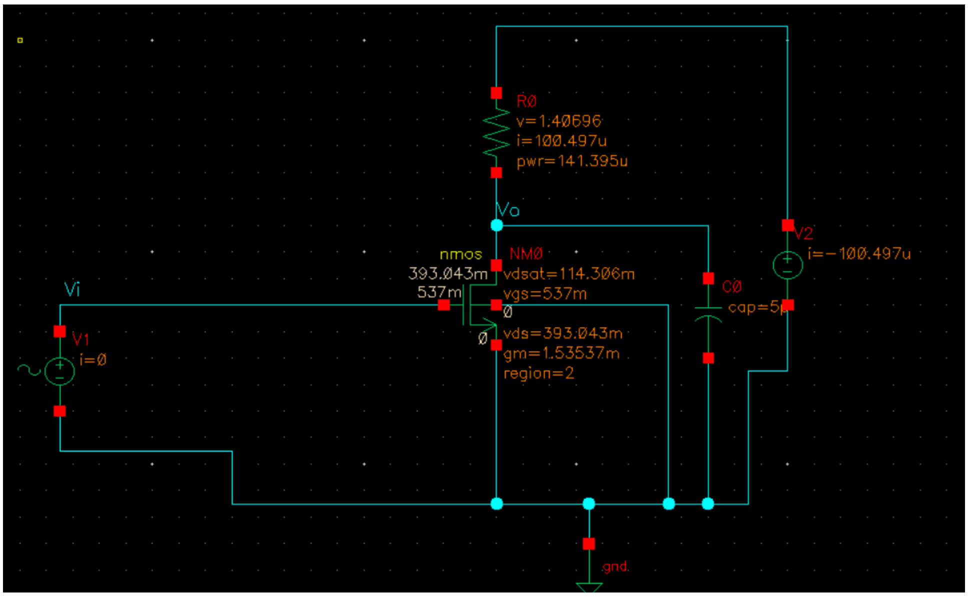

Figure 1: Ckt diagram of resistive loaded cs amplifier

$$fugb > 40MHz \tag{1}$$

$$\frac{gm}{2\pi Cl} > 40MHz \tag{2}$$

$$gm > 1.26mS \tag{3}$$

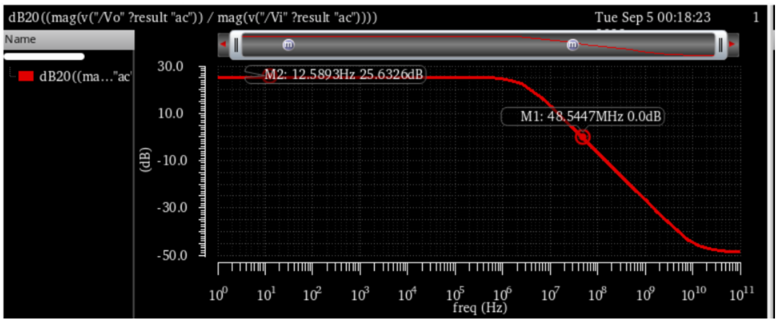

Figure 2: ac response of cs amplifier with resistive load

Also,

$$\frac{2Id}{Vgs - Vth} > 1.26mS \tag{4}$$

or

$$Vgs - Vth < 159.2mV \tag{5}$$

and

$$\frac{\mu_n CoxW}{L} = 70.4593m \tag{6}$$

From this we can say

$$\mu_n Cox = 1.48mA/(V^2) \tag{7}$$

$$Id = \frac{\mu_n CoxW(Vgs - Vt)^2}{2L} \tag{8}$$

Vgs=537mV, Vt=483.597mV, Id = 100μA Calculating we get,

$$\frac{W}{L} = 55.05 \tag{9}$$

For calculating Rd

$$Vds = Vdd - IdRd \tag{10}$$

For Vds we can say

$$Vds > \frac{gmRd}{2} + Vov \tag{11}$$

$$Vov = Vgs - Vt, Vov = 53.403mV, TakingVds = 400mV \tag{12}$$

Using 10

$$Rd = 14k\Omega \tag{13}$$

Maximising the gain, we get

$$Gain = -gmRd \tag{14}$$

we observe a gain of 25.143dB. To get the proper swing we need to calculate amplitude which is equal to (output amplitude swing)/Gain

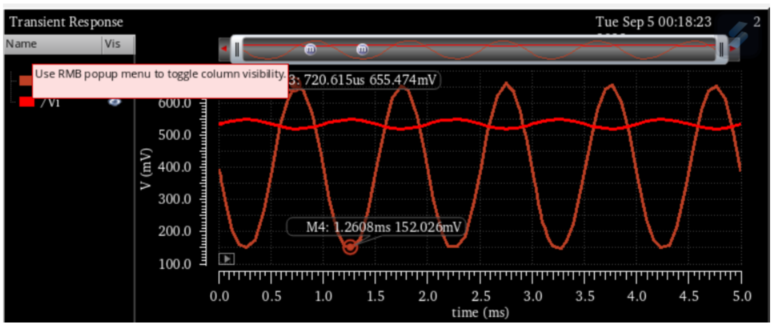

Figure 3: transient response of cs amplifier with resistive load

1.2 With diode connected PMOS load.

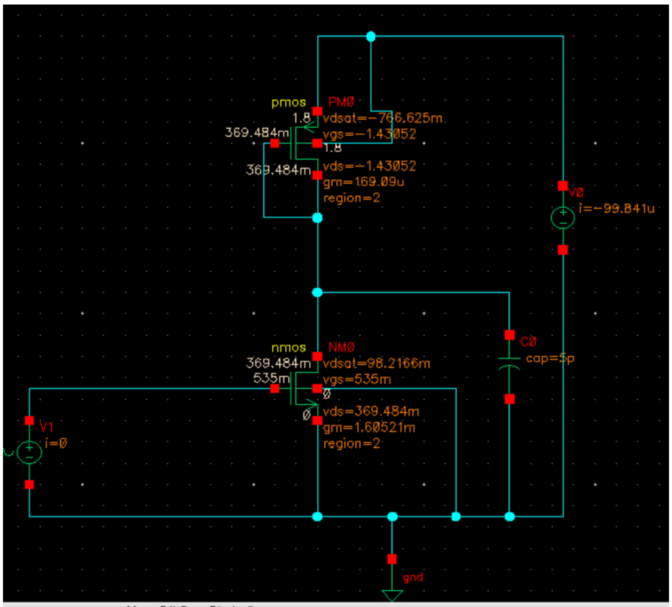

Figure 4: ckt diagram of diode connected load in cs amplifier

$$fugb > 40MHz \tag{15}$$

$$\frac{gm}{2\pi Cl} > 40MHz \tag{16}$$

$$gm > 1.26mS \tag{17}$$

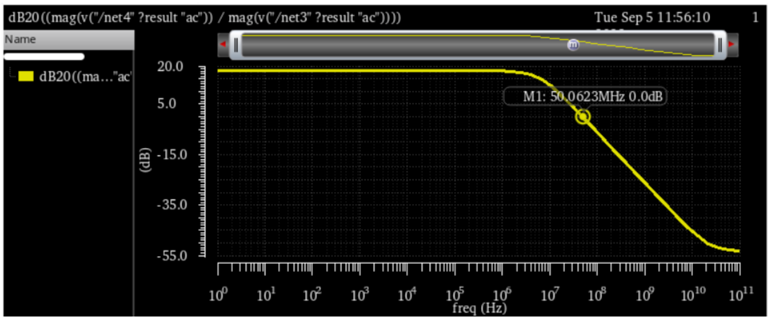

Figure 5: ac respone of diode connected load in cs amplifier

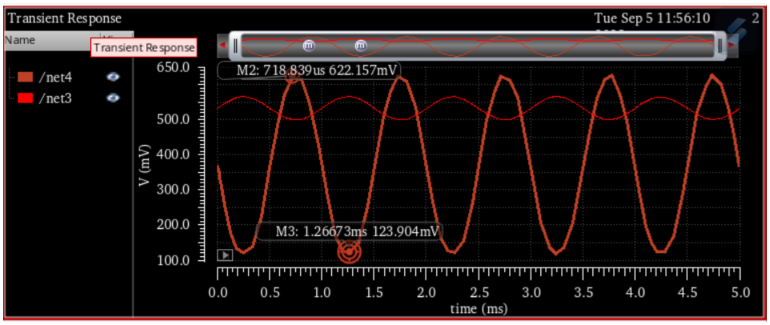

Figure 6: transient response of cs amplifier with a diode connected load

Also,

$$\frac{2Id}{Vgs - Vth} > 1.26mS \tag{18}$$

or

$$Vgs - Vth < 159.2mV \tag{19}$$

and

$$\frac{\mu_n CoxW}{L} = 125.602m \tag{20}$$

From this we can say

$$\mu_n Cox = 1.88mA/(V^2) \tag{21}$$

$$Id = \frac{\mu_n CoxW(|Vgs| - |Vt|)^2}{2L} \tag{22}$$

Vgs=-1.43V, Vt=-460mV, Id = 99.841μA Calculating we get,

$$\frac{W}{L} = 66.67 \tag{23}$$

For Vds we can say

$$Vds > \frac{gmRd}{2} + Vov \tag{24}$$

$$Vov = |Vgs| - |Vt|, Vov = 0.97V, \tag{25}$$

For PMOS,

Id1 = Id2 = 99.841μA Also

$$\frac{\mu_p CoxW}{L} = 212.062\mu \tag{26}$$

or

$\mu pCox = 45.024\mu A/V^2$

$$Id1 = 99.841\mu = \frac{\mu pCoxW(|Vgs| - |Vt|)^2}{2L} \tag{27}$$

Calculating we get,

$$\frac{W}{L} = 4.71 \tag{28}$$

For Vds, we can say that

$$Vsd > 250mV + 0.97 \tag{29}$$

For calculating the gain

$$Av = -\frac{gm1}{gm2(1+\eta)} \tag{30}$$

As the source and substrate of both the pmos and nmos are at same potential, we can say that there is no body effect observed in any of the mosfet. Taking η to be 0.

The gain can be said to be $\frac{-gm1}{gm2}$ The maximum gain observed in this case is 18.553dB. To get the proper swing we need to calculate amplitude which is equal to (output amplitude swing)/Gain

1.3 With PMOS current source as load.

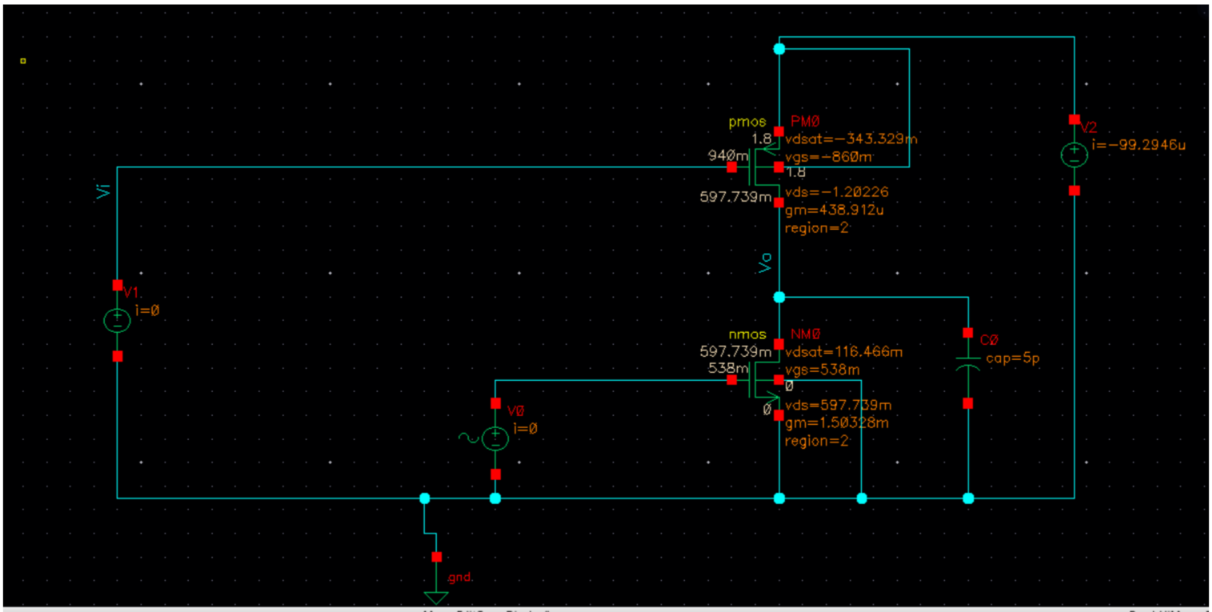

Figure 7: Ckt diagram of pmos current source connected with cs amplifier

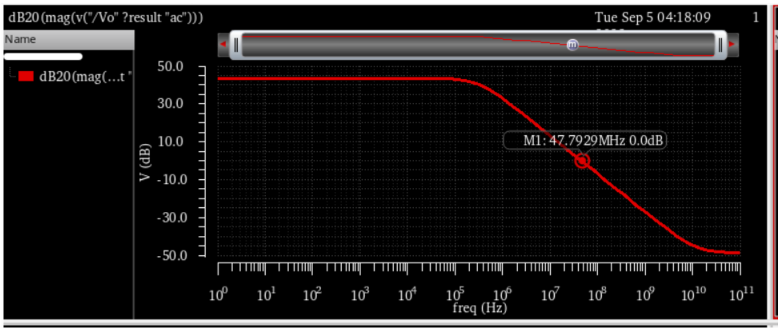

Figure 8: Ac response of pmos current source connected to cs amplifier

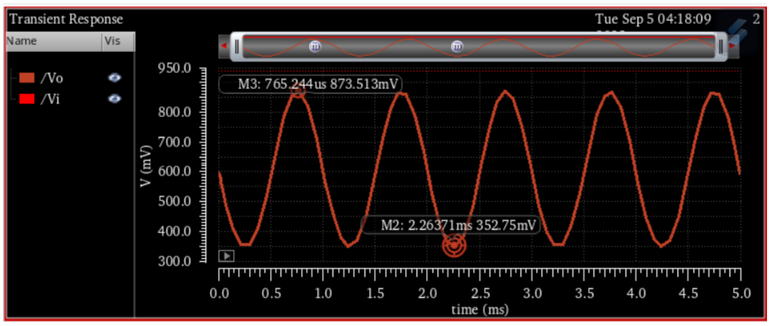

Figure 9: Transient response of pmos current source with CS amplifier

The gain observed in this case is given by

$$Av = -gm1(ro1||r02) \tag{31}$$

here in this case the most difficult aspect is to control the current sources. It is observed that if there is even a small current difference the voltage at the output node shifts drastically from minimum to maximum voltage. Initial aspects of this circuit are similar to what is done in Equations 1-5. For proper working of the circuit the two current sources must carry similar currents. i.e. Id1 = Id2

$$\frac{\mu nCoxW}{L} = 64.3197m \tag{32}$$

or

$$\mu nCox = 1.2369m \tag{33}$$

$$Id1 = \frac{\mu nCoxW(Vgs - Vt)^2}{2L}$$

Id1 = $99.2946\mu A, Vgs = 538mV Vt = 482.434mV$ From here the nmos W/L is given as

$$\frac{W}{L} = 51.99$$

(34)

For PMOS

$$Id2 = \frac{\mu pCoxW(|Vgs| - |Vt|)^2}{2L} \tag{35}$$

Also,

$$\frac{\mu pCoxW}{L} = 1.26m \tag{36}$$

μ p Cox = 0.063mA/V^2

How to bias the pmos?

Vds of the NMos is taken in a similar way as above to be around 500mV. $Vsg - |Vt| < Vsd$ for pmos in saturation or $Vg > 40mV$. Considering the bias as 940mV. Putting the value of Vsg = 860mV and Vt=462.981mV we can find W/L.

$$\frac{W}{L} = 19.99$$

The values of ro1 and ro2 are 169.314kohm and 286.789kohm respectively as observed from the DC operating points. The gain observed in this case is around 44dB. The calculated value of gain is given by gm1(ro1||ro2) gm1 =1.50328mS and it is about 160 in magnitude or 44dB.

1.4 With resistive load and source degeneration

In this case also the initial steps remains the same as we have done before Vgs-Vt should be mimimum so that the mosfet gm is increased. Vds > 250m+ Vov taking it to be near 400mV we can get the value of Rd from equation 10 as Rd = 14KΩ As Id is constant we can find the value of $\frac{W}{L}$ from the square law equation. To find the μn Cox we need to find the beff from the operating point table. Taking the value of μ nCox as 0.3mS we can find that $\frac{W}{L} > 27$ Now for higher values of $\frac{W}{L}$ μnCox will reduce and we can find the exact value by putting this value.

Taking Vg= 620mV Due to the current flowing in the circuit we can say that there will be drop in across the load. The gain in this case will be

$$Av = \frac{-gmRd}{1 + gmRs} \tag{37}$$

The maximum gain observed in this case is also near 18dB. The value of fugb in this case has not met the expectations. To get the proper swing we need to calculate amplitude which is equal to (output amplitude swing)/Gain

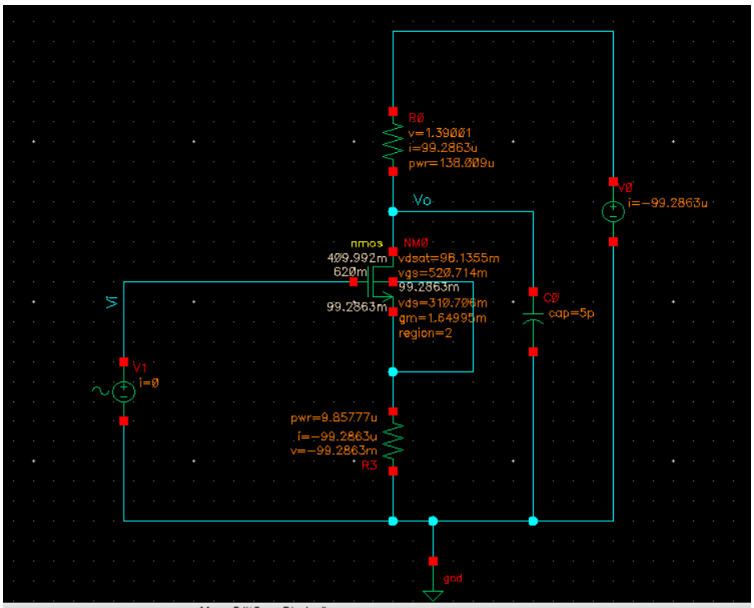

Figure 10: CS amplifier with source degeneration and resistive load

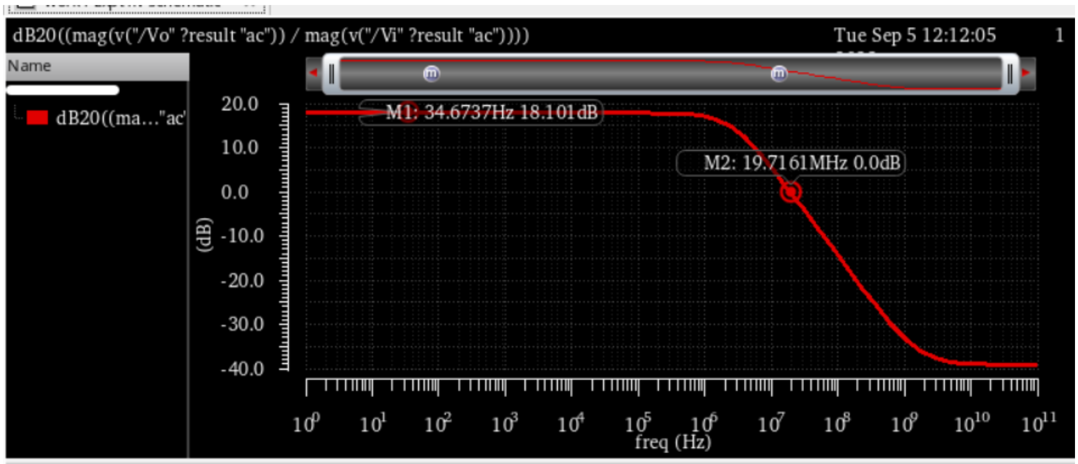

Figure 11: AC response of CS with resistive load and source degeneration

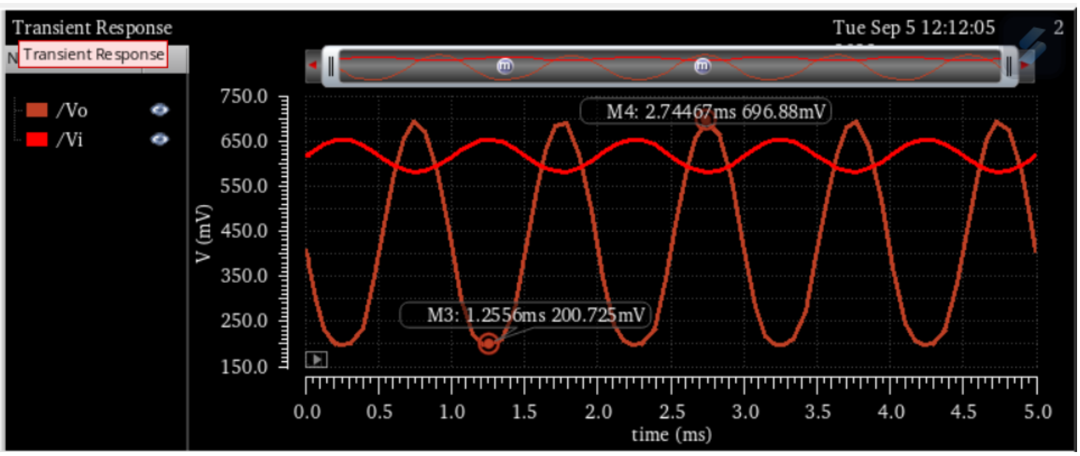

Figure 12: Transient response of CS with resistive load and source degeneration

2 Design a Common-Gate (CG) amplifier stage

2.1 Design the CG amplifier with resistive load, total current consumption of 100 μ A, output voltage swing of 500 mV, CL = 5 pF, $fugb$ > 40 MHz and maximize the voltage gain. Show the DC operating point simulation and annotate Id, gm, region and overdrive. Show the results using transient and AC analysis

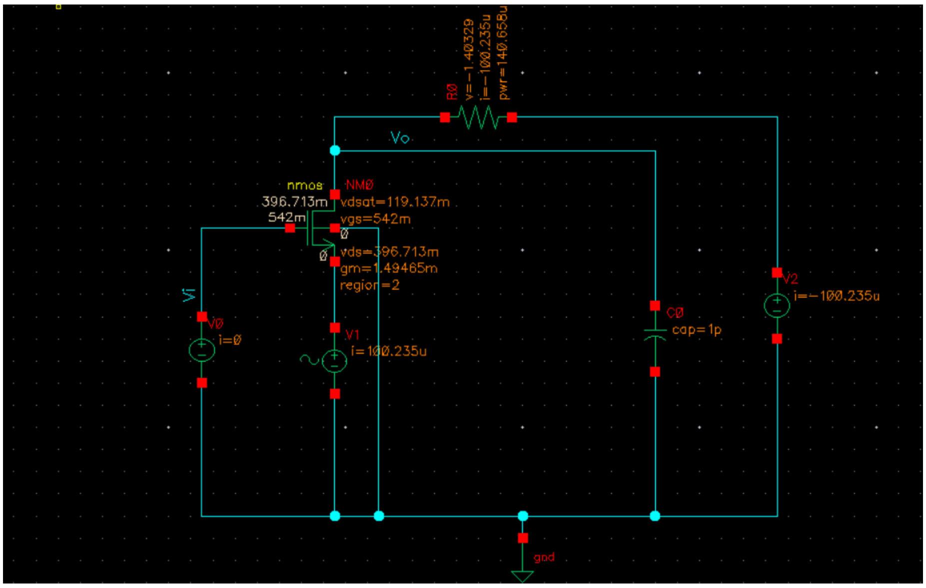

Figure 13: Ckt of CG with resistive load

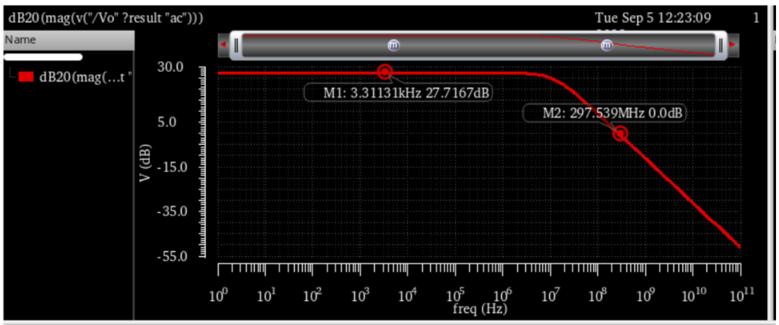

Figure 14: AC response of CG with resistive load

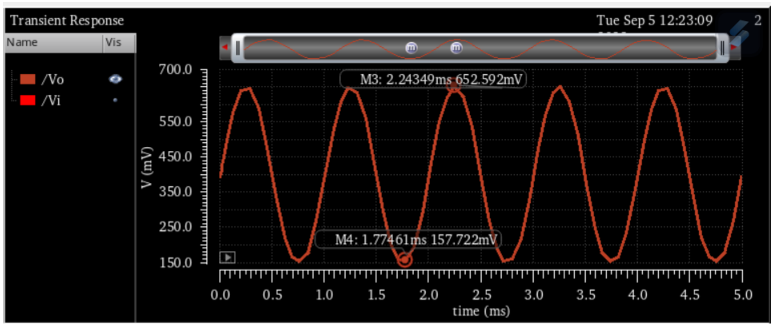

Figure 15: Transient response of CG with resistive load

Here also the procedure remains the same and can be calculated using the equations 1-5. gm ¿ 1.26mS Vgs-Vt < 159mV As the input is on the source terminal and Vgs<640mV, we can take Vs = 0V and Vg =542mV. The Vds needs to be

$$Vds = 250mV + Vov \tag{38}$$

Considering Vds = 400mV Rd can be calculated as shown below

$$Vdd - IdRd = Vds \tag{39}$$

or Rd = 14Kohm. now

$$\frac{\mu nCoxW}{L} = 56.3676m \tag{40}$$

or

$\mu nCox = 1.127mA/V^2$ Calculating $\frac{W}{L}$ from the current equation in saturation we get W/L = 50 The gain in this case is given by

$$Av = gm(1 + \eta)Rd \tag{41}$$

Now we can see that the gain can improve in this case if there is body effect so without keeping substrate and source at the same potential we can improve the gain. the observed value of gain is 27.717dB. The calculated value can be given as from operating points gm= 1.49465mS gmb = 431.655uS Rd = 14Kohm or Av = 29.94 or 29.52dB which is little larger than expected. To get the proper swing we need to calculate amplitude which is equal to (output amplitude swing)/Gain

2.2 Determine the input impedance by simulation and verify the same by hand calculations.

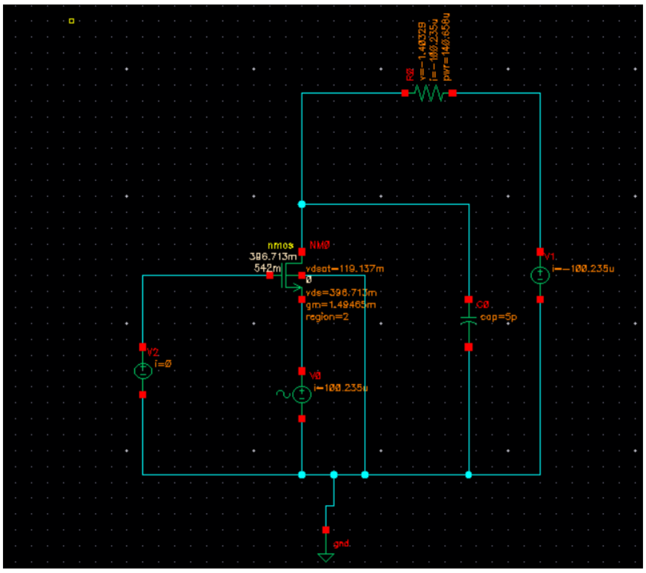

Figure 16: Ckt For calculating the Rin

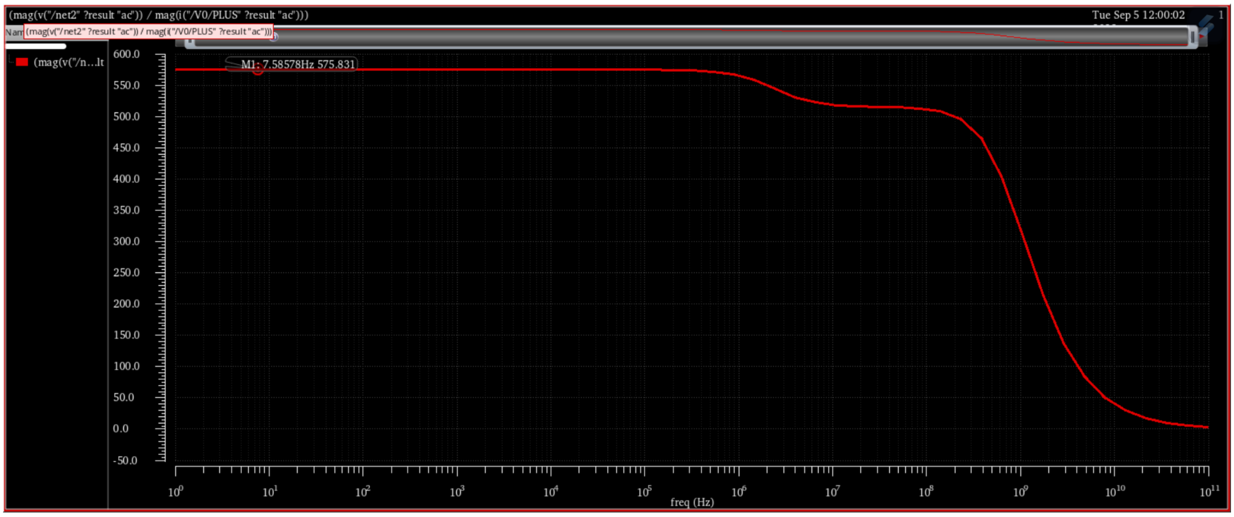

Figure 17: Rin wrt frequency

Rin can be calculated very easily from the small signal model of the circuit and is given by

$$Rin = \frac{\frac{1}{Rd} + \frac{1}{ro}}{(gmb + gm + \frac{1}{Ro})(\frac{1}{Rd} + \frac{1}{ro} - 1)} \tag{42}$$

Rd =14kohm ro = 122.964kohm, gm= 1.49468mS, gmb = 431.664μ S Calculating we Rin = 561Ω The observed value 575.737Ω