Part 1: sizing chart

1) From the square law, we have

$$gm = \frac{2I_D}{V_{OV}} \rightarrow \quad V_{OV} = \frac{2I_D}{gm}$$

For a real MOSFET, if we compute Vov and 2 gm/ID they will not be equal. Let's define a new parameter called V-star (V^*) which is calculated from actual simulation data using the formula.

$$V^* = \frac{2I_D}{gm} \leftrightarrow gm = \frac{2I_D}{V^*}$$

The lower the $V*$ the higher the gm, but the larger the area and the lower the speed. An often-used sweet spot that provides good compromise between different trade-offs is V^* = 200mV.

2) Although the V^* is a nice parameter that is inspired by the square-law, it does not have an intuitive or a physical meaning (it is not an actual voltage in the circuit). We defined V^* to be able to define a relation between the gm and I_D. Thus, the real parameter that we should care about is the gm over I_D ratio (gm/ID).
3) There are many good things about using the gm/ID as a design knob:
4) a. The gm/ID gives a direct relation between the most important MOSFET parameter (gm) and the most valuable resource (ID). For example, a gm/ID = 10 S/A means you get 10 μS of gm for every 1 μA of bias current.
   b. The gm/ID is a normalized knob: it has a limited search range (typically from 5 to 25 S/A) independent of the technology or the device type.
   c. The gm/ID is intuitive because it tells you directly about the inversion level (bias point) and consequently all related trade-offs. For example, gm/ID = 5 S/A means strong inversion (SI), gm/ID = 15 S/A means moderate inversion (MI), and gm/ID = 25 S/A means weak inversion (WI).
   d. The gm/ID is an orthogonal knob: If we define the gm/ID then we define the inversion level (bias point). If you change ID or L while keeping gm/ID fixed, then the inversion level (bias point) is kept fixed. The W is treated as an output variable instead of being treated as an
   e. The higher the gm/ID (the lower the V^*) the higher the efficiency, but the larger the area and the lower the speed. An often-used sweet spot that provides good compromise between different trade-offs is gm/ID = 10 S/A (V^* = 200mV).

1) We want to design a CD amplifier that has ideal current source load with the parameters

Parameter	
Input transistor	PMOS
$\boldsymbol{L}$	$1\mu m$
$\boldsymbol{V^*}$	$200mV$
Quiescent (DC) input voltage	$0V$
Supply	$1.8V$
Current consumption	$10\mu A$

1) We assume we use a PMOS transistor that is placed in a dedicated n-well to be able to connect the body and source terminals. This will avoid the degradation of the CD amplifier gain due to body effect.
2) Since the square-law is not accurate, we cannot use it to calculate the sizing. Instead, we will use the Sizing Assistant (SA) which is a powerful analog calculator that uses LUTs that are pre-generated from the simulations. The input and output of SA are shown below. Note that since we assume body

and source are connected, we can set VDS = VGS. Draw the circuit schematic to be able tounderstand this properly. Note that the load is connected to the source, not to the drain.

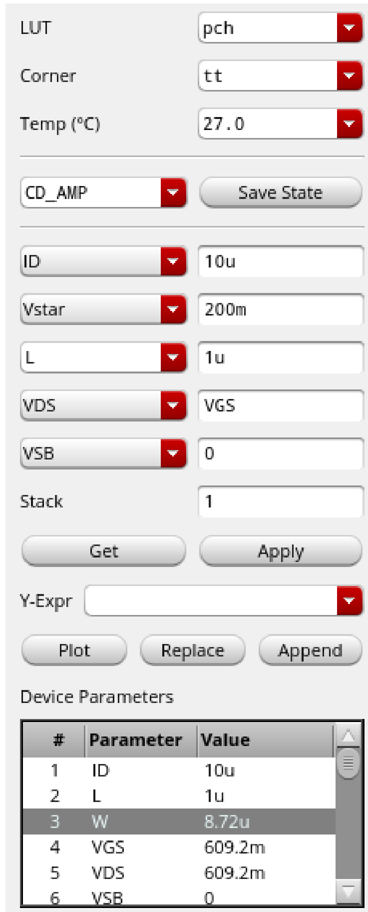


Figure 1 Sizing assistant results

After using sizing assistant that generates W=8.72µm and $V_{GS} = 609..2mV\ and\ V_{DS} = 609.2mV$

Part 2: CD Amplifier

1. OP (Operating Point) Analysis

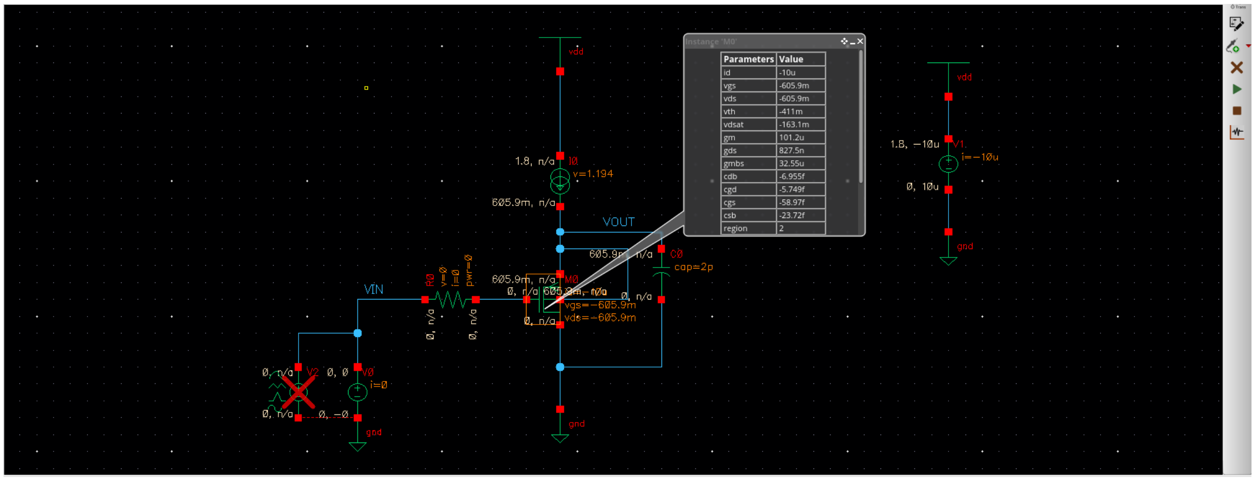


Figure 2 DC Operating point

Transistor in region 2 (saturation).

2. AC Analysis

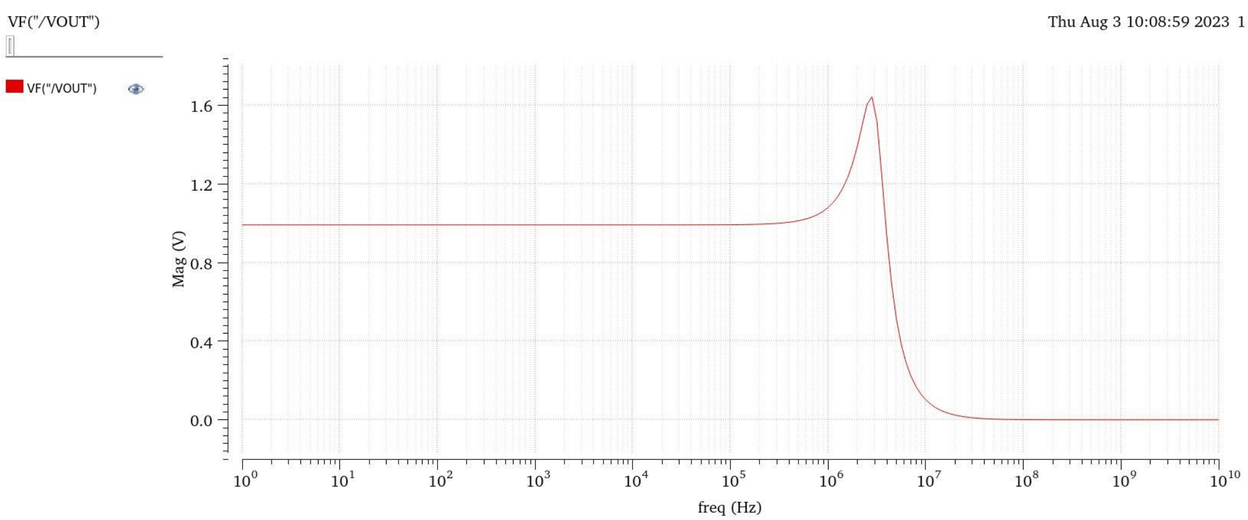


Figure 3 ac analysis gain

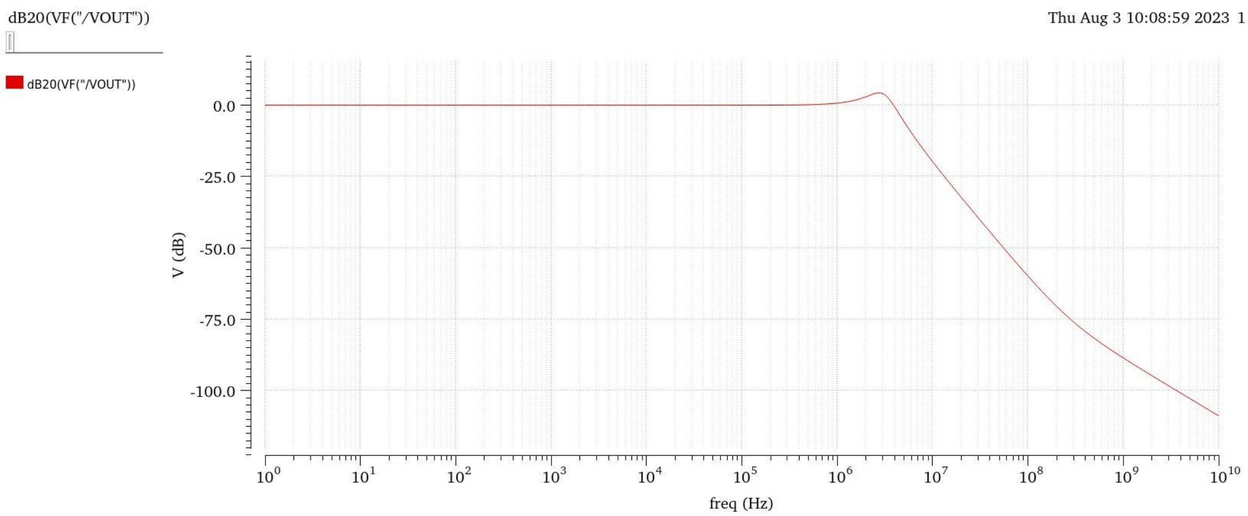
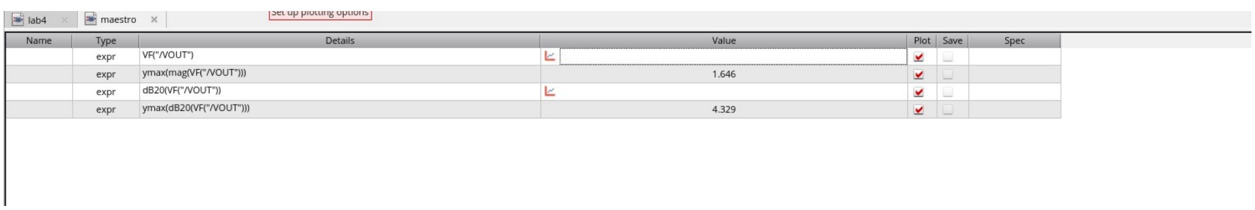


Figure 4 ac analysis in dB(BODE PLOT)



Name	Type	Details	Value	Plot	Save	Spec
	expr	VF("/VOUT")		✔		
	expr	ymax(mag(VF("/VOUT")))	1.646	✔		
	expr	dB20(VF("/VOUT"))		✔		
	expr	ymax(dB20(VF("/VOUT")))	4.329	✔		

Figure 5 peaking values.

As shown in the figures there is a peaking in frequency domain equal 4.329dB.

4) $Q = \sqrt{\frac{gm(C_{gs}+C_{gd})R_{SIG}}{C_L}} = \sqrt{\frac{101.2*10^{-6}*(58.97+5.749)*10^{-15}*2*10^{6}}{2*10^{-12}}} = 2.56$

Q > 0.5 system is underdamped

5)

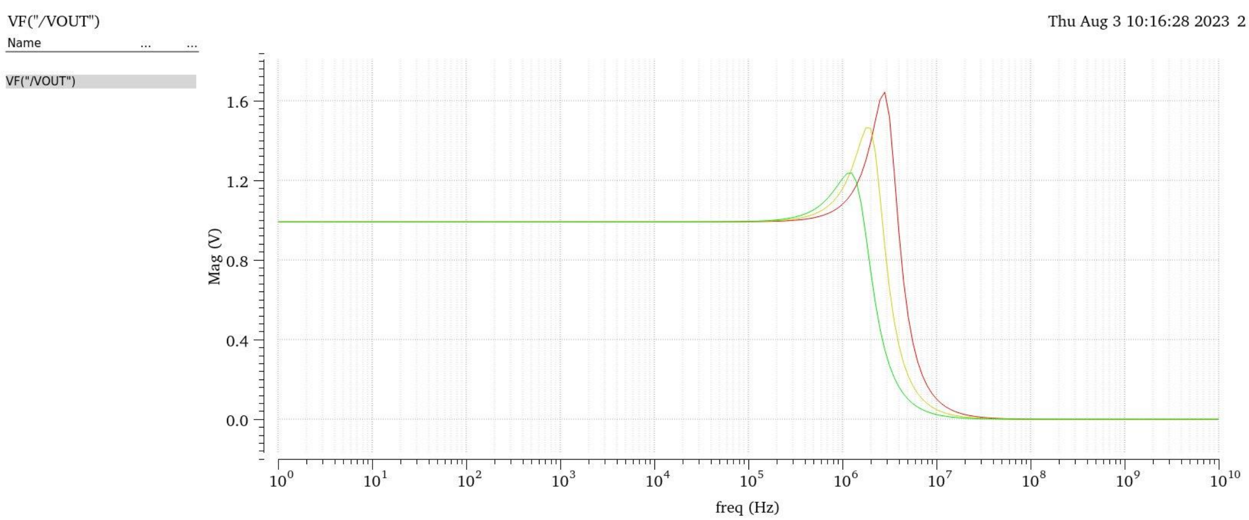


Figure 6 ac analysis parametric sweep: CL = 2p, 4p, 8p.

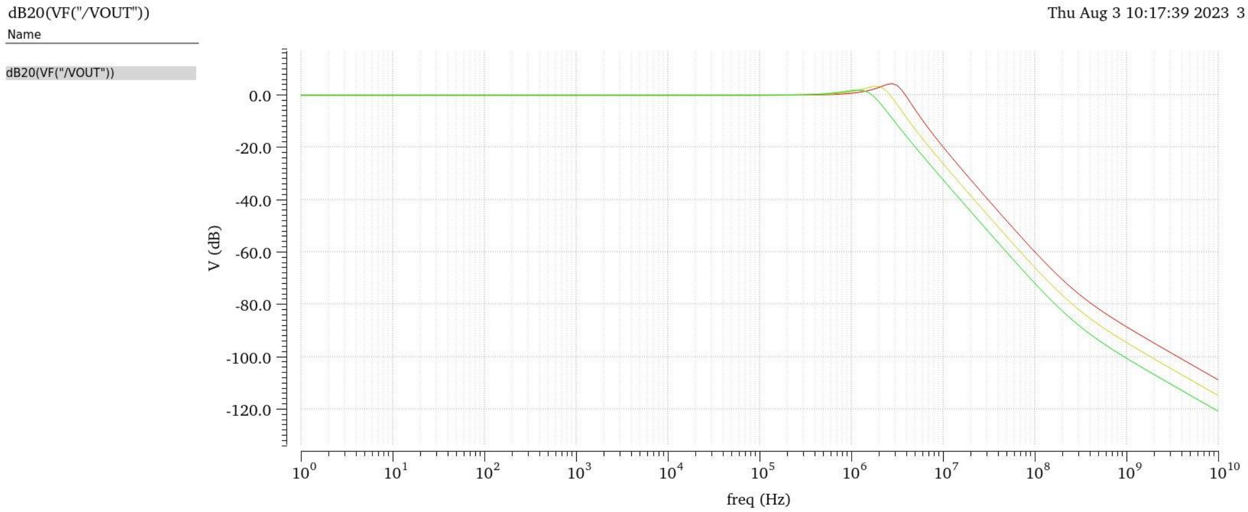
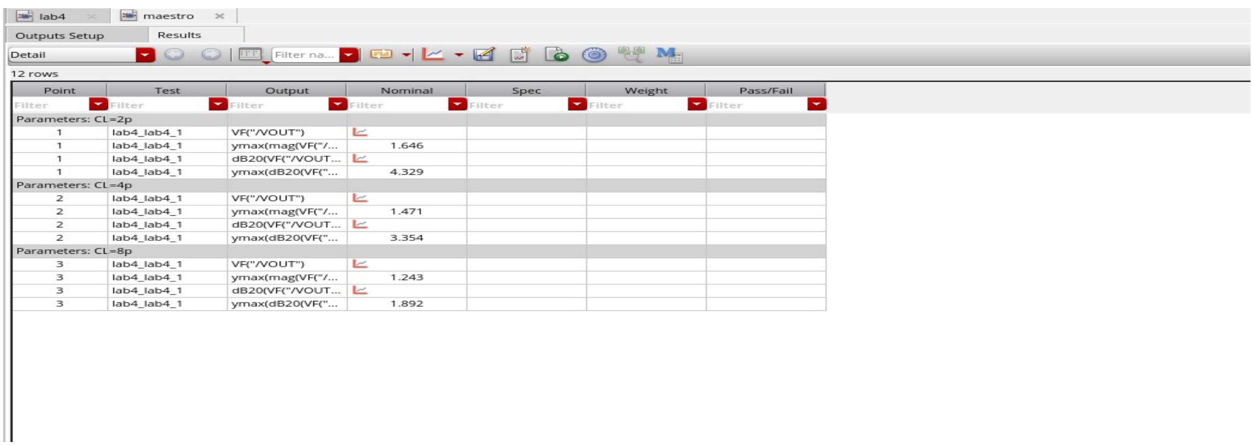


Figure 7 ac analysis parametric sweep: CL = 2p, 4p, 8p. in dB



Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CL=2p						
1	lab4_lab4_1	VF("/VOUT")				
1	lab4_lab4_1	ymax(mag(VF("/...	1.646			
1	lab4_lab4_1	dB20(VF("/VOUT...				
1	lab4_lab4_1	ymax(dB20(VF("...	4.329			
Parameters: CL=4p						
2	lab4_lab4_1	VF("/VOUT")				
2	lab4_lab4_1	ymax(mag(VF("/...	1.471			
2	lab4_lab4_1	dB20(VF("/VOUT...				
2	lab4_lab4_1	ymax(dB20(VF("...	3.354			
Parameters: CL=8p						
3	lab4_lab4_1	VF("/VOUT")				
3	lab4_lab4_1	ymax(mag(VF("/...	1.243			
3	lab4_lab4_1	dB20(VF("/VOUT...				
3	lab4_lab4_1	ymax(dB20(VF("...	1.892			

Figure 8 peaking results

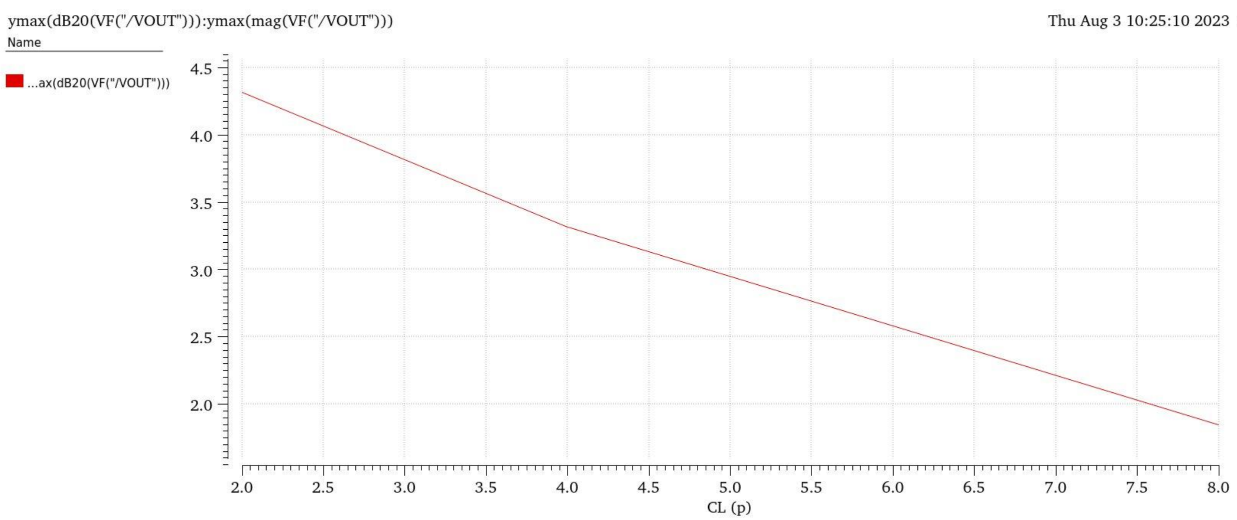


Figure 9 plot of peaking vs caps

Comment: as cap C_L increases the peaking value decreases and the range where peaking occurs decreases, because the peaking is ringing effect there is a strong interaction between input and output as they are close to each other so by increasing C_L, the output pole decreases so the distance between the two poles increases so ringing effect decreases and peaking decreases their value and range.

6)

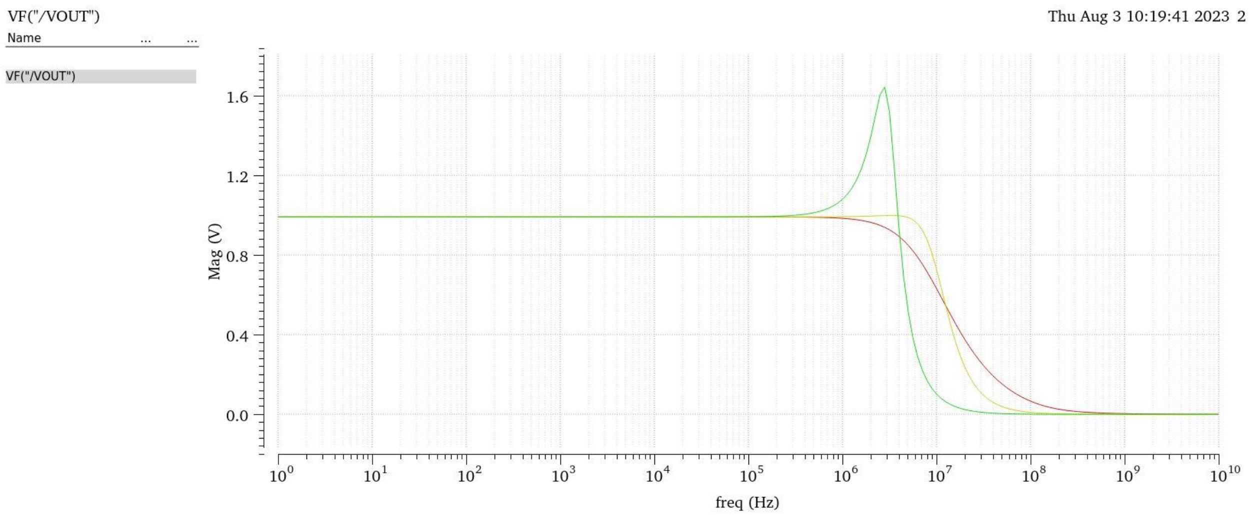


Figure 10 ac analysis parametric sweep: Rsig = 20k, 200k, 2M.

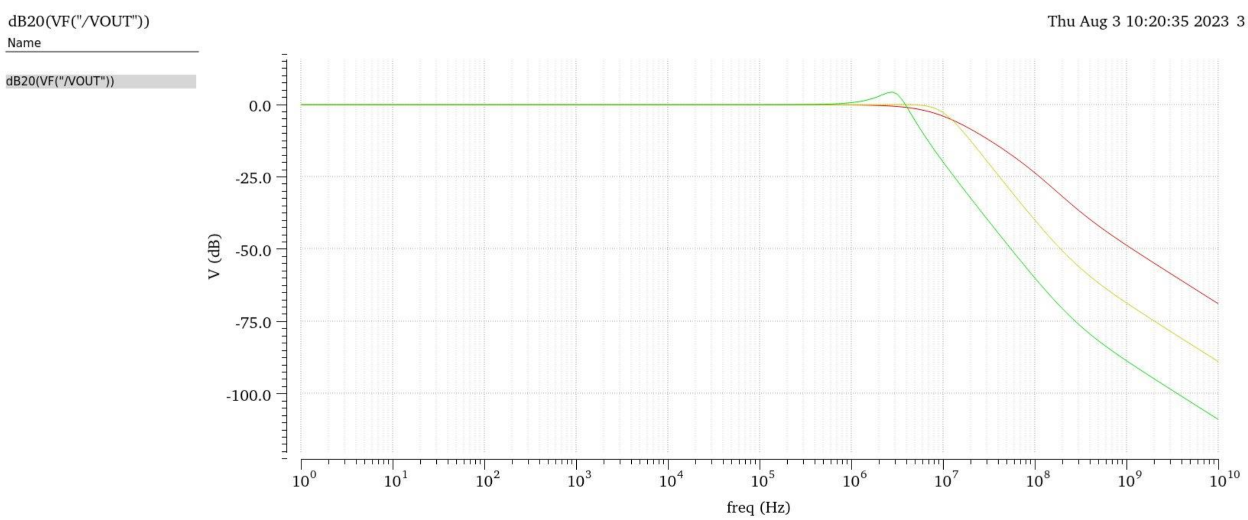
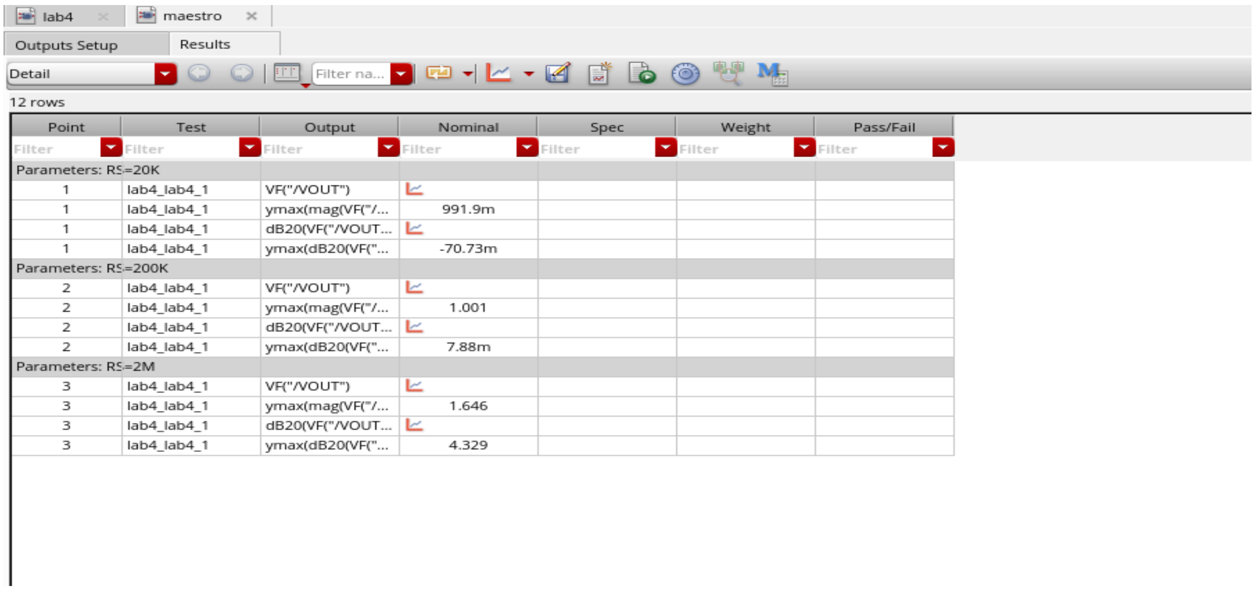


Figure 11 ac analysis parametric sweep: Rsig = 20k, 200k, 2M. in dB



Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: RS=20K						
1	lab4_lab4_1	VF("/VOUT")				
1	lab4_lab4_1	ymax(mag(VF("/...	991.9m			
1	lab4_lab4_1	dB20(VF("/VOUT...				
1	lab4_lab4_1	ymax(dB20(VF("...	-70.73m			
Parameters: RS=200K						
2	lab4_lab4_1	VF("/VOUT")				
2	lab4_lab4_1	ymax(mag(VF("/...	1.001			
2	lab4_lab4_1	dB20(VF("/VOUT...				
2	lab4_lab4_1	ymax(dB20(VF("...	7.88m			
Parameters: RS=2M						
3	lab4_lab4_1	VF("/VOUT")				
3	lab4_lab4_1	ymax(mag(VF("/...	1.646			
3	lab4_lab4_1	dB20(VF("/VOUT...				
3	lab4_lab4_1	ymax(dB20(VF("...	4.329			

Figure 12 peaking results

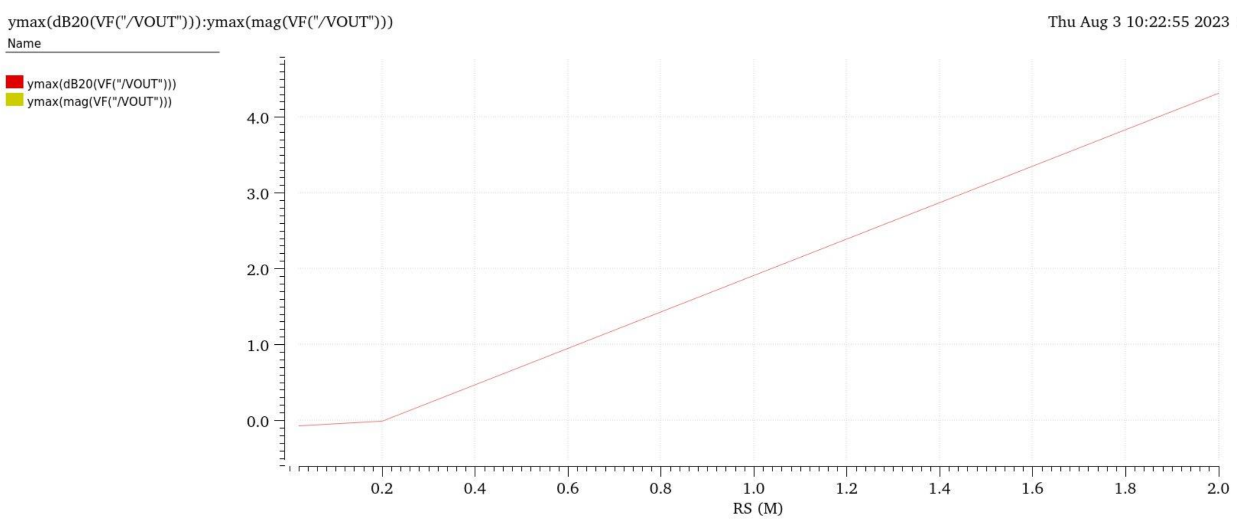


Figure 13 peaking vs RSIG

Comment: as R_{SIG} increases, peaking value, and range increases because the non-dominant pole is at input will decrease and thus approaches the dominant pole at output and this will increase the ringing effect and peaking value and range increases.

3. Transient Analysis

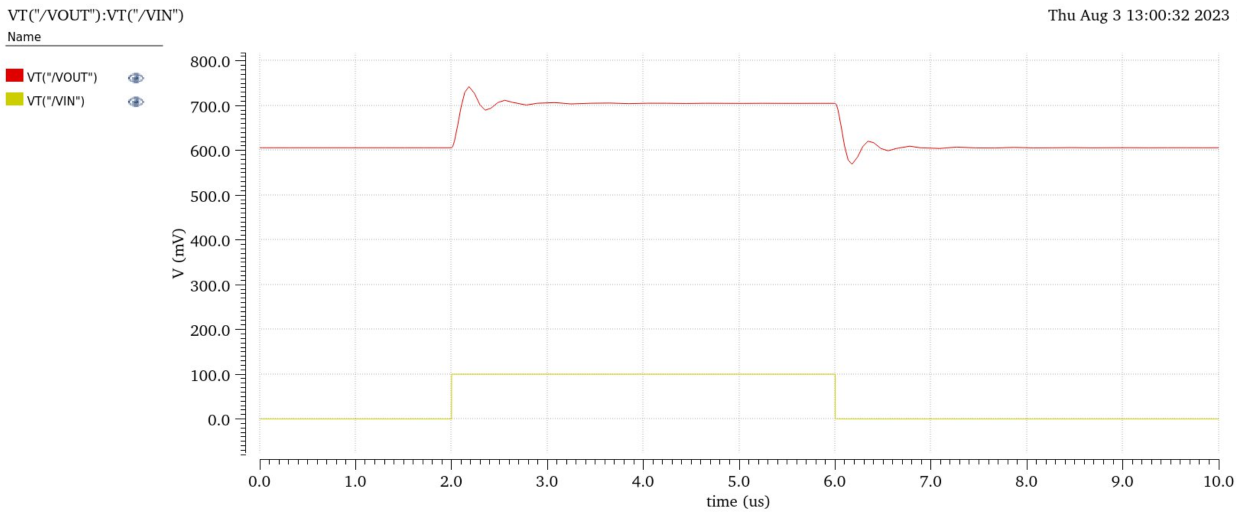
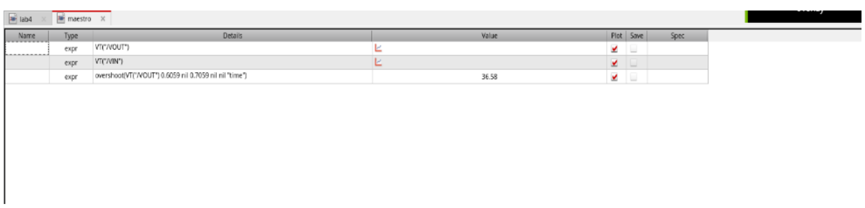


Figure 14 plot Vin and Vout overlaid vs time

4) DC shift between Vin and V_{OUT} equals V_{GS} because common drain amplifier considered as voltage buffer (source follower), so it doesn't effect on gain but only shift DC level for input signal.

• If we want to shift signal down use NMOS common drain stage.



Name	Type	Details	Value	Plot	Save	Spec
	expr	VT("/VOUT")				
	expr	VT("/VIN")				
	expr	overshoot(VT("/VOUT") 0.6059 nil 0.7059 nil nil "time")	36.58			

Figure 15 Over shot value

•Yes, there is ringing Overshoot percentage equal=36.58%

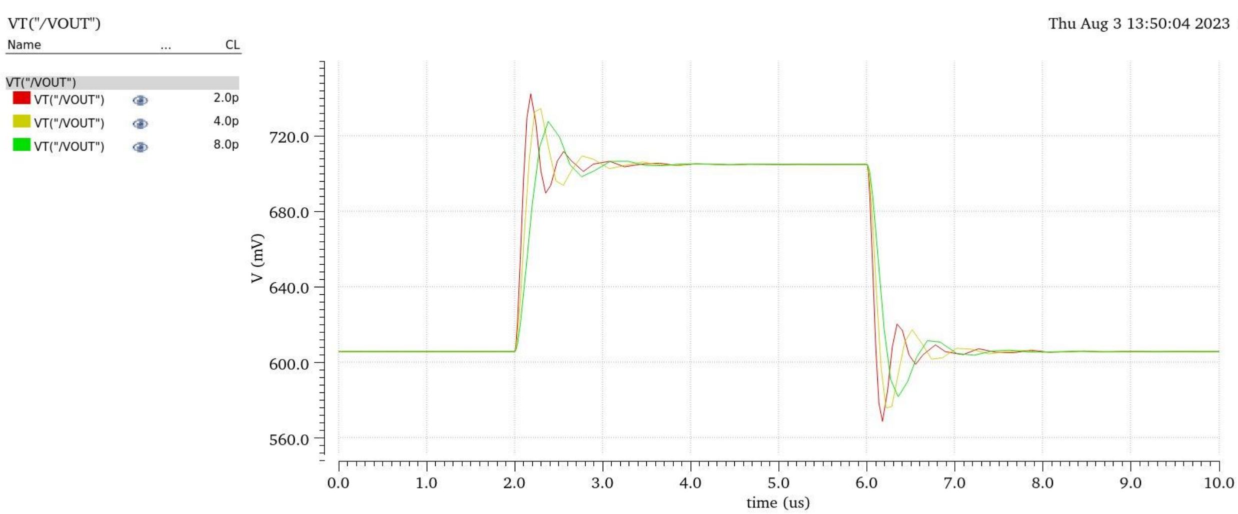
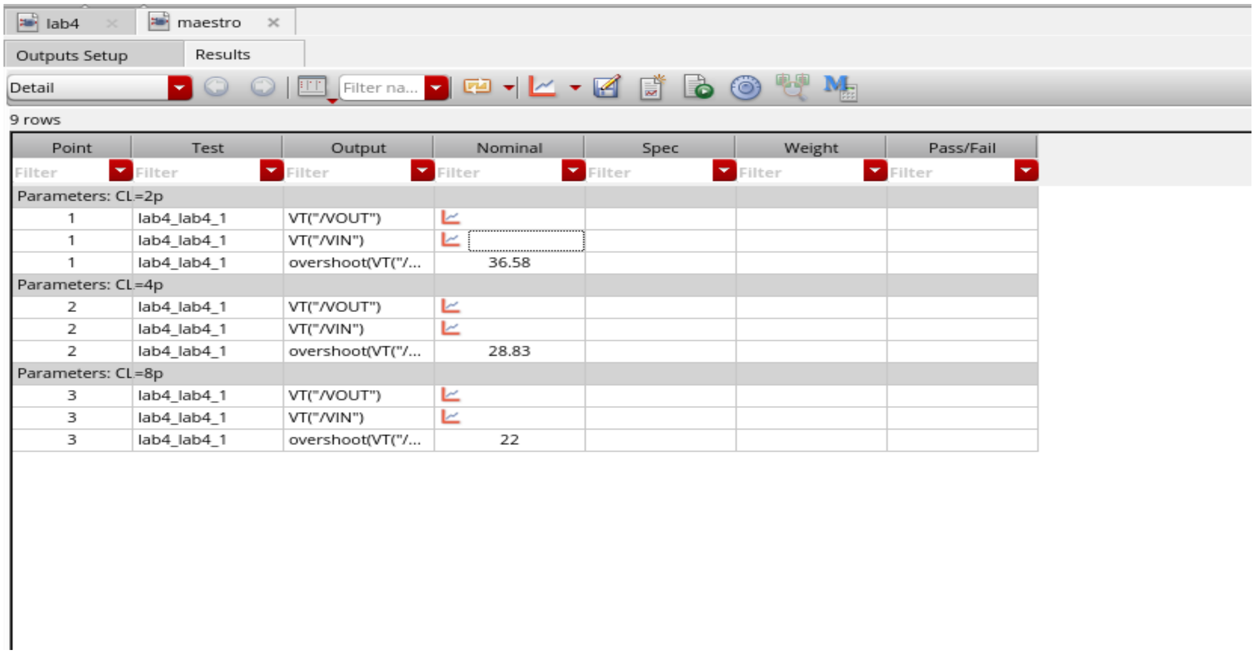


Figure 16 parametric sweep: CL = 2p, 4p, 8p



Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Parameters: CL=2p						
1	lab4_lab4_1	VT("/VOUT")				
1	lab4_lab4_1	VT("/VIN")				
1	lab4_lab4_1	overshoot(VT("/...	36.58			
Parameters: CL=4p						
2	lab4_lab4_1	VT("/VOUT")				
2	lab4_lab4_1	VT("/VIN")				
2	lab4_lab4_1	overshoot(VT("/...	28.83			
Parameters: CL=8p						
3	lab4_lab4_1	VT("/VOUT")				
3	lab4_lab4_1	VT("/VIN")				
3	lab4_lab4_1	overshoot(VT("/...	22			

Figure 17 overshoot values

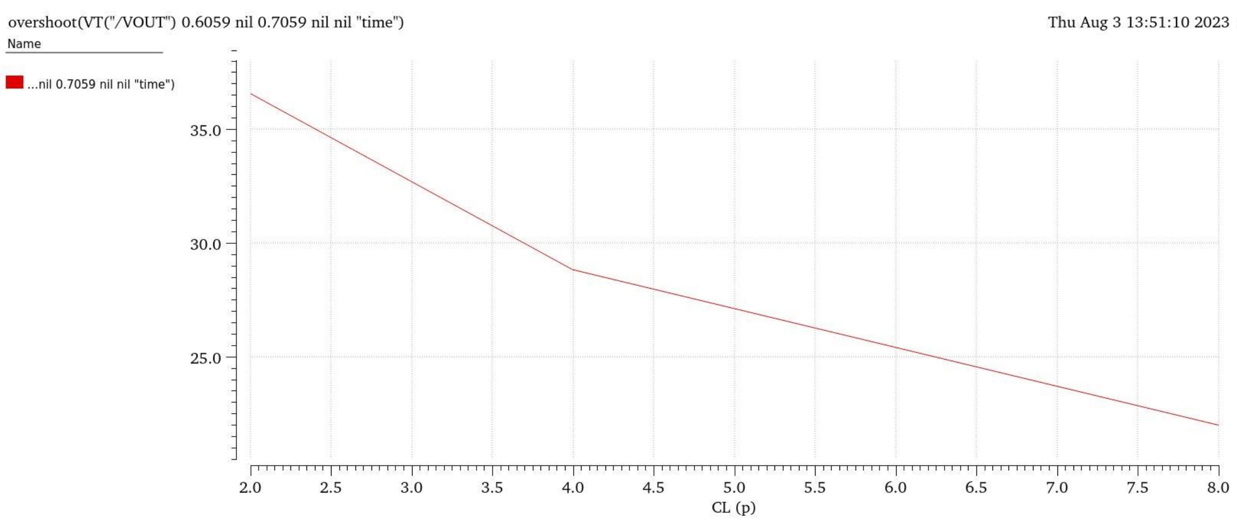


Figure 18 plot overshoot vs cl

Comment: as C_L increases peak overshoot decreases for the same reason on ac analysis.

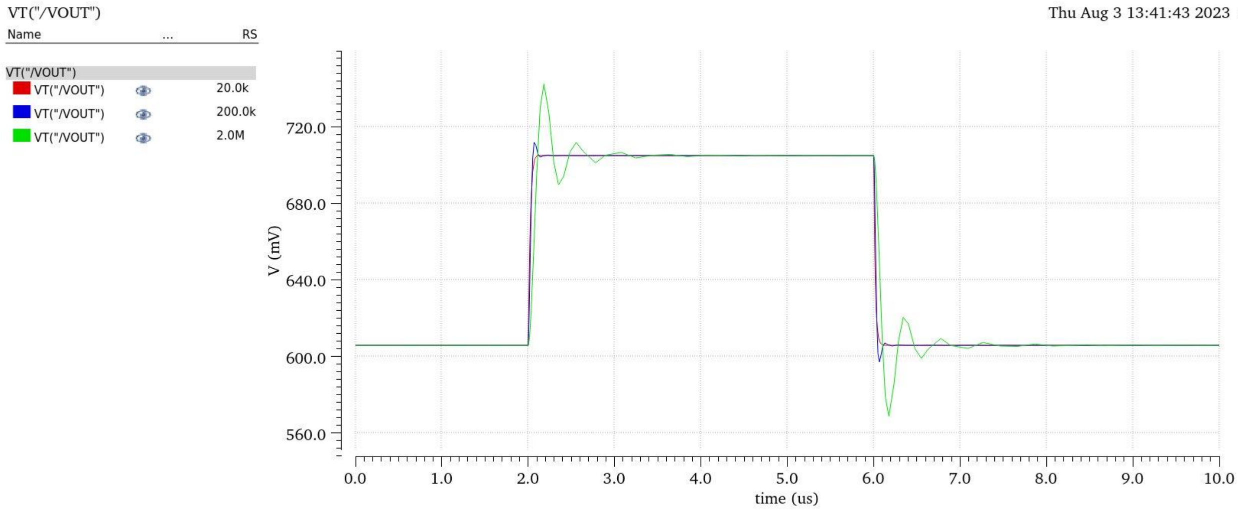


Figure 19 parametric sweep: Rsig = 20k, 200k, 2M.

Point	Test	Output	Nominal	Spec	Weight	Pass/Fail
Filter	Filter	Filter	Filter	Filter	Filter	Filter
Parameters: RS=20K						
1	lab4_lab4_1	VT("/VOUT")				
1	lab4_lab4_1	VT("/VIN")				
1	lab4_lab4_1	overshoot(VT("/...	0			
Parameters: RS=200K						
2	lab4_lab4_1	VT("/VOUT")				
2	lab4_lab4_1	VT("/VIN")				
2	lab4_lab4_1	overshoot(VT("/...	5.618			
Parameters: RS=2M						
3	lab4_lab4_1	VT("/VOUT")				
3	lab4_lab4_1	VT("/VIN")				
3	lab4_lab4_1	overshoot(VT("/...	36.58			

Figure 20 overshoot values

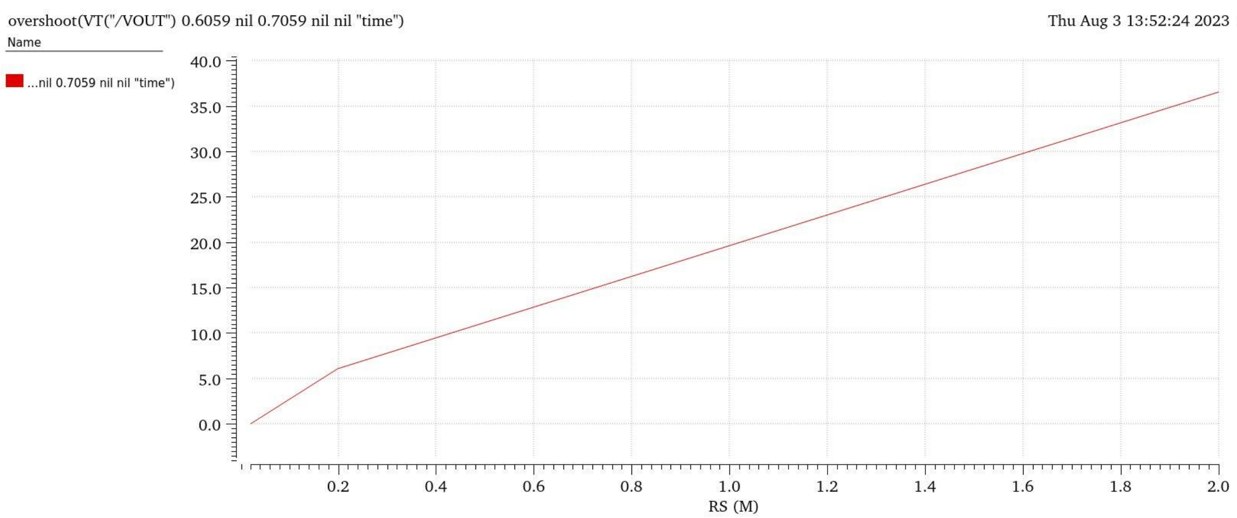


Figure 21 plot overshoot vs RSIG

Comment: as R_{SIG} increases peak overshoot increases for the reason in ac analysis.

4. $Zout$ (Inductive Rise)

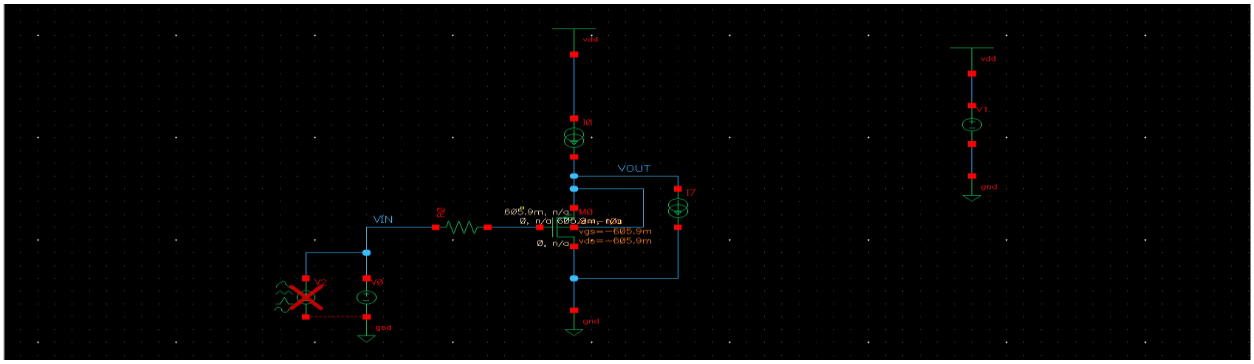


Figure 22 schematic

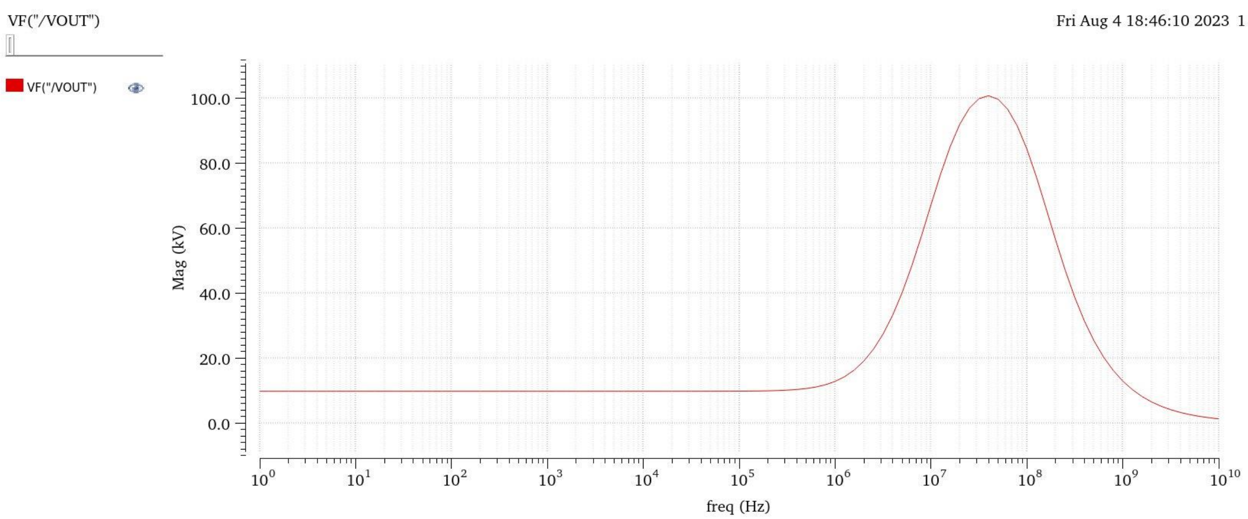


Figure 23 plot zout magnitude

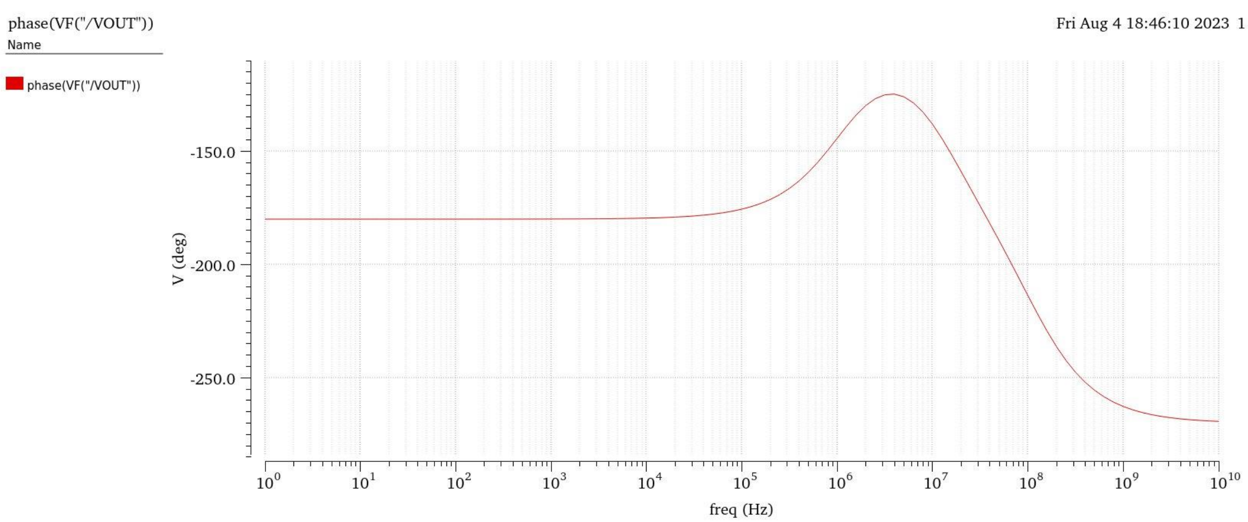


Figure 24 plot zout phase

3)Yes, there is inductive rise reason is analysis below.

$$Z_{OUT} = \frac{V_X}{I_X} = \left(\frac{1 + sR_{SIG}C_{gs}}{1 + s\frac{C_{gs}}{gm}}\right) * \frac{1}{gm}$$

And r_o $added\ parallel\ to\ Z_{OUT}$

$$Z_{OUT} = \frac{V_X}{I_X} = \left(\left(\frac{1 + sR_{SIG}C_{gs}}{1 + s\frac{C_{gs}}{gm}}\right) * \frac{1}{gm}\right)||r_o$$

At low frequency $Z_{OUT} \approx \frac{1}{gm}$

At high frequencies $Z_{OUT} = R_{SIG}$

Thus, by increasing frequency there would be inductive rise in Z_{OUT} *until it falls as shown in figure.*

4)Z_{OUT} *will fall at very high frequency we have* C_{gd} *in parallel with* R_{SIG}

$R_{eq} = R_{SIG}||C_{gd} = \frac{R_{SIG}}{1+sC_{gd}R_{SIG}}$

At low frequency $R_{eq} \approx R_{SIG}$

At high frequency $R_{eq} \approx \frac{1}{s\,C_{gd}}$ *which is causes a drop in output impedance since* C_{gd} $is\ very\ small.$

5) $Z_{OUT} = \frac{V_X}{I_X} = \left(\left(\frac{1+sR_{eq}C_{gs}}{1+s\frac{C_{gs}}{gm}}\right) * \frac{1}{gm}\right)||r_o = \frac{1+sR_{eq}C_{gs}}{gm+sC_{gs}}||r_o$

As $R_{eq} = R_{SIG}||C_{gd} = \frac{R_{SIG}}{1+sC_{gd}R_{SIG}}$

After simplification

$$Z_{OUT} = \frac{\left(1+sC_{gs}\frac{R_{SIG}}{1+sC_{gd}R_{SIG}}\right)r_o}{\left(1+sC_{gs}\frac{R_{SIG}}{1+sC_{gd}R_{SIG}}\right)+\left(1+s\frac{C_{gs}}{gm}\right)gmr_o}$$

$$F_{ZERO} = \frac{1}{2\pi(C_{gs}+C_{gd})R_{SIG}} = 1.228MMHZ$$

$$W_{PD} = \frac{gm+\frac{1}{r_o}}{C_{gs}+R_{SIG}C_{gs}\frac{1}{r_o}+R_{SIG}C_{gd}(gm+\frac{1}{r_o})} = \qquad F_{pd} = \frac{W_{PD}}{2\pi} = 12.3MHZ$$

To get second pole I have simplify equation by ignore C_{gd} $because\ equation\ will\ be\ complex.$

$$Z_{OUT\_SIMPLE} = \frac{1 + sR_{SIG}C_{gs}}{g_m + sC_{gs} + sg_{ds} + sR_{SIG}g_{ds}C_{gs}}$$

$$W_{P2} = \frac{gm1 + gds1}{C_{gs} + C_{gs}R_{SIG}gds} \qquad F_{P2} = \frac{W_{P2}}{2\pi} = 103.72MHZ$$

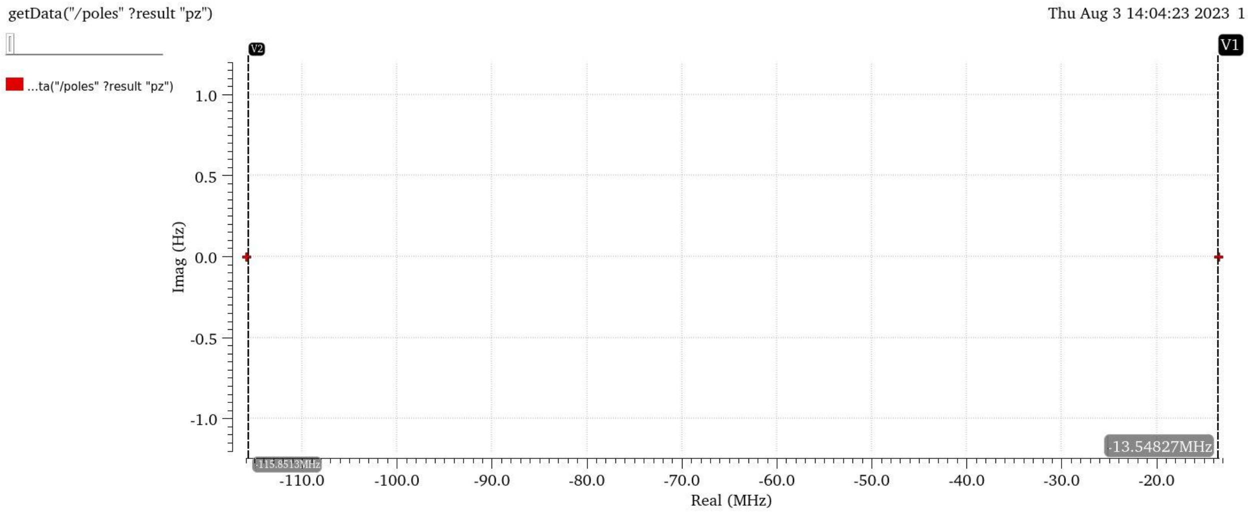


Figure 25 POLES

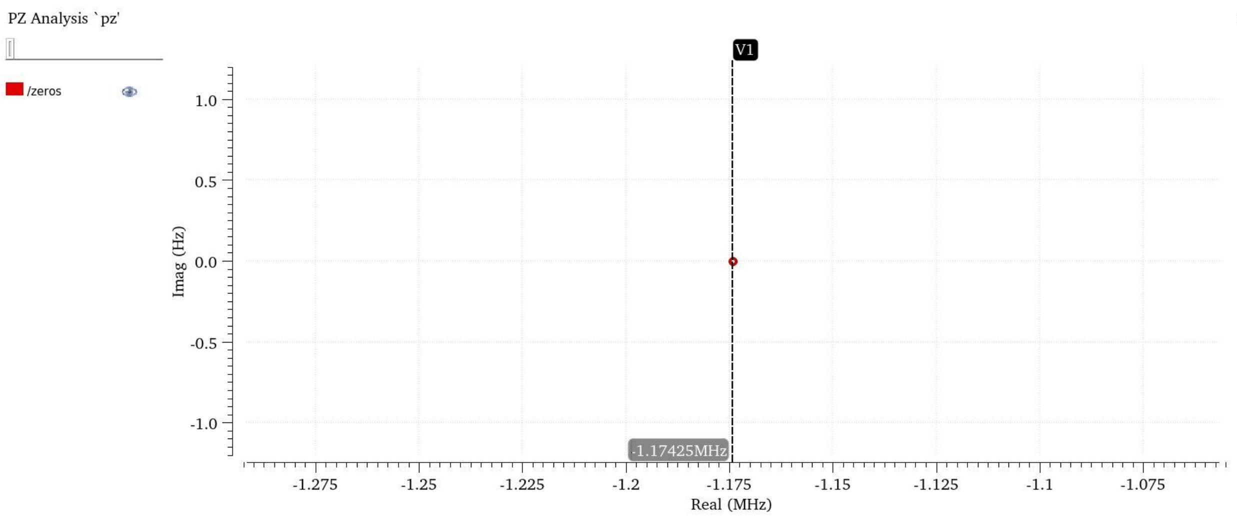


Figure 26 ZEROS

	Simulator	Hand analysis
Zero	1.17MHZ	1.228MHZ
Dominant pole	13.54MHZ	12.3MHZ
Non dominant pole	115.85MHZ	103.72MHZ

The reason of this different the approximation when calculate the zeros and poles because equation will be complex, I used simplify equations in the lecture, and section notes.

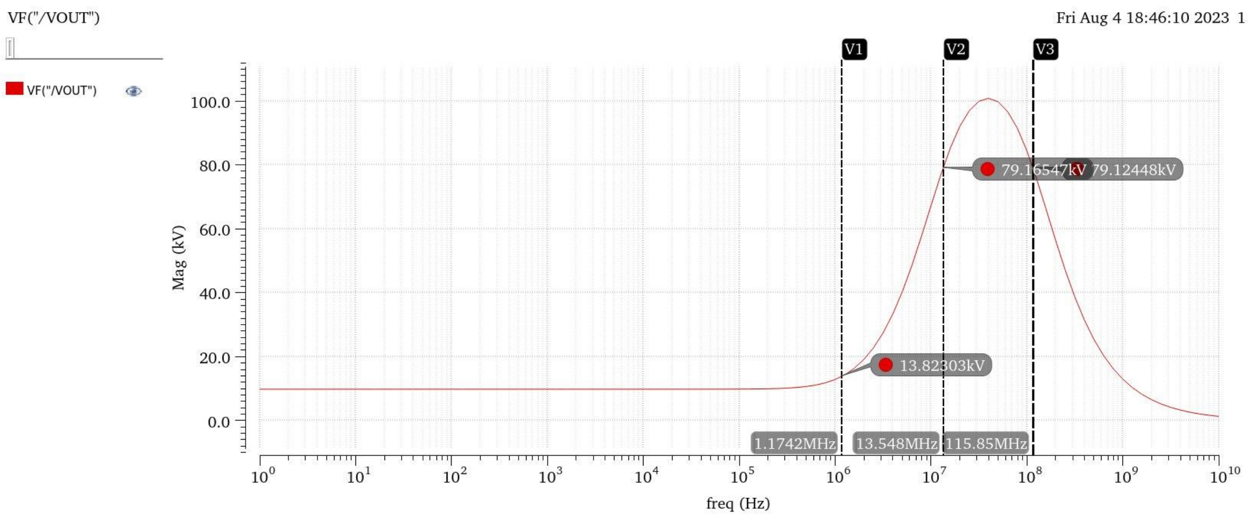


Figure 27 zout at zereos and poles