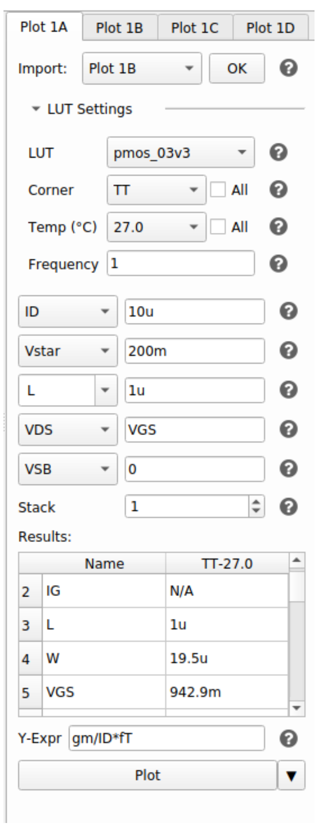
Lab 04

PART 1: Sizing chart:

- **parameters:**

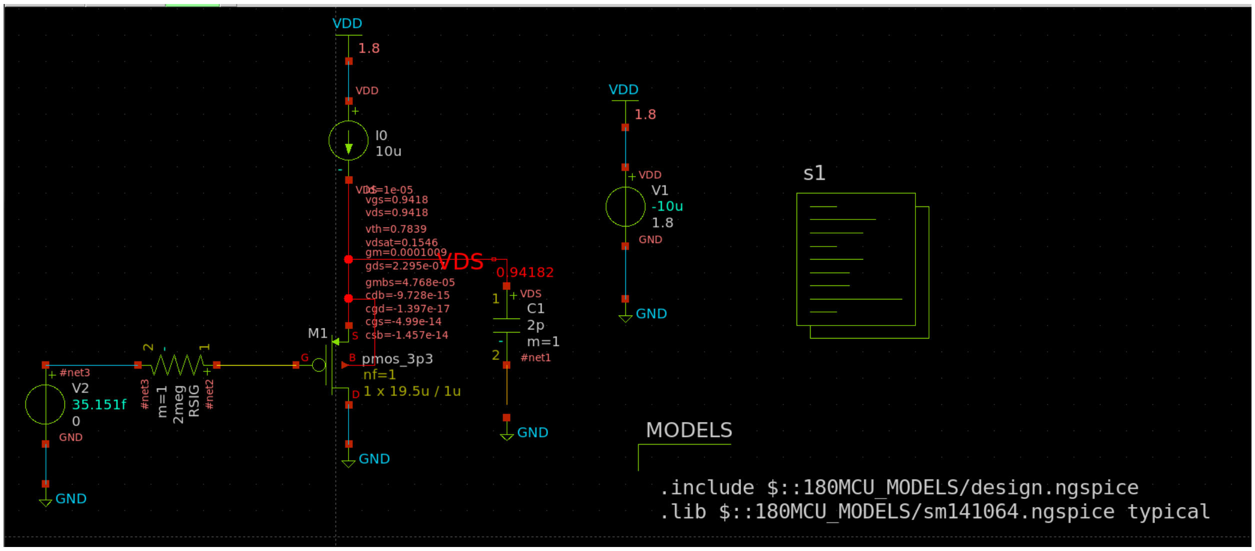
Parameter	value
L	$1\mu m$
$\boldsymbol{V^*}$	$200mV$
DC input voltage	$0V$
Supply	$1.8V$
Current	$10\mu A$

➢ We put that VDS=VGS as drain and gate are connected to ground. Now we will use the sizing assistant to get the width. We got $W = 19.5\mu m$.



PART 2: CD Amplifier:

1. Schematic and OP Analysis:



- **Check that the transistor operates in saturation:**

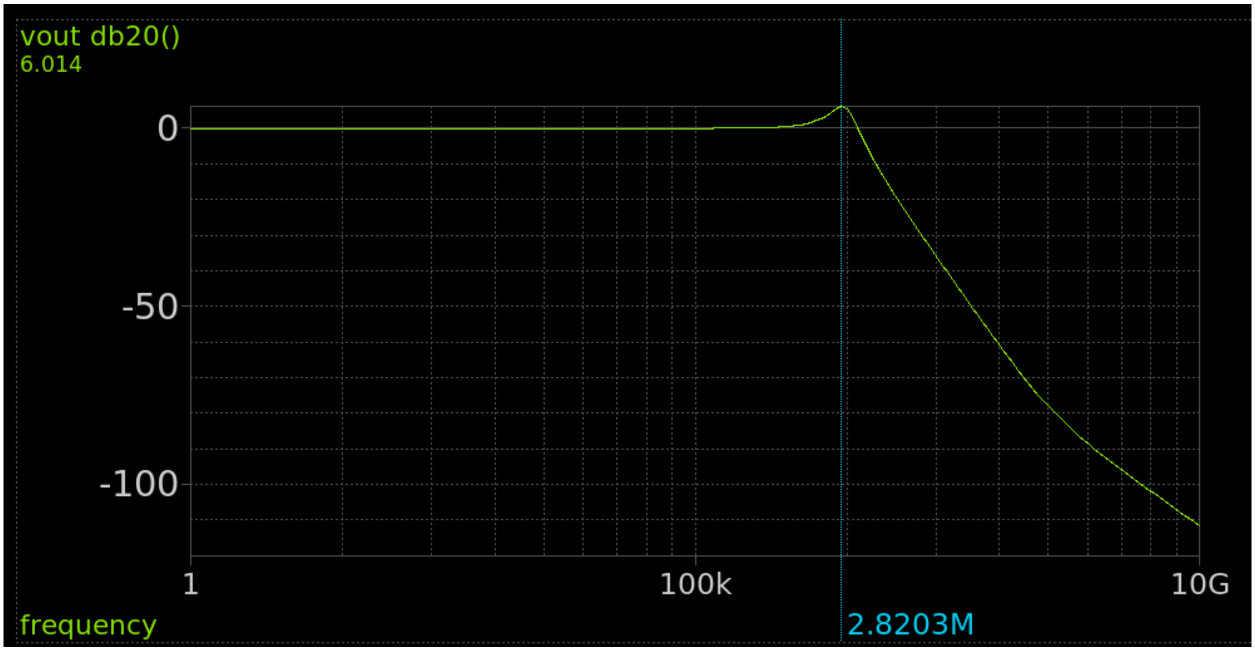
  The transistor is in saturation as (VDS=0.9418)> (VDSsat=0.1546).

2. AC Analysis:

- **Bode plot magnitude (in db):**

- **Do you notice frequency domain peaking? How much is the peaking?**

Yes, there is peaking at $f = 2.82\ MHz$, and its value graphically is 6dB.



Expression to calculate peaking: meas ac peaking MAX vmag(vout) FROM=1 TO=10G.

```
No. of Data Rows : 201
peaking               =  1.999430e+00 at=  2.818383e+06
```

- **Analytically calculate the quality factor (use approximate expressions). Is the system underdamped or overdamped?**

  $b1 = C_{gd} * R_{sig} + \frac{C_{gs}+C_L}{g_m} = 1.98 * 10^{-8} \approx 2 * 10^{-8}$

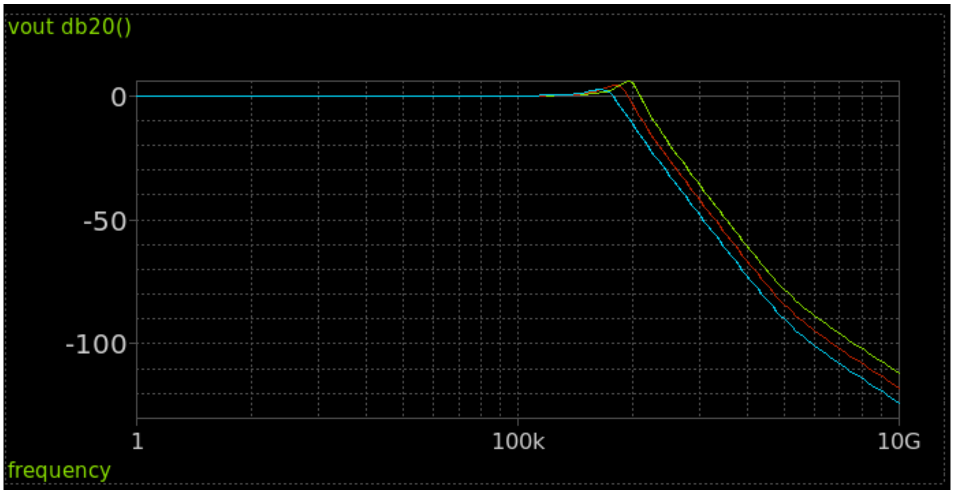
  $b2 = \frac{(C_{gd}+C_{gs})C_L + C_{gs}C_{gd}}{g_m} * R_{sig} = 1.978 * 10^{-15} \approx 2 * 10^{-15}$

  $Q = \frac{\sqrt{b2}}{b1} = 2.236$

  The system is under damped as Q > 0.5.

  Note: I used the caps values from xschem.

- **Perform parametric sweep: CL = 2p (green), 4p (red), 8p (blue).**
  - **Report Bode plot magnitude overlaid on same plot:**



  - **Report the peaking vs CL:**

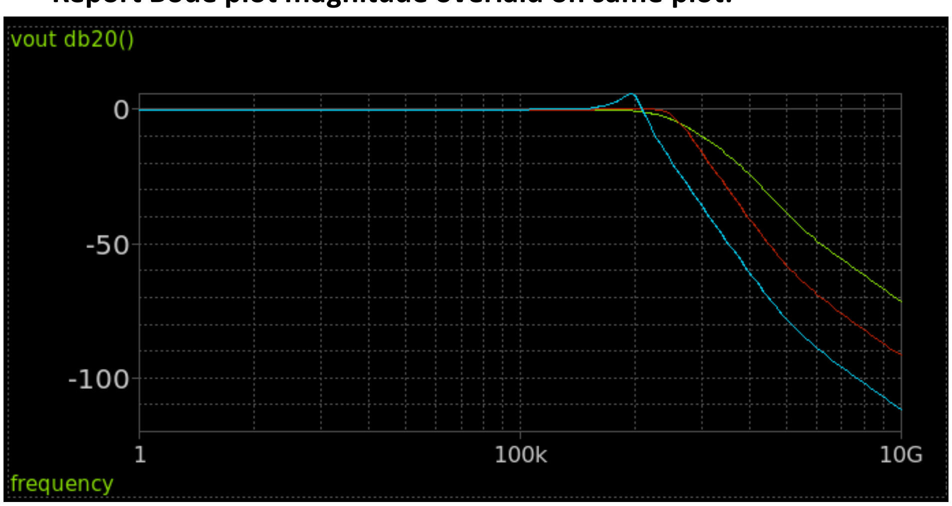
CL	Peaking on linear scale
$2pF$	2
$4pF$	1.65
$8pF$	1.32

  - **Comment on results:**

    when CL increases both b1 and b2 approximately increase linearly but we know that $Q = \frac{\sqrt{b2}}{b1}$ then Q decrease then the peaking decreases as Q gets closer to 0.707.

    also the $\omega_o = \frac{1}{\sqrt{b2}}$ so the frequency at which peaking happens decreases.

- **Perform parametric sweep: Rsig = 20k (green), 200k (red), 2M (blue):**
  - **Report Bode plot magnitude overlaid on same plot:**



- **Report the peaking vs RSIG:**

Rsig	Peaking on linear scale
$\boldsymbol{20k\Omega}$	0.997
$\boldsymbol{200k\Omega}$	1.015
$\boldsymbol{2M\Omega}$	2

- **Comment on results:**

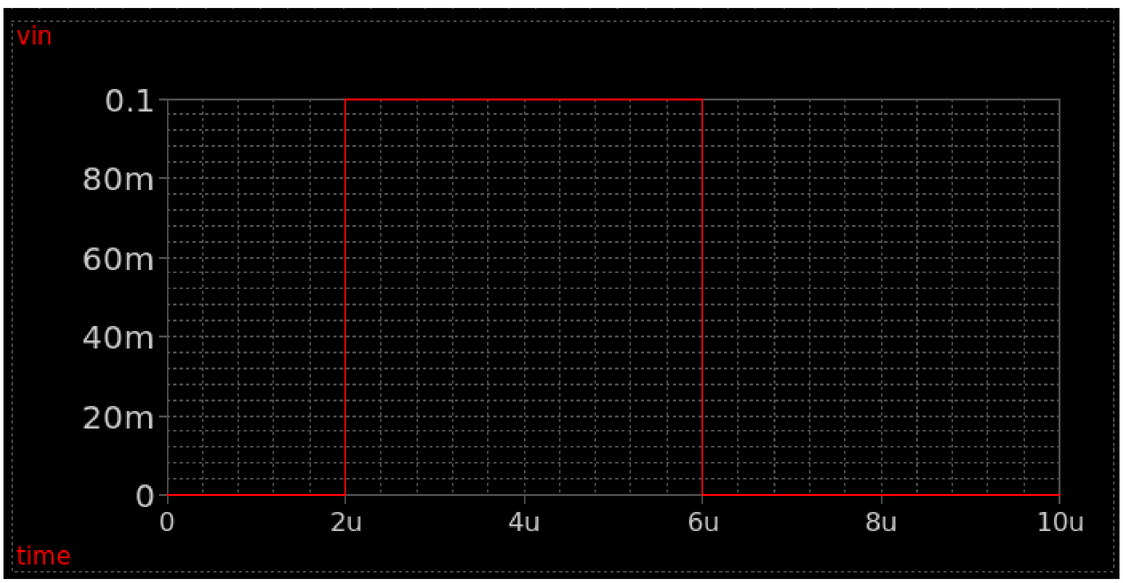
  When we increase Rsig we increase b2 linearly but b1 increase but not with the same magnitude and we know $Q = \frac{\sqrt{b2}}{b1}$ so Q increases then peaking has a higher value.

  For $\omega_o = \frac{1}{\sqrt{b2}}$ and b2 increases so the frequency at which peaking happens decreases.

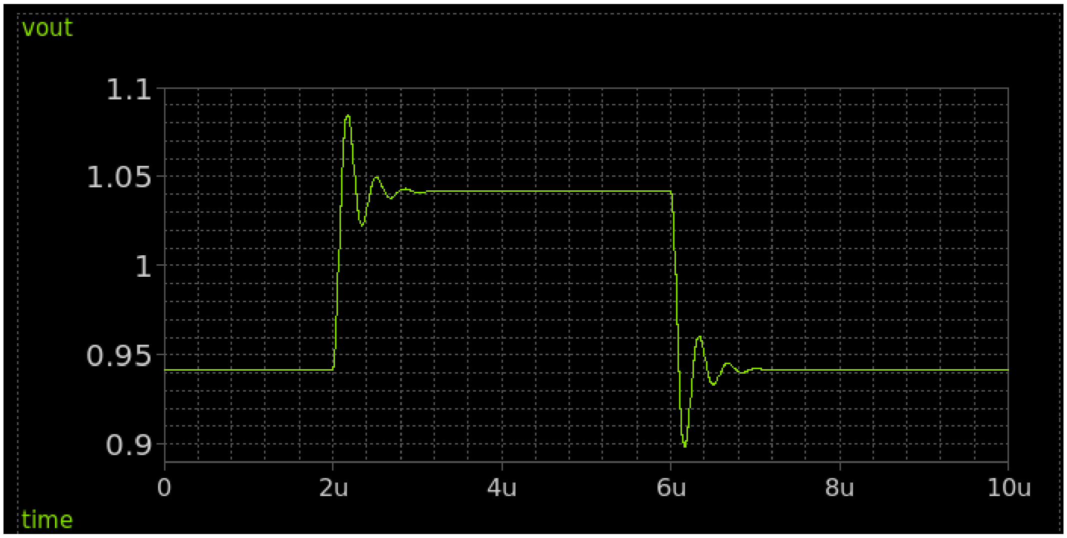
3. Transient Analysis:

➢ **Report Vin and Vout overlaid vs time**:

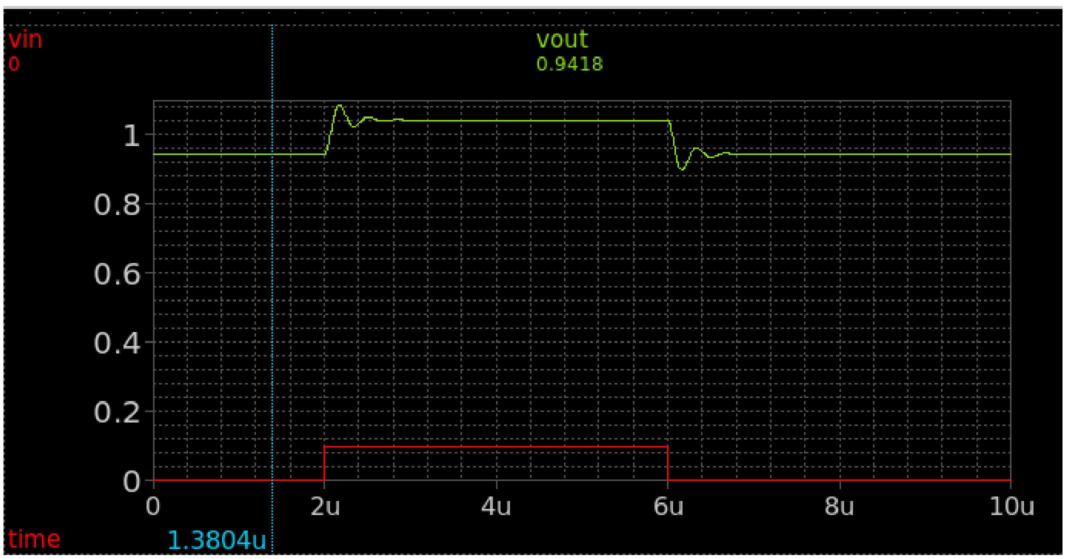
- **Vin Vs time**:



- **Vout Vs time**:



- **Vin and Vout Vs time overlaid**:



➢ **What is the relation between the DC shift and VGS of the transistor? How to shift the signal down instead of shifting it up?**

The DC shift from the graph is 0.9418 V which equals the VSG of the transistor.

To shift the signal down we can use CD NMOS transistor.

➢ **Do you notice time domain ringing? How much is the overshoot?**

Yes, there is ringing in time domain.

Expression to calculate overshoot:

meas tran V_peak MAX v(vout) FROM=2u TO=4u

meas tran V_normal FIND v(vout) AT=5u

meas tran V_min MIN v(vout) FROM=0 TO=1.5u

let overshoot = (V_peak-V_normal)*100/(V_normal-V_min) print overshoot

the value of overshoot=43.1%

```
v_peak                  =  1.084609e+00 at=  2.171160e-06
v_normal                =  1.041602e+00
v_min                   =  9.418202e-01 at=  9.280000e-08
overshoot = 4.310105e+01
```

- **Perform parametric sweep: CL = 2p, 4p, 8p**:
  - **Report Bode plot magnitude overlaid on same plot:**

  - **Report the peaking vs CL:**

CL	overshoot
$2pF$	43.1%
$4pF$	34.2%
$8pF$	22.59%

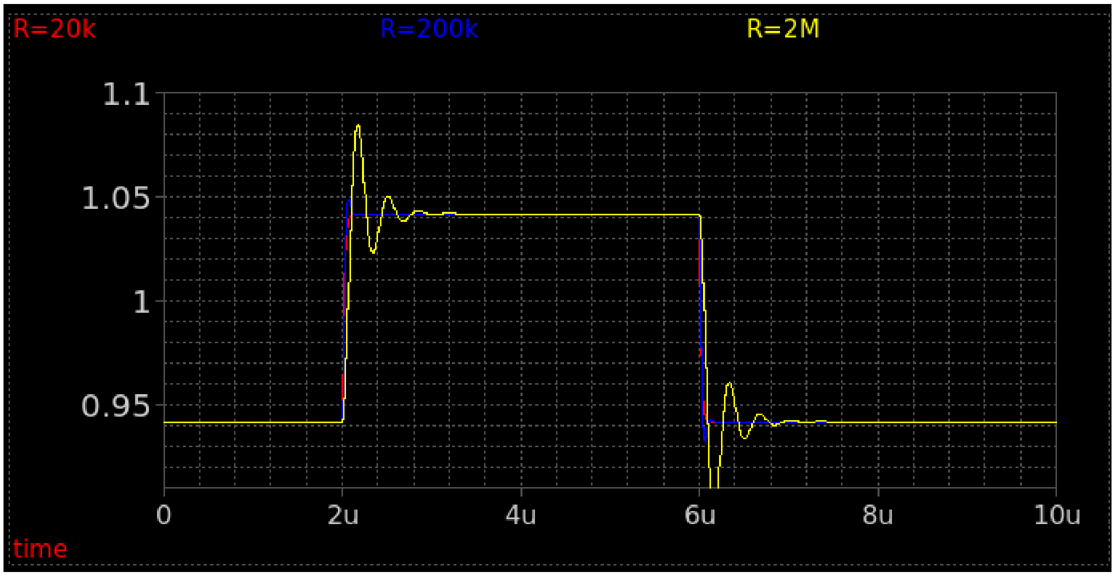
  - **Comment on results:**

When CL increases Q decreases (proved in p.4) and we know that

$overshoot = 100 * e^{\frac{-\pi}{\sqrt{4Q^2-1}}}$ so the exponent increases with a negative value which decreases the overshoot.

➢ **Perform parametric sweep: Rsig = 20k, 200k, 2M:**

- **Report Bode plot magnitude overlaid on same plot:**



- **Report the peaking vs RSIG:**

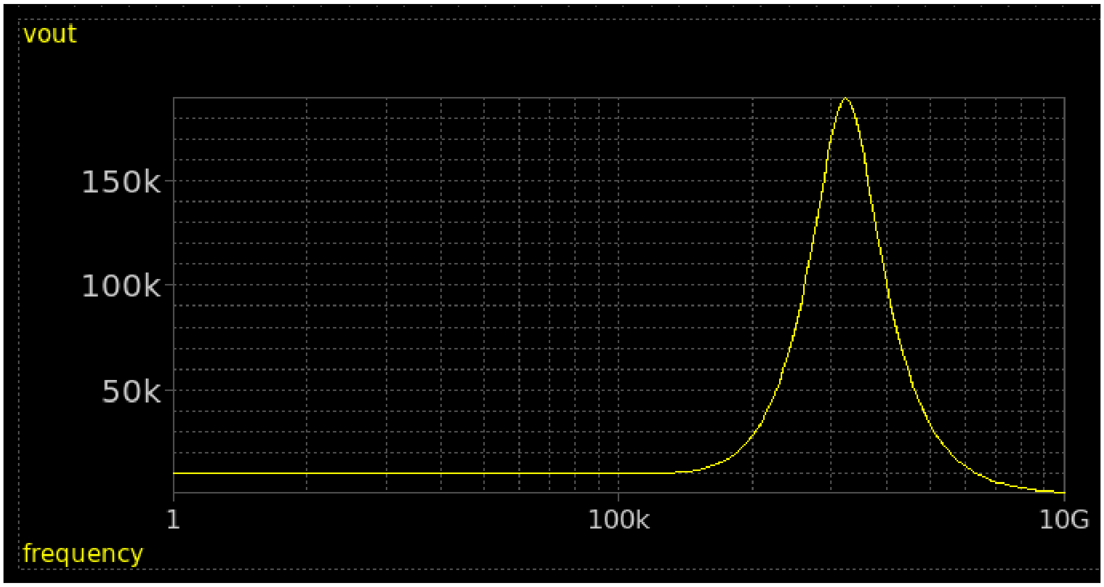
Rsig	Overshoot
$\mathbf{20k\Omega}$	0
$\mathbf{200k\Omega}$	6.72%
$\mathbf{2M\Omega}$	43.1%

- **Comment on results:**

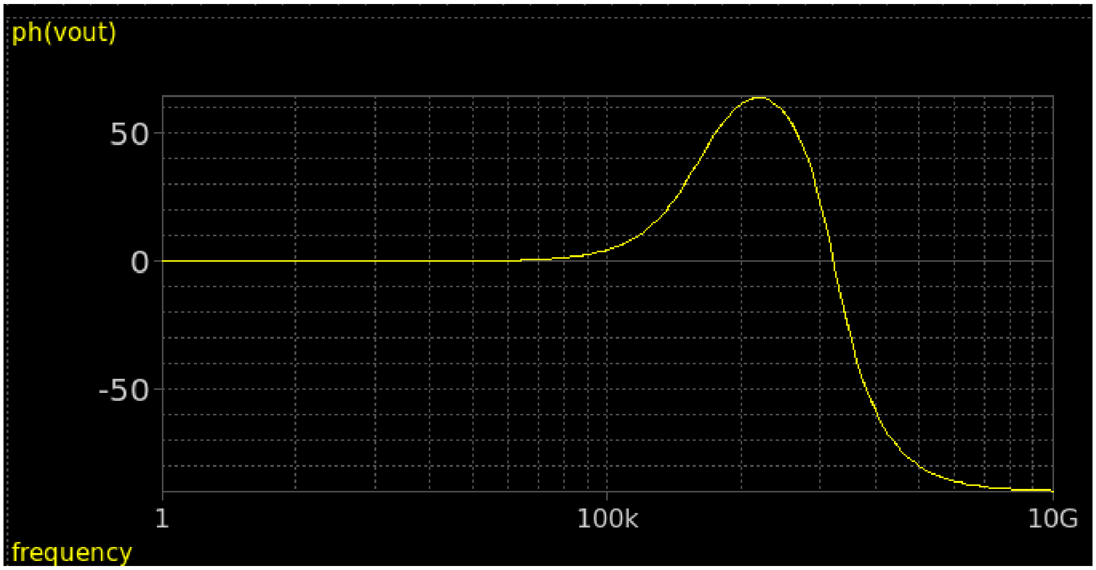
When we increase Rsig Q increases (proved in p.5) and we know that $overshoot = 100 * e^{\frac{-\pi}{\sqrt{4Q^2-1}}}$ then the exponent decreases with negative value so overshoot increses.

4. $Zout$ (Inductive Rise):

- **Plot the output impedance (magnitude and phase) vs frequency. Do you notice an inductive rise? Why?**
  - Magnitude:



  - Phase:



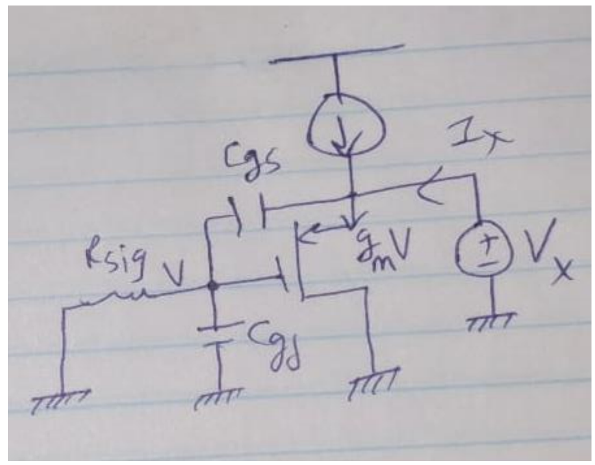
Yes, there is an inductive rise as the CD acts as an inductor, its output impedance increases in this region and also the phase which is like the inductor exactly and the reason for that is that usually the pole comes at a higher frequency than the zero so the zero increases the magnitude and phase like an inductor.

- **Does $Zout$ fall at high frequency? Why?**

  Yes, it falls at high frequencies as $Zout = \frac{1}{g_m} * \frac{1+sC_{gs}*R_{sig}}{1+\frac{sC_{gs}}{g_m}}$ and at high frequencies the impedance of Cgd decreases a lot and Cgd is parallel with Rsig so Zout decreases.

- **Analytically calculate the zeros, poles, and magnitude at low/high frequency for $Zout$. Compare with simulation results in a table:**

  we will not consider ro as it will be parallel with what we will calculate



  Note: it is not professorial to put hand drawn but I added it to demonstrate the symbols.

  Analysis:

  we know that $\mathrm{Vgs} = \frac{Vx}{\frac{1}{sCgs}+Zsig} * \frac{-1}{\mathrm{sCgs}}$

  Doing kcl at the source node we find

  $\mathrm{Ix} = \frac{Vx}{\frac{1}{sCgs}+Zsig} * \frac{\mathrm{gm}}{\mathrm{sCgs}} + \frac{Vx}{\frac{1}{sCgs}+Zsig}$

  Where $Zsig = Rsig // \frac{1}{\mathrm{sCgd}}$

  Then $Zout = \frac{1+(Cgs+Cgd)*sRsig}{(gm+sCgs)*(1+sCgdRsig)}$

  We will use values of capacitors from ADT Cgs=53.16 fF and Cgd=3.113fF

We have zero at $f = \frac{1}{2\pi*(Cgs+Cgd)*Rsig} = 1.4\ MHz$

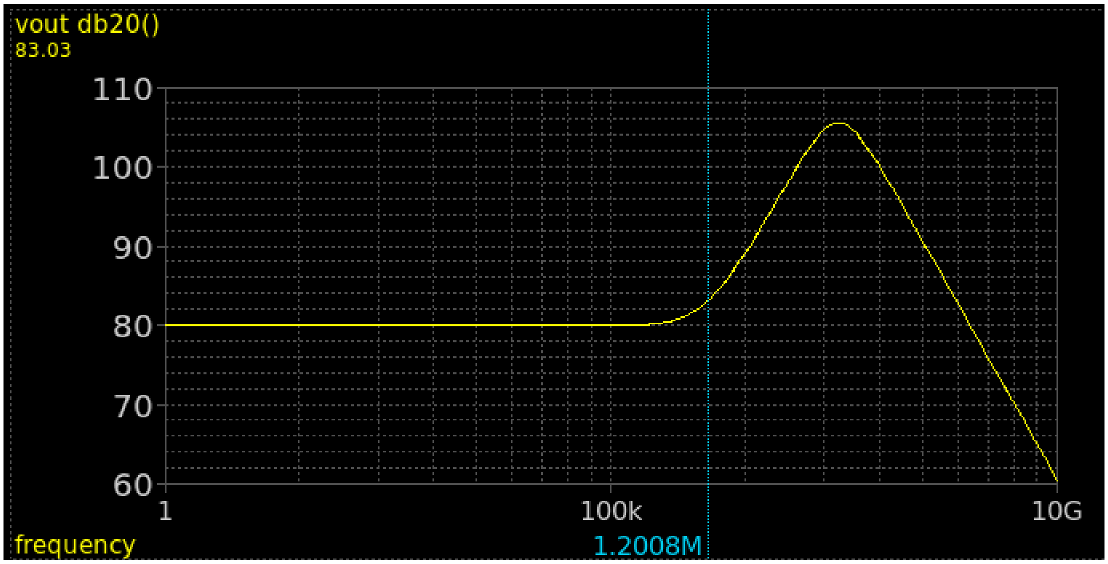
We have a pole at $f = \frac{gm}{2\pi*Cgs} = 302\ MHz$

We have a pole at $f = \frac{1}{Rsig*Cgd} = 25.56MHz$

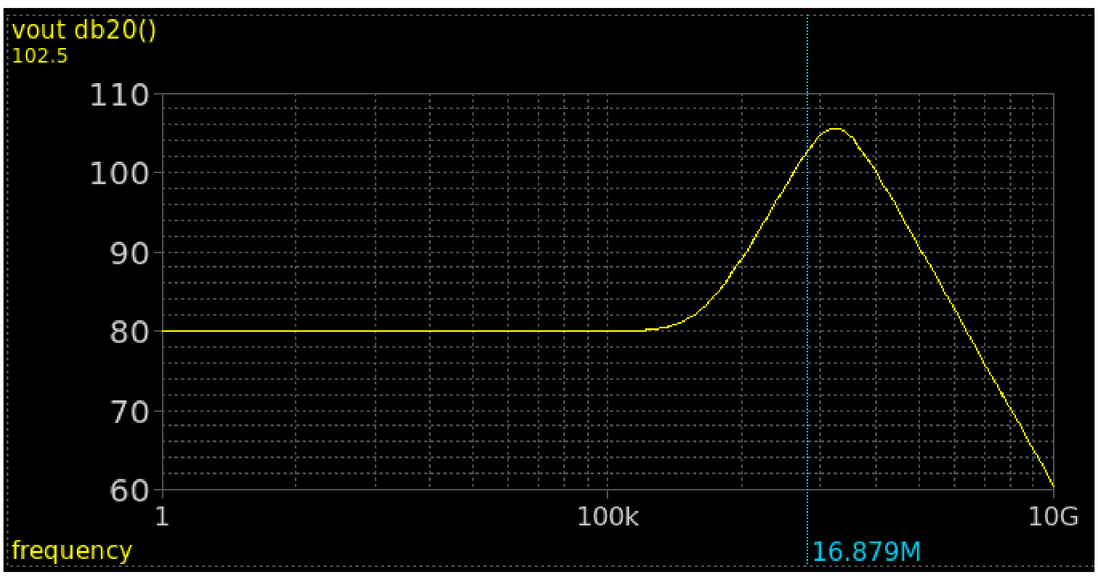
To get Zout at low frequencies we will put s=0 then $Zout = \frac{1}{gm} = \frac{1}{0.0001009} = 9.9k\Omega$.

At high frequencies at the peak we know that$sCgdRsig$>>1 and $(Cgs + Cgd) * sRsig$>>1 and $\frac{sCgs}{gm} << 1$ then we have $\mathrm{Zout} = \frac{\mathrm{Cgs+Cgd}}{\mathrm{gm*Cgd}} = 179.155\mathrm{K}\Omega$.

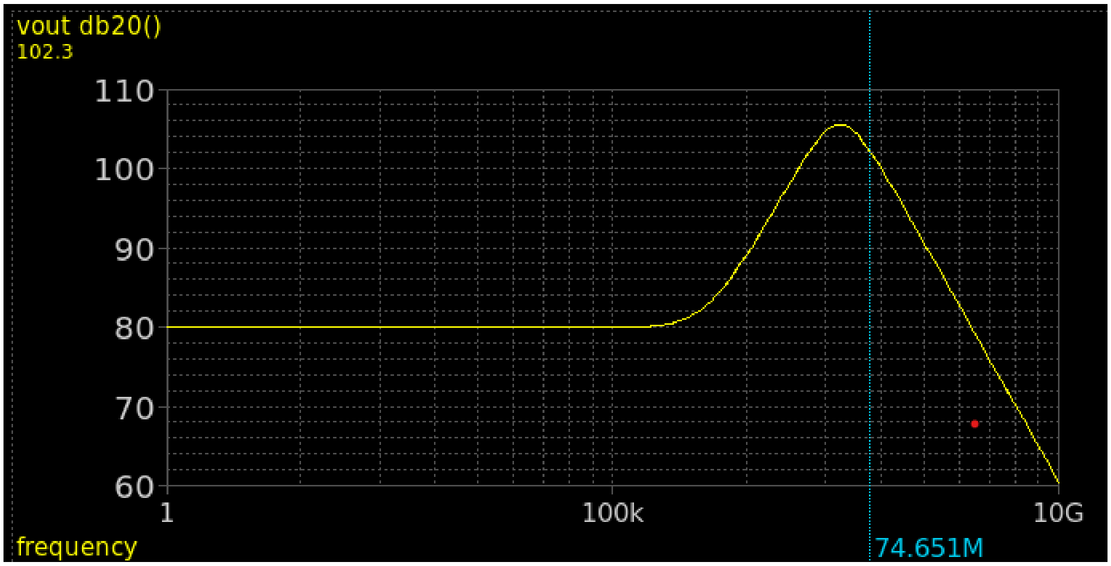
- **Simulation results:**
  - Zero:



  - First pole:



- Second pole:



parameter	Hand Analysis	simulation
zero frequency	$1.4MHz$	$1.2MHz$
First pole frequency	$25.56MHz$	$16.88MHz$
Second pole frequency	$302MHz$	$74.65MHz$
Zout at low frequencies	$9.9K\Omega$	$9.885K\Omega$
Zout at high frequencies	$179.155K\Omega$	$188K\Omega$

Note: the calculations aren't accurate I tried also the code that was sent and got bad results roo at calculating poles and zeros.

The error is in the calculations as we neglected Cgd and ro so the second pole wasn't accurate in the analysis.

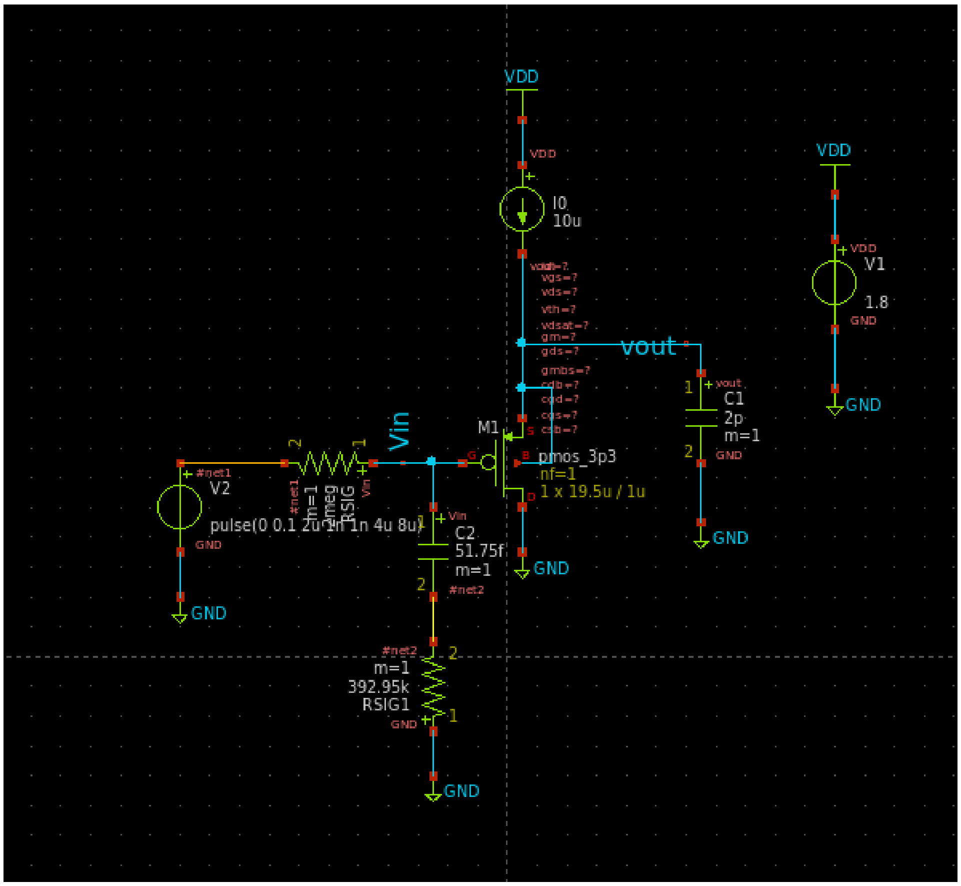
5. [Optional] How to solve the peaking/ringing problem?

We can use compensation network of a series R and C to compensate the effect of negative input impedance and we can calculate the values of them by the following equations:

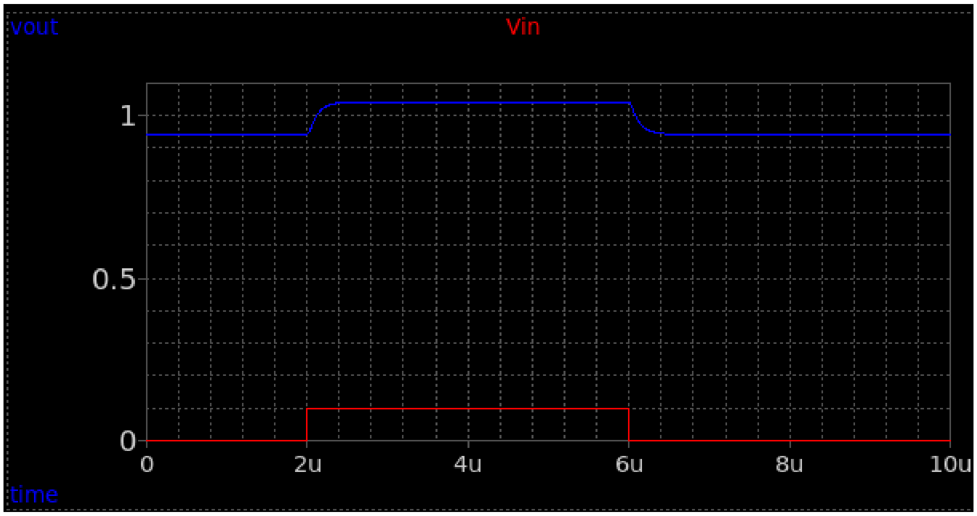
$$C = \frac{gm\ Cgs\ CL}{(gm+Cgs)*(Cgs+CL)} = 51.75fF \qquad \text{Note: Gs=0}$$

$$R = \frac{(Cgs+CL)^2}{(gm*Cgs*CL)} = 392.95K\Omega$$

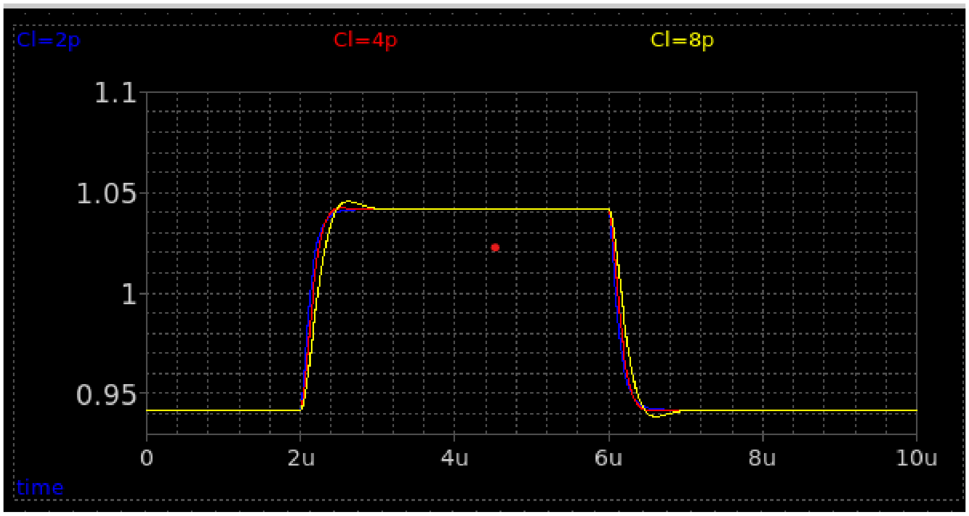
- Schematic:



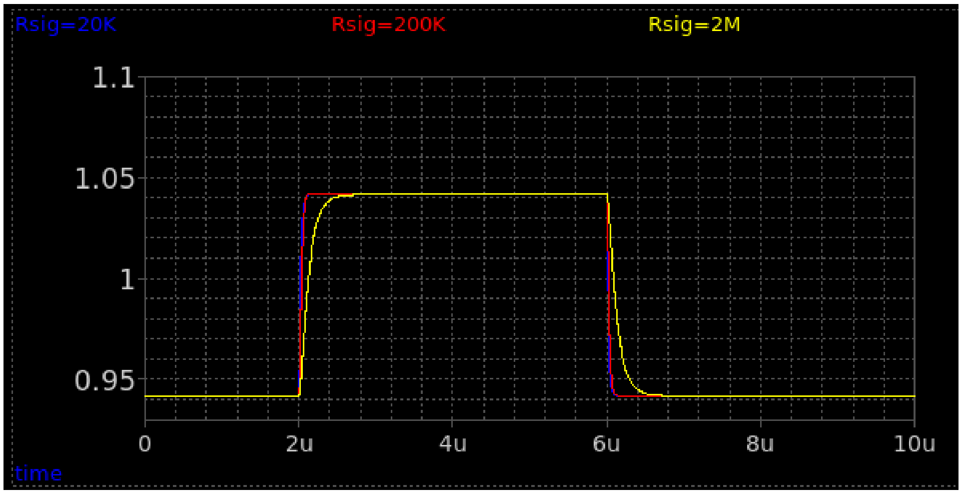
- We will study ringing and the same will happen to peaking as peaking is the same effect but in frequency domain.
- At $Rsig = 2M\Omega$ and $CL = 2pF$



  - Sweeping CL to see the effect on other values:



- Sweeping Rsig to see the effect on other values:



- We can find from the previous graphs that the ringing disappears or reduces a lot compared to the circuit without the compensation circuit.