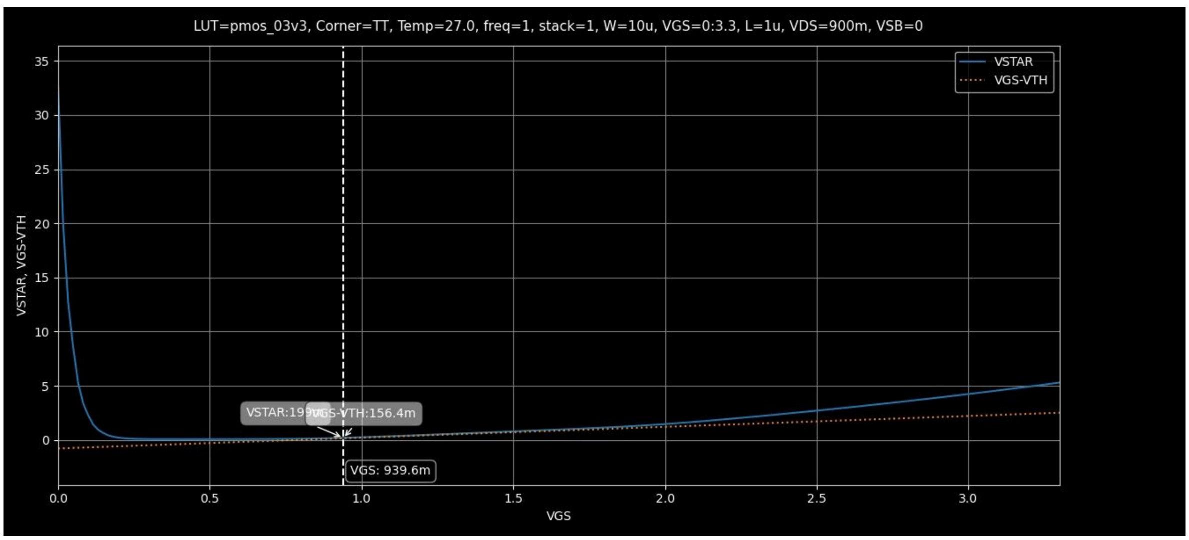
CMOS AIC design - ITI - Lab 4

Part 1: Sizing Chart Using ADT SA

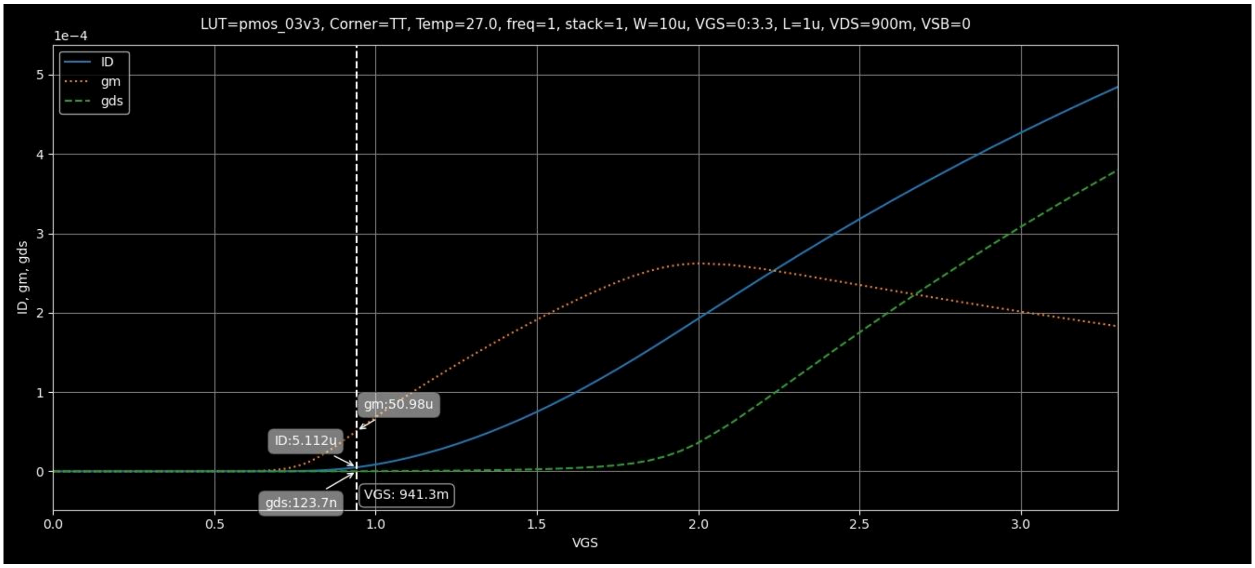
- An often used sweet-spot that provides good compromise between different trade-offs is $V^* = 200mV$. On the V^* and V_{OV} chart locate the point at which $V^* = 200mV$. Find the corresponding V_{OVQ} and V_{GSQ}.



V and Vov vs VGS*

$$V_{OVQ} \approx 160mV,\ V_{GSQ} \approx 940mV.$$

- Plot I_D, g_m and g_{ds} vs V_{GS}. Find their values at V_{GSQ}. Let's name these values I_{DX}, g_{mX} and g_{dsX}.



ID, gm, gds vs VGS

$$I_{DX} \approx 5uA,\ g_{mX} \approx 50uS,\ g_{dsX} \approx 125nS.$$

- Now back to the assumption that we made that $W = 10\mu m$. This is not the actual value that we will use for our design. But the good news is that I_D is always proportional to W irrespective of the operating region and the model of the MOSFET (regardless square-law is valid or no). Thus, we can use ratio and proportion (cross-multiplication) to determine the correct width at which the current will be $I_{DQ} = 10uA$ as given in the specs. Calculate W as shown below.

$W = 10um$	$W_{actual} = ??$
$I_D = 5uA$	$I_D = 10uA$

$$W_{actual} \approx 20um.$$

- Now we are almost done with the design of the amplifier. Note that g_m is also proportional to W as long as V_{OV} is constant. On the other hand, $r_o = 1/g_{ds}$ is inversely proportional to $W(I_D)$ as long as L is constant. Before leaving this part, calculate g_{mQ} and g_{dsQ} using ratio and proportion (cross-multiplication).

$W = 10um$	$W = 20um$
$g_m = 50uS$	$g_{mQ} =??$

$g_{mQ} \approx 100uS.$

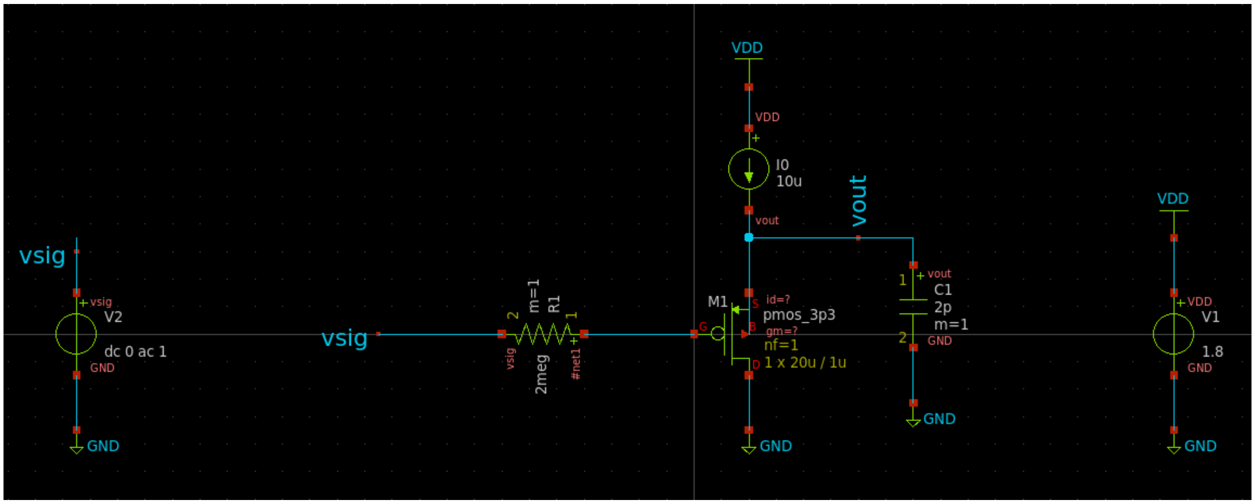
$W = 10um$	$W = 20um$
$g_{ds} = 125nS$	$g_{dsQ} =??$

$g_{dsQ} \approx 250nS.$

Part 2: CD Amplifier

1. OP (Operating Point) Analysis

- Create a new schematic for the CD amplifier (the schematic is not included in the lab document and is left for the student as an exercise). Use a PMOS and use a $10uA$ ideal current source for biasing (note that the current source will be connected to the source terminal). Connect the source to the bulk. Use $L = 1\mu m$ and W as determined in Part 1. Use $C_L = 2pF, R_{sig} = 2M\Omega$, (in xschem resistor, use “value =2 meg”, and a DC input voltage $= 0V$.

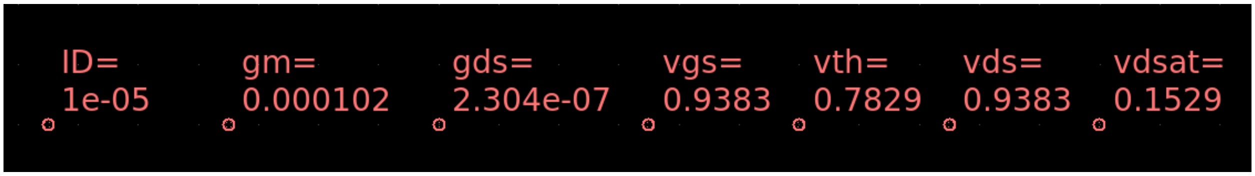


Required schematic

- Simulate the OP point. Report a snapshot clearly showing the following parameters using the following code (in another “code_shown” dedicated for simulations only).

device	m.xm1.m0
model	pmos_3p3.13
gm	0.000101952
gds	2.30032e-07
id	1e-05
vgs	0.939892
vth	0.784486
vds	0.939892
vdsat	0.152948
gmbs	4.81794e-05
cdb	-9.96716e-15
cgd	-1.42526e-17
cgs	-5.11101e-14
csb	-1.49263e-14

Required parameters



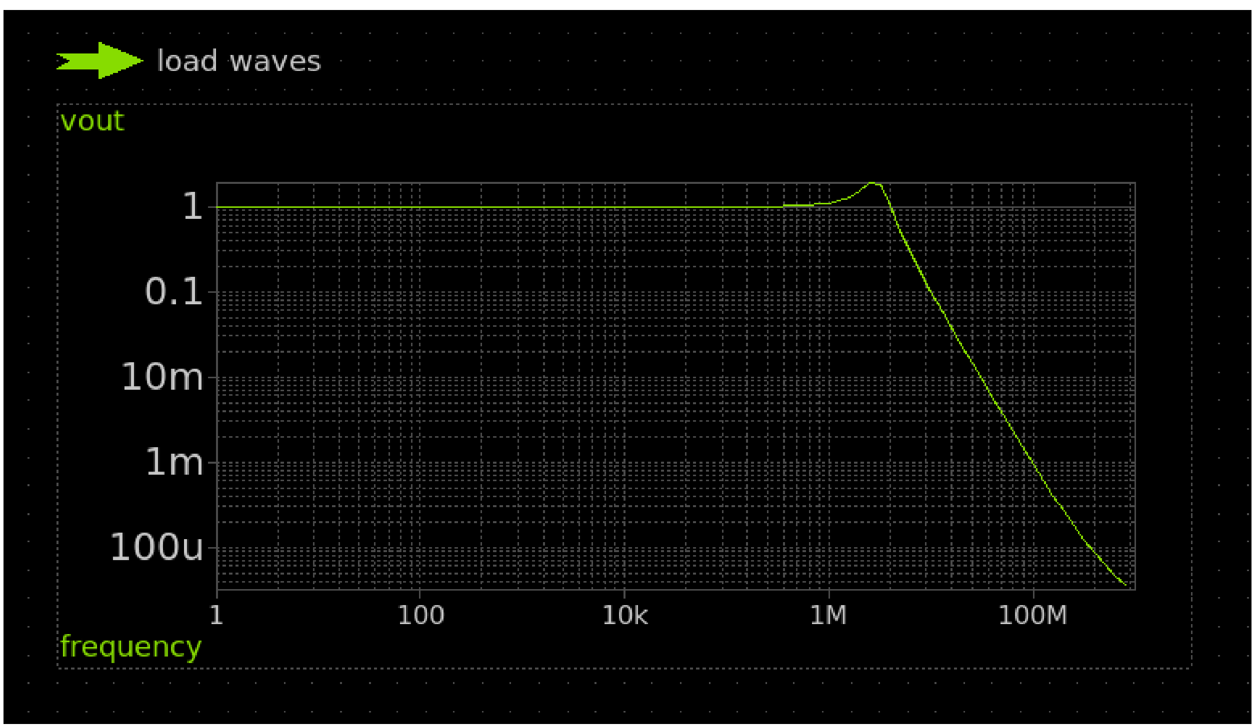
Parameter annotation

- Check that the transistor operates in saturation.

V_{DS}	V_{Dsat}	$Sat??$
$0.93V$	$0.15V$	Yes

2. AC Analysis

- Create a new simulation configuration and run AC analysis (from 1Hz to 1GHz) (For ignoring previous code, add ** in the beginning of each line. Always let .control and .endc) Report Bode plot magnitude in dB vs frequency.



Bode mag plot

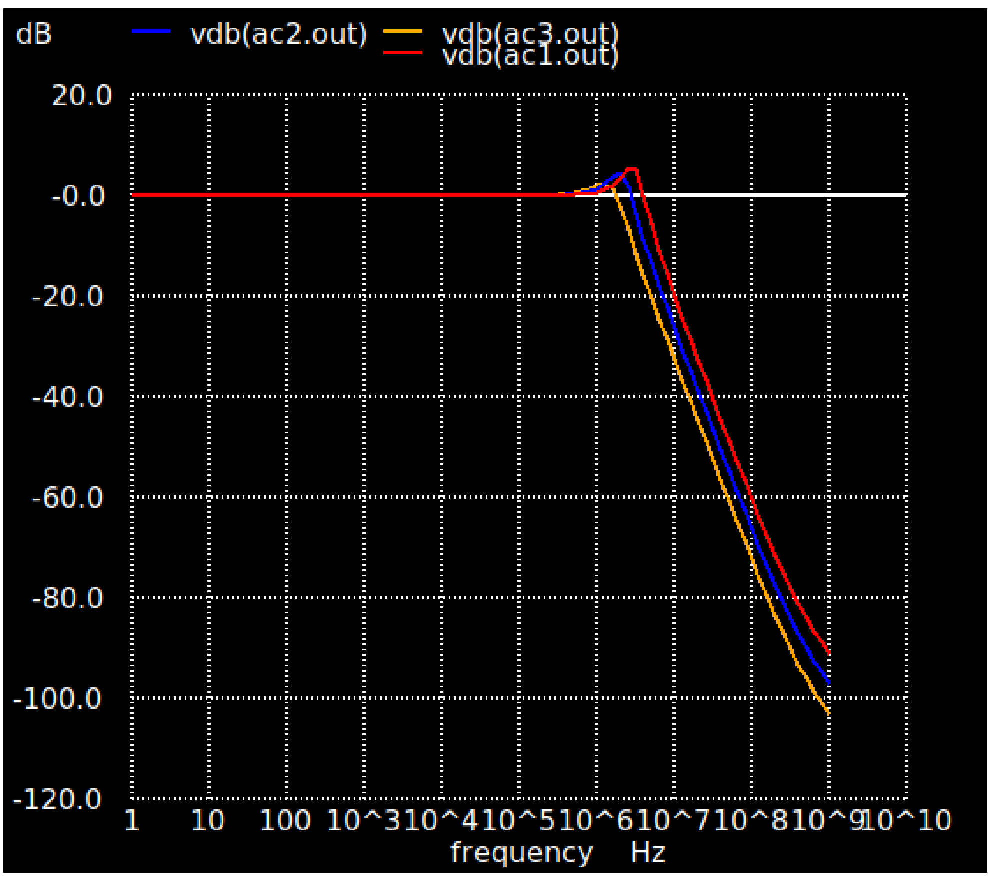
- Do you notice frequency domain peaking?
    - The peaking in frequency domain is noticeable.

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

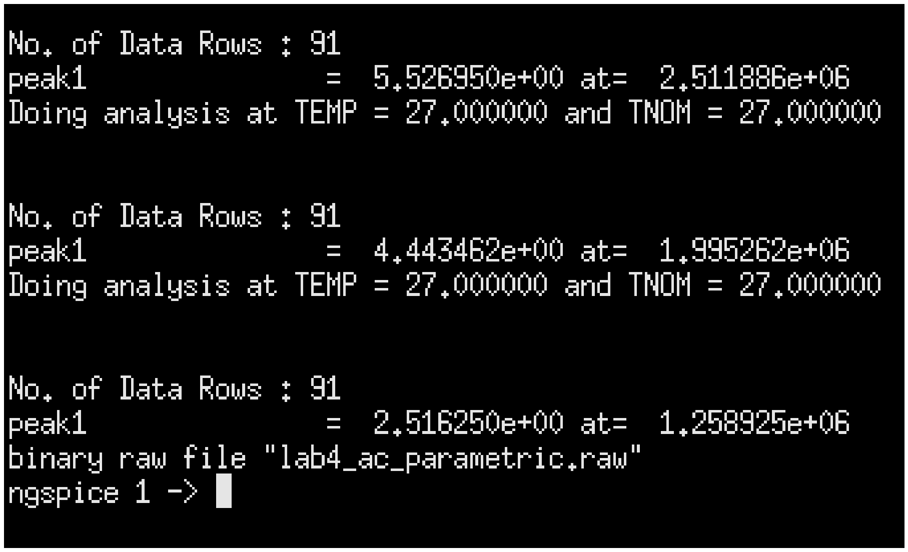
$$Q = \sqrt{\frac{g_m(C_{gs}+C_{gd})R_{sig}}{C_L}} \approx 2.6 > 0.5$$

- The system is underdamped.

- (Optional) Perform parametric sweep: CL = 2p, 4p, 8p.
    - ➔ Report Bode plot magnitude overlaid on same plot.
    - ➔ Report the peaking vs CL.
    - ➔ Comment.



Bode mag plot

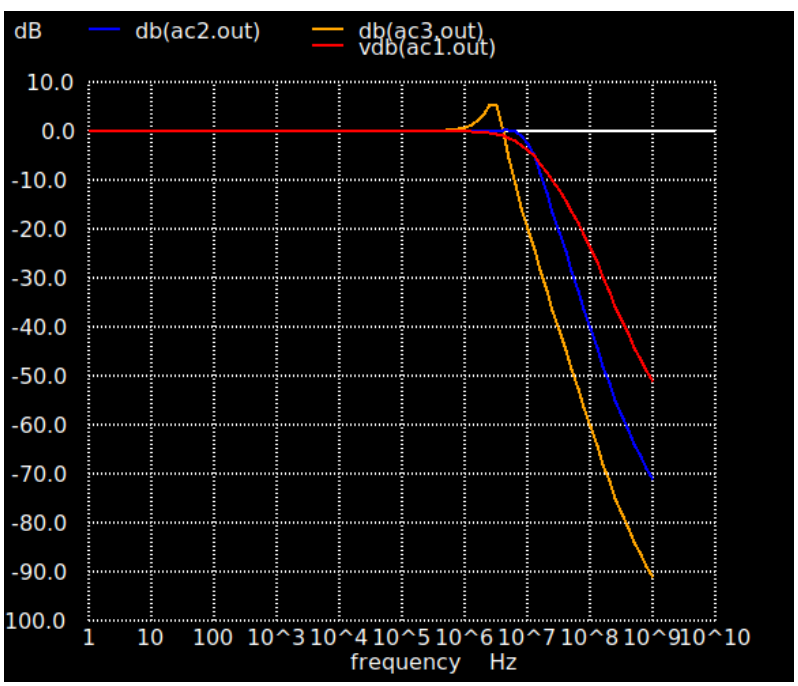


```
No. of Data Rows : 91
peak1                   =  5.526950e+00 at=  2.511886e+06
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000


No. of Data Rows : 91
peak1                   =  4.443462e+00 at=  1.995262e+06
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000


No. of Data Rows : 91
peak1                   =  2.516250e+00 at=  1.258925e+06
binary raw file "lab4_ac_parametric.raw"
ngspice 1 ->
```

Peaking vs CL

- Comment: as C_L increases, Q decreases and so does the peak.

- (Optional) Perform parametric sweep: Rsig = 20k, 200k, 2M.
  - ➔ Report Bode plot magnitude overlaid on same plot.
  - ➔ Report the peaking vs Rsig.
  - ➔ Comment.



Bode mag plot

```
No. of Data Rows : 91
peak1                 =  -1.957876e-02 at=  1.000000e+00
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

No. of Data Rows : 91
peak1                 =  1.725993e-01 at=  3.981072e+06
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000

No. of Data Rows : 91
peak1                 =  5.527842e+00 at=  2.511886e+06
binary raw file "lab4_ac_parametric.raw"
ngspice 1 ->
```

Peaking vs Rsig

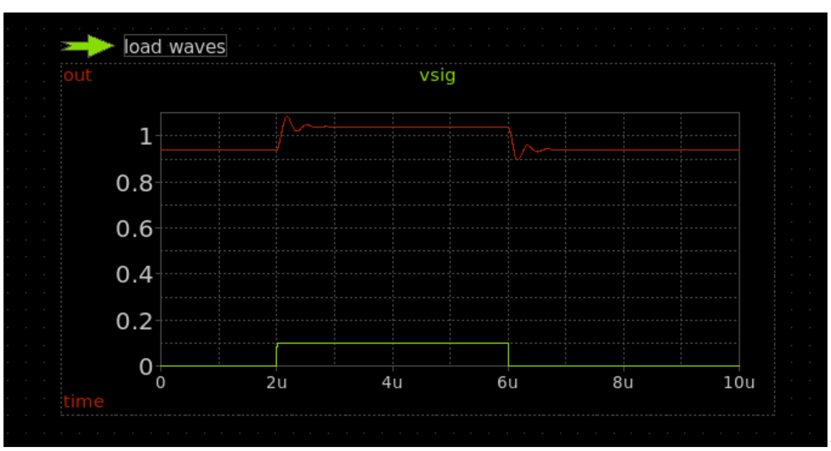
- Comment: as R_{sig} increases, Q increases and so does the peak.

3. Transient Analysis

- Use a pulse source as your transient stimulus and set it as follows (delay = 2us, initial = 0V, period = 8us, pulse_value = 100mV, t_fall = 1ns, t_rise = 1ns, width = 4us). Run transient analysis for 10us to investigate the time domain ringing. Report Vin and Vout overlaid vs time.

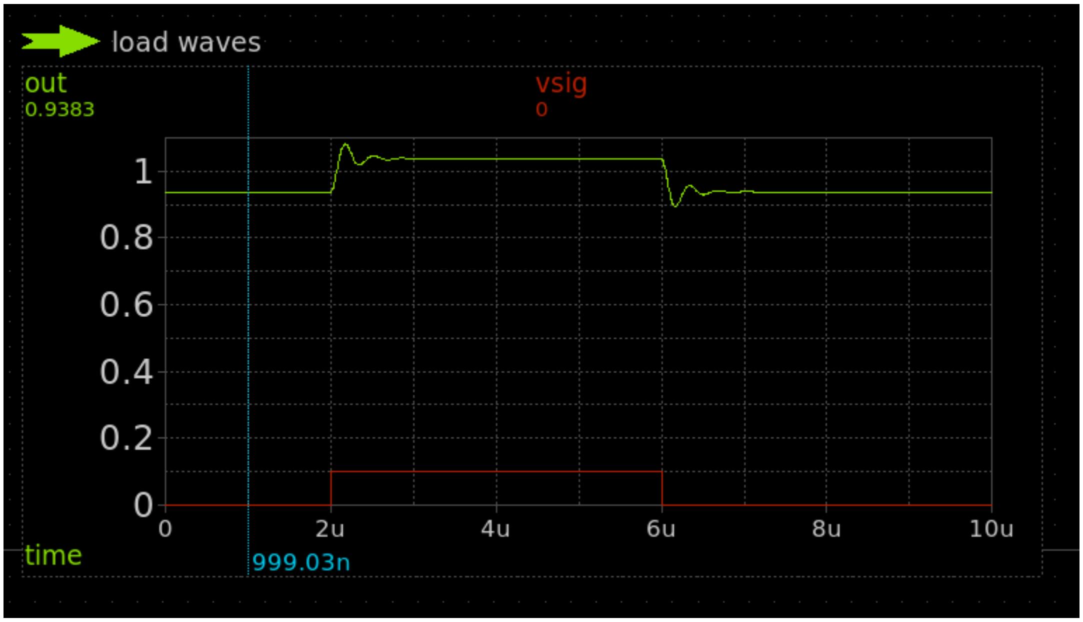
```
No. of Data Rows : 1028
peak1                 =  1.084662e+00 at=  2.181160e-06
overshoot             =  4.606572e+00 at=  5.151160e-06
```

Required calculations



vout and vin vs time

- Calculate the DC voltage difference (DC shift) between Vin and Vout.
    - ➔ What is the relation between the DC shift and VGS of the transistor?
    - ➔ How to shift the signal down instead of shifting it up?



DC voltage difference between vin and vout

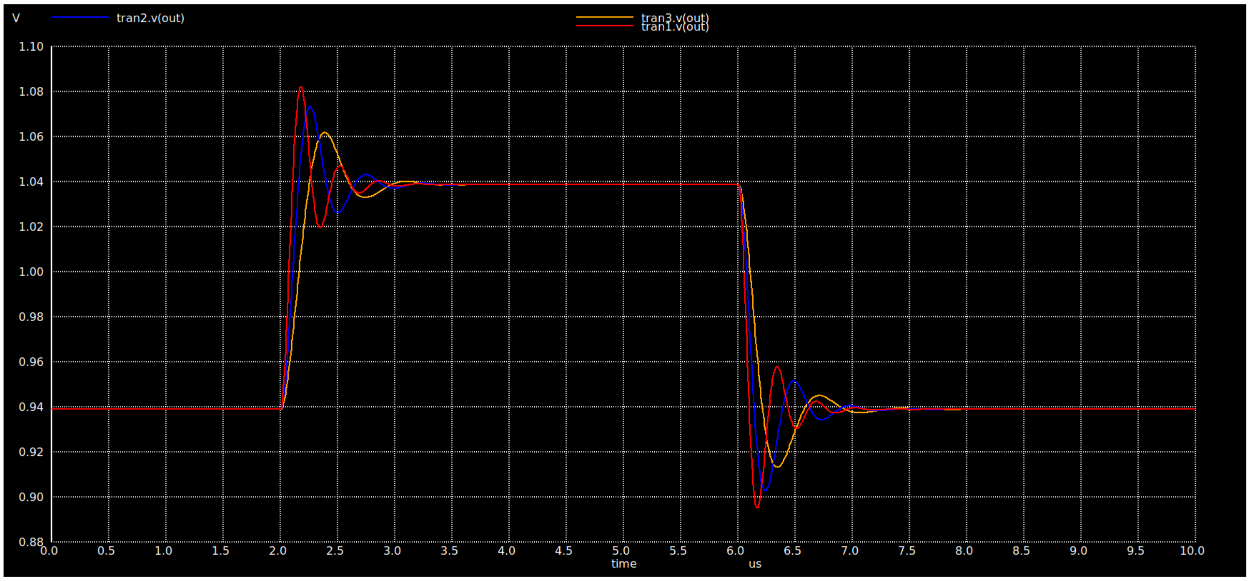
- The DC shift between the i/p and the o/p is exactly the same as V_{GS}.
- By using NMOS.

- Do you notice time domain ringing? How much is the overshoot?
    - Time domain ringing is noticeable.

$$Overshoot\ =\ 100e^{\frac{-\pi}{\sqrt{4Q^2-1}}}\ \approx\ 54\%$$

- [Optional] Perform parametric sweep: CL = 2p, 4p, 8p.
    - ➔ Report Vout vs time overlaid on same plot.
    - ➔ Report the overshoot vs CL.

➔ Comment.



vout vs time (parametric sweep)

```
peak1                  =  1.080741e+00 at=  2.181160e-06
overshoot              =  4.625822e+00 at=  5.151160e-06
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
```

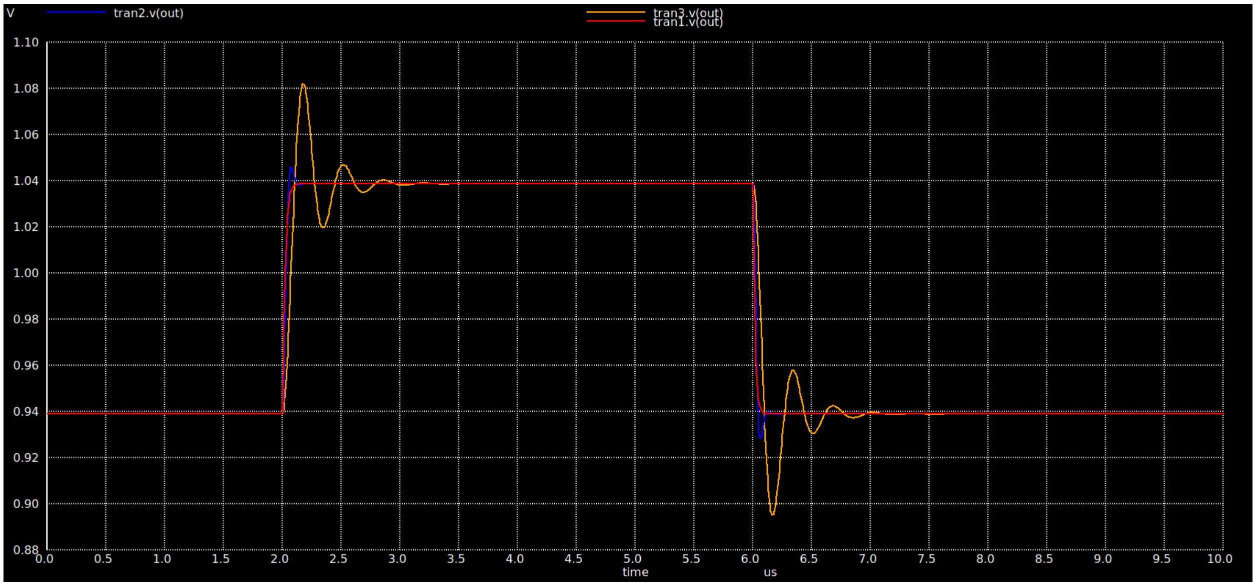
```
peak1                  =  1.072077e+00 at=  2.261160e-06
overshoot              =  3.701559e+00 at=  5.041160e-06
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
```

```
peak1                  =  1.060525e+00 at=  2.381160e-06
overshoot              =  2.469233e+00 at=  5.031160e-06
binary raw file "lab4_parametric.raw"
binary raw file "/home/tare/.xschem/simulations/lab4.raw"
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
```

Overshoot vs CL

- Comment: as C_L increases, Q decreases and thus the overshoot is suppressed more and more.

- [Optional] Perform parametric sweep: Rsig = 20k, 200k, 2M.
  - ➔ Report Vout vs time overlaid on same plot.
  - ➔ Report the overshoot vs Rsig.
  - ➔ Comment.



vout vs time (parametric sweep over Rsig)

```
peak1                  =  1.038241e+00 at=  3.235523e-06
overshoot              =  1.091740e-04 at=  5.675523e-06
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
```

```
peak1                  =  1.045456e+00 at=  2.071160e-06
overshoot              =  7.691022e-01 at=  5.241160e-06
Doing analysis at TEMP = 27.000000 and TNOM = 27.000000
```

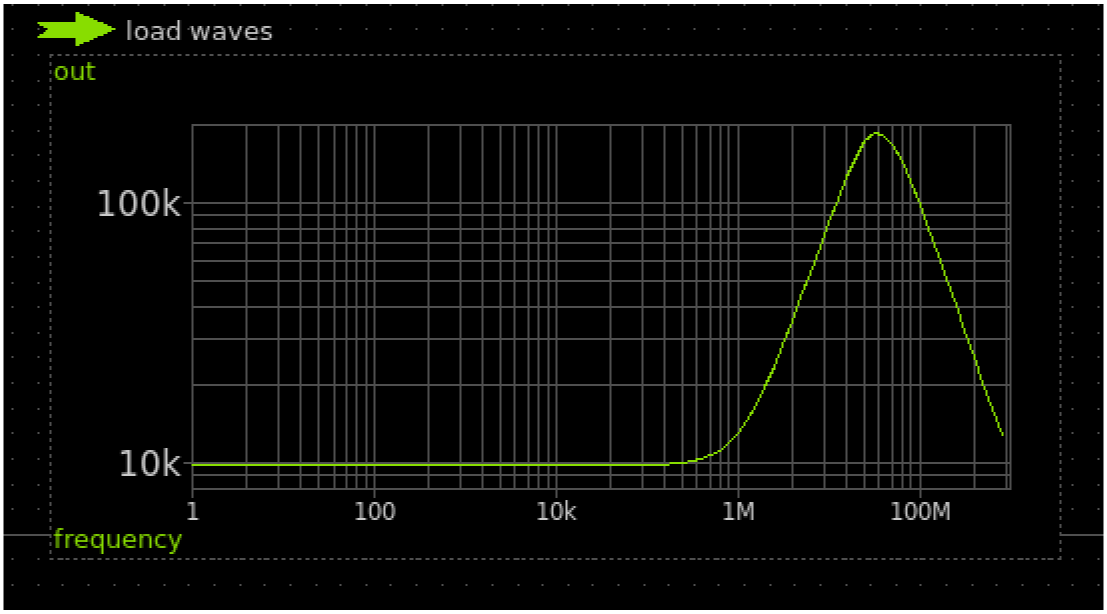
```
peak1                  =  1.081602e+00 at=  2.181160e-06
overshoot              =  4.621636e+00 at=  5.151160e-06
binary raw file "lab4_parametric.raw"
```

Overshoot vs Rsig

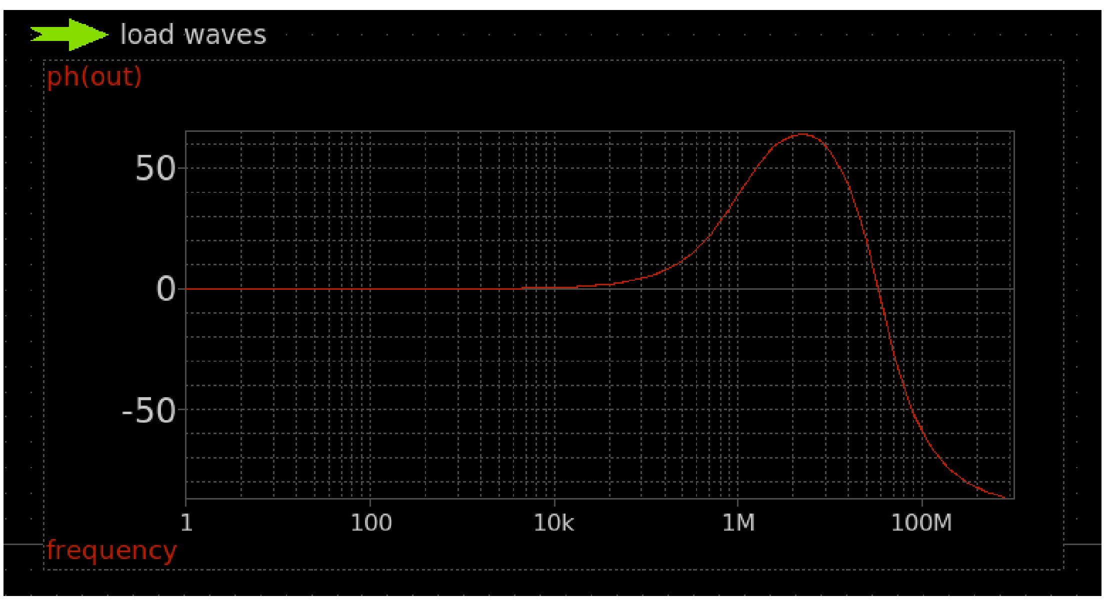
- Comment: As R_{sig} increases, Q increases and so does the overshoot.

4. [Optional] Z_{out} (Inductive Rise)

- We want to simulate the CD amplifier output impedance. Replace CL with an current source (isource) with ac magnitude = 1. Remove the AC input signal. Perform AC analysis (1Hz:10GHz, logarithmic, 10points/decade). The voltage across the AC current source is itself the output impedance. Plot the output impedance (magnitude and phase) vs frequency. Do you notice an inductive rise? Why?



Zout vs frequency



ϕ(Zout) vs frequency

- The inductive rise is noticeable, since there is a zero formed by C_{gs} and R_{sig}.

- Does Z_{out} fall at high frequency? Why?
  - Z_{out} falls at high frequency due to the dominance of the pole formed by R_{sig} and C_{gd}.