Lab 4

Common Drain Amplifier

Part 1: Sizing Chart

Required Spec:

L	1um
V*	200mV
Quiescent (DC) Input Voltage	0 V
S	1.8 V
Bias Current	10 uA

Analytic Calculations:

$$|A_v| \approx g_m ro = \frac{2I_D}{V_{ov}} \times \frac{V_A}{I_D} = \frac{2V_A}{V_{ov}}$$

$$In\ Simulation\ V_{ov} \neq \frac{2I_D}{gm}\ all\ the\ time, \qquad Instead\ use\ V^* = \frac{2I_D}{gm}$$

$$|A_v| = \frac{2V_A}{V^*}$$

$$gm = \frac{2I_D}{Vov} \rightarrow \frac{gm}{I_D} = \frac{2}{Vov}$$

Sizing Using ADT:

Inputting the Design parameters into ADT SA we get:

$$W = 19.39\mu m \approx \mathbf{20\mu m}$$

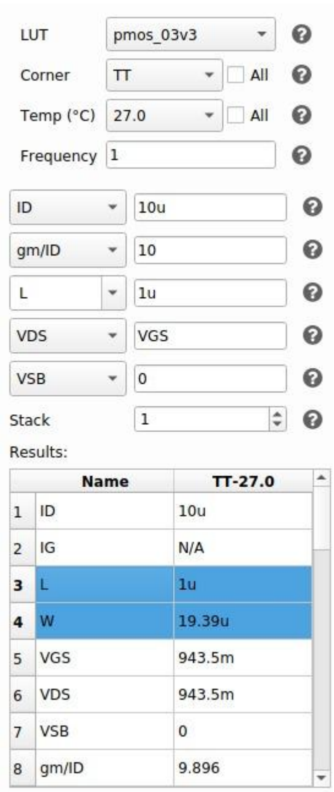

Figure 1 Sizing Using ADT

Part 2: Common Drain Amplifier

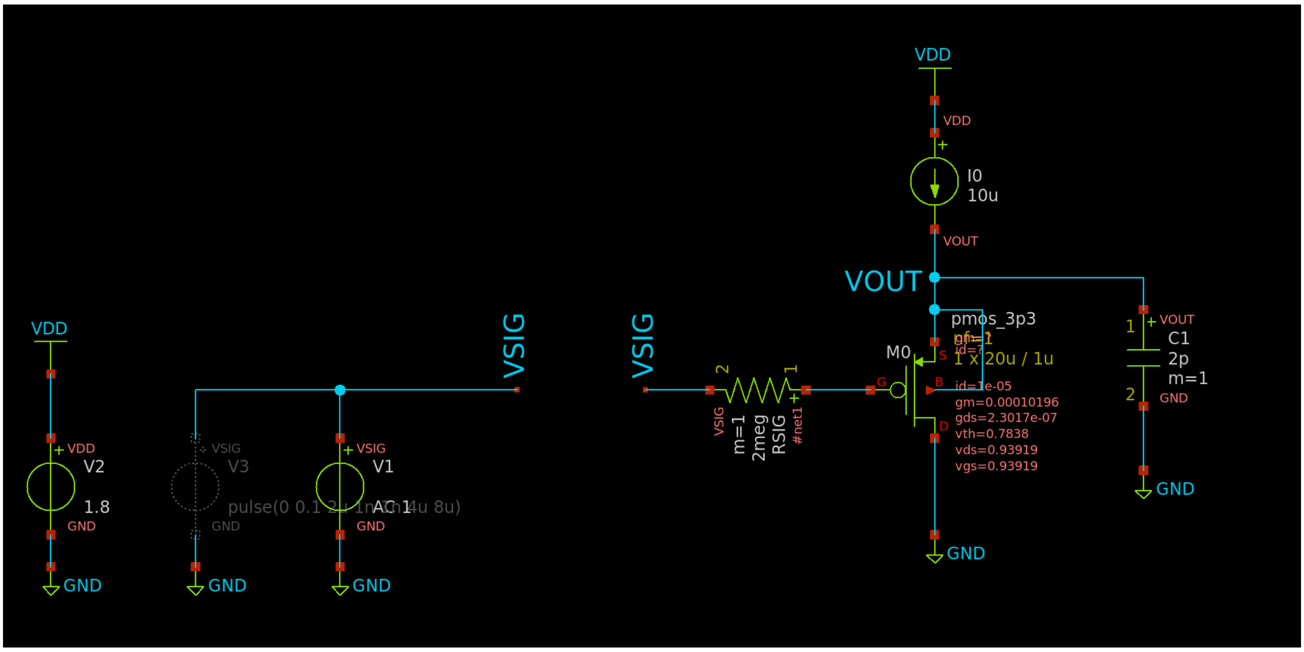

Figure 2 Testbench Schematic for both AC and Tran Analysis

Operating Point:

	id	vgs	vds	vth	vdsat	gm	gds	gmbs	Cdb	Cgd	Cgs	Csb
M0	10uA	0.94V	0.94V	0.785V	0.153V	102uS	230nS	48.2uS	9.97fF	14.2aF	51.1fF	14.9fF

Transistor Operates in Saturation!

Values of Capacitances from ADT:

Calculating the capacitance value from ADT instead of Xschem as it is more accurate for hand analysis.

	Cdb	Cgd	Cgs	Csb
M0	8.969fF	3.073fF	51.1fF	14.9fF

AC Analysis:

Outputs:

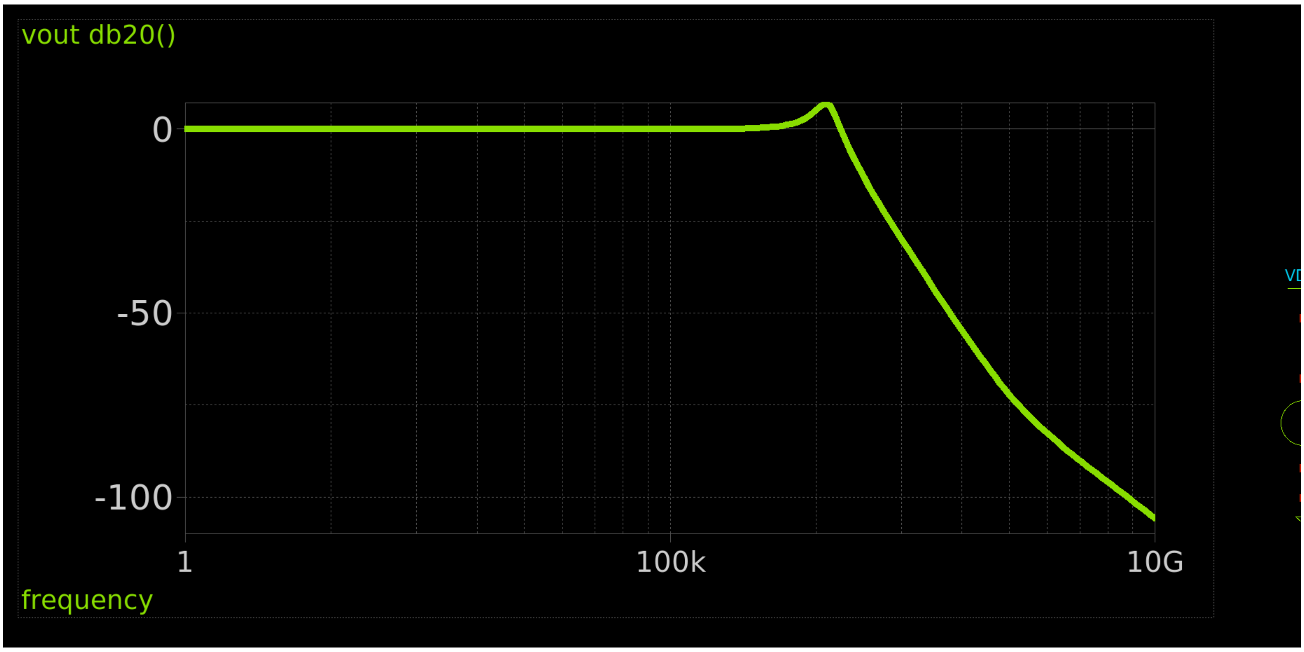

Figure 3 Bode Plot of Common Drain Amplifier

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

Yes, there is peaking. Its value is about **2 in magnitude** or around **6dB**

```
peaking              =   2.016180e+00 at=   2.818383e+06
```

Figure 4 Value of Peaking from Simulation

Quality Factor Calculation:

Using the values calculated earlier from OP Analysis

$$Q = \frac{\sqrt{b_2}}{b_1}, \quad b_1 = C_{gd}R_{sig} + \frac{C_{gs}+C_L}{g_m} = 2.625 * 10^{-8},$$

$$b_2 = \frac{(C_{gs} + C_{gd})C_L + G_{gs}C_{gd}}{g_m}R_{sig} = 2.175f$$

$$Q = 1.76 > 0.5$$

The System is Underdamped!

Note: Using the approximated equation for Q here is not recommended as the poles are close to each other resulting in inaccurate variables

- **Parametric sweep: CL = 2p, 4p, 8p:**

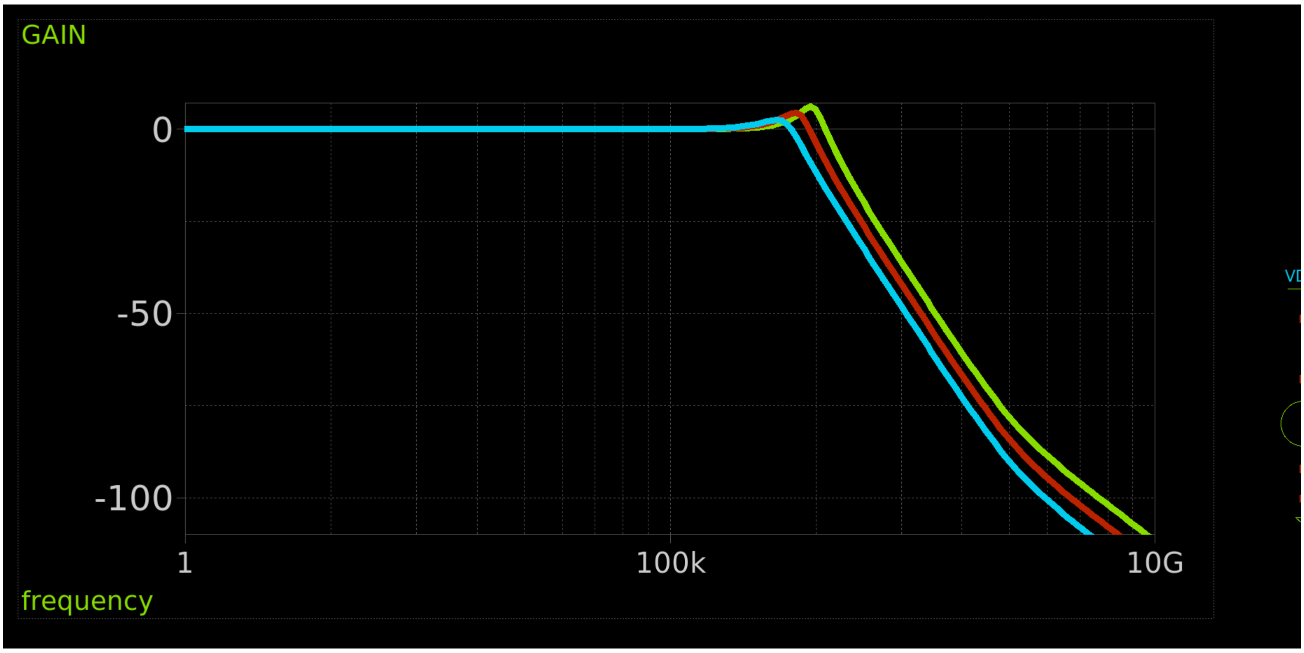

Figure 5 AC Analysis Parametric Sweep of CL

Peaking vs CL:

CL Value	2pF	4pF	8pF
Peaking	2.0161	1.667	1.3358

Peaking decreases as we increase the Value of CL

Comment:

Increasing CL decreases Q closer to 0.5 thus reducing the Peaking and making the system overdamped.

- **Parametric sweep: Rsig = 20K, 200K, 2M:**

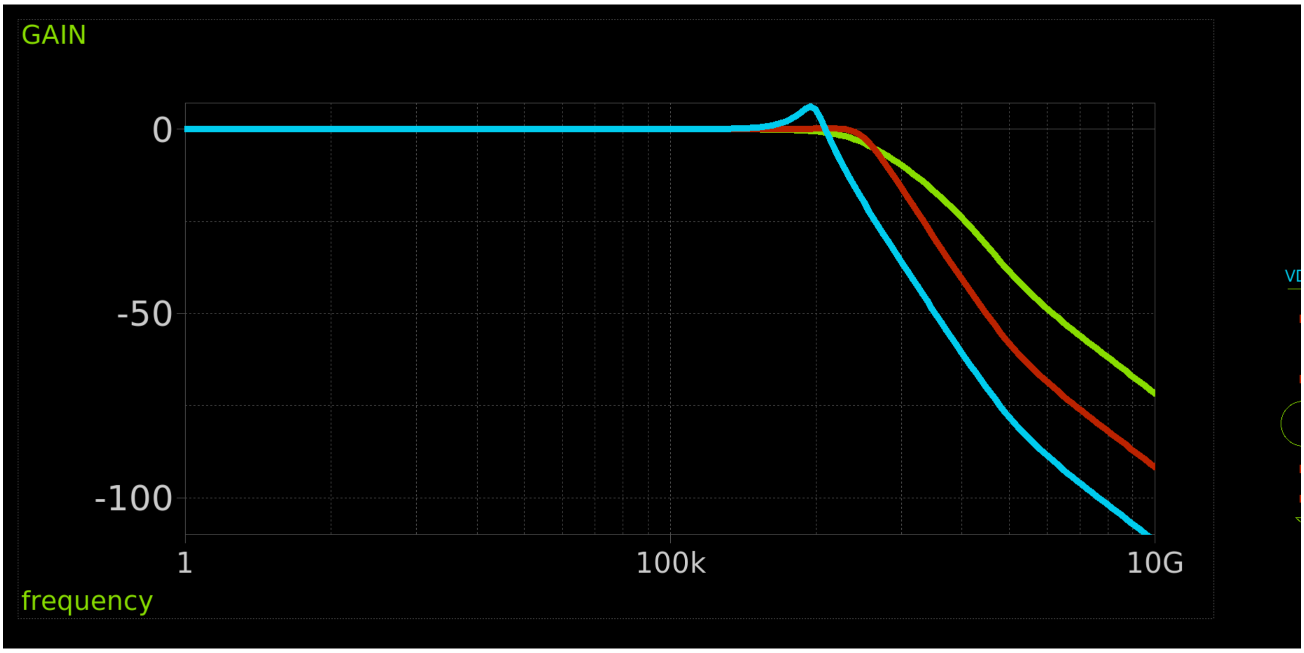

Figure 6 AC Analysis Parametric Sweep of Rsig

Peaking vs Rsig:

Rsig Value	20K	200K	2M
Peaking	0.997	1.021	2.0161

Peaking increases as we increase the value of Rsig

Comment:

Increasing Rsig Increases Q thus increasing the peaking and underdamping the system.

Transient Analysis:

Outputs:

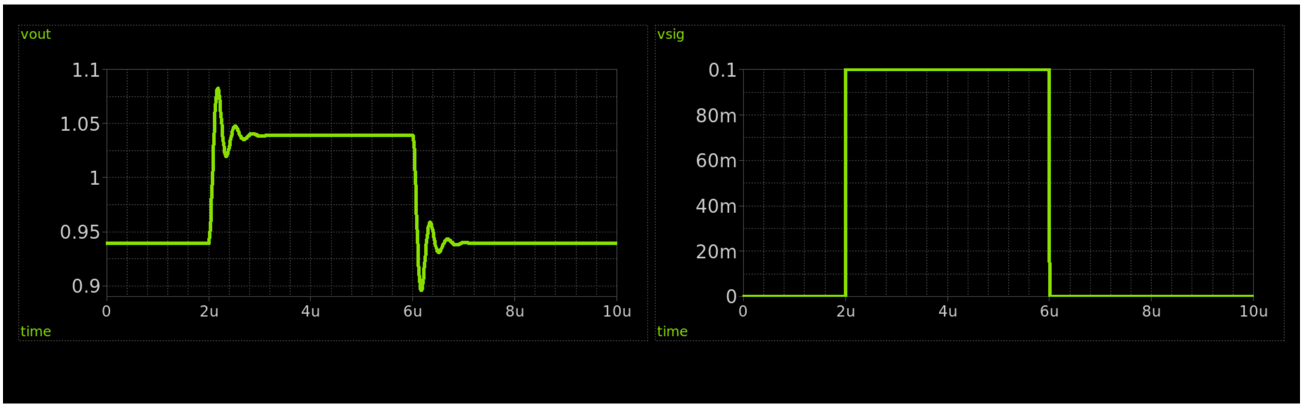

Figure 7 VIN and VOUT vs Time (Transient Analysis)

- **DC Voltage difference:**

```
v_peak                =  1.082476e+00
v_normal              =  1.039115e+00
v_min                 =  9.393322e-01
```

Figure 8 Values of VOUT from simulation

The DC shifted up about **0.94V**, the minimum value of Vin is 0 and the Minimum value of Vout is 0.94V.

How to shift the signal down instead of shifting it up?

By using an NMOS CD configuration instead of the PMOS configuration.

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

Yes, there is an overshoot of about **43.45%**

```
overshoot = 4.345539e+01
```

Figure 9 Value of overshoot from Simulation

Parametric sweep: CL = 2p, 4p, 8p:

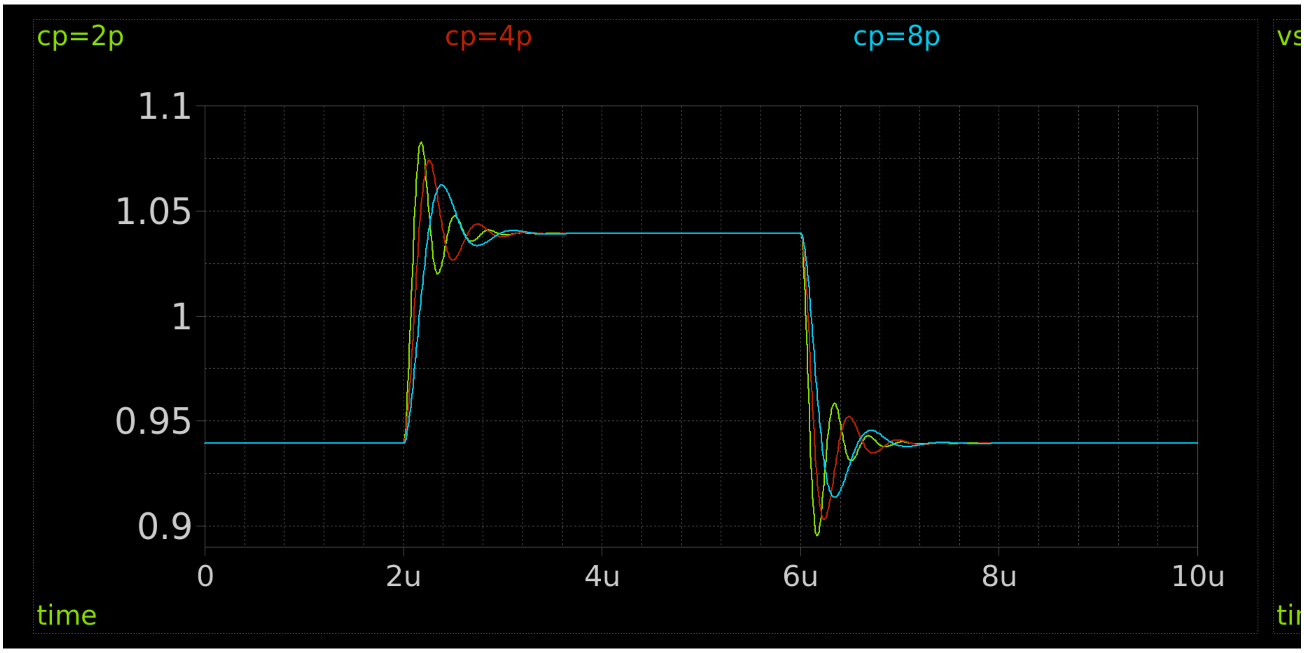

Figure 10 Transient Analysis Parametric Sweep of CL

Peaking vs CL:

CL Value	2pF	4pF	8pF
Peaking	43.456%	34.77%	23.2%

Overshoot decreases as we increase the Value of CL

Comment:

Increasing CL decreases Q closer to 0.5 thus reducing the ringing and making the system overdamped.

- **Parametric sweep: Rsig = 20K, 200K, 2M:**

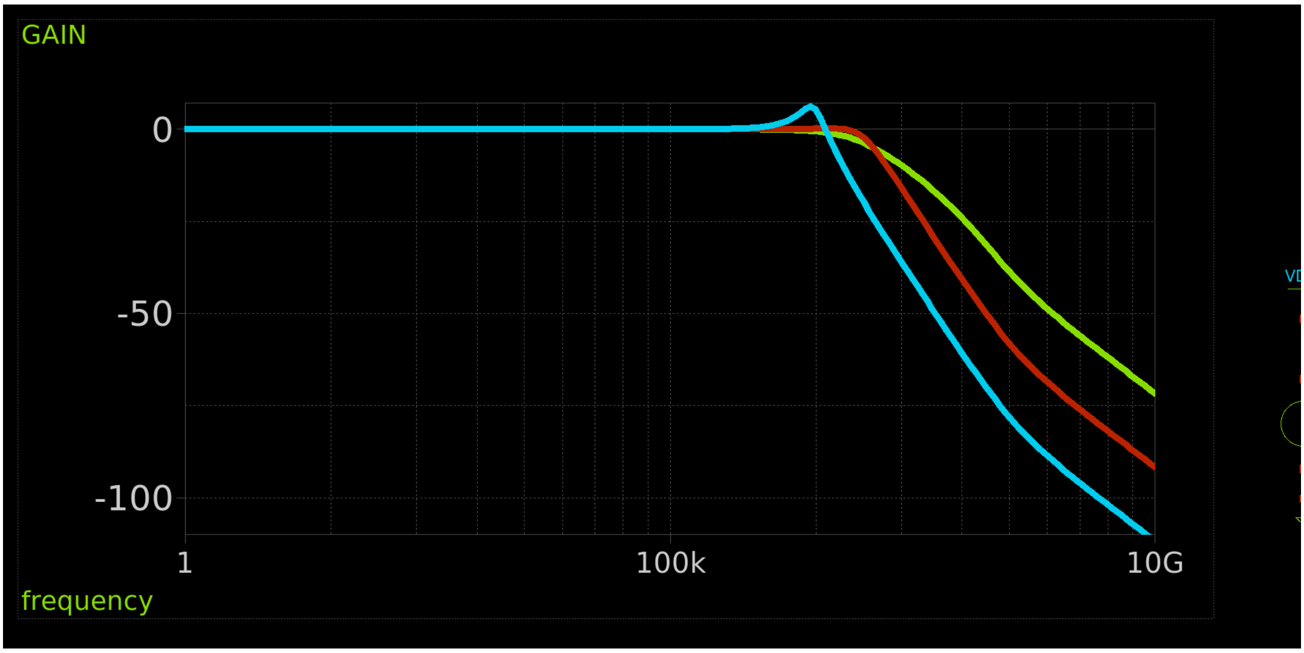

Figure 11 AC Analysis Parametric Sweep of Rsig

Peaking vs Rsig:

Rsig Value	20K	200K	2M
Peaking	0.997	1.021	2.0161

Peaking increases as we increase the value of Rsig

Comment:

Increasing Rsig Increases Q thus increasing the peaking and underdamping the system.

- **Parametric sweep: Rsig = 20K, 200K, 2M:**

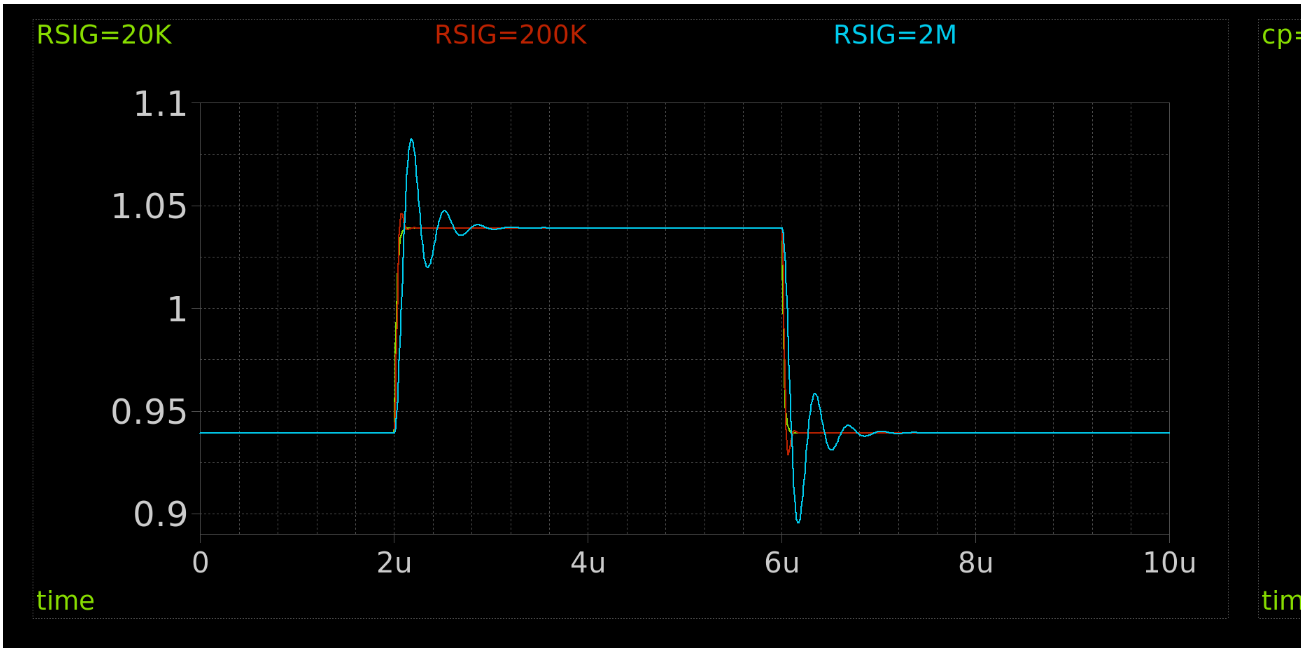

Figure 12 Transient Analysis Parametric Sweep of Rsig

Peaking vs Rsig:

Rsig Value	20K	200K	2M
Peaking	0%	7.23%	43.456%

Ringing increases massively as we increase the value of Rsig

Comment:

Increasing Rsig Increases Q thus increasing the ringing and underdamping the system.

Zout Inductive Rise:

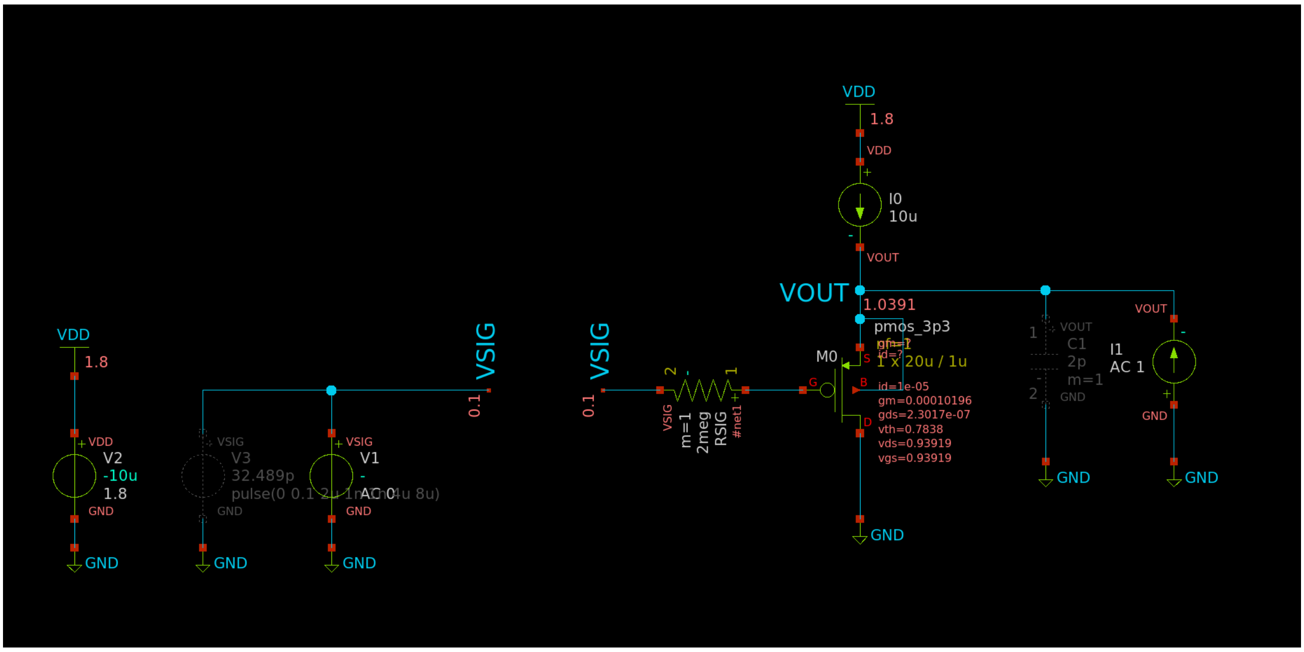

Figure 13 Modified Testbench to Calculate Zout

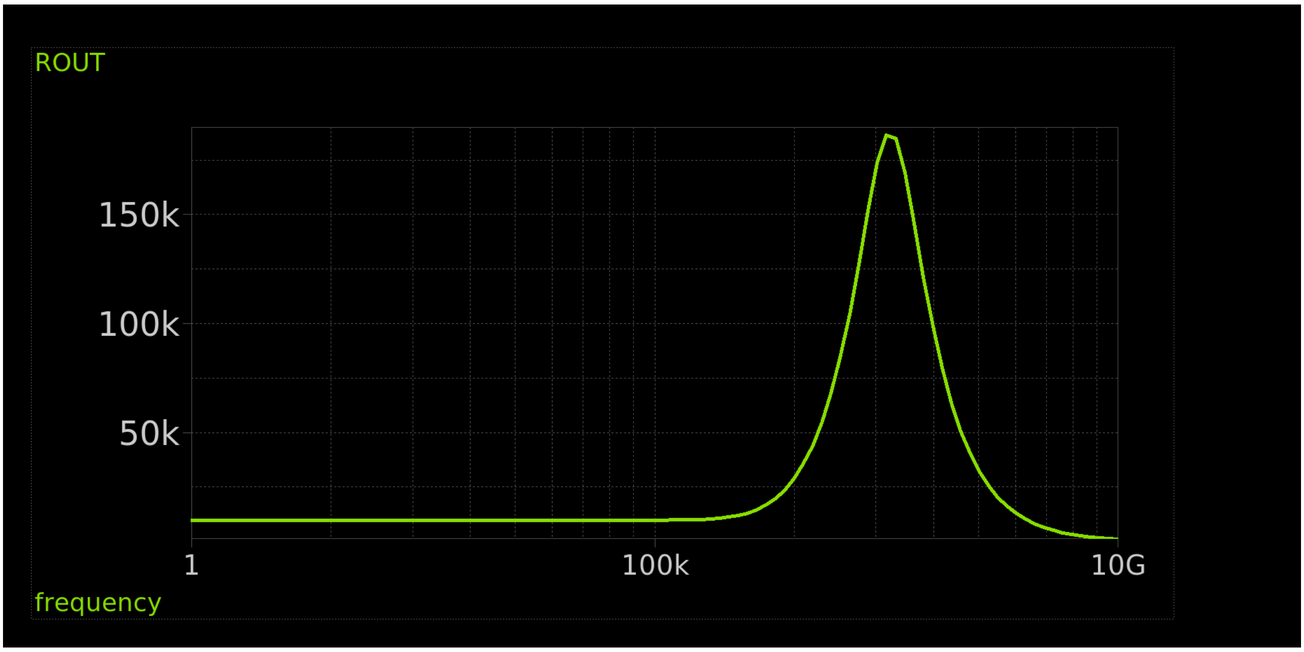

Figure 14 ZOUT vs Frequency

```
rout_max            =  1.866052e+05 at=  3.162278e+07
rout                =  9.785972e+03
```

Figure 15 Zout at High and Low Frequencies

- **Do you notice an inductive rise? Why?**

Yes, because at high frequencies, Cgs is shorted so Zout becomes equal to Rsig.

But in the simulation the it does not quite reach Rsig this is due to Cgd taking over before Cgs can short completley

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

Due to the Pole generated by Cgs Zout falls quickly.

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

Poles and Zeros Analytically:

$$\omega_{p2} = \frac{1}{\frac{C_{gs}}{gm}} = 1.996Grad \approx 2Grad \rightarrow 318.31MHz \quad ,$$

$$\omega_z = \frac{1}{R_{sig}C_{gs}} = 9.78Mrad \rightarrow 1.55MHz$$

$$\omega_{p1} = \frac{1}{R_{sig}C_{gd}} = 162.7Mrad \rightarrow 25.89MHz$$

Simulation Results:

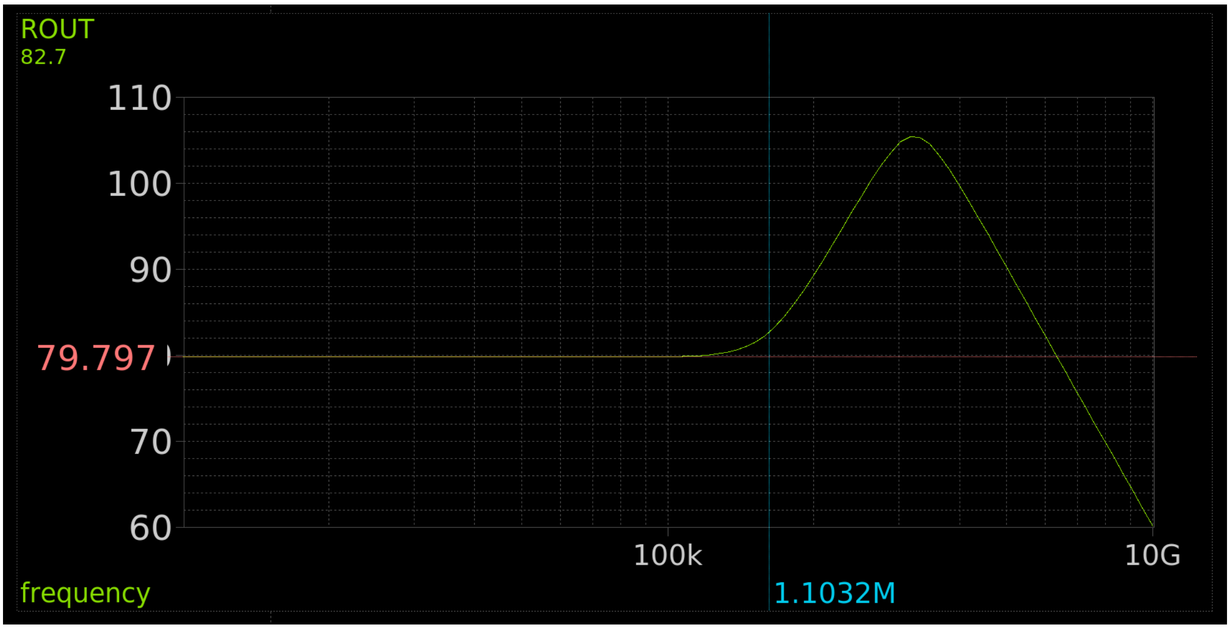

Figure 16 Zero Location @ 1.1MHz

$$\omega_z \approx 1.1MHz$$

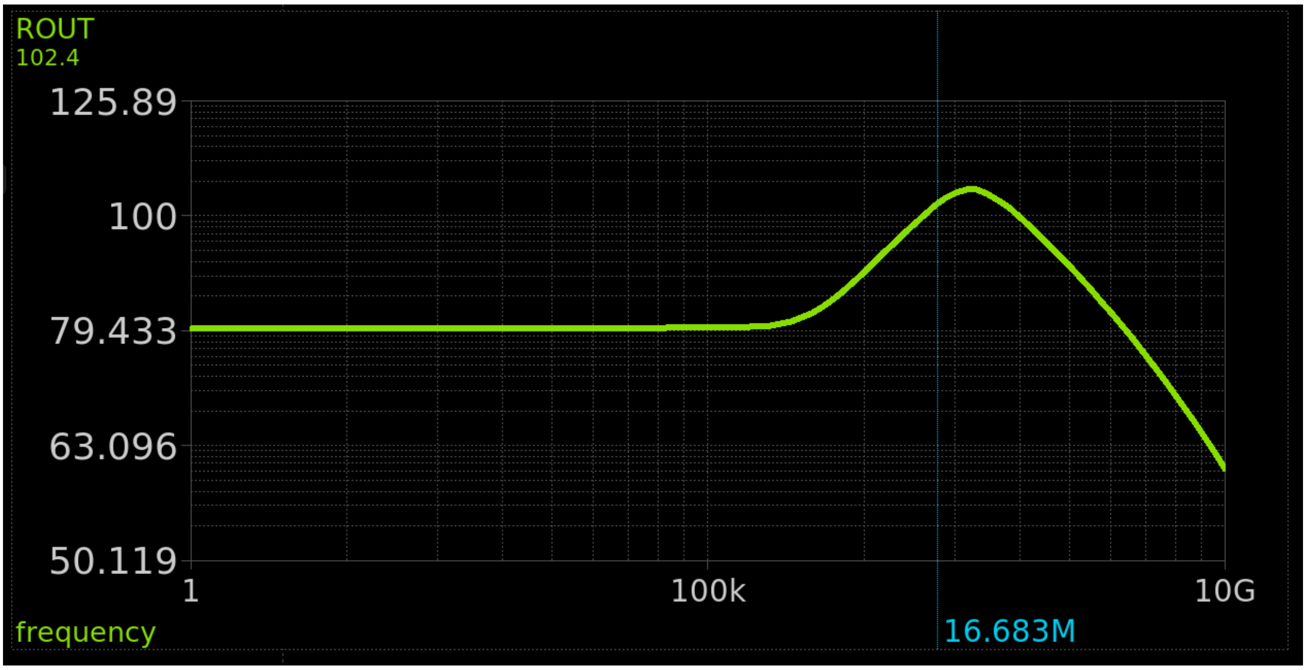

Figure 17 First Pole Location @ 16.683 MHz

$$\omega_{p1} \approx 16.683MHz$$

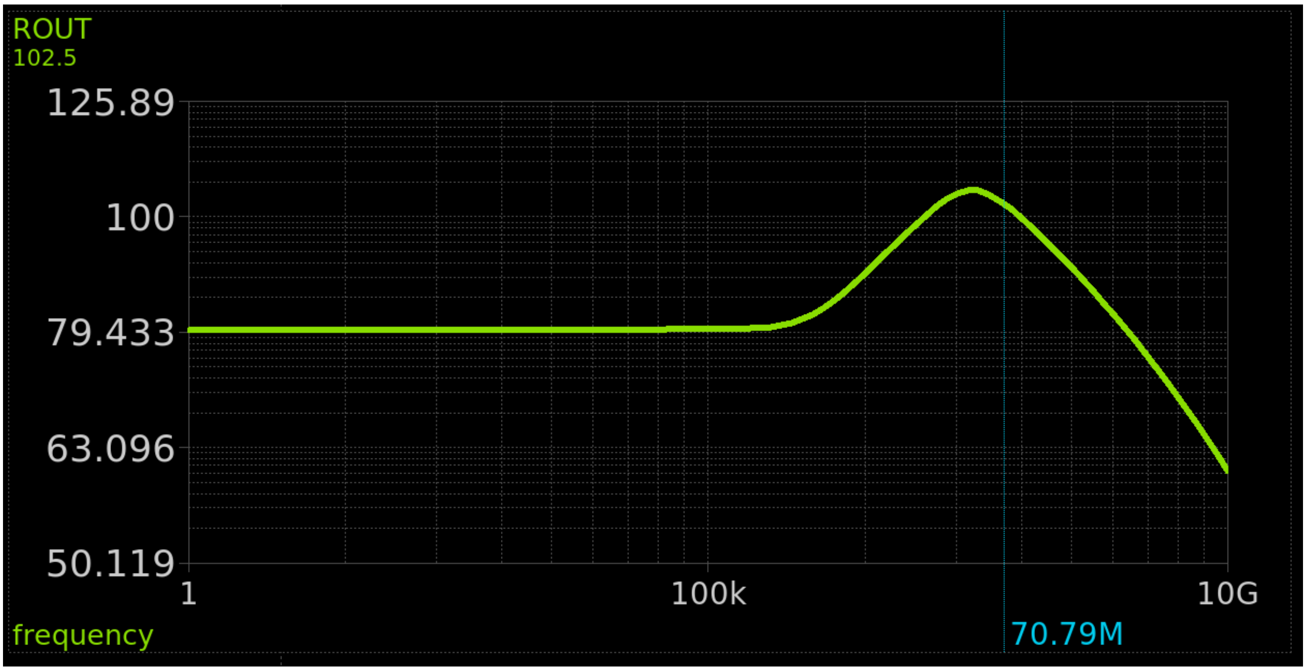

Figure 18 Second Pole Location @ 70MHz

$$\omega_{p2} \approx 70MHz$$

	Hand Analysis	Simulation
Zout HFR	Rsig=2Mohm	186.6Kohm
Zout LFR	1/gm =9.8Kohm	9.78Kohm
Zero	1.55MHz	1.11MHz
First Pole	25.89MHz	16.683MHz
Second Pole	318.3MHz	70MHz

Comment:

There is a huge difference between the hand analysis calculation and the simulation results, this is because the hand analysis I used assumed the poles are further away from each other than they really are, which is incorrect as the poles are close to each other and are complex thus causing the ringing and peaking in transient and frequency analyses.

Only values calculated at the LFR (Zero and ZOUT at LFT) produced accurate results compared to the simulation, but the HFR results are far off especially the second pole which was expected at a way higher range that it was found.

To get more accurate poles using hand analysis the original long form equation should be used:

$$\frac{V_x}{i_x} = \frac{\left(1 + SR_{sig}\left(C_{gs} + C_{gd}\right)\right) r_0}{S^2\left[R_{sig}\left(C_{gs} + C_{gd}\right)C_{dB}r_0 + R_{sig}C_{gd}r_0C_{gs}\right] + S\left[C_{dB}r_0 + R_{sig}\left(C_{gs} + C_{gd}\right) + C_{gs}r_0 + g_m r_0 C_{gd} R_{sig}\right] + g_m r_0 + 1}$$

Figure 19 Zout Out long form equation for this configuration

Further more, from the simple hand analysis we did earlier we neglected the effect of Cgd and assumed its pole would come after Cgs giving us Rsig at the HFR, this is incorrect as seen from the simulation, Zout drops before it reaches Rsig as Cgd shorts the output and drops quickly to zero.

Overall, I do realize my hand analysis equations are inaccurate due to the above mentioned reasons and the proper way to calculate the poles would be using the equation in Figure 19. But it's still a good indicator for understanding how the circuit behaves and should be analyzed correctly using the long equation when designing a system that utilizes it

Also their might be an error in the simulation results as I had to depend on the graph due to the pz simulation not functioning correctly. But again, it's a good indicator as to how the circuit behaves.

Compensation Network:

From [Johns and Martin, 2012] Section 4.4 we conclude that a compensating RC network can be connected in parallel to the input to fix the ringing problem in the circuit, it looks as follows:

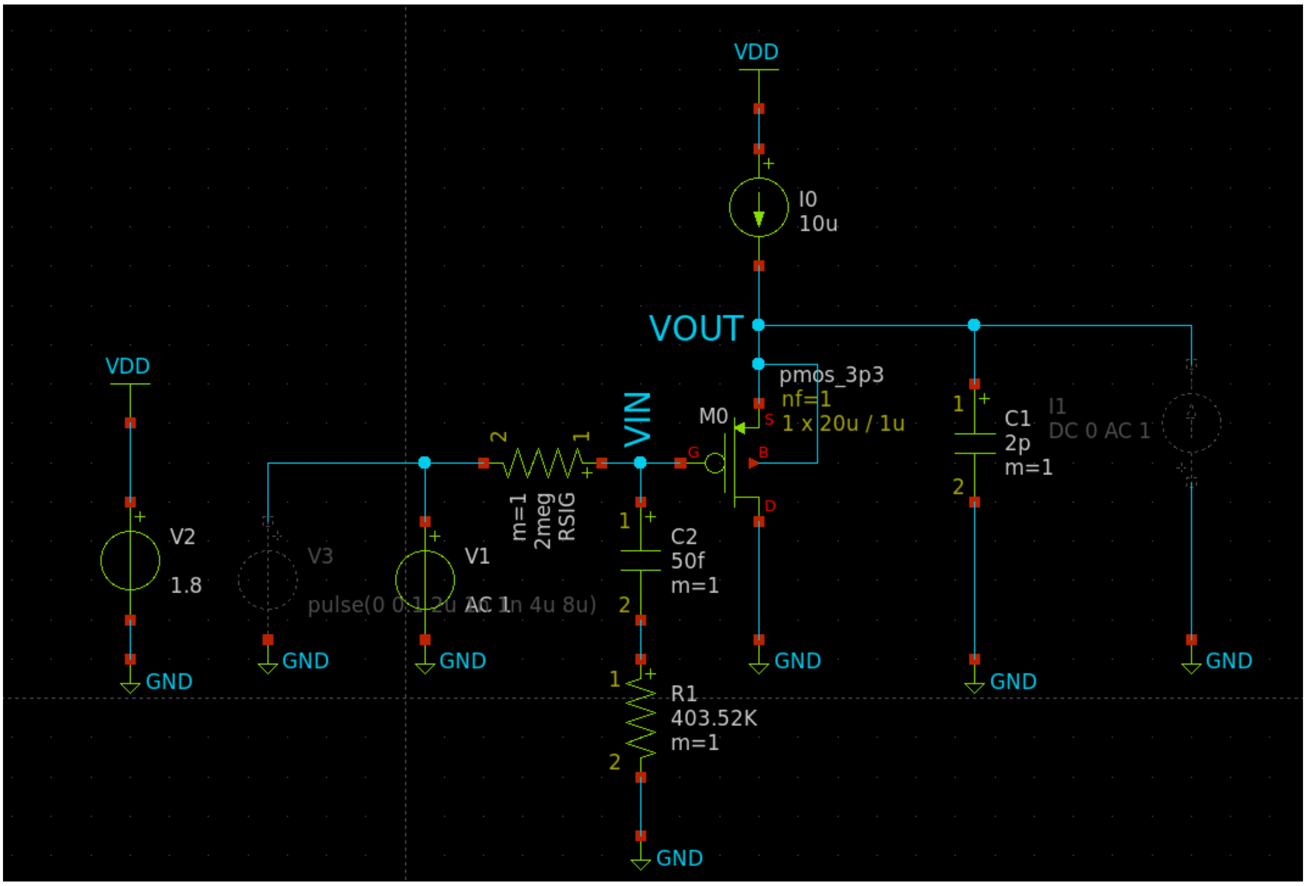

Figure 20 Altered Circuit using Compensation Network

We can calculate the values of R and C using the equations analyzed in reference.

Using the values found from ADT again for the capacitances.

$$C \approx \frac{g_m C_{gs} C_s}{(g_m + G_s)(C_{gs} + C_s)} = 49.82fF \approx \mathbf{50fF}$$

$$R \approx \frac{(C_{gs} + C_s)^2}{C_{gs} C_s g_m} = \mathbf{403.54K\Omega}$$

Results:

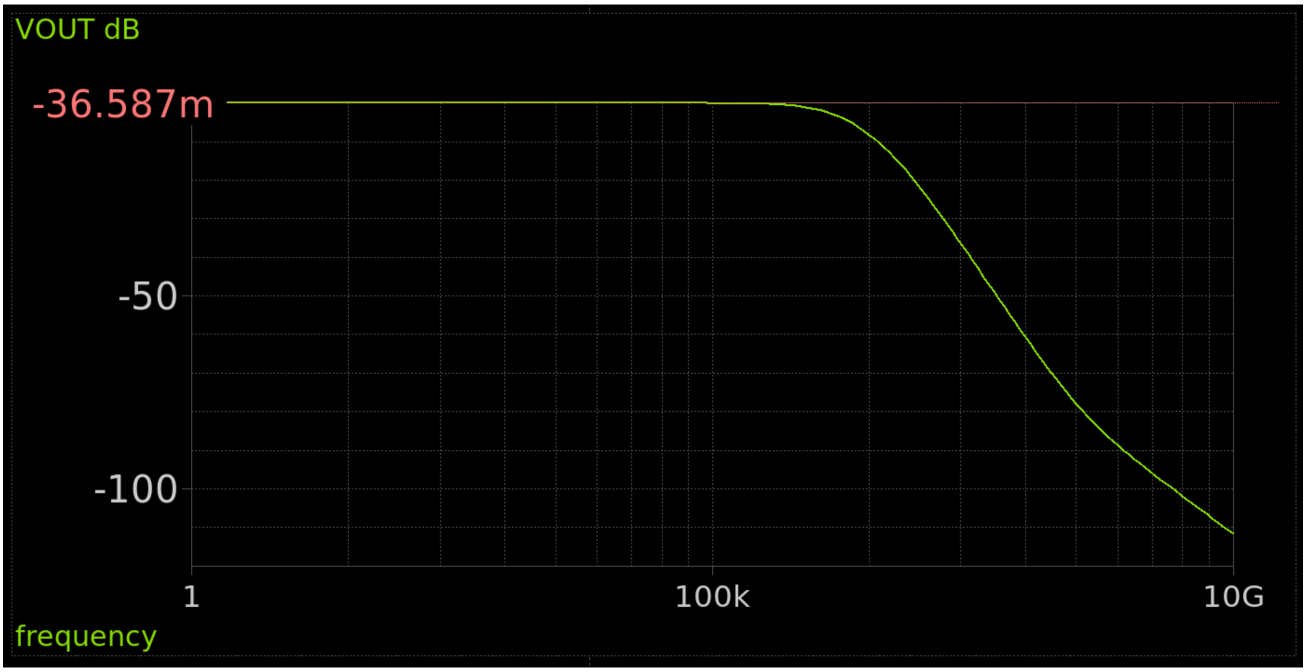

Figure 21 VOUT Bode Plot Parametric Sweep with CL

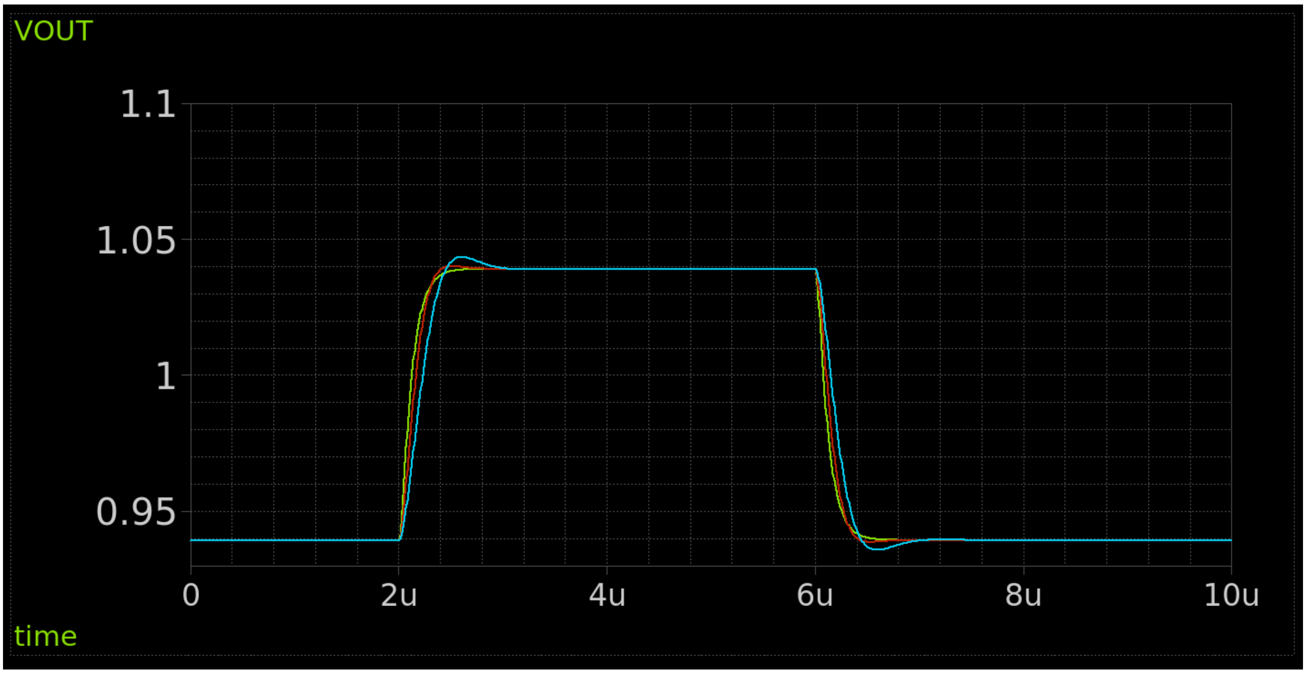

Figure 22 Transient Vout vs Time, Parametric Sweep with CL

In the bode plot the circuit seems to not be affected by CL at all anymore after adding the compensating circuit, also in the transient analysis overshooting seems to be greatly reduced.