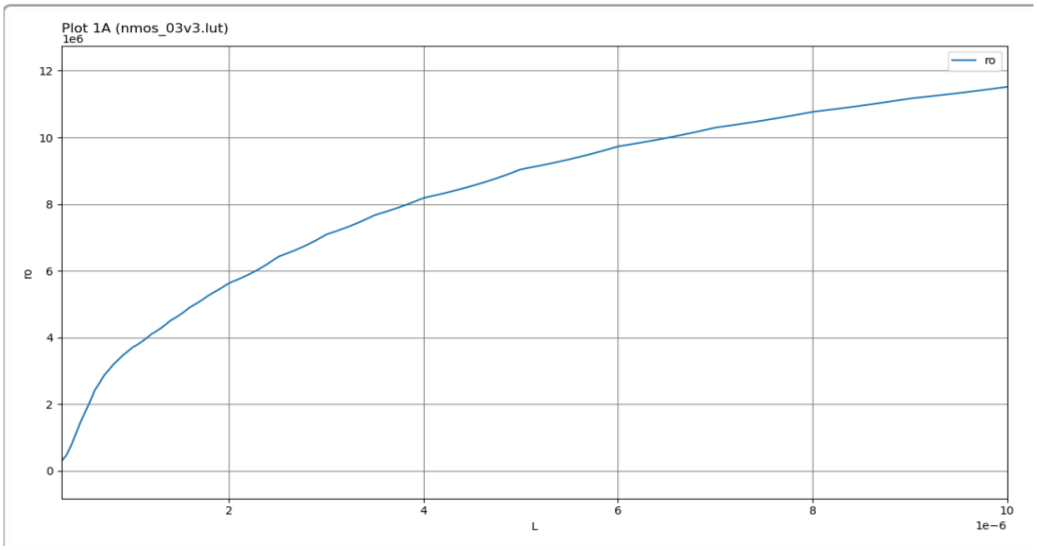
Lab 02

PART 1: Sizing chart:

- **Analysis:**

➢ We need to get DC gain= -10 and$\mathrm{ID} = 10\ \mu\mathrm{A}$. First, we will choose $\mathrm{L} = 2\ \mu\mathrm{m}$ to avoid short channel effects and get high ro and we can check that we have high ro from graph.

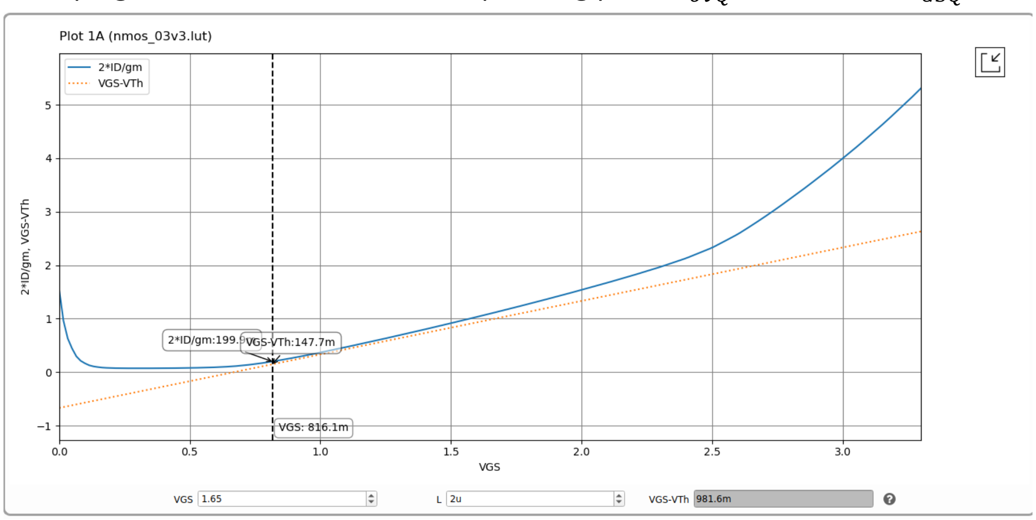


➢ $V_{RD} = 1$ then we get the resistance $RD = \frac{V_{RD}}{ID} = \frac{1}{10*10^{-6}} = 100\ k\Omega$.

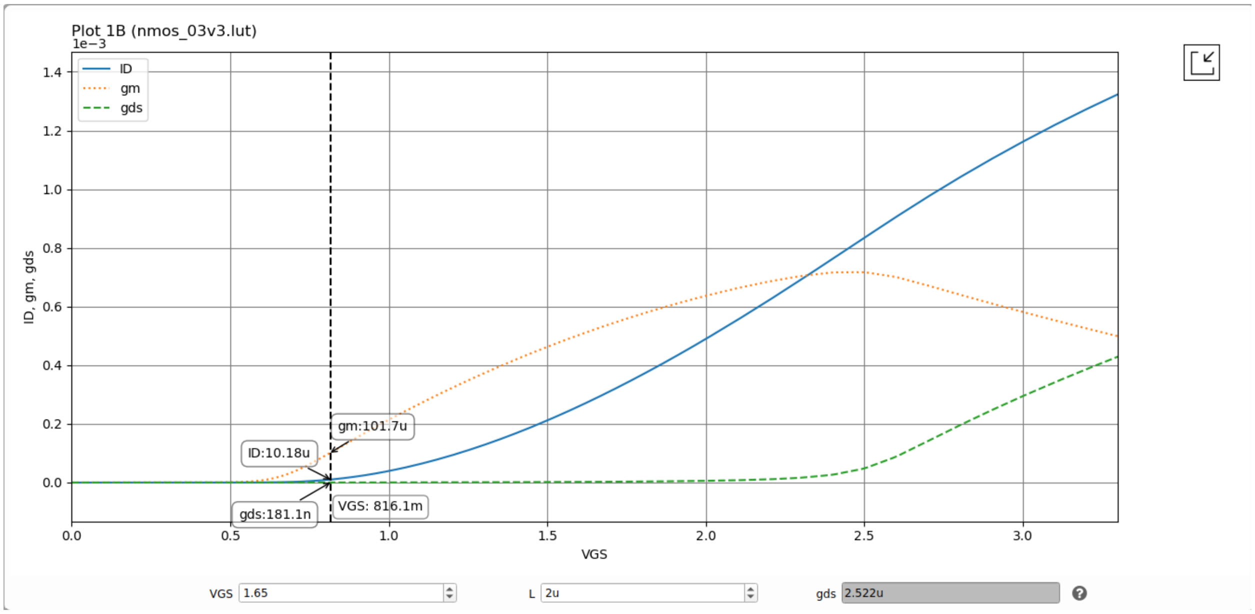
➢ Now, we know that the gain $A = gm * RD = \frac{2ID}{V^*} * RD = \frac{2V_{RD}}{V^*}$ so $V^* = \frac{2}{10} = 200\ mv$.

➢ We will assume $W = 10\mu m$ and we know that $I \propto W$ so we can get the right W with cross multiplication.

➢ Sweeping V^* with VGS to know the operating point.$V_{ovQ} = 147.7mv$,$V_{GSQ} = 816.1mv$.



- We got VGS=816.1mv. Now to calculate W and check that the gain is true we will sweep ID, gm, gds with VGS. $I_{DX} = 10.18\mu A$, $g_{mx} = 101.7\mu S$,$g_{dsx} = 181.1nS$.



- Using cross multiplication $W = 9.82\ \mu m.$
- The values of ID, gm, gds at the operating point are:

	At point X	At operating point
ID	$10.18\mu A$	$10\mu A$
$\boldsymbol{W}$	$10\mu A$	$\mathbf{9.82\ \mu m}$
gm	$101.7\mu S$	$99.9\mu S$
gds	$181.1nS$	$177.9nS$

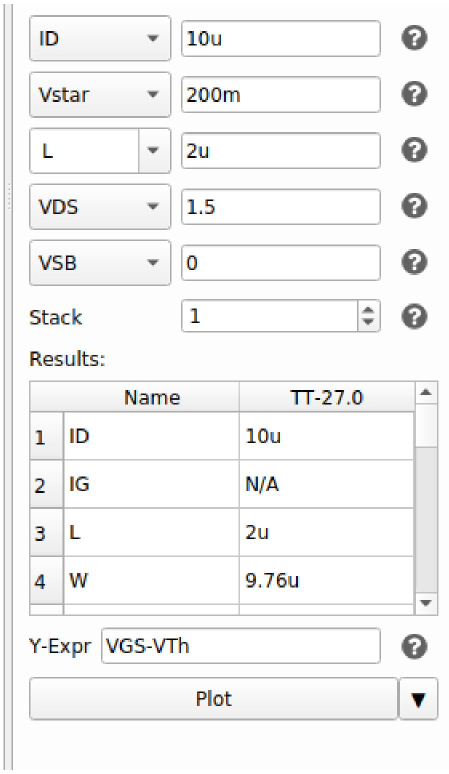
- Using the simulated results, we will check for the gain:

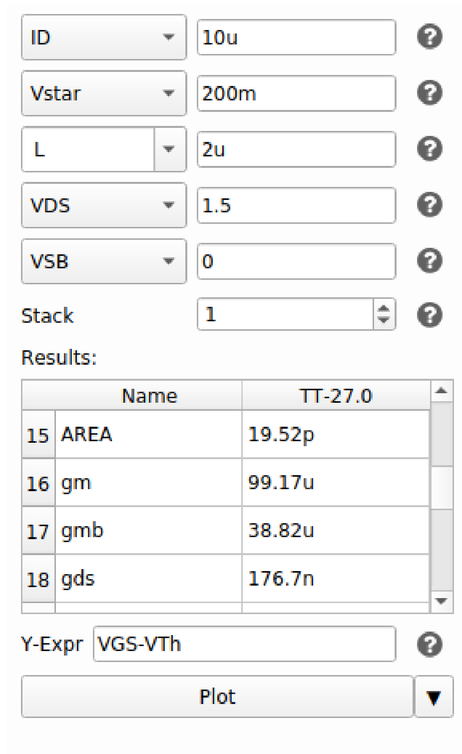
  $A = -gm(RD//ro) = -9.81.$

  and when neglecting ro $A = -gm * RD = -9.99.$

  The gain almost meats the specs this errors because we neglected ro in our analysis.

- Calculating operating point using ADT



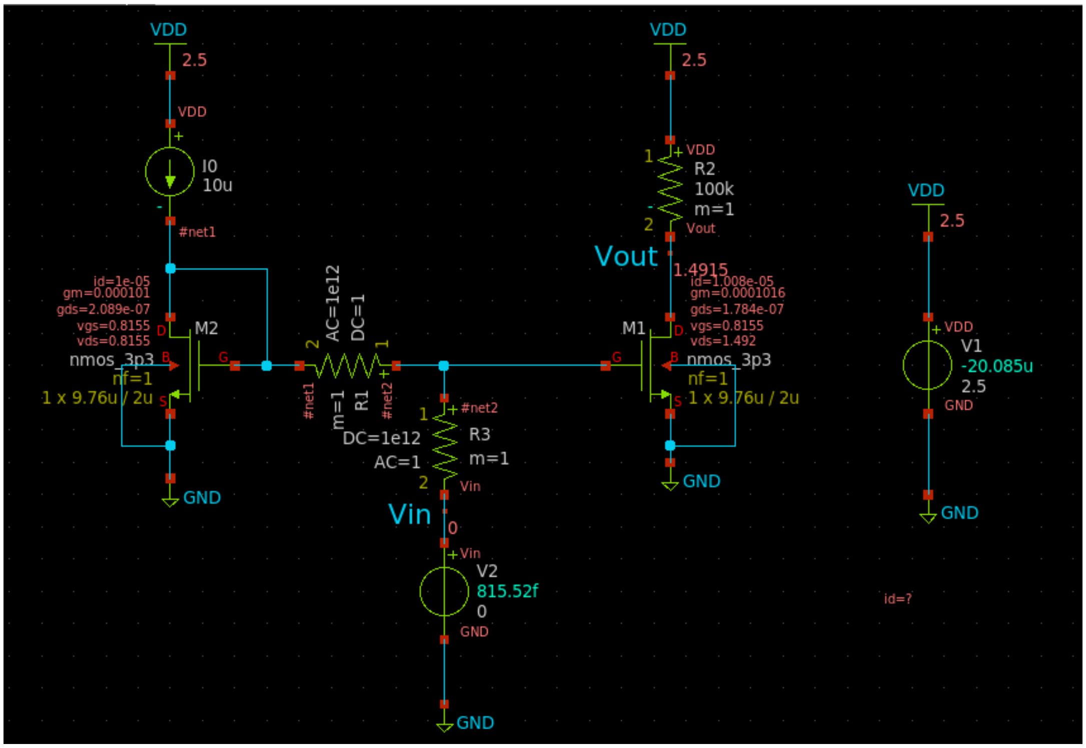


	Analytical	Simulation (ADT)
ID	$10\mu A$	$10\mu A$
W	$9.82\mu m$	$9.76\mu m$
gm	$99.9\mu S$	$99.17\mu S$
gds	$177.9nS$	$176.7nS$

PART 2: CS Amplifier:

1. OP Analysis:

- **Schematic:**



- **DC Operating point:**
  - ➢ DC OP:

```
ngspice 1 -> print all
@m.xm1.m0[gds] = 1.784013e-07
@m.xm1.m0[gm] = 1.016166e-04
@m.xm1.m0[id] = 1.008491e-05
@m.xm1.m0[vds] = 1.491508e+00
@m.xm1.m0[vgs] = 8.155202e-01
@m.xm2.m0[gds] = 2.088986e-07
@m.xm2.m0[gm] = 1.010052e-04
@m.xm2.m0[id] = 1.000003e-05
@m.xm2.m0[vds] = 8.155189e-01
@m.xm2.m0[vgs] = 8.155202e-01
net1 = 8.155215e-01
net2 = 8.155215e-01
v1#branch = -2.00849e-05
v2#branch = 8.155215e-13
vdd = 2.500000e+00
vin = 0.000000e+00
vout = 1.491511e+00
```

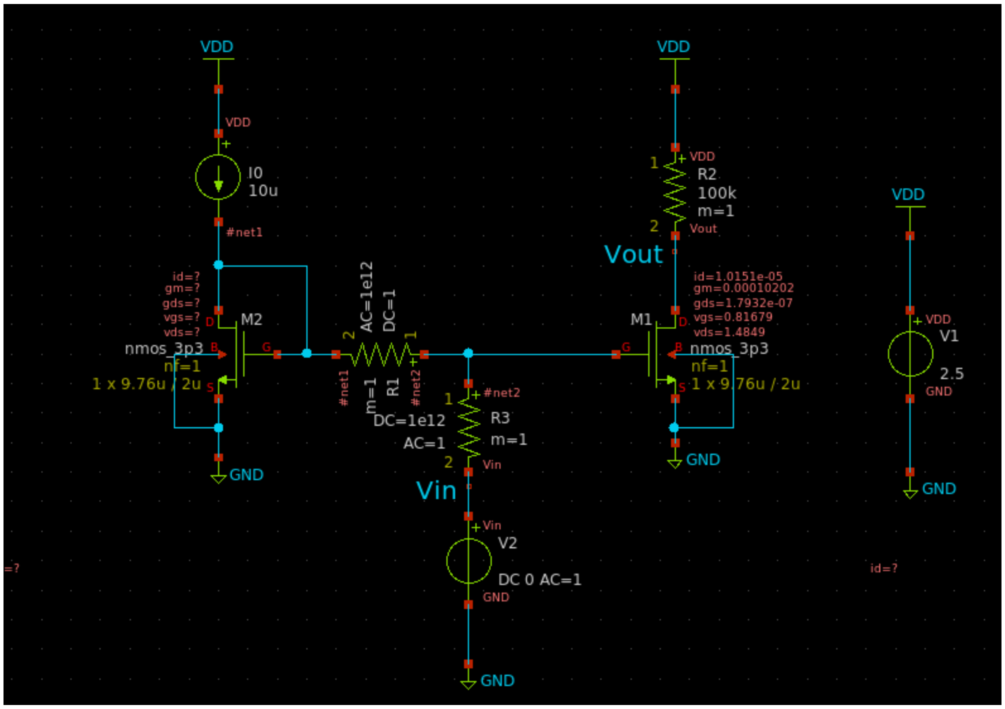
- Note: the DC OP annotation and the snapshot of the key parameters are on the schematic and DC OP above.
- Comparison between part1 and DC OP:

	Part1	DC OP
ID	$10\mu A$	$10.085\mu A$
VGS	$816.1mv$	$815.52mv$
VDS	$1.5v$	$1.4915v$
gm	$99.9\mu S$	$101.6\mu S$
gds	$176.7nS$	$178.4nS$
ro	$5.659\text{M}\Omega$	$5.605\text{M}\Omega$

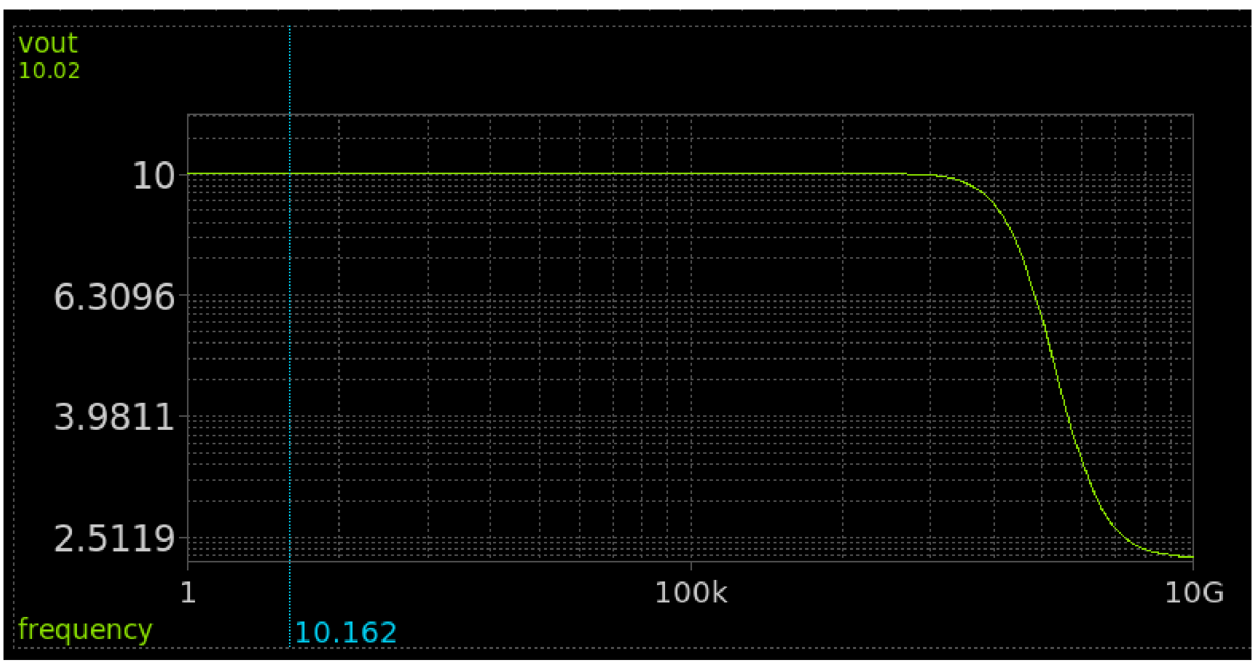
- ro and RD comparison:
  $ro = 5.605\text{M}\Omega\ and\ RD = 100k\Omega$ so ro is much higher than Rd and can be neglected. When we use minimum L, ro will decrease so we may consider it.
- Calculate the intrinsic gain of the transistor:
  From simulation $intrinsic\ gain = \frac{gm}{gds} = 569.5$
  While analytically using the simulation results: $A = gm * (RD//ro) = 9.98$
  The amplifier gain << the intrinsic gain as RD is very small compared to ro which reduces the gain a lot and we expect that as the intrinsic gain is the highest gain we can get.

2. AC Analysis:

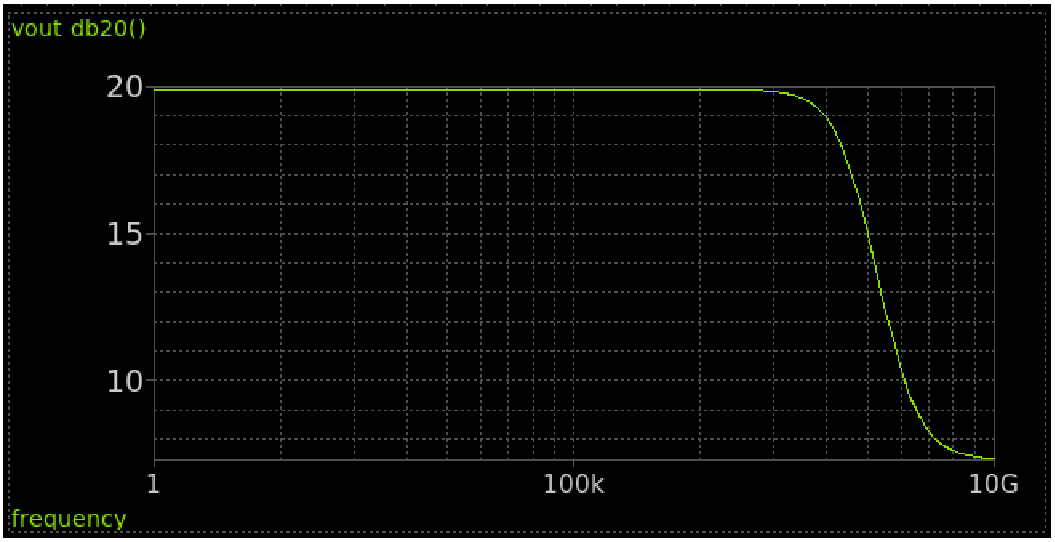
- **Schematic:**



- **Bode plot:**
  - ➢ Vout magnitude in log scale at on Y axis:



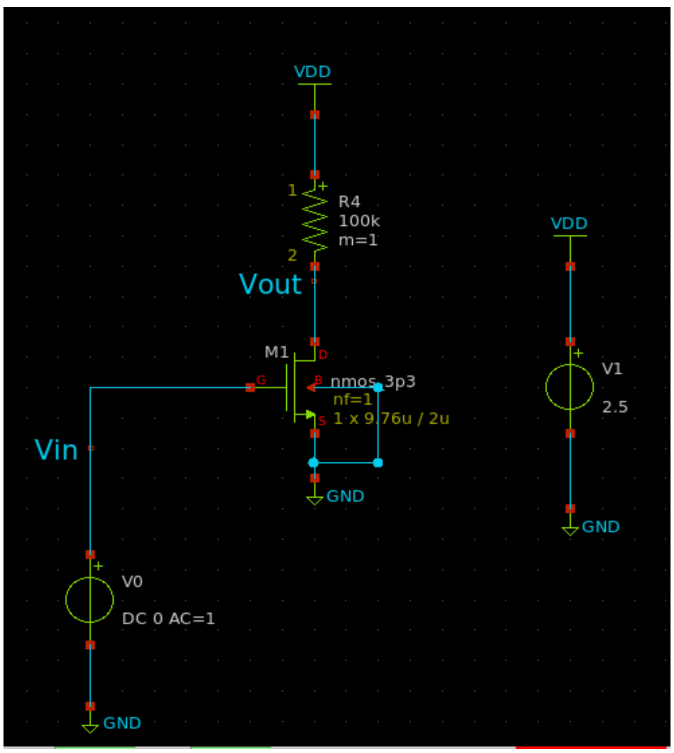
➢ Vout magnitude in dB:



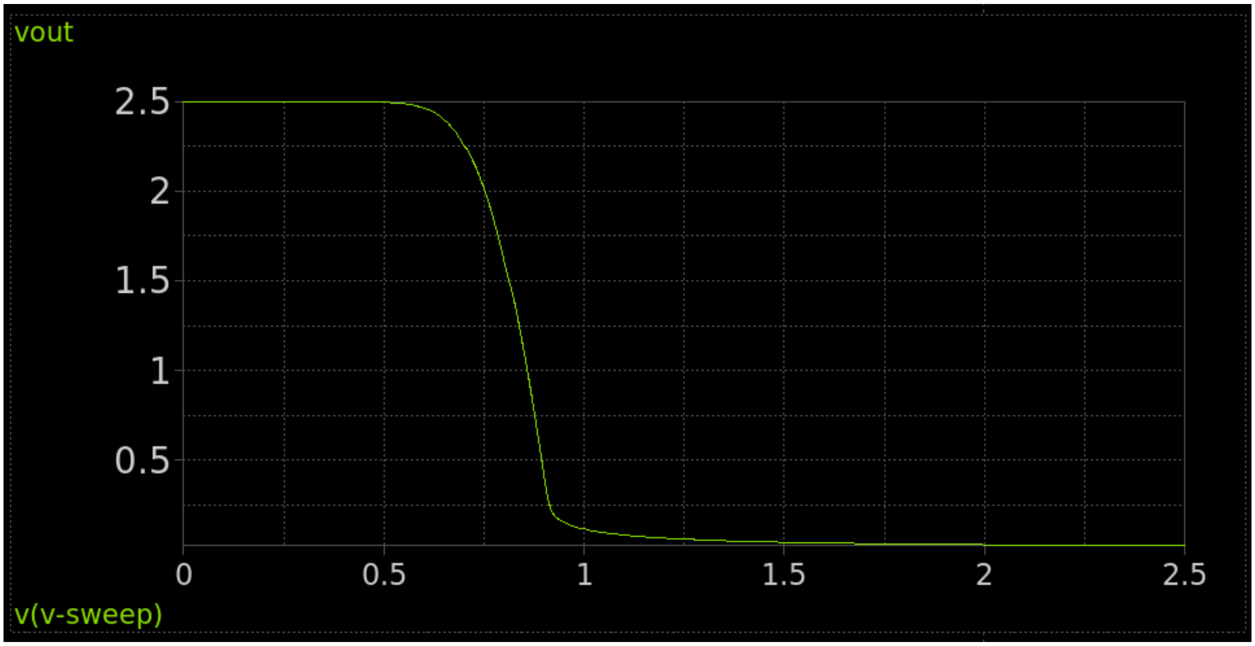
➢ DC gain=10.02 which meets the specs.

3. Gain Non-Linearity (Large Signal Operation DC Sweep):

- **Schematic:**

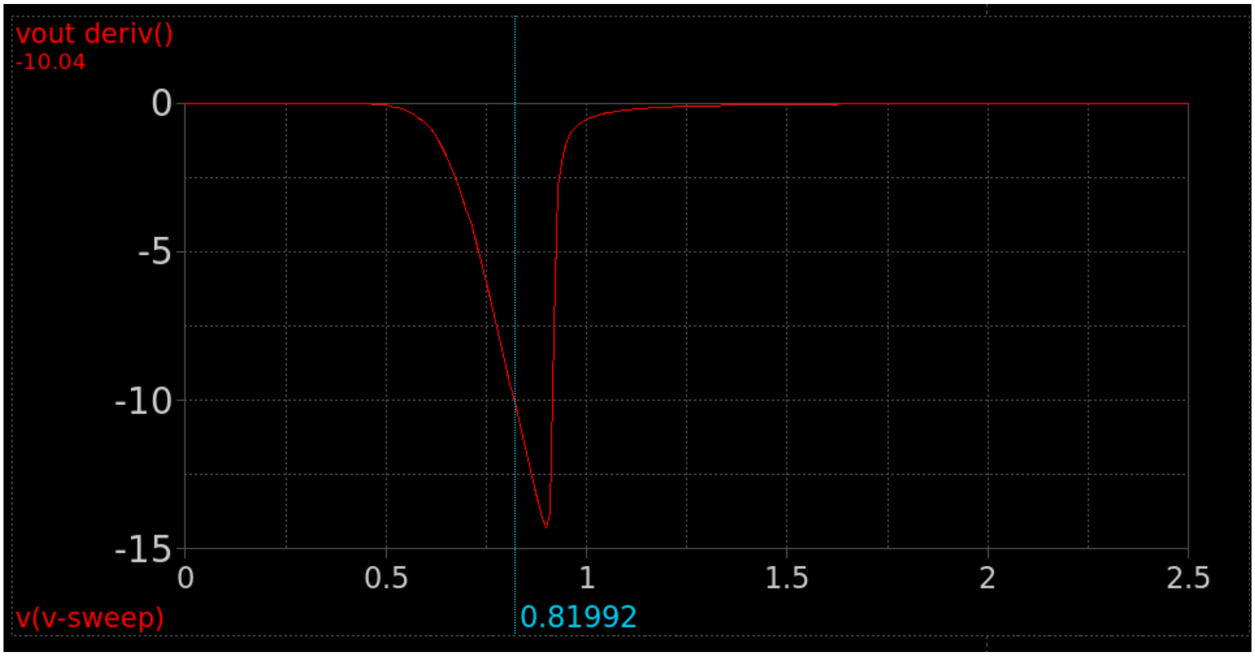


- VOUT vs VIN:



It is a non-linear relation as in the saturation region $vout = VDD - ID * RD$ and ID in saturation follows the square law with Vin so Vout has a quadratic relation with Vin in saturation. We can only consider it linear as an assumption for small signals only .

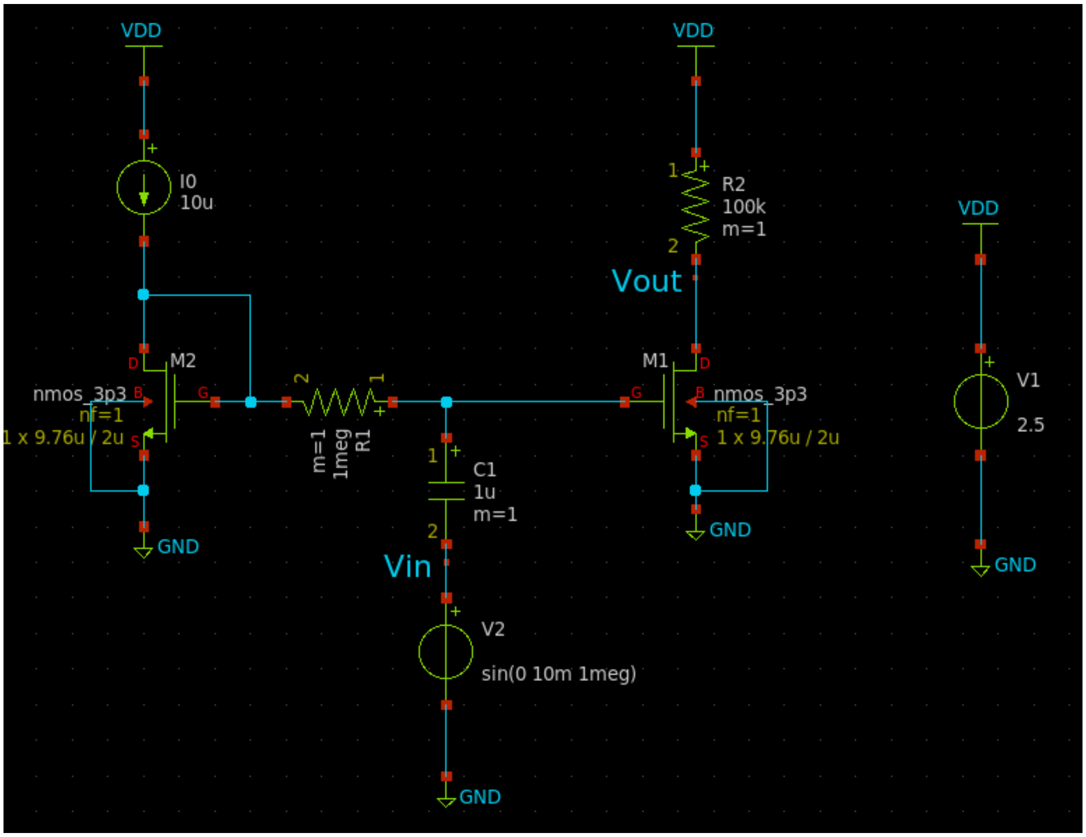
- Derivative of Vout VS Vin:



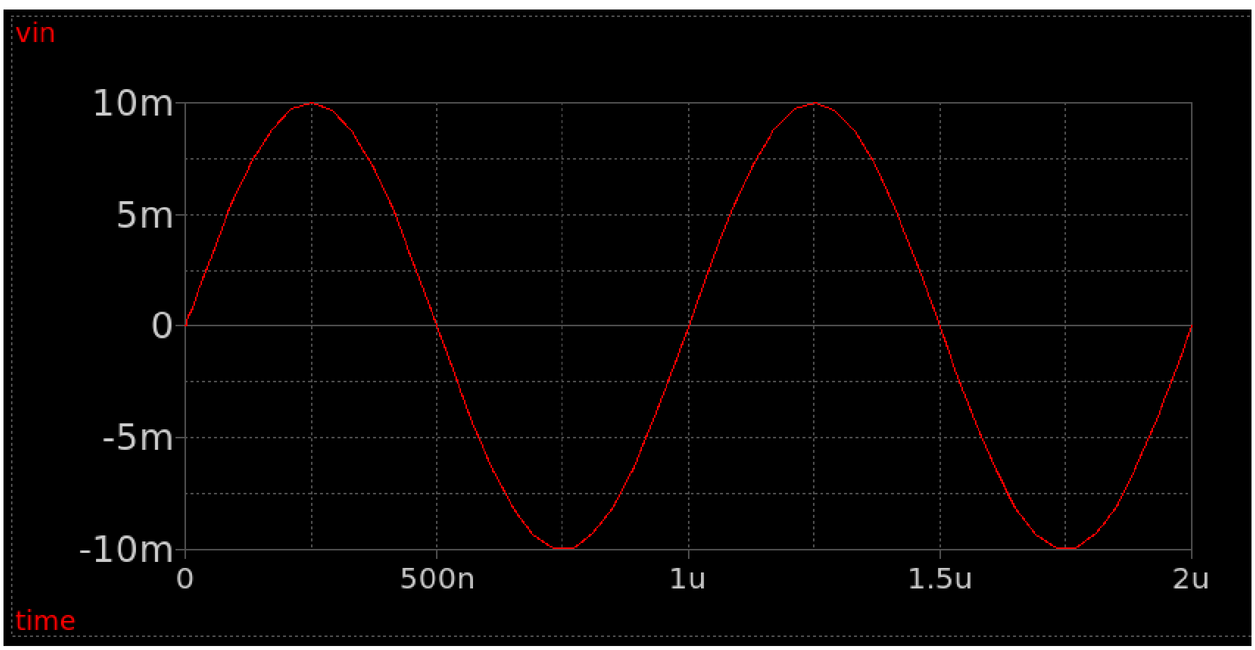
Gain is nonlinear with Vin as gm depends on Vin and $A = gm * RD$ then the gain is dependent on Vin and for the circuit to be linear the gain should be constant.

4. Gain Non-Linearity (Transient Analysis):

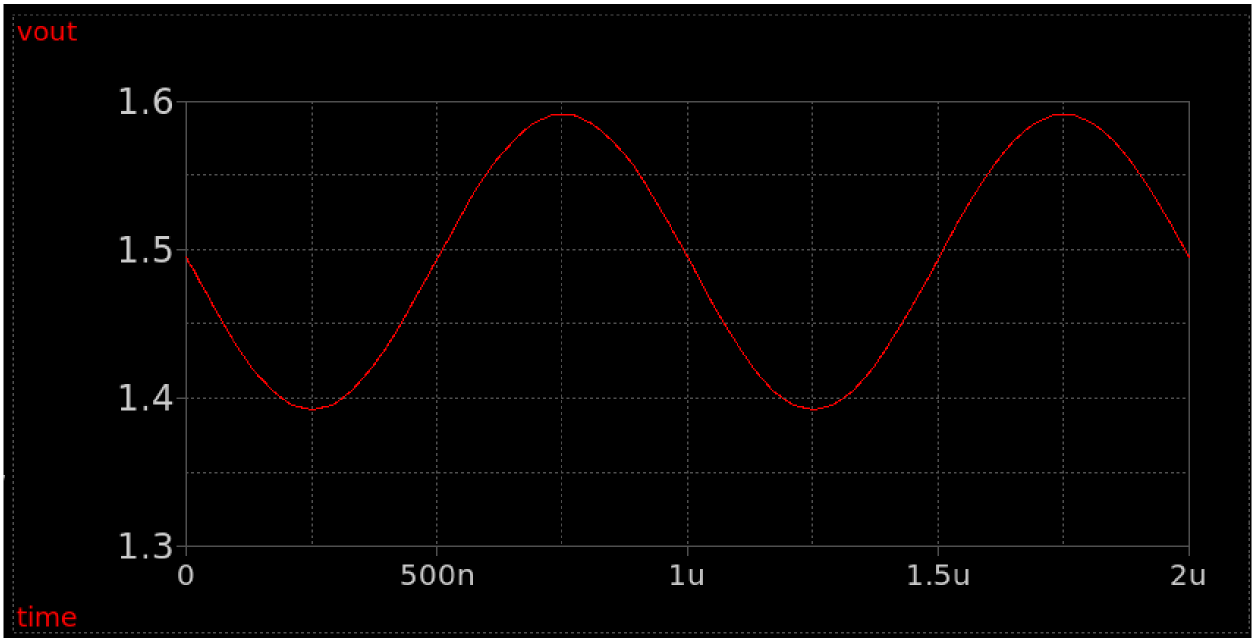
- **Schematic:**



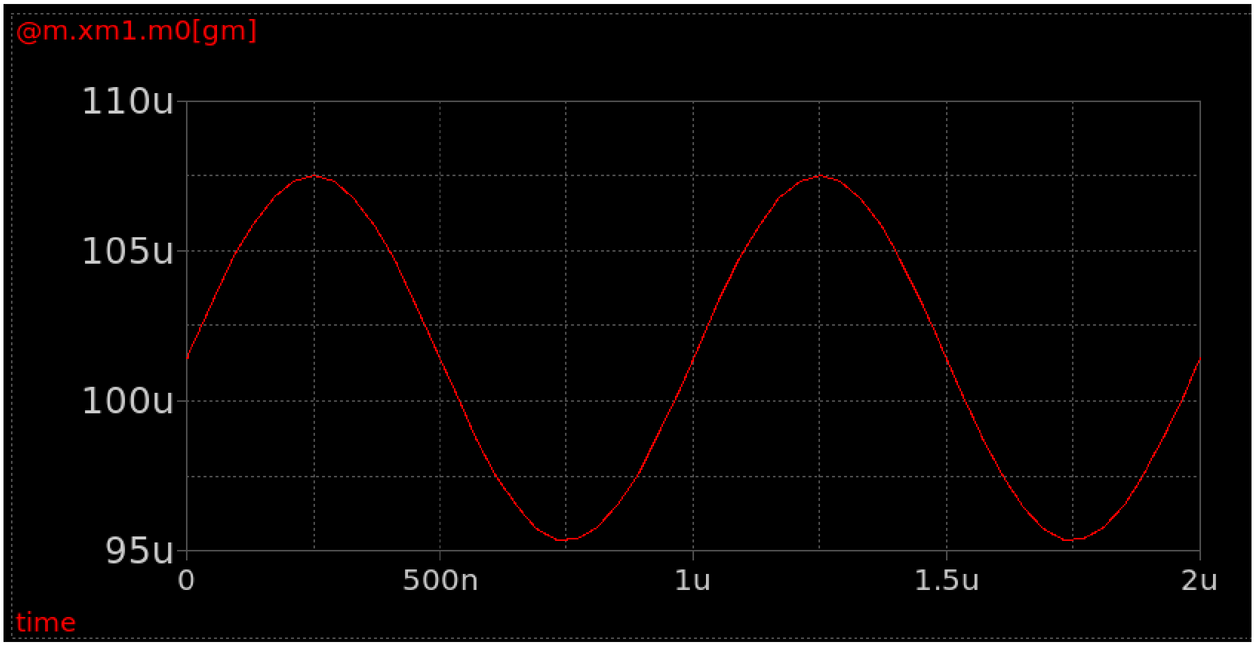
➢ Vin vs time:



- Vout vs time:



- gm vs time:



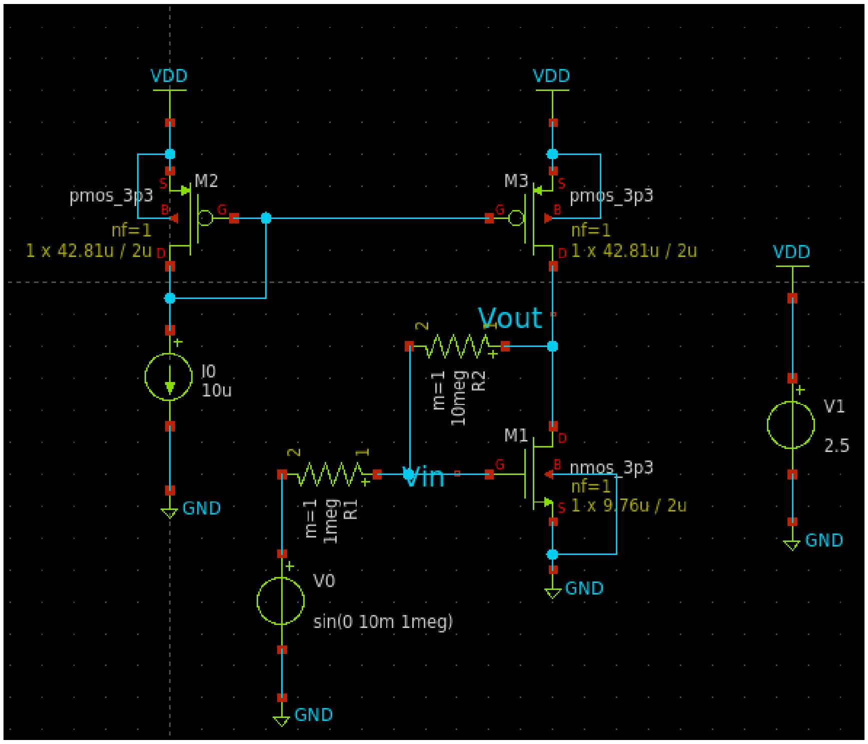
gm changes with time which means that gm vary with the change in the operating point (the change in VGS (Vin)) and this makes the gain depends on Vin so the gain is nonlinear.

- Is this amplifier linear?

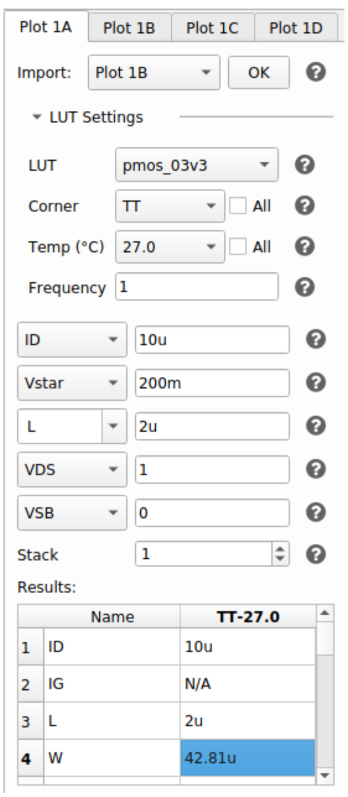
No, the amplifier is not linear as the gain is not constant with the change in Vin. And as we saw in the Vout vs Vin graph doesn't show a linear relation.

5. Gain Linearization (Negative Feedback):

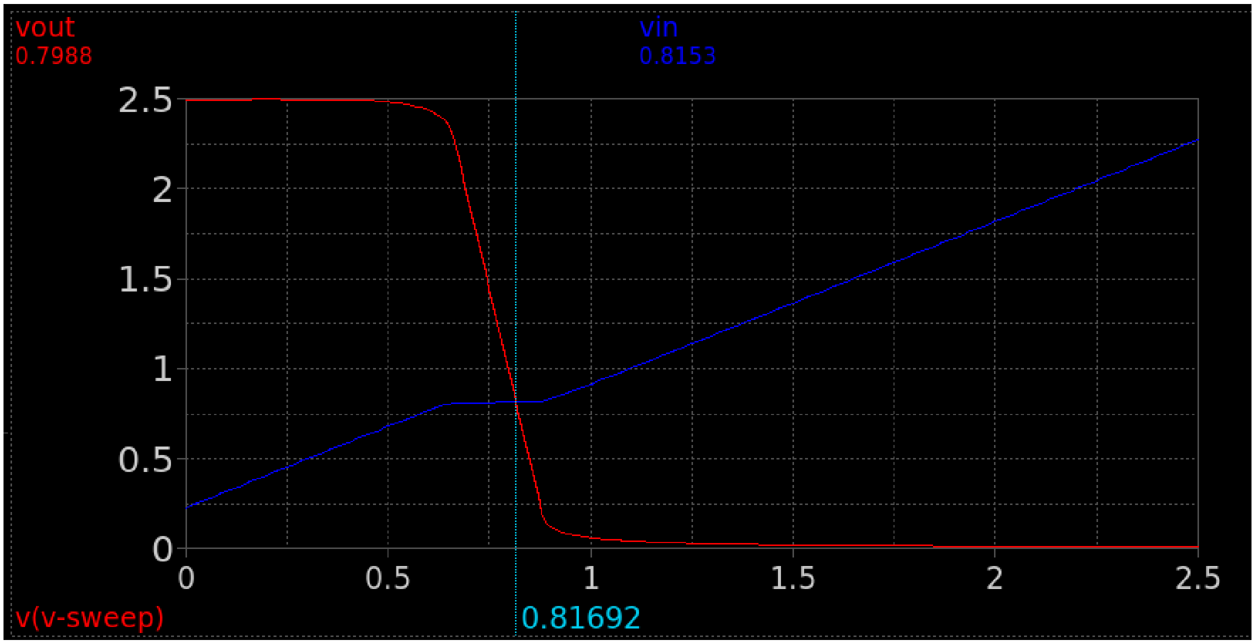
- **Schematic:**



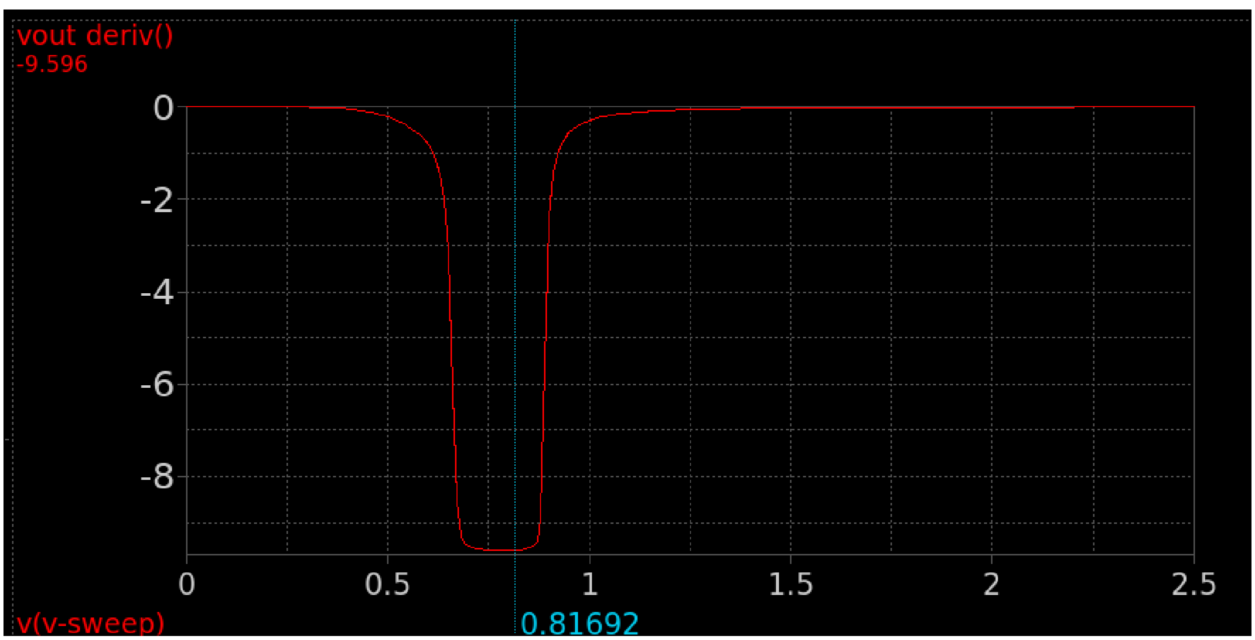
- **Getting the sizing of PMOS:**



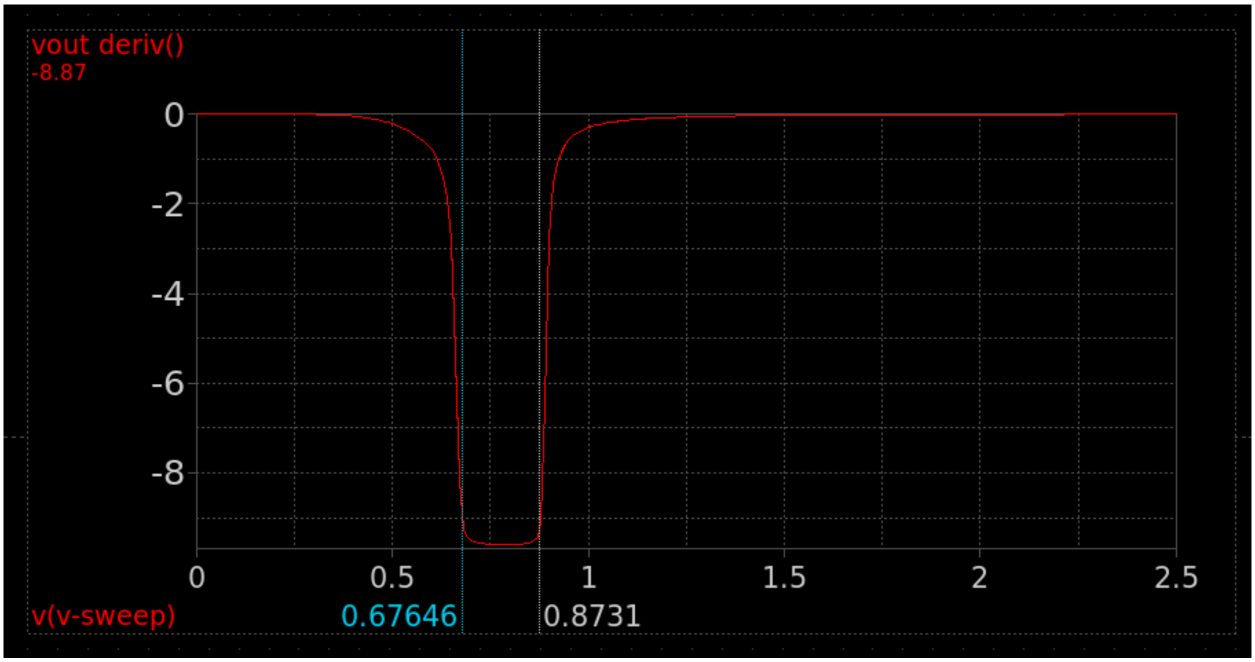
- We know that $A = \frac{-Rf}{Rin} = -10$ then $Rin = 1\ M\Omega$.
- Vin and Vout vs Vsig:



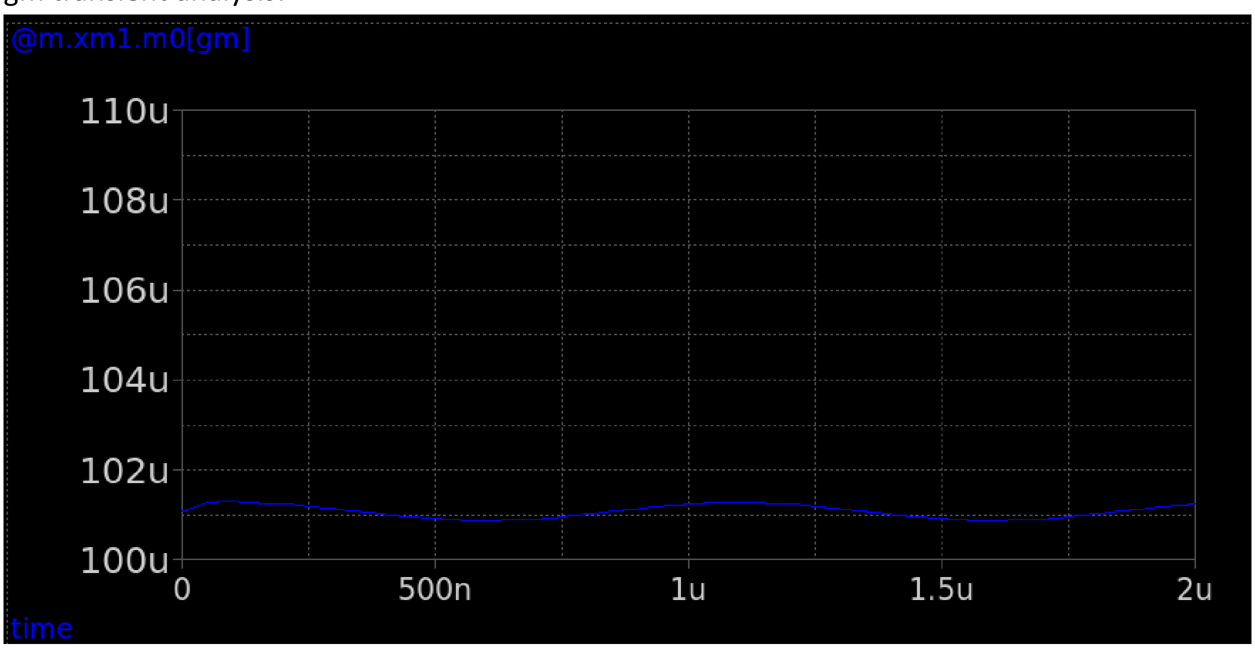
- Vin equal Vout at the operating point VGSQ as this makes the nmos have the same current as pmos then there is no current in the feedback resistance so voltage drop=0 and vout=vin.
- Vout is linear in the region as the feedback makes the relation between vout and vsig constant as $\frac{Vout}{Vsig} = closed\ loop\ gain = \frac{-RF}{Rin} = -10$ then the relation is linear.
- derivative of VOUT vs VSIG:



- the gain is linear (independent of Vin) because of the feedback resistance which stabilizes the input and reduce the changes in gm, $A = \frac{-RF}{Rin}$.
- Vin is almost constant at 816 mv as $\frac{Vout}{Vin} = gm * (ron//rop)$ which is very high so the change in vin is very small.
- Calculating DC input range at which gain is linear



- Analytically $range = \frac{VDD-v^*}{A} = \frac{2.2-2*0.2}{10} = 210mv$ and from graph equals $196.6mv$.
- gm transient analysis:



- gm became more stable (less change) as the change in the input became smaller.