# Lab 02

## Common Source Amplifier

## Part 1: Sizing Chart

- For real MOSFET $V_{ov} \neq \frac{2I_D}{g_m}$, so we define expression $V^* = \frac{2I_D}{g_m}$, and $V_{ov} = V^*$ in case of square law MOSFET only.

  So actual gain will be $A_v = \frac{2V_{RD}}{V^*} = \frac{2I_D R_D}{V^*}$.
- And we assume that channel length value will be L=2um, to avoid short channel effects.
- We choose the value of $V_{RD} = {}^{V_{DD}}/_{2} = 0.9V$, which is a common mode output level voltage.
- We have $I_D = 50uA \rightarrow \therefore R_D = \frac{V_{RD}}{I_D} = 18k\Omega$.
- Also we have $A_v = -10 \rightarrow \therefore V^* = \frac{2V_{RD}}{A_V} = 0.18V$, which we make the OP voltage of real MOSFET overdrive voltage: $V_Q^* = 0.18V$.
- Calculations of MOSFET width (W) from cadence:

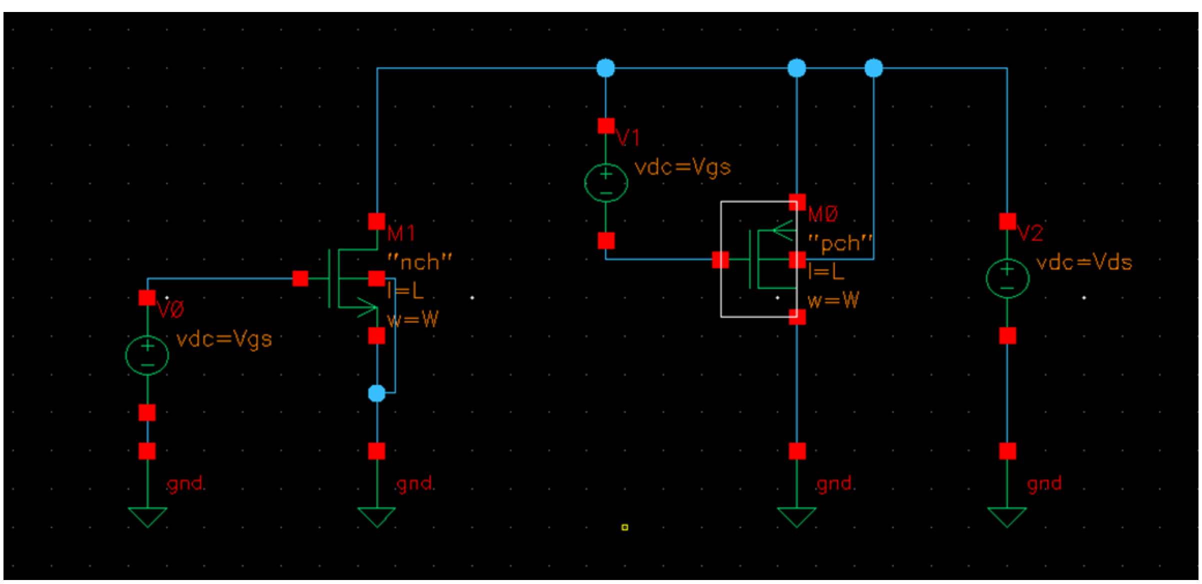


Fig.1 Circuit -schematic from cadence used for selecting MOSFET width

After DC simulation we found that value of threshold voltage will be

$V_{th} = 382.625mV.$

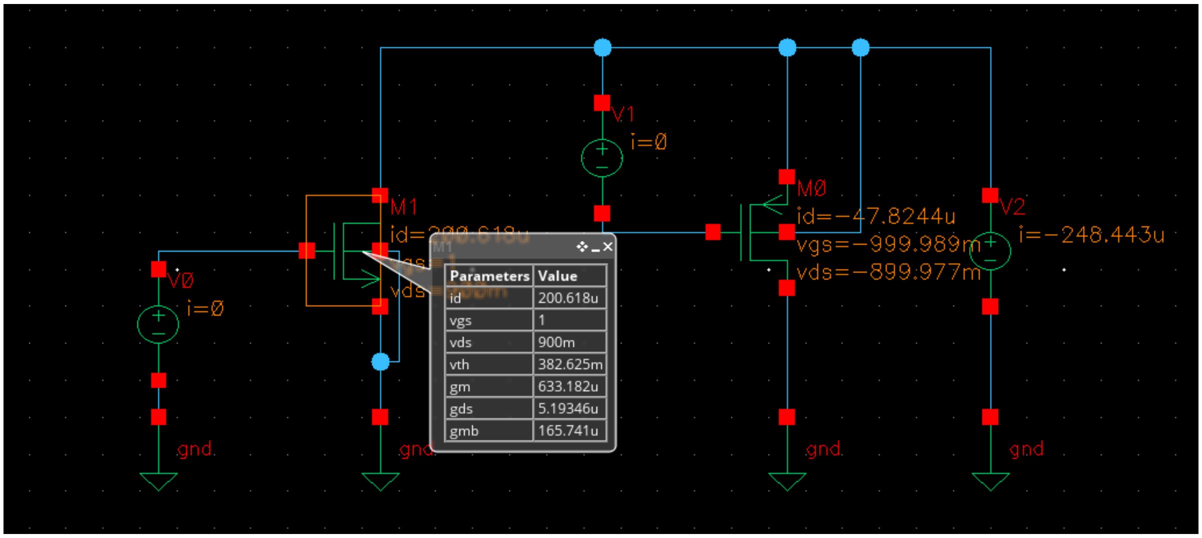


Fig.2 Circuit schematic from cadence

So select to sweep $V_{gs} = 0 \rightarrow V_{th} + 0.4 = 0 \rightarrow 782.625mV$, and select $V_{ds} = \frac{V_{DD}}{2} = 0.9\text{V}$.

And firstly assume the width of MOSFET to be W=10um, L=2um.

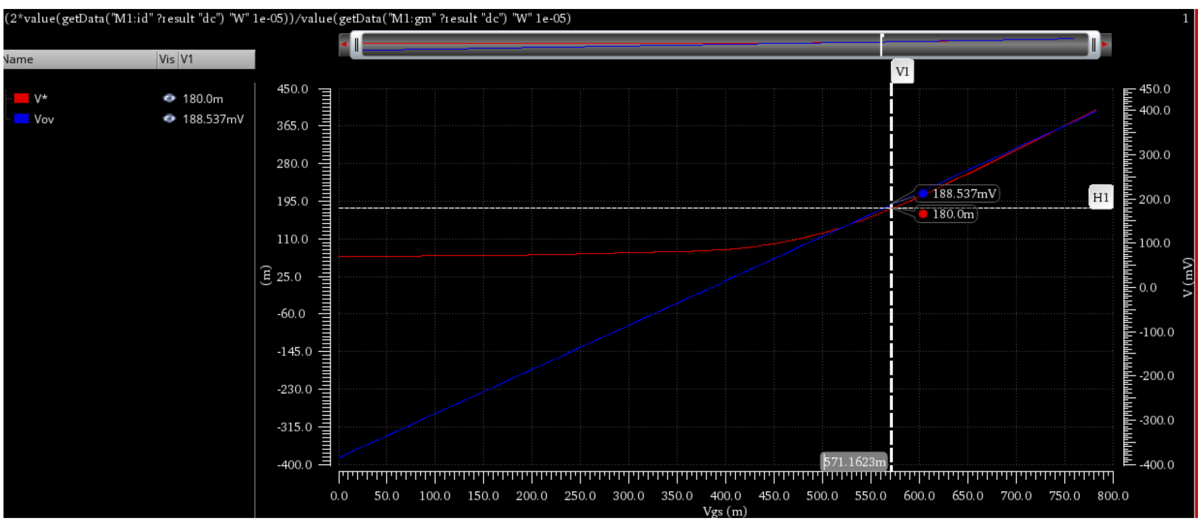


Fig.3 $V_{ov}$& $V^*$ versus $V_{gs}$

So we found values of $V_{gsQ} = 571.1623mV, V_{ovQ} = 188.537mV,$

$at\ value\ V_Q^* = 180mV.$

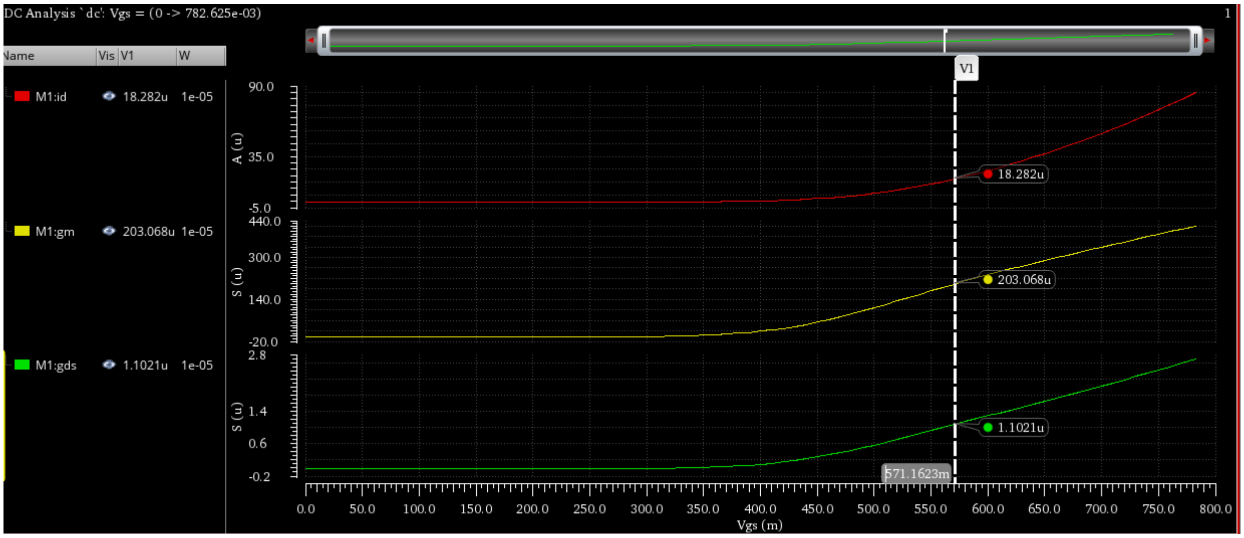


Fig.4 $I_D, g_m$ *and* $g_{ds}$ versus $V_{gs}$

As shown in previous simulation results that at operating point

$V_{gs} = 571.1623mV$, we have the following results

$I_{dQ} = 18.282uA, g_{mQ} = 203.068uS\ and\ g_{dsQ} = 1.1021uS.$

| Parameter | Value |
|---|---|
| $V_Q^*$ | 180mV |
| $V_{gsQ}$ | 571.1623mV |
| $V_{ovQ}$ | 188.537mV |
| $I_{dQ}$ | 18.282uA |
| $g_{mQ}$ | 203.068uS |
| $g_{dsQ}$ | 1.1021uS |

Now return to our assumption of width of MOSFET W=10um, and as we know that $I_D \propto W$ at any instant even square law is valid or not.

So at $W = 10um \rightarrow I_{DQ} = 18.282uA$, using the cross multiplication we can get width value at $I_{DQ} = 50uA$ which will be W=27.35um.

And also width of MOSFET is proportional to $g_m$ and $g_{ds}$, at $W = 10um \rightarrow g_{mQ} = 203.068uS\ and\ g_{dsQ} = 1.1021uS$, so using cross multiplication we can get values of $g_{mQ}\ and\ g_{dsQ}$, which will be as following:

$W = 27.35um \rightarrow g_{mQ} = 555.39uS\ and\ g_{dsQ} = 3.014uS.$

And since $r_o = \frac{1}{g_{dsQ}} = 331.785k\Omega.$

So Common Source Parameters:

| Parameter | Value |
|---|---|
| L | 2um |
| W | 27.35um |
| $V_{gsQ}$ | 571.1623mV |
| $R_D$ | 18kΩ |
| $I_{DQ}$ | 50uA |
| $g_m$ | 555.39uS |
| $g_{ds}$ | 3.014uS |
| $r_o$ | 331.785kΩ |

Check: $A_v = g_m * (R_D \parallel r_o) = 9.48$.

# Part 2: CS Amplifier

## 1.OP and AC Analysis:

- Operating point parameters comparison from CS simulation and our results in part 1:

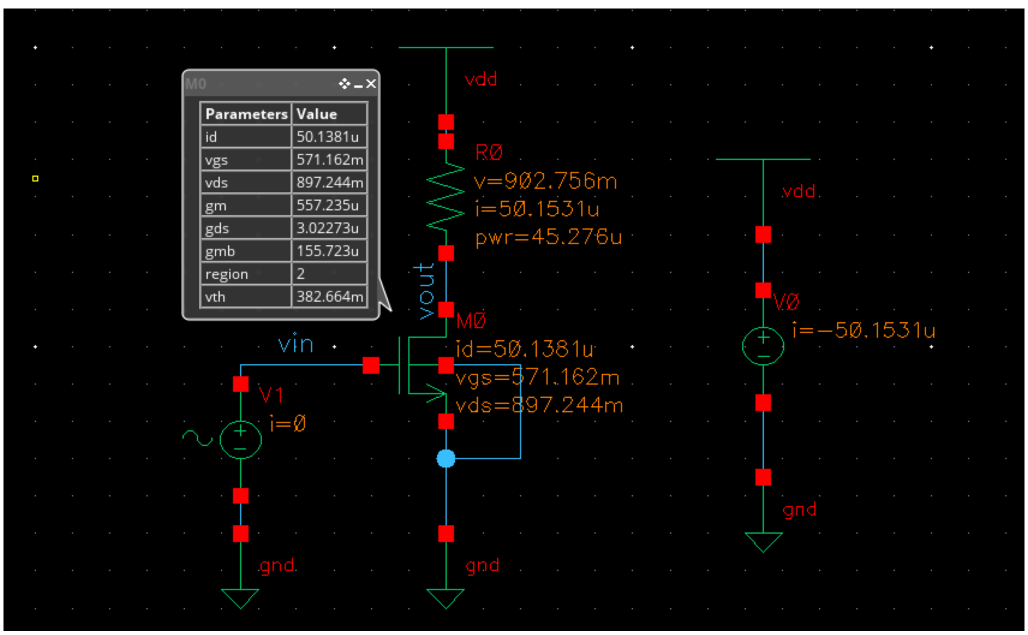


Fig.5 CS schematic with OP parameters simulation

| OP parameter | Part 1 Result | CS Simulation Result |
|---|---|---|
| $I_{DQ}$ | 50uA | 50.1381uA |
| $g_m$ | 555.39uS | 557.235uS |
| $g_{ds}$ | 3.014uS | 3.02273uS |
| $r_o$ | 331.785kΩ | 330.827kΩ |
| $V_{gsQ}$ | 571.1623mV | 571.1623mV |

And as shown in previous table that there is a great agreement between our results in part 1 and CS amplifier simulation part.

And as shown in figure that region of MOSFET equal 2 which mean that MOSFET is in saturation region.

- $R_D \ vs \ r_o$:
  As shown from fig.6 that $r_o = 330.8k\Omega$, and we have value of $R_D = 18k\Omega$. So $r_o \gg R_D$, therefor we can neglect the value of $r_o$ as the two resistances are connected in parallel. And this is clear also in fig.6 simulation results of CS amplifier that $R_{out} = 17.9k\Omega \approx R_D$.

| | 1 |
|---|---|
| W | 27.35E-6 |
| M0:id | 50.14E-6 |
| M0:gm | 557.2E-6 |
| M0:gds | 3.023E-6 |
| M0:gmb | 155.7E-6 |
| M0:vgs (V) | 571.2E-3 |
| M0:region | 2 |
| M0:ron | 17.90E3 |
| M0:rout | 330.8E3 |

Fig.6 OP parameters from CS amplifier simulation

  If we use minimum channel length we have to take the value of $r_o$ in consideration because its value will decrease following the relation $r_o = \frac{1}{\lambda I_{DS}} \rightarrow \lambda \propto \frac{1}{L} \rightarrow \therefore r_o \propto L$.
- Intrinsic gain of MOSFET will be:
  $A_V = g_m * r_o = 557.2uS * 330.8k\Omega = 184.3217$.
- Amplifier gain analytically:
  $A_v = g_m * (R_D \parallel r_o) = 9.5$.
  And from previous calculations it's clear that intrinsic gain is much greater than amplifier gain.
- AC Analysis:
  Amplifier gain magnitude $A_v = \frac{V_{out}}{V_{in}} = 9.5$.
  Amplifier gain in dB $A_v = 20 * \log\left(\frac{V_{out}}{V_{in}}\right) = 19.55$.
  And we select value of input voltage to be 1 volt and plot output voltage which is considered to be voltage gain as shown in fig.7, and this meet our spec.

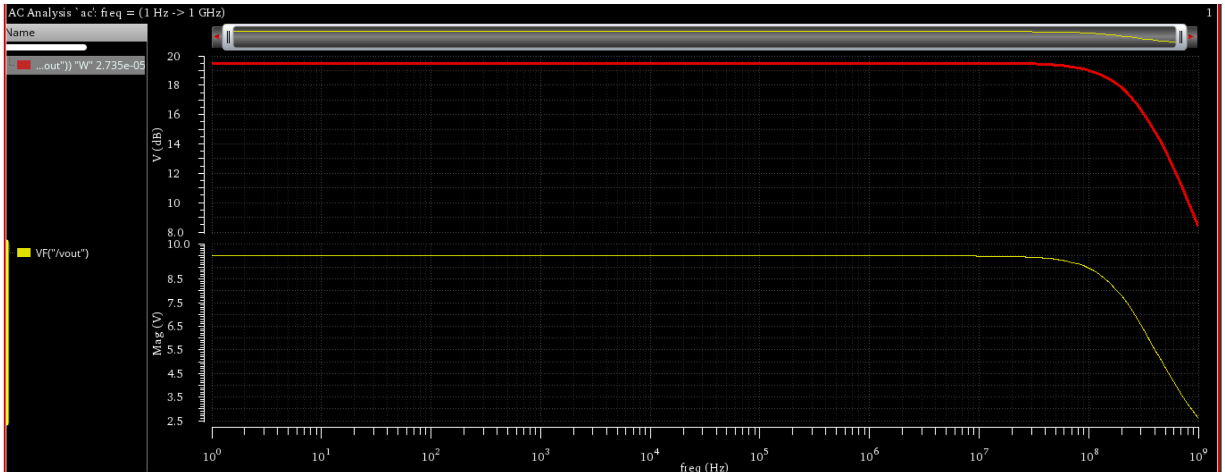


Fig.7 AC analysis simulation result for CS amplifier

# 2.Gain Non-Linearity:

- Output voltage $V_{out}$ versus input voltage $V_{gs}$:

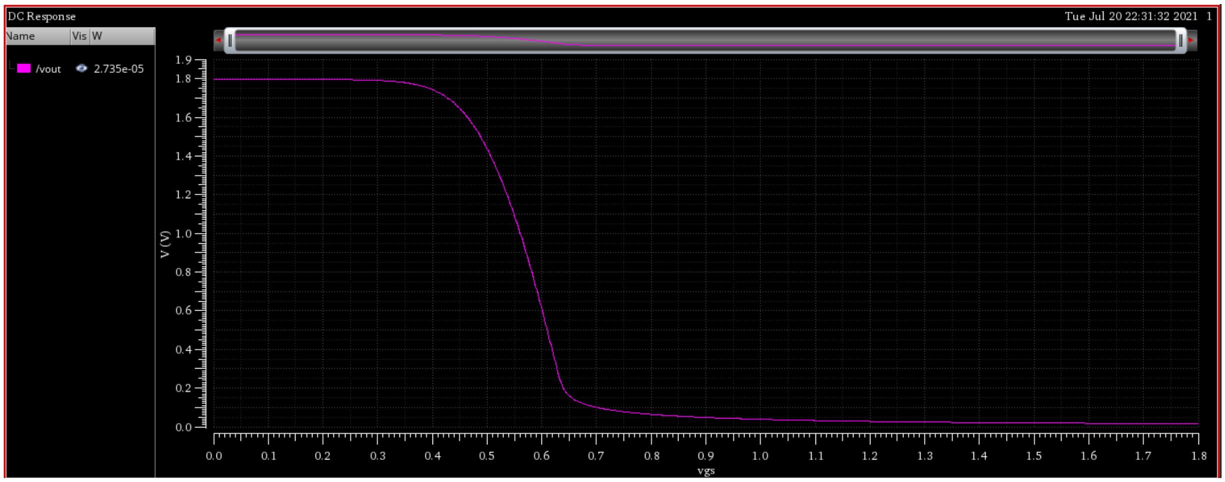


Fig.8 Vout versus Vin

As shown in fig.8 that the relation between $V_{out}$ and $V_{in}$ which is the gain relation is a non-linear relation and this because of dapendence of gain on $g_m$, as the gain equation as following $A_v = g_m * R_D$, and $g_m$ is a strong dependentant on input voltage $V_{gs}$.

- Derivative of $V_{out}$ versus $V_{in}$:

  As shown in fig.9 that derivatve of $V_{out}$ is not constant value and this because that relation between $V_{out}\ and\ V_{in}$ is not a linear relation due to dependance on $g_m$ which is dependent on input voltage $V_{gs}$.

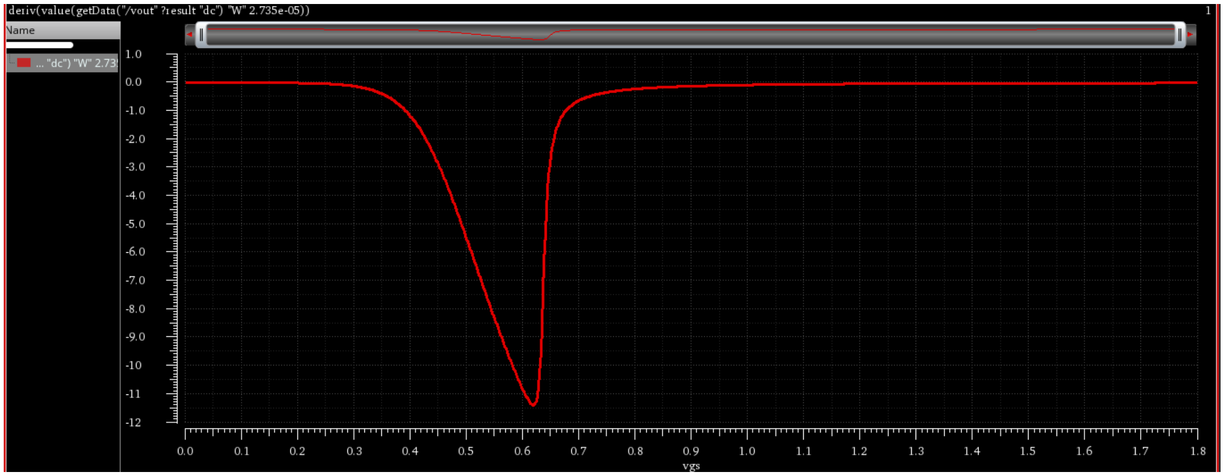


Fig.9 derivatve of Vout versus Vin

- Transient analysis by a sine wave superimposed on input DC voltage level:

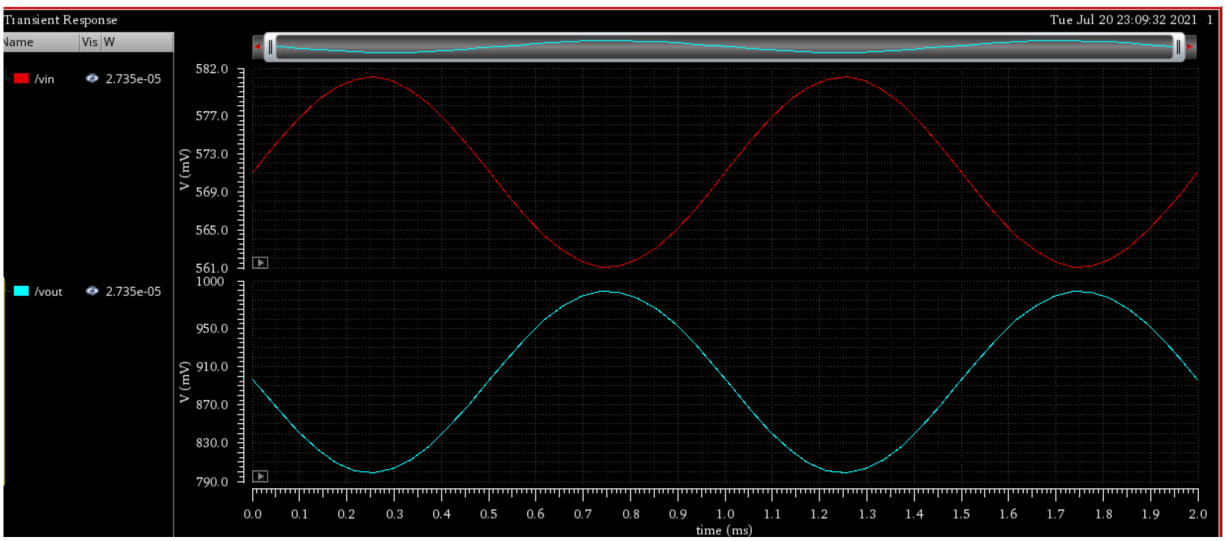


Fig.10 transient analysis simulation for input voltage and output voltage

- $g_m$versus time simulation:
  As shown in fig.11 that $g_m$ is varied with time and this proves the dependence of $g_m$ on input voltage $V_{gs}$ which also depend on time, so $g_m$ is strong dependent on input voltage $V_{gs}$.

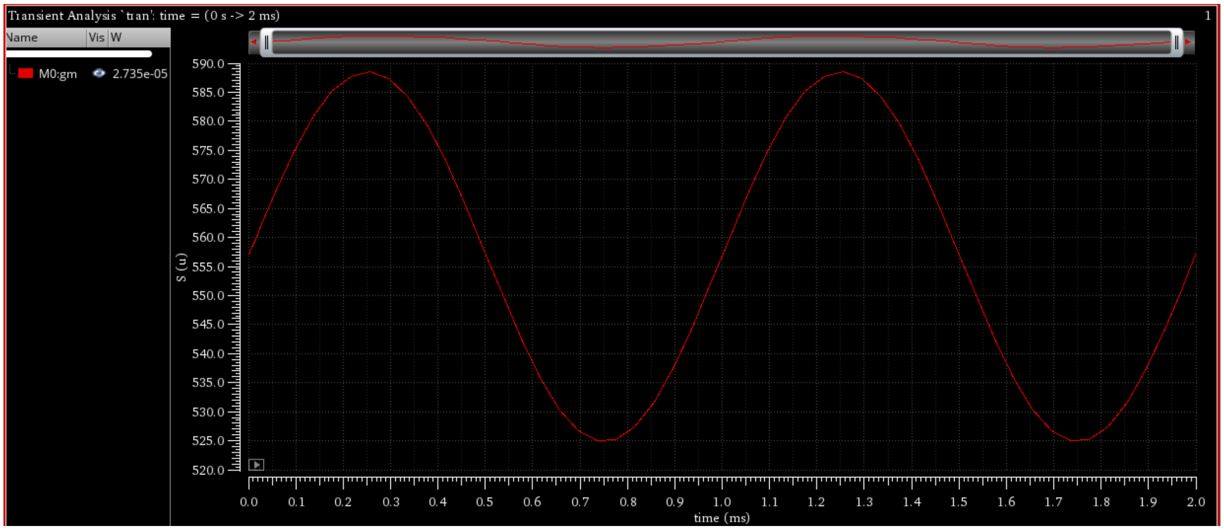


Fig.11 $g_m$ versus time in transient analysis

- From previous analysis it's clear that our amplifier is a non-linear amplifier becauce the relation between it's input voltage and output voltage is a non-linear relation, this because the gain of amplifier is depentant on $g_m$ which is strongly dependentant on input voltage $V_{gs}$, and this cause the non-linearity in the amplifier gain.