Design, simulation and analysis (dc and small signal) of

Common-Source Amplifier

for transconductance (g_m) of 20 mS.

Submitted By

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M.Tech. SSD

OBJECTIVE

The objective of this assignment is to design the common source amplifier for **transconductance (g_m) of 20 mS** and analyse the circuit with dc analysis and small signal analysis.

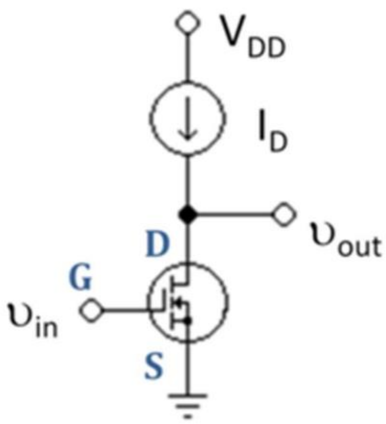
The analysis is done in two parts:

1. **DC ANALYSIS:**
   This analysis is done with different plots of following DC parameters.
   - $\log_{10}(I_D)$ Vs. V_{GS}
   - $\log_{10}(I_D/W)$ Vs. g_m/I_D
   - $\log_{10}(f_T)$ Vs. g_m/I_D

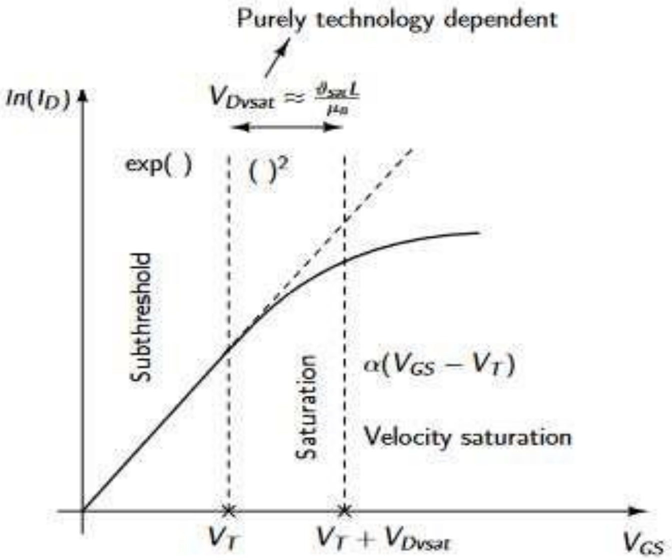
2. **AC ANALYSIS**
   - By fixing V_{GS} and W, varying I_D
   - By fixing W and I_D, varying V_{GS}
   - By fixing I_D and V_{GS}, varying W

INTRODUCTION TO COMMON SOURCE AMPLIFIER

The most used MOS-small signal amplifier that we have is the common source (CS) amplifier.



➢ ***DC ANALYSIS***



Plot for $\log_{10}(I_D)$ Vs. V_{GS}

$$I_D = \begin{cases} 0 & \forall \;\; V_{GS} \leq V_T \\ \mu_n C_{ox} \frac{W}{L}[(V_{GS} - V_T)V_{Dmin} - \frac{V_{Dmin}^2}{2}](1 + \lambda V_{DS}) & \forall \;\; V_{GS} > V_T \end{cases}$$

where V_{Dmin} = minimum of $\{V_{DS}, (V_{GS} - V_T), V_{Dvsat}\}$.

- Above expression is valid for linear, saturation and velocity saturation regions.

➢ ***SMALL SIGNAL ANALYSIS***

- The gain of the amplifier is defined as

$$\textit{Gain} = g_m\, r_0$$

- The transconductance (g_m) is defined as

$$g_m = \mu_n C_{ox} \frac{W}{L} (V_{GS} - V_{TH})$$

$$= \left(2I_D\, \mu_n C_{ox} \frac{W}{L} \right)^{1/2}$$

$$= (2I_D) / (V_{GS} - V_{TH})$$

- The Bandwidth is defined as

$$BW = 1/(2\pi r_0\, C_L)$$

The variation of I_D, W and V_{GS} is governed by the equation,

$$g_m\, r_0 = \frac{1}{\lambda} \frac{gm}{ID} = \frac{2}{VGS - VTH}$$

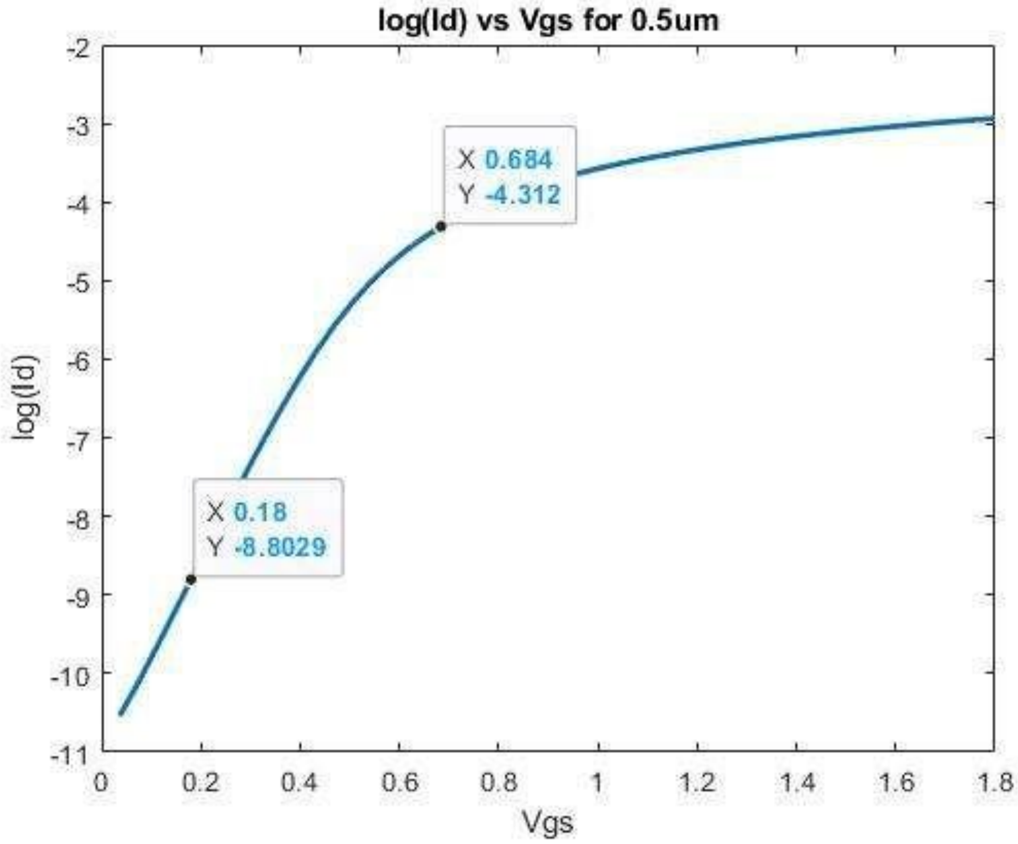
&

$$\mathrm{GBW} = \frac{gm}{2\pi C0}$$

OBSERVATIONS AND CALCULATIONS

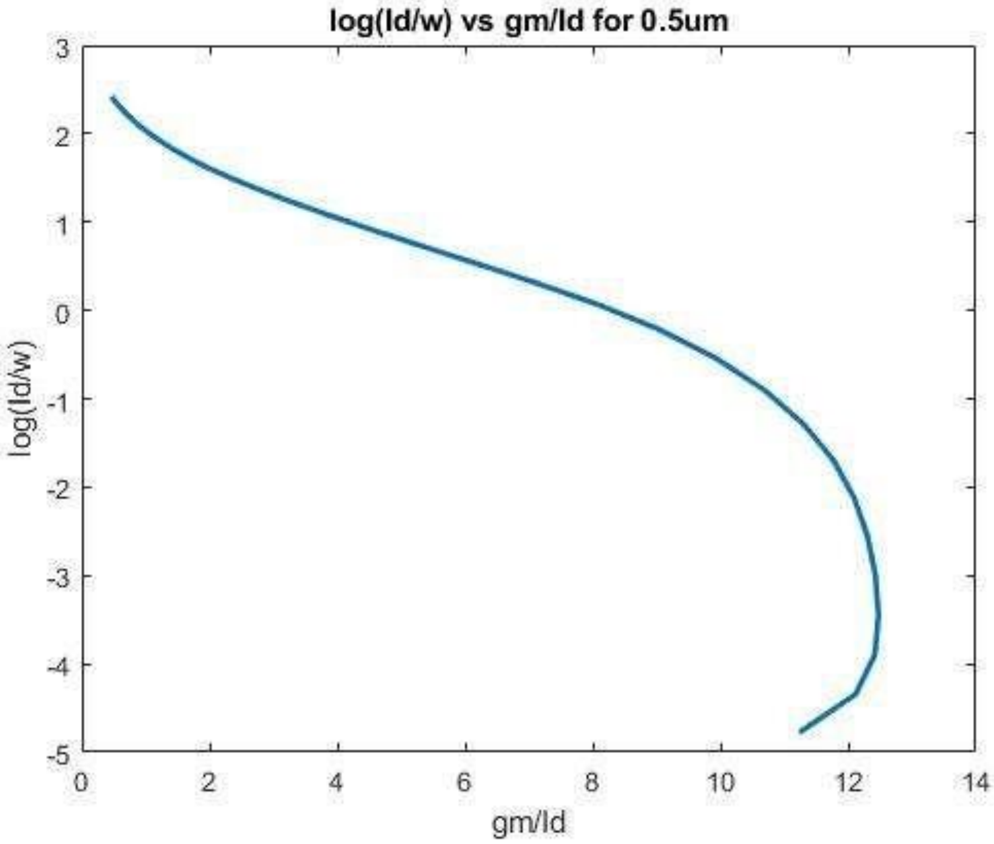
- ***DC ANALYSIS***

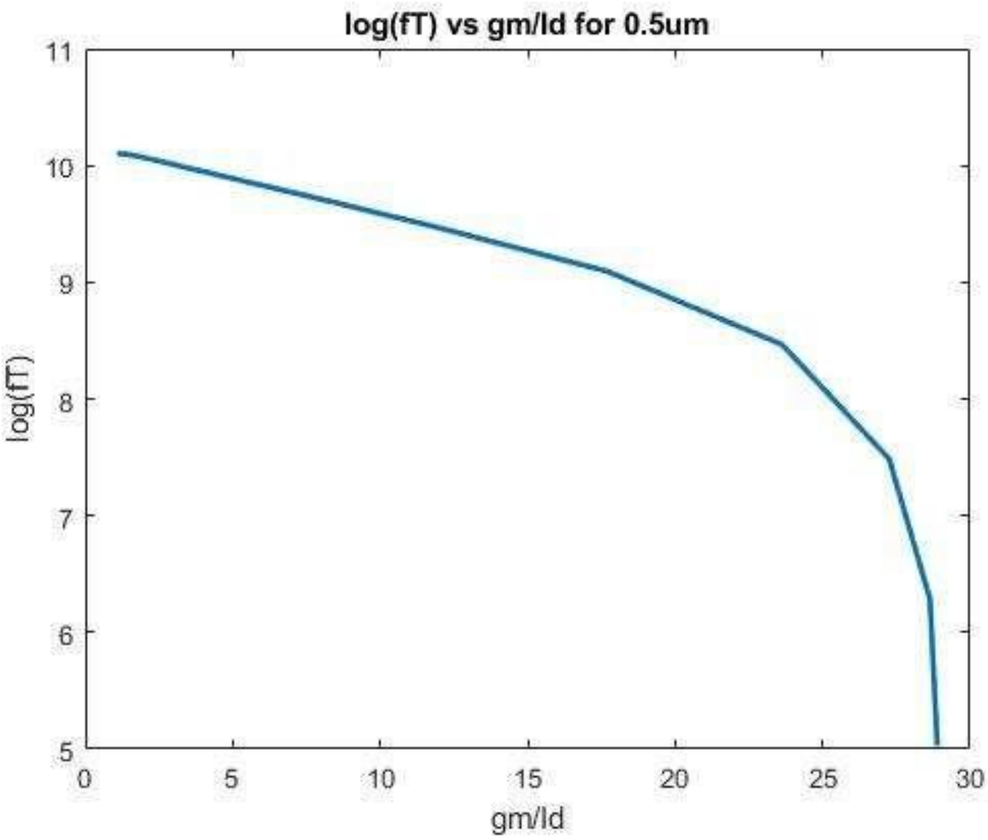
1. For V_{GS} = 1.8V and V_{DS} = 1.8V
   W = 0.5 µm and L = 4.2 µm



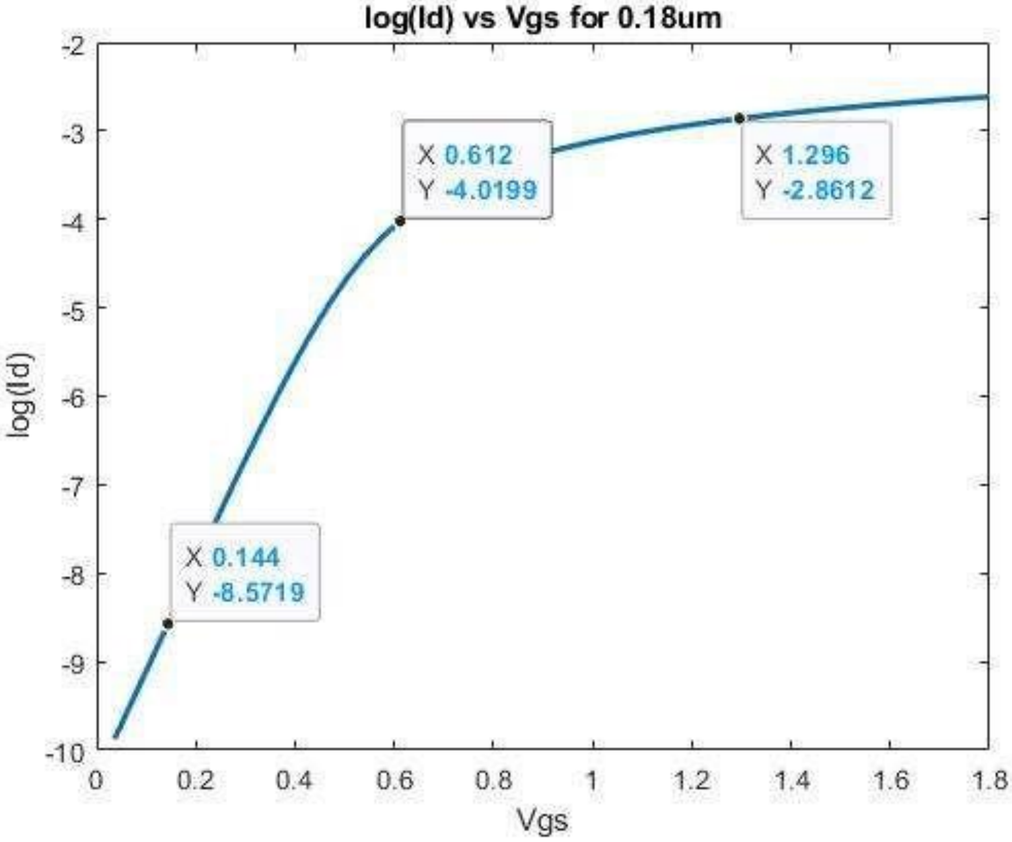
Weak Inversion starts from V_{GS} = 0.18 V to V_{GS} = 0.684 V

Strong Inversion starts from V_{GS} = 0.684 V


log(Id/w) vs gm/Id for 0.5um
log(Id/w)
gm/Id
3
2
1
0
-1
-2
-3
-4
-5
0
2
4
6
8
10
12
14


log(fT) vs gm/Id for 0.5um
log(fT)
gm/Id
11
10
9
8
7
6
5
0
5
10
15
20
25
30

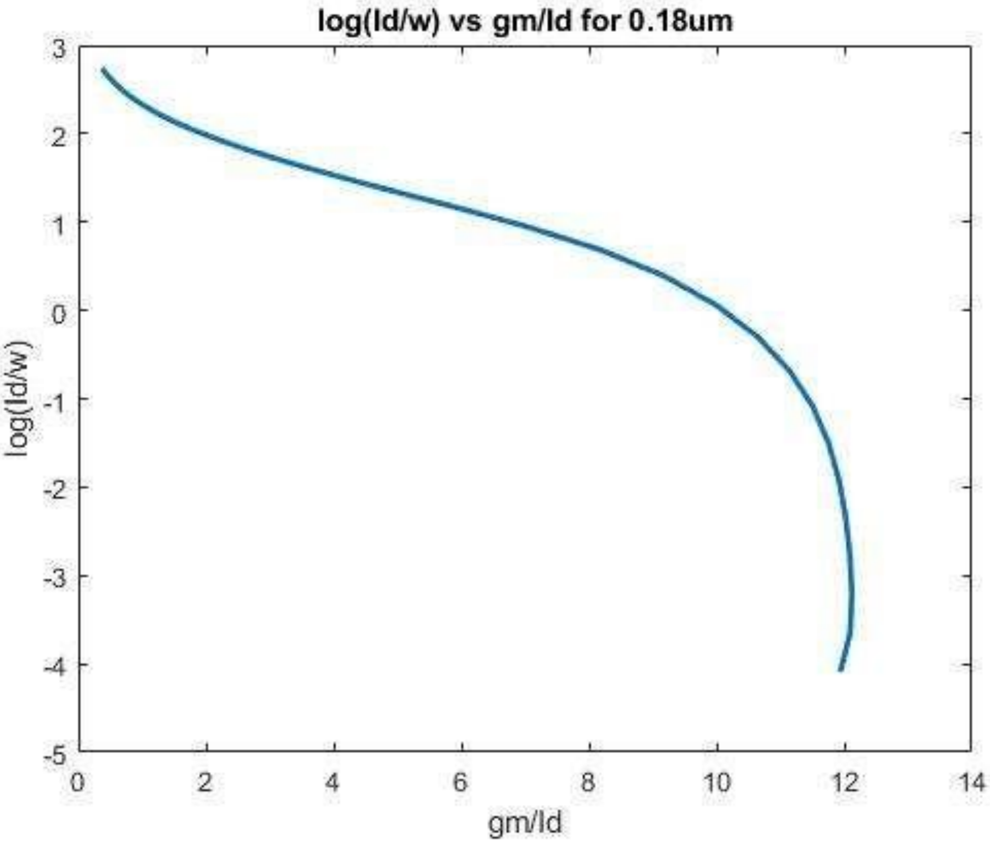
2. For V_{GS} = 1.8V and V_{DS} = 1.8V
   W = 0.18 µm and L = 4.2 µm

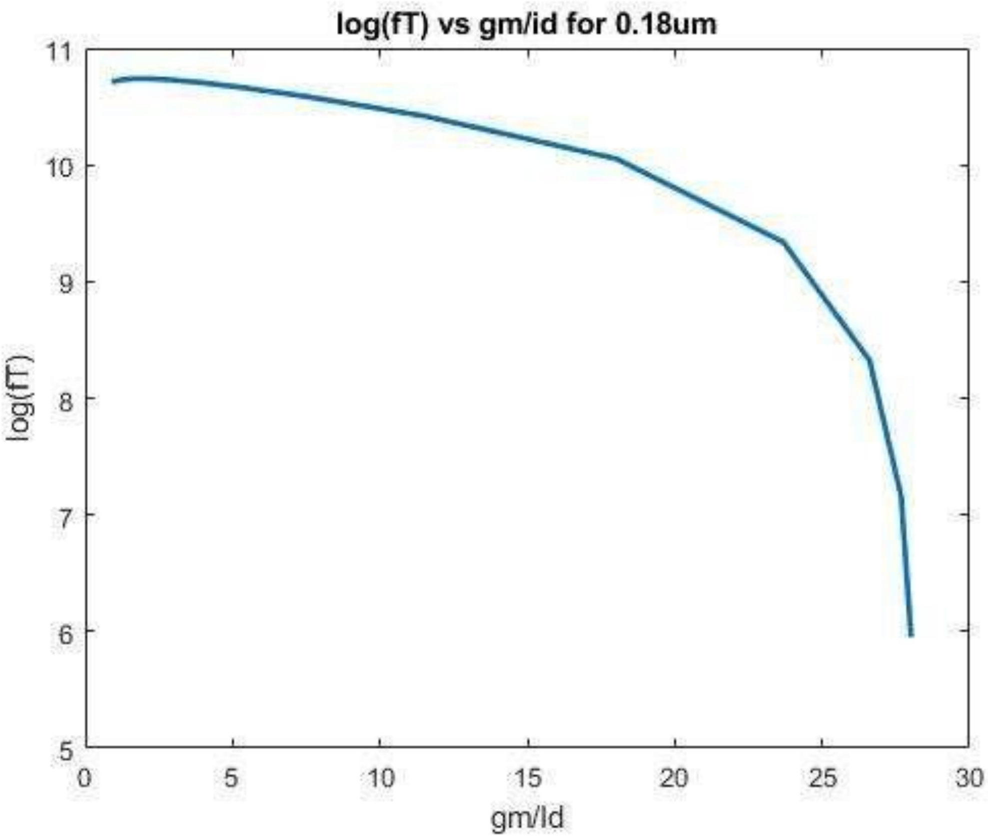


Weak Inversion starts from V_{GS} = 0.144 V to V_{GS} = 0.612 V

Strong Inversion starts from V_{GS} = 0.612 V to V_{GS} = 1.296 V

Velocity Saturation starts from V_{GS} = 1.296 V

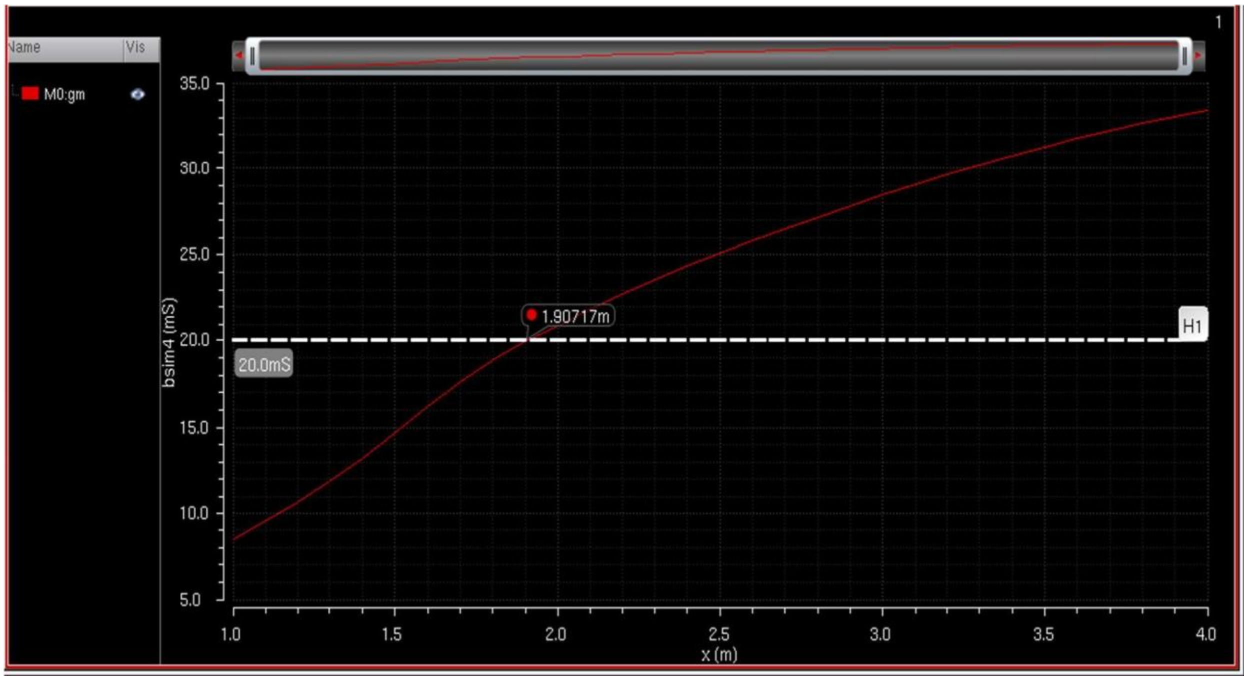

log(Id/w) vs gm/Id for 0.18um
log(Id/w)
gm/Id
3
2
1
0
-1
-2
-3
-4
-5
0
2
4
6
8
10
12
14


log(fT) vs gm/id for 0.18um
log(fT)
gm/Id
11
10
9
8
7
6
5
0
5
10
15
20
25
30

- ***SMALL SIGNAL ANALYSIS***

1. **For V_{GS} = 0.640 V and W = 23 x 4.2 µm = 96.6 µm**

   By varying I_D, we get



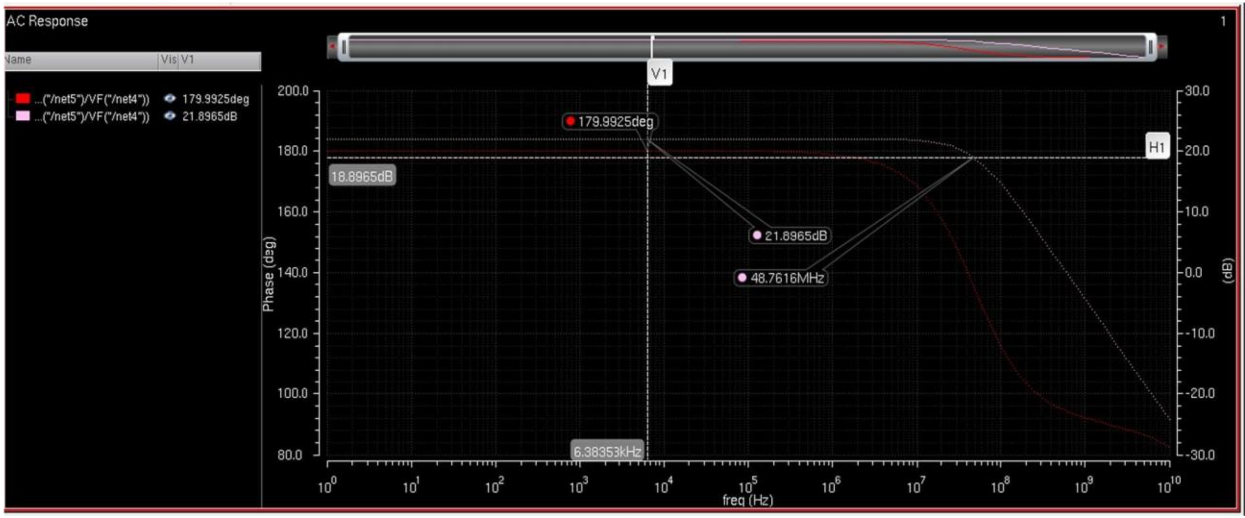
At g_m = 20 mS,

I_D = 1.90717 mA and

$\frac{gm}{ID}$ = 10.5

a. GAIN

For I_D = 1.90717 mA and v_{in} =5 mV (Small signal sinusoidal)



Gain = g_m r_0 = 21.8965 dB

= 12.44

b. BANDWIDTH

BW = 48.7616 MHz *(After Simulation)*

$$r_0 = \frac{Gain}{gm} = 622.2\ \Omega$$

Calculated BW = $1/(2\pi r_0 C_L)$ = 51.175 MHz

c. POWER

$$Power = I_D^2\ r_0$$

$$=(1.90717mA)^2\ (622.2\Omega)$$

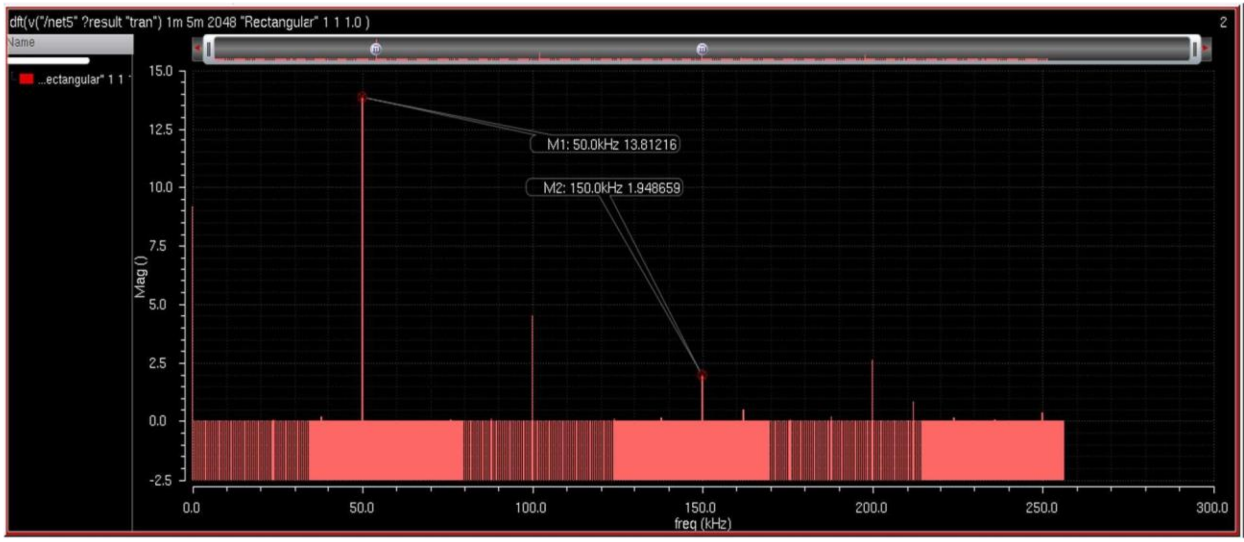
$$=2.263\ mW$$

d. *AREA*

$$Area = WL$$
$$= (96.6\ \mu m)(4.2\ \mu m)$$
$$= 405.72 \times 10^{-12}\ m^2$$

e. LINEARITY

The magnitude of first and third harmonics in DFT analysis for 50 KHz is observed in the following plot:



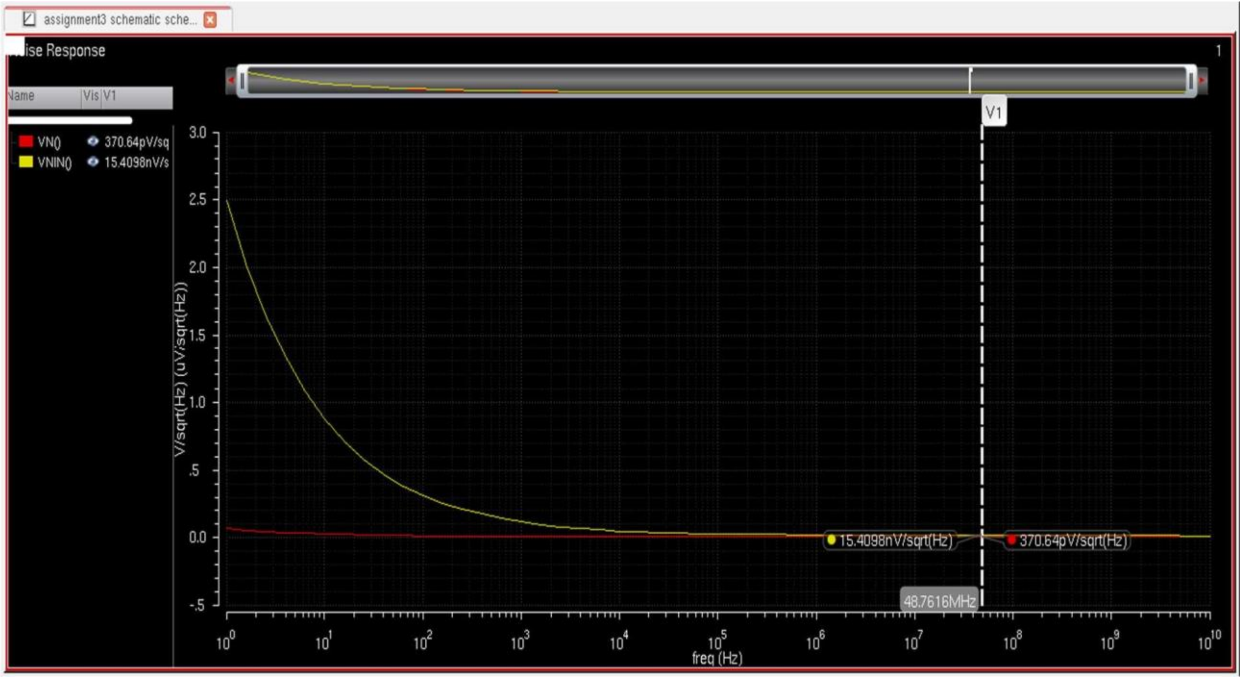
Harmonic distortion due to third harmonic component is given by

$$HD_3 = \frac{Third\ Harmonic\ Component}{First\ \ Harmonic\ \ Component}$$

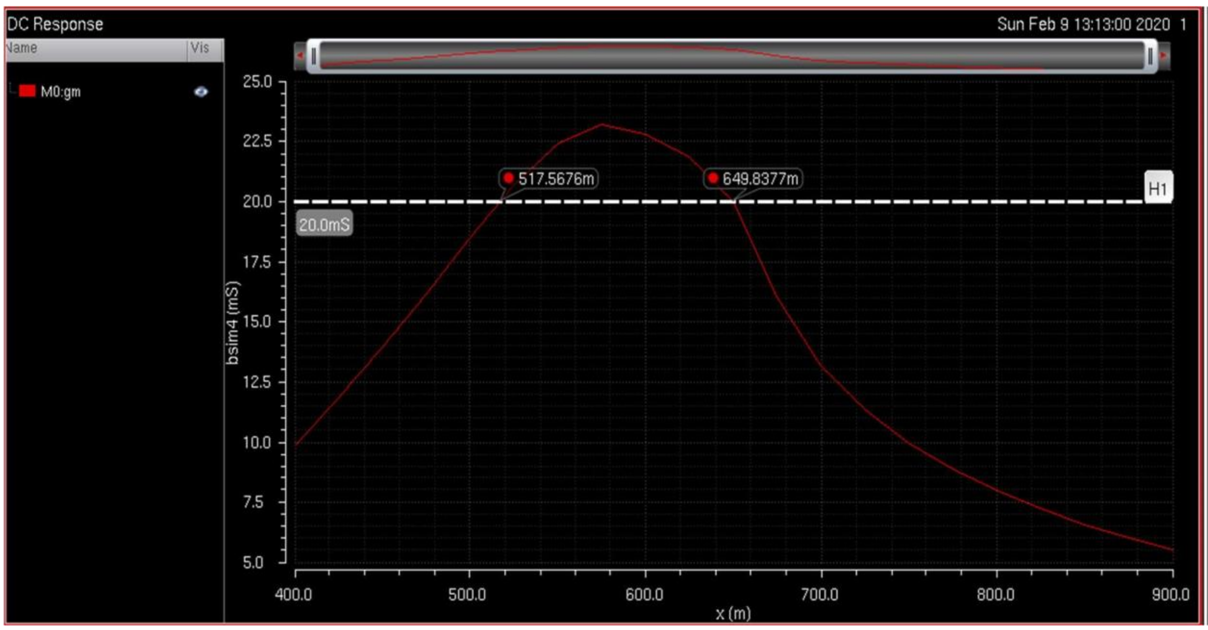
$$= \frac{1.948659}{13.81216} = 0.14108 = 14.108\ \%$$

f. **NOISE**

Input and output Noise is simulated in the following plot



2. **<u>For I_D = 2 mA and W = 23 x 4.2 µm = 96.6 µm</u>**
<u>By varying V_{GS},</u> we get



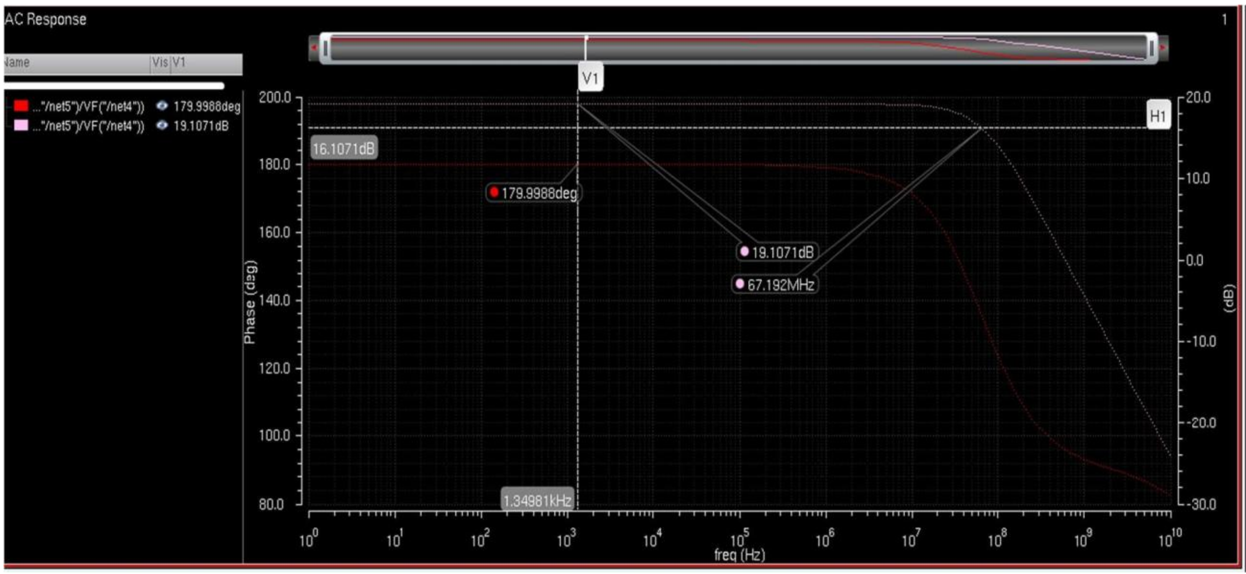
At g_m = 20 mS,

V_{GS} = 0.64983 V and

$\frac{gm}{ID}$ = 10

a. GAIN

For V_{GS} = 0.64983 V and v_{in} =5 mV (Small signal sinusoidal)



Gain = g_m r_0 = 19.1071 dB

= 9.023

b. BANDWIDTH

BW = 67.192 MHz *(After Simulation)*

$$r_0 = \frac{Gain}{gm} = 451.15\,\Omega$$

Calculated BW = 1/(2πr_0 C_L) = 70.554 MHz

c. POWER

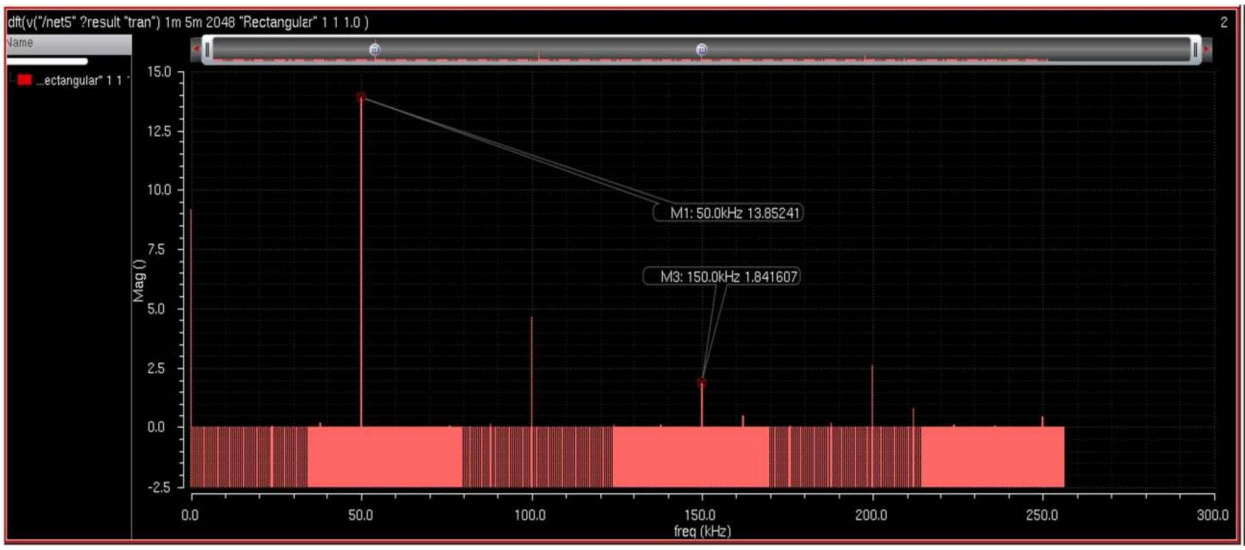
$$Power = I_D^2 r_0$$
$$=(2\ mA)^2\ (451.15\ \Omega)$$
$$=1.8046\ mW$$

d. AREA

$$Area = WL$$
$$= (96.6\ \mu m)(4.2\ \mu m)$$
$$= 405.72 \times 10^{-12}\ m^2$$

e. LINEARITY

The magnitude of first and third harmonics in DFT analysis for 50 KHz is observed in the following plot:



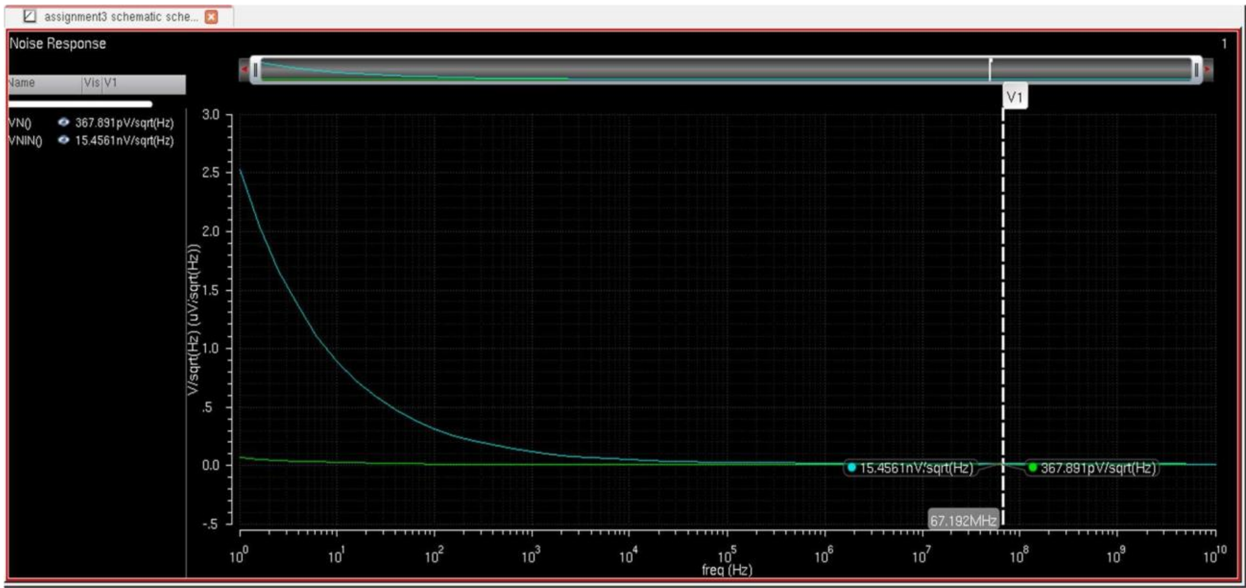
Harmonic distortion due to third harmonic component is given by

$$HD_3 = \frac{Third\ Harmonic\ Component}{First\ Harmonic\ Component}$$

$$= \frac{1.841607}{13.85241} = 0.132944 = 13.29\ \%$$

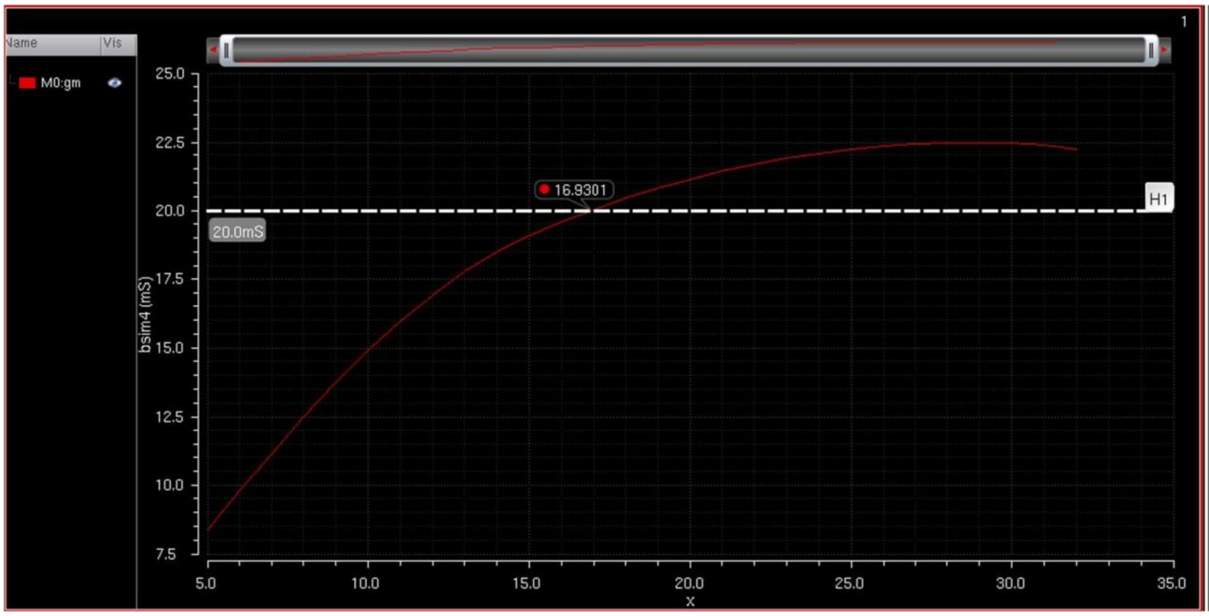
f. NOISE

Input and output Noise is simulated in the following plot



3. For $I_D = 2$ mA and $V_{GS} = 0.625$ V

By varying W, we get



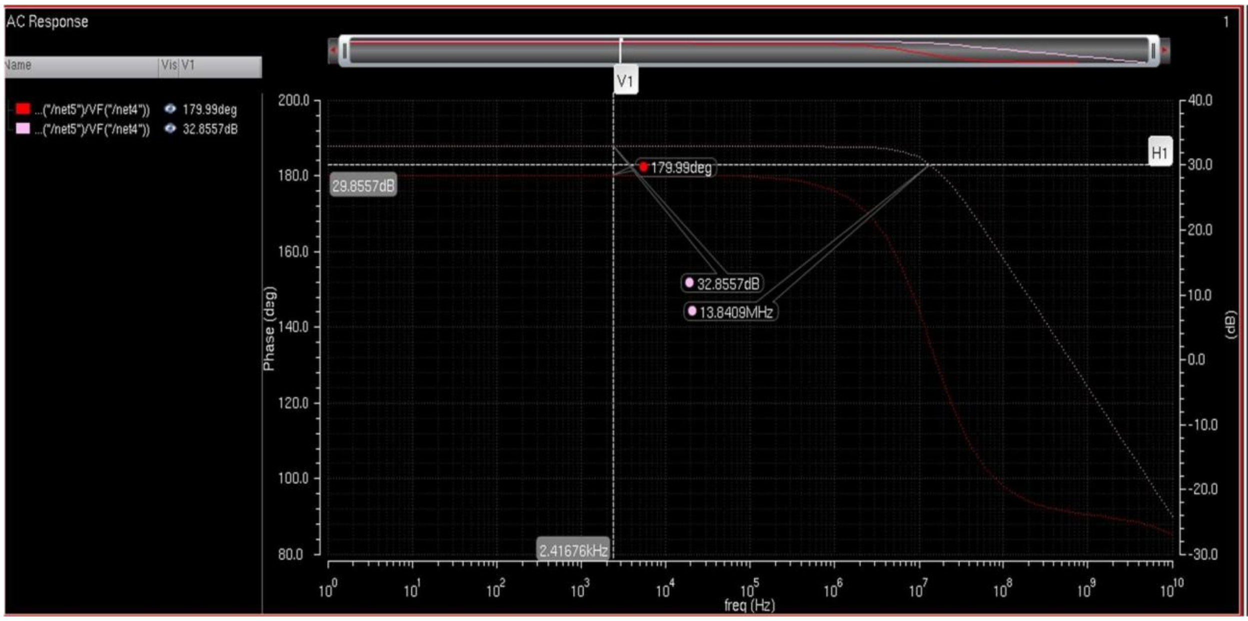
At g_m = 20 mS,

W = (16.9301 ~ 17) x (4.2 µm) = 71.4 µm, and

$\frac{gm}{ID}$ = 10.01

a. GAIN

For V_{GS} = 0.64983 V and v_{in} =5 mV (Small signal sinusoidal)



Gain = g_m r_0 = 32.8557 dB

= 43.932

b. BANDWIDTH

BW = 13.8409 MHz *(After Simulation)*

$r_0 = \frac{Gain}{gm}$ *=2196.6 Ω = 2.1966 KΩ*

Calculated BW = 1/(2πr_0 C_L) = 14.491 MHz

c. POWER

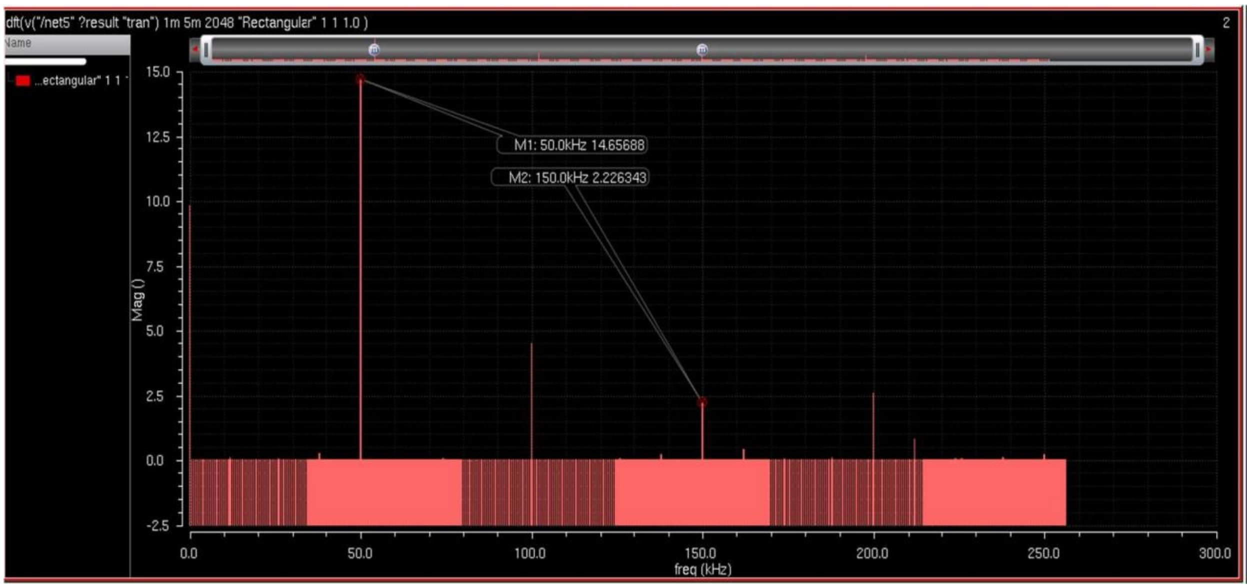
$$Power = I_D^2\, r_0$$
$$= (2\ mA)^2\ (2196.6\ \Omega)$$
$$= 8.786\ mW$$

d. AREA

$$Area = WL$$
$$= (71.4\ \mu m)(4.2\ \mu m)$$
$$= 299.8 \times 10^{-12}\ m^2$$

e. LINEARITY

The magnitude of first and third harmonics in DFT analysis for 50 KHz is observed in the following plot:



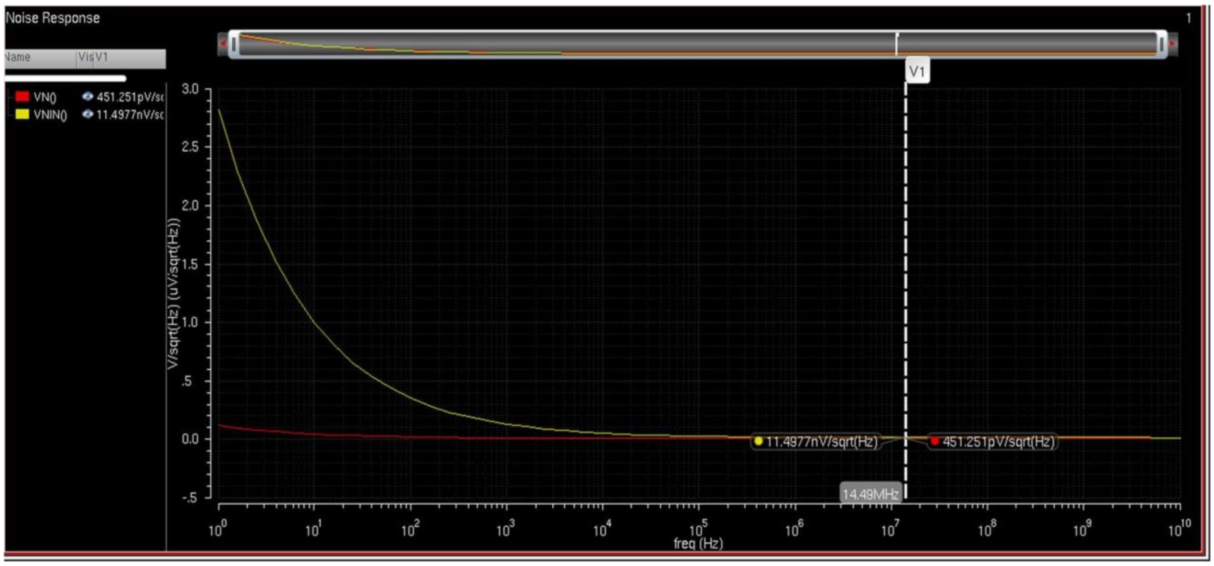
Harmonic distortion due to third harmonic component is given by

$$HD_3 = \frac{Third\ Harmonic\ Component}{First\ Harmonic\ Component}$$

$$= \frac{2.226343}{14.65688} = 0.151897 = 15.18\ \%$$

f. NOISE

Input and output Noise is simulated in the following plot



CONCLUSIONS

For g_m = 20 mS	**GAIN**	**BANDWIDTH**	***POWER***	***AREA***	***LINEARITY***
By varying I_D, I_D = 1.90717mA	***21.8965 dB = 12.44***	***48.7616 MHz***	***2.262 mW***	***405.72 x 10^{-12} m^2***	***HD_3 = 14.108 %***
By varying V_{GS}, V_{GS} = 0.64983 V	***19.1071 dB = 9.023***	***67.192 MHz***	***1.804 mW***	***405.72 x 10^{-12} m^2***	***HD_3 = 13.294 %***
By varying W, W = 17	***32.8557 dB =***	***13.8409 MHz***	***8.76 mW***	***299.8 x 10^{-12} m^2***	***HD_3 =15.1897 %***

1. For a fixed g_m, increment in the no. of fingers and thus, the width of the MOSFET will decrease the r_0 and that will decrease the gain while decrease in the no. of fingers will reduce the Bandwidth but increase the gain.

2. $\frac{gm}{ID}$, gain and V_{GS} have a straight inter-dependency with each other for a given Gain-Bandwidth Product.

3. The circuit will work as an amplifier only for specific a range of V_{GS} as well as C_L.

4. The difference between Weak Inversion V_{GS} and strong Inversion V_{GS} is purely technology dependant and is same for a given nm-technology.