

## Aim: Design of MOS amplifiers using gm/Id method

### Q1. Characterization of MOS-T

Plot the following curves for NMOS

- (a)  $g_m/I_D$  vs  $V_{OV}$
- (b)  $I_D/(W/L)$  vs  $g_m/I_D$
- (c)  $f_t$  vs  $g_m/I_D$
- (d)  $g_m \cdot r_o$  vs  $V_{DS}$

### Q2. Design of Common Source amplifier with resistive load

(Take  $V_{DD}=3.0V$  and  $C_L=25fF$ )

- (a) Design for maximum gain  
 $L = 2L_{min}, \quad I_D < 100\mu A$
- (b) Design for maximum Bandwidth  
DC Gain = 2,  $I_D < 100\mu A$

Do transient and ac simulation to get gain and -3dB frequency

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**Theory:** The methodology is intended for low-power analog and digital circuits where the weak as well as moderate inversion regions are often used because they provide a good compromise between speed and power consumption. The  $g_m/I_D$  ratio indeed is a universal characteristic of all transistors formed by the same process.

MOS transistors are either in strong inversion or in weak inversion. Mainstream methods assume generally strong inversion and use the transistor gate voltage overdrive ( $V_{OV}$ ) as the key parameter, where  $V_{OV} = V_{GS} - V_T$ .

If we consider a simple common source amplifier, the power and bandwidth are given by following equations

$$P = \frac{1}{2} \frac{V_{DD}}{R_L} \cdot A_{DC} \cdot V_{OV}$$

$$\omega_{-3dB} = \frac{3}{2} \frac{R_L}{R_i} \cdot \frac{1}{A_{DC}} \cdot \frac{\mu}{L^2} \cdot V_{OV}$$

With the assumed fixed design specifications, and a given technology ( $\mu$ ,  $L_{min}$ ), both power and bandwidth of our circuit are completely determined by the choice of  $V_{OV}$ . Making  $V_{OV}$  small to save power also means that we lose bandwidth.

This makes intuitive sense since

$$\frac{W}{L} = \frac{g_m}{\mu C_{ox} V_{OV}}$$

With  $g_m$  and  $L$  fixed, smaller  $V_{OV}$  translates into a bigger (wider) device, and thus larger  $C_{gs}$ . So we conclude from this that the  $V_{OV}$  is not a good design parameter.

What we really want from MOS transistor

- Large  $g_m$  without investing much current
- Large  $g_m$  without having large  $C_{gs}$

To quantify how good of a job our transistor does, we can therefore define the following "figures of merit"

Performance Metrics of Interest:

- **Transit Frequency:**

$$\omega_T = \frac{g_m}{C_{gs}}$$

- **Trans-conductor Efficiency:**

$$\frac{g_m}{I_D}$$

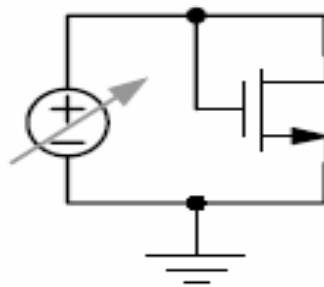
- **Intrinsic Gain:**

$$g_m r_o$$

We find that  $V_{OV}$  is not "directly" related to performance metric. Hence, we switch towards a strategy called "gm/ $I_D$  design methodology", in which gm/ $I_D$ , rather than  $V_{OV}$  is used directly as a central design variable.

## Generation of Performance Curves:

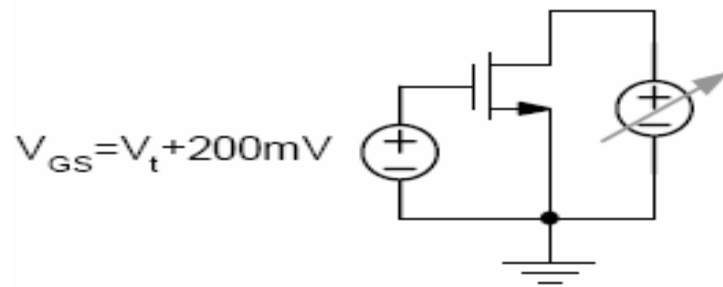
### 1. $f_T$ Simulation:



#### Steps:

- 1) After the simulation of above circuit, we get all current and voltage plots in waveform window.
- 2) Plot gate overdrive  $V_{ov} = V_{gs} - V_t$
- 3) Plot gm curve by taking derivative of  $I_D$  Vs  $V_{gs}$
- 4) Divide gm curve by  $I_D$  curve to get gm/ $I_D$ .
- 5) Divide gm curve by  $C_{gs}$  to get  $f_T$ .
- 6) Plot ( $f_T$  Vs gm/ $I_D$ ) transit frequency chart by taking  $f_T$  as Y-axis and gm/ $I_D$  as X-axis

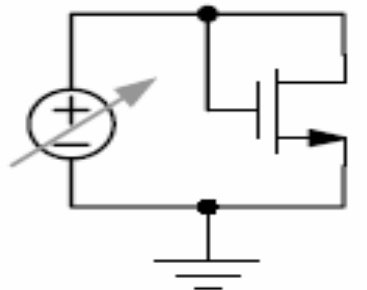
### 2. Intrinsic Gain Simulation:



**Steps:**

1. After the simulation of above circuit, we get all current and voltage plots in waveform window.
2. Get  $1/r_o$  curve by taking derivative of  $I_D$  Vs  $V_{ds}$ .
3. To get  $r_o$  plot, take the reciprocal of above curve. At very small value of  $V_{ds}$ ,  $g_m$  is constant. Take that value as  $g_{m0}$ .  $g_{m0}$  can also be find out by dividing  $I_d$  by  $(V_{gs}-V_t)$ . Then plot  $g_m = g_{m0}*(1+\lambda V_{ds})$ , where  $\lambda = 1/(r_o*I_D)$
4. Get  $g_m*r_o$  Vs  $V_{ds}$  plot.

**3. gm/ID Simulation:**



**Steps:**

1. After the simulation of above circuit, we get all current and voltage plots in waveform window.
2. Find out gate overdrive  $V_{ov} = V_{gs} - V_t$ .  $V_t$  can be seen in log files after running simulation after making the transistor in saturation.
3. Plot  $g_m$  curve by taking derivative of  $I_D$  Vs  $V_{gs}$ .

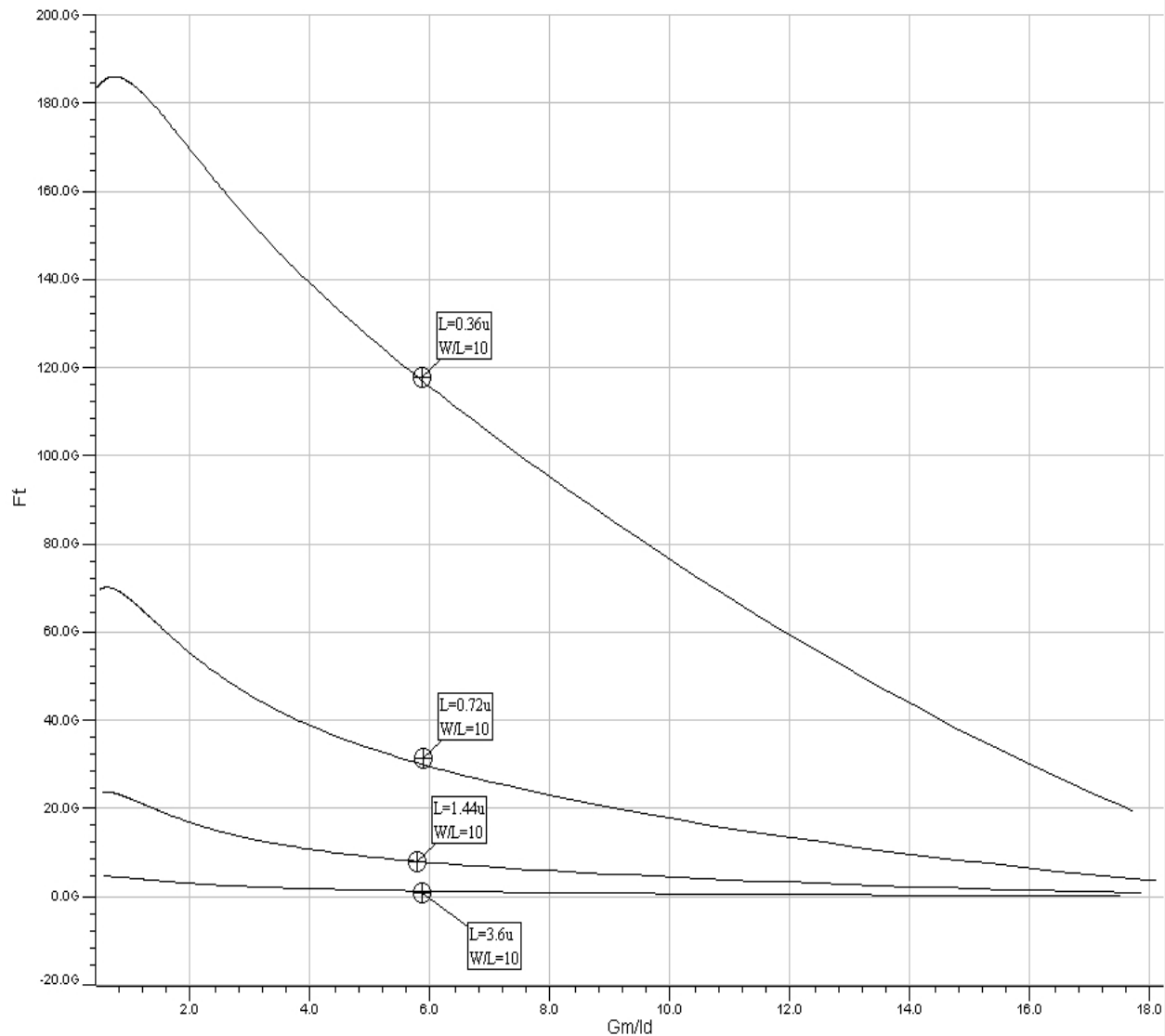
4. Divide  $g_m$  curve by  $I_D$  curve to get  $g_m/I_D$ .
5. Divide  $I_D$  curve by  $W/L$  value to get  $I_D/W/L$  plot.
6. Setting  $g_m/I_D$  as X-axis, plot  $I_D/W/L$  which is called current density plot.

Using the above method,  $g_m/I_D$  plots are generated for various  $L$ s. This helps in design process.

### **1. Plots for $F_T$**

The following is the plot for  $F_T$  Vs  $g_m/I_D$  for four different  $L$ 's

Presumably for a  $0.35\mu\text{m}$  process  
(drawn min.  $L=0.36\mu\text{m}$ )

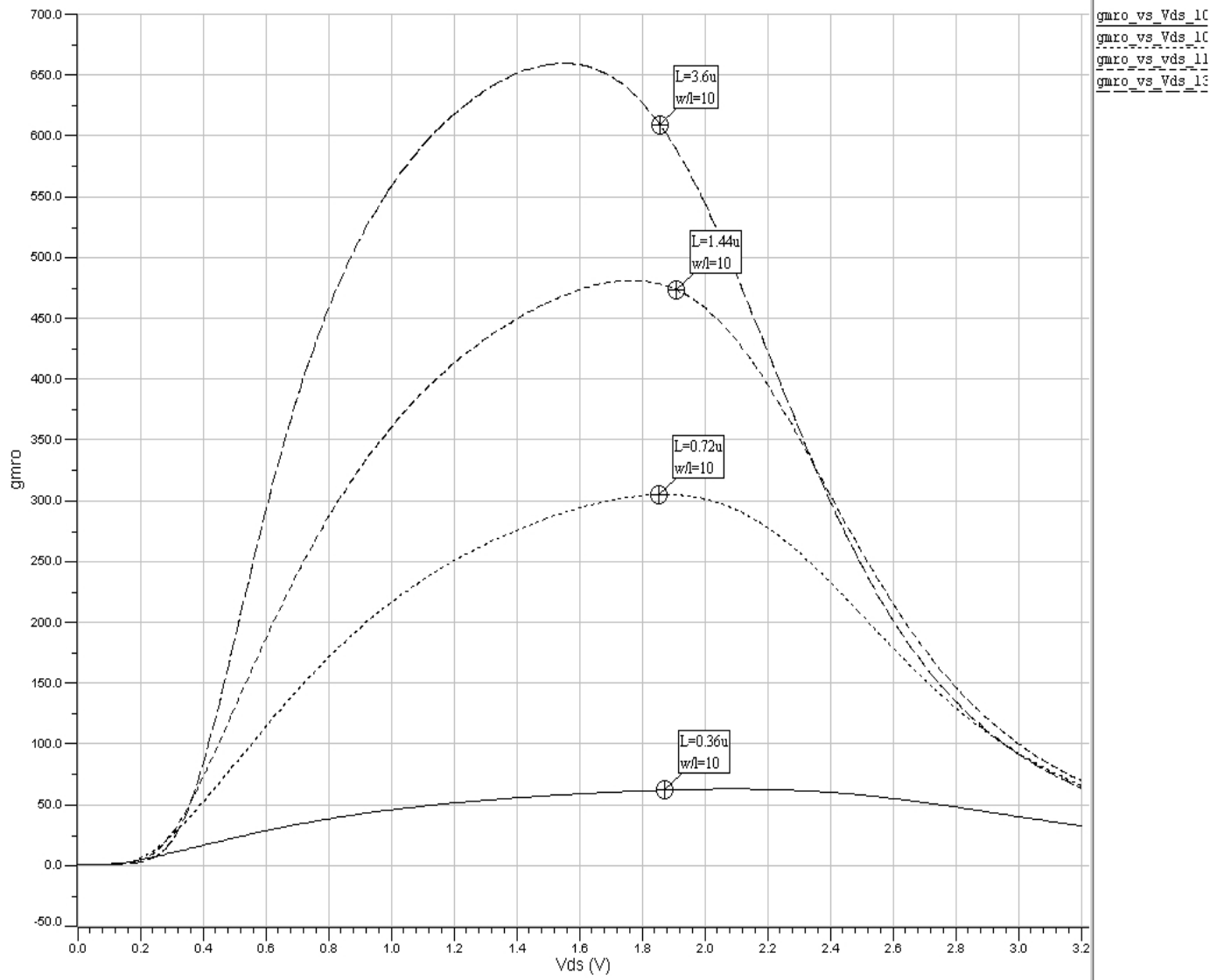


ft\_036(gm\_by\_i  
ft\_072(gm\_by\_i  
ft\_144(gm\_by\_i  
ft\_36(gm\_by\_i

It had been stated earlier that the -3dB bandwidth is inversely proportional to  $L^2$ . Similar same effect can also be seen in case of  $F_T$ .

## 2. Plots for Intrinsic Gain

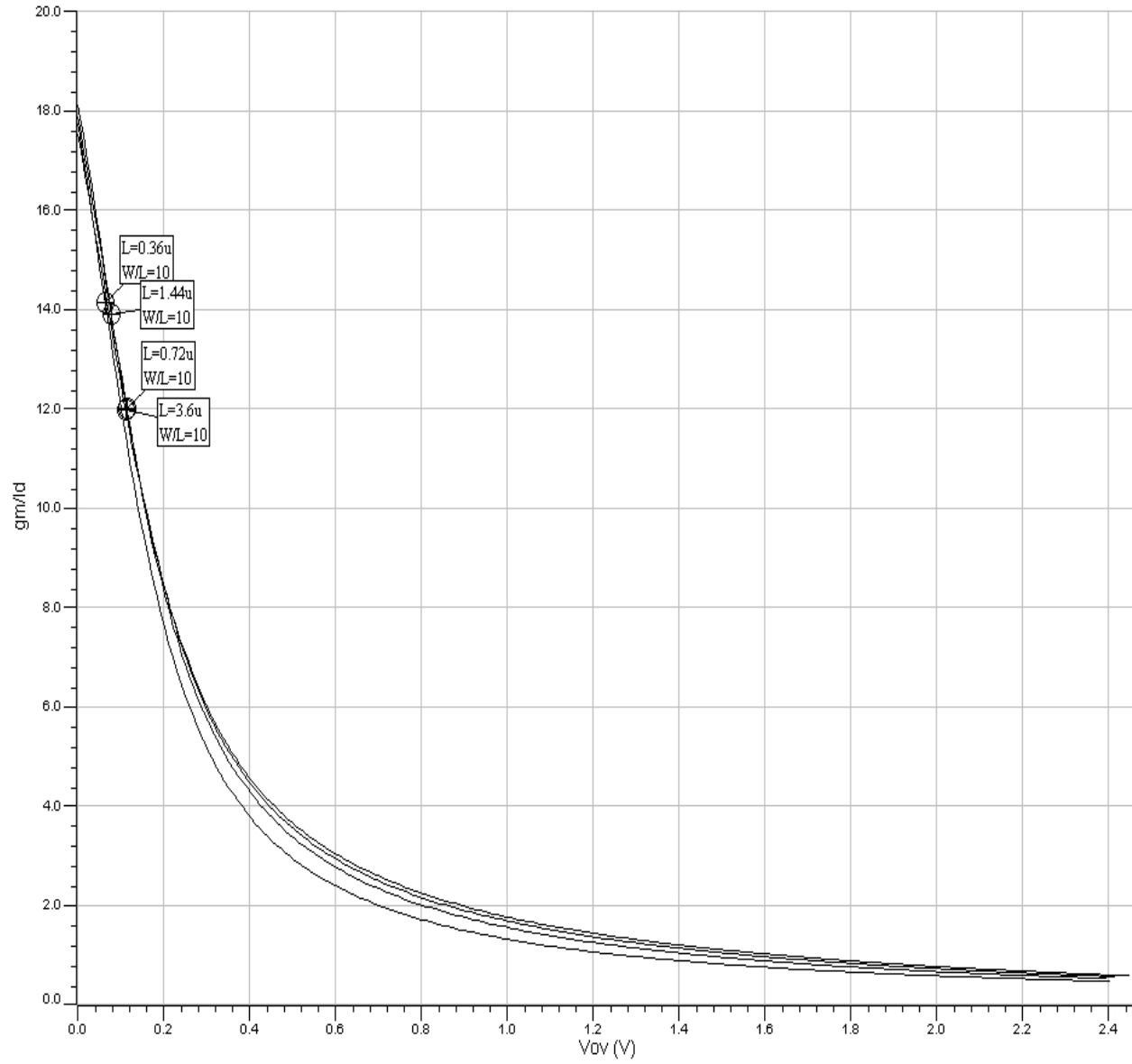
The plot for intrinsic gain ( $gm \cdot r_o$ ) has been given below.  
Note how drastically the gain increases with increase in  $L$ .



**gm\*r<sub>0</sub> Vs Vds**

### 3. gm/Id Plots

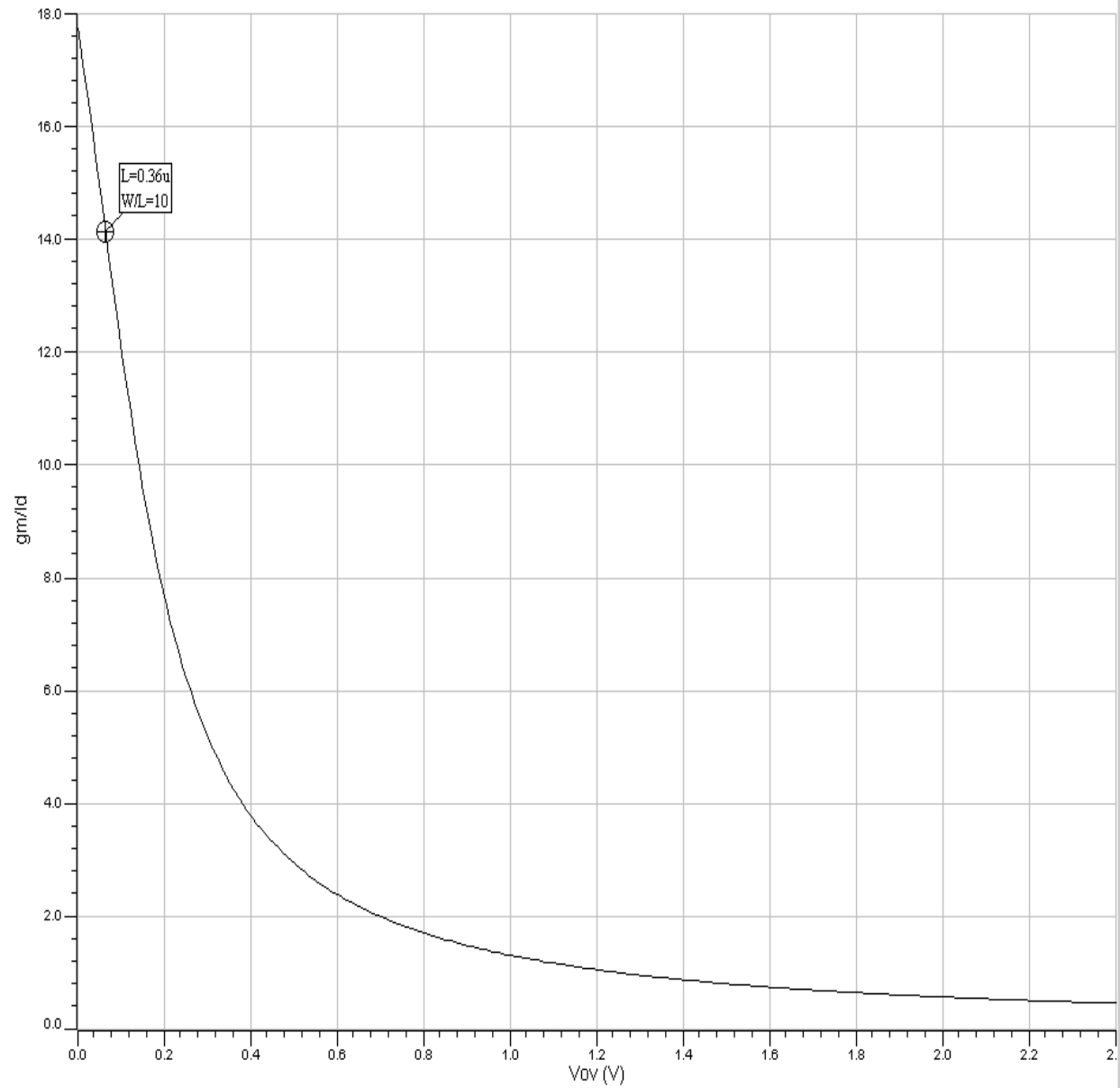
A comparative plot for gm/Id Vs Vov is given below:



gm\_by\_id\_036(v  
gm\_by\_id\_072(v  
gm\_by\_id\_36(v  
gm\_by\_id\_144(v

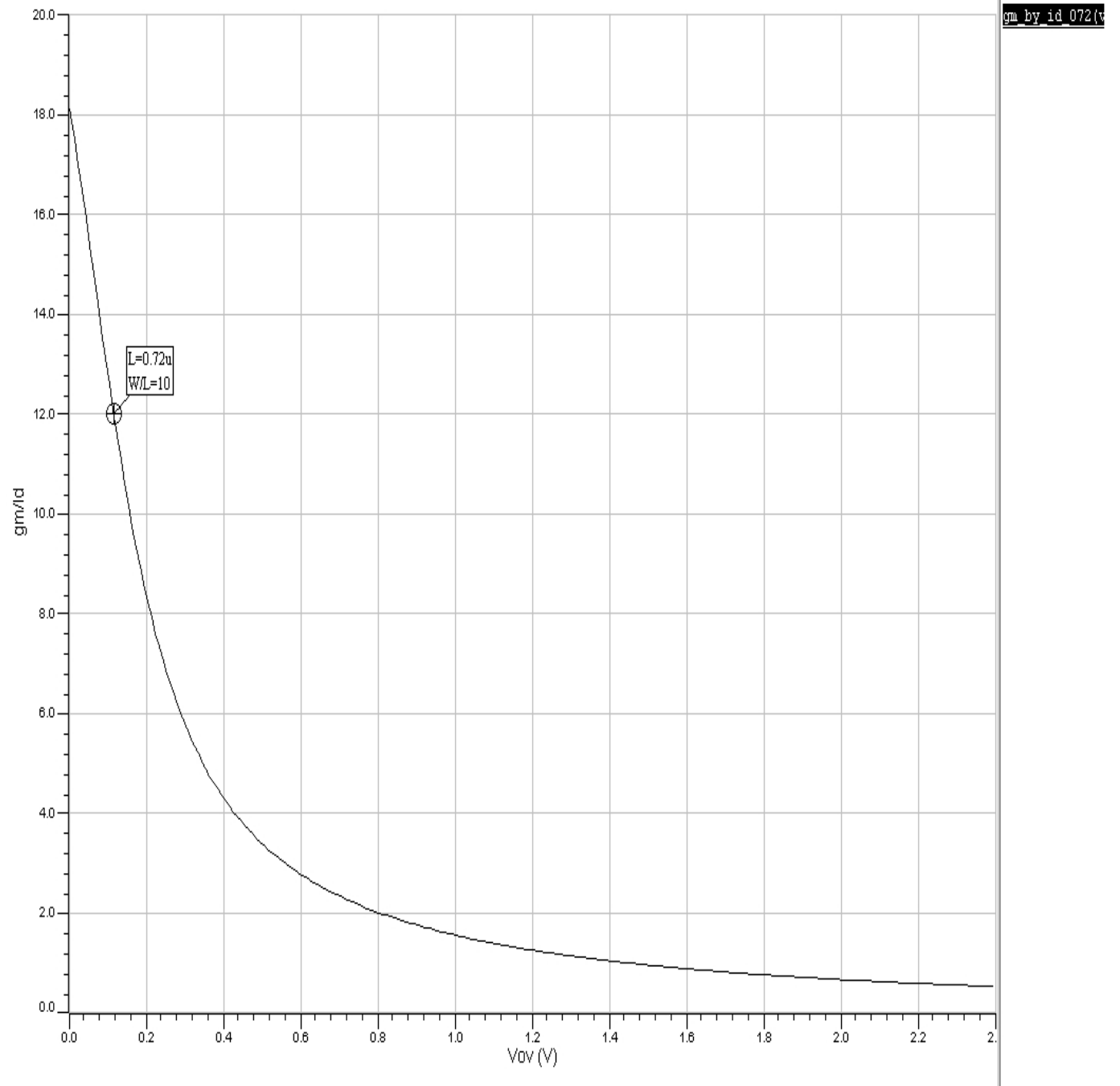
Since  $g_m/I_d$  Vs  $V_{ov}$  plots are very important in the design procedure, Separate plots for each  $L$  have been generated.



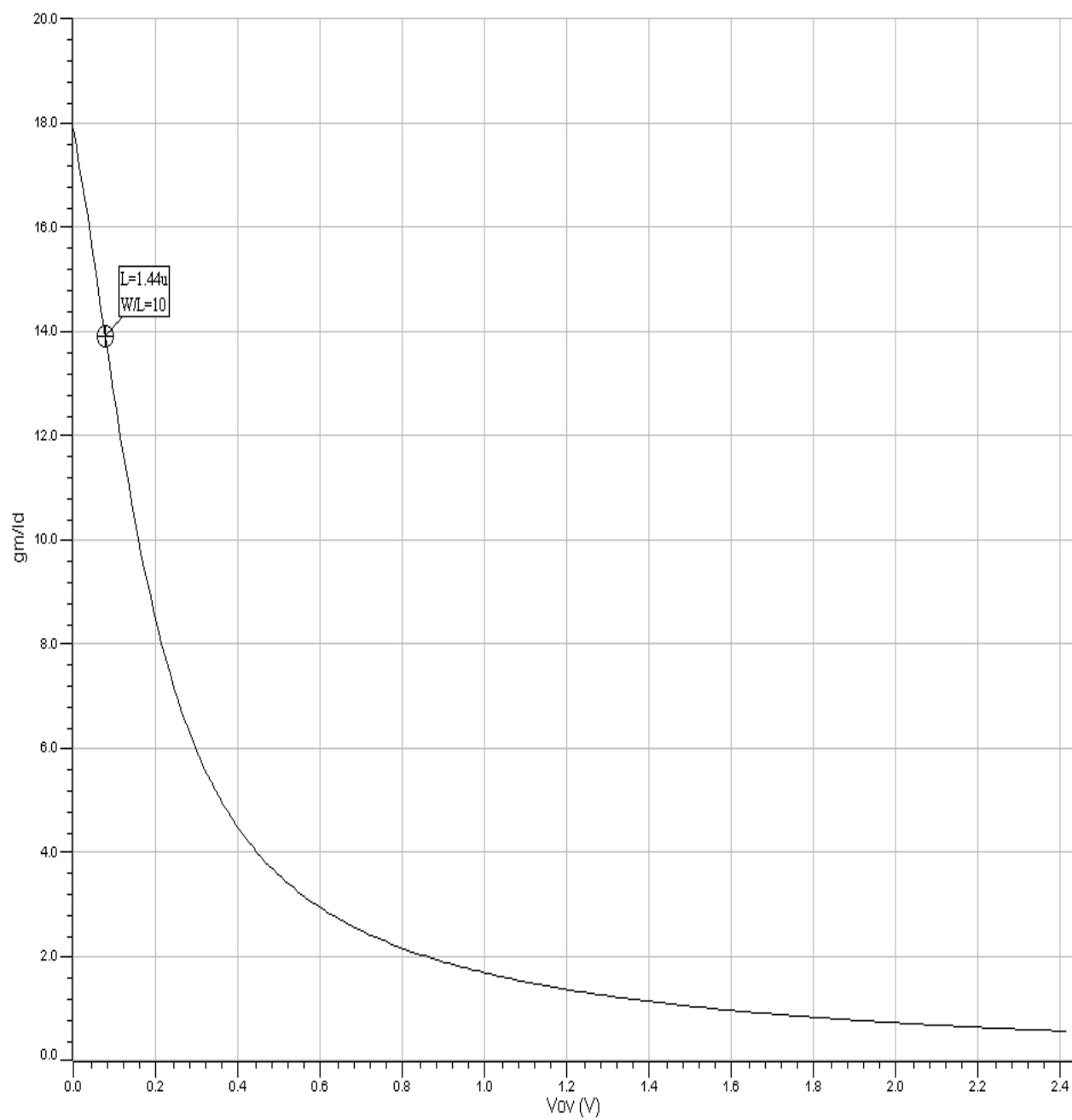


**gm/Id Vs Vov ( L=0.36 $\mu m$ )**

gm\_by\_id\_036(u

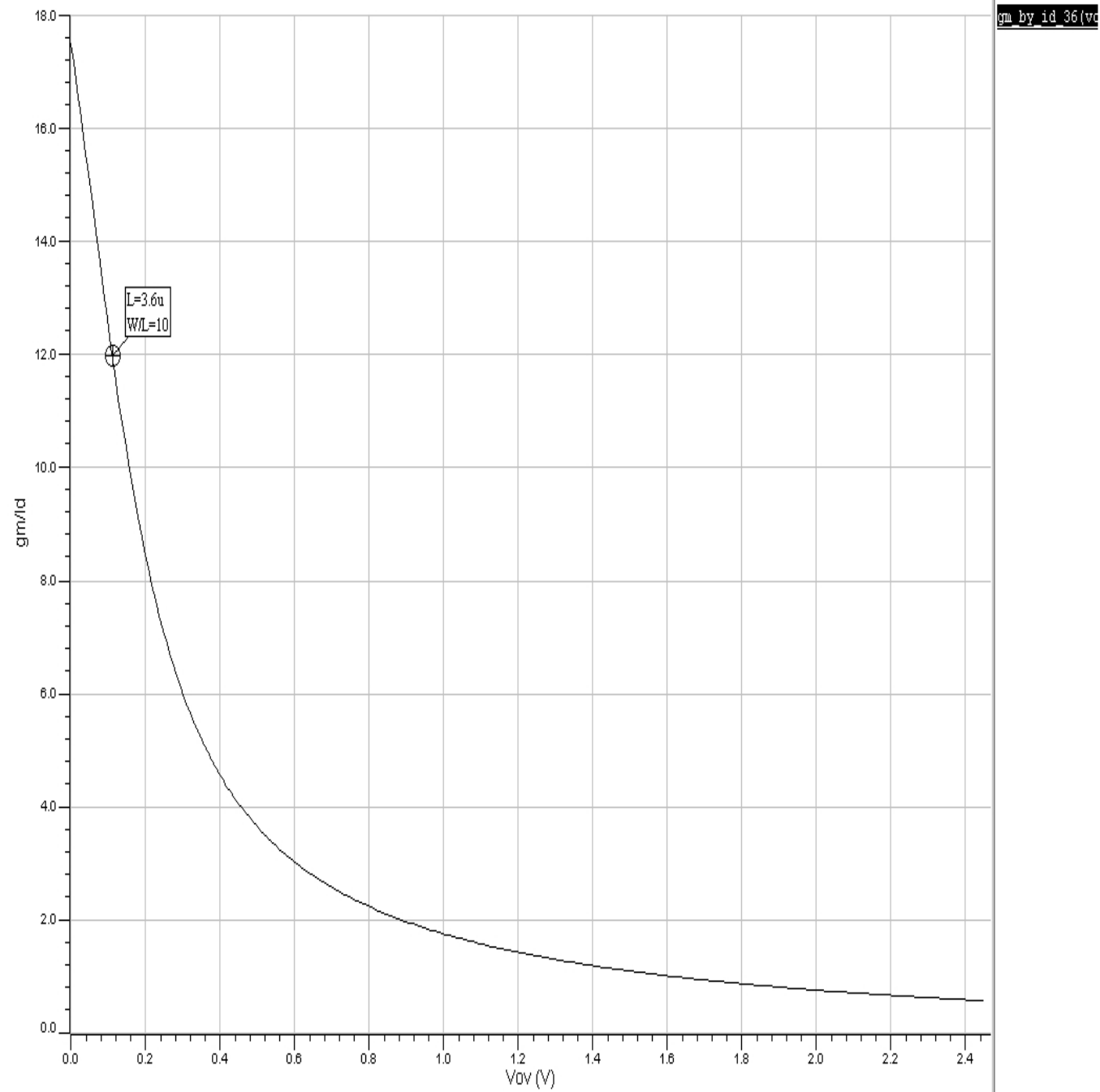


**gm/Id Vs Vov ( L=0.72 $\mu m$ )**



**gm/Id Vs Vov ( L=1.44 $\mu m$ )**

gm\_by\_id\_144/v

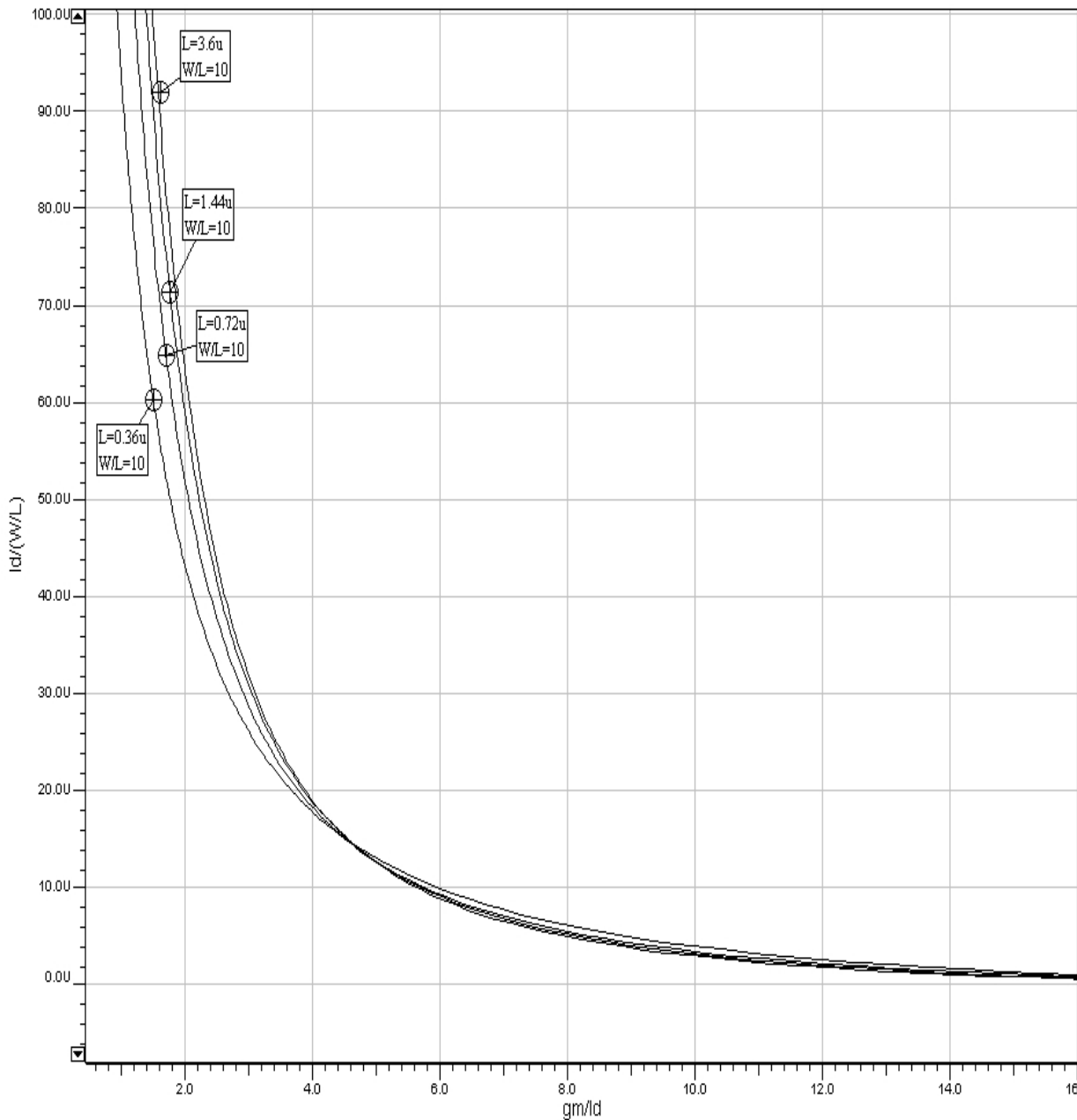


**gm/Id Vs Vov ( L=3.6 $\mu m$ )**

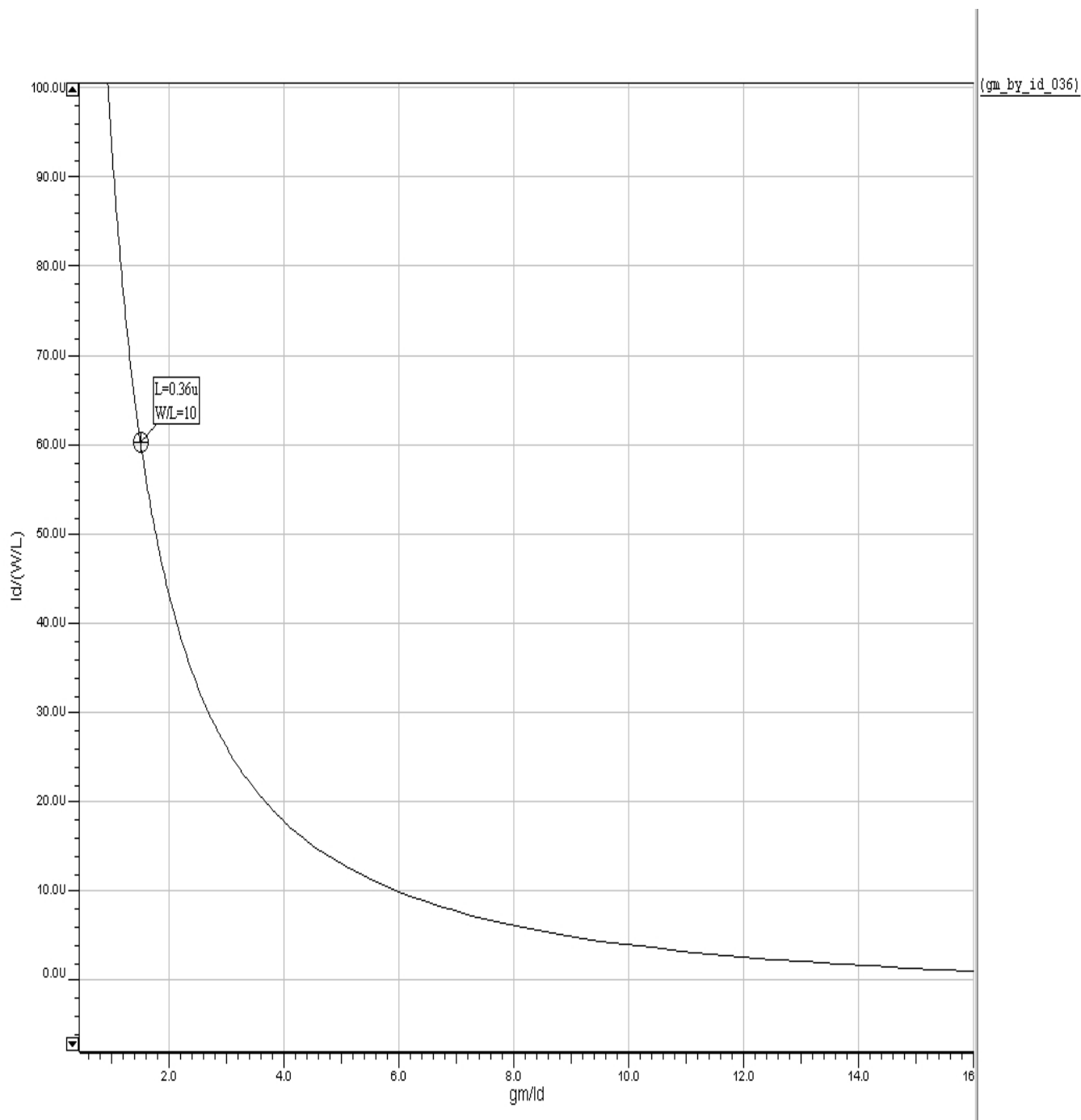
#### 4. $I_d/(W/L)$ Vs $g_m/I_d$ Plots

These plots help in determining the required  $W/L$  for a given current. If we have chosen the  $g_m/I_d$  values, we can choose the aspect ration of the MOST from these plots.

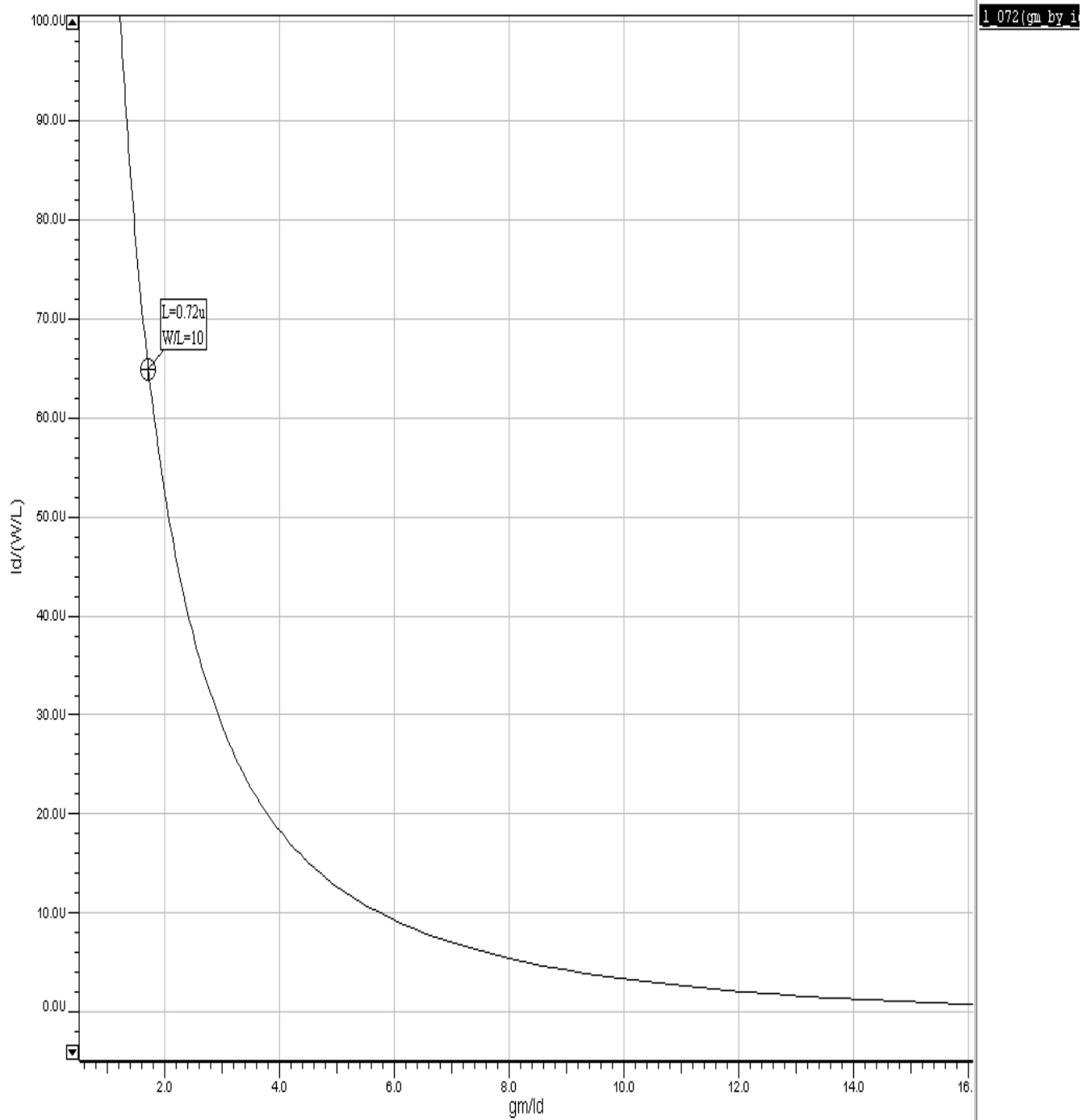
First, a comparative plot is shown. Here  $L$  varies from  $0.36\mu\text{m}$  to  $3.6\mu\text{m}$ .



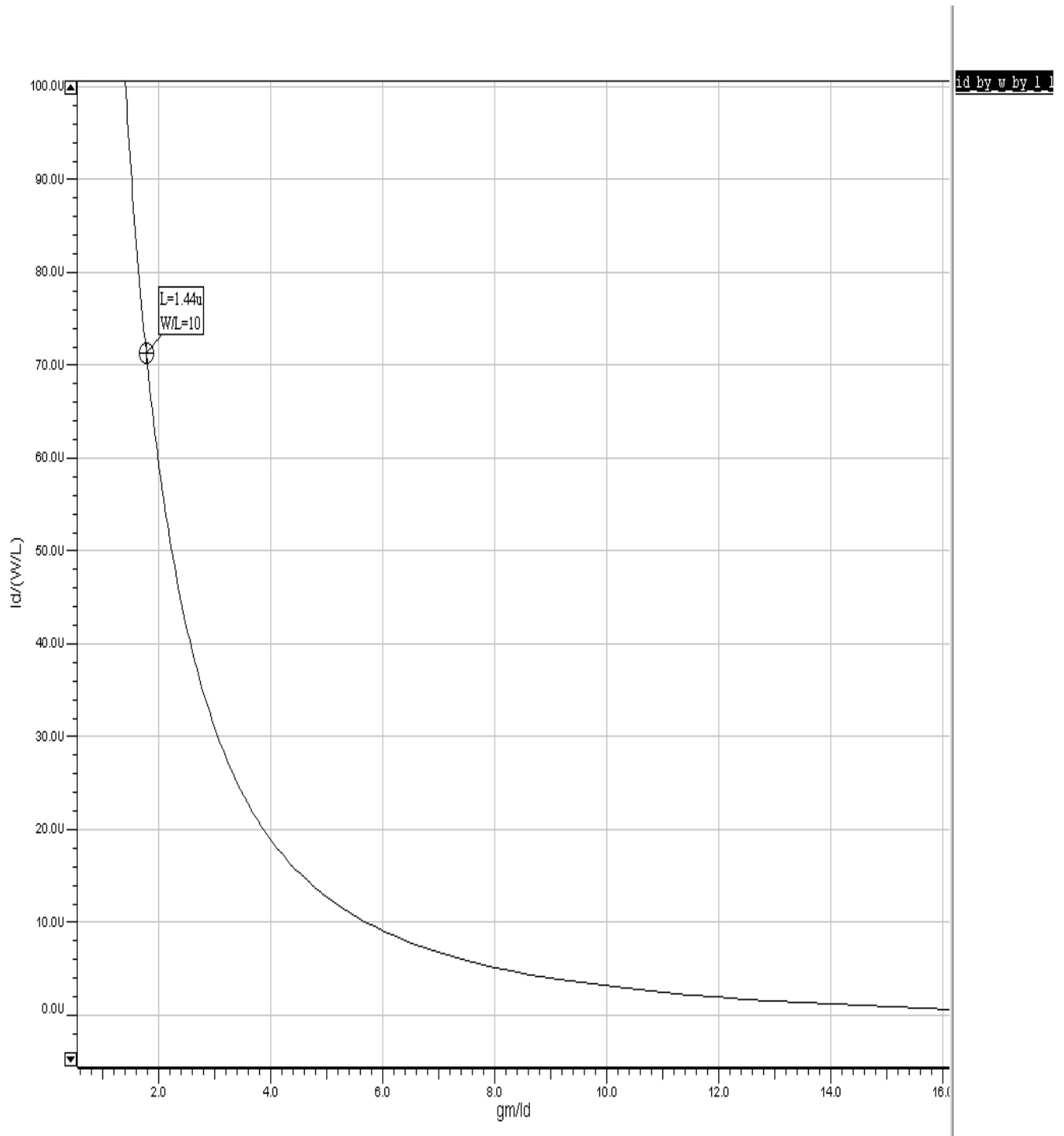
Separate  $I_d/(W/L)$  Vs  $g_m/I_d$  plots have been generated for each  $L$  ( $0.36\mu\text{m}$ ,  $0.72\mu\text{m}$ ,  $1.44\mu\text{m}$ ,  $3.6\mu\text{m}$ )



**$I_d/(W/L)$  Vs  $g_m/I_d$  plot for  $L = 0.36\mu\text{m}$**

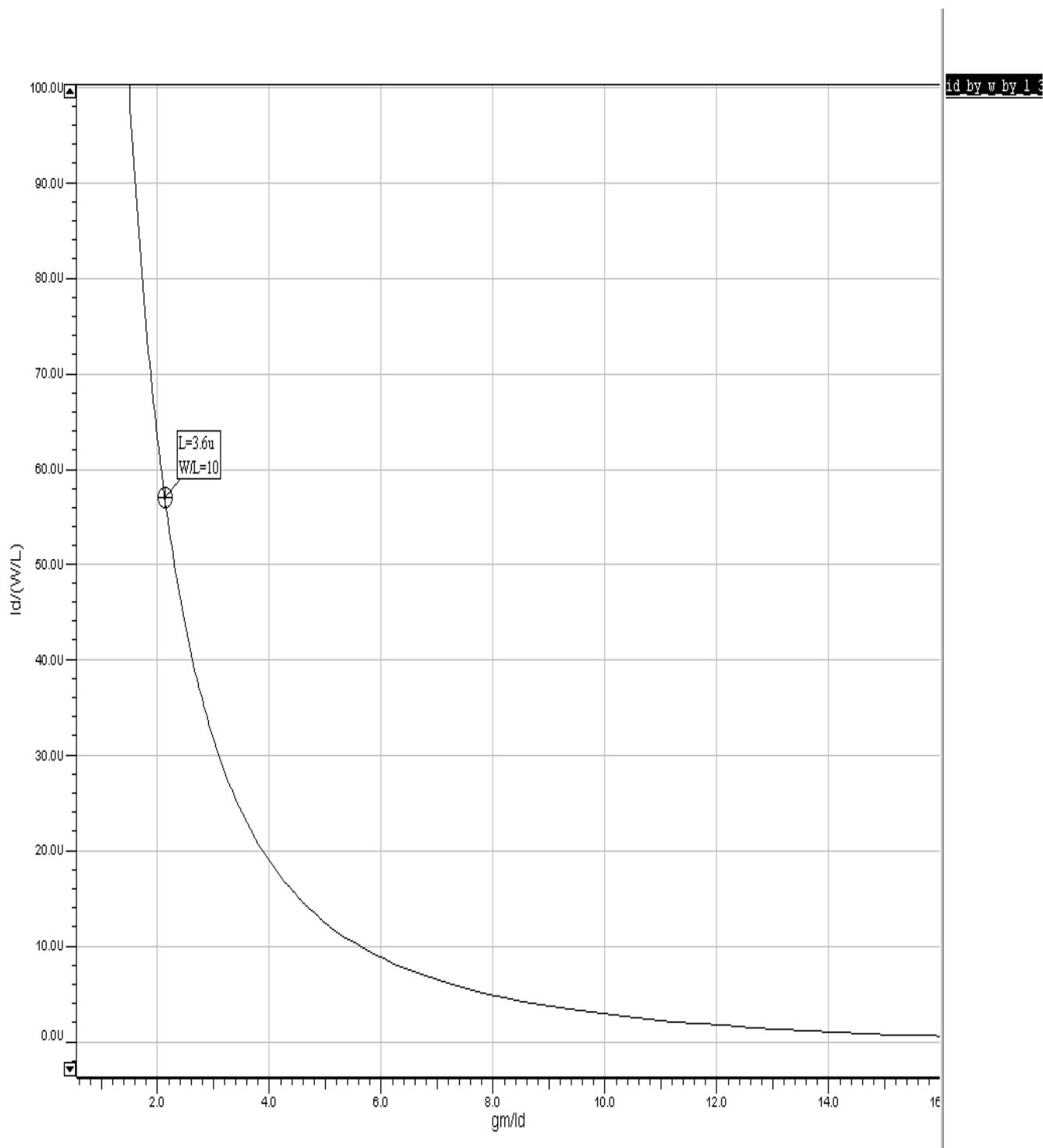


**$I_d/(W/L)$  Vs  $g_m/I_d$  plot for  $L = 0.72\mu\text{m}$**



**$I_d/(W/L)$  Vs  $g_m/I_d$  plot for  $L = 1.44\mu\text{m}$**





**$I_d/(W/L)$  Vs  $g_m/I_d$  plot for  $L = 3.6\mu\text{m}$**

***Design of Common Source and Differential amplifiers using Gm/Id method.***

This part of the experiment was done using TSMC 0.25 $\mu$ m technology files.  
So the Gm/Id plots given previously were not used.

Library used is:

/edatools/dk/tsmc025/models/eldo/logic025.eldo

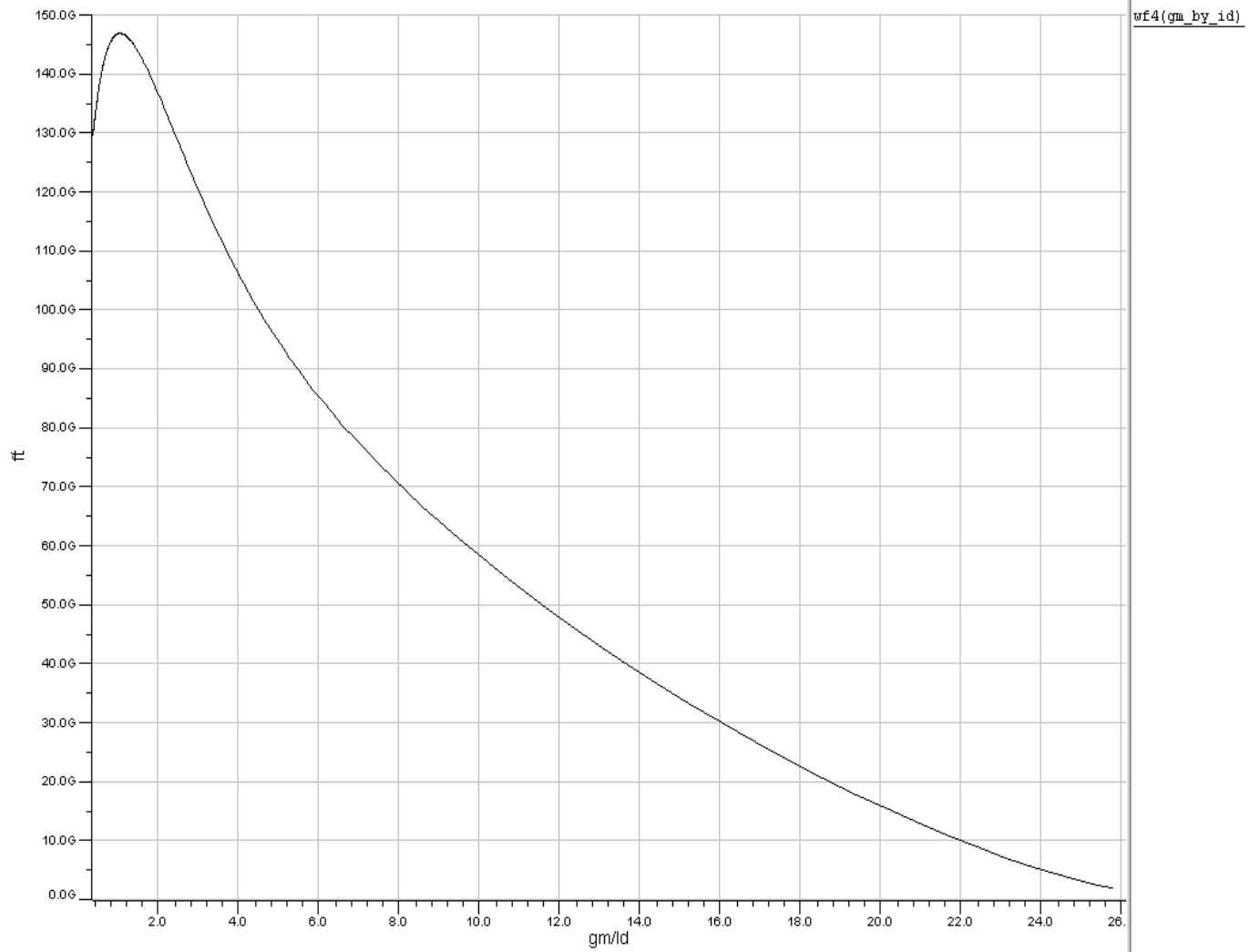
Gm/Id plots for this technology have been given below.

These plots will be used for designing the amplifiers in the subsequent stages.

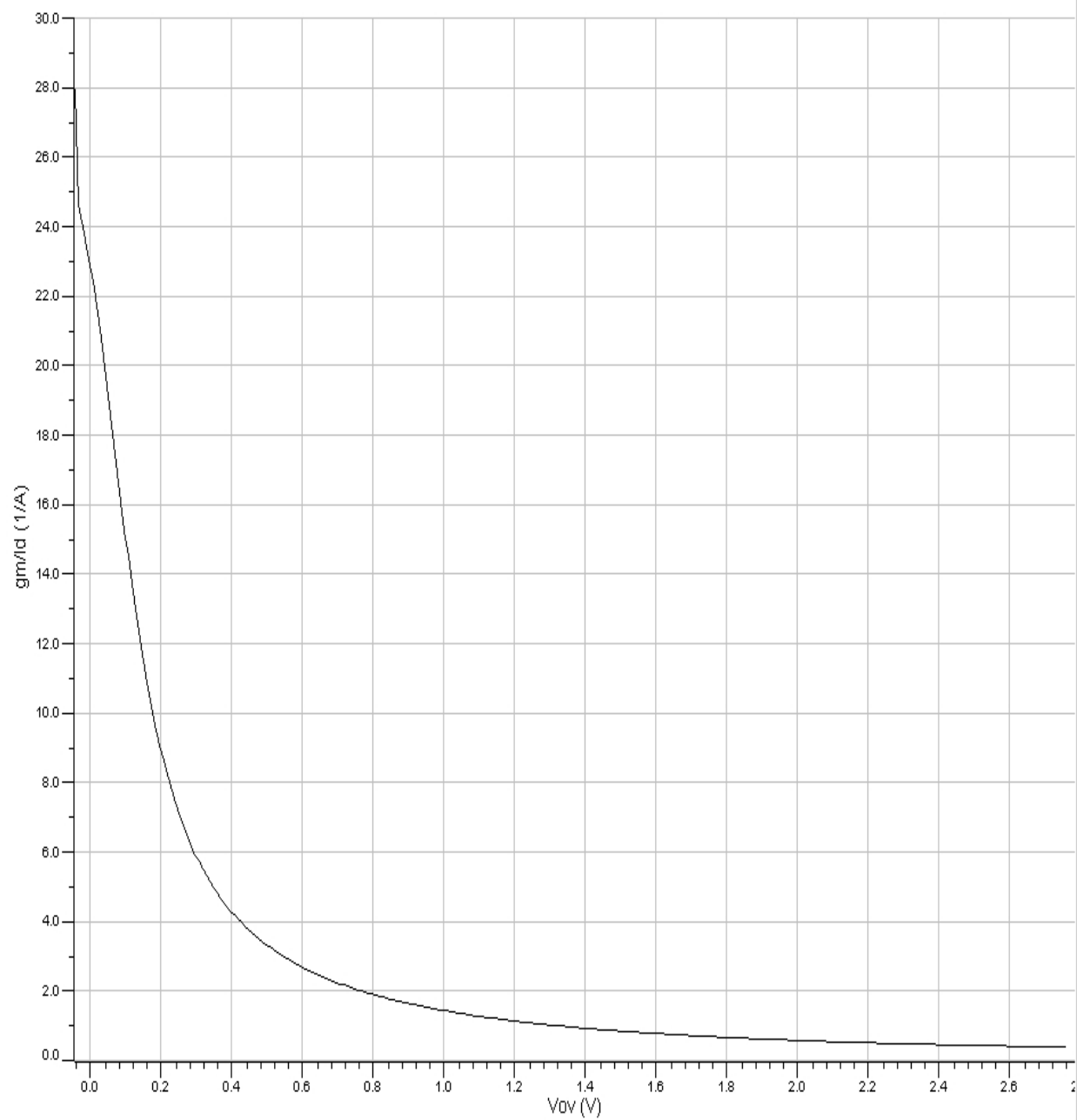
W/L = 10 $\mu$ /0.25 $\mu$

Plot 1:

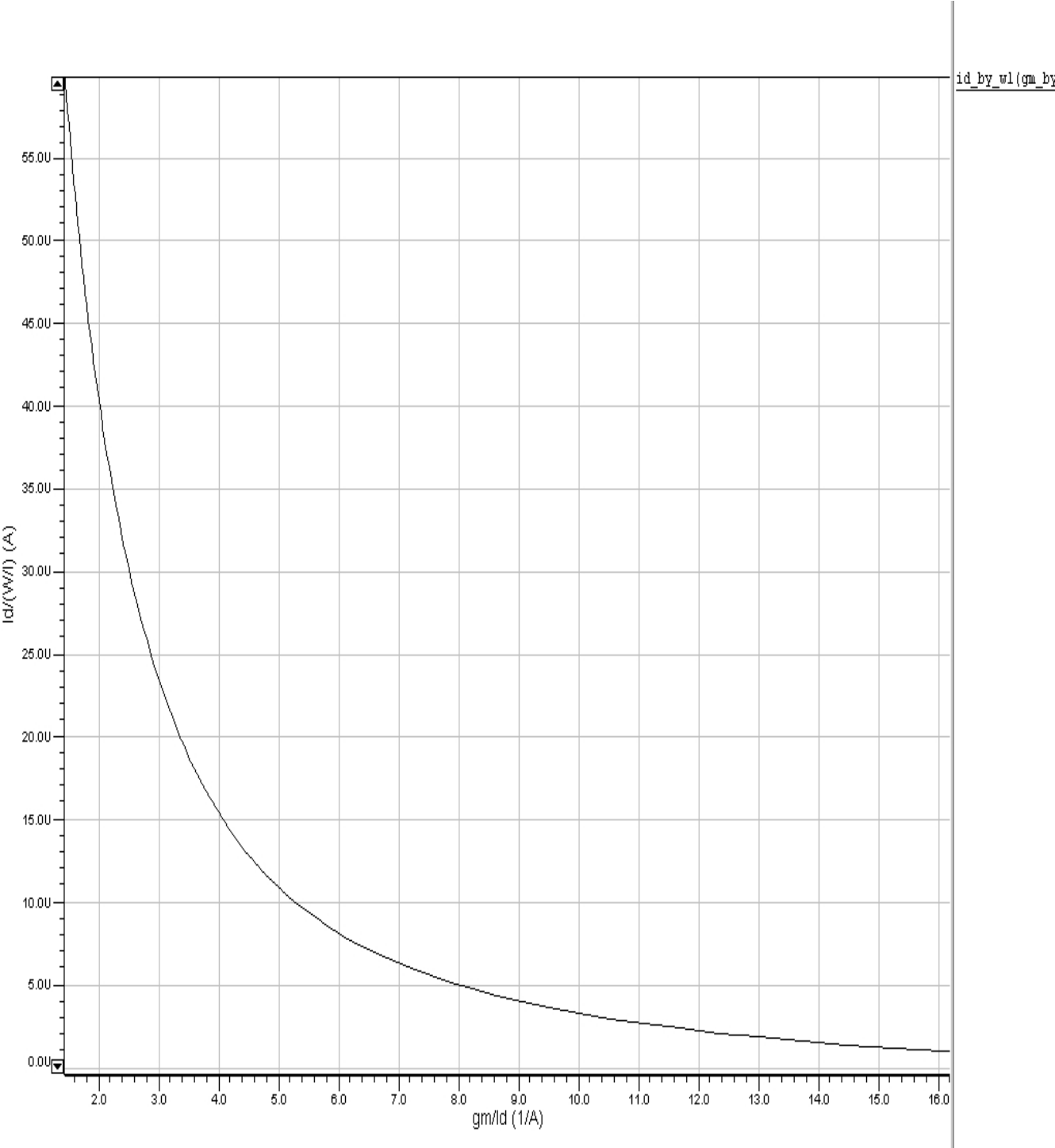
$F_T$  Vs gm/Id



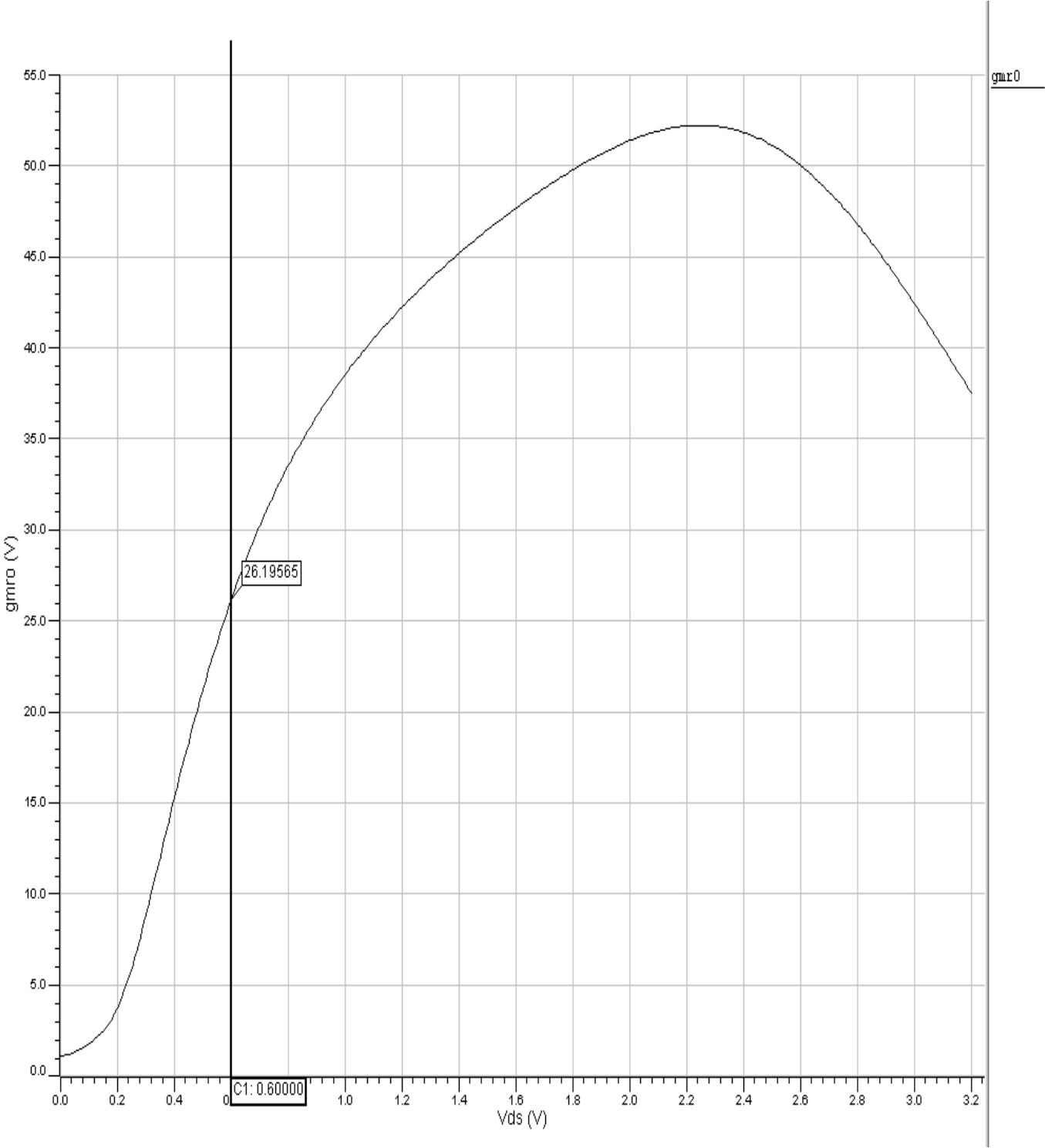
Plot 2:  
Gm/Id Vs Vov :



Plot 3:  
Id/(W/l) Vs Gm/Id

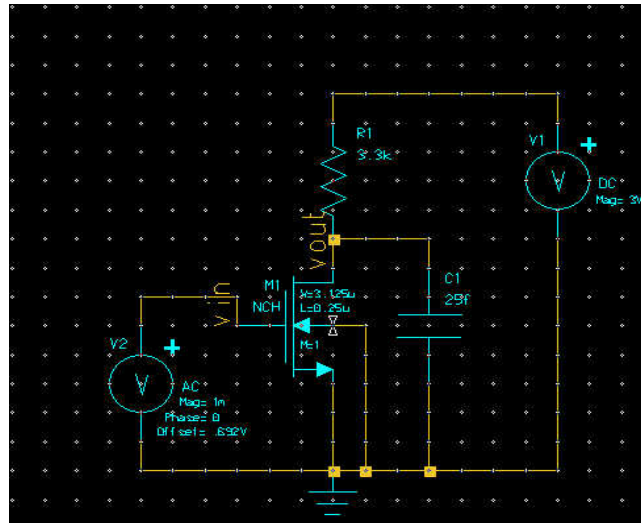


Plot 4:  
 $G_m \cdot r_0$  Vs  $V_{ds}$



## Design of Common Source Amplifier

The circuit diagram is given below.



### Design for Maximum Gain

When designing for maximum gain, we need to get the maximum  $g_m$  possible, since the gain of CS amplifier is simply  $-g_m \cdot R_L$ . Apart from increasing  $g_m$ ,  $R_L$  can also be increased, but in case of a resistive load, the resistance will be set by the output common mode voltage requirements.

From the  $g_m/I_d$  Vs  $V_{ov}$  plot, we can see that to obtain higher transconductance efficiency, we need to work at lower overdrive voltages. At the same time, the overdrive voltage cannot be arbitrarily small otherwise the  $W/L$  of the transistor will be very large.

So we select a  $g_m/I_d$  value of 15 from this plot and read the corresponding  $V_{ov}$ .

Next, we refer to the  $I_d/(W/L)$  Vs  $g_m/I_d$  plot and read the  $I_d/(W/L)$  value from it.

$I_d/(W/L) = 1.6\mu$  ( approximate value)

Setting  $I_d = 100\mu A$ ,

we get  $W/L = 60$

If  $L = 0.5\mu m$ ,  $W = 30\mu m$

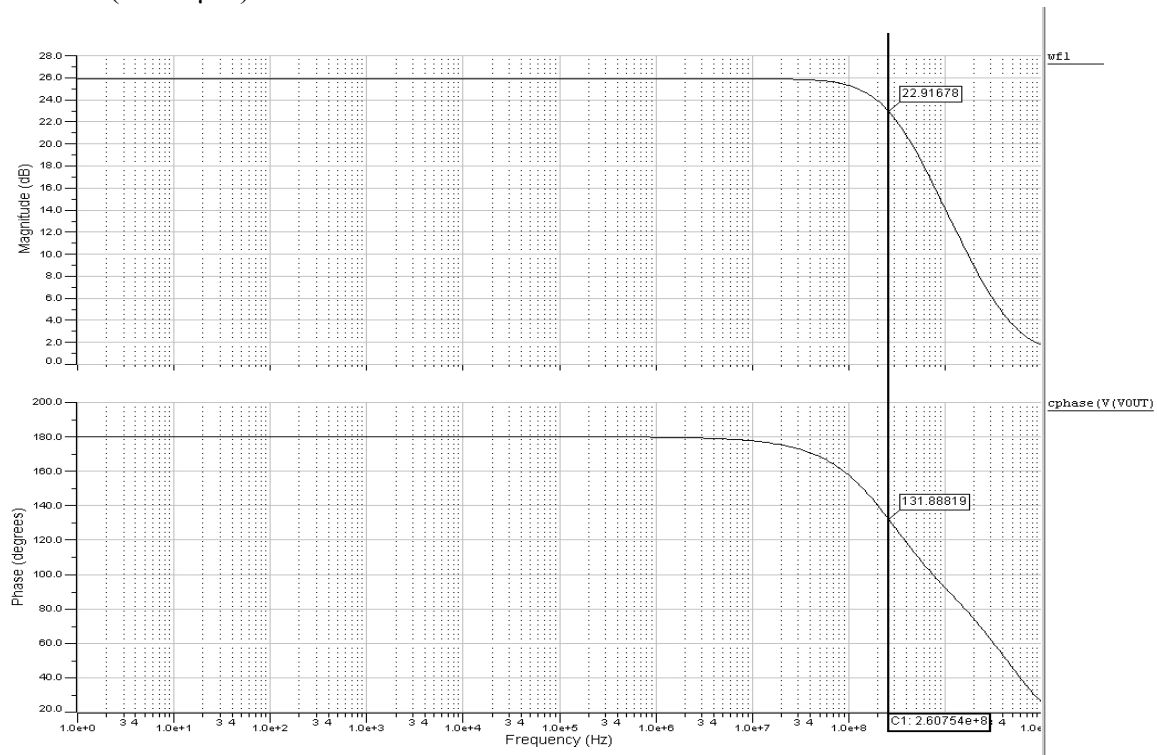
To get a 1.0v as output common mode voltage,

$R_L = (3-1)/100\mu A = 20K$

The simulation results using these values are shown below:

Note that, according to the  $g_m \cdot r_0$  plot, the maximum gain achievable is around 50 v/v but we are getting only about 20 v/v. This is because  $R_L$  is much smaller compared to  $r_0$ .

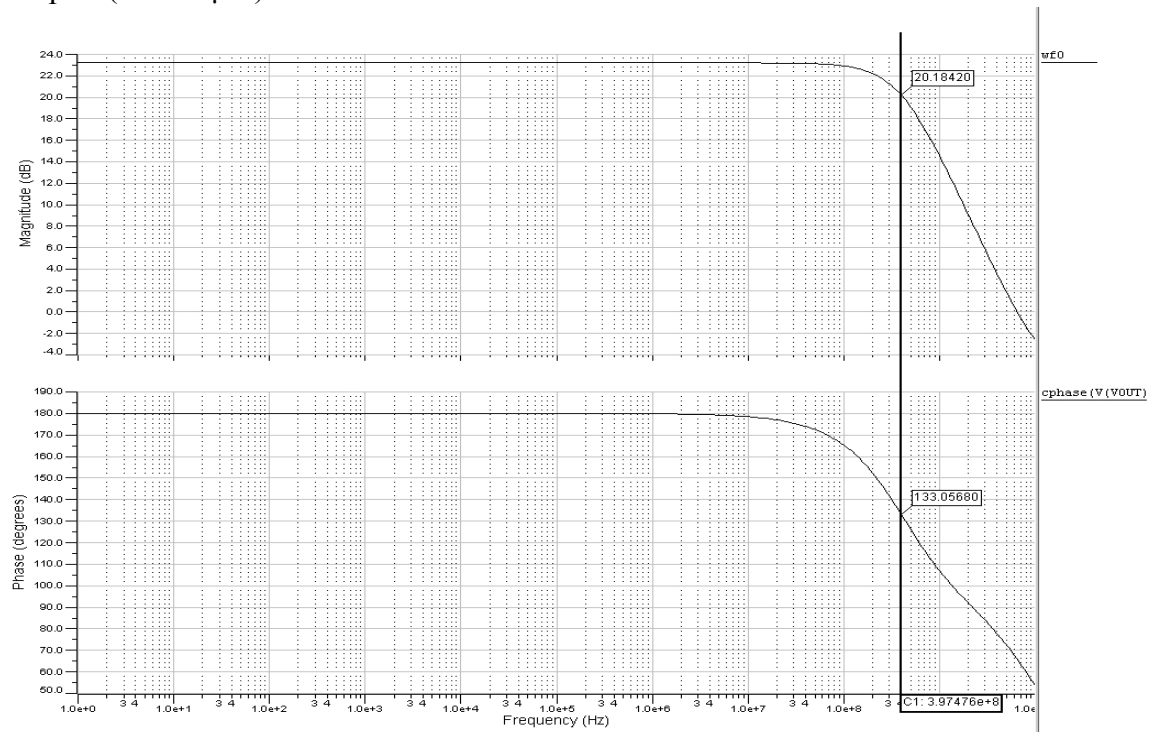
Ac Plot ( $L=0.5\mu\text{m}$ ):



Gain = 19.95 v/v

-3dB frequency = 260MHz

Ac plot ( $L=0.25\mu\text{m}$ ):



Gain = 14.1 v/v

-3dB frequency = 397MH