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Homework #1
Solution

EECS140
Fall 2004

1. Figure 1 shows the measured I_D-V_{DS} curves of a 5um/0.15um (*W/L*) NMOS transistor.

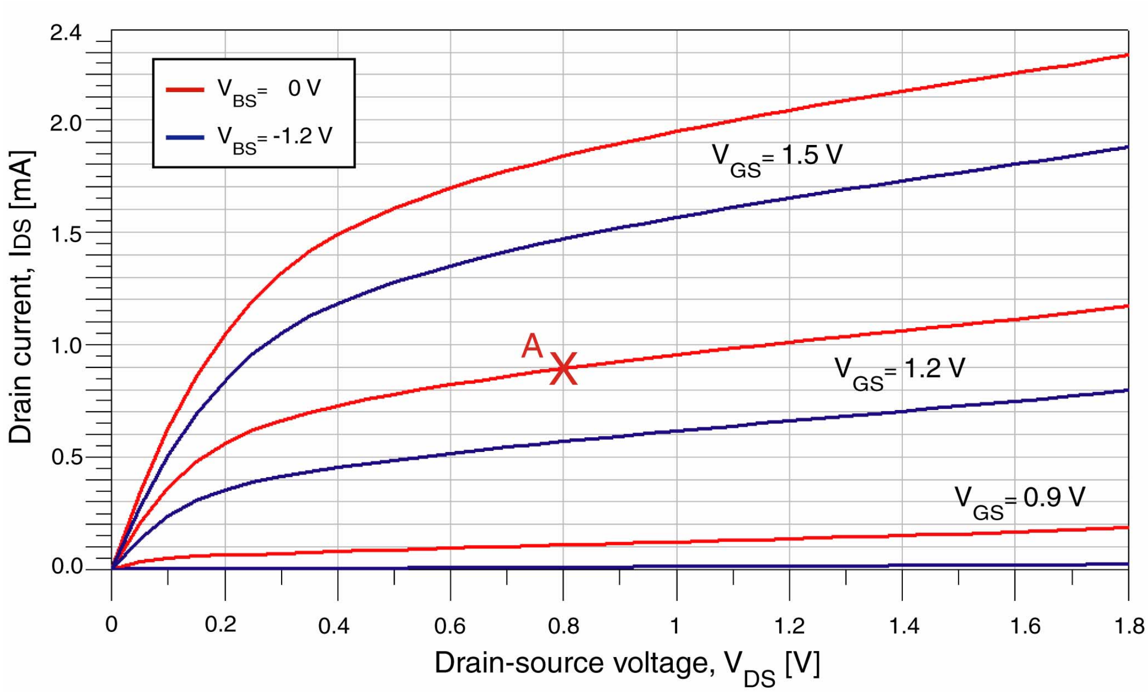

Figure 1

a) The parameters can be estimated by choosing appropriate measured points on different curves. It is better to use the operation points where the simple Level 1 model is adequate. (for example don't use V_{GS}=1.5V curves where mobility degradation and velocity saturation effects are very visible.)

V_{T0} : At V_{DS} = 0.7V, V_{BS} = 0 we measure I_{DS} at two different V_{GS} and take the ratio to eliminate other unknown parameters.

$$\frac{I_{DS}(V_{GS}=1.2V, V_{DS}=0.7V, V_{BS}=0V)}{I_{DS}(V_{GS}=0.9V, V_{DS}=0.7V, V_{BS}=0V)} = \left(\frac{1.2V - V_{T0}}{0.9V - V_{T0}}\right)^2 = \frac{859\mu A}{102\mu A} \Rightarrow V_{T0} \approx 740mV$$

γ : At V_{DS} = 1.0V, V_{GS} = 1.2 we measure I_{DS} at two different V_{BS} and take the ratio to eliminate other unknown parameters.

$$\frac{I_{DS}(V_{GS}=1.2V, V_{DS}=1V, V_{BS}=0V)}{I_{DS}(V_{GS}=1.2V, V_{DS}=1V, V_{BS}=-1.2V)} = \left(\frac{1.2V - V_{T0}}{1.2V - V_{T}}\right)^2 = \frac{954\mu A}{615\mu A}$$

$$\Rightarrow\ V_T - V_{T0} \approx 90mV = \gamma(\sqrt{0.6+1.2} - \sqrt{0.6}) \Rightarrow \gamma \approx 0.160V^{1/2}$$

λ: At V_{GS} = 1.2V, V_{BS} = 0 we measure I_{DS} at two different V_{DS} and take the ratio to estimate λ.

$$\frac{I_{DS}(V_{GS}=1.2V, V_{DS}=1.1V, V_{BS}=0V)}{I_{DS}(V_{GS}=1.2V, V_{DS}=0.7V, V_{BS}=0V)} = \frac{1.0V + \lambda \times 1.1V}{1.0V + \lambda \times 0.7V} = \frac{983\mu A}{859\mu A} \Rightarrow\ \lambda \approx 0.47$$

k_p: A single point data is sufficient to estimate k_p since this is the last parameter.

$$I_{DS}(V_{GS}=1.2V, V_{DS}=1.1V, V_{BS}=0V) = \frac{k_p}{2}\frac{5.00\mu m}{0.15\mu m}(1.2V - 0.74V)^2(1+0.47\times 1.2) = 983\mu A$$

$$\Rightarrow\ k_p \approx 180\mu A/V^2$$

b) Calculate the small signal parameters (g_m, g_{mb}, and r_o) at the operating point A. (V_{GS} = 1.2 V, V_{BS} = 0, V_{DS} = 0.8 V)

$$g_m = k_p \frac{W}{L}(V_{GS} - V_T)(1 + \lambda \times V_{DS}) = 180\ \mu A/V^2\ \frac{5.00\mu m}{0.15\mu m}(1.2V - 0.74V)(1+0.47\times 0.8)$$

$$\Rightarrow\ g_m \approx 3.8mS$$

$$\chi = \frac{\gamma}{2\sqrt{(2\phi_F + V_{SB})}} = \frac{0.16}{2\sqrt{(0.6+0)}} = 0.1$$

$$\Rightarrow g_{mb} = \chi\ g_m = 0.38mS$$

$$r_o = \frac{1}{\lambda\ I_{DS}} = \frac{1}{0.47\times 0.893mA} = 2.38k\Omega$$

c, d, e, f) The simulated and measured curves are shown in figure 2. Level 1 model doesn't model mobility degradation and velocity saturation effects and therefore doesn't fit the curves with high overdrive voltage. (V_{GS}=1.5V) Also there is some inaccuracy in transition between triode and saturation regions. In addition we will see in problem 2 that Level 1 model doesn't account for subthreshold current.

```
.title Problem 1(f)
.option nomod post
.model xtor nmos level=1 vt0=0.74 gamma=0.16 lambda=0.47 kp=128u capop=0
m1 d g 0 b xtor w=5u l=0.15u
vds d 0 dc=0.8
vgs g 0 dc=1.2
vbs b 0 dc=-1.2

.probe dc id=i1(m1)
.dc vds start=0 stop=1.8 step=0.01 vgs 0.9 1.5 0.3
.end
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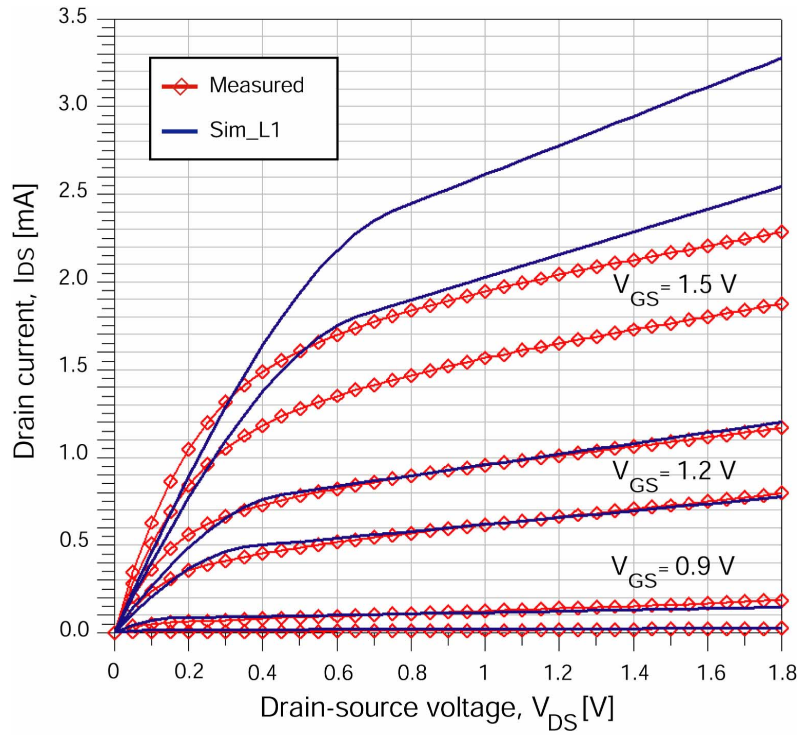

Figure 2

2. Figure 3 shows the measured log(I_D) $-V_{GS}$ curves of the same NMOS transistor.

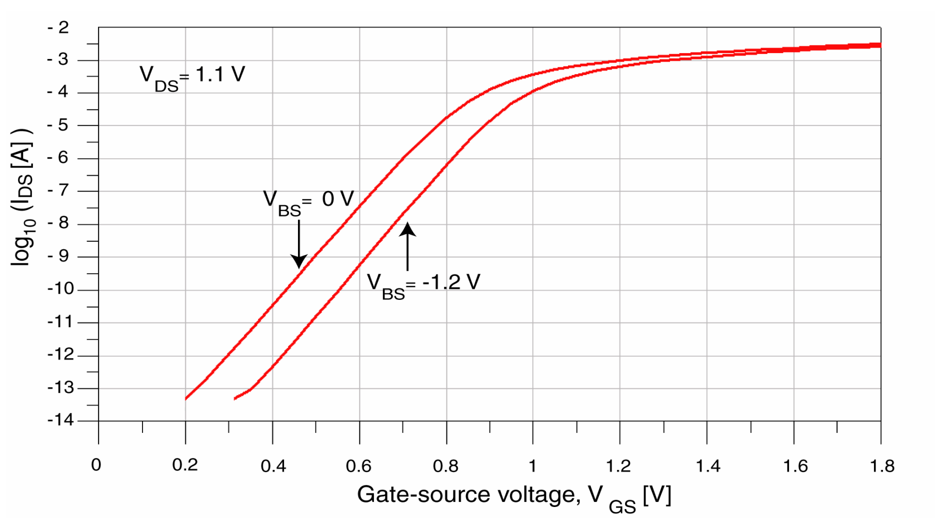

Figure 3

a) The subthreshold slop can be calculated by using 2 measured data points. (ex. V_{GS}=0.4V and 0.6V, V_{BS}=0V, V_{DS}=1.1V)

$$I_D = \mu C_d \frac{W}{L} V_T^2 (\exp \frac{V_{GS} - V_T}{nV_T})$$

$$\frac{\partial(\log_{10} I_D)}{\partial V_{GS}} = (\log_{10} e) \frac{1}{nV_T} \approx 15$$

$$\Rightarrow n \approx 1.115$$

b) The extracted model and procedure of problem 1 is used to compare the simulation and measurement results. (Figure 4) Again it can be noticed that Level 1 model doesn't account for subthreshold current. Also it is not accurate when the overdrive voltage is very high. (>1.3V in this case)

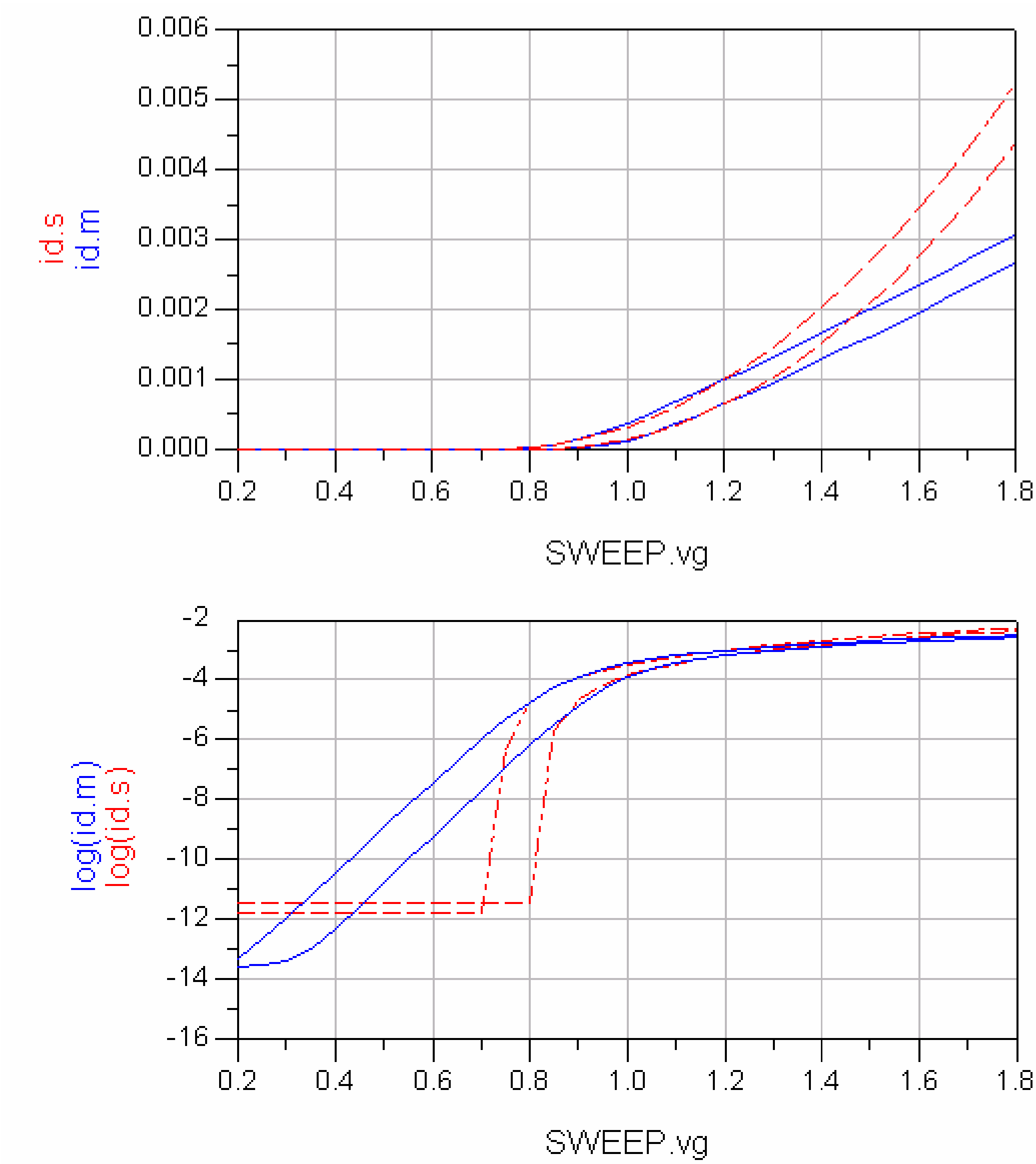

Figure 4