Chapter Six

Problem 6.1

For zero-bias threshold voltage, VSB=0. From Eq. (6.4),

$$V_{THP0} = VFB + PHI + K1\times(PHI)^{0.5} - K2\times PHI$$

From Appendix A, p-channel BSIM model,

$$V_{THP0} = -0.265 + 0.676 + 0.569\times(0.676)^{0.5} - (-.055)\times 0.676 = \underline{0.916V}$$

Problem 6.2

1) N-channel MOSFET, from appendix A BSIM model,

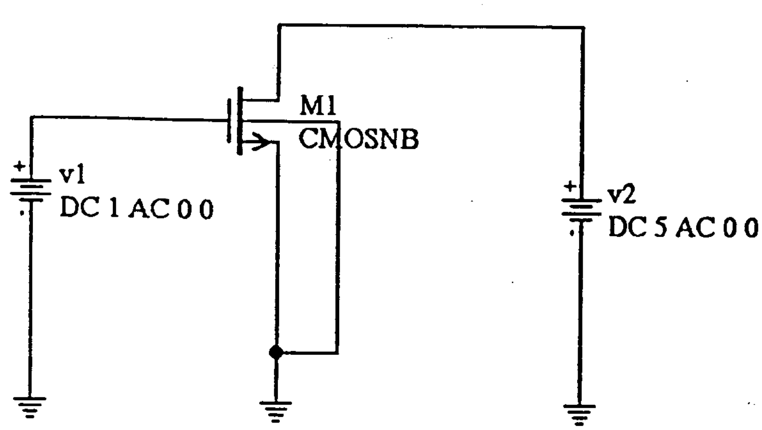
$$KP_N = MUZ \times \varepsilon_{ox} / TOX = 598.328\ cm^2/Vs \times 3.97\times 8.85aF/\mu m / 0.0435\mu m$$
$$\approx \underline{48.326\mu A/V^2}$$
$$C'_{ox} = \varepsilon_{ox} / TOX = (8.85 \times 3.97\ aF/\mu m) / (435\times 10^{-10}\ m) = \underline{807.69aF/\mu m^2}$$

2) P-channel MOSFET,

$$C'_{ox} = \varepsilon_{ox} / TOX = (8.85 \times 3.97\ aF/\mu m) / (435\times 10^{-10}\ m) = \underline{807.69aF/\mu m^2}$$
$$KP_N = MUZ \times C'_{ox} = \underline{17.018\mu A/V^2}$$

Problem 6.3

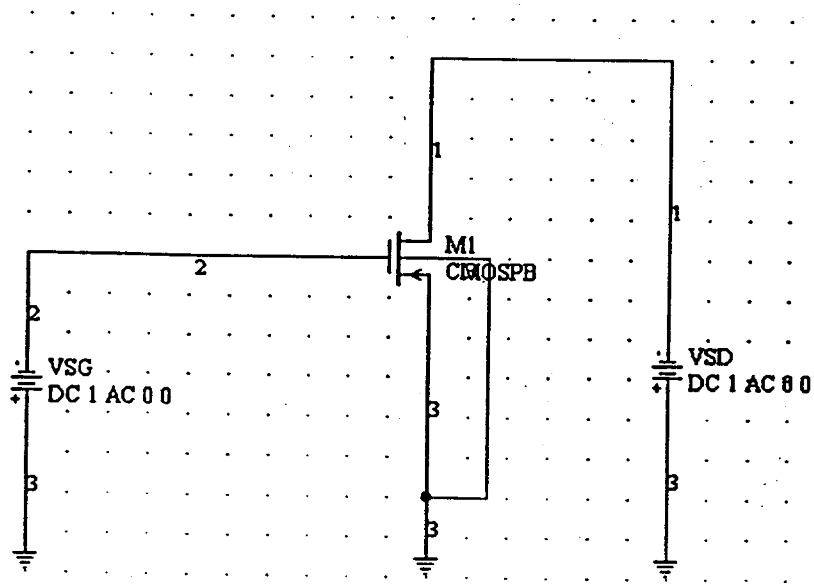
Solution: The circuit of n-channel MOSFET is shown below and with the Netlist. The plot of I_D vs V_{DS} is shown in the next page.



Problem 6.3 (continued)

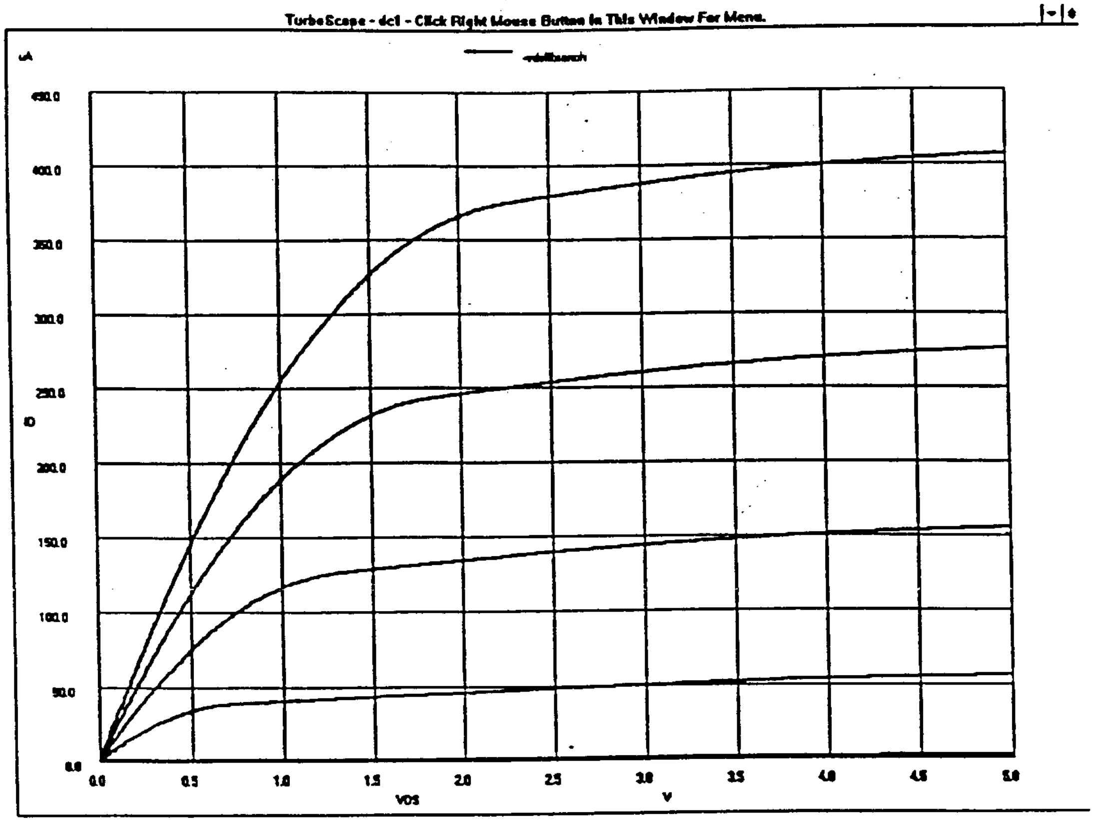
```
*** (TurboSim V 1.1) Netlist for C:\TS\P603.CKT

*** Top Level Netlist ***
M1      3 1 0 0 CMOSNB L=2u W=3u
v1      1 0     DC 1 AC 0 0
v2      3 0     DC 5 AC 0 0

***** Spice models and macro models *****

.MODEL CMOSNB NMOS LEVEL=4
+VFB=-9.73820E-01, LVFB=3.67458E-01,WVFB=-4.72340E-02
+phi=7.46556E-01,lphi=-1.92454E-24, wphi=8.06093E-24
+k1=1.49134E+00,lk1=-4.98139E-01, wk1=2.78225E-01
+k2=3.15199E-01,lk2=-6.95350E-02,wk2=-1.40057E-01
+eta=-1.19300E-02, leta=5.44713E-02,weta=-2.67784E-02
+muz=5.98328E+02,dl=6.38067E-001,dw=1.35520E-001
+u0=5.27788E-02, lu0=4.85686E-02,wu0=-8.55329E-02
+u1=1.09730E-01, lu1=7.28376E-01,wu1=-4.22283E-01
+x2mz=7.18857E+00,lx2mz=-2.47335E+00, wx2mz=7.12327E+01
+x2e=-3.00000E-03,lx2e=-7.20276E-03,wx2e=-5.57093E-03
+x3e=3.71969E-04,lx3e=-3.16123E-03,wx3e=-3.80806E-03
+x2u0=1.30153E-03, lx2u0=3.81838E-04, wx2u0=2.53131E-02
+x2u1=-2.04836E-02, lx2u1=3.48053E-02, wx2u1=4.44747E-02
+mus=7.79064E+02, lmus=3.62270E+02,wmus=-2.71207E+02
+x2ms=-2.65485E+00, lx2ms=3.68637E+01, wx2ms=1.12899E+02
+x3ms=1.18139E+01, lx3ms=7.24951E+01,wx3ms=-5.25361E+01
+x3u1=2.12924E-02, lx3u1=5.85329E-02,wx3u1=-5.29634E-02
+tox=4.35000E-002, temp=2.70000E+01, vdd=5.00000E+00
+cgdo=3.79886E-010,cgso=3.79886E-010,cgbo=3.78415E-010
+xpart=1.00000E+000
+n0=1.00000E+000 ln0=0.00000E+000 wn0=0.00000E+000
+nb=0.00000E+000 lnb=0.00000E+000 wnb=0.00000E+000
+nd=0.00000E+000 lnd=0.00000E+000 wnd=0.00000E+000
+rsh=27.9  cj=1.037500e-04  cjsw=2.169400e-10  js=1.000000e-08  pb=0.8
+pbsw=0.8  mj=0.66036  mjsw=0.178543  wdf=0  dell=0

***** End of spice models and macro models *****

.DC v2 0 5 .01 v1 0 5 1
.end
```

The circuit of p-channel MOSFET is shown below and with the Netlist. The plot of I vs V is shown in the next page.

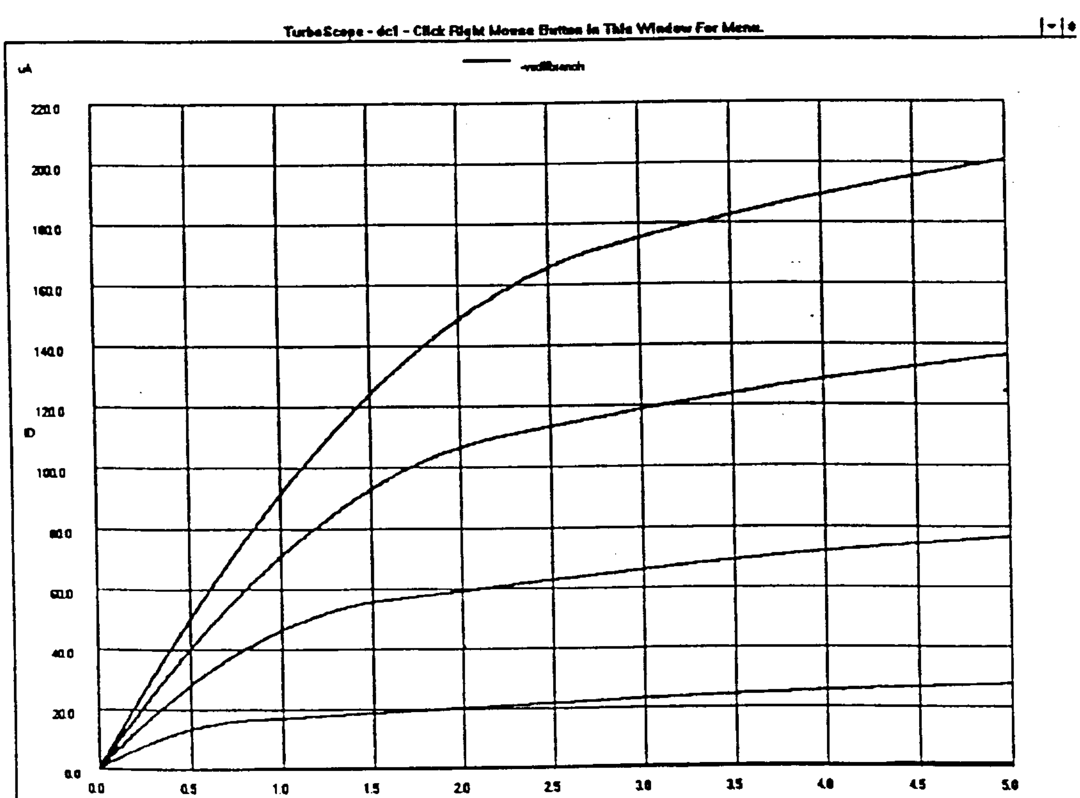



```
*** (TurboSim V 1.1) Netlist for C:\TS\P603P.CKT

*** Top Level Netlist ***
M1        1 2 0 0 CMOSPB  L=2u W=3u
VSD       0 1        DC 1 AC 0 0
VSG       0 2        DC 1 AC 0 0

***** Spice models and macro models *****

.MODEL CMOSPB PMOS LEVEL=4
+ vfb=-2.65334E-01, lvfb=6.50066E-02, wvfb=1.48093E-01
+ phi=6.75823E-01,lphi=-1.61406E-24, wphi=8.03764E-24
+ k1=5.68962E-01, lk1=3.88845E-02,wk1=-5.33948E-02
+ k2=-5.52938E-02, lk2=1.17906E-01,wk2=-6.89149E-02
+ eta=-1.51784E-02, leta=5.87976E-02,weta=-7.51570E-04
+ muz=2.10669E+02,dl=8.44240E-001,dw=1.62551E-001
+ u0=1.04713E-01, lu0=5.50950E-02,wu0=-7.56659E-02
+ u1=1.46638E-02, lu1=2.13581E-01,wu1=-1.22509E-01
+ x2mz=8.76354E+00,lx2mz=-3.64793E+00, wx2mz=4.30934E+00
+ x2e=-2.13631E-03,lx2e=-2.94140E-03,wx2e=-2.48293E-03
+ x3e=2.78813E-04,lx3e=-1.60711E-03,wx3e=-4.57237E-03
+ x2u0=3.93706E-03,lx2u0=-5.66051E-04, wx2u0=5.69621E-04
+ x2u1=1.07707E-04, lx2u1=8.85125E-03, wx2u1=1.71537E-03
+ mus=2.06464E+02, lmus=1.39151E+02,wmus=-4.95671E+01
+ x2ms=5.86401E+00, lx2ms=6.98887E+00, wx2ms=5.55782E+00
+ x3ms=-2.03430E-01, lx3ms=1.16170E+01,wx3ms=-3.44342E+00
+ x3u1=-1.17893E-02, lx3u1=5.72098E-04, wx3u1=8.29791E-03
+ tox=4.35000E-002, temp=2.70000E+01, vdd=5.00000E+00
+ cgdo=5.02635E-010,cgso=5.02635E-010,cgbo=3.85017E-010
+ xpart=1.00000E+000
+ n0=1.00000E+000,ln0=0.00000E+000,wn0=0.00000E+000
+ nb=0.00000E+000,lnb=0.00000E+000,wnb=0.00000E+000
+ nd=0.00000E+000,lnd=0.00000E+000,wnd=0.00000E+000
+ rsh=54.7,   cj=3.245600e-04,   cjsw=2.543000e-10,   js=1.000000e-08,   pb=0.8
+ pbsw=0.8,   mj=0.60438,   mjsw=0.244194,   wdf=0,   dell=0


***** End of spice models and macro models *****

.DC VSD 0 5 .01 VSG 0 5 1
.end
```

N-channel Plot

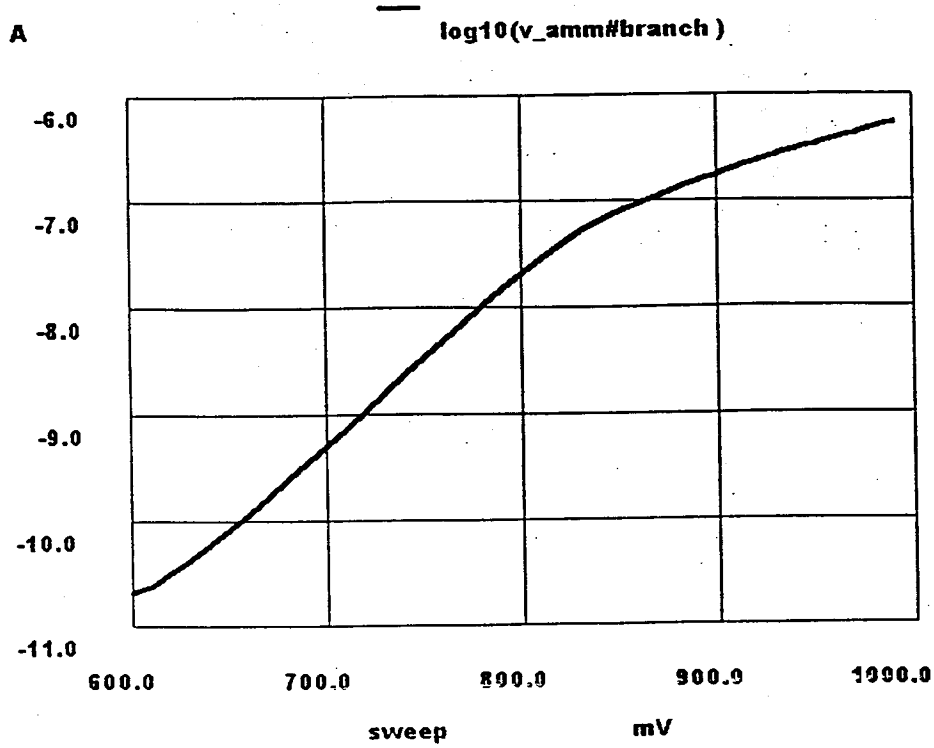


P-channel Plot



Problem 6.4

Using SPICE and BSIM to generate figure 6.5. The subthreshold slope is about 65mV/decade.



Problem 6.5

The drive current of a short-channel MOSFET is given by Eq. (6.41)

$I_{drive} = v_{sat} \times C'_{ox} \times (V_{GS} - V_{THN} - V_{DS,sat})$,

$C'_{ox} = \varepsilon_{ox} / TOX = (8.85 \times 3.97\ aF/\mu m) / (75 \times 10^{-10}\ m) = 4.685 fF/\mu m^2$

$I_{drive} = 10^7 cm/s \times 4.685 fF/\mu m^2 \times (2.5 - .5 - 1.5)V = \underline{234.25 \mu A/\mu m}$

For the long channel MOSFET in chapter five, we assume that electron mobility μ does not vary with V_{DS}. For short-channel MOSFETs, $V_{DS,sat}$ is not directly dependent on the V_{GS} and V_{TH}, but it is used to change the drift velocity. From figure 6.8 and Eq. (6.39), the $V_{DS,sat}$ is dependent directly on the critical electrical field which causes the drift velocity to v_{sat}. Therefore, $V_{DS,sat}$ is not equal to $V_{GS} - V_{THN}$ for short-channel MOSFETs.

Problem 6.6

From figure 6.8, at 10^5V/cm, both electron and hole velocity are at saturation velocity. $v_{nsat} \approx 10^7$cm/s and $v_{psat} \approx 9 \times 10^6$cm/s. From eq. (6.39), the mobility of electron is 100 cm^2/Vs and mobility of holes is 90 cm^2/Vs.

Problem 6.7

From eq. (6.21), the output resistance is given by $r_o = 1/(\lambda \bullet I_D)$. Using level 1 MOSFET SPICE model, in saturation region, $I_D = MUZ \bullet C_{ox} \bullet W \bullet (V_{GS} - V_{THN})^2 / 2L$

Therefore,

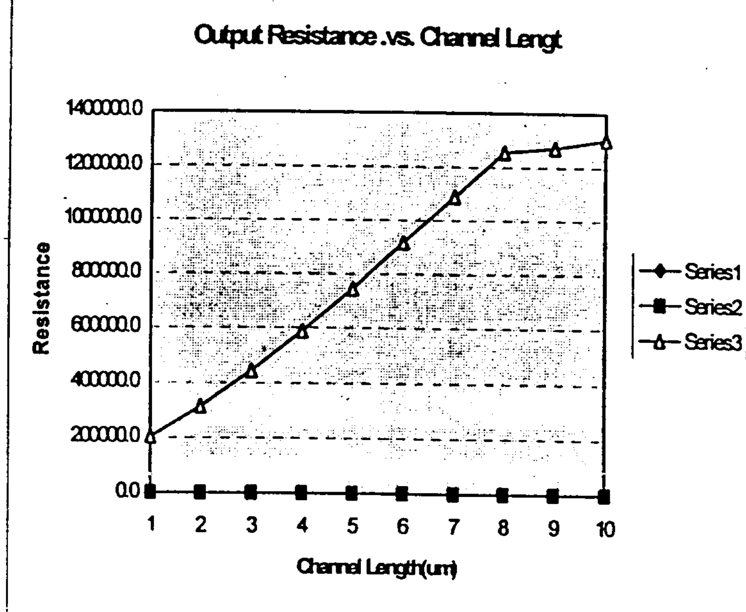
$r_o = 2L / [\lambda \bullet MUZ \bullet C_{ox} \bullet W \bullet (V_{GS} - V_{THN})^2]$

Set $K = 2/[MUZ \bullet C_{ox} \bullet W \bullet (V_{GS} - V_{THN})^2]$,

$r_o = L/(\lambda \bullet K)$

Probelm 6.8

length	gds	1/gds
2.0	4.92E-06	2.03E+05
2.5	3.18E-06	3.14E+05
3.0	2.26E-06	4.42E+05
3.5	1.70E-06	5.88E+05
4.0	1.34E-06	7.46E+05
4.5	1.09E-06	9.17E+05
5.0	9.18E-07	1.09E+06
6.5	7.97E-07	1.25E+06
7.5	7.87E-07	1.27E+06
10.0	7.68E-07	1.30E+06

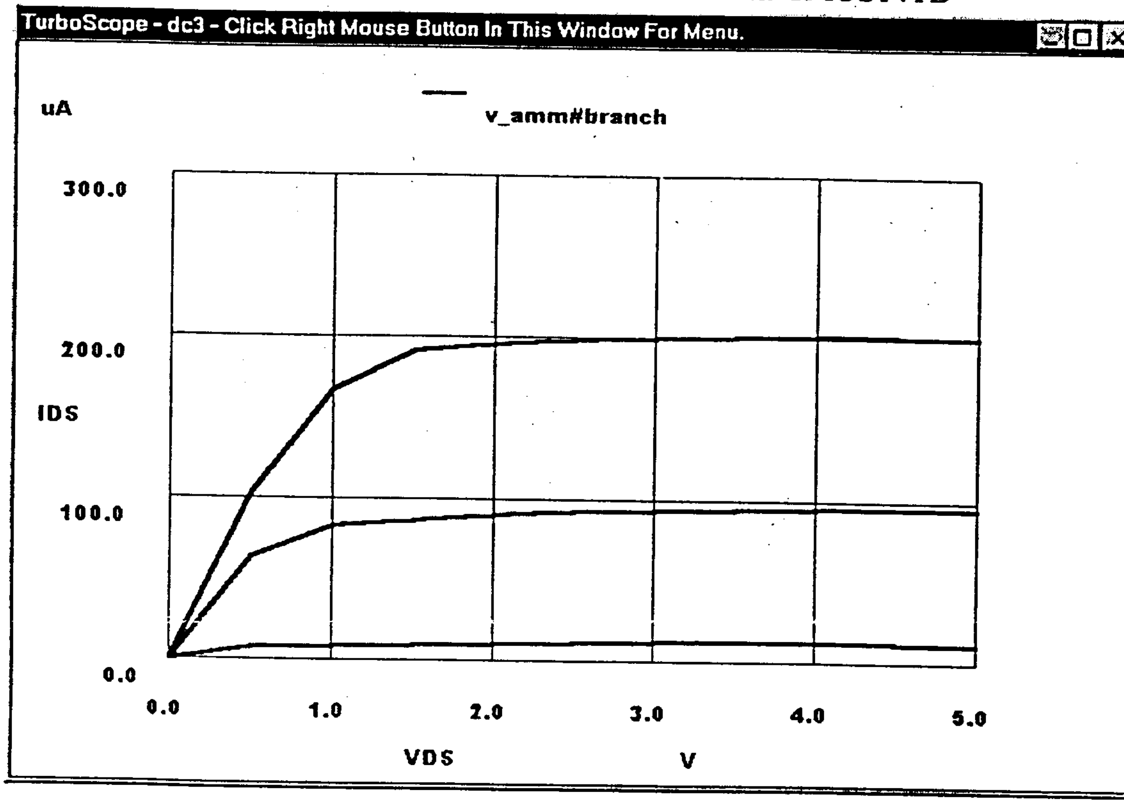


Problem 6.9

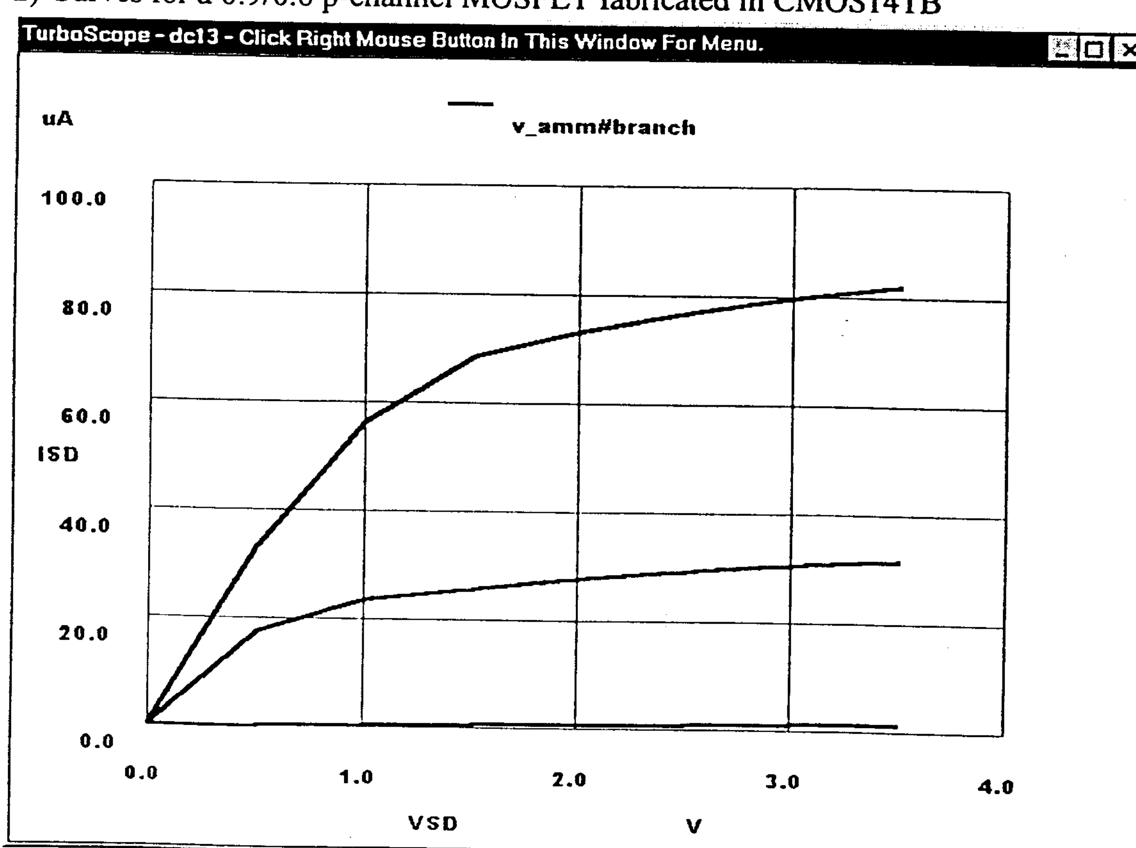
(Refer to Appendix C in pg. 888 to pg. 890)

Problem 6.10

1) Curves for a 0.9/0.6 n-channel MOSFET fabricated in CMOS14TB



2) Curves for a 0.9/0.6 p-channel MOSFET fabricated in CMOS14TB



Problem 6.11

From figures shown in Problem 6.10, the drive current of MOSFET fabricated in CMOS14TB can be estimated using the data in the plots by

$I_{drive} = ID(@VDD)/W_{eff}$

For n-mosfet, $I_{drive} = 200\mu A/(0.9-0.4)\mu m = 400\ \mu A/\mu m$
For p-mosfet, $I_{drive} = 80\mu a/(0.9-0.43)\mu m = 170\mu A/\mu m$

(For CMOS14TB process, refer to Appendix C for details.)