

ENEE 303H HW1 09/21/09 YH

2.

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.MODEL MNMOSIS NMOS LEVEL=2 LD=0.250000U TOX=418.000008E-10
+ NSUB=9.236187E+14 VTO=0.858153 KP=5.048000E-05 GAMMA=0.198
+ PHI=0.6 UO=596.729 UEXP=7.029586E-02 UCRIT=10266.7
+ DELTA=2.7371 VMAX=65701.4 XJ=0.250000U LAMBDA=1.843384E-02
+ NFS=1.086360E+12 NEFF=1 NSS=1.000000E+10 TPG=1.000000
+ RSH=28.760000 CGDO=3.097916E-10 CGSO=3.097916E-10 CGBO=3.838441E-10
+ CJ=8.997900E-05 MJ=0.783638 CJSW=5.524800E-10 MJSW=0.285064
PB=0.800000
* Weff = Wdrawn - Delta_W
* The suggested Delta_W is -0.24 um
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.MODEL AM12L3N NMOS LEVEL=3 PHI=0.700000 TOX=3.0600E-08 XJ=0.200000U
TPG=1
+ VTO=0.5666 DELTA=8.7630E-01 LD=9.0910E-10 KP=7.7684E-05
+ UO=688.4 THETA=1.1640E-01 RSH=1.0310E+01 GAMMA=0.5904
+ NSUB=1.3370E+16 NFS=5.9090E+11 VMAX=1.9740E+05 ETA=9.3470E-02
+ KAPPA=2.1020E-01 CGDO=5.0000E-11 CGSO=5.0000E-11
+ CGBO=3.1008E-10 CJ=2.7477E-04 MJ=5.5020E-01 CJSW=1.9263E-10
+ MJSW=1.0000E-01 PB=9.9000E-01
* Weff = Wdrawn - Delta_W
* The suggested Delta_W is 7.4960E-07
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```
.MODEL MPMOSIS PMOS LEVEL=2 LD=0.250000U TOX=418.000008E-10
+ NSUB=9.309300E+15 VTO=-0.889271 KP=1.908000E-05 GAMMA=0.6289
+ PHI=0.6 UO=216.28 UEXP=0.218144 UCRIT=62664
+ DELTA=0.164572 VMAX=100000 XJ=0.250000U LAMBDA=5.011626E-02
+ NFS=9.266623E+11 NEFF=1.001 NSS=1.000000E+10 TPG=-1.000000
+ RSH=66.820000 CGDO=3.097916E-10 CGSO=3.097916E-10 CGBO=3.727276E-10
+ CJ=2.981300E-04 MJ=0.556944 CJSW=3.002100E-10 MJSW=0.243045
PB=0.800000
* Weff = Wdrawn - Delta_W
* The suggested Delta_W is -0.17 um
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```
.MODEL AM12L3P PMOS LEVEL=3 PHI=0.700000 TOX=3.0600E-08 XJ=0.200000U
TPG=-1
+ VTO=-0.7996 DELTA=2.4370E+00 LD=1.1000E-09 KP=1.8891E-05
+ UO=167.4 THETA=9.5600E-02 RSH=1.0210E+01 GAMMA=0.3265
+ NSUB=4.0890E+15 NFS=7.1500E+11 VMAX=1.2590E+05 ETA=8.2820E-02
+ KAPPA=5.5040E+00 CGDO=5.0000E-11 CGSO=5.0000E-11
+ CGBO=3.2338E-10 CJ=2.8023E-04 MJ=4.6284E-01 CJSW=2.1036E-10
+ MJSW=1.2846E-01 PB=9.0211E-01
* Weff = Wdrawn - Delta_W
* The suggested Delta_W is 8.1180E-07
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```
.MODEL AM12L4N NMOS (LEVEL=4
+ vfb=-8.06994E-01      lvfb=-5.98523E-02      wvfb=1.83983E-01
+ phi= 7.09900E-01      lphi=0.00000E+00      wphi=0.00000E+00
+ k1=8.05940E-01      lk1=-2.70684E-02      wk1=-1.72483E-01
+ k2=3.89459E-02      lk2=6.26916E-02      wk2=-1.09229E-01
+ eta=-9.44377E-03      leta=2.15242E-02      weta=-1.21061E-03
+ muz=6.00737E+02      dl=2.46200E-001      dw=9.08623E-001
+ u0=6.22230E-02      lu0=1.17470E-01      wu0=-7.71631E-02
+ u1=6.27596E-02      lu1=2.21627E-01      wu1=-2.15900E-02
+ x2mz=8.68504E+00      lx2mz=-4.81283E+00      wx2mz=7.56247E+00
+ x2e=1.12616E-04      lx2e=-6.38946E-03      wx2e=7.73713E-04
+ x3e=1.30124E-03      lx3e=-1.48876E-03      wx3e=-1.13874E-03
+ x2u0=8.69750E-04      lx2u0=-2.54167E-03      wx2u0=-5.15114E-04
+ x2u1=-2.00977E-02      lx2u1=2.07604E-02      wx2u1=3.97394E-03
+ mus=6.43404E+02      lmus=1.32267E+02      wmus=-6.35893E+01
+ x2ms=-7.80666E+00      lx2ms=1.62811E+01      wx2ms=5.93444E+00
+ x3ms=3.39725E+00      lx3ms=1.12997E+01      wx3ms=-2.23374E+00
+ x3u1=5.69136E-03      lx3u1=6.96099E-04      wx3u1=-7.35842E-04
+ tox=3.06000E-002      temp=2.70000E+01      vdd=5.00000E+00
+ cgdo=2.08374E-010      cgso=2.08374E-010      cgbo=3.44085E-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=53.5              cj=2.747700e-04      cjsw=1.926300e-10
js=1e-08      pb=0.99
+ pbsw=0.99              mj=0.5502              mjsw=0.1
wdf=0)
*
* Gate Oxide Thickness is 306 Angstroms
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```
.MODEL AM12L3N NMOS LEVEL=3 PHI=0.700000 TOX=3.0600E-08 XJ=0.200000U
TPG=1
+ VTO=0.5666 DELTA=8.7630E-01 LD=9.0910E-10 KP=7.7684E-05
+ UO=688.4 THETA=1.1640E-01 RSH=1.0310E+01 GAMMA=0.5904
+ NSUB=1.3370E+16 NFS=5.9090E+11 VMAX=1.9740E+05 ETA=9.3470E-02
+ KAPPA=2.1020E-01 CGDO=5.0000E-11 CGSO=5.0000E-11
+ CGBO=3.1008E-10 CJ=2.7477E-04 MJ=5.5020E-01 CJSW=1.9263E-10
+ MJSW=1.0000E-01 PB=9.9000E-01
* Weff = Wdrawn - Delta_W
* The suggested Delta_W is 7.4960E-07
```

	mnmosis	mam12l3n	mpmosis	Mam12l3p
VTO (V)	0.858153	0.5666	-0.889271	-0.7996
KP (A/V ²)	5.048e-5	7.7684e-5	1.908e-5	1.8891e-5

Note that VTO is positive for NMOS (to induce n-channel), negative for PMOS (to induce p-channel).
Generally KP(NMOS) is bigger than KP(PMOS) because electrons have higher mobility than holes.

```
VTO(mnmosis) > VTO(mam12l3n) but KP(mnmosis) < KP(mam12l3n)
|VTO|(mpmosis) > |VTO|(mam12l3p) and KP(mpmosis) ~= KP(mam12l3p)
```

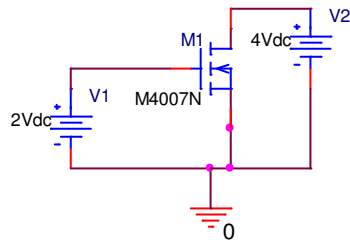
3. (a)

```
.model nch nmos(Level=1 Tox=300n Uo=600 Kp=20.54u W=144u L=8u Vto= 1.3
+
+          Lambda=15m Cbd=4p Cbs=4p Cgdo=1.7n Cgso=1.7n Rs=1 Rd=1)
.model pch pmos(Level=1 Tox=300n Uo=300 Kp=10.32u W=328u L=8u Vto=-1.5
+
+          Lambda=15m Cbd=8p Cbs=8p Cgdo=1.7n Cgso=1.7n Rs=1 Rd=1)
.model r_zap res(r=1.73K)
.model d_zap D(Is= 1p Rs=1 N=1 Xti=3 Eg=1.11 Cjo=.01p M=0 Bv=20
Ibv=.1u)
.model d_body D(Is=15n Rs=1 N=1 Xti=3 Eg=1.11 Cjo=10p M=.5 Vj=.75
+
+          Fc=.5 Isr=.15n Nr=2 Bv=20 Ibv=100u)
.ends
```

	KP (A/V ²)	W (m)	L (m)	VTO (V)	Lambda (1/V)	KP/2*(W/L) (A/V ²)
M4007N	20.54u	144u	8u	1.3	15m	184.86u
M4007P	10.32u	328u	8u	-1.5	15m	211.56u

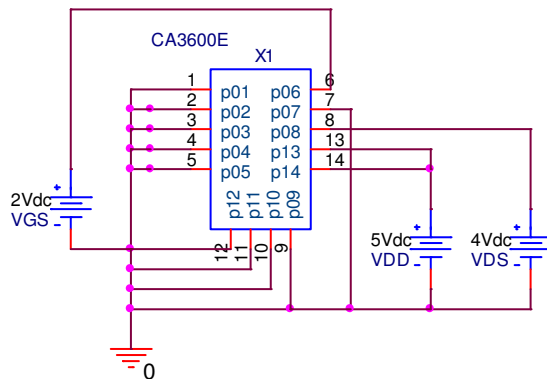
Since $KP(NMOS) > KP(PMOS)$, $W(M4007P)$ is made bigger so that their $KP/2*(W/L)$ can match (get closer).

3. (b) $V_{GD} = 2-4 = -2 < V_{TO}(M4007N)$, so M4007N works in saturation region. $I_D = KP/2*(W/L)*(V_{GS}-V_{TO})^2 = 9.06e-5$ (A), which is smaller than what spice gives because channel length modulation is not taken into account. Spice:



```
ID          9.60E-05 (A)
VGS          2.00E+00
VDS          4.00E+00
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or use CA3600E: there are 3 PMOS and 3 NMOS in CA3600E, for example, use 1 NMOS and let the other 5 MOS off by making $V_{GS}=0$ (no channel formed) or $V_{DS}=0$ (no driving voltage). We get $I_D = 9.60E-05$ (A).



NAME	X_X1.m_N1	X_X1.m_N2	X_X1.m_N3	X_X1.m_P1	X_X1.m_P2
MODEL	X_X1.nch	X_X1.nch	X_X1.nch	X_X1.pch	X_X1.pch
ID	9.60E-05	0.00E+00	0.00E+00	-5.64E-19	-5.01E-12
VGS	2.00E+00	1.04E-08	1.04E-08	-3.00E+00	1.04E-08
VDS	4.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
VBS	0.00E+00	0.00E+00	0.00E+00	0.00E+00	5.00E+00
VTH	1.30E+00	1.30E+00	1.30E+00	-1.50E+00	-1.50E+00

NAME	X_X1.m_P3
MODEL	X_X1.pch
ID	-5.01E-12
VGS	1.04E-08
VDS	0.00E+00
VBS	5.00E+00
VTH	-1.50E+00

3.(c) consider channel length modulation,
 $ID' = K_p/2 * (W/L) * (VGS - VTO)^2 * (1 + \lambda * VDS) = 9.60e-5 \text{ (A)}$, which is the same as what Spice gives.

4. (a)

```
.model Q2N3904 NPN(Is=6.734f Xti=3 Eg=1.11 Vaf=74.03 Bf=416.4
Ne=1.259
+ Ise=6.734f Ikf=66.78m Xtb=1.5 Br=.7371 Nc=2 Isc=0 Ikr=0
Rc=1
+ Cjc=3.638p Mjc=.3085 Vjc=.75 Fc=.5 Cje=4.493p Mje=.2593
Vje=.75
+ Tr=239.5n Tf=301.2p Itf=.4 Vtf=4 Xtf=2 Rb=10)
* National pid=23 case=TO92
```

```
.model Q2N3906 PNP(Is=1.41f Xti=3 Eg=1.11 Vaf=18.7 Bf=180.7 Ne=1.5
Ise=0
+ Ikf=80m Xtb=1.5 Br=4.977 Nc=2 Isc=0 Ikr=0 Rc=2.5
Cjc=9.728p
+ Mjc=.5776 Vjc=.75 Fc=.5 Cje=8.063p Mje=.3677 Vje=.75
Tr=33.42n
+ Tf=179.3p Itf=.4 Vtf=4 Xtf=6 Rb=10)
* National pid=66 case=TO92
```

	BF	BR	ISE (A)	VAF (V)	VAR (V)
Q2N3904	416.4	0.7371	6.734f	74.03	infinity
Q2N3906	180.7	4.977	0	18.7	infinity

4. (b) (c)

$$V_T = kT/q = 1.3806503e-23 \cdot 300.15 / 1.60217646e-19 = 25.865 \text{ (mV)}$$

$$V_{CE} = 7 \text{ (V)}, V_{BE} = 0.7 \text{ (V)}$$

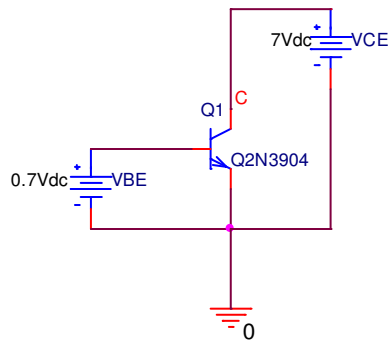
$$V_{BC} = -(V_{CE} - V_{BE}) = -6.3 \text{ (V)}$$

$$\alpha_R = \beta_R / (1 + \beta_R) = 0.4243$$

$$I_C = I_{SE} \cdot (\exp(V_{BE}/V_T) - 1) - I_{SE} \cdot (\exp(V_{BC}/V_T) - 1) / \alpha_R = 3.818 \text{ mA}$$

Actually $V_{BC} = -6.3 \ll V_T$, so the second term can be neglected.

Spice:



```
IC          3.90E-03 (A)
VBE         7.00E-01
VBC        -6.30E+00
VCE         7.00E+00
```

Now consider Early effect,

$$I_C' = (I_{SE} \cdot (\exp(V_{BE}/V_T) - 1) - I_{SE} \cdot (\exp(V_{BC}/V_T) - 1) / \alpha_R) \cdot (1 + V_{CE}/V_{AF})$$

$$= 4.179 \text{ mA}$$

They are all close to what Spice gives.