Homework 3

1) CMOS Inverter

a) Use HSpice to plot the transfer characteristics (output vs. input) of a CMOS inverter with $(W/L)_n$=2.4μm/1.2μm and $(W/L)_p$=6.0μm/1.2μm, respectively. Simulate your circuit for the two bipolar supply voltages of ±1.5V and ±2.5 V. For each case, deduce the voltage gain and the approximate linear output range.

b) Compute the voltage gain from a linear equivalent circuit and compare your results with the values deduced from HSpice simulations.

c) Load the inverter with a capacitor of 100 fF and simulate its response to a symmetrical pulsed input voltage with rail-to-rail voltage swing, a period of 50 ns and rise and fall times of 0.5 ns. Run your simulations for both ±1.5V and ±2.5 V supply rails and find the corresponding 10-90% rise and fall times of the output voltage.

d) Repeat the above simulations for an inverter with $(W/L)_n$=1.2μm/0.6μm and $(W/L)_p$=3.0μm/0.6μm. Explain the differences.

2) Common-Drain Amplifier (Source Follower)

Design a common-drain amplifier that keeps the voltage gain close to unity and yields an output resistance of less than 5 kΩ. Use a p-channel device as the active gain stage and establish the Q-point current I_{DQ} by means of a current source. The latter will also be realized by a p-channel device. The supply rails are ±2.5 V.

a) Find the relationship between output resistance r_{out} and bias current I_{DQ}.

b) Assume that the p-channel output stage features a (W/L) ratio of 30μm/1.2μm. What is the minimum value of the bias current I_{DQ} that guarantees r_{out} to be less than 5 kΩ?

c) Compute the voltage gain in the absence of a body effect.

d) How much voltage gain is lost (in %) if you include the body effect?

e) Apply a sinusoidal input voltage of 1 V and use HSpice to confirm your theoretical results.

f) What is the maximum input voltage swing (peak-to-peak) your circuit can accommodate? Define the swing limit as the voltage that causes a total harmonic distortion in excess of 1%. Use HSpice to find the answer and analyze the circuit both with and without a body effect.

SPICE BSIM3 VERSION 3.1 PARAMETERS

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.MODEL nfet NMOS (                                LEVEL   = 49
+VERSION = 3.1           TNOM    = 27             TOX     = 1.39E-8
+XJ      = 1.5E-7        NCH     = 1.7E17         VTH0    = 0.6398186
+K1      = 0.8857752     K2      = -0.0935679     K3      = 22.1010569
+K3B     = -7.6711263    W0      = 1E-8           NLX     = 1E-9
+DVT0W   = 0             DVT1W   = 0              DVT2W   = 0
+DVT0    = 2.7950058     DVT1    = 0.4085592      DVT2    = -0.1237812
+U0      = 453.2010286   UA      = 2.494433E-13   UB      = 1.488658E-18
+UC      = 2.022743E-11  VSAT    = 1.730467E5     A0      = 0.5543744
+AGS     = 0.1151449     B0      = 2.792031E-6    B1      = 5E-6
+KETA    = -1.371458E-3  A1      = 0              A2      = 0.3560219
+RDSW    = 1.319508E3    PRWG    = 0.0381943      PRWB    = 0.0141195
+WR      = 1             WINT    = 2.507126E-7    LINT    = 2.304464E-8
+XL      = 0             XW      = 0              DWG     =-1.755808E-8
+DWB     = 4.946821E-8   VOFF    = 0              NFACTOR = 0.7910748
+CIT     = 0             CDSC    = 2.4E-4         CDSCD   = 0
+CDSCB   = 0             ETA0    = 0.0051332      ETAB    = -1.252309E-3
+DSUB    = 0.1945608     PCLM    = 2.253484       PDIBLC1 = -1
+PDIBLC2 = 2.440187E-3   PDIBLCB = -0.1294159     DROUT   = 0.6751288
+PSCBE1  = 5.348212E8    PSCBE2  = 3.233314E-5    PVAG    = 0
+DELTA   = 0.01          RSH     = 80.3           MOBMOD  = 1
+PRT     = 0             UTE     = -1.5           KT1     = -0.11
+KT1L    = 0             KT2     = 0.022          UA1     = 4.31E-9
+UB1     = -7.61E-18     UC1     = -5.6E-11       AT      = 3.3E4
+WL      = 0             WLN     = 1              WW      = 0
+WWN     = 1             WWL     = 0              LL      = 0
+LLN     = 1             LW      = 0              LWN     = 1
+LWL     = 0             CAPMOD  = 2              XPART   = 0.5
+CGDO    = 2.12E-10      CGSO    = 2.12E-10       CGBO    = 1E-9
+CJ      = 4.279445E-4   PB      = 0.9616445      MJ      = 0.4374524
+CJSW    = 3.492439E-10  PBSW    = 0.1            MJSW    = 0.1245165
+CJSWG   = 1.64E-10      PBSWG   = 0.1            MJSWG   = 0.1245165
+CF      = 0             PVTH0   = 0.0431719      PRDSW   = -30.376525
+PK2     = -0.0350028    WKETA   = -0.0230093     LKETA   = 2.090253E-3)
*
.MODEL pfet PMOS (                                LEVEL   = 49
+VERSION = 3.1           TNOM    = 27             TOX     = 1.39E-8
+XJ      = 1.5E-7        NCH     = 1.7E17         VTH0    = -0.9488171
+K1      = 0.5429357     K2      = 9.433657E-3    K3      = 3.2656684
+K3B     = -0.8567156    W0      = 1E-8           NLX     = 1.48542E-8
+DVT0W   = 0             DVT1W   = 0              DVT2W   = 0
+DVT0    = 2.530444      DVT1    = 0.5291909      DVT2    = -0.1040273
+U0      = 220.9301068   UA      = 3.049951E-9    UB      = 1E-21
+UC      = -5.63429E-11  VSAT    = 2E5            A0      = 0.9085767
+AGS     = 0.1506017     B0      = 9.121548E-7    B1      = 5E-6
+KETA    = -2.819843E-3  A1      = 0              A2      = 0.3
+RDSW    = 3E3           PRWG    = -0.0464229     PRWB    = -0.0398483
+WR      = 1             WINT    = 2.90101E-7     LINT    = 4.254314E-8
+XL      = 0             XW      = 0              DWG     = -2.169468E-8
+DWB     = 1.788287E-8   VOFF    = -0.0659109     NFACTOR = 0.8188201
+CIT     = 0             CDSC    = 2.4E-4         CDSCD   = 0
+CDSCB   = 0             ETA0    = 1.380153E-3    ETAB    = -0.0429727
+DSUB    = 0.7658995     PCLM    = 2.0797597      PDIBLC1 = 0.1113965
+PDIBLC2 = 4.521707E-3   PDIBLCB = -0.0437905     DROUT   = 0.3065171
+PSCBE1  = 1.25116E10    PSCBE2  = 1.227353E-9    PVAG    = 8.477076E-6
+DELTA   = 0.01          RSH     = 104.9          MOBMOD  = 1
+PRT     = 0             UTE     = -1.5           KT1     = -0.11
+KT1L    = 0             KT2     = 0.022          UA1     = 4.31E-9
+UB1     = -7.61E-18     UC1     = -5.6E-11       AT      = 3.3E4
+WL      = 0             WLN     = 1              WW      = 0
+WWN     = 1             WWL     = 0              LL      = 0
+LLN     = 1             LW      = 0              LWN     = 1
+LWL     = 0             CAPMOD  = 2              XPART   = 0.5
+CGDO    = 2.25E-10      CGSO    = 2.25E-10       CGBO    = 1E-9
+CJ      = 7.308538E-4   PB      = 0.9416073      MJ      = 0.4948413
+CJSW    = 2.852637E-10  PBSW    = 0.99           MJSW    = 0.3001719
+CJSWG   = 6.4E-11       PBSWG   = 0.99           MJSWG   = 0.3001719
+CF      = 0             PVTH0   = 5.98016E-3     PRDSW   = 14.8598424
+PK2     = 3.73981E-3    WKETA   = 4.127712E-3    LKETA   = -2.567864E-3)
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