Solutions Manual

# DIGITAL INTEGRATED CIRCUITS

Thomas A. DeMassa
Zack Ciccone

SOLUTIONS MANUAL TO ACCOMPANY

# Digital Integrated Circuits

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Section entitled "90 Minutes to SPICE" can be found at the end of this book.



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# EEE425/591 ASU COURSE OUTLINE

**EEE 425 is a 4 credit hour undergraduate course with a lab**
**EEE 591 is a 3 credit hour graduate course without a lab**

# DIGITAL INTEGRATED CIRCUITS AND SYSTEMS

NUMBER OF LECTURE HOURS: 30 LECTURES
CLASS MEETINGS: twice a week for 15 weeks
SESSION LENGTH: 1hr and 15 minutes

PREREQUISITES: COURSE(S) IN ELECTRONIC CIRCUITS AND DIGITAL LOGIC

TEXTBOOK: "DIGITAL INTEGRATED CIRCUITS" T.A.DEMASSA, Z.CICCONE
John Wiley & Sons, November 1995

COURSE OBJECTIVES: TO PROVIDE EXTENSIVE KNOWLEDGE OF THE OPERATION AND DESIGN OF DIGITAL ICs INCLUDING TTL, ECL, NMOS, AND CMOS TECHNOLOGIES WITH EMPHASIS ON CMOS; TO INTRODUCE BiCMOS AND TO PROVIDE AN EXTENSIVE DESCRIPTION OF THE OPERATION AND DESIGN OF GaAs DIGITAL LOGIC FAMILIES; TO PROVIDE COMPUTATIONAL AND SPICE COMPARISONS REGARDING THE VOLTAGE TRANSFER CHARACTERISTIC, FAN-OUT, POWER DISSIPATION AND SPEED OF EACH; TO PROVIDE A DESCRIPTION OF RANDOM ACCESS MEMORY (RAM) AND READ-ONLY MEMORY(ROM).

COURSE DESCIPTION: DIGITAL INTEGRATED CIRCUITS WITH EMPHASIS ON CMOS. OPERATION AND DESIGN OF TTL, ECL, NMOS, CMOS AND GaAs DIGITAL LOGIC CIRCUITS. ADDITIONAL TOPICS INCLUDE BiCMOS AND SEMICONDUCTOR MEMORY CIRCUITS.

500 LEVEL MEZZANINE COURSE AVAILABLE FOR GRADUATE CREDIT AT ASU

COURSE REQUIREMENTS:
HOMEWORK: 3 HOMEWORK SETS
EXAMINATIONS: 2 EXAMS AND A FINAL EXAM

| | | | | | |
|---|---|---|---|---|---|
| GRADING: | 3 EXAMS (1hr and 15 min) | 60% | OR | 3 EXAMS | 50% |
| | FINAL EXAM | 30% | | FINAL EXAM | 25% |
| | HOMEWORK | 10% | | HOMEWORK | 10% |
| | | | | LAB | 15% |

## COURSE OUTLINE BY TOPICAL AREAS AND CHAPTERS

LECTURE 1: HMWORK PROBLs ASSIGNED(HPA):1.1,4,7,10,22,25
PROPERTIES OF DIGITAL CIRCUITS: inverting and noninverting gates, ideal logic elements, voltage transfer characteristic(VTC), logic swing, transition width, noise, fan-in, fan-out, transient characteristics, power dissipation, power-delay product

LECTURE 2: HPA:2.1,5,9,10,16,19; 3.1,2,6,9,11,14
DIODES: PN junction and MN Schottky, modeling, capacitance, SPICE model, diode-resistor logic, level-shifting and clamping diodes
BIPOLAR JUNCTION TRANSISTORS (BJTs): junction isolated and oxide isolated NPNs, multi-emitter, Schottky-clamped,lateral PNP,Ebers-Moll model, Gummel-Poon model, modes of operation, SPICE model, IC resistors and diodes

LECTURE 3: HPA: 4.1,4,8,12,17,23; 5.1,6,11,23,27
INTRODUCTION TO BJT DIGITAL CIRCUITS: analysis, BJT inverter,power dissipation
RESISTOR-TRANSISTOR LOGIC (RTL): inverter and noninverter, NOR gate, NAND gate, fan-out, power dissipation, active pull-up SPICE simulation, DCTL and current hogging

LECTURE 4: HPA: 6.1,3,7,22,24,27
DIODE TRANSISTOR LOGIC (DTL): inverter, modified DTL, BJT modified, NAND gate, fan-out, power dissipation, SPICE simulation

LECTURE 5: HPA: 7.1,3,6,10,14,18,21
TRANSISTOR-TRANSISTOR LOGIC (TTL):inverter, charge removal, NAND gate, totem pole output, VTC, fanout, power dissipation, open collector, low power, high speed, SPICE simulation

LECTURE 6,7: HPA: 8.1,3,6,9,15,20,25; 9.1,5,13,15
SCHOTTKY TRANSISTOR-TRANSISTOR LOGIC (STTL): Schottky diodes, Schottky BJTs, STTL inverter, NAND gate, VTC, fan-out, power dissipation, low power LSTTL, SPICE simulation

LECTURE 8: HPA: 10.2,3,16,24
OTHER TTL GATES: AND gates, NOR gates, OR gates, AOI gates, XOR gates, Schmitt inverters and NAND gates, tri-state buffers

LECTURE 9: HPA: 11.1,6,8,14,19; 12.1,4,7,10
EMITTER-COUPLED LOGIC (ECL): BJT current switch, VTC, NOR/OR gate, output buffers, MECL I, fan-out, power dissipation, SPICE simulation. TEMPERATURE COMPENSATING ECL: MECL II, bias network, fan-out, power dissipation, SPICE simulation

LECTURE 10: HPA: 13.1,3,10,14; 14.1,5,8,10
MORE ECL: MECL III, ECL 10K, ECL100K, power dissipation, SPICE simulation

LECTURE 11: HPA: 15.2,3,5,6
OTHER ECL GATES: NOR/OR gates, collector dotting, series gating, NAND/AND gates, OR-AND gates, XNOR/XOR gates Schmitt triggers

SESSION 12: **REVIEW AND PROBLEM SESSION**

SESSION 13: **EXAM 1**

SESSION 14: **EXAM 1 REVIEW AND INTRODUCTION TO MOSFETs**

LECTURE 15: HPA:16.2,6,11,12;17.2,9,13,20;18.1,2,3,10
MOSFETs: metal gate, silicon gate, N- & P-channel, modes of operation, transconductance parameter, threshold voltage,capacitance, SPICE model, CMOS devices, IC caps, stacked MOSFETs
RESISTOR LOADED NMOS INVERTER: operation, graphical determination of VTC, calculation of critical voltages, power dissipation, SPICE simulation

LECTURE 16,17: 19.1,2,3,17; 20.1; 21.1,2,3,11
SATURATED ENHANCEMENT-ONLY LOADED NMOS INVERTER: same as R-loaded
LINEAR E-O LOADED NMOS INVERTER: same as R-loaded
ENHANCEMENT-DEPLETION LOADED NMOS INVERTER: same as R-loaded

LECTURE 18: HPA: 22.2,3,5,9,15,31,38,40,43,50
NMOS GATES: NOR, NAND, OR, AND, AOIs, OIAs, XOR/XNOR, transmission gates, Schmitt inverter

LECTURE 19,20: HPA: 23.1,2,3,4
CMOS INVERTER: operation, power dissipation, graphical determination of VTC, calculation of critical voltages, design of symmetric inverter or minimum size, inverter capacitance, dynamic response, SPICE simulation, latch-up, input clamping

LECTURE 21: HPA: 24.1,2,3,4,7,12,13,21,31,34,35
CMOS LOGIC GATES: NAND, NOR, AND, OR, AOI, OAI, XNOR/XOR

**LECTURE 22 REVIEW FOR EXAM 2**

**LECTURE 23 EXAM 2**

LECTURE 24: HPA: 25.1,2,4,7,11
CMOS TRI-STATE LOGIC GATES: high impedance Z-states, contention X-states, tri-state inverters, applications, transmission gates

LECT 25: HPA: 26.1,3,8,10,13,15; 27.1,3,5,7;28.2,4,8,16,19
CMOS SCHMITT TRIGGER GATES: inverter, operation and VTC, design, buffered, output, feedback, NAND gate. CMOS DRIVERS: cascaded inverters driving a load cap, multi-stage inverter driver, tri-state pad drivers, break-before-make circuit; DYNAMIC CMOS

LECTURE 26: HPA: 34.3,6,7,10; 35.2,5,7,10; 36.2,3,4,6
GaAs METAL SEMICONDUCTOR FETs (MESFETs): N-channel, E-D, E-O, modes of operation, transconductance parameter, threshold voltage, capacitance, SPICE simulation
DIRECT COUPLED NMESFET INVERTER (DCFL): E-O inverter, operation, graphical determination of VTC, calculation of critical voltages, power dissipation, fan-out, SPICE simulation SCHOTTKY DIODE NMESFET LOGIC (SDFL) INVERTER: E-D inverters,operation, calculation of critical voltages, power dissipation, fan-out, SPICE simulation.BUFFERED NMESFET LOGIC (BFL) INVERTER: same as SDFL inverter.

LECTURE 27: HPA: 37.1,2,3,4;38.1,2,3,9
GaAs LOGIC FAMILY GATES: DCFL NOR, NAND and OR GATES, SDFL NOR and NAND gates, BFL NOR and NAND gates, complex AOI & OIA gates, DCFL XOR, other OR/NOR gates

LECTURE 28/29: HPA: 32&33 All odd problems
SEMICONDUCTOR READ ONLY AND STATIC RANDOM ACCESS MEMORIES

**LECTURE 30 EXAM 3**

**FINAL EXAM TO BE ANNOUNCED**

# CHAPTER 1 SOLUTIONS

1.1 (a) $V_{OH} = 3V$, $V_{OL} = 0.2V$, $V_{IL} = 0.7V$, $V_{IH} = 0.8V$, $V_M = 0.78V$

(b) $V_{LS} = V_{OH} - V_{OL} = 3 - 0.2 = 2.8V$

(c) $V_{TW} = V_{IH} - V_{IL} = 0.8 - 0.7 = 0.1V$

(d) $V_{NMH} = V_{OH} - V_{IH} = 3 - 0.8 = 2.2V$

$V_{NML} = V_{IL} - V_{OL} = 0.7 - 0.2 = 0.5V$

$V_{NSH} = V_{OH} - V_M = 3 - 0.75 = 2.25V$

$V_{NSL} = V_M - V_{OL} = 0.75 - 0.2 = 0.55V$

$V_{NIH} = V_{NSH}/V_{LS} = 2.25/2.8 = 0.8V$

$V_{NIL} = V_{NSL}/V_{LS} = 0.55/2.8 = 0.2V$

1.2 (a) $V_{OH} = 5V$, $V_{OL} = 0.4V$, $V_{IL} = 1.2V$, $V_{IH} = 1.4V$, $V_M = 1.36V$

(b) $V_{LS} = V_{OH} - V_{OL} = 5 - 0.4 = 4.6V$

(c) $V_{TW} = V_{IH} - V_{IL} = 1.4 - 1.2 = 0.2V$

(d) $V_{NMH} = V_{OH} - V_{IH} = 5 - 1.4 = 3.6V$

$V_{NML} = V_{IL} - V_{OL} = 1.2 - 0.4 = 0.8V$

$V_{NSH} = V_{OH} - V_M = 5 - 1.36 = 3.64V$

$V_{NSL} = V_M - V_{OL} = 1.36 - 0.4 = 0.96V$

$V_{NIH} = V_{NSH}/V_{LS} = 3.64/4.6 = 0.79V$

$V_{NIL} = V_{NSL}/V_{LS} = 0.96/4.6 = 0.21V$

1.3 (a) $V_{OH} = -0.8V$, $V_{OL} = -1.6V$, $V_{IL} = -1.2V$, $V_{IH} = -1V$, $V_M = -1.12V$

(b) $V_{LS} = V_{OH} - V_{OL} = -0.8 - (-1.6) = 0.8V$

(c) $V_{TW} = V_{IH} - V_{IL} = -1 - (-1.2) = 0.2V$

(d) $V_{NMH} = V_{OH} - V_{IH} = -0.8 - (-1) = 0.2V$

$V_{NML} = V_{IL} - V_{OL} = -1.2 - (-1.6) = 0.4V$

$V_{NSH} = V_{OH} - V_M = -0.8 - (-1.12) = 0.32V$

$V_{NSL} = V_M - V_{OL} = -1.12 - (-1.6) = 0.48V$

1.3 (cont'd)

$V_{NIH} = V_{NSH} / V_{LS} = 0.32/0.8 = 0.4V$

$V_{NIL} = V_{NSL} / V_{LS} = 0.48/0.8 = 0.6V$

1.4

(a) $V_{OH} = 4.3V$ $V_{OL} = 0.2V$ $V_{IL} = 1.9V$ $V_{IH} = 2.1V$ $V_{M} = 1.99V$

(b) $V_{LS} = V_{OH} - V_{OL} = 4.3 - 0.2 = 4.1V$

(c) $V_{TW} = V_{IH} - V_{IL} = 2.1 - 1.9 = 0.2V$

(d) $V_{NMH} = V_{OH} - V_{IH} = 4.3 - 2.1 = 2.2V$

$V_{NML} = V_{IL} - V_{OL} = 1.9 - 0.2 = 1.7V$

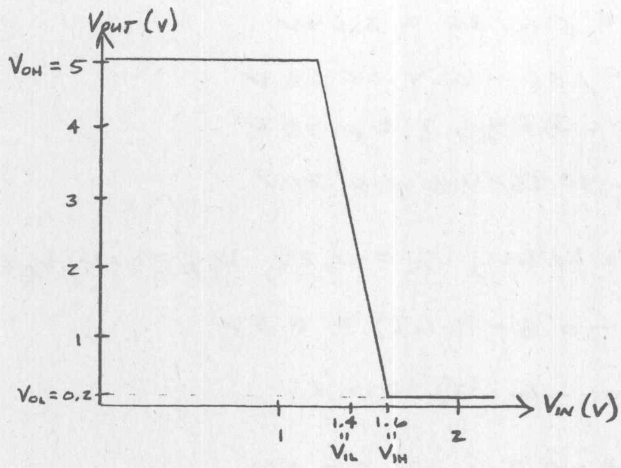
$V_{NSH} = V_{OH} - V_{M} = 4.3 - 1.99 = 2.31V$

$V_{NSL} = V_{M} - V_{OL} = 1.99 - 0.2 = 1.79V$

$V_{NIH} = V_{NSH} / V_{LS} = 2.31/4.1 = 0.56V$

$V_{NIL} = V_{NSL} / V_{LS} = 1.79/4.1 = 0.44V$

1.5



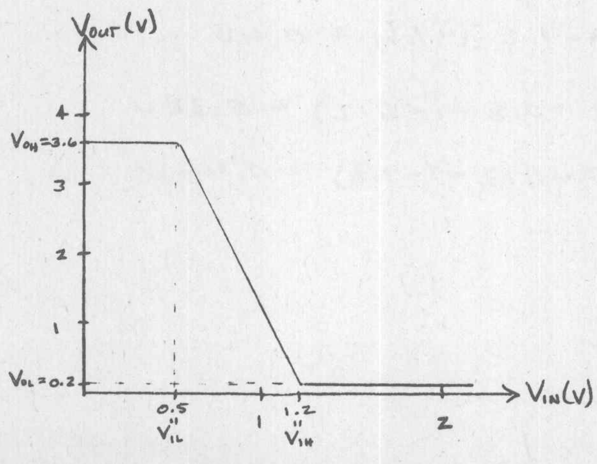

$V_{LS} = V_{OH} - V_{OL} = 5 - 0.2 = 4.8V$

$V_{TW} = V_{IH} - V_{IL} = 1.6 - 1.4 = 0.2V$

$V_{NMH} = V_{OH} - V_{IH} = 5 - 1.6 = 3.4V$

$V_{NML} = V_{IL} - V_{OL} = 1.4 - 0.2 = 1.2V$

1.6



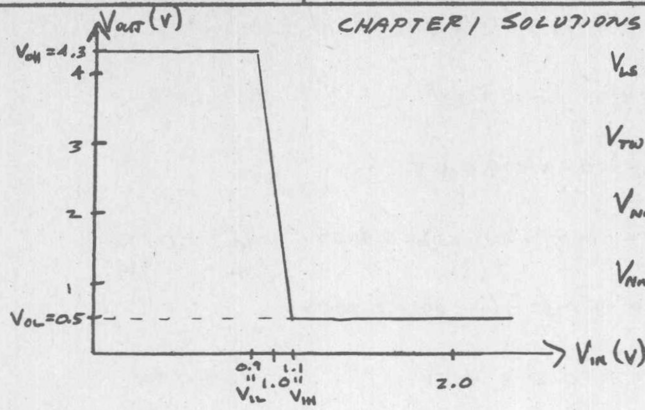

$V_{LS} = V_{OH} - V_{OL} = 3.6 - 0.2 = 3.4V$

$V_{TW} = V_{IH} - V_{IL} = 1.2 - 0.5 = 0.7V$

$V_{NMH} = V_{OH} - V_{IH} = 3.6 - 1.2 = 2.4V$

$V_{NML} = V_{IL} - V_{OL} = 0.5 - 0.2 = 0.3V$

1.7



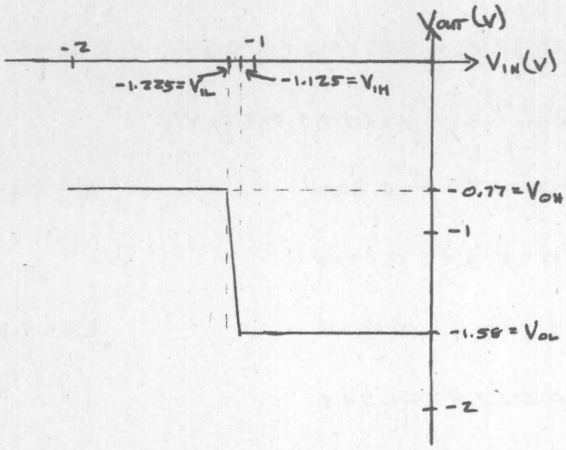

$V_{LS} = V_{OH} - V_{OL} = 4.3 - 0.5 = 3.8V$

$V_{TW} = V_{IH} - V_{IL} = 1.1 - 0.9 = 0.2V$

$V_{NMH} = V_{OH} - V_{IH} = 4.3 - 1.1 = 3.2V$

$V_{NML} = V_{IL} - V_{OL} = 0.9 - 0.5 = 0.4V$

1.8



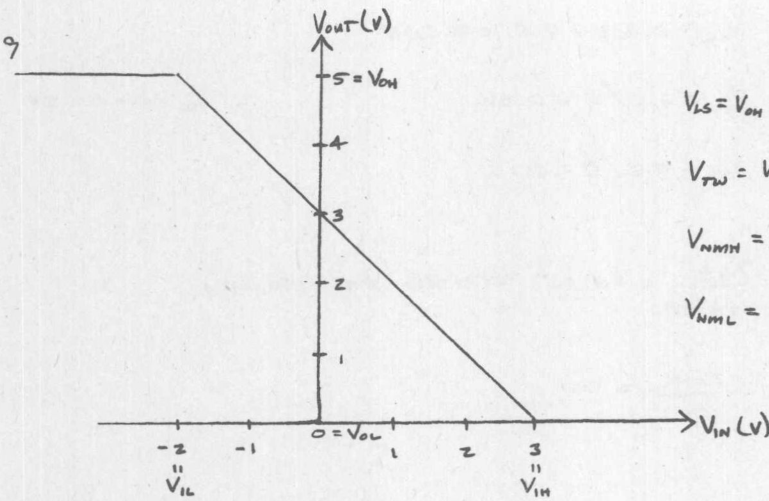

$V_{LS} = V_{OH} - V_{OL} = -0.77 - (-1.58) = 0.81V$

$V_{TW} = V_{IH} - V_{IL} = -1.125 - (-1.225) = 0.1V$

$V_{NMH} = V_{OH} - V_{IH} = -0.77 - (-1.125) = 0.355V$

$V_{NML} = V_{IL} - V_{OL} = -1.225 - (-1.58) = 0.355V$

1.9




$V_{LS} = V_{OH} - V_{OL} = 5 - 0 = 5V$

$V_{TW} = V_{IH} - V_{IL} = 3 - (-2) = 5V$

$V_{NMH} = V_{OH} - V_{IH} = 5 - 3 = 2V$

$V_{NML} = V_{IL} - V_{OL} = -2 - 0 = -2V$

1.10

a) PROBLEM 1.5 $V_{NSH} = V_{OH} - V_m = 5 - 1.5 = 3.5V$ $V_m = 1.5V$

$V_{NSL} = V_m - V_{OL} = 1.5 - 0.2 = 1.3V$

PROBLEM 1.6 $V_{NSH} = 3.6 - 0.85 = 2.75V$ $V_m = 0.85$

$V_{NSL} = 0.85 - 0.2 = 0.65V$

PROBLEM 1.7 $V_{NSH} = 4.3 - 1.0 = 3.3V$ $V_m = 1.0V$

$V_{NSL} = 1.0 - 0.5 = 0.5V$

PROBLEM 1.8 $V_{NSH} = -0.77 - (-1.175) = 0.405V$ $V_m = -1.175$

$V_{NSL} = -1.175 - (-1.58) = 0.405V$

PROBLEM 1.9 $V_{NSH} = 5 - 0.5 = 4.5V$ $V_m = 0.5V$

$V_{NSL} = 0.5 - 0 = 0.5V$

(b) PROBLEM 1.5 $V_{NIH} = V_{NSH} / V_{LS} = 3.5 / 4.8 = 0.729V$ $V_{LS} = 5 - 0.2 = 4.8V$

$V_{NIL} = V_{NSL} / V_{LS} = 1.3 / 4.8 = 0.271V$

PROBLEM 1.6 $V_{NIH} = 2.75 / 3.4 = 0.809V$ $V_{LS} = 3.6 - 0.2 = 3.4V$

$V_{NIL} = 0.65 / 3.4 = 0.191V$

PROBLEM 1.7 $V_{NIH} = 3.3 / 3.8 = 0.868V$ $V_{LS} = 4.3 - 0.5 = 3.8V$

$V_{NIL} = 0.5 / 3.8 = 0.132V$

PROBLEM 1.8 $V_{NIH} = 0.405 / 0.81 = 0.50V$ $V_{LS} = -0.77 - (-1.58) = 0.81V$

$V_{NIL} = 0.405 / 0.81 = 0.50V$

PROBLEM 1.9 $V_{NIH} = 4.5 / 5 = 0.9V$ $V_{LS} = 5 - 0 = 5V$

$V_{NIL} = 0.5 / 5 = 0.1V$

1.11

$$N_{LOW} = \frac{I_{OUT}(LOW)}{I_{IN}(LOW)} = \frac{7mA}{124\mu A} = 56.45 \Rightarrow 56 \text{ (MAX. FAN OUT)}$$

$$N_{HIGH} = \frac{I_{OUT}(HIGH)}{I_{IN}(HIGH)} = \frac{12mA}{0} = \infty$$

1.12

$$N_{LOW} = \frac{6.2mA}{0} = \infty$$

$$N_{HIGH} = \frac{4mA}{240\mu A} = 16.67 \Rightarrow 16 \text{ (MAX. FAN OUT)}$$

1.13 $N_{LOW} = \frac{57.5mA}{1.09mA} = 52.75 \Rightarrow 52$ (MAX. FAN OUT)

$N_{HIGH} = \infty$

1.14 $N_{LOW} = \frac{79.3mA}{1mA} = 79.3 \Rightarrow 79$ (MAX. FAN OUT)

$N_{HIGH} = \infty$

1.15 $N_{LOW} = \frac{199mA}{1.32mA} = 150.76 \Rightarrow 150$ (MAX FAN OUT)

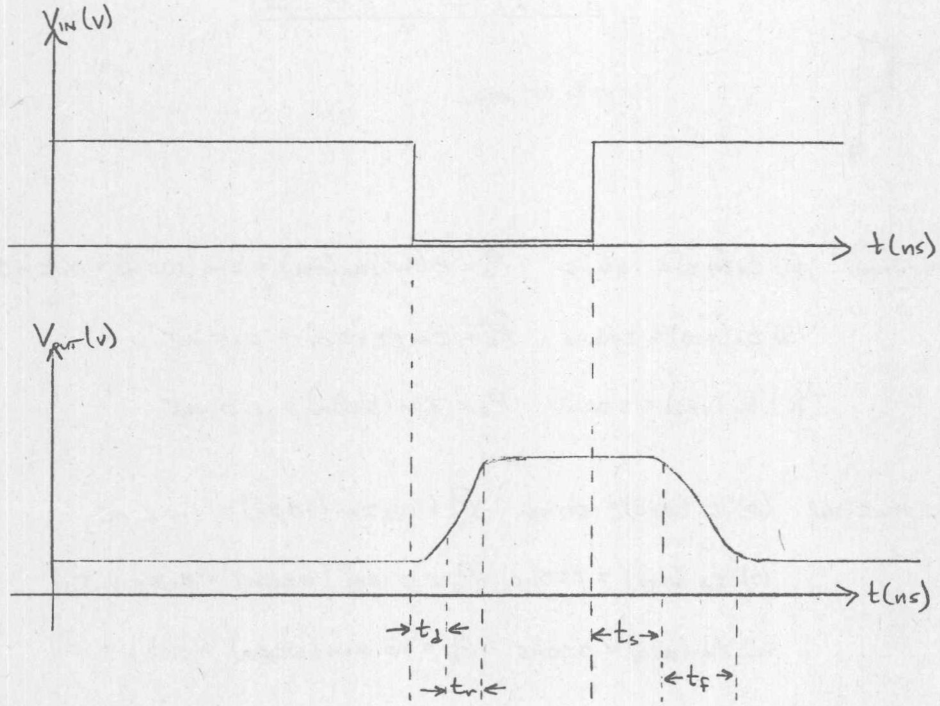
$N_{HIGH} = \infty$

1.16 YES ! $I_{OL}$ AND $I_{IL}$ ARE BOTH IN. THIS IS PHYSICALLY IMPOSSIBLE.

1.17 $t_d \approx 20s$ $t_s \approx 20s$ $t_r \approx t_f \approx 15s$ $t_{PHL} \approx t_{PLH} \approx 27.5\mu s$ $t_p(AVG) = 27.5\mu s$

1.18 $t_d \approx 20s$ $t_s \approx 20s$ $t_r \approx 40s$ $t_f \approx 20s$ $t_{PHL} \approx t_{PLH} \approx 27.5\mu s$ $t_p(AVG) = 27.5\mu s$

1.19




WHERE, $t_r = 10ns$ AND $t_f = 30ns$

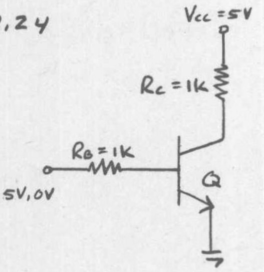
1.20 SAME SKETCH AS #19, BUT WITH $t_r = 5ns$ AND $t_f = 7ns$.

1.21 SAME SKETCH AS #19, BUT WITH $t_r = 2ns$ AND $t_f = 3ns$.

1.22 $P_{cc}(AVG) = \frac{I_{cc}(OH) + I_{cc}(OL)}{2} V_{cc} = \frac{(4.2m + 1.7m)}{2}(5) = 14.75 mW$

1.23 $P_{cc}(AVG) = \frac{(0.52m + 42\mu)}{2}(5) = 1.41 mW$

1.24




$$P_{SUPPLIED} = \frac{P_{DISS} \text{ FOR Q CUTOFF} + P_{DISS} \text{ FOR Q SAT}}{2}$$

$$= \frac{0 + 5\left(\frac{5-0.7}{1}\right) - 5\left(\frac{5-0.2}{1}\right)}{2}$$

$$= 22.75 \text{ mW}$$

1.25 $P(AVG) = 2mW$

(a) $t_p(AVG) = 100ns$ $P_D = P(AVG)t_p(AVG) = 2m(100n) = 0.2 nJ$

(b) $t_p(AVG) = 250ns$ $P_D = 2m(250n) = 0.5 nJ$

(c) $t_p(AVG) = 500ns$ $P_D = 2m(500n) = 1.0 nJ$

1.26

$P(AVG) = 10.2mW$

(a) $t_p(AVG) = 100ns$ $P_D = 10.2m(100n) = 1.02 nJ$

(b) $t_p(AVG) = 250ns$ $P_D = 10.2m(250n) = 2.55 nJ$

(c) $t_p(AVG) = 500ns$ $P_D = 10.2m(500n) = 5.1 nJ$

# CHAPTER 2 SOLUTIONS

2.1 SEE FIGURE 2.2 (a)

2.2 SEE FIGURE 2.2 (b)

2.3 THE TYPE OF METAL MOST OFTEN USED IN SCHOTTKY MN SILICON DIODES IS PLATINUM SILICIDE ($Pt_5 Si_2$) WHICH PROVIDES A BARRIER TO ELECTRON FLOW IN ONE DIRECTION.

THIS IS ACCOMPLISHED THROUGH THE DEPOSITION OF Pt ON Si AND HEATING (ANNEALING) AT 600°C TO FORM $Pt_5 Si_2$.

2.4 $I_D = 1mA$ $V_D = 0.7V$ $\phi_T = 25.9\,mV$ (AT ROOM TEMP.)

$$I_D = I_S\left(e^{V_D/\phi_T} - 1\right)$$

$$I_S = \frac{I_D}{e^{V_D/\phi_T} - 1} = \frac{1m}{e^{0.7/25.9m} - 1} = 1.83 \times 10^{-15}\ A$$

2.5 AT ROOM TEMP.:

$$V_1 \rightarrow I_1$$

$$V_2 \rightarrow 10 I_2$$

$$I_1 = 10 I_2$$

$$\frac{I_1}{I_2} = 10 = \frac{e^{40v_1}}{e^{40v_2}} = e^{40(v_1 - v_2)}$$

$$\ln 10 = \ln e^{40(v_1 - v_2)}$$

$$\ln 10 = 40(v_1 - v_2)$$

$$(v_1 - v_2) = 0.06V$$

2.6

(a) $I_{D1} = I_{S1}\left(e^{V_{D1}/\phi_T} - 1\right)$

$$I_{D2} = I_{S2}\left(e^{V_{D2}/\phi_T} - 1\right)$$

$$V_{D1} + V_{D2} = 1$$

$$V_{D1} = 1 - V_{D2}$$

$I_{D1} = I_{D2}$ (SERIES CIRCUIT)

$$I_{S1}\left(e^{V_{D1}/\phi_T}-1\right)=I_{S2}\left(e^{V_{D2}/\phi_T}-1\right)$$

$$I_{S1}\left(e^{(1-V_{D2})/\phi_T}-1\right)=I_{S2}\left(e^{V_{D2}/\phi_T}-1\right)$$

1 IS NEGLIGIBLE:

$$\frac{I_{S1}}{I_{S2}}=\frac{e^{V_{D2}/\phi_T}}{e^{(1-V_{D2})/\phi_T}-1}=e^{\frac{1}{\phi_T}(2V_{D2}-1)}$$

$$\ln\left(\frac{I_{S1}}{I_{S2}}\right)=\frac{1}{\phi_T}(2V_{D2}-1)$$

$$1+\phi_T\ln\left(\frac{I_{S1}}{I_{S2}}\right)=2V_{D2}$$

$$\frac{1}{2}\left(1+\phi_T\ln\left(\frac{I_{S1}}{I_{S2}}\right)\right)=V_{D2}=0.44V$$

$$V_{D1}=1-V_{D2}=1-0.44=0.56V$$

SUBSTITUTE VALUES INTO $I_{D1}$ OR $I_{D2}$:

$$I_{D1}=I_{S1}\left(e^{V_{D1}/\phi_T}-1\right)=10^{-14}\left(e^{0.56/0.0259}-1\right)=0.02\,mA$$

(b) $I_{D1}=I_{S1}\left(e^{V_D/\phi_T}-1\right)$

$$I_{D2}=I_{S2}\left(e^{V_D/\phi_T}-1\right)$$

$I_{D1}+I_{D2}=1mA$ $\quad V_{D1}=V_{D2}$ (PARALLEL CIRCUIT)

$$I_{D2}=(1\times10^{-3})-I_{D1}$$

$$\frac{I_{D1}}{I_{S1}}=\frac{I_{D2}}{I_{S2}}$$

$$\frac{I_{D1}}{I_{S1}}=\frac{(1\times10^{-3})-I_{D1}}{I_{S2}}$$

$$I_{D1}+\frac{I_{S2}}{I_{S1}}I_{D1}=1\times10^{-3}$$

$$I_{D1}=\frac{1\times10^{-3}}{(1+I_{S2}/I_{S1})}=\frac{1\times10^{-3}}{(1+10^{-12}/10^{-14})}=0.01mA$$

$$I_{D2}=(1\times10^{-3})-(0.01\times10^{-3})=0.99mA$$

SUBSTITUTE CURRENT VALUES INTO EITHER EQUATION:

$$V_D=\ln\left(\frac{I_{D1}}{I_{S1}}+1\right)\phi_T=\ln\left(\frac{0.01\times10^{-3}}{1\times10^{-14}}+1\right)0.0259=0.54V$$

2.7 (a) $I_D = I_S\left(e^{v_d/\phi_T} - 1\right)$

$$I_S = \frac{I_D}{e^{v_d/\phi_T} - 1} = \frac{1m}{e^{0.3/25.9m} - 1} = 9.32\ nA \text{ (AT ROOM TEMP.)}$$

(b) $I_D = I_S\left(e^{v_d/\phi_T} - 1\right) = 10^{-14}\left(e^{0.3/25.9m} - 1\right) = 1.07\ nA$ (AT ROOM TEMP.)

2.8 $I_D = I_S\left(e^{v_d/\phi_T} - 1\right)$, USE $I_S = 10nA$, $\phi_T = 25.9mA$ AT ROOM TEMP.

$$I_D(V_D = 0.1) = 10n\left(e^{0.1/25.9m} - 1\right) = 0.465\ \mu A$$

$$I_D(V_D = 0.2) = 10n\left(e^{0.2/25.9m} - 1\right) = 0.02\ mA$$

$$I_D(V_D = 0.5) = 10n\left(e^{0.5/25.9m} - 1\right) = 2.42\ A$$

$$I_D(V_D = 0.7) = 10n\left(e^{0.7/25.9m} - 1\right) = 5.466\ kA$$

$$I_D(V_D = 0.8) = 10n\left(e^{0.8/25.9m} - 1\right) = 259.7\ kA$$

$$I_D(V_D = 1) = 10n\left(e^{1/25.9m} - 1\right) = 586.3\ MA$$

$$I_D(V_D = 2) = 10n\left(e^{2/25.9m} - 1\right) = 3.44 \times 10^{25}\ A$$

2.9 $I_D = I_S\left(e^{v_d/\phi_T} - 1\right)$, USE $\phi_T = 0.0259V$ AND $I_S = 10^{-14}A$

$$I_D(V_D = 0.1) = 10^{-14}\left(e^{0.1/0.0259} - 1\right) = 465\ fA$$

$$I_D(V_D = 0.2) = 10^{-14}\left(e^{0.2/0.0259} - 1\right) = 22.6\ pA$$

$$I_D(V_D = 0.5) = 10^{-14}\left(e^{0.5/0.0259} - 1\right) = 2.42\ \mu A$$

$$I_D(V_D = 0.7) = 10^{-14}\left(e^{0.7/0.0259} - 1\right) = 5.47\ mA$$

$$I_D(V_D = 0.8) = 10^{-14}\left(e^{0.8/0.0259} - 1\right) = 259.7\ mA$$

$$I_D(V_D = 1.0) = 10^{-14}\left(e^{1/0.0259} - 1\right) = 586.3\ A$$

2.10

$I_D = I_S\left(e^{v_d/\phi_T} - 1\right)$, USE $\phi_T = 0.0259V$ AND $I_S = 10^{-14}A$

$$I_D(V_D = -1m) = 10^{-14}\left(e^{-1m/0.0259} - 1\right) = -0.379\ fA$$

$$I_D(V_D = -2m) = 10^{-14}\left(e^{-2m/0.0259} - 1\right) = -0.743\ fA$$

$$I_D(V_D = -10m) = 10^{-14}\left(e^{-10m/0.0259} - 1\right) = -3.20\ fA$$

$$I_D(V_D = -200m) = 10^{-14}\left(e^{-200m/0.0259} - 1\right) = -9.99\ fA$$

$$I_D(V_D = -500m) = 10^{-14}\left(e^{-500m/0.0259} - 1\right) = -10.0\ fA$$

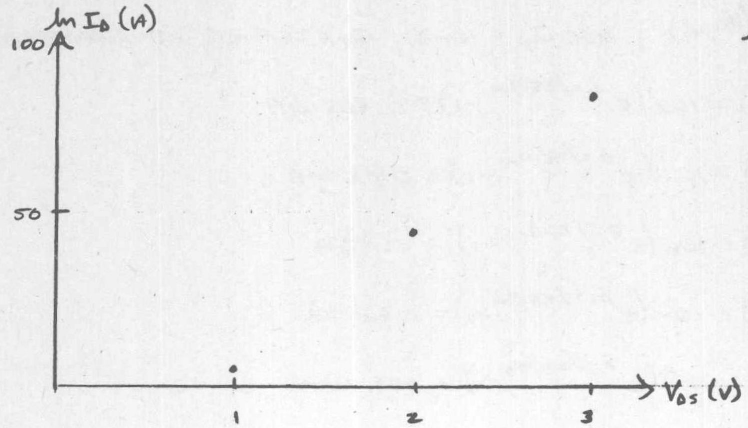
2.11 $I_S = 10^{-14} A \qquad \phi_T = 0.0259 V$

$I_D(V_{DS}=1) = 10^{-14}(e^{1/0.0259} - 1) = 586.3 A \qquad \ln I_D = 6.37 A$

$I_D(V_{DS}=2) = 10^{-14}(e^{2/0.0259} - 1) = 3.44 A \qquad \ln I_D = 44.98 A$

$I_D(V_{DS}=3) = 10^{-14}(e^{3/0.0259} - 1) = 2.02 \times 10^{36} A \qquad \ln I_D = 83.6$

$\ln I_D = \ln I_S + \frac{qV_D}{kT}$ → 0




2.12 $I_D = I_S(e^{v_d/\phi_T} - 1)$, USE $\phi_T = 0.0259 V$ AND $I_S = 10^{-15} A$

PROBLEM 2.9

$I_D(V_D = 0.1) = 10^{-15}(e^{0.1/0.0259} - 1) = 46.5 fA$

$I_D(V_D = 0.2) = 10^{-15}(e^{0.2/0.0259} - 1) = 2.26 pA$

$I_D(V_D = 0.5) = 10^{-15}(e^{0.5/0.0259} - 1) = 0.242 \mu A$

$I_D(V_D = 0.7) = 10^{-15}(e^{0.7/0.0259} - 1) = 0.547 mA$

$I_D(V_D = 0.8) = 10^{-15}(e^{0.8/0.0259} - 1) = 25.97 mA$

$I_D(V_D = 1) = 10^{-15}(e^{1/0.0259} - 1) = 58.63 A$

PROBLEM 2.10

$I_D(V_D = -1m) = 10^{-15}(e^{-1m/0.0259} - 1) = -0.0379 fA$

$I_D(V_D = -2m) = 10^{-15}(e^{-2m/0.0259} - 1) = -0.0743 fA$

$I_D(V_D = -10m) = 10^{-15}(e^{-10m/0.0259} - 1) = 0.32 fA$

$I_D(V_D = -200m) = 10^{-15}(e^{-200m/0.0259} - 1) = -0.999 fA$

$I_D(V_D = -500m) = 10^{-15}(e^{-500m/0.0259} - 1) = -1.0 fA$