

Microelectronic Circuit Design

Fourth Edition - Part II

Solutions to Exercises

CHAPTER 6

Page 292

$$NM_L = 0.8V - 0.4V = 0.4 \text{ V} \quad | \quad NM_H = 3.6V - 2.0V = 1.6 \text{ V}$$

Page 294

$$V_{10\%} = V_L + 0.1(\Delta V) = -2.6V + 0.1[-0.6 - (-2.6)] = -2.4 \text{ V}$$

$$\text{Checking: } V_{10\%} = V_H - 0.9(\Delta V) = -0.6V - 0.9[-0.6 - (-2.6)] = -2.4 \text{ V}$$

$$V_{90\%} = V_H - 0.1(\Delta V) = -0.6V - 0.1[-0.6 - (-2.6)] = -0.8 \text{ V}$$

$$\text{Checking: } V_{90\%} = V_L + 0.9(\Delta V) = -2.6V + 0.9[-0.6 - (-2.6)] = -0.8 \text{ V}$$

$$V_{50\%} = \frac{V_H + V_L}{2} = \frac{-0.6 - 2.6}{2} = -1.6 \text{ V} \quad | \quad t_r = t_4 - t_3 = 3 \text{ ns} \quad | \quad t_f = t_2 - t_1 = 5 \text{ ns}$$

Page 295

$$\text{At } P = 1 \text{ mW: } PDP = 1 \text{ mW}(1 \text{ ns}) = 1 \text{ pJ}$$

$$\text{At } P = 3 \text{ mW: } PDP = 3 \text{ mW}(1 \text{ ns}) = 3 \text{ pJ}$$

$$\text{At } P = 20 \text{ mW: } PDP = 20 \text{ mW}(2 \text{ ns}) = 40 \text{ pJ}$$

Page 297

$$Z = (A + B)(B + C) = AB + AC + BB + BC = AB + BB + AC + BB + BC$$

$$Z = AB + B + AC + B + BC = B(A + 1) + AC + B(C + 1) = B + AC + B$$

$$Z = B + B + AC = B + AC$$

Page 300

$$I_{DD} = \frac{P}{V_{DD}} = \frac{0.4mW}{2.5V} = 160 \mu A \quad | \quad R = \frac{V_{DD} - V_L}{I_{DD}} = \frac{2.5V - 0.2V}{160\mu A} = 14.4 k\Omega$$

$$1.6 \times 10^{-4} A = 10^{-4} \frac{A}{V^2} \left(\frac{W}{L} \right)_S \left(2.5 - 0.6 - \frac{0.2}{2} \right) 0.2 V^2 \rightarrow \left(\frac{W}{L} \right)_S = \frac{4.44}{1}$$

Page 301

$$I_{DD} = \frac{V_{DD} - V_L}{R} = \frac{3.3V - 0.1V}{102k\Omega} = 31.4 \mu A$$

$$31.4 \times 10^{-6} A = 6 \times 10^{-5} \frac{A}{V^2} \left(\frac{W}{L} \right)_S \left(3.3 - 0.75 - \frac{0.1}{2} \right) 0.1 V^2 \rightarrow \left(\frac{W}{L} \right)_S = \frac{2.09}{1}$$

Page 303

$$0.15V = \frac{R_{on}}{R_{on} + 28.8k\Omega} 2.5V \rightarrow R_{on} = 1.84 k\Omega$$

$$\left(\frac{W}{L} \right)_S = \frac{1}{10^{-4} \left(2.5 - 0.60 - \frac{0.15}{2} \right) (1.84k\Omega)} \rightarrow \left(\frac{W}{L} \right)_S = \frac{2.98}{1}$$

$$R_{on} = \frac{1}{6 \times 10^{-5} \left(\frac{1.03}{1} \right) \left(3.3 - 0.75 - \frac{0.2}{2} \right)} = 6.61 k\Omega \quad | \quad V_L = \frac{6.61k\Omega}{6.61k\Omega + 102k\Omega} 3.3V = 0.201 V$$

$$\left[\frac{1}{K_n R} \right] = \frac{V^2}{A} \frac{1}{\Omega} = \frac{V^2}{V} = V$$

Page 305

$$K_n R = \left(6 \times 10^{-5} \right) \left(\frac{1.03}{1} \right) \left(1.02 \times 10^5 \right) = \frac{6.30}{V}$$

$$NM_H = 3.3 - 0.75 + \frac{1}{2(6.30)} - 1.63 \sqrt{\frac{3.3}{6.30}} = 1.45 V \quad NM_L = 0.75 + \frac{1}{6.30} - \sqrt{\frac{2(3.3)}{3(6.30)}} = 0.318 V$$

Page 309

Using MATLAB :

```
fzero(@(vh) ((vh - 1.9 - 0.5 * sqrt(0.6))^2 - 0.25(vh + 0.6)), 1) | ans = 1.5535
```

```
fzero(@(vh) ((vh - 1.9 - 0.5 * sqrt(0.6))^2 - 0.25(vh + 0.6)), 4) | ans = 3.2710
```

$$V_H = 5 - \left[0.75 + 0.5 \left(\sqrt{V_H + 0.6} - \sqrt{0.6} \right) \right] \rightarrow V_H = 3.61 \text{ V}$$

```
fzero(@(vh) (5 - 0.75 - 0.5 * (sqrt(vh + 0.6) - sqrt(0.6)) - vh), 1) | ans = 3.6112
```

$$(a) 80x10^{-6} A = 100x10^{-6} \frac{A}{V^2} \left(\frac{W}{L} \right)_S \left(1.55 - 0.60 - \frac{0.15}{2} \right) 0.15 V^2 \rightarrow \left(\frac{W}{L} \right)_S = \frac{6.10}{1}$$

$$V_{TNL} = 0.6 + 0.5 \left(\sqrt{1.15 + 0.6} - \sqrt{0.6} \right) = 0.646 \text{ V}$$

$$80x10^{-6} A = \frac{100x10^{-6}}{2} \frac{A}{V^2} \left(\frac{W}{L} \right)_L (2.5 - 0.15 - 0.646)^2 V^2 \rightarrow \left(\frac{W}{L} \right)_L = \frac{0.551}{1} = \frac{1}{1.82}$$

$$(b) 80x10^{-6} A = 100x10^{-6} \frac{A}{V^2} \left(\frac{W}{L} \right)_S \left(1.55 - 0.60 - \frac{0.1}{2} \right) 0.1 V^2 \rightarrow \left(\frac{W}{L} \right)_S = \frac{8.89}{1}$$

$$V_{TNL} = 0.6 + 0.5 \left(\sqrt{1.15 + 0.6} - \sqrt{0.6} \right) = 0.631 \text{ V}$$

$$80x10^{-6} A = \frac{100x10^{-6}}{2} \frac{A}{V^2} \left(\frac{W}{L} \right)_L (2.5 - 0.1 - 0.631)^2 V^2 \rightarrow \left(\frac{W}{L} \right)_L = \frac{0.511}{1} = \frac{1}{1.96}$$

Page 312

The high logic level is unchanged : $V_H = 2.11$

$$60x10^{-6} A = 50x10^{-6} \frac{A}{V^2} \left(\frac{W}{L} \right)_S \left(2.11 - 0.75 - \frac{0.1}{2} \right) 0.1 V^2 \rightarrow \left(\frac{W}{L} \right)_S = \frac{9.16}{1}$$

$$V_{TNL} = 0.75 + 0.5 \left(\sqrt{1.11 + 0.6} - \sqrt{0.6} \right) = 0.781 \text{ V}$$

$$60x10^{-6} A = \frac{50x10^{-6}}{2} \frac{A}{V^2} \left(\frac{W}{L} \right)_L (3.3 - 0.1 - 0.781)^2 V^2 \rightarrow \left(\frac{W}{L} \right)_L = \frac{0.410}{1} = \frac{1}{2.44}$$

Page 314

Using MATLAB :

```
fzero(@(vh) ((vh - 1.9 - 0.5 * sqrt(0.6))^2 - 0.25(vh + 0.6)), 1) | ans = 1.5535
```

$$\gamma = 0 \rightarrow V_{TN} = 0.6V \quad | \quad V_H = 2.5 - 0.6 = 1.9V \quad | \quad I_{DD} = 0 \text{ for } v_O = V_H$$

$$100x10^{-6} \left(\frac{10}{1} \right) \left(1.9 - 0.6 - \frac{V_L}{2} \right) V_L = \frac{100x10^{-6}}{2} \left(\frac{2}{1} \right) \left(2.5 - V_L - 0.6 \right)^2$$

$$6V_L^2 - 116.8V_L + 3.61 = 0 \rightarrow V_L = 0.235V \quad | \quad I_{DD} = 100x10^{-6} \left(\frac{10}{1} \right) \left(1.9 - 0.6 - \frac{0.235}{2} \right) 0.235 = 278 \mu A$$

$$\text{Checking: } I_{DD} = \frac{100x10^{-6}}{2} \left(\frac{2}{1} \right) \left(2.5 - 0.235 - 0.6 \right)^2 = 277 \mu A$$

Page 319

$$V_{TNL} = -1.5 + 0.5 \left(\sqrt{0.2 + 0.6} - \sqrt{0.6} \right) = -1.44V$$

$$60.6x10^{-6} = 100x10^{-6} \left(\frac{W}{L} \right)_S \left(3.3 - 0.6 - \frac{0.2}{2} \right) 0.2 \rightarrow \left(\frac{W}{L} \right)_S = \frac{1.17}{1}$$

$$60.6x10^{-6} = \frac{100x10^{-6}}{2} \left(\frac{W}{L} \right)_L \left(0 - 1.44 \right)^2 \rightarrow \left(\frac{W}{L} \right)_L = \frac{0.585}{1} = \frac{1}{1.71}$$

Page 320

$$I_{DS} = 100x10^{-6} \left(\frac{2.22}{1} \right) \left(2.5 - 0.6 - \frac{0.2}{2} \right) 0.2 = 79.9 \mu A \text{ which checks.}$$

Page 321The PMOS transistor is still saturated so $I_{DL} = 144 \mu A$, and $V_H = 2.5V$.

$$144x10^{-6} = 100x10^{-6} \left(\frac{5}{1} \right) \left(2.5 - 0.6 - \frac{V_L}{2} \right) V_L \rightarrow V_L = 0.158V$$

Page 326Place a third transistor with $\frac{W}{L} = \frac{2.22}{1}$ in parallel with transistors A and B.The W/L ratio of the load transistor remains unchanged: $\left(\frac{W}{L} \right)_L = \frac{1.81}{1}$

Page 327

Place a third transistor in series with transistors A and B.

The new W/L ratios of transistors A, B and C are $\left(\frac{W}{L}\right)_{ABC} = 3 \frac{2.22}{1} = \frac{6.66}{1}$.

The W/L ratio of the load transistor remains unchanged: $\left(\frac{W}{L}\right)_L = \frac{1.81}{1}$

Page 333

M_{L1} is saturated for all three voltages. $I_{DD} = \frac{40 \times 10^{-6}}{2} \left(\frac{1.11}{1} \right)_L \left[-2.5 - (-0.6) \right]^2 = 80.1 \mu A$

The voltages can be estimated using the on - resistance method.

For the 11000 case, $R_{onA} = \frac{132mV - 64.4mV}{80.1\mu A} = 844 \Omega$ $R_{onB} = \frac{64.4mV}{80.1\mu A} = 804 \Omega$

For the 00101 case, $R_{onE} = \frac{64.4mV}{80.1\mu A} = 804 \Omega$.

For the 01110 case, $R_{onC} = \frac{203mV - 132mV}{80.1\mu A} = 886 \Omega$ $R_{onD} = \frac{132mV - 64.4mV}{80.1\mu A} = 844 \Omega$

The voltage across a given conducting device is $I_D R_{on}$. Small variations in R_{on} are ignored.

ABCDE	Y (mV)	2 (mV)	3 (mV)	I_{DD} (uA)	ABCDE	Y (mV)	2 (mV)	3 (mV)	I_{DD} (uA)
00000	2.5 V	0	0	0	10000	2.5 V	2.5 V	0	0
00001	2.5 V	0	0	0	10001	2.5 V	2.5 V	0	0
00010	2.5 V	0	0	0	10010	2.5 V	2.5 V	2.5 V	0
00011	2.5 V	0	0	0	10011	200	130	64	80.1
00100	2.5 V	0	2.5 V	0	10100	2.5 V	2.5 V	2.5 V	0
00101	130	0	64	80.1	10101	130	130	64	80.1
00110	2.5 V	2.5 V	2.5 V	0	10110	2.5 V	2.5 V	2.5 V	0
00111	130	64	64	80.1	10111	100	83	64	80.1
01000	2.5 V	0	0	0	11000	130	64	0	80.1
01001	2.5 V	0	0	0	11001	130	64	0	80.1
01010	2.5 V	0	0	0	11010	130	64	64	80.1
01011	2.5 V	0	0	0	11011	110	43	22	80.1
01100	2.5 V	0	2.5 V	0	11100	130	64	64	80.1
01101	130	0	64	80.1	11101	66	32	32	80.1
01110	200	64	130	80.1	11110	110	64	87	80.1
01111	114	21	43	80.1	11111	65	32	32	80.1

Page 334

$$P_{av} = \frac{2.5V(80\mu A)}{2} = 0.100 \text{ mW}$$

Page 335

$$P_D = 10^{-12} F(2.5V)^2 (32 \times 10^6 \text{ Hz}) = 2 \times 10^{-4} W = 200 \mu W \text{ or } 0.200 \text{ mW}$$

$$P_D = 10^{-12} F(2.5V)^2 (3.2 \times 10^9 \text{ Hz}) = 2 \times 10^{-4} W = 0.02 W \text{ or } 20 \text{ mW}$$

Page 336

The inverter in Fig. 6.38(a) was designed for a power dissipation of 0.2 mW.

To reduce the power by a factor of two, we must reduce the W/L ratios by a factor of 2.

$$\left(\frac{W}{L}\right)_L = \frac{1}{2} \left(\frac{1}{1.68}\right) = \frac{1}{3.36} \quad | \quad \left(\frac{W}{L}\right)_S = \frac{1}{2} \left(\frac{4.71}{1}\right) = \frac{2.36}{1}$$

To increase the power by a factor of $\frac{4\text{mW}}{0.2\text{mW}}$, we must increase the W/L ratios by a factor of 20.

$$\left(\frac{W}{L}\right)_L = 20 \left(\frac{1.81}{1}\right) = \frac{36.2}{1} \quad | \quad \left(\frac{W}{L}\right)_S = 20 \left(\frac{2.22}{1}\right) = \frac{44.4}{1}$$

To reduce the power by a factor of three, we must reduce the W/L ratios by a factor of 3.

$$\left(\frac{W}{L}\right)_L = \frac{1}{3} \left(\frac{1.81}{1}\right) = \frac{0.603}{1} = \frac{1}{1.66} \quad | \quad \left(\frac{W}{L}\right)_A = \frac{1}{3} \left(\frac{3.33}{1}\right) = \frac{1.11}{1} \quad | \quad \left(\frac{W}{L}\right)_{BCD} = \frac{1}{3} \left(\frac{6.66}{1}\right) = \frac{2.22}{1}$$

Page 339

$$t_r = 2.2RC = 2.2(28.8 \times 10^3 \Omega)(2 \times 10^{-13} F) = 12.7 \text{ ns}$$

$$\tau_{PLH} = 0.69RC = 0.69(28.8 \times 10^3 \Omega)(2 \times 10^{-13} F) = 3.97 \text{ ns}$$

--

$$v_o(t) = V_F - (V_F - V_I) \exp\left(-\frac{t}{RC}\right) \quad | \quad v_o(\tau_{PHL}) = V_H - 0.5\left(\frac{V_H + V_L}{2}\right) = 2.5 - 1.15 = 1.35 \text{ V}$$

$$1.35 = 0.2 - (0.2 - 2.5) \exp\left(-\frac{\tau_{PHL}}{RC}\right) \rightarrow \tau_{PLH} = -RC \ln 0.5 = 0.69RC$$

$$v_o(t_1) = V_H - 0.1(V_H + V_L) = 2.5 + 0.23 = 2.27 \text{ V}$$

$$2.27 = 0.2 - (0.2 - 2.5) \exp\left(-\frac{t_1}{RC}\right) \rightarrow t_1 = -RC \ln 0.9$$

$$v_o(t_2) = V_L + 0.1(V_H + V_L) = 0.2 + 0.23 = 0.43 \text{ V}$$

$$0.43 = 0.2 - (0.2 - 2.5) \exp\left(-\frac{t_2}{RC}\right) \rightarrow t_2 = -RC \ln 0.1$$

$$t_f = t_2 - t_1 = -RC \ln 0.1 + RC \ln 0.9 = RC \ln 9 = 2.2RC$$

Page 343

$$t_f = 3.7(2.37 \times 10^3 \Omega)(2.5 \times 10^{-13} F) = 2.19 \text{ ns} \quad | \quad \tau_{PHL} = 1.2(2.37 \times 10^3 \Omega)(2.5 \times 10^{-13} F) = 0.711 \text{ ns}$$

$$t_r = 2.2(28.8 \times 10^3 \Omega)(2.5 \times 10^{-13} F) = 15.8 \text{ ns} \quad | \quad \tau_{PLH} = 0.69(28.8 \times 10^3 \Omega)(2.5 \times 10^{-13} F) = 4.97 \text{ ns}$$

$$\tau_p = \frac{0.711 \text{ ns} + 4.97 \text{ ns}}{2} = 2.84 \text{ ns}$$

Page 346

$$T = 2N\tau_{p0} = 2(401)(10^{-9} \text{ s}) = 802 \text{ ns} \quad | \quad f = \frac{1}{T} = \frac{1}{802 \text{ ns}} = 1.25 \text{ MHz}$$

Page 347

For our Psuedo NMOS inverter with $V_L = 0.2 V$,

$$\tau_{PHL} = 1.2 R_{onS} C = 1.2 \frac{C''_{ox} WL}{\mu_n C''_{ox} \frac{W}{L} (V_{GS} - V_{TN})} = 1.2 \frac{L^2}{\mu_n (V_{GS} - V_{TN})}$$

$$\tau_{PHL} = 1.2 \frac{(250 \times 10^{-9} m)^2 (100 cm/m)^2}{(500 cm^2/V - s)(3.3 - 0.825)V} = 0.606 ps$$

$$\tau_{PLH} = 1.2 R_{onL} C = 1.2 \frac{L^2}{0.4 \mu_p (V_{GS} - V_{TN})} = 1.2 \frac{(250 \times 10^{-9} m)^2 (100 cm/m)^2}{(125 cm^2/V - s)(3.1 - 0.825)V} = 2.63 ps$$

$$\tau_P = \frac{0.606 ps + 2.63 ps}{2} = 1.62 ps$$

Page 349

The PMOS transistor is saturated for $v_O = V_L$. $I_{DD} = \frac{40 \times 10^{-6}}{2} \left(\frac{23.7}{1} \right) \left[-2.5 - (-0.6) \right]^2 = 1.71 mA$

$$P_{av} = \frac{2.5V(1.71mA)}{2} = 2.14 mW \quad | \quad P_D = 5 \times 10^{-12} F (2.5V - 0.2V)^2 \left(\frac{1}{2 \times 10^{-9} s} \right) = 13.2 mW$$

We must increase the power by a factor of $\left(\frac{20 pF}{5 pF} \right) \left(\frac{2 ns}{1 ns} \right) = 8$,

so the W/L ratios must also be increased by a factor of 8.

$$\left(\frac{W}{L} \right)_L = 8 \left(\frac{23.7}{1} \right) = \frac{190}{1} \quad | \quad \left(\frac{W}{L} \right)_S = 8 \left(\frac{47.4}{1} \right) = \frac{379}{1} \quad | \quad P_D = 20 \times 10^{-12} F (2.5V - 0.2V)^2 \left(\frac{1}{10^{-9} s} \right) = 106 mW$$

CHAPTER 7

Page 370

$$(a) K_p = 40 \times 10^{-6} \left(\frac{20}{1} \right) = 800 \frac{\mu A}{V^2} \quad | \quad K_n = 100 \times 10^{-6} \left(\frac{20}{1} \right) = 2000 \frac{\mu A}{V^2} = 2.00 \frac{mA}{V^2}$$

$$(b) V_{TN} = 0.6 + 0.5 \left(\sqrt{2.5 + 0.6} - \sqrt{0.6} \right) = 1.09 V$$

$$(c) V_{TP} = -0.6 - 0.75 \left(\sqrt{2.5 + 0.7} - \sqrt{0.7} \right) = -1.31 V$$

Page 372

$$(a) \text{ For } v_I = 1 V, V_{GSN} - V_{TN} = 1 - 0.6 = 0.4V \text{ and } V_{GSP} - V_{TP} = -1.5 + 0.6 = -0.9V$$

M_N is saturated for $v_O \geq 0.4 V$. M_P is in the triode region for $v_O \geq 1.6 V$. $\therefore 1.6 V \leq v_O \leq 2.5 V$

$$(b) M_P \text{ is saturated for } v_O \leq 1.6 V. \quad \therefore 0.4 V \leq v_O \leq 1.6 V$$

$$(c) M_N \text{ is in the triode region for } v_O \leq 0.4 V. \quad M_P \text{ is saturated for } v_O \leq 1.6 V. \quad \therefore 0 \leq v_O \leq 0.4 V$$

$$\left(\frac{W}{L} \right)_P = \frac{K_n}{K_p} \left(\frac{W}{L} \right)_N = 2.5 \left(\frac{10}{1} \right) = \frac{25}{1}$$

Page 373

Both transistors are saturated since $|V_{GS}| = |V_{DS}|$.

$$\frac{K_n}{2} (V_{GSN} - V_{TN})^2 = \frac{K_p}{2} (V_{GSP} - V_{TP})^2 \quad K_n = K_p \quad |V_{TN}| = |V_{TP}|$$

$$V_{GSN} = -V_{GSP} \rightarrow v_I = V_{DD} - v_I \rightarrow v_I = \frac{V_{DD}}{2}$$

$$\frac{10K_p}{2} (V_{GSN} - V_{TN})^2 = \frac{K_p}{2} (V_{GSP} - V_{TP})^2 \rightarrow \sqrt{10} (V_{GSN} - V_{TN}) = -V_{GSP} + V_{TP}$$

$$\sqrt{10} (v_I - 0.6) = 4 - v_I - 0.6 \rightarrow v_I = 1.273 V$$

$$\frac{K_p}{2} (V_{GSN} - V_{TN})^2 = \frac{10K_p}{2} (V_{GSP} - V_{TP})^2 \rightarrow (V_{GSN} - V_{TN}) = \sqrt{10} (-V_{GSP} + V_{TP})$$

$$v_I - 0.6 = \sqrt{10} (4 - v_I - 0.6) \rightarrow v_I = 2.37 V$$

Page 375

$$K_R = \frac{K_n \left(\frac{W}{L} \right)_N}{K_p \left(\frac{W}{L} \right)_P} = \frac{K_n}{K_p} = 2.5$$

$$V_{IH} = \frac{2K_R(V_{DD} - V_{TN} + V_{TP})}{(K_R - 1)\sqrt{1 + 3K_R}} - \frac{(V_{DD} - K_R V_{TN} + V_{TP})}{K_R - 1}$$

$$V_{IH} = \frac{2(2.5)(2.5 - 0.6 - 0.6)}{(2.5 - 1)\sqrt{1 + 3(2.5)}} - \frac{(2.5 - 2.5(0.6) - 0.6)}{2.5 - 1} = 1.22V$$

$$V_{OL} = \frac{(K_R + 1)V_{IH} - V_{DD} - K_R V_{TN} - V_{TP}}{2K_R} = \frac{(2.5 + 1)1.22 - 2.5 - 2.5(0.6) + 0.6}{2(2.5)} = 0.174V$$

$$V_{IL} = \frac{2\sqrt{K_R}(V_{DD} - V_{TN} + V_{TP})}{(K_R - 1)\sqrt{K_R + 3}} - \frac{(V_{DD} - K_R V_{TN} + V_{TP})}{K_R - 1}$$

$$V_{IL} = \frac{2\sqrt{2.5}(2.5 - 0.6 - 0.6)}{(2.5 - 1)\sqrt{2.5 + 3}} - \frac{(2.5 - 2.5(0.6) - 0.6)}{2.5 - 1} = 0.902V$$

$$V_{OH} = \frac{(K_R + 1)V_{IL} + V_{DD} - K_R V_{TN} - V_{TP}}{2} = \frac{(2.5 + 1)0.902 + 2.5 - 2.5(0.6) + 0.6}{2} = 2.38V$$

$$NM_H = V_{OH} - V_{IH} = 2.38 - 1.22 = 1.16 \text{ V} \quad | \quad NM_L = V_{IL} - V_{OL} = 0.902 - 0.174 = 0.728 \text{ V}$$

Page 376

$$\text{Symmetrical Inverter : } \tau_P = 1.2R_{onn}C = 1.2 \frac{10^{-12}F}{2(10^{-4})(2.5 - 0.6)} \Omega = 3.16 \text{ ns}$$

Page 377

$$\text{Symmetrical Inverter : } R_{onn} = \frac{\tau_P}{1.2C} = \frac{10^{-9}s}{1.2(5 \times 10^{-12}F)} = 167\Omega$$

$$\left(\frac{W}{L} \right)_N = \frac{1}{R_{onn} K_n (V_{GS} - V_{TN})} = \frac{1}{167(10^{-4})(2.5 - 0.6)} = \frac{31.5}{1} \quad | \quad \left(\frac{W}{L} \right)_P = 2.5 \left(\frac{W}{L} \right)_N = \frac{78.8}{1}$$

Page 379

The inverters need to be increased in size by a factor of $\frac{280\text{ps}}{250\text{ps}} = 1.12$.

$$\left(\frac{W}{L}\right)_N = 1.12 \left(\frac{3.77}{1}\right) = \frac{4.22}{1} \quad | \quad \left(\frac{W}{L}\right)_P = 1.12 \left(\frac{9.43}{1}\right) = \frac{10.6}{1}$$

$$\left(\frac{W}{L}\right)_N = \left(\frac{3.77}{1}\right) \left(\frac{3.3 - 0.75}{3.3 - 0.5}\right) = \frac{3.43}{1} \quad | \quad \left(\frac{W}{L}\right)_P = \left(\frac{9.43}{1}\right) \left(\frac{3.3 - 0.75}{3.3 - 0.5}\right) = \frac{8.59}{1}$$

Page 380

$$\tau_{PHL} = 2.4R_{on}C = \frac{2.4C}{K_n(V_{GS} - V_{TN})} = \frac{2.4C}{K_n(2.5 - 0.6)} = 1.26 \frac{C}{K_n}$$

$$\tau_{PLH} = 2.4R_{onp}C = \frac{2.4C}{K_p(V_{GS} - V_{TN})} = \frac{2.4C}{K_p(2.5 - 0.6)} = 1.26 \frac{C}{K_p}$$

$$\tau_{PHL} = 2.4R_{on}C = \frac{2.4C}{K_n(V_{GS} - V_{TN})} = \frac{2.4C}{K_n(3.3 - 0.75)} = 0.94 \frac{C}{K_n}$$

$$\tau_{PLH} = 2.4R_{onp}C = \frac{2.4C}{K_p(V_{GS} - V_{TN})} = \frac{2.4C}{K_p(3.3 - 0.75)} = 0.94 \frac{C}{K_p}$$

Page 381

The inverter in Fig. 7.12 is a symmetrical design, so the maximum current occurs

for $v_O = v_I = \frac{V_{DD}}{2}$. Both transistors are saturated: $i_{DN} = \frac{10^{-4}}{2} \left(\frac{2}{1}\right) (1.25 - 0.6)^2 = 42.3 \mu A$

Checking: $i_{DP} = \frac{4 \times 10^{-5}}{2} \left(\frac{5}{1}\right) (1.25 - 0.6)^2 = 42.3 \mu A$

Page 382

$$(a) PDP \cong \frac{CV_{DD}^2}{5} = \frac{10^{-13} F(2.5V)^2}{5} = 0.13 pJ = 130 fJ$$

$$(b) PDP \cong \frac{CV_{DD}^2}{5} = \frac{10^{-13} F(3.3V)^2}{5} = 0.22 pJ = 220 fJ$$

$$(c) PDP \cong \frac{CV_{DD}^2}{5} = \frac{10^{-13} F(1.8V)^2}{5} = 0.065 pJ = 65 fJ$$

Page 388

Remove the NMOS and PMOS transistors connected to input E, and ground the source of the NMOS transistor connected to input D. There are now 4 NMOS transistors in series, and

$$\left(\frac{W}{L}\right)_N = 4\left(\frac{2}{1}\right) = \frac{8}{1} \quad | \quad \left(\frac{W}{L}\right)_P = \frac{5}{1}$$

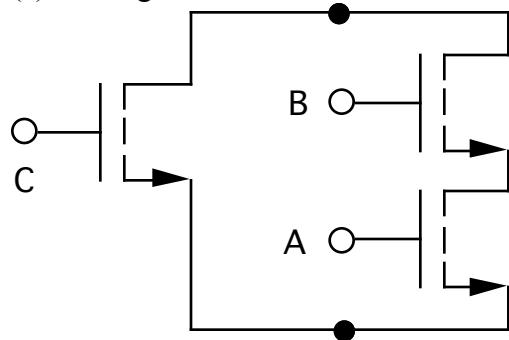
Page 392

There are two NMOS transistors in series in the AB and CD NMOS paths, and three PMOS transistors in the ACE and BDE PMOS paths. Therefore:

$$\left(\frac{W}{L}\right)_{N-ABCD} = 2\left(\frac{2}{1}\right) = \frac{4}{1} \quad | \quad \left(\frac{W}{L}\right)_{N-E} = \frac{2}{1} \quad | \quad \left(\frac{W}{L}\right)_P = 3\left(\frac{5}{1}\right) = \frac{15}{1}$$

Page 396

(a) The logic network for $F = AB + C$ is



$$P = CV_{DD}^2f = (50 \times 10^{-12} F)(5V)^2(10^7 Hz) = 12.5 mW$$

Page 400

$$\beta = \left(\frac{50 \text{ pF}}{50 \text{ fF}} \right)^{\frac{1}{2}} = 31.6 \quad \tau_p = 31.6 \tau_o + 31.6 \tau_o = 63.2 \tau_o$$

$$z = e^{\ln z} \quad | \quad z^{\frac{1}{\ln z}} = \left(e^{\ln z} \right)^{\frac{1}{\ln z}} = e$$

$$\beta = \left(\frac{50 \text{ pF}}{50 \text{ fF}} \right)^{\frac{1}{7}} = 2.683$$

$$1, 2.68, 2.683^2 = 7.20, 2.683^3 = 19.3, 2.683^4 = 51.8, 2.683^5 = 139, 2.683^6 = 373$$

$$A_6 = (1 + 3.16 + 10 + 31.6 + 100 + 316) A_o = 462 A_o$$

$$A_7 = (1 + 2.68 + 7.20 + 19.3 + 51.8 + 139 + 373) A_o = 594 A_o$$

Page 401

From the figure, 10/1 devices give a maximum R_{on} of 4 k Ω . The W/L ratios must be 4 times larger in order to reduce the maximum R_{on} to 1 k Ω . $\therefore \left(\frac{W}{L} \right) = 4 \left(\frac{10}{1} \right) = \frac{40}{1}$

CHAPTER 8

Page 419

$$(a) NS = \frac{2^8 \cdot 2^{20}}{2^7 \cdot 2^{10}} = 2^{11} = 2048 \text{ segments} \quad | \quad (b) NS = \frac{2^{30}}{2^9 \cdot 2^{10}} = 2^{11} = 2048 \text{ segments}$$

Page 422

$$(a) N = 2^8 \cdot 2^{20} = 2^{28} = 268,435,456$$

$$(b) I_{DD} = \frac{0.05W}{3.3V} = 15.2 \text{ mA} \quad | \quad \text{Current/cell} = \frac{15.2 \text{ mA}}{2^{28} \text{ cells}} = 56.4 \text{ pA}$$

Reverse the direction of the substrate arrows, and connect the substrates of the PMOS transistors to V_{DD}.

Page 426

M_{A1}: At t = 0⁺, V_{GS} - V_{TN} = 4 V and V_{DS} = 2.5V, so transistor M_{A1} is operating in the triode region.

$$i_1 = 60 \times 10^{-6} \left(\frac{1}{1} \right) \left(5 - 1 - \frac{2.5}{2} \right) 2.5 = 413 \mu A$$

M_{A2}: At t = 0⁺, V_{GS} = V_{DS}, so transistor M_{A2} is operating in the saturation region.

$$V_{TN2} = 1 + 0.6 \left(\sqrt{2.5 + 0.6} - \sqrt{0.6} \right) = 1.592V \quad i_2 = \frac{60 \times 10^{-6}}{2} \left(\frac{1}{1} \right) \left(5 - 2.5 - 1.592 \right)^2 = 24.8 \mu A$$

Page 428

M_{A1}: At t = 0⁺, V_{GS} = V_{DS}, so transistor M_{A1} is operating in the saturation region.

$$i_1 = \frac{60 \times 10^{-6}}{2} \left(\frac{1}{1} \right) \left(5 - 1 \right)^2 = 480 \mu A$$

M_{A2}: At t = 0⁺, V_{GS} = V_{DS}, so transistor M_{A2} is operating in the saturation region.

$$i_1 = \frac{60 \times 10^{-6}}{2} \left(\frac{1}{1} \right) \left(5 - 1 \right)^2 = 480 \mu A$$

Page 431

(a) At $t = 0^+$, $V_{GS} - V_{TN} = 3 - 0.7 = 2.3$ V and $V_{DS} = 1.9$ V, so transistor M_A is operating in the triode region. $i_l = 60 \times 10^{-6} \left(\frac{1}{1} \right) \left(3 - 0 - 0.7 - \frac{1.9}{2} \right) 1.9 = 154 \mu A$

(b) From Table 6.10: $t_f = 3.7 R_{on} C = 3.7 \frac{50 \times 10^{-15} F}{60 \times 10^{-6} (3 - 0.7)} = 1.34$ ns

$$V_C = V_{BL} - V_{TN} \quad | \quad V_C = 3 - \left[0.7 + 0.5 \left(\sqrt{V_C + 0.6} - \sqrt{0.6} \right) \right] \rightarrow V_C = 1.89$$
 V $| \quad V_C = 3 - 0.7 = 2.3$ V

$$n = \frac{CV}{q} = \frac{25 \times 10^{-15} F (1.89 V)}{1.60 \times 10^{-19} C} = 2.95 \times 10^5 \text{ electrons}$$

Page 432

(a) $\Delta V = \frac{V_C - V_{BL}}{\frac{C_{BL}}{C_C} + 1} = \frac{1.9 - 0.95}{\frac{49C_C}{C_C} + 1} V = 19.0$ mV $| \quad \Delta V = \frac{V_C - V_{BL}}{\frac{C_{BL}}{C_C} + 1} = \frac{0 - 0.95}{\frac{49C_C}{C_C} + 1} V = -19.0$ mV

(b) $\tau = R_{on} \frac{C_C}{\frac{C_C}{C_{BL}} + 1} = 5k\Omega \frac{25fF}{\frac{1}{49} + 1} = 0.123$ ns or $\tau \approx R_{on} C_C = 5k\Omega (25fF) = 0.125$ ns

Page 434

At $t = 0^+$, $V_{GS} - V_{TN} = (3 - 0) - 0.7 = 2.3$ V and $V_{DS} = 1.5$ V, so transistor M_{A2} is operating in the triode region. $i_D = 60 \times 10^{-6} \left(\frac{2}{1} \right) \left(3 - 0.7 - \frac{1.5}{2} \right) 1.5 = 279 \mu A$

Page 436

In setting the drain currents equal, we see that the change in W/L cancels out, and the voltages remain the same.

$$\therefore i_D = \frac{1}{2} \left(60 \times 10^{-6} \right) \left(\frac{5}{1} \right) (1.33 - 0.7)^2 = 59.5 \mu A \quad | \quad P_D = 2(59.5 \mu A)(3V) = 0.357 mW$$

As a check, the current should scale with W/L: $i_D = \frac{5}{2}(23.5 \mu A) = 58.8 \mu A$

Equating drain currents: $\frac{1}{2} \left(25 \times 10^{-6} \right) \left(\frac{2}{1} \right) (2.5 - V_o - 0.6)^2 = \frac{1}{2} \left(60 \times 10^{-6} \right) \left(\frac{2}{1} \right) (V_o - 0.6)^2$

$$1.4V_o^2 + 0.92V_o - 2.746 = 0 \rightarrow V_o = 1.11V$$

$$i_D = \frac{1}{2} \left(25 \times 10^{-6} \right) \left(\frac{2}{1} \right) (2.5 - 1.11 - 0.6)^2 = 15.6 \mu A \quad | \quad P_D = 2(15.6 \mu A)(2.5V) = 78.0 \mu W$$

Checking: $\frac{1}{2} \left(60 \times 10^{-6} \right) \left(\frac{2}{1} \right) (1.11 - 0.6)^2 = 15.6 \mu A$

Page 488

$$R_{on} = \frac{1}{60 \times 10^{-6} (3 - 1.3 - 1)} = 23.8 k\Omega \quad | \quad \tau = 23.8 k\Omega (25 fF) = 0.595 ns$$

Page 440

For all possible input combinations there will be two inverters and 3 output lines in the low state.

$$P_D = 5(0.2 mW) = 1.0 mW$$

Page 442

$$\left(\frac{W}{L} \right)_L = \frac{2}{2.22} \left(\frac{1.81}{1} \right) = \frac{1.63}{1}$$

Page 444

For a 0 - V input, all transistors will be on and the input nodes will all discharge to 0 V.

For the 3 - V input, the nodes will all charge to 3 V as long as $V_{TN} \leq 2\text{ V}$.

$$V_{TN} = 0.7 + 0.5(\sqrt{3+0.6} - \sqrt{0.6}) = 1.26\text{ V}. \text{ Thus the nodes will all be a } 3\text{ V}.$$

$$2 \geq 0.7 + \gamma(\sqrt{3+0.6} - \sqrt{0.6}) \rightarrow \gamma \leq 1.158$$

The output will drop below $V_{DD}/2$. For the PMOS device, $|V_{GS} - V_{TP}| = 3 - 1.9 - 0.7 = 0.4V$.

The PMOS transistor will be saturated. For the NMOS device, $|V_{GS} - V_{TP}| = 1.9 - 0.7 = 1.2V$.

Assume linear region operation.

$$\frac{40 \times 10^{-6}}{2} \left(\frac{5}{1} \right) (-1.1 + 0.7)^2 = 100 \times 10^{-6} \left(\frac{2}{1} \right) \left(1.9 - 0.7 - \frac{V_o}{2} \right) V_o$$

$$V_o^2 - 2.4V_o + 0.16 = 0 \rightarrow V_o = 68.6\text{ mV}$$

CHAPTER 9

Page 462

$$\frac{i_{C2}}{i_{C1}} = \exp\left(\frac{0.2V}{0.025V}\right) = 2.98 \times 10^3 \quad | \quad \frac{i_{C2}}{i_{C1}} = \exp\left(\frac{0.3V}{0.025V}\right) = 1.63 \times 10^5 \quad | \quad \frac{i_{C2}}{i_{C1}} = \exp\left(\frac{0.4V}{0.025V}\right) = 8.89 \times 10^6$$

Page 464

The current must be reduced by 5 while the voltages remain the same.

$$I_{EE} = \frac{300\mu A}{5} = 60 \mu A \quad | \quad R_C = 5(2k\Omega) = 10 k\Omega$$

Page 465

$$I_B = \frac{I_E}{\beta_F + 1} \quad | \quad I_{B3} = \frac{92.9\mu A}{21} = 4.42 \mu A \quad | \quad I_{B4} = \frac{107\mu A}{21} = 5.10 \mu A$$

$$I_{B3}R_C = 4.42\mu A(2k\Omega) = 8.84 mV << 0.7 V \quad | \quad I_{B4}R_C = 5.10\mu A(2k\Omega) = 10.2 mV << 0.7 V$$

Page 467

$$V_H = 0 - 0.7 = -0.7 V \quad | \quad V_L = 0 - 0.2mA(2k\Omega) - 0.7V = -1.1 V$$

$$V_{REF} = \frac{-0.7V + (-1.10V)}{2} = -0.9 V \quad | \quad \Delta V = -0.7V - (1.1V) - 0.4 V$$

Page 469

$$NM_H = NM_L = \frac{0.4V}{2} - 0.025V \left[1 + \ln\left(\frac{0.4}{0.025} - 1\right) \right] = 0.107 V$$

Page 471

$$P = 3.3V(0.3mA + 0.2mA) = 1.65 \text{ mW} \quad | \quad P = 3.3V(0.357mA + 0.2mA) = 1.84 \text{ mW}$$

$$NM_H = NM_L = \frac{0.6V}{2} - 0.025V \left[1 + \ln \left(\frac{0.6}{0.025} - 1 \right) \right] = 0.20 \text{ V}$$

From the graph, the VTC slope is -1 for $V_{IL} = -1.08 \text{ V}$, $V_{OH} = -0.71 \text{ V}$ and

$$V_{IH} = -0.91 \text{ V}, V_{OL} = -1.28 \text{ V}. \quad NM_H = -0.71 - (-0.91) = 0.20 \text{ V}. \quad NM_L = -1.08 - (-1.28) = 0.20 \text{ V}$$

The voltages remain the same. Thus the currents must be reduced by a factor of 3, and the resistor values must be increased by a factor of 3.

$$R_{EE} = \frac{-1.7V - (-5.2V)}{0.20mA} = 17.5 \text{ k}\Omega \quad | \quad I_E = \frac{-1.4V - (-5.2V)}{18 \text{ k}\Omega} = 0.211 \text{ mA} \quad | \quad R_{C1} = \frac{0.4V}{0.211mA} = 1.90 \text{ k}\Omega$$

Page 472

$$\text{For all inputs low : } I_{EE} = \frac{-1 - 0.7 - (-5.2)}{11.7} \frac{V}{k\Omega} = 299 \mu A$$

$$\frac{\Delta V}{2} = V_H - V_{REF} = -0.7 - (-1) = 0.3 \text{ V} \quad | \quad \Delta V = 0.6 \text{ V} \quad | \quad R_{C2} = \frac{0.6V}{299\mu A} = 2.00 \text{ k}\Omega$$

$$\text{For an inputs high : } I_{EE} = \frac{-0.7 - 0.7 - (-5.2)}{11.7} \frac{V}{k\Omega} = 325 \mu A \quad | \quad R_{C1} = \frac{0.6V}{325\mu A} = 1.85 \text{ k}\Omega$$

$$\text{Based upon analysis above, } R_C = \frac{0.6V}{325\mu A} = 1.85 \text{ k}\Omega$$

Page 473

$$\text{For all inputs low : } I_{EE} = \frac{-1 - 0.7 - (-5.2)}{11.7} \frac{V}{k\Omega} = 299 \mu A$$

$$\frac{\Delta V}{2} = V_H - V_{REF} = -0.7 - (-1) = 0.3 \text{ V} \quad | \quad \Delta V = 0.6 \text{ V} \quad | \quad R_C = \frac{0.6V}{299\mu A} = 2.00 \text{ k}\Omega$$

Page 474

$$R_E = \frac{V_E - (-V_{EE})}{0.3mA} = \frac{0 - 0.7 - (-5.2V)}{0.3} \frac{V}{mA} = 15.0 \text{ k}\Omega$$

Page 475

$$(a) \text{ For } I_E = 0, v_O = -5.2 \text{ V. } (b) \text{ For } I_E = 0, v_O = -5.2V \frac{10k\Omega}{10k\Omega + 15k\Omega} = -2.08 \text{ V}$$

Page 476

The transistor's power dissipation is

$$P = V_{CB}I_C + V_{BE}I_E = 5V \left(2.55mA \frac{50}{51} \right) + 0.7V(2.55mA) = 14.3 \text{ mW}$$

The total power dissipation in the circuit is

$$P = V_{CC}I_C + V_{EE}I_E = 5V \left(2.55mA \frac{50}{51} \right) + 5V(2.55mA) = 25.3 \text{ mW}$$

$$\text{For } v_O = -3.7V, I_E = \frac{-3.7 - (-5)}{1300} - \frac{3.7}{5000} = 260 \mu A.$$

$$\text{At the Q-point, } I_E = \frac{-0.7 - (-5)}{1300} - \frac{0.7}{5000} = 3.17 \text{ mA}$$

The transistor's power dissipation is

$$P = V_{CB}I_C + V_{BE}I_E = 5V \left(3.17mA \frac{50}{51} \right) + 0.7V(3.17mA) = 17.8 \text{ mW}$$

$$(a) -4V = -5.2V \frac{10k\Omega}{10k\Omega + R_E} \rightarrow R_E = 3.00 k\Omega$$

$$(b) I_E = \frac{5.2V}{3k\Omega} = 1.73 \text{ mA} \quad | \quad I_E = \frac{-4 - (-5.2)}{3000} - \frac{4}{10000} = 0 \quad | \quad I_E = \frac{4 - (-5.2)}{3000} + \frac{4}{10000} = 3.47 \text{ mA}$$

Page 478

Increase the value of each resistor by a factor of 10.

Page 481

$$R_C = \frac{\Delta V}{I_{EE}} = \frac{0.6V}{0.5mA} = 1.2 \text{ k}\Omega \quad | \quad \tau_P = 0.69(1.2k\Omega)(2pF) = 1.66 \text{ ns}$$

$$P = 5.2V(0.5 + 0.1 + 0.1)mA = 3.64 \text{ mW} \quad | \quad PDP = 6.0 \text{ pJ}$$

Page 483

$$R_{C2} = R_{C1} = \frac{0 - V_L}{I_{EE}} = \frac{0.4V}{0.5mA} = 800 \Omega \quad | \quad P = I_{EE}V_{EE} = 0.5mA(2.8V) = 1.40 mW$$

$$PDP = 1.4mW(50ps) = 70 fJ$$

$$I_{EF} = \frac{I_{EE}}{2} = 250 \mu A \quad | \quad P = I_{EE}V_{EE} = 0.25mA(2.8V) = 0.70 mW$$

$$V_H = 0 \quad | \quad V_L = -0.2 V \quad | \quad V_{Bias} = 0.1 V \quad | \quad V_{BH} = -0.7 \quad | \quad V_{BL} = -0.9 V \quad | \quad V_{BiasB} = -0.8 V$$

$$V_{AH} = -1.4 \quad | \quad V_{AL} = -1.6 V \quad | \quad V_{BiasA} = -1.5 V$$

$$-V_{EE} = V_{AH} - 0.7V - 0.7V = -1.4 - 0.7 - 0.7 = -2.8 V \quad | \quad V_{EE} = 2.8 V$$

$$V_H = 0 V, \quad V_L = -0.4 V, \quad : \text{ The C-level bias is } V_{BiasC} = \frac{V_H + V_L}{2} = -0.2 V$$

Using the level shifter in Fig. 9.27,

$$V_{BH} = -0.7 \quad | \quad V_{BL} = -1.1 V \quad | \quad V_{BiasB} = -0.9 V$$

$$V_{AH} = -1.4 \quad | \quad V_{AL} = -1.8 V \quad | \quad V_{BiasA} = -1.6 V$$

$$-V_{EE} = V_{emitterA} - 0.7V = -0.7 = -2.8 V \quad | \quad V_{EE} = 2.8 V$$

Page 488

$$\text{For } v_O = V_H, \quad I_C = 0, \quad \text{and } P = 0. \quad P = V_{DD}I_{DD} = 5V(2.43mA) = 12.1 mA$$

$$\text{Increase R by a factor of 10: } R = 10(2k\Omega) = 20k\Omega.$$

Page 490

$$\Gamma = \exp\left(\frac{0.1}{0.0258}\right) = 48.2 \quad | \quad I_B \geq \frac{10A}{20} \left[\frac{1 + \frac{20}{0.1(48.2)}}{1 - \frac{11}{48.2}} \right] = 3.34 A \quad | \quad \beta_{FOR} = \frac{10A}{3.34A} = 3.00$$

$$\alpha_R = \frac{0.2}{0.2+1} = \frac{1}{6} \quad | \quad I_B \geq \frac{10A}{20} \left[\frac{1 + \frac{20}{0.2(54.6)}}{1 - \frac{6}{54.6}} \right] = 1.59 A$$

Page 491

$$\Gamma = \exp\left(\frac{0.15}{0.025}\right) = 403 \quad | \quad I_B \geq \frac{10A}{20} \left[\frac{1 + \frac{20}{0.1(403)}}{1 - \frac{11}{403}} \right] = 0.769 A$$

$$V_T = \frac{1.38 \times 10^{-23} (273 + 150)}{1.60 \times 10^{-19}} = 36.5 \text{ mV} \quad | \quad V_{CEMIN} = 36.5 \text{ mV} \ln\left(\frac{0.05 + 1}{0.05}\right) = 111 \text{ mV}$$

$$\Gamma = \exp\left(\frac{0.1}{0.025}\right) = 54.6 \quad | \quad \alpha_R = \frac{0.25}{1 + 0.25} = \frac{1}{5}$$

$$I_B \geq \frac{10mA}{40} \left[\frac{1 + \frac{40}{0.25(54.6)}}{1 - \frac{5}{54.6}} \right] = 1.08 \text{ mA} \quad | \quad \beta_{FOR} = \frac{10mA}{1.08mA} = 9.24$$

Page 494

$$1ns = 6.4ns \ln \left(\frac{1mA - I_{BR}}{\frac{2.5mA}{40.7} - I_{BR}} \right) \quad | \quad 1.169 = \frac{1mA - I_{BR}}{0.0614mA - I_{BR}} \rightarrow I_{BR} = -5.49 \text{ mA}$$

$$i_{CMAX} = \frac{V_{CC} - V_{CE}}{\beta_F} \cong \frac{5-0}{2500} = 2.5mA \quad | \quad Q_{XS} = 6.4ns \left(1mA - \frac{2.5mA}{40.7} \right) = 6.01 \text{ pC}$$

$$Q_F = i_F \tau_F = 2.5mA(0.25ns) = 0.625 \text{ pC} \quad | \quad Q_{XS} >> Q_F$$

Page 495

$$\text{For } v_I = V_L = 0.15 \text{ V:} \quad i_{IL} = -\frac{5-0.95}{4000} = -1.01 \text{ mA} \quad | \quad V_{BE2} = V_L + V_{CESAT1}$$

Using the value of V_{CESAT} in Fig. 9.32, $V_{BE2} = 0.15 + 0.04 = 0.19 \text{ V}$

$$\text{A better estimate is } V_{CESAT1} = 25mV \ln \left(\frac{2+1}{2} \right) = 10.1 \text{ mV}$$

$$V_{BE2} = 0.15 + 0.010 = 0.16 \text{ V}$$

Page 496

$$\text{For } v_I = V_H = 5 \text{ V:} \quad i_{IH} = 2 \frac{5-1.5}{4000} = 1.75 \text{ mA} \quad | \quad V_{BE2} = 0.8 \text{ V}$$

$$\text{Using Eq. (5.29), } V_{BESAT} = 0.025V \ln \frac{0.875mA + \left(1 - \frac{2}{3} \right)(2.4mA)}{10^{-15}A \left[\frac{1}{40} + \left(1 - \frac{2}{3} \right) \right]} = 0.729 \text{ V}$$

Page 499

$$5V - N(2k\Omega)\beta_R I_B \geq 1.5V \quad | \quad I_B = \frac{5-1.5}{4000} = 0.875mA$$

$$\beta_R \leq \frac{3.5V}{5(2k\Omega)(0.875mA)} = 0.4 \quad | \quad \beta_R \leq \frac{3.5V}{10(2k\Omega)(0.875mA)} = 0.2$$

Page 500

$$I_{B2} = (2+1) \frac{5-1.5}{4000} = 2.63 \text{ mA} \quad | \quad 2.43mA + N(1.01mA) \leq 28.3(2.63mA) \rightarrow N \leq 71$$

Page 501

$$v_I = V_L \text{ and } v_O = 0 : I_{B4} = \frac{5 - V_{B4}}{1600} = \frac{5 - (0 + 0.7 + 0.7)}{1600} = 2.25 \text{ mA} \quad | \quad I_L = 41I_{B4} = 92.3 \text{ mA}$$

$$5 - 1600 \frac{I_L}{41} - 0.7 - 0.7 \geq 3 \rightarrow I_L \leq 15.4 \text{ mA}$$

$$I_{B4} = \frac{5 - (3 + 0.7 + 0.7)}{1600} = 0.375 \text{ mA} \quad | \quad I_L = 41I_{B4} = 15.4 \text{ mA}$$

$$V_{CE} = 5 - 130\Omega I_C - V_O = 5V - 130\Omega(15.4 \text{ mA}) - 3.7 = -0.702 \text{ V}$$

Oops! - the transistor is not in the forward - active region. Assume saturation with $V_{CESAT} = 0.15V$.

$$I_L = I_B + I_C = \frac{5 - (0.8 + 0.7 + 3.0)}{1600} + \frac{5 - (0.15 + 0.7 + 3)}{130} = 9.16 \text{ mA}$$

Page 513

(a) BiCMOS NAND gate : Replace the CMOS NOR - gate with a two - input CMOS

NAND - gate, and connect its output to the bases of Q_3 and Q_4 .

(b) BiNMOS NAND gate : Replace the input CMOS NOR - gate with a two - input CMOS

NAND - gate, and connect M_6 and M_7 in series instead of parallel.
